PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

EVK2-CT-1999-00022

Final report

Submitted May 30th 2003

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Project home page:	http://ugamp.nerc.ac.uk/promise

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PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

Year 3 Report

Contract number: EVK2-CT-1999-00022

Project reporting period: March 2002 to February 2003

Project Coordinator: Professor Julia Slingo, University of Reading

Project Home Page: http://ugamp.nerc.ac.uk/promise/

SECTION 1

1.1 Objectives of the reporting period

- To investigate further the natural variability of monsoonal systems on subseasonal to interdecal timescales.
- To assess the ability of new generation coupled and atmosphere-only models to simulate mean monsoon climates and their variability.
- To investigate the impact of regional SST anomalies on African and Asian monsoon climates, particularly ENSO and Indian Ocean variability.
- To investigate the role of land surface/vegetation processes and feedbacks in determining the variability and predictability of monsoon climates.
- To complete the assessment of the impact of seasonally varying vegetation on monsoon climates.
- To assess the seasonal predictability for monsoon climates using ensembles of model integrations.
- To assess the value of high resolution regional model simulations for describing the future impacts of anthropogenic climate change on the Indian and African monsoons, with particular reference to extreme events.
- To complete the assessment of the impacts of anthropogenic climate on India and West Africa.
- To complete the assessment of the impact of land use changes in West Africa.
- To complete the assessment of water availability in future climates for West Africa.
- To implement irrigation processes in an interactive land surface model used within a coupled climate model to enable assessment of the impact of climate change on the water balance in the major river catchments.
- To test the ability of crop models to translate climate change scenarios into agronomic impact scenarios for the dry zones of West Africa
- To progress further a general methodology to link weather and crop yields on a spatial scale typical of that used by seasonal and climate prediction models, including the development of a general large area model for annual crops.
- To update the PROMISE database of observed and simulated data on meteorology, hydrology and agriculture for monsoon climates.
- To hold an international conference with participation from scientists from monsoon-affected countries to communicate the results of PROMISE and to establish priorities for future research.

1.2 Scientific/Technical progress

Good progress has been made in all the work packages. The objectives for Year 3, as summarized in Section 1.1, have been met. Figure 1 shows the updated GANTT chart as presented in the original contract.

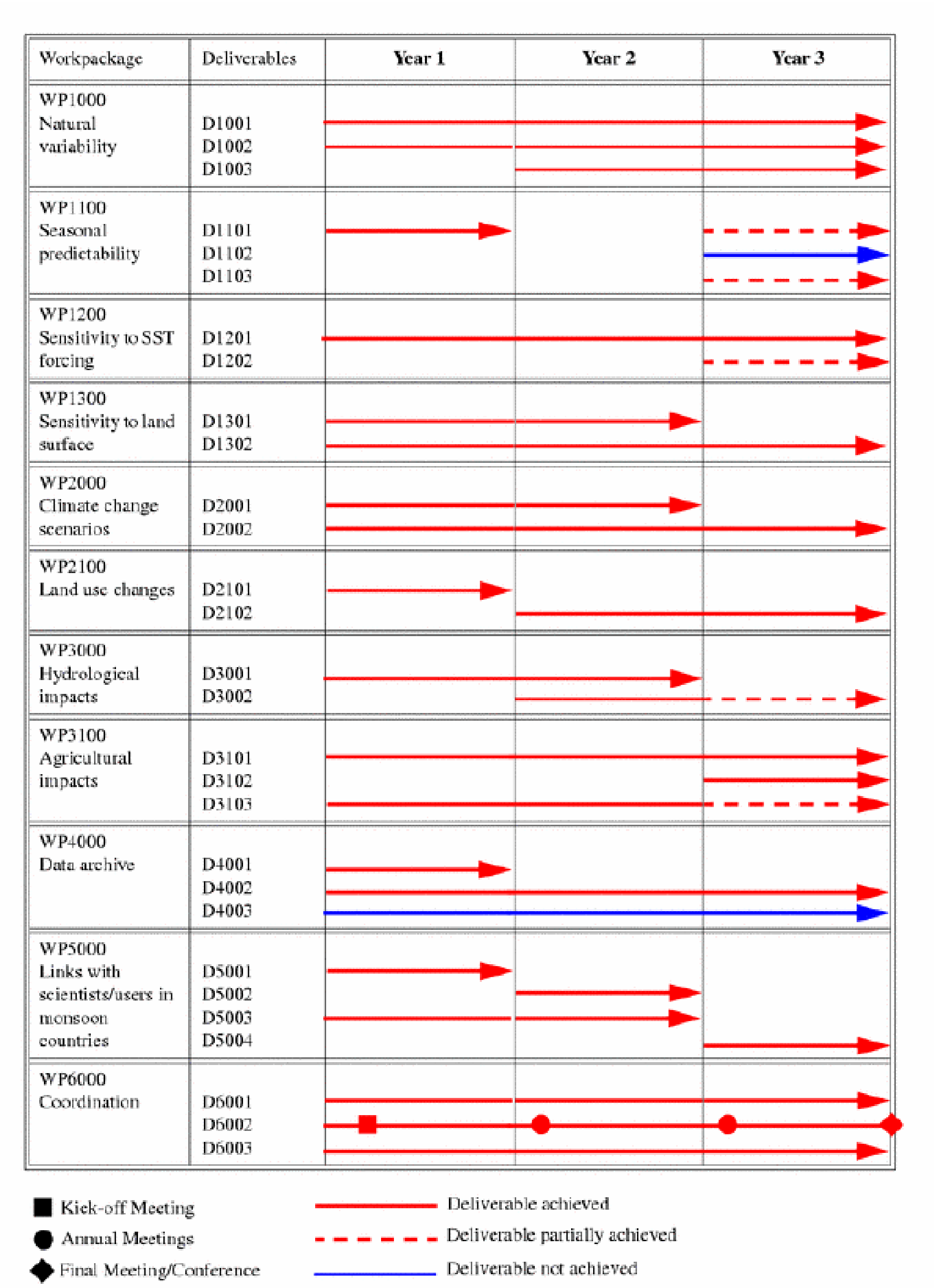

Figure 1: Updated GANTT Chart for Year 3 showing the final status of PROMISE Deliverables

The final GANTT chart shows that the majority of the deliverables have been completed by the end of the project. Two deliverables were not completed:

D1102: Development of advanced statistical techniques for evaluating the skill and worth of seasonal forecasts. Progress in WP1100 was affected significantly by the delays in the production of ERA40 and hence in the DEMETER seasonal prediction ensembles. Consequently effort planned by UREADMY was re-directed to WP1000 and the assessment of the impact of seasonally varying vegetation on monsoon climates.

D4003: Caching of relevant observational datasets for impact studies. Due to staffing difficulties at CINECA the development of the PROMISE data archive was delayed and this activity was not completed. However, ICTP and CINECA plan to maintain the archive beyond the life-time if PROMISE and we anticipate that these data will be cached in future.

The partial completion of D1101 and D1103 reflects again the delay in the production of the DEMETER ensembles noted above. The component of D1202 that deals with the Caribbean was not undertaken due to lack of staff (and hence reduced costs) at the Met Office. In D3002, the assessment of the water balance was only completed for the major basins in India and West Africa due to the additional effort required to develop the model of irrigation and river discharge. Although excellent progress has been made in WP3100, the final step of assessing the impact of climate change on crop productivity was hindered by serious systematic biases in the climate models. These were characterised by major errors in the onset of the monsoon rains and in the spatial and temporal variability of the rainfall through the wet season. However, this research has highlighted the need for a continuing major effort to improve model simulations and as such is an important deliverable of the project.

The planned and used manpower and finances are summarized in Table 1. Differences between planned and used resources reflect changes in the scheduling of work for some partners with more research being carried out during the last year of the project.

Table 1: Planned and used manpower (man months) and finances (Euros)

Partner	*Planned Manpower*	*Used Manpower*	*Planned Spend*	*Actual Spend*
UREADMY	27.0	34.0	147 998	140 411
CIRAD	3.0	4.1	23 812	30 566
MF	10.4	17.0	43 650	63 657
DMI	12.0	10.7	71 490	71 758
ICTP	8.0	-	-	-
NERC	10.8	11.8	56 601	66 279
LMD	14.6	23.1	54 927	56 988
MPG.IMET	0.0	7.0	0	45 862
Met Office	11.0	6.8	54 042	29 884
UREADAG	2.0	4.5	19 451	20 874
ECMWF	1.0	-	-	-
UB	0.0	3.7	1 050	8 656

A list of staff working on PROMISE during Year 3 is provided in Table 2:

Staff working on PROMISE during Year 3

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1.3 Milestones and Deliverables obtained

The following milestones were obtained:

- Complete diagnosis of natural variability of monsoon systems in climate integrations forced with observed SSTs, including assessment of the effects of model improvements.
- Assessment of the current skill in seasonal prediction ensembles for monsoon climates
- Complete SST sensitivity experiments. Complete paper on investigation of changes in interannual variability and response to idealised SST anomalies.
- Assessment of the influence of local, regional anomalies in land surface/vegetation conditions on monsoon variability on intraseasonal to decadal timescales.
- Assessment of the change in extreme events in future climates
- Numerical experimentation on the effects of irrigation over India
- Analysis of results and conclusions on the importance of taking into account anthropogenic vegetation changes in future climate scenarios.
- Documentation of the impact of changed land use and climate on water resources.
- Report on progress towards the development of a combined seasonal weather and crop productivity forecasting system
- Report on importance of land use change for tropical climate change.
- Further update of the archive with selected results of PROMISE integrations
- Complete development of protocol for examining impacts of seasonal forecasts of monsoon climates on the productivity of cropping systems in India and Africa.
- Further development of website. Final report. Final meeting.

The deliverables for Year 3 are summarized in the GANTT chart in Figure 1 and deviations from th original work plan have been summarised in Section1.1. The following table lists the Deliverables achieved in Year 3.

No.	Deliverable Title
D1001	Description of the natural variability of monsoon systems for the current climate
D1002	Assessment of the skill of current climate models to represent the natural variability of the monsoon climates
D1101	Assessment of the seasonal predictability of monsoon systems using ensemble techniques
D1103	Assessment of the origins of monsoon predictability
D1201	Assessment of the sensitivity of monsoon variability/predictability to regional SST anomalies
D1302	Assessment of the sensitivity of monsoon variability to anomalies in land surface/vegetation conditions
D2001	Documentation of the impacts of anthropogenic climate change on the characteristics of monsoon climates
D2002	Assessment of the value of high resolution regional model simulations for use in climate change impact studies
D2102	Assessment of the impact of land use changes on monsoon climates.
D3002	Assessment of the impact of climate change on water resources and on the water balance in large river catchments
D3102	Towards an integrated system for the interpretation of seasonal forecasts in terms of crop development and yields
D4002	Provision of model data for selected surface climate variables
D5004	Report on the protocol for integrating information from seasonal forecasts with impact assessments of crop productivity

D6001	Development and maintenance of PROMISE web site
D6002	Annual meetings. Publication of final report.
D6003	General dissemination of the aims and achievements of PROMISE.

1.4 Deviations from the work plan and/or time schedule

The main deviations from the work plan in Year 3 occurred in WP1100, which focused on the analysis of the DEMETER seasonal prediction ensembles. As noted in Section 1.1, the delays in the production of ERA40 meant that the DEMETER ensembles were not available earlier enough for the proposed work to be undertaken. The delays in ERA40 also had an impact on the description of monsoon variability, including decadal timescales, proposed in WP1000. Fortunately, the lack of availability of ERA40 and the DEMETER ensembles was not critical to the project. Instead more research was carried out on the influence of the land surface, particularly seasonally varying vegetation, on monsoon climates and their variability.

1.5 Coordination of information

The PROMISE website has continued to provide a useful tool for administrating and coordinating PROMISE. Various Powerpoint presentations and online versions of the PROMISE brochures are available on the site, and a major section on the PROMISE International Conference in March 2003 has been added. The PROMISE data archive has provided climate model data to project partners working on crop modeling. PROMISE partners have continued to be involved in the project meetings for EU FP5 DEMETER, ERA-40. The final PROMISE partners' meeting (incorporated into the PROMISE International Conference on Monsoon Environments: Agricultural and hydrological impacts of seasonal variability and climate change) was held during March 2003 at ICTP. PROMISE research was covered comprehensively at the International Conference on Monsoon Environments, with most of the partners giving keynote talks. A CDROM containing nearly all the conference presentations (in Powerpoint) has been prepared for distribution into scientists in developing countries that do not have access to the internet. PROMISE was also presented at the following meetings:

Sept. 2002	Royal Meteorological Society Conference on Quantitative Precipitation Forecasting	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

1.6 Difficulties encountered at management and coordination level

None

SECTION 2

Contract n°	**EVK2-CT-1999-00022**	Reporting period:	March 2002 - March 2003
Title	Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change: PROMISE		

Objectives:

- To investigate further the natural variability of monsoonal systems on seasonal, interannual and interdecal timescales, and to assess the ability of new generation coupled and atmosphere-only models to simulate mean monsoon climates and their variability.
- To investigate the impact of regional SST anomalies on African and Asian monsoon climates, particularly ENSO and Indian Ocean variability.
- To investigate the role of land surface/vegetation processes and feedbacks in determining the variability and predictability of monsoon climates, and to complete the assessment of the impact of seasonally varying vegetation on monsoon climates.
- To assess the value of high resolution regional model simulations for describing the future impacts of anthropogenic climate change on the Indian and African monsoons, with particular reference to extreme events.
- To complete the assessment of the impacts of global warming and land use changes on the future climates of India and West Africa.
- To complete the assessment of water availability in future climates for West Africa.
- To implement irrigation processes in an interactive land surface model used within a coupled climate model to enable assessment of the impact of climate change on the water balance in the major river catchments.
- To test the ability of crop models to translate climate change scenarios into agronomic impact scenarios for the dry zones of West Africa
- To progress further a general methodology to link weather and crop yields on a spatial scale typical of that used by seasonal and climate prediction models, including the development of a general large area model for annual crops.
- To hold an international conference with participation from scientists from monsoon-affected countries to communicate the results of PROMISE and to establish priorities for future research.

Scientific achievements:

PROMISE has achieved significant progress in understanding vegetation-climate interactions and how these vary in importance for different monsoon systems. The importance of seasonally varying vegetation in determining both winter and summer climates and the soil hydrological cycle has been demonstrated. As part of this study, the sensitivity of vegetation-climate interactions to soil properties (such as drainage, hydraulic conductivity) has also been investigated. The results have shown that the climatic effects of changes in vegetation cover (e.g. deforestation) are highly dependent on the soil specification. In addition, there are large geographical variations in the climate sensitivity. For example, India is largely insensitive to vegetation-climate interactions because the moisture supply for the monsoon rains comes primarily from the oceans. Conversely, China and Africa are much more sensitive since more of the moisture comes from local recycling.

Climate model systematic error and attempts to understand them and reduce them have continued to be a major research effort. A detailed study of the sensitivity of monsoon simulations to model formulation and coupling with the ocean has been performed. It has shown that different atmosphere-only models can exhibit very similar dominant modes of interannual variability, despite having quite different monsoon climatologies. This is contrary to previous suggestions that a realistic monsoon climatology is required in order that interannual variability is simulated realistically. It has also been shown that coupling with the ocean does not affect significantly the characteristics of interannual or intraseasonal variability, even though the mean state may be very different from that of the atmosphere-only model.

Further progress has been made in understanding the causes of the marked decadal variability in Sahel rainfall during the last 50 years. It has been shown that the warming of the tropical Indian Ocean, observed during recent decades, seems to be most important for the drying trend in West Sahelian rainfall. Studies of the influence of historical land use change suggest that it has been a secondary factor in Sahel drought. However, the role of dynamic vegetation in enhancing the variability and persistence of rainfall anomalies over the Sahel and Sahara regions, through biophysical feedbacks, has been demonstrated. On shorter timescales, the need for a correct specification of soil moisture for seasonal predictions of Sahel rainfall has been confirmed.

New high-resolution climate change scenarios have been produced which confirm the previous projections of enhanced monsoon precipitation for both the West African and Indian monsoons. The higher resolution has also enabled a detailed study of changes in extreme precipitation. The enhanced rainfall during the Indian summer monsoon in a warmer climate is mainly related to an increase in rainfall intensity, as opposed to the frequency of rainfall occurrences, with an indication that heavy precipitation extremes will be more frequent.

Scenarios of future land use change over West Africa, developed in the earlier phases of PROMISE, have been used to explore their climatic effects. The results have shown that the greenhouse gas forcing is the dominant process in determining the major characteristics of climate change over Africa, with vegetation changes having only a local impact over deforested areas.

Increasingly, seasonally arid regions use irrigation to enable crop production in the dry season and to support crop development in the rainy season. PROMISE has enabled the development of an integrated land surface and hydrology scheme that includes the effects of irrigation in the fully coupled climate model. This has provided one of the first estimates of the effects of water extraction for irrigation on river flows for the major rivers of India under future climate scenarios.

Following the successful development of a comprehensive model of water resources in West Africa, an assessment of water availability for 2050 has been completed. The results clearly indicate the likelihood of increasing water shortages in the semi-arid Sahel zone where population densities are high and water is already scarce.

Significant progress has been made in linking the disciplines of crop modelling and climate prediction. A new general large area model for annual crops has been developed and tested. This is aimed at bridging the gap in spatial scales between regional climate models and field-based crop models. However, attempts to drive crop models with climate model output have raised a number of important issues, particularly those related to biases within climate models and the distribution of rainfall in space and time. A key recommendation from PROMISE is that, given the great importance of the space/time distribution of rainfall for crop and soil water balance, future work on climate applications for agriculture should place more emphasis on the intra-seasonal variability of weather. The importance, at least for semi-arid environments, of reliable and timely predictions of the onset of the rainy season have been highlighted.

Socio-economic relevance and policy implications: The land surface is key to providing more accurate climate simulations that will be of significant value for regional climate change forecasting and for impact assessment. Changes in vegetation, particularly those associated with changes in land-use, may act to mitigate or exacerbate climate change.

The assessment of the impact of climate change due to anthropogenic causes on monsoon areas has obviously a direct economic implication for these regions. As the demand for water increases, an important issue is the evaluation of changes of the hydrological budget, not only due to climatic change related to CO_2 increase, but also due to human disturbances through changes in land use and water use by agriculture. The water resource modeling developed in PROMISE will allow policy makers and others to make better informed resource allocation decisions, and will facilitate the assessment of impacts of human activities (such as climate change) on global water distributions.

Food production in seasonally arid areas is inherently risky. PROMISE has initiated an important collaboration between climate and crop modelers. An international network of scientists concerned with the impacts of climate variability and change on cropping systems of Africa and India has been established through a series of visits and has provided valuable feedback on the key issues that need to be addressed in PROMISE.

The transfer of technology to developing countries is essential if EU research is to be properly exploited. The provision of the PROMISE data archive, a well-maintained website and the organization of an international conference to mark the end of PROMISE, with sponsorship for scientists from developing countries, have all contributed to the achievement of this goal.

Conclusions: As a result of PROMISE, improvements in our understanding of the predictability and variability of monsoon climates have been achieved. Considerable progress has been made in developing the crop and water resource models that can take advantage of the information from weather and climate prediction models. Constructive links with scientists in monsoon-affected countries have been established.

Keywords: monsoons, climate change, seasonal prediction, crop modelling, water resources

Refereed Publications

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
Annamalai, H. and J.M. Slingo	2001	Active/Break Cycles: Diagnosis of the Intraseasonal Variability of the Asian Summer Monsoon	Climate Dynamics	18	85 - 102		UREADMY
Ashrit R.G., H. Douville, K. Rupa Kumar, J.F. Royer, F. Chauvin	2003	Response of the Indian Monsoon and ENSO-monsoon teleconnection to enhanced greenhouse effect in transient simulations of the CNRM coupled model	J. Meteorol. Soc. Japan			submitted	MF
Bader, J., M. Latif, and R. Schnur	2003	The Impact of Decadal-Scale Indian Ocean SST Anomalies on Tropical and Extra-Tropical Climate				in preparation	MPG.IMET
Baquero-Bernal, A., M. Latif, and S. Legutke	2001	On Dipole like Variability of Sea Surface Temperature in the Indian Ocean	Journal of Climate	15	1358-1368		MPG.IMET
Becker, B. D., Slingo, J.M., L. Ferranti, L. and Molteni, F.	2001	Seasonal predictability of the Indian Summer Monsoon: What role do land surface conditions play?	Mausam	52	175-190		UREADMY
Black, E., J. Slingo and K.R. Sperber	2003	An Observational Study of the Relationship between Excessively Strong Short Rains in Coastal East Afrcia and Indian Ocean SST	Monthly Weather Review	131	74 - 91		UREADMY
Camberlin P. and N. Philippon	2002	The East African March-May rainy season, its teleconnections and predictability over the 1968-1997 period	Journal of Climate	15	1002-1019		UB

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
Challinor A.J., J.M. Slingo, T.R. Wheeler, P.Q. Craufurd and Grimes D.I.F.	2003	Towards a combined seasonal weather and crop productivity forecasting system: determination of the spatial correlation scale	Journal of Applied Meteorology	42	175-192		UREADAG
Challinor A.J., T.R. Wheeler, P.Q. Craufurd, J.M. Slingo, and D.I.F. Grimes	2003	Design and optimisation of a large-area process-based model for annual crops	Agricultural and Forest Meteorology			submitted	UREADAG
Challinor A.J., T.R. Wheeler, P.Q. Craufurd, J.M. Slingo, and D.I.F. Grimes	2003	Crop growth modelling for use with large-area input data (published abstract)	Journal of Agricultural Science			in press	UREADAG
Challinor A.J., T.R. Wheeler, P.Q. Craufurd, J.M. Slingo, and D.I.F. Grimes	2002	Towards the development of integrated weather/crop forecasting systems	Journal of Agricultural Science	139	108-109		UREADAG
Cramer W., A. Bondeau, F.I. Woodward, I.C. Prentice, R.A. Betts, V. Brovkin, P.M. Cox, V. Fisher, J.A. Foley, A.D. Friend, C. Kucharik, M.R. Lomas, N. Ramankutty, G. Stitch, B. Smith, A. White and C. Young-Molling	2001	Global response of terrestrial ecosystem structure and function to CO2 and climate change. Results from six dynamic global vegetation models	Global Change Biology	7	357-374		The Met Office
de Rosnay, P. J. Polcher, M. Bruen and K. Laval	2002	Impact of a physically based soil water flow and soil plant interaction representation for modelling large scale land surface processes	Journal of Geophys. Research	D 107	1029		LMD

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
de Rosnay, P., J. Polcher and K. Laval	2003	A Modelling experiment on the interactions between irrigation and land surface fluxes over Indian Peninsula	Geophysical Research Letters			submitted	LMD
Diedhiou, A., S. Janicot, A. Viltard and P. de Felice	2001	Energetics of easterly wave disturbances over West Africa and the tropical Atlantic : A climatology from the 1979-95 NCEP/NCAR reanalyses	Climate Dynamics	18	487-500		LMD
Diedhiou, A., S. Janicot, A. Viltard and P. de Felice	2001	Composite patterns of easterly disturbances over West Africa and the tropical Atlantic : A climatology from the 1979-95 NCEP/NCAR reanalyses	Climate Dynamics	18	241-253		LMD
Douville H.	2002	Influence of soil moisture on the Asian and African monsoons. Part II: Interannual variability	Journal of Climate	15	701-720		MF
Douville H.	2002	Assessing the influence of soil moisture on seasonal climate variability with AGCMs	J. Hydrometeorology			submitted	MF
Douville H., F. Chauvin, S. Planton, J.F. Royer, D. Salas y Mélia and S. Tyteca	2002	Sensitivity of the hydrological cycle to increasing amounts of greenhouse gases and aerosols.	Climate Dynamics	20	45-68		MF
Ducharne A., C. Golaz, E. Leblois, K. Laval J. Polcher, E. Ledoux and G. de Marsily	2003	RiTHM, a runoff routine scheme for GCMs	Journal of Hydrology			in press	LMD
Fontaine B. and N. Philippon	2002	The relationship between the Sahelian and previous 2nd Guinean rainy seasons: a monsoon regulation by soil wetness?	Annales Geophysicae	20	575-582		UB
Fontaine B., Philippon, N., Trzaska S. and Roucou P.	2002	Spring to summer changes in the West African monsoon through NCEP/NCAR reanalyses (1968-1998)	Journal of Geophysical Research	107	10.1029-10.1037		UB

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
Fontaine B., P. Roucou P. and S.Trzaska	2003	Atmospheric water cycle and moisture fluxes in the West African monsoon: mean annual cycles and relationship using NCEP/NCAR reanalyses	Geophysical Research Letters	30	10.1029-10.1032		UB
Fontaine B. and N. Philippon	2000	Seasonal evolution of boundary layer heat content in the West African monsoon from the NCEP/NCAR reanalysis (1968-1998)	International Journal of Climatology	20	1777-1790		UB
Garric G., H. Douville and M. Déqué	2002	Prospects for improved seasonal predictions of monsoon precipitation over the Sahel	International Journal of Climatology	22	331-345		MF
Gissila, T., E. Black, D. Grimes, and J. Slingo	2003	A new seasonal forecasting system for the Ethiopian Summer Rains	International Journal of Climatology			submitted	UREADMY
Hu, Z.-Z., M. Latif, E. Roeckner, and L. Bengtsson	2000	Intensified Asian summer monsoon and its variability in a coupled model forced by increasing greenhouse gas concentrations	Geophys. Res. Letters	27	2681-2684		MPG.IMET
Janicot, S., S. Trzaska and I. Poccard	2001	Summer Sahel-ENSO teleconnection and decadal time scale SST variations	Climate Dynamics	18	303-320		LMD
Janicot, S. and B. Sultan	2001	Intra-seasonal modulation of convection in the West African monsoon	Geophysical Research Letters	28	523-526		LMD
Lawrence, D.M. and J.M. Slingo	2003	An annual cycle of vegetation in a GCM. Part II: Global impacts on climate and hydrology	Climate Dynamics			submitted	UREADMY
Lawrence, D.M. and J.M. Slingo	2003	An annual cycle of vegetation in a GCM. Part I: Implementation and impact on evaporation	Climate Dynamics			submitted	UREADMY
May W. and E. Roeckner	2001	A time-slice experiment with the ECHAM4 AGCM at high resolution: the impact of horizontal resolution on annual mean climate change	Climate Dynamics	17	407-420		DMI

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
May W	2003	Mechanisms of the predicted future changes in the Indian summer monsoon due to greenhouse warming	Climate Dynamics			in preparation	DMI
May W	2003	Simulation of the variability and extremes of daily rainfall during the Indian summer monsoon for present and future times in a global time-slice experiment	Climate Dynamics			submitted	DMI
May W.	2002	The Indian summer monsoon and its sensitivity to the means SSTs: Simulations with the ECHAM4 AGCM at T106 horizontal resolution	Journal of the Meteorological Society of Japan	81	57-73		DMI
May W.	2002	Simulated changes of the Indian summer monsoon under enhanced greenhouse gas conditions in a global time-slice experiment	Geophysical Research Letters	29	1029		DMI
Maynard K. and J.F. Royer	2003	Sensitivity of a General Circulation Model to land surface parameters.	Climate Dynamics			submitted	MF
Maynard K., J.F. Royer and F. Chauvin	2002	Impact of greenhouse warming on the West African summer monsoon	Climate Dynamics	19	499-514		MF
Maynard K. and J.F. Royer	2003	The influence of surface roughness on African afforestation experiments	Journal of Climate			submitted	MF
Maynard K. and J.F. Royer	2003	Impact of realistic deforestation on West African monsoon	Climate Dynamics			submitted	MF
Maynard, K. and J. Polcher	2002	Impact of land-surface processes on the interannual variability of tropical climate in the LMD GCM	Climate Dynamics			accepted	LMD
Meigh, J. and S. Folwell	2003	Combined impacts of climate and land use change on water resources vulnerability in West Africa				in preparation	NERC

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
Molteni, F., S. Corti, L. Ferranti and J. M. Slingo	2003	Predictability experiments for the Asian Summer Monsoon: Impact of SST anomalies on interannual and intraseasonal variability	Journal of Climate			in press	UREADMY
Molteni F	2003	Atmospheric simulations using a GCM with simplified physical parametrizations. I: model climatology and variability in multi-decadal experiments	Climate Dynamics	20	175-191		ICTP
Neale, R. B. and Slingo, J.M.	2003	The Maritime Continent and its role in the global circulation: A GCM study	Journal of Climate	16	834 - 848		UREADMY
Philippon N., P. Camberlin P., and N. Fauchereau	2002	Empirical Predictability study of October-December East African rainfall	Quarterly Journal of the Royal Meteorological Society	128	2239-2256		UB
Poccard, I., S. Janicot and P. Camberlin	2000	Comparison of rainfall structures between NCEP/NCAR reanalysis and observed data over tropical Africa	Climate Dynamics	16	897-915		LMD
Quadrelli R, V. Pavan and F. Molteni	2001	Wintertime variability of Mediterranean precipitation and its links with large-scale circulation anomalies	Climate Dynamics	17	457-466		ICTP
Rowell, D.P.	2003	The Impact of Mediterranean SSTs on the Sahelian Rainfall Season	Journal of Climate	16	849-862		The Met Office
Royer J.F., D. Cariolle, F. Chauvin, M. Déqué, H. Douville, R.M. Hu, S. Planton, A. Rascol, J.L. Ricard, D. Salas y Mélia, F. Sevault, P. Simon, S. Somot, S. Tyteca L. Terray and S. Valcke	2002	Simulation des changements climatiques au cours du 21-ème siècle incluant l'ozone stratosphérique (Simulation of climate changes during the 21-st century including stratospheric ozone).	Comptes Rendues de Geoscience	334	147-154		MF

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
Schnitzler, K.-G., N. Zeng, M. Latif, W. Knorr, and M. Scholze	2003	Impact of vegetation feedback on climate variability in a coupled GCM land-vegetation model				in preparation	MPG.IMET
Slingo, J. M. and H. Annamalai,	2000	1997: The El Nino of the century and the response of the Indian Summer Monsoon	Monthly Weather Review	128	1778-1797		UREADMY
Spencer, H., J.M. Slingo. and M. Davey	2003	The influence of the response by the remote ocean basins on the seasonal predictability of ENSO teleconnections	Climate Dynamics			submitted	UREADMY
Spencer, H. and J.M.Slingo	2003	The simulation of peak and delayed ENSO teleconnections	Journal of Climate			in press	UREADMY
Sperber, K. R., J.M. Slingo, and H. Annamalai	2000	Predictability and the relationship between subseasonal and interannual variability during the Asian Summer Monsoon	Quarterly Journal of the Royal Meteorological Society	126	2545-2574		UREADMY
Sultan, B., S. Janicot and A. Diedhiou	2003	The West African monsoon dynamics. Part I: Documentation of intra-seasonal variability				in press	LMD
Sultan, B. and S. Janicot	2003	The West African monsoon dynamics. Part II: The pre-onset and the onset of the summer monsoon	Journal of Climate			in press	LMD
Sultan, B. and S. Janicot	2000	Abrupt shift of the ITCZ over West Africa and intra-seasonal variability	Geophysical Research Letters	27	3353-3356		LMD
Taylor, C., D. O'Regan, Lambin and Stephenne	2003	Assessing the sensitivity of West African climate to land use change				in preparation	NERC
Taylor, C. M., E. F. Lambin, N. Stephenne, R. J. Harding and R. L. H. Essery	2002	The influence of land use change on climate in the Sahel	Journal of Climate	15	3615-3629		NERC

Authors	Year	Title	Journal	Volume	Pages	Status of unpublished papers	Institution
Verant S., K. Laval, J. Polcher and M. de Castro	2003	Sensitivity of the continental hydrological cycle to the spatial resolution over the Iberian Peninsula	Journal of Hydrometeorology			in review	LMD

Unrefereed Publications

Authors	Date	Title	Publication article included in	Pages	Institution
Baleux F., A. Begue, J.D. Corbet, D. Rollin, G. Grellet, J.W. White	2001	L'almanach numérique de planification à Madagascar.	Modélisation des agrosystèmes et aide à la décision. Collection Repères. CIRAD INRA, France.		CIRAD
Camberlin P. and N. Philippon	2001	The stationarity of lead-lag teleconnections with East Africa rainfall and its incidence on seasonal predictability	Detecting and Modelling Regional Climate Change Brunet India M., Lopez Bonillo D., (Eds), Springer-Verlag, Berlin, (672 p.)	291-308	UB
Cox P.M., Betts R.A., Jones C.D., Spall S.A., Totterdell I.J.	2002	Modelling vegetation and the carbon cycle as interactive elements of the climate system	Meteorology at the millennium Pearce R.P.(Ed) Academic Press	259-279	The Met Office
de Rosnay, P., J. Polcher, K. Laval, M. Sabre	2003	Modelling experiment of irrigation over Indian Peninsula with Orchidee.	Gewex news.		LMD
Lo Seen D, M. Areola, A. Clopes, E. Scopel, A. Begue	2001	Coupler modèle agronomique et système d'information géographique	Modélisation des agrosystèmes et aide à la décision. Collection Repères. CIRAD INRA, France		CIRAD
Samba A, B. Sarr, C. Baron, E. Gozé, F. Maraux, B. Clerget, M. Dingkuhn	2001	La prévision agricole à l'échelle du Sahel. In: p..	Modélisation des agro-écosystèmes et aide à la décision. Malézieux E, Trébuil G, Jaeger M (Eds.). Cirad and INRA, Montpellier, France,	243-262	CIRAD
Slingo, J. M.	2002	Monsoon Overview.	Encyclopedia of Atmospheric Sciences, Academic Press	1356-1370	UREADMY
Syahbuddin, H.	2001	Effet du changement climatique sur le rendement de l'arachide (Arachis hypogaea L.) dans de cas du Sénégal, réalisé avec le modèle ARPEGE Climat V. 3.0 et SARRA-H.	Masters thesis, Météorologie Tropicale, Ecole Nationale de la Météorologie, Toulouse, France, 129 pages.		CIRAD

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

Contract number:	EVK2-CT-1999-00022
Project reporting period:	March 2002 to February 2003
Sections included:	Section 3
Work-package coordinator:	Roy Kershaw, Met Office, Bracknell, UK
Work-package number:	WP1000

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SECTION 3:

3.1 Objectives

To investigate the natural variability of monsoonal systems on seasonal, interannual and interdecadal timescales, using observations and model results, and including the application of advanced statistical techniques. The interaction between various time and space scales will be investigated.

3.2 Methodology and scientific achievements

UREADMY: Due to the delays in the production of ERA-40 and the consequent effects on the availability of DEMETER ensembles, there has been some adjustment in the work plan for Year 3 with a greater emphasis being placed on understanding vegetation-climate interactions in the tropics and their sensitivity to soil properties.

An Annual Cycle of Vegetation in a GCM. Part I: Implementation and Impact on Evaporation

The sensitivity of surface evaporation to a prescribed vegetation annual cycle is examined globally in the Met Office Hadley Centre Unified Model (HadAM3) which incorporates the Met Office Surface Exchange Scheme (MOSES2) as the land surface scheme. A vegetation annual cycle for each plant functional type in each grid box is derived based on satellite estimates of Leaf Area Index (LAI) obtained from the nine-year International Satellite Land Surface Climatology Project II dataset. The prescribed model vegetation seasonality consists of annual cycles of a number of structural vegetation characteristics including LAI as well as canopy height, surface roughness, canopy water capacity, and canopy heat capacity, which themselves are based on empirical relationships with LAI. An annual cycle of surface albedo, which in the model is a function of soil albedo, surface soil moisture, and LAI, is also taken into account and agrees reasonably with observed estimates of the surface albedo annual cycle.

Two 25-yr numerical experiments are completed: the first with vegetation characteristics held at annual mean values, the second with realistic seasonally varying vegetation. Initial analysis uncovered an unrealistically weak relationship in the HadAM3/MOSES2 system between surface evaporation and vegetation state. This weak relationship is strengthened by adjusting two MOSES2 parameters, kpar, the extinction coefficient for photosynthetically active radiation, and ksh, a canopy shading extinction coefficient that controls what fraction of the surface is exposed through the canopy to the overlying atmosphere. When the adjusted parameters are used, summer (or wet season) evaporation is found to be notably stronger in nearly all locations in the phenology experiment at the peak of the growing season. Evaporation is significantly smaller in the phenology experiment during the tropical dry season when most vegetation is in a dormant state.

An Annual Cycle of Vegetation in a GCM. Part II: Global Impacts on Climate and Hydrology

The Met Office Hadley Centre Unified Model (HadAM3) with the tiled version of the Met Office Surface Exchange Scheme (MOSES2) land surface scheme is used to assess the impact of a comprehensive imposed vegetation annual cycle on global climate and hydrology. Two 25-yr numerical experiments are completed: the first with structural vegetation characteristics (Leaf Area Index (LAI), canopy height, canopy water capacity, canopy heat capacity, albedo) held at annual mean values, the second with realistic seasonally varying vegetation characteristics. It is found that the seasonalities of latent heat flux and surface temperature are widely affected. The difference in latent heat flux between experiments is proportional to the difference in LAI. Summer growing season surface temperatures are between 1 and 4 K lower in the phenology experiment over a majority of grid points with a significant vegetation annual cycle. During winter, midlatitude surface temperatures are also cooler due to brighter surface albedo over low LAI surfaces whereas during the dry season in the Tropics, characterised by dormant vegetation, surface temperatures are slightly warmer due to reduced transpiration. Precipitation is not as systematically affected as surface temperature by a vegetation annual cycle, but enhanced growing season precipitation rates are seen in regions where the latent heat flux (evaporation) difference is large. Differences between experiments in evapotranspiration, soil moisture storage, the timing of soil thaw, and canopy interception generate regional perturbations to surface and sub-surface runoff annual cycles in the model.

As part of our research into the role of vegetation seasonality on surface climate, the sensitivity of the surface climate to soil parametrization has been explored. Chris Taylor at CEH has developed a soil parametrization dataset based on IGBP satellite information. This soil parametrization represents a considerably different, but realistic, representation of soil properties compared to the standard soil parametrization used in the Met Office land surface scheme (MOSES-2).

In general, the IGBP soil dataset generates much drier soils throughout the column, leading to reduced surface evaporation and higher surface temperatures. Annual mean precipitation is relatively unaffected, except for a few areas including northern South America, which exhibits an interesting east-west dipole difference that is strongest in southern winter. The cause of this dipolar precipitation difference is unclear but is associated with enhanced easterly winds across the northeast coastline and enhanced northerly winds during June and July. Significant enhancement of sub-surface runoff is seen throughout the Tropics, even though precipitation differences over land are relatively small. This enhancement of sub-surface runoff and the drying of the soils in with the IGBP soil parameters are due to enhanced infiltration through the soil profile.

In contrast, the wetter soils in the Met Office specification leads to higher soil moisture availability, evaporation efficiency, total surface conductance, and soil conductance throughout the year. An interesting result is that the change in evaporation efficiency in response to a precipitation event, which is some measure of the land-atmosphere coupling strength, exhibits an interesting annual cycle. During the spring and winter, the change in evaporation efficiency is nearly the same for both soil datasets, but during the summer, the Met Office soil dataset results in significantly greater changes in evaporation efficiency by comparison to the IGBP soil dataset.

In a related study, the dependence of climate sensitivity to vegetation on the specification of soil hydraulic parameters has been studied. The results have shown that the climatic effects of changes in vegetation cover (e.g. deforestation) are highly dependent on the soil specification. In addition, there are large geographical variations in the climate sensitivity with the various monsoon climates responding differently. For example, India is largely insensitive to vegetation-climate interactions because the moisture supply for the monsoon rains comes primarily from the oceans through large-scale atmospheric convergence. On the other hand, China and Africa are much more sensitive since more of the moisture comes from local recycling of soil water.

Met Office: We have continued to assess the mean monsoon climate and interannual variability in the semi-Lagrangian, non-hydrostatic version of the Met Office Unified Model called HadGEM. This model incorporates numerous changes to the physical parametrizations in both the atmosphere and ocean components, as well as to the model grid and vertical resolution, and includes additional processes such as the sulphur cycle and cloud aerosol effects. This year we have compared the sensitivity of the monsoon simulation to changes in the model physics with the impact of coupling the atmosphere and ocean models.

Our previous PROMISE work showed that the monsoon climatology in HadGAM improves on the standard climate version, HadAM3, in terms of the circulation strength and in some aspects of the precipitation distribution. Comparing these atmosphere-only models with their coupled counterparts, we find changes in the monsoon simulations which are associated with errors in the sea surface temperature (SST) climatologies of the coupled models. In HadCM3, the monsoon circulation is weaker and there is far less precipitation over and around the Indian peninsula, in association with colder surface temperatures in the northern hemisphere. Instead, precipitation over Indonesia is increased, in association with warmer SSTs here. These changes occur as a result of systematic errors in the atmosphere model, namely too much cloud over the subtropical and midlatitude oceans and too little convection over Indonesia. Similarly warm SSTs and increased precipitation around Indonesia are seen in HadGEM. In this model the northern hemisphere temperature errors are reduced but a strong equatorial cold bias develops as a result of problems with near-surface winds in the tropics. There is an associated decrease in winds and precipitation over the equatorial west Pacific, but little change in the strength of the monsoon circulation.

Both atmosphere-only models have a dominant mode of interannual variability which explains of order 40% of the variance, far higher than is observed. Despite the vast differences between the two models, their dominant modes are very similar. Easterly 850 hPa wind anomalies across east Asia and most of the Indian peninsula are associated with decreases in precipitation here, while increased convergence over Indonesia, western India and the Arabian Sea is associated with increased precipitation there. The coupled versions of the two models also show aspects of this mode, but both show additional anomalies over the southeastern equatorial Indian Ocean. This is particularly evident in HadCM3, where the anomalies in this region are stronger than those over India and east Asia. The dominance of this first mode in HadCM3 is rather less than in HadAM3, while in HadGEM the dominant mode is very similar to, and explains the same amount of variance as, the atmosphere-only model. The appearance of anomalies over the southeastern equatorial Indian Ocean in the coupled models may indicate an improved representation of the Indian Ocean SST dipole mode when the atmosphere and ocean are allowed to interact. However, recent work at CGAM (Reading University) suggests that it may the changes in the SST distribution, rather than the coupling, which is influencing this mode.

Previous work (done under WP1200) suggested that internal variability may be prevalent in HadGAM/GEM, while HadAM3/CM3 both appear to respond too strongly to both local and remote SST forcing. Preliminary analysis of the intraseasonal variability in the models shows a strong similarity between the second mode of intraseasonal variability and the dominant interannual mode in HadAM3, and a link between the predominant phase of this mode and Pacific SSTs. Conversely, there is little similarity between the intraseasonal and interannual modes in HadGAM, suggesting once again that internal variability dominates.

We conclude several things from this work. Different atmosphere-only models can exhibit very similar dominant modes of interannual variability, despite having quite different monsoon climatologies. This is contrary to the suggestion by several authors that a realistic monsoon climatology is required in order that interannual variability is simulated realistically. However, in the case of HadAM3, the variability is strongly linked to SST forcing, while internal variability dominates in HadGAM. Coupling the models appears to improve the variability associated with the Indian Ocean SST dipole, although it is possible that this is associated with SST errors over Indonesia. Ultimately, we find that the simulation of interannual variability is surprisingly robust to either change, and problems with it remain. This may be a result of remaining systematic errors which are common to all the models, or it may suggest that a fundamental forcing is not represented properly in either model version. Investigation of these aspects should help to inform future model development.

Meteo France/ CNRM:

Objectives

The aim was to apply a statistical methodology package for studying space-time varying phenomena to the study of intra-seasonal space-time variability, in particular for African Easterly Waves (AEWs).

Methodology and scientific achievements

A set of statistical procedures including a sequence of spectral techniques, classical and complex empirical orthogonal function (CEOF), based on the work of Guérémy and Céron (1999, J of Climate, 12, 2831-2855) has been assembled, for the analysis of intraseasonal variability in climate simulations.

As an application of the methods a new approach was adopted for the study of African Easterly Waves (AEWs) by the use of multi-year ensemble simulations to assess the predictability of AEWs. Experiments were carried out over the 1979-93 period, each year being represented by an ensemble of 10 simulations. The 10 runs differ only by their initial conditions, taken from ECMWF reanalysis (ERA15). Two set of experiments were performed: a control experiment with the standard land-surface scheme (ISBA), and another one with relaxation of the soil moisture toward the control mean. After a selection of the appropriate space-time spectral window by the STSA method, the raw data was filtered before application of the CEOF techniques. This analysis has confirmed that soil moisture was an important component of the variability of the AEWs.

Comparisons between the two sets of experiments shows that relaxing soil moisture tends to weaken the predictability of simulated easterly waves over West Africa, especially over the Guinean region. This predictability is largely due to teleconnections between Atlantic SSTs and a dipolar pattern of the AEWs activity over West Africa. Positive SST anomalies over equatorial Atlantic (region between 10°S and 10°N) are associated with positive/negative anomalies of the first CEOF mode over respectively Guinean/Sahel regions. Relaxation of soil moisture tends also to enhance the remote teleconnections between the West African dipole and SSTs over Indian and East Pacific basins. This teleconnection is weak in the control run. This suggests a negative feedback of the soil moisture on the AEWs remote teleconnections. Finally, one must be aware that such results reflect the model behavior and should be validated by observed analyses. This has been started using the ECMWF re-analysis (ERA15) and will be extended with the help of the recently achieved 40-year reanalysis (ERA40).4

Discussion and Conclusion

The application of statistical methods devised to study wave propagation has been applied to the analysis of African Easterly waves in hindcast experiments over the past 15 years. The results have shown some relationships with SST anomalies in the Atlantic that need to be confirmed over a longer period using the new ERA-40 reanalysis.

LMD (Polytechnique): Our investigation of the West African monsoon dynamics has known further development through two main aspects : the intra-seasonal variability and the monsoon onset. In collaboration with CIRAD we have documented the agricultural impacts of these large-scale features of the West African monsoon.

Intra-seasonal variability in West Africa

A more precise study on the intra-seasonal variability has been done over the 1968-1990 period. We have shown that rainfall and convection over West Africa are significantly modulated at two intra-seasonal time scales, 10-25-day and 25-60-day, leading to recurrent variations of plus or minus 30% of the seasonal amplitude. A composite analysis based on a regional rainfall index has pointed out a main quasi-periodic signal of about 15 days. We have shown that during an intra-seasonal wet sequence, convection in ITCZ is enhanced and its northern boundary moves to the north, while the speed of the AEJ decreases and the monsoon flow becomes stronger. This modulation of convection at intra-seasonal time scales is not limited to West Africa but corresponds to a westward propagating signal from eastern Africa to the western tropical Atlantic. The enhanced (weakened) phases of the West African monsoon are associated with a stronger cyclonic (anticyclonic) activity over the Sahel controlling a stronger (weaker) moisture advection over West Africa. We also shown that the activity of African Easterly Waves between 3 and 10 days is significantly modulated at this intra-seasonal time scale around 15 days. A paper of these results has been recently accepted to *Journal of Climate*.

The monsoon onset

Further investigations have been done on the abrupt shift of the ITCZ and its relation with the monsoon onset. We have first described the seasonal cycle of the West African monsoon to point out the atmospheric patterns associated with the abrupt shift of the ITCZ. A scenario has been suggested to explain the mechanisms leading to the monsoon onset. Ten days before the northward shift of the ITCZ, an enhancement of the atmospheric circulation in the heat low seems to inhibit convection while the local and regional potential instability increases. A stronger zonal monsoon flux, may be due to an orographic influence, could decrease this inhibition leading to the abrupt shift of the ITCZ and the monsoon onset. This study is the topic of a new paper that has been accepted to *Journal of Climate*.

Agricultural impacts in Sahelian area

Precipitation in the Sahel is produced by one rainy season during the northern summer monsoon. The onset of these rains and their intra-seasonal fluctuations are then important for the agricultural community. In collaboration with CIRAD, we have investigated some relationships between rainfall variability at regional scale and crops development at local scale in the Sahel. By using a crop model SARRA-H (CIRAD), we have studied the agricultural impacts of these aspects of the West African monsoon dynamics. We have shown that our definition of the onset of summer monsoon can improve the potential yield through a better choice of the sowing date. It is also shown a strong impact of the intra-seasonal dry sequences around 40 days on the potential yield when these dry sequences appear during the flowering and the grain ripening phases of the crop.

3.3 Socio-economic relevance and policy implication

Understanding the natural variability of monsoon climates is a prerequisite for understanding and quantifying climate change in these sensitive regions and for making seasonal predictions.

3.4 Discussion and conclusion

All WP1000 deliverables and milestones have been achieved.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

Contract number:	EVK2-CT-1999-00022
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Sections included:	Section 3
Project co-ordinator:	Wilhelm May, Danish Meteorological Institute, Copenhagen.
Work-package number:	WP1100

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SECTION 3:

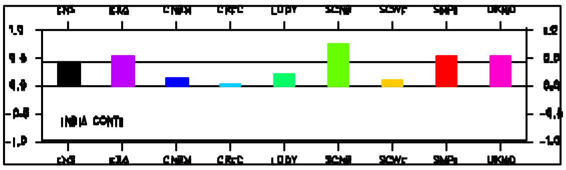
3.1 Objectives

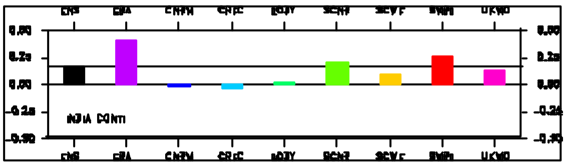
To assess the seasonal predictability for monsoon climates using ensembles of model integrations, and with the application of advanced statistical techniques. The origins of internal and/or external predictability will be sought.

3.2 Methodology and scientific achievements

DMI: At DMI, the performance of the DEMETER multi-model ensemble system for seasonal predictions has been assessed with respect to the Indian summer monsoon. The prediction system consists of 7 different coupled models, each of them performing an ensemble of 9 seasonal forecasts. Due to the delays in the production of ERA-40 and, hence, in the DEMETER predictions, only 12 years of data (1987-1998) could be considered. Due to the short period of data available, we have not applied any technique to combine the predictions with the different models in such a way that the forecast skill of the multi-model ensemble mean is maximized. However, preliminary results taking the interannual variability of the various models into account suggest a potential for improving the forecasts of the Indian summer monsoon by weighting the forecasts of the individual models in an optimal way.

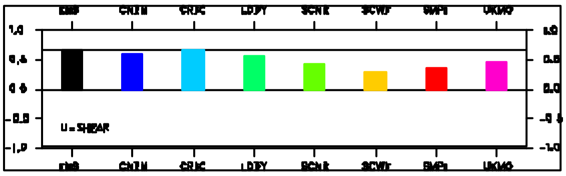
The seasonal predictions of the Indian summer monsoon have been verified against the CMAP data set for precipitation and against ERA-40 for the other atmospheric variables. Both large-scale indices describing the strength of the monsoon, i.e., the rainfall in India and the vertical shear of the zonal and the meridional wind component, respectively, and the local values of the rainfall and the winds are considered. The results are shown in the following:

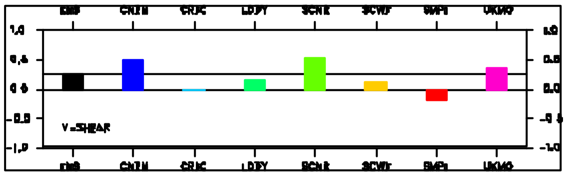


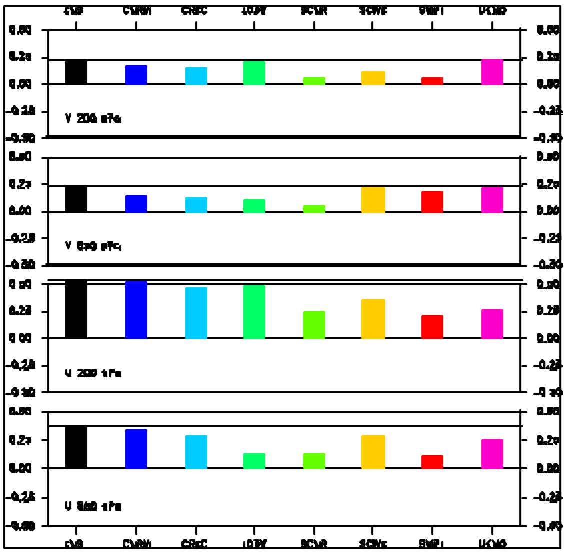


The panel on the left shows the forecast skills, i.e., the anomaly correlation coefficients ("ACCs"), for the All India Rainfall (AIR) for the multi-model ensemble ("ENS"), the 7 different models ("CNRM", … "UKMO"), and ERA-40 ("ERA"). The panel on the ride, on the other hand, shows the mean values of the local ACCs of the rainfall averaged over India. According to this, 3 of the models have a better skill for predicting AIR than ENS with an ACC of about 0.5. The other 4 models have, however, a very poor skill. The picture is somewhat different, when the local predictions are considered. In this case, only two of the models exceed ENS, and the ranking of the 2 best models is different than for AIR. 2 of the models actually have a negative skill. In general, the forecast skills are better for AIR than for the local changes of rainfall, i.e., about a factor of 2 for the corresponding ACCs.

In the other case, the two upper panels show the forecast skills for the vertical shear of the zonal wind component ("U-SHEAR") and the vertical shear of the meridional wind component ("V-SHEAR") and the four lower panels on the right the mean values of the local ACCs of the meridional and zonal wind components in the upper and the lower troposphere, i.e., at 200 and at 850 hPa, respectively. For U-SHEAR, none of the individual models has a better forecast skill than ENS, while for V-SHEAR, 3 of the models exceed ENS. 2 of these 3 models also have a rather good skill for predicting AIR. Different to AIR and V-SHEAR, none of the models has a particularly low forecast skill for U-SHEAR. Most models are better suited for predicting U-SHEAR, i.e., changes in the Walker circulation, than for predicting V-SHEAR, i.e., changes in the local Hadley circulation. This is consistent with the fact that the models have a better forecast skill for the local changes in the zonal wind component than for the local changes in the meridional wind component at the two levels. In particular, the forecast skills of the changes in the zonal wind component are generally higher in the upper than in the lower troposphere.

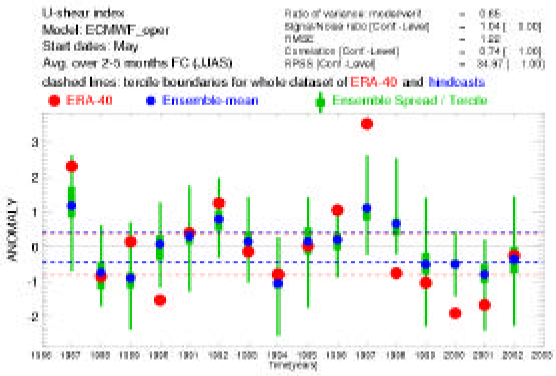


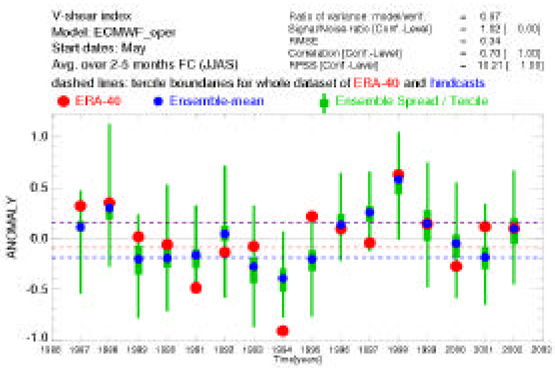




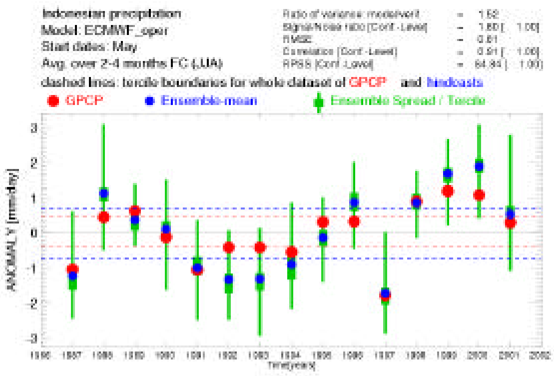
ECMWF: At ECMWF, the seasonal forecast performance with respect to the Asian summer monsoon is monitored operationally. For this purpose, we consider the ensemble forecasts, initiated in May at forecast range 2-5 months. The forecast ensembles, consisting of 40 members, span the period 1987-2002.

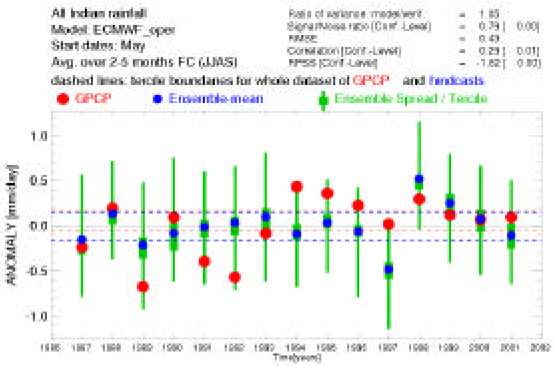
Dynamical indices (the vertical shear of the zonal and of the meridional wind component) and spatial averages of rainfall anomalies (India and Indonesia) are used to estimate the observed interannual variability and the skill of the seasonal forecast predictions. GPCP data are used to verify precipitation, while the other atmospheric variables are verified against a combination of ERA-40 and the operational analyses. The results are shown in the following figures:





According to this, interannual fluctuations in the strength of the monsoon circulation are predicted with some skill. Forecasts of rainfall anomalies over Indonesia are also successful, but rainfall predictions for India show very little skill.





UREADMY: Due to the delays in the production of ERA-40 and the consequent effects on the availability of DEMETER ensembles, the work planned on seasonal predictability has been limited. As reported in WP1000, a major project on vegetation-climate interactions has been undertaken.

3.3 Socio-economic and policy implication

The need for a skilful forecast of the Asian summer monsoon is obvious due to its pronounced socio-economic impact of this phenomenon in the area. However, for precipitation the operational ECMWF seasonal forecast system has only very little skill, but has some skill for predicting changes in the large-scale flow. The DEMETER multi-model ensemble seasonal forecasting system, on the other hand, has also some skill for predicting changes of the overall rainfall and, to a smaller extent, of the local rainfall anomalies. Apparently seasonal forecasts of the Asian summer monsoon can be improved by combining different models, in particular when the predictions of these models are combined in such a way that the "best" forecast is achieved.

3.4 Discussion and conclusion

The fact that the DEMETER multi-model ensemble seasonal forecasting system also has some skill for predicting changes of the overall monsoon rainfall and, to a smaller extent, of the local rainfall anomalies is quite encouraging. (This is, however, only the case when the anomalies for a particular season rather than the actual values are considered, because by this the systematic errors of the models are removed.) Apparently seasonal forecasts of the Asian summer monsoon can already be improved by just adding the anomalies from different models. But in the light of the varying forecast skill of the individual models, one can expect a marked increase of the forecast skill when the predictions of these models are combined in such a way that the "best" forecast is achieved. Due to the delays in the production of ERA-40 and, hence, in the DEMETER predictions, only 12 years of data were available for evaluating the forecast skill of the Asian summer monsoon. Unfortunately, this short period of data did not allow for a meaningful attempt to "optimize" the seasonal forecast of the Asian summer monsoon by an "optimal" combination of the predictions by the different models.

3.5 Plan and objectives for the next period

This has been the final year of the project, but it would be desirable to continue with the work when all the DEMETER predictions become available.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

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Project co-ordinator:	Julia Slingo, CGAM, University of Reading, Reading, UK
Work-package number:	WP1200

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SECTION 3:

3.1 Objectives

To investigate the influence of SST anomalies on the variability of monsoon climates, in particular the role of ENSO with the aim of raising awareness of the processes which must be well simulated by models before climate change predictions for the tropics can be judged useful.

3.2 Methodology and scientific achievements

UREADMY: A series of idealised experiments with the Hadley Centre atmospheric GCM, HadAM3, have been designed to investigate this relationship further. The model has been forced first with SST anomalies in the western Indian Ocean then by SST anomalies in the east and finally by symmetrical dipoles (anomalies of opposite sign in the east and west). These experiments suggest that, in the formulation of HadAM3 used, East African rainfall is linearly dependent on the SST of the western Indian Ocean. The zonal gradient in SST has been found to have no effect, independent of the SST in the western Indian Ocean. Comparison with observational and reanalysis data suggests that this behaviour is dissimilar to that observed - probably as a result of the model's poor representation of the mean state of October low level winds and rainfall.

MPI: The Sahelian region has a decadal variability being among the most pronounced identified in the historical climate records of the 20th century. The rainfall over the West Sahel shows a multidecadal drying trend from the 1950s (wet mode) to the beginning of the 1990s (dry mode), with a slight recovery in recent years. There is scientific agreement that this multidecadal trend is primarily induced by sea surface temperature anomalies (SSTA) and amplified and prolonged by local feedbacks, e.g. vegetation and soil moisture (see our contribution to WP1300). We investigated the impact of tropical decadal-scale SST forcing on West Sahelian rainfall by using the ECHAM4 general circulation model. In contrast to the idealized sensitivity experiments performed previously, more realistic tropical composite SSTA anomaly fields were used to focus on the transition between the wet and the dry mode by perturbing the climatological AMIP2 SST from 1979-1995 (“dry control”) with observed Reynolds SST from 1951-1960 (“wet”) in all or certain ocean basins. The model response (perturbed sensitivity minus control experiment) to individual components and combinations of these tropical composite SST fields in the Atlantic, Pacific and Indian Ocean was then analysed.

The results show that decadal changes in tropical SST are able to produce a dry and wet mode in the Sahel. The tropical Atlantic is not responsible for the recent decadal change in West Sahelian rainfall; in particular, the inter-hemispheric Atlantic SST gradient is not the cause of the decadal drying trend over the West Sahel. The western tropical Pacific decadal SSTAs are more important for the eastern Sahel. Our experiments indicate that the warming of the tropical Indian Ocean that has been observed during recent decades seems to be most important for the recent decadal drying trend in West Sahelian rainfall. A large-scale atmospheric east-west pattern is associated with the warming of the Indian Ocean. As a result, a large-scale divergence response (accompanied by an intensified subsidence) occurs over West Africa in the dry mode. These model results are confirmed by observational results (e.g. Shinoda and Kawamura, J. Met. Soc. Jap., 1994). The experiments also show that the tropical SST warming, especially of the Indian Ocean, might have contributed to the recent decadal change of the North Atlantic Oscillation.

One of the leading modes of rainfall variability over West Africa is a dipole between Sahelian and Guinea Coast rainfall. The experiments show that this Guinea-Sahel rainfall dipole can be induced by simultaneous SST anomalies in the tropical Indian Ocean and in the eastern tropical Atlantic. This mechanism also explains why there is no significant anti-correlation between Guinea Coast and West Sahel rainfall. The SSTs in the tropical Indian Ocean and in the eastern tropical Atlantic evolve more or less independently.

The African monsoon was further investigated by analysing the coupled control integration with the new ECHAM5/HOPE-C GCM. In this control run, there was a high correlation between Sahelian precipitation and a dipole SST pattern (EOF) along the northwest coast of Africa. A similar relationship was found in the observations. To investigate this phenomenon, two SST sensitivity experiments were performed in which the climatological SST was modified by an idealized dipole pattern in this region. However, no significant impacts on Sahelian rainfall were found in these experiments, so that the nature of this relationship in the coupled control integration remains unclear at the moment.

In addition to the experiments described above, the influence of SST anomalies on precipitation over northeast Brazil was also investigated. Three sensitivity experiments have been performed where the climatological SST was increased (decreased) by 1 K in the North Atlantic and decreased (increased) by 1 K in the South Atlantic, and increased by 2 K in the Nino3 region, respectively. All experiments caused significant changes over northeast Brazil, with an enhanced/reduced SST gradient in the Atlantic increasing/reducing rainfall. The response is nearly linear. The main effect of the enhanced Atlantic SST gradient was a shift of the ITCZ, caused by trade wind changes. The 'El Nino'–type perturbation caused a significant reduction in northeast Brazil rainfall. A significant positive sea level pressure (SLP) anomaly occurred over northeast Brazil, which may be associated with the descending branch of the Walker circulation. Also, a significant positive SLP anomaly over the Atlantic region between 30º S and 10º N occurred, resulting in a reduced SLP Gradient from the subtropical highs to the equator and a weakening of the trade winds.

Met Office: We have continued to investigate whether the semi-Lagrangian, non-hydrostatic version of the Met Office Unified Model called HadGEM shows an improved simulation of the teleconnection between the Asian summer monsoon and global sea surface temperatures (SSTs). During year 3 we have also assessed the impact of coupling the atmosphere and ocean models on these teleconnections. Despite the vast differences between the two atmosphere-only models, their dominant modes of interannual variability are very similar (see summary under WP1000). The coupled versions of the two models also show aspects of this mode, but both show additional anomalies over the southeastern equatorial Indian Ocean. Both the atmosphere-only and coupled configurations of HadAM3/CM3 show significant teleconnections between the dominant mode of interannual variability and SSTs in the central and eastern Pacific. Wind and precipitation anomalies in El Nino years are very similar to the dominant modes of variability in these models. This even extends to the additional wind anomalies over the southeastern equatorial Indian Ocean in the coupled model. These teleconnections are rather weak in HadGAM/GEM, suggesting that internal variability may be prevalent in this model. However, anomalies in El Nino years in HadGAM are quite similar to those observed, suggesting that strong SST forcing can outweigh the internal variability on some occasions. In contrast, HadAM3/CM3 responds too strongly to both local and remote SST forcing, such that teleconnections with SST, and anomalies in El Nino years, are less realistic than in HadGAM/GEM.

The appearance of anomalies over the southeastern equatorial Indian Ocean in the coupled models may indicate an improved representation of the Indian Ocean SST dipole mode when the atmosphere and ocean are allowed to interact. Both coupled models also show rather stronger teleconnections with SSTs than their atmosphere-only counterparts in this region. Distinct occurrences of an Indian Ocean SST dipole occur in HadCM3. Anomalies in these years are fairly realistic when compared with observed anomalies from 1994. Occurences of the SST dipole in the HadGEM run are hard to identify, but a realistic representation of the associated atmospheric anomalies can be found in the second mode of interannual variability in HadGEM, and explains 12% of the variance. In the observations, this mode of variability is more prominent than in the models. We note, however, that tests carried out at CGAM (Reading University), where HadAM3 was run with the SST climatology from HadCM3, suggest that it may be the change in SST distribution, rather than the coupling, that improves the representation of this mode. It remains to be seen whether this is the case in HadGEM.

Preliminary analysis of the intraseasonal variability in the models shows a strong similarity between the second mode of intraseasonal variability and the dominant interannual mode in HadAM3. A bias towards positive/negative phases of this intraseasonal mode in El Nino/La Nina years is also apparent. This characteristic has been noted in other climate models. Conversely, there is little similarity between the intraseasonal and interannual modes in HadGAM, suggesting once again that internal variability dominates.

We conclude several things from this work. Different atmosphere-only models can exhibit very similar dominant modes of interannual variability, despite having quite different monsoon climatologies. However, in the case of HadAM3, the variability is strongly linked to SST forcing, while internal variability dominates in HadGAM. In spite of this, we find that strong SST forcing can outweigh the internal variability in HadGAM on some occasions. Coupling the models appears to improve the variability associated with the Indian Ocean SST dipole, although it is possible that this is associated with SST errors over Indonesia. However, links to ENSO are not altered much by the coupling of either model version. Neither model really captures the impact of global SST changes on the monsoon. This may be a result of remaining systematic errors, which are common between the models, or it may suggest that the impact of SST forcing on the atmosphere is not represented properly in either model version. Investigation of these aspects should help to inform future model development.

3.3 Socio-economic and policy implication

Since the oceans provide the fundamental forcing for seasonal variations in climate it is important to understand how the climate system responds to SST anomalies and which aspects of the SST field are relevant for predictability. Improvements in our ability to provide seasonal predictions would have enormous benefits particular in marginal climates such as Africa.

3.4 Discussion and conclusion

The year 2 milestone was to complete the SST sensitivity experiments, to complete the analysis of the causes and mechanisms of climate variability over the Caribbean and to complete the report on investigation of changes in interannual variability and response to idealised SST anomalies. The first and third parts of this milestone have been met. It was explained in the previous annual reports that because of changes in Met Office staffing the Caribbean work will not be done.

A range of modelling studies and analysis of observational data has been used to elucidate the relationship between African rainfall and tropical SST:

- a series of idealised experiments using an atmosphere only model forced with idealised Indian Ocean SST anomalies show that, in the model, rainfall in East Africa is linearly controlled by local SST anomalies. This is inconsistent with observations, suggesting that atmosphere only models cannot capture the interaction between East African rainfall and Indian Ocean SST.
- Model experiments show that the observed dipole between Sahelian and Guinea Coast rainfall can be induced by simultaneous SST anomalies in the tropical Indian Ocean and in the eastern tropical Atlantic
- A control integration of the ECHAM5/HOPE-C GCM revealed a high correlation between Sahelian precipitation and a dipole SST pattern (EOF) along the northwest coast of Africa, which is consistent with observations

Comparing atmosphere-only and coupled simulations of the Asian monsoon, in very different versions of the Met Office's GCM has demonstrated some interesting aspects of model behaviour, which will inform future model development:

- Different atmosphere-only models can exhibit very similar dominant modes of interannual variability, despite having quite different monsoon climatologies
- Coupling the models appears to improve the variability associated with the Indian Ocean SST dipole, although it is possible that this is associated with SST errors over Indonesia. However, links to ENSO are not significantly affected by the coupling of either model version

PROMISE
Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

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Sections included:	Section 3
Work-package coordinator:	Jean-François Royer, Meteo-France CNRM, Toulouse, France
Work-package number:	WP1300

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SECTION 3:

3.1 Objectives

The aim of this work-package is to investigate the role of land surface processes and of anomalies in land surface conditions in determining the variability and predictability of monsoon climates. The modelling group at CNRM (MF) has studied the interannual variability of the African monsoon, particularly the sensitivity of seasonal hindcasts of the monsoon to soil moisture specification. ICTP has analysed the sensitivity of tropical rainfall to soil moisture and evapotranspiration anomalies. MPG.IMET has investigated dimate variability on decadal time scales as resulting from feedback processes between the physical climate system and dynamic land vegetation in the Sahel. CRC-Dijon (UB) has studied the role of seasonal vegetation development in sensitivity experiments with Arpege-Climat to assess the respective roles of the oceanic versus continental surfaces.

3.2 Methodology and scientific achievements

CNRM (MF): The results of the ensembles of seasonal hindcasts based on the ARPEGE-Climat atmospheric GCM over two boreal summer seasons (1987-88) have shown that a relaxation of soil moisture towards the climatology produced by the Global Soil Wetness Project (GSWP) not only improves the model's climatology, but also its ability to reproduce some differences between the two seasons (Douville, 2002). Ensembles of boreal summer atmospheric hindcasts, spanning a longer 15-year period (1979-1993), have been analysed (Douville, 2003a). Each ensemble is made up of ten 4-month integrations from June to September (results are averaged only over the last three months), generated by adding a weak random perturbation to the ERA15 reanalyses. All members of a given season share the same land surface initial conditions. Besides a control experiment using interactive soil moisture (SM) computed by the ISBA land-surface scheme, two sensitivity experiments have been performed with a relaxation of deep SM toward different monthly mean datasets: the ARPEGE climatology (based on the 15 years of the control experiment) and a presumably more realistic climatology (based on the 2 years available from GSWP).

Few tropical areas show a possible influence of SM on predictability at the seasonal timescale. The main exception is the impact found on the predictability of the low-level temperature during the dry season in the southern tropics. In the mid-latitudes, North America shows consistent patterns of decreased predictability of low-level temperature and precipitation in the relaxed SM experiments. In such regions, there is some hope to improve the dynamical seasonal forecasts through a better treatment of the land surface (improved land surface model formulation and/or land surface initialization). Our sensitivity experiments do not allow us to distinguish between the role of initial conditions and boundary conditions of SM, since both are set to climatological values. For this reason, a third ensemble of seasonal hindcasts has been conducted, in which the relaxation is implemented only during the month of June (Douville, 2003b). The results suggest that, in the regions where SM appears as a source of predictability, a large fraction of this extra-predictability originates from the initial conditions of SM. Additional experiments based on other GCMs and on more reliable soil moisture analyses than ERA15 (for example the forthcoming ERA40 or GSWP2 datasets) will be necessary to confirm these results.

<u>*References:*</u>

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Douville H. (2003b): Relevance of soil moisture for seasonal climate predictions: Is it an initial value problem ? Climate Dynamics (in preparation)

ICTP: The Global wind patterns and associated snow anomalies over Eurasia, their predictability and influence on large scale monsoon circulation have been studied in detail (Corti, Molteni and Brankovic). Another contribution of ICTP has consisted in sensitivity experiments with locally modified land surface. In order to study the impact of locally modified boundary conditions on seasonal time-scale predictability, a series of experiments with a recent version of ECMWF GCM was carried out. The experiments were run in ensemble mode at a relatively high resolution, T159-L40. The model was forced with observed SSTs, and initial conditions were taken from ERA-15. The broadleaf and mixed forests over the northern part of South America were replaced by tall grass. In one set of experiments, albedo was set to the appropriate value for tall grass (normal albedo), and in the other was forced to a higher value (extreme albedo).

The model response in forcing experiments was compared against control ensemble. The largest response is found in surface and near surface fields over South America. The amplitude of surface warming and the reduction in surface pressure are stronger in the case with extreme albedo than with the normal one. These changes are also seasonally dependent – they are larger in JAS than in JFM. The reduction in local precipitation rate is consistent with increased temperatures and reduced evaporation due to reduced soil moisture. For global precipitation, the model response is confined mostly to the tropics and to relatively smaller spatial scales. Despite such a patchy precipitation pattern, the response is stronger away from the centre of imposed forcing, in the eastern Pacific and in the Indian Ocean, than in the central and western equatorial Pacific. In the northern winter upper-air fields, a coherent wavetrain across the northern hemisphere emerges.

MPG.IMET: During this year the effect of mid-Holocene changes in the Earth's orbit and the presence of vegetation, lakes and wetlands in today's Saharan region has been studied. Experiments with ECHAM4 using today's and mid-Holocene insolation and SST forcings emphasize the importance of the changed land surface for the realistic simulation of the "green Sahara". Orbital changes alone were not able to maintain the increased amplitude and northward shift of the West African monsoon. Preliminary results from coupled experiments using the ECHAM5-MPI/OM1 AOGCM suggest a somewhat larger role of the insolation changes.

UB-CRC: UB has carried out further analyses of the performed AGCM sensitivity experiments to seasonal vegetation development in West Africa. The results show that changes in the seasonal cycle of the vegetation over Sudan-Guinean region significantly impact Sahelian rainy season onset and rainfall amounts in ARPEGE-Climat via local changes in lower atmospheric conditions. These impacts are however smaller than global SST-related changes. Still they highlight the model sensitivity to the vegetation feedback. Further vegetation monitoring in this region is needed to better assess the magnitude of interannual changes in the vegetation cycle during the pre-onset period. An other part of the work, based on data analyses, also pointed out the importance of the low level zonal dynamic and moisture convergence for the Sahelian Monsoon. The links to the global circulation vs local conditions are currently being investigated.

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3.3 Socio-economic relevance and policy implication

The results obtained confirm the importance of understanding and including the feedbacks between land surface conditions and the atmosphere on regional climate systems, such as the African and Indian monsoon. Further improvements of the land surface component and of its initial state by means of suitable measurements of the soil water content, will need to be introduced to produce more accurate climate simulations, which will be of significant value for regional climate change forecasting, and for impact assessment.

3.4 Discussion and Conclusion

During the third year of this project the participating groups have completed the analysis and published the results of their numerical simulations documenting the sensitivity of the monsoon to different aspects of land surface processes. The importance of a correct specification of soil moisture for seasonal predictions of Sahel rainfall is confirmed by the sensitivity experiments carried out at MF. Simulations at UB have shown that changes in the seasonal cycle of the vegetation over Sudan-Guinean region could have a significantly impact on the onset and rainfall amounts of the Sahelian rainy season. ICTP has carried out ensemble simulations at high resolution to investigate the impact of Amazonian deforestation. The simulations with a coupled vegetation model at MGP.IMET have shown the importance of using a dynamic vegetation for enhancing the variability and persistence of rainfall anomalies over the Sahel and Sahara regions.

PROMISE

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3rd Periodic Report

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SECTION 3

3.1 Objectives

The objective of this work package is to evaluate the future impacts of anthropogenic climate change on monsoon climates using control and transient GCM model integrations, including regional and high-resolution models. During the third project year, the evaluation of high-resolution global time-slice integrations with respect to the Indian and African monsoon climates has been continued.

3.2 Methodology and scientific achievements

High-resolution model integrations are used to study changes in the characteristics of monsoon climates, including extreme events, and to provide the higher spatial resolution needed for the impact studies involving agriculture and hydrology. These higher-resolution simulations are performed using time-slice experiments with global AGCMs. In the 'time-slice' setup, the output from standard transient simulations is used as boundary conditions for high-resolution atmospheric GCMs that are run for relatively short present-day and future time periods.

CNRM (MF): The aim of MF-CNRM was to develop new climate scenarios for studying the impact of anthropogenic climate change with specific focus on the African monsoon region. This has been done by performing first transient coupled climate scenarios for the 21st century, and then time-slice simulations for present and future climate with both a uniform and a stretched resolution version of ARPEGE-Climat.

MF-CNRM has performed several new 150-year long transient climate change simulations over the period 1950-2100 with the coupled atmosphere-ocean-sea ice model developed at CNRM and CERFACS, in order to provide the input data for the evaluation of the impact of anthropogenic climate change on monsoon climate (Royer et al, 2002). The overall analysis of the scenario and of the impact on the hydrological cycle (Douville et al, 2002), and the detailed analysis of the scenario for the impact over Africa (Maynard et al, 2002) have been published. A systematic verification of the simulated late 20th century has been made, for the mean climate, the interannual variability and the teleconnections. Trends simulated in surface air temperature and precipitation have been compared to the CRU climatology. An analysis of the response of the Indian monsoon and its teleconnections with ENSO has been performed (Ashrit et al., 2003). The climate anomalies for the second half of the 21-st century, when compared to the second half of the 20-th century, show a significant increase in the mean annual surface air temperature over India of 2K with a maximum in winter, and of about 9-10% in monsoon rainfall due to increased moisture convergence. A northward shift of the westerly monsoon flow over the Arabian Sea and India, along with a relative weakening of the zonal monsoon circulation is simulated, together with a strengthening of the regional meridional Hadley circulation. The increase in precipitation has been attributed to the large increase of total precipitable water over India in the warmer climate, which plays a more important role than the circulation changes. Large multi-decadal fluctuations are found in addition to the long-term increase in simulated precipitation. The simulations show a Nino- like warming in summer, but no systematic change in SST variability in the Pacific. A strong correlation of Indian monsoon rainfall with east equatorial Pacific SST is found during summer and fall. The simulated ENSO-monsoon teleconnections have a strong modulation at the multi-decadal time scale but no systematic weakening in response to global warming.

The scenarios over Africa performed in "time slice" mode with the variable resolution version of ARPEGE-Climat (T106, with stretching factor of 2.5) have been analysed. The comparison of the time slice simulations with the coupled simulations shows several improvements in the simulations of the African monsoon. The improvements are due to the use of more realistic observed SST climatology which allow to remove the bias in SSTs produced by the coupled model, in particular the excessively warm SSTs in the Gulf of Guinea. Similar "time slice" simulations have been repeated with a uniform resolution (T63). The comparison of the variable resolution and the uniform resolution simulations shows broadly similar deficiencies in their climate, with only a small improvement with the increased resolution. The patterns of response to greenhouse warming are also very similar.

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DMI: The potential future change of various aspects of the Indian summer monsoon as a consequence of the anticipated increase in the atmospheric greenhouse gas concentrations was further investigated. This was done on the basis of a global time-slice experiment with the ECHAM4 atmospheric GCM at a high horizontal resolution of T106. The first time slice (period: 1970-1999) represents the present-day climate and the second one (period: 2060-2089) the future climate. The investigation includes aspects of the large-scale flow as well as of the hydrological cycle, in particular the day-to-day variation and the extremes of daily rainfall during the monsoon season. The time-slice experiment (period 1970-1999) simulates many aspects of the Indian summer monsoon very well, and due to the fine horizontal resolution of about 120 km many regional details of the rainfall pattern are well captured. Therefore, the time-slice experiment is quite suitable for assessing the potential future change of the Indian summer monsoon.

Despite a weakening of the large-scale monsoon flow in the future, the time-slice experiment predicts an increase of the mean rainfall during the Indian summer monsoon over most of the Indian region. The strongest increases occur in those regions, where the monsoon rainfall is rather strong, namely along the west coast of the Indian peninsula, over the tropical Indian Ocean, over the Bay of Bengal, and in Bangladesh and in the foothills of the Himalayas. Decreases, on the other hand, are found in the central part of the Indian peninsula and over the adjacent part of the Bay of Bengal, in Pakistan, in Tibet, and in southeast China, namely in the regions with rather weak monsoon rainfall. Apparently, the regional pattern of the monsoon rainfall is more pronounced in the future, due to an intensification of the atmospheric moisture transport into the Indian region in the future.

The future changes in the mean monsoon rainfall are only to a small extent due to changes in the frequency of days with rainfall, the so-called wet days, defined as days with precipitation exceeding 0.1 mm. There is, however, a general tendency of wet days occurring more often over the Indian Ocean and the Indian peninsula and occurring less frequently elsewhere. As a consequence, the future changes in the intensity of daily rainfall mainly account for the changes in the mean monsoon rainfall, and, hence, the distribution of the future change of the mean rainfall on wet days, giving the so-called rainfall intensity, has various features in common with the changes in the mean monsoon rainfall. But for the rainfall intensity, some of the areas with a reduction of the rainfall are smaller than for the mean monsoon rainfall, namely over the eastern part of the Indian peninsula, in Pakistan, in Tibet, and in southeast China.

One way to capture the heavy monsoon rainfall is by the 95%-percentile of the precipitation on wet days. That is, more precisely, the average amount of precipitation occurring on the 5% of the wet days with the strongest rainfall. For the future, the time-slice experiment predicts an increase of the amount of precipitation associated with heavy rainfall in most of the area. The strongest increases occur over the northern end of the Bay of Bengal, in the Himalayan foothills, over the Indian Ocean south of about 10° N, and over the Arabian Sea. Except for the region over the northern part of the Arabian Sea and, to a small extent, over the eastern Indian Ocean, these are the regions where also the maxima of the 95-percentile are located. But the values of the 95%-percentile are markedly reduced in the northeastern part of the Indian peninsula and over the adjacent part of the Bay of Bengal.

The comparison with the future changes in the rainfall intensity reveals a number of differences: As for the quantity, the changes in the 95%-percentile are considerably stronger than the corresponding changes in the rainfall intensity. In some regions, such as over the northern part of the Arabian Sea, in Pakistan, over the centre of the Indian peninsula, and in Indochina, the change in the 95%-percentile is up to 20 times as strong as for the intensity. As for the quality of the changes in the 95%-percentile, two regions with different signs of the respective changes stand out. In southeast China (Pakistan) the heavy rainfall, i.e., the 95%-percentile, is increased (reduced) in the future, while the rainfall intensity is reduced (increased). Further, in the central part of the Indian peninsula the area with a decrease of the heavy rainfall is larger than the corresponding area with a reduction of the rainfall intensity.

3.3 Socio-economic and policy implications

Obviously, improved projections of future monsoon climates, in particular for extreme precipitation events and surface hydrology, based on regional and high-resolution global climate models is important for the impact assessment of anthropogenic climate change on the Asian and African monsoon regions. The needs for water resources are increasing with the growth of the population and intensification of agriculture and a good prediction of monsoon variability is of paramount importance to plan ahead and limit climate-induced socio-economic problems. The simulations performed have confirmed a large impact of global warming on the monsoon rainfall in Africa and India, both in the mean change and the increase of extreme events.

3.4 Discussion and conclusion

The precipitation changes simulated by CNRM-MF for the 21st century show an enhanced monsoon precipitation over the African and Indian monsoon regions. These results have been confirmed by time-slice simulations for the periods 1970-1990 and 2040-2060 using a stretched grid version of ARPEGE-Climat with higher resolution over Africa. Though the use of a finer resolution allows to represent in more details regional features such as orography and the land cover distribution, it has only a very limited local effect and improve only marginally the large scale biases of the model, which apparently are mainly dependent on the physical parametrizations. DMI has further evaluated its high-resolution time-slice experiments with regard to changes in extreme precipitation in the Indian monsoon system. The simulated increase of mean rainfall during the Indian summer monsoon in a warmer climate are mainly related to an increase in rainfall intensity, as opposed to the frequency of rainfall occurrences. In addition, the results indicate an increase of heavy precipitation extremes in the future.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

Contract number:	EVK2-CT-1999-00022
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Sections included:	Section 3
Workpackage co-ordinator:	Katia Laval, CNRS-LMD, Paris, France
Workpackage number:	WP2100

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SECTION 3:

3.1 Objectives

The objectives of this work package is to study the influence of anthropogenic changes of the surface on tropical climate. The CNRS-LMD is focused on the effect of irrigation on the hydrological budget.

The objective of MF-CNRM in this workpackage was to use scenario integrations to investigate the possible influence of future anthropogenic land-use changes (deforestation or afforestation) on the surface climate over Africa. The land surface plays an essential role in the heat and water balance of the ground, and changes in the land cover can influence the local climate conditions. The potential role of anthropic vegetation changes such as tropical deforestation is considered as a major environmental issue, but most of the previous sensitivity experiments with GCMs have been of the massive deforestation type and are not truly representative of expected future conditions.

3.2 Methodology and scientific achievements

CEH: Three vegetation scenarios to be input into the Unified Model GCM were finalised, based on land use estimates for 1961, 1996 and 2030. Historical changes are dominated by loss of vegetation in the Sahel due to agricultural expansion, and deforestation in Ivory Coast. Predictions of future changes in Sahelian vegetation are less dramatic, due to the lack of remaining natural vegetation. However, large areas of tropical forest in the Congo basin are expected to be lost in the coming decades.

These scenarios have been used in a series of GCM simulations, initially using climatological mean sea surface temperatures (SSTs). In general the model produces a small but consistent reduction in precipitation throughout the region due to changes in land use. The largest changes occur in regions with the greatest deforestation (e.g. Ivory Coast, Congo Basin), with reductions of up to 10% annual rainfall at individual grid points. Interestingly, the precipitation in the west African monsoon region increased with the change from 1996 to 2030 land use, in spite of regional losses in vegetation. An additional simulation was performed to investigate the impact of the remote deforestation occurring during this period in the Congo Basin. The model suggests that the anticipated deforestation in that region may produce enhanced precipitation in the Soudan and southern Sahel, offsetting any local effect.

The importance of land use change for understanding the historical record of Sahel rainfall was examined with further simulations adopting alternative SST scenarios from extreme years. The sensitivity of summer rainfall to SST is an order of magnitude larger than the sensitivity to land use change. This suggests that the impact of land use change on climate in the region is second order compared to the natural climate variability of the region. Additional runs with imposed leaf area index anomalies were performed to examine the role of biophysical feedbacks on rainfall in extreme years. The runs support the suggestion that the natural response of the vegetation to rainfall amplifies the external (SST) forcing. In addition, the results suggest that this feedback may become more important with loss of natural vegetation.

MF-CNRM: The response to the future vegetation changes over Africa in time-slice simulations with the variable resolution of ARPEGE-Climat has been compared to the response due to greenhouse forcing alone (Maynard and Royer, 2002a). The response to African deforestation has been found to be generally smaller than in previously published deforestation experiments. Annual mean precipitation was reduced significantly only in equatorial Africa. A relatively small evaporation reduction is also found to be significant. A detailed analysis has been made to outline the role of different land surface parameters in the overall response, in particular the interactive role of soil wetness and stomatal resistance variations due to changes in the vegetation cover. Changes in stomatal resistance are found to modulate significantly the surface latent heat fluxes. Evapotranspiration generally increases with decreasing stomatal resistance, and the impact of changes in stomatal resistance is higher wherever soil moisture is not a limiting factor, such as in African tropical forests. With high soil moisture availability, lower stomatal resistance allows larger water vapor release, leading to higher evapotranspirative flux. The study thus indicates that the evapotranspiration control is more via soil moisture availability, than directly via vegetation cover changes.

Additional sensitivity experiments have been made to separate the influence of the different land surface parameters in the response to tropical vegetation changes (Maynard and Royer, 2002b). A simulation has been made with a scenario of large scale reforestation over Africa by using the potential vegetation map produced by the IMAGE model for 2050. However the impact was found to be dependent on changes in the computation of some land surface parameters in ISBA, such as the inclusion of subgrid-scale orography in the computation of the surface roughness length (Maynard and Royer, 2003)

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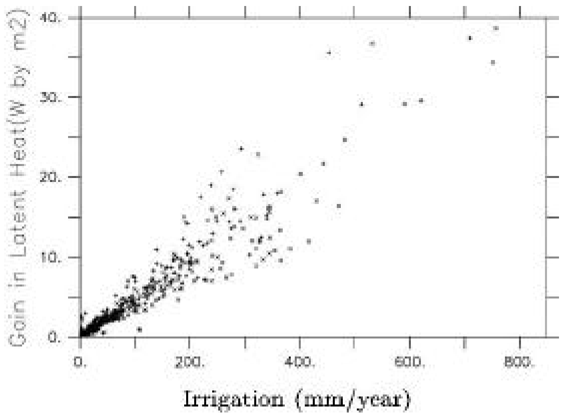
LMD-CNRS : An irrigation scheme was developed in ORCHIDEE during the PROMISE project. Particular attention was devoted to the relevance of the irrigation requirement parametrization. The FAO formulation (Smith, 1992) was chosen for the representation of irrigation water requirement. Since this is a local scale parameterization, an important part of the work was devoted to adapte and adjust this parameterization to the large scale representation of the land surface processes in ORCHIDEE (from which water demand is computed) and to the interaction with the river routing scheme (which represents the water supply). Accordingly, irrigation scheme allows to make a link between the routing scheme and the land surface scheme. The developped irrigation scheme includes three components. First the irrigation water requirement is computed. Second, the actual irrigation is computed according to the relative equilibrium between water demand and supply of each grid cell. The resulting actual irrigation is withdrawed from the river system and aquifer reservoirs. Third, the computed irrigation is added to the land covered surfaces of each irrigated grid boxes of the model. To validate this innovative parameterization, different numerical experiments, with and without irrigation, were conducted with the land surface scheme ORCHIDEE forced by the ISLSCP(I) atmospheric data set (Meeson et al., 1995) at 1 degree spatial resolution. The simulated irrigation over Indian Peninsula was validated by comparison with different estimates (Doell and Siebert, 2002; FAO, 1999) and the sensitivity of the surface fluxes and the rivers flow to the irrigation was also studied. The model is shown to captures the main features of the geographical and temporal variations of the irrigation over India. As expected the intensive irrigation over the Indian Peninsula leads to increase the annual mean value of the latent heat fluxes (Figure). The increased values of the latent heat fluxes influence the surface energy budget which in turn affects the plant water demand through a positive feedback. Based on the feasibility and relevance of this preliminary approach, further numerical experiments with the land surface scheme ORCHIDEE and coupled to the LMD General Circulation Model are devoted to study the interactions and feedbacks between irrigation and climate, from regional to global scales.



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3.3 Socio-economic relevance and policy implication

MF-CNRM: Vegetation changes of anthropogenic origin need to be considered for improving the realism and regional accuracy of the assessments of the land surface impact in future climate scenarios. The conclusion that can be drawn from these simulations is that realistic future vegetation changes have only a limited impact on the simulated climate, but which may be important to consider to improve the simulation of the regional climates.

LMD-CNRS: The problem of water resources can be the most serious problem our society will face in the next decades. As the demand for water increase, an important issue is the evaluation of changes of the hydrological budget that countries experience, not only due to climatic change related to CO2 increase but also due to human disturbances through reservoir construction and water use by agriculture. Our study is focused on this issue of major importance for the future.

3.4 Discussion and Conclusion

MF-CNRM: The impact of greenhouse forcing and vegetation changes have been compared, with particular emphasis on the surface climate changes over Africa. The results show that the greenhouse forcing is the dominant factor on the climate change over the whole of Africa, with vegetation changes having only a local impact over the deforested areas. The response seems also to be dependent on the choice of parameters in the land surface scheme.

LMD-CNRS: We have developed the tools needed to study the effect of irrigation on climate. The land-surface scheme, ORCHIDEE, has been prepared and coupled with an irrigation scheme to simulate the influence of irrigation on the water budget over India. We have shown that irrigation over Indus and Ganges basins is able to increase the latent heat fluxes over irrigated areas and to perturb the river flows of these two basins.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Annual Report

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Sections included:	Section 3
Project co-ordinator:	Jeremy Meigh, NERC, CEH Wallingford, UK.
Work-package number:	WP3000

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SECTION 3:
3.1 Objectives
The objective of the work package was to develop methods of assessing the impacts of natural and anthropogenic climate change on ground hydrology and water resources for monsoon-affected countries. For NERC this involved the adaptation and setting up of a detailed hydrological model of the West African region to assess the impacts of land cover change and climate change on water resources. For CNRS-LMD the objective was to use an on-line hydrological model to analyse river discharge in climate simulations for the tropical areas of the Parana and the Niger.

3.2 Methodology and scientific achievements
NERC: Our work made use of the Global Water AVailability Assessment method (GWAVA) which was developed by the Centre for Ecology & Hydrology and the British Geological Survey in order to provide an improved methodology for the assessment of water resources in relation to water demand for application at the global scale. The approach is based on a 0.5 by 0.5 degree latitude-longitude grid, and it attempts to improve on previous work by:

- adequately representing the spatial and temporal variation in both water availability and water demands, thus avoiding the distortions of national averages;
- simulating the effects of natural features (lakes and wetlands) and human-made features (reservoirs, abstractions and long-distance transfers) which have major effects on the availability and flow of water;
- accounting for the full range of demands, including domestic use, industry, irrigation and livestock;
- treating the problems of international river basins in a realistic manner; and
- providing for the assessment of future scenarios of the balance between water availability and demand due to climate change, population growth, urbanisation and increasing per capita consumption.

The main output of GWAVA is the comparison of water availability and demand at the scale of the grid cell, enabling the variability and complexity of the water resources situation to be appreciated.

Within the PROMISE project, GWAVA was set up to model the West African region, and the necessary input data on current baseline conditions were assembled, as well as scenarios of change in climate, population, water demands and land use. The modelling area covered the whole of the West African region, a box of approximately 17°W to 24°E and 0°N to 23°N. This area comprises more than 2500 0.5° by 0.5° grid cells (*i.e.* a grid size of around 50 km by 50 km), and includes 22 countries, having a wide range of hydrological regimes and climates. Topographic maps of the whole region were used to identify the river network so that flow routing within the model could be made to mimic the natural drainage system (Figure 1). Information on lakes, reservoirs, wetlands, soil types and vegetation cover was assembled from a variety of sources and set up for input to the model on a gridded basis. Grid-based data on the baseline climate for the region were acquired from the Climatic Research Unit at the University of East Anglia. Observed flow data at key sites in the region were assembled to be used as calibration data. Using this information, the model was set up and run to simulate baseline conditions across the region. A reasonable degree of calibration against observed flows was attained. For the many areas for which no observed flow data were available, model parameters were determined based on the general similarity with neighbouring areas which did have data.

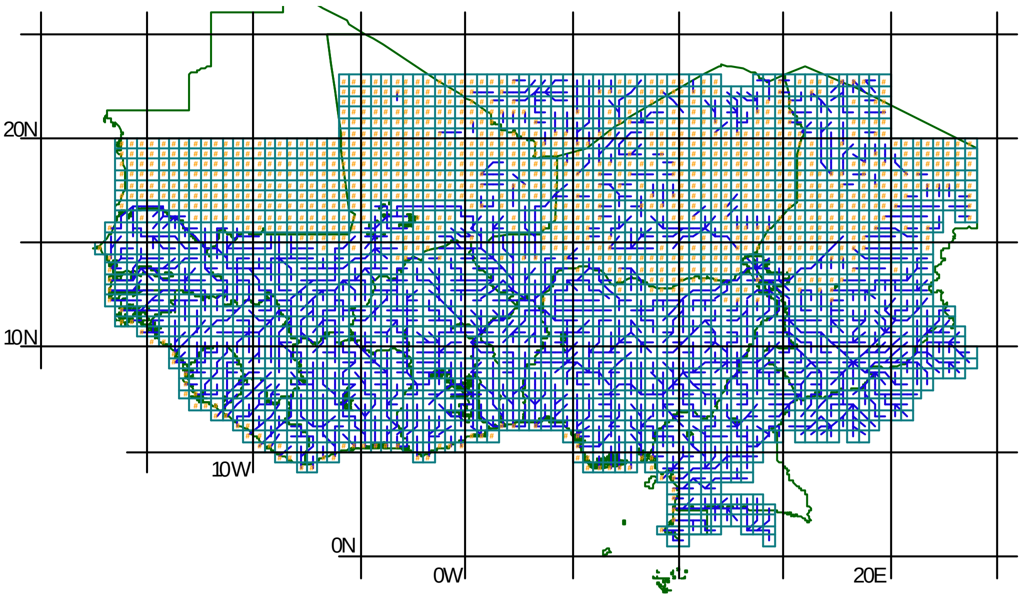

Figure 1 *River network, modelling grid and cell linkages for the West African study region.*

The main controlling factors on the parameters of the GWAVA model are the soil type and land cover type. Because the West African region has experienced very extensive changes in land cover due to forest and woodland clearance and livestock grazing, and these changes are expected to continue into the future, the modelling system was modified and tested to enable a wider range of land cover types to be accommodated. Data on land coverages were obtained from IGBP-DIS, and re-classified from their 17 classes to a set of four (tree, shrub, grass, and bare soil). Sample catchments were identified to test the modified land cover data, and to test the sensitivity of the model to those inputs. Scenarios of future land cover at the national level were taken from work done under WP2100, and distributed across the grid based on the distribution for baseline conditions.

CNRS-LMD: During the last year of the PROMISE project we have integrated into the coupled atmosphere/land-surface mode the routing schemes which was developed over the last two years of the project and includes the impact on the water cycle of tropical floodplains and irrigation. In order to test the ability of the model to simulate the discharge of the large tropical rivers an AMIP integration over the period 1979-1999 was conducted.

With this simulation and the off-line experiment which only uses the land-surface scheme and the routing scheme, we could analyse the results from the coupled experiment and distinguish between errors induced by the atmospheric forcing provided by the model and the errors due to the land-surface. For this analysis we concentrated on the annual cycle and the inter-annual variability of the discharge of the Parana and the Niger rivers.

The comparison of these two basins is interesting in many aspects. First they both are under the influence of tropical climates and have within their catchment major floodplains. The precipitation simulated by the atmospheric model is quite realistic in both areas except for a systematic underestimation of the annual mean rainfall. For the Parana this has the consequence that in the coupled model the river nearly dries up in October and November at the station of Corrientes, something which does not occur in the off-line simulation. Introducing the floodplains of the Pantanal improves the annual cycle of the discharge but does not correct the systematic bias which results from the low precipitation.

Over the Niger, the under-estimation of precipitation does not have such severe consequences and the discharge at the Niamey station is of comparable quality to what is obtained in the off-line mode. The difference between the precipitation used in the off-line mode and our reference climatology is comparable to the difference with the values produced by the AGCM. On the other hand the impact of the floodplain on the hydrograph obtained off-line can not be reproduced in the coupled mode. When the land-surface is forced by the AGCM there is no difference at the Niamey station between the simulations with and without the floodplains.

A more detailed analysis of this result has shown that the synoptic variability of the precipitation in the GCM is much too low. This results in very small fluctuations in the flow of the river and thus no generation of floods in the inner delta of the Niger. For the model to reproduce correctly the discharge of the river at Niamey it is thus paramount to improve the daily variability of the convective systems which generate the largest fraction of the rainfall.

It is a remarkable feature of the hydrological cycle of the West African region that the relative inter-annual variability of the discharge of the Niger is nearly twice as large as that of the precipitation. It was thus tempting to see if this new model could reproduce this result.

Std Variations of anomalies in %	***Precipitation***	***Discharge***
Observed at Koulikoro	10.7	28.0
Koulikoro: AMIP	9.9	31.2
Koulikoro: AMIP + floodplains	11.2	35.3
Observed at Niamey	9.9	26.6
Niamey: AMIP	11.1	31.2
Niamey: AMIP + floodplains	12.2	35.3

The atmospheric model produces an inter-annual variability of rainfall which is larger than observed. The land-surface scheme is able to amplify this signal and probably exaggerates the effect as the variability of the discharge in Niamey is too large. As noted above, the inter-annual variability occurs around a mean annual cycle of which the amplitude is underestimated. This result shows that the processes involved in the runoff generation in the land-surface scheme, and which will have a tendency to amplify the precipitation anomalies, work well at the annual scale. To refine the diagnostic of these processes in the model longer integrations of the model are needed and an ensemble of simulation is needed. As previous studies have shown, these results will probably not hold at shorter time-scales.

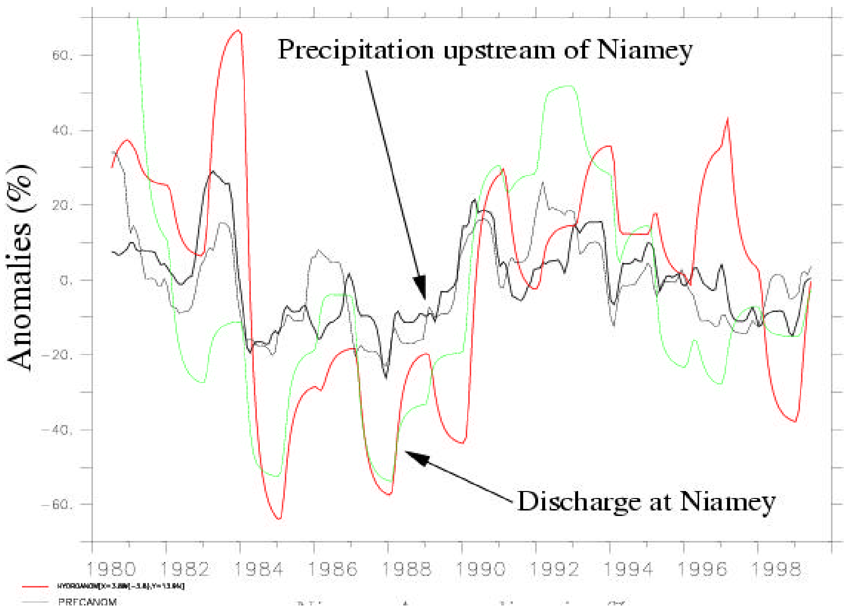

Figure 2 *The anomalies for precipitation upstream of Niamey and the discharge at Niamey are shown over the length of both simulations. The amplification of the precipitation variability by the hydrological basin is visible.*

3.3 Socio-economic and policy implications

With regard to the grid-based hydrological model, the key objective of GWAVA was to develop a method which was based on a more realistic representation of the world than had been achieved in previous assessments and which provides more meaningful and more detailed results. It is an approach which allows policy makers and others to make better informed resource allocation decisions, and facilitates the assessment of impacts of human activities – such as climate change and land use change – on water availability in relation to people's needs for water for all purposes. The results (see below) clearly indicate the likelihood of increasing water shortages in the semi-arid Sahel zone of the region where population densities are high and water is already scarce. This region is one which already suffers from high levels of poverty and water stress, and the results reinforce the pressing need to promote and fund adaptation strategies for improved water resources provision and management in this area.

3.4 Discussion and conclusion

NERC: The grid-based approach requires large amounts of data, but the benefits of modelling the spatial and temporal variation in water availability and demand mean that it is ideal for assessing the impacts of climate and land use change on water resources at this scale.

Using the modified GWAVA model we examined the expected changes in water stress over the study range for a variety of scenarios, including climate, population, water demand and land use changes. All these changes were examined together because it is inevitable that the changes will all occur at the same time, rather than in a piecemeal fashion. The climate scenarios used were the Hadley Centre's HadCM3 (with low and high emissions assumptions) and the ARPEGE-Climat model of Meteo France. There were some marked differences between the models, but these were mainly in areas of high rainfall where water availability is good, so the final results, when looked at in terms of water resources, are reasonably similar. Overall they indicate a marked increase in the areas suffering high water stress in the Sahel zone (Figure 3).

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

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Project co-ordinator:	Julia Slingo, CGAM, University of Reading, Reading, UK
Work-package number:	WP3100

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SECTION 3:

3.1. Objectives

Workpackage 3100 is entitled '<u>Seasonal prediction of crop yields and assessment of climate change impacts on crop productivity</u>", with deliverables 3101 (Identification of parameters for crop models and evaluation of seasonal prediction and crop models), 3102 (Integrated system for interpretation of seasonal forecasts in terms of crop development and yield) and 3103 (Assessment of impacts on crop productivity). The objective of WP 3100 is therefore to <u>develop tools to derive agronomic scenarios (crop performance) from seasonal and longterm climate simulations, and to evaluate these scenarios</u>. Target areas for these activities are the <u>Sahel</u> (main annual crops) and <u>India</u> (groundnut).

3.2 Methodology and scientific achievements

UREADAG/UREADMY: The large area model developed at the University of Reading (GLAM) has been tested for groundnut yield across India in deterministic mode, using observed gridded data on a 2.5 by 2.5 degree grid (a similar resolution to that of climate models). Optimal model parameters and diagnostic outputs such as the Specific Leaf Area were consistent with field experiments. Optimal parameters were stable over space and time. All parameters except the yield gap parameter were stable across two input weather datasets. The optimal yield gap parameter varied only across space and input data set; hence it can account for some of the bias in input weather data in addition to some of the yield gap. Temporal stability in optimal parameters was disrupted if a two- rather than one- piece linear yield technology trend is assumed for the full twenty-five year period. Hence for any future operational system, care will be needed when accounting for the technology trend.

Three sites have been examined in detail - grid cells from Gujarat in the west, Andhra Pradesh towards the south, and Uttah Pradesh in the north. Agreement between observed and modelled yield was variable, with correlation coefficients of 0.74, 0.42 and 0, respectively. Skill was highest where the climate signal was greatest, and correlations were comparable to or greater than correlations with seasonal mean rainfall. Yield from all 35 cells were aggregated to simulate all-India yield. The correlation coefficient between observed and simulated yields was 0.76, and the root mean square error was 8.4% of the mean yield.

The model is suitable for use with large--scale input data such as GCM output, where an exploitable correlation exists between weather and yield on the scale in question (Challinor et. al. 2003a). The model has a relatively low input data requirement, and can be used where more spatially detailed modelling followed by aggregation is not plausible (due to, for example, resource limitations or input data availability/quality). The results outlined briefly above have been presented in detail in Challinor et. al. (2003b).

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Challinor, A.J., J. M. Slingo, T. R. Wheeler, P. Q. Craufurd and D. I. F. Grimes, 2003a: Towards a combined seasonal weather and crop productivity forecasting system: Determination of the spatial correlation scale. *Journal of Applied Meteorology*, in press.

Challinor, A.J., T. R. Wheeler, J. M. Slingo, T. R. Wheeler, P. Q. Craufurd and D. I. F. Grimes, 2003b: Design and optimisation of a large-area process-based model for annual crops. Submitted to *Agricultural and Forest Meteorology*.

CIRAD

Advances in local-scale modelling

On-farm and on-station validation of the crop model SARRA-H

For the on-station calibration and validation of SARRA-H, detailed datasets on millet were provided by CERAAS, permitting growth analyses for 3 years and several water regimes at the Bambey site in Senegal.

The model represented realistically the dynamics of dry matter, yield (Fig. 1) and water use (Fig. 2) of the crop in various stress situations, with attainable yields of up to 11 t/ha (above-ground biomass) and 4 t/ha (grain). By contrast, the model over-estimated 3-4 fold farmer's millet yields surveyed for 2001 in various regions of Senegal (data aggregated for groups of villages), covering 200-650 mm rainfall (cumulative during crop growth), and 13.8° to 15.7° N latitude (Fig. 3). Indeed, according to practitioners' experience, farmers' yields are usually between 0.2 and 1.0 t/ha depending on rainfall, but may reach 4 t/ha occasionally. Importantly, the crop model explained 78% of yield variation among sites, indicating that climate explains most of the variation of yield, whereas the low absolute level of yields compared to the attainable level must be due to other factors.

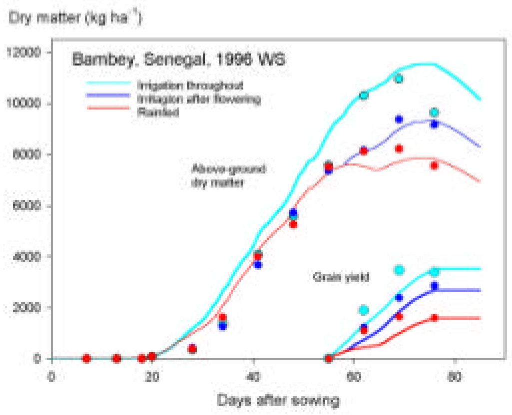


Fig. 1. Simulated (lines) and observed (points) biomass and yield of a millet crop in summer 1996 in Bambey, Senegal.

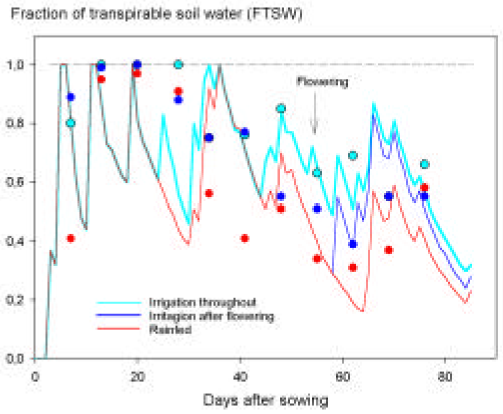
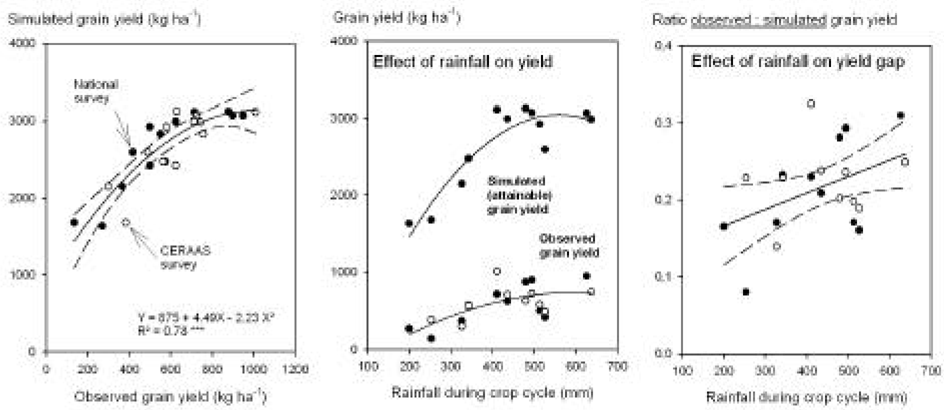


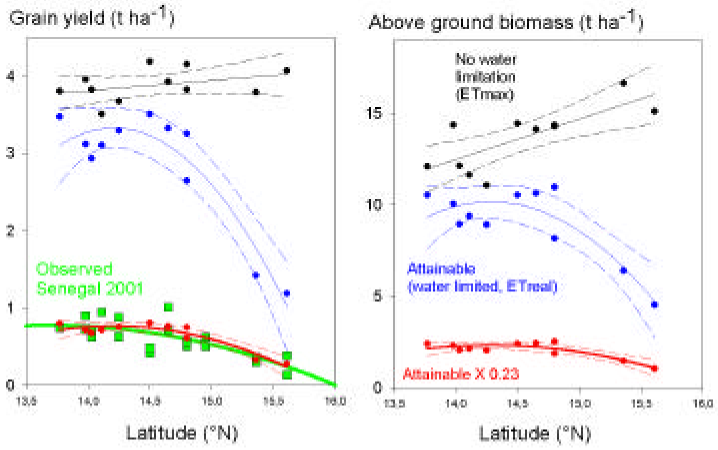
Fig. 2. Simulated (lines) and observed (points) fraction of transpirable soil water (FTSW) in the field for the same crops as in Fig. 1. Simulations take into account drought dependent progress of the root front.

Fig. 3. On-farm validation of the SARRA-H crop model in Senegal, 2001. Left: relationship between simulated (attainable) and observed grain yield for millet. Centre: Simulated and observed grain yield as a function of rainfall received during the season. Right: Relationship between the fraction observed : simulated grain yield and seasonal rainfall, indicating that the yield gap increases as rains decrease.



A comparison between potential (water unlimited), attainable (water limited) and actual farmers' yields (Fig. 4) indicated that with increasing latitude, potential yield increases due to increased radiation, and attainable and farmers' yields decrease due to water limitation. Above-ground biomass production was thereby more sensitive to solar radiation, and grain yield was more sensitive to water limitation.

Fig. 4. Simulated potential, attainable and farmers' yield levels as a function of latitude in Senegal. Broken lines indicate 5%-confidence interval.



Evaluate and minimise model sensitivity to geographical scale

Model sensitivity to spatial aggregation and disaggregation of rainfall

The sensitivity of plot-scale crop simulation to spatial aggregation of climate was tested by experimentally aggregating and disaggregating available rainfall data for an area in Senegal centered on 14.5°N 15°E. The study area covered 7 weather stations (1° pixel square) or 17 stations (2.8° pixel). Aggregation (up-scaling) of yield and rainfall data for the pixels using simple or weighted averages by kriging gave the same results. Analyses were done for 31 years (1950-1980).

Running the crop model for points (plot scale) and large aggregated pixels gave very different partitioning of water (Fig. 5) and yield levels for millet (Fig. 6). On average, the "useful" fraction of rains (transpiration) was much greater when aggregated data was used, reflecting an under-estimation of runoff and deep drainage due to "smoothened" rainfall distribution. This led to an over-estimation of yield by 63% for the 2.8° pixel (50% for 1°).

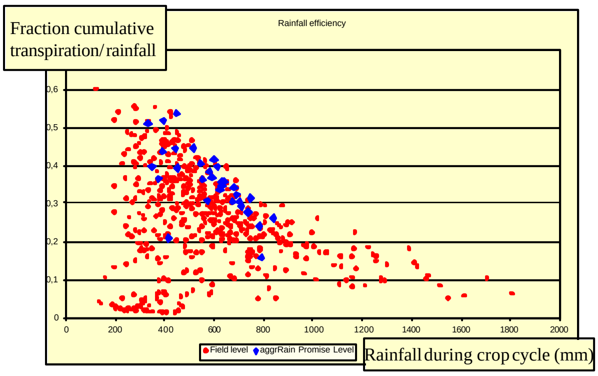


Fig. 5. Simulated fraction of useful rainfall (seasonal transpiration over rainfall during crop cycle) for 31 years on individual locations (red) and an aggregated, 2.8° pixel (blue). Simulations with SARRA-H.

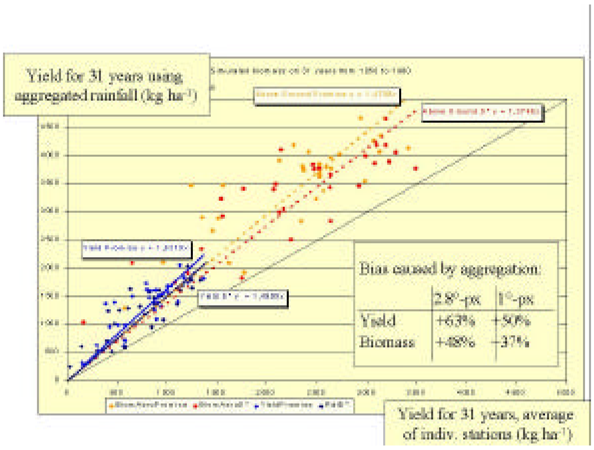


Fig. 6. Relationship between yield (blue) and biomass (red) simulated with aggregated rains (2.8° and 1° pixels) and plot level rain distribution using SARRA-H.

Disaggregation of large pixels to permit plot-scale crop simulation

The results of scaling studies showed clearly that plot level water balances cannot be predicted with spatially aggregated rainfall data. On the other hand, it was shown that plot level intensity distribution of rains is a major determinant of crop water use and thus, yield. A disggregation (down-scaling) tool developed at IRD in Grenoble, France (T Lebel, unpublished) was therefore used to reconstitute point (plot) data from large pixels using a probabilistic method calibrated for Sahel environments (Niamey, Rep. Niger). The method essentially creates a user-defines number of virtual locations within the pixel at which rainfall is distributed according the passage of virtual rain fields.

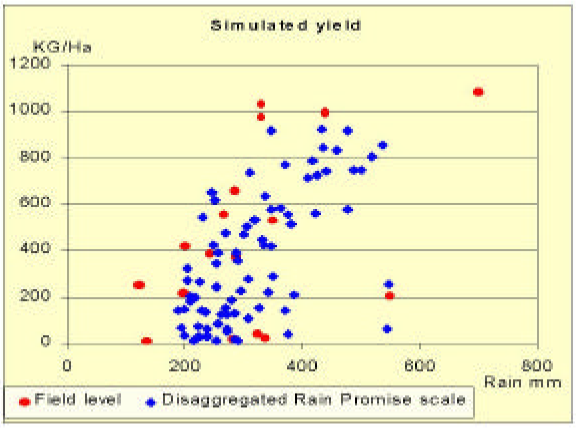


Fig. 7. Millet yields simulated with SARRA-H on a 2.8°-pixel in Senegal for 1972, using observed climate for 17 locations, and 82 hypothetical locations reconstituted from the aggregated pixel with a down-scaling model (T Lebel, IRD, unpublished).

Figure 7 shows the disaggregation results for the extreme example of 1972, a disastrous drought year in the Sahel. The combination of SARRA-H and the down-scaling model gives a reasonable accuracy of case distributions on the yield-rainfall scatter, and can therefore be used for agronomic impact simulations on large pixels. Further research is needed, however, to calibrate and validate this method for different types of climate and different seasons, and to improve handling of the combined tool, which at this stage is still quite cumbersome. Lastly, it must be noted that climate change may affect the values of down-scaling parameters in an unknown fashion.

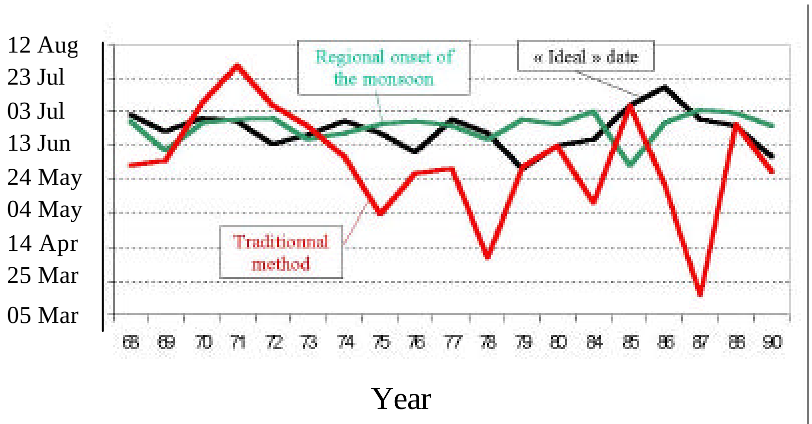
This work was conducted in collaboration with other PROMISE partners, notably IRD in Grenoble, France (T Lebel and team).

First crop model applications

In collaboration with partner 7 (CNRS and LMD,Paris), SARRA-H was used to evaluate different criteria for sowing dates of millet) in the Niamey area (Rep Niger), namely a regional criterion (onset of monsoon) and a local criterion (1st rain event >20mm, followed by re-sowing after 20d if the crop fails). One of the important future applications of GCM based forecasting might be advice on when and what to plant, depending on the onset date of the rainy season. Agrhymet's current DHC yield forecasting system is not able to predict the onsets of rains, and simulates the crop at mid-season using observed rainfall and the local (farmers') criterion for sowing dates.

Sowing dates derived from regional and local criteria were evaluated by comparing grain yield with that achieved with the "ideal" sowing date, determined by simulating all possible dates (Fig. 9). The exclusively climate and hydrology driven analysis suggests that over a 32-year period, the farmer's local criterion gives earlier and much more variable sowing dates than the regional criterion, and that the regional criterion gives sowing dates that are very close to the simulated, local optimum. This translates into 75% ± 26%SD of maximal yield (optimal date) when the regional criterion is used, as opposed to 56% ± 36%SD for the farmers' rule. However, this result must be interpreted with caution because it does not consider the higher soil N availability and lower weed pressure associated with earlier (farmers') sowing dates.

Fig. 9. Simulated sowing dates for millet at Niamey from 1968 to 1990 using 3 criteria. Red: farmers' rule based on local rain events. Green : Regional meteorological rule based on onset of monsoon. Black : Retrospectively « ideal » date giving the highest simulated yields. Simulations with SARRA-H by B Sultan, 2002.



3.3. Socio-economic and policy implication

The work presented is mainly methodological in nature and thus provides limited new knowledge that can be used "on the ground". However, the crop model SARRA-H has been made available to Agrhymet for use in its existing yield forecasting system, where it can provide information on the productivity of different crops and crop varieties, or levels of crop intensification. In conjunction with the downscaling software, SARRA-H can be directly used to translate GCM outputs into potential impact on crops. The socio-economic impact is potentially very high, provided that yield predictions are made available to decision makers in politics and production in a timely fashion, but this depends in the first place on how good and how cheap GCM weather and climate forecasts are going to be.

3.4 Discussion and conclusion

Significant progress has been made towards establishing a toolbox for evaluating the impact of GCM output scenarios on crops in semiarid environments. This toolbox comprises a generic, plot-level crop model suited for West African grain crops (e.g., millet, sorghum, maize, peanut) and a down-scaling tool translating aggregated "pixel" weather into local "point" weather. This is of great methodological significance because as it turned out, the limited spatial resolution of GCM outputs (for both technical and cost reasons) leads to systematic errors in the plot-level water balance, particularly with respect to the fraction of water effectively used for transpiration and growth. These errors are particularly large in semi-arid environments, where rainfall distribution is comparatively erratic and where, because of high evapotranspiration, only relatively large rains are able to replenish the soil water reserve.

Unfortunately, it was not possible to use the new tools to measure the impact of concrete GCM scenarios, because climate simulations of satisfactory quality could not yet be provided. We suggest that given the great importance of rainfall size distribution for the crop and field-level water balance, further work on GCM applications for agriculture should put more emphasis on the intra-seasonal variability of weather, particularly rainfall, both in terms of short-term predictions and climate change . Lastly, we restate the importance, at least for semi-arid environments, of reliable and timely predictions of the onset of the rainy season. This information is crucial for sowing dates and the choice of crop and crop variety -- unless a modified cropping system is developed that uses less variable sowing dates associated with the regional onset of monsoons as described earlier. In this hypothetical case, nitrogen catch crops and/or weed suppressive crops may be necessary to occupy the land between the first major rains and the "true" onset of the monsoon, from when on the crop can be safely sown.

Further documentation of these results:

Lo Seen D, Areola M, Clopes A, Scopel E, Begue A. 2001. Coupler modèle agronomique et système d'information géographique. In : Modélisation des agrosystèmes et aide à la décision. Collection Repères. CIRAD INRA, France.

Baleux F, Begue A, Corbet JD, Rollin D, Grellet G, White JW. 2001. L'almanach numérique de planification à Madagascar. In : Modélisation des agrosystèmes et aide à la décision. Collection Repères. CIRAD INRA, France.

Haris Syahbuddin. 2001. Effet du changement climatique sur le rendement de l'arachide (Arachis hypogaea L.) dans de cas du Sénégal, réalisé avec le modèle ARPEGE Climat V. 3.0 et SARRA-H. Masters thesis, Météorologie Tropicale, Ecole Nationale de la Météorologie, Toulouse, France, 129 pages.

Samba A, Sarr B, Baron C, Gozé E, Maraux F, Clerget B, Dingkuhn M. 2001. La prévision agricole à l'échelle du Sahel. In: Malézieux E, Trébuil G, Jaeger M (Eds.). Modélisation des agro-écosystèmes et aide à la décision. Cirad and INRA, Montpellier, France, p. 243-262.

(Further publications are soon to appear, including refereed articles on SARRA-H applications and a chapter on SARRA-H as part of a book on agricultural decision aids for Africa, published by IFDC (International Fertiliser Development Center).)

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

Contract number:	EVK2-CT-1999-00022
Project reporting period:	March 2002 to February 2003
Sections included:	3
Project co-ordinator:	Julia Slingo, CGAM, University of Reading, Reading, UK
Work-package number:	WP4000

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SECTION 3:

3.1 Objectives

To develop a database of observed and simulated data on meteorology, hydrology and agriculture for monsoon climates with the aim of improving the collaboration and exchange of results between research institutions in European and extra-European countries, and between scientists with expertise on climatology, hydrology and agricultural resources.

3.2 Methodology and scientific achievements

UREADMY with CINECA and ICTP: The PROMISE data archive is implemented by the CINECA Inter-University Consortium in Bologna and designed in collaboration with the Department of Meteorology of the University of Reading and the Physics of Weather and Climate Group at the Abdus Salam International Centre for Theoretical Physics in Trieste. A web-based interface allows both data retrieval and direct visualization of a subset of the archived fields, In the third year of the project, a specific software protocol (DODS) has been introduced, which allows users to access remote data over the internet using data analysis and visualisation packages such as Matlab, Ferrat, IDL, and GrADS. Processing of data by DODS-enabled packages is actually performed on the remote data server, with results sent to the "client" in numerical form; therefore users can process a large amount of data without being limited by the memory capacity of their local machines or the speed of their internet connections.

The PROMISE data archive will be maintained (and possibly expanded) in the next years through an agreement between CINECA and the Abdus Salam International Centre for Theoretical Physics.

Short description of currently available datasets accessible through DODS.

The GHG (Greenhouse Gas) Experiment by DKRZ (Deutsches Klimarechenzentrum GmbH)

Future climate scenario simulations performed using the CSIRO-Mk2 to investigate the impacts of increases in concentrations of greenhouse gases. The greenhouse gas forcing is increased gradually to represent the observed changes in forcing due to all the greenhouse gases from 1881 - 1990. From 1990 - 2100 increases in concentrations specified by the IPCC'92 scenario IS92a are used.

The GSDIO (sulfate aerosol (direct effect), greenhouse gas, and ozone experiment) by DKRZ (Deutsches Klimarechenzentrum GmbH)

This experiment GSDIO is the one with the most comprehensive (realistic) forcing scenario. The forcing includes not only the greenhouse gas forcing described with the "greenhouse run" (GHG) but also the direct radiative effect and the indirect cloud effect of historic sulphate aerosol concentrations from 1860 to 1990 and a scenario of sulphate aerosol concentrations from 1990 to 2049. The sulphate aerosol concentrations are calculated in the ECHAM4 model from the sulphur emissions according to the IPCC'92 scenario IS92a. Additionally, the tropospheric ozone has been modified according to IS92a.

The AAXOBA experiment by the U.K. MetOffice
Simulations designed to assess the response to climate change of the Indian monsoon using a regional climate model with boundary conditions provided by a coupled ocean-atmosphere GCM (HadCM2).

CNRM (MF): No work done on WP4000 during this reporting period

Met Office: No work done on WP4000 during the reporting period

3.3 Socio-economic and policy implication

The establishment of an easily accessible database with selected results from numerical simulations and observational datasets on atmospheric, hydrological and agricultural parameters is important for improving the exchange of results between research institutions in European and extra-European countries, and between scientists with expertise on climatology, hydrology and agricultural resources. The transfer of technology to developing countries is essential if EU research is to be properly exploited. In PROMISE this is planned to be a two-way process in which those with the modelling expertise provide model datasets, climate scenarios and advice on analysing model results and assessing their statistical significance. The development of the promise data archive is seen as essential in this regard.

3.4 Discussion and conclusions

The data archive has been established and all model data provided by the PROMISE partners has been added. The archive was demonstrated at the final PROMISE meeting to a wide variety of researchers from Europe, America and monsoon-affected countries.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

Contract number:	EVK2-CT-1999-00022
Project reporting period:	March 2002 to February 2003
Sections included:	3
Project co-ordinator:	Franco Molteni, ICTP, Trieste, Italy
Work-package number:	WP5000

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1	UREADMY	Earley Gate	RG6 6BB	Reading	UK	Prof	Slingo	Julia	+44 (0)118 931 8424	+44 (0)118 9318316	j.m.slingo@reading.ac.uk
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SECTION 3:

3.1 Objectives

To establish active links with climate scientists in monsoon-affected countries and with international hydrological and agricultural research centres.

3.2 Methodology and scientific achievements

UREADMY and ICTP: 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).

UREADAG: Deliverable 5003. Establish an international network of scientists concerned with the impacts of monsoon climates on cropping systems of Africa and India

Introduction

Links with international scientists working within agriculture have been established through a series of visits on behalf of the PROMISE project. Missions have now been undertaken to four key institutes of the Consultative Group for International Agricultural Research (CGIAR), to the Food and Agriculture Organisation, 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 meetings attended during the final year of the PROMISE project

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

Key emergent ideas

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 inter-comparison 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.

3.3 Socio-economic and policy implication

The transfer of technology to developing countries is essential if EU research is to be properly exploited. In PROMISE this is planned to be a two-way process in which those with the modelling expertise provide model datasets, climate scenarios and advice on analysing model results and assessing their statistical significance. The monsoon countries would reciprocate with information on local needs, data on local monitoring and likely future stresses on their socio-economic development (e.g. growing population and needs). The final goal of the collaboration is to achieve substantial progress towards the development of an integrated system for the interpretation of seasonal forecasts and climate change predictions in terms of the hydrological and agricultural impacts.

Publicizing the data archive through the brochure website and a demonstration at the final meeting will ensure that the archive has maximum impact on scientists in monsoon-affected countries in line with the EU policy on External Relations.

3.4 Discussion and conclusions

The ICTP conference on monsoon environments, which was organised within PROMISE, provided an opportunity to disseminate the results of the project, including the data archive to a wide audience of researchers from monsoon-affected countries. Links with international scientists working within agriculture have been established through a series of visits on behalf of the PROMISE project.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

3rd Periodic Report

Contract number: EVK2-CT-1999-00022
Project reporting period: March 2002 to February 2003
Sections included: 3
Project co-ordinator: Julia Slingo, CGAM, University of Reading, Reading, UK
Work-package number: WP6000

Information on participants:

No	Institution/ organisation	Street name & number	Postcode	Town/city	Country code	Title	Family name	First name	Telephone number	Fax number	E-mail
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1	UREADMY	Earley Gate	RG6 6BB	Reading	UK	Prof	Slingo	Julia	+44 (0)118 931 8424	+44 (0)118 9318316	j.m.slingo@reading.ac.uk
5	ICTP	Strada Costiera 11	I-34014	Miramare (Trieste)	IT	Senior Scientist	Molteni	Franco	+39 040224057 2	+30 040 2240449	Molteni@ictp.trieste.it

SECTION 3:

3.1 Objectives

To coordinate and promote the aims, activities and achievements of the PROMISE project.

3.2 Methodology and scientific achievements related to WP6000

UREADMY: The end of PROMISE was marked by a conference held at ICTP entitled: *Monsoon Environments: Agricultural and Hydrological variability of seasonal variability and climate change*. The meeting was hosted by ICTP and sponsored by PROMISE, ICTP, START/CLIMAG and the WCRP. The sponsorship enabled 60 researchers from developing countries to participate. In total, there were 125 participants, most of whom made either poster or oral presentations.

All the PROMISE partners were represented at the conference, and several made keynote talks. The meeting provided an excellent opportunity to disseminate PROMISE work to the European and American scientific communities as well as to scientists from monsoon-affected countries. The powerpoint presentations from the meeting will be made available from the PROMISE web site. To facilitate the dissemination of PROMISE results to researchers with slow internet connections, the presentations will also be distributed to some participants on a cd-rom. For further details of the conference see
http://ugamp.nerc.ac.uk/promise/research/conference2003

Development of the PROMISE website has continued. It now contains detailed sections on all aspects of PROMISE including highlights of the project's progress so far. The PROMISE web site has been promoted in presentations about PROMISE, on the PROMISE brochure and through registering with search engines. The site now gets approximately 400-500 unique hits per month and has provided the first point of contact about PROMISE for many subscribers to the mailing list.

The main part of the website, which focuses on the achievements and aims of PROMISE, is complimented by the educational information included on the Monsoon Online site (http://www.met.rdg.ac.uk/cag/MOL/). This is linked closely to the PROMISE site and is maintained by David Stephenson (UREADMY), Rupa Kumar Kolli (IITM, Pune, India) and Emily Black (UREADMY), all of whom are associated with PROMISE.

ICTP: ICTP hosted and were responsible for the local arrangements for the Monsoon Environments conference referred to above. They also provided sponsorship for approximately 50 researchers from monsoon-affected countries to attend.

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3.3 Socio-economic and policy implication

The website aims to facilitate communication of results and ideas between PROMISE partners. This ensures that the optimum value is gained from the combination of expertise from the European groups in line with the EU's policy on Research and Technological Development. The website also publicizes EU research within monsoon-affected countries and therefore promotes EU scientific leadership and the International Role of Community Research.

3.4 Discussion and conclusions

UREADMY: The conference on Monsoon Environments provided a good opportunity to disseminate the final results of the PROMISE project. The web site has been a useful tool for both the administration of PROMISE and the dissemination of PROMISE results.

TECHNOLOGICAL IMPLEMENTATION PLAN

A Framework for the further development, dissemination and use of the results of EC RTD Projects (including also thematic networks and concerted actions)

DATA SHEETS

• Preliminary version at mid-term (optional, programme per programme)

X Final version before final term (contractual obligation)

Part 1: Overview and description of all your project and its results

Publishable

This section will be used to document your result(s) in CORDIS and to inform any appropriate audience.

1.1: Executive summary (to be used for an accurate update of the programme synopsis of projects)
1.2: Overview of all results
1.3: Quantified data on the project
1.4: Description of each single result (one form per result)
1.5: Quantified data on the result (one form per result)

Part 2: Description of the intentions for dissemination and use by each partner

Confidential

This section enables each partner - individually or as a consortium – to describe its use and dissemination intentions (including a timetable of its future activities).

2.1 : Description of the use and the dissemination of result(s)
2.2 : Quantified data by partners

Part 3: Search for Collaboration through Commission services (optional)

Publishable

This section enables each partner - individually or as a consortium – to describe its needs in further collaboration in view of the dissemination and use of its result(s).

Part 4: Assessment of the European interests

Publishable

This section enables the co-ordinator to explain the interest for the European Union (the competitiveness of its industries, the usefulness for (part of) its population, etc.) of the achieved results and of their foreseen impacts.

- The Technological Implementation Plan data sheets are available as a predefined form in Microsoft Word format. The file may be downloaded from the European Commission's CORDIS web site at: http://www.cordis.lu/fp5/tip.htm or may be obtained by e-mail from your EC programme help desk or your Project Officer.
- The form should be completed and returned preferably by e-mail to your project officer (Firstname.Lastname@cec.eu.int). Alternatively it can be sent on a diskette to the address provided by your Project Officer :
  - ✓ Part 1, 3 & 4 by the project co-ordinator;
  - ✓ Part 2 by the project co-ordinator or by each partner individually, as preferred.

Part 1 Overview and description of your project and its results

EC PROGRAMME :	**Environment and Sustainable Development**
PROJECT TITLE & ACRONYM:	**Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change: PROMISE**
CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PROJECT WEB SITE (if any) :	**http://ugamp.nerc.ac.uk/promise/**
PARTNERS NAMES :	**1. Department of Meteorology, The University of Reading (UREADMY)** **2. Centre de coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)** **3. Meteo-France (MF)** **4. Danish Meteorological Institute (DMI)** **5. The Abdus Salam International Centre for Theoretical Physics (ICTP)** **6. National Environment Research Council Institute of Hydrology (NERC)** **7. Laboratoire de Meteorologie Dynamique (CNRS-LMD)** **8. Max-Planck-Institut fur Meteorologie (MPG-IMET)** **9. U.K. Meteorological Office (The Met Office)** **10. Department of Agriculture, The University of Reading (UREADAG)** **11. European Centre for Medium-range Weather Forecasts (ECMWF)** **12. Centre de Recherches Climatiques, Universite de Bourgogne (UB)**

1.1 Executive summary

Please, synthesise (in 1 or 2 pages) your project original objectives and final outcome.

a) Original research objectives:

PROMISE is an interdisciplinary project which aims to address two key issues for monsoon-affected countries: (i) the potential for seasonal prediction and the benefits that would accrue in terms of the management of water resources and agriculture, and (ii) the impacts of anthropogenic climate change on monsoon climates, in particular on the availability of water resources for human use, and on the productivity of crops and the potential changes in the natural vegetation. A particular aim of PROMISE is to develop an integrated approach towards seasonal and climate change prediction in which the impacts on local hydrology and agriculture are part of the prediction process.

The specific objectives of the project are:
(1) Description of the natural variability of monsoon systems for the current climate, and assessment of the skill of climate models to represent this variability.

(2) Assessment of the seasonal predictability of monsoon systems using ensemble integrations, and development of advanced statistical techniques for evaluating the skill of seasonal forecasts.

(3) Assessment of the sensitivity of monsoon variability to regional anomalies in SST and land surface conditions, including vegetation.

(4) Documentation of the impacts of anthropogenic climate change on the characteristics of monsoon climates.

(5) Development of future scenarios of land use changes and assessment of the impact of these changes on monsoon climates.

(6) Development of methods for assessing the impact of natural and anthropogenic climate change on water resources, in particular the water balance of major river basins.

(7) Progress towards the development of an integrated system for the interpretation of probabilistic seasonal forecasts in terms of the crop development and yields.

(8) Assessment of anthropogenic climate change on crop productivity for selected regions.

(9) Provision of a web-accessible data archive, open to EU and non-EU institutions, containing data for selected surface climate variables from (a) global and regional simulations of the present day and 2041-2060 climate, (b) seasonal prediction ensembles, as well as relevant observational datasets for impact studies, e.g. records of crop yields, river flows.

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

b) Expected deliverables:

PROMISE will improve our capability to make seasonal and climate predictions, including regional scale climate change. It will lead to a better quantification of the links between climate change and the frequency and scale of extreme events. Through the involvement of all the major European atmospheric modelling centres, PROMISE will lead to improved integration of model development, prediction capabilities and scenario assessments.

By the establishment of a data archive, the use of existing and planned reanalysis datasets, and the exploitation of existing seasonal prediction and climate change integrations, PROMISE will ensure that existing datasets are effectively exploited. The data archive will also bring in relevant hydrological and agricultural datasets (e.g. river flows, crop yields), which are important for impact assessment and for validating models.

Through the active involvement of the hydrological and agricultural research communities, PROMISE will address the impacts of climate change on water resources and crop productivity. PROMISE will evaluate the impacts of land use changes (e.g. deforestation, overgrazing, irrigation) on local climate and the implications for water resources and agriculture.

c) Project's actual outcome:

- Advances in our ability to understand, simulate and predict monsoon climates, their mean behaviour and their variability on intraseasonal and interannual timescales, and how these will change in the future due to anthropogenic influences.
- Improved assessments of climate change for India and West Africa, including high-resolution scenarios, which can be used by impacts modellers and policy makers.
- Development of improved land surface schemes for climate models, including the effects of irrigation and flood plains on soil hydrology and river discharge.
- New estimates of future water availability for West Africa, which include the effects of changes in land use, human consumption.
- Major advances in linking the disciplines of crop modelling and climate prediction for monsoon environments.
- Effective measures for disseminating the results of PROMISE to scientists and users in monsoon-affected countries.

d) Broad dissemination and use intentions for the expected outputs

- A PROMISE web site has been established. This is used for (a) project management, (b) communication of PROMISE results between the partners, (c) hyperlinks to related sites, and (d) providing information on PROMISE to the international community.
- Two brochures outlining the aims and results of PROMISE have been prepared and widely distributed to the meteorological, agricultural and hydrological research and user communities, particularly those with interests in monsoon-affected countries.
- A mailing list has been created and is used (a) to maintain and develop contacts, (b) to distribute information sheets on PROMISE achievements, and (c) to invite feedback to the project.
- The aims and achievements of PROMISE have been disseminated to relevant scientific and user communities through conference presentations. PROMISE has been promoted at Agricultural Research Centres in Colombia, Mexico and the.
- Mid term Workshop on PROMISE has been held as part of the ICTP Summer School on "Land-Atmosphere Interactions in Climate Models" and "Climate Variability and Land-Surface Processes: Physical Interactions and Regional Impacts". 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.
- The end of PROMISE was marked by an international conference held at ICTP entitled 'Monsoon Environments: Agricultural and Hydrological variability of seasonal variability and climate change'. The conference was hosted by ICTP and sponsored by PROMISE, ICTP, START/CLIMAG and the WCRP. The sponsorship enabled 60 researchers from developing countries to participate. In total, there were 125 participants, most of whom made either poster or oral presentations. All the PROMISE partners were represented at the conference, and several made keynote talks.
- The Powerpoint presentations from the meeting have been made available from the PROMISE website. To facilitate the dissemination of PROMISE results to researchers with slow internet connections, the presentations are also being distributed to participants on a CDROM. For further details of the conference see: http://ugamp.nerc.ac.uk/promise/research/conference2003 .

1.2 Overview of all your main project results

No.	Self-descriptive title of the result	Category *	Partner(s) owning the result(s) (referring in particular to specific patents, copyrights, etc.) & involved in their further use
1	Improved understanding of the natural variability and predictability of current monsoon climates on seasonal, interannual and interdecadal timescales.	A	UREADMY, MF, CNRS-LMD, MPG.IMET, The Met Office, DMI, ECMWF, ICTP, UB
2	Development of sophisticated land surface schemes which incorporate (i) more sophisticated representations of seasonally varying vegetation phenology into the climate models, (ii) a detailed treatment of soil water including the effects of irrigation and (iii) changes in vegetation and land use based on satellite-derived, high-resolution observations of vegetation cover.	A	CNRS-LMD, MF, NERC, UREADMY
3	Development and assessment of anthropogenic climate change scenarios, including land use, for monsoon climates. High-resolution global and regional simulations to provide a more complete picture of potential changes in monsoon climates under the influence of enhanced greenhouse gases with a focus on extreme events.	A	MPG.IMET, MF, DMI, CNRS-LMD, The Met Office, UB, NERC
4	Development of a water resource model for West Africa that will provide an improved methodology for the assessment of water resources in relation to water demand. On the larger scale, an integrated soil hydrology scheme has been used to study river routing and the water balance of major river basins.	A	NERC, CNRS-LMD
5	Development of crop models and the methodology required to link crop models with seasonal weather and climate prediction models.	A	CIRAD, UREADAG, UREADMY
6	Establishment of a web-based data archive, website, network to develop active links with, and support for scientists in monsoon-affected countries	A	UREADMY, ICTP, UREADAG, CIRAD

* A: results usable outside the consortium / B: results usable within the consortium / C: non usable results

1.3 Quantified Data on the dissemination and use of the project results

Items about the dissemination and use of the project results (consolidated numbers)	Currently achieved quantity	Estimated future* quantity
# of product innovations (commercial)	0	0
# of process innovations (commercial)	0	0
# of new services (commercial)	0	0
# of new services (public)	2	0
# of new methods (academic)	2	0
# of scientific breakthrough	5	0
# of technical standards to which this project has contributed	0	0
# of EU regulations/directives to which this project has contributed	0	0
# of international regulations to which this project has contributed	0	0
# of PhDs generated by the project	1	0
# of grantees/trainees including transnational exchange of personnel	2	1

*# = number of ... / * “Future” means expectations within the next 3 years following the end of the project*

1.4 Description of each single result *(one form per result)*

No. & TITLE OF RESULT *(as in section 1.2)*

1	Improved understanding of the natural variability and predictability of current monsoon climates on seasonal, interannual and interdecadal timescales.

SUMMARY *(200 words maximum)*

Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

Good progress has been made in developing our understanding of the seasonal predictability of monsoon climates and of the factors that influence that predictability. Modeling studies have been used to elucidate the relationship between African rainfall and SST anomalies in adjacent oceans, and significant progress has been made in relating regional rainfall variations to specific aspects of the SST anomaly field. As well as SST, land surface anomalies, particularly those associated with snow and soil moisture, can provide memory to the climate system. Soil moisture and dynamic vegetation have both been demonstrated as important for simulating the observed interannual to decadal variations in Sahel rainfall. Also, some aspects of the observed relationship between Eurasian snow anomalies and Indian rainfall have been successfully reproduced in models. However, model systematic error in the mean climate and variability on sub-seasonal, seasonal and inter-annual timescales still presents major obstacles to skilful seasonal prediction.

The response of the climate system to SST forcing lies at the heart of seasonal prediction, and several studies have reported on the non-linearity in this response. For example, further analysis of the relationship between ENSO, the Indian Ocean Zonal Mode (IOZM) and East African Rainfall has shown that only IOZM events which reverse the east-west SST gradient in the Indian Ocean for several months lead to heavy rainfall. It has also been shown that when ENSO forcing is sufficiently strong, it can predispose the Indian Ocean to an IOZM event. Non-linearity has also been noted in the response of Sahelian rainfall to Atlantic SST anomalies.

Please categorise the result using codes from Annex 1

Subject descriptor	269			

CURRENT STAGE OF DEVELOPMENT

Please tick one category only 🗐

Scientific and/or Technical knowledge (Basic research)	☐ X
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	**Details(Title, ref. number, general description, language)**	**Status:** ***PU*=Public** ***CO*=Confidential**

INTELLECTUAL PROPERTY RIGHTS

Indicate all generated knowledge and possible pre-existing know-how (background or sideground) being exploited

Type of IPR	**Tick a box and give the corresponding details (reference numbers, etc.) if appropriate.**		**Knowledge *(K)*/ Pre-existing know-how *(P)***
	Current	**Foresee**	
Patent applied for	• ……………………………..	•	
Patent search carried out	• ……………………………..	•	
Patent granted	• ……………………………..	•	
Registered design	• ……………………………..	•	
Trademark applications	• ……………………………..	•	
Copyrights	• ……………………………..	•	
Secret know-how	• ……………………………………..	•	
other – please specify :	• ……………………………..	•	

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors				

1.4 Description of each single result *(one form per result)*

No. & TITLE OF RESULT *(as in section 1.2)*

2	Development of sophisticated land surface schemes which incorporate (i) a detailed treatment of soil water including the effects of irrigation and (ii) changes in vegetation and land use based on satellite-derived, high-resolution (1km) observations of vegetation cover.

SUMMARY *(200 words maximum)*

Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

PROMISE has shown that the land surface is a crucial driver in monsoon variability on timescales from days to decades and that the influence of vegetation and soil hydrology must be well represented in climate models. A sophisticated soil scheme has been developed to improve the simulated seasonal cycle and to enable the impact of irrigation on the Indian climate to be assessed. Irrigation will alter the water balance in the soil and thus affect the surface temperature and climate; it will also alter the levels of river run-off into the ocean and hence the freshwater budget.

To improve the representation of land-surface properties for the current climate more account has been taken of recent satellite-derived remote sensing information on the land surface vegetation cover at fine resolution. Detailed satellite mapping of land surface properties has been used to develop new scenarios of global land use for the current climate, which can be implemented in land surface models to investigate the interaction between climate and vegetation. Based on the integrated assessments of IPCC, a methodology has been developed which will produce future changes in land use, which can then be used to investigate their impact on local climate. A detailed description of changes in land use over the Sahel has been developed from 1960 and projected into the future. Sensitivity experiments suggest that past changes in land use may have contributed to a modest reduction in precipitation in this region.

A representation of the seasonal cycle in vegetation has been developed from observational data; this can influence the lower atmosphere through changes in leaf area index (LAI), roughness length and surface albedo. Initial results suggest that surface temperatures and water budgets are most significantly impacted in semi-arid and continental regions. The main impact on monsoon environments is seen primarily outside the main rainy season. Better representations of vegetation phenology and surface albedo have also been shown to improve simulations of the multidecadal variability in Sahelian rainfall. The dynamic response of the vegetation to precipitation changes acts as an amplifier for low frequency behaviour associated with SST forcing.

Please categorise the result using codes from Annex 1

Subject descriptor	669	580	274	640

CURRENT STAGE OF DEVELOPMENT

Please tick one category only 🗐

Scientific and/or Technical knowledge (Basic research)	☐ X
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	**Details(Title, ref. number, general description, language)**	**Status:** ***PU***=**Public** ***CO***=**Confidential**

INTELLECTUAL PROPERTY RIGHTS

Indicate all generated knowledge and possible pre-existing know-how (background or sideground) being exploited

Type of IPR	**Tick a box and give the corresponding details (reference numbers, etc.) if appropriate.**		**Knowledge** ***(K)***/ **Pre-existing know-how** ***(P)***
	Current	**Foresee**	
Patent applied for	• ……………………………..	•	
Patent search carried out	• ……………………………..	•	
Patent granted	• ……………………………..	•	
Registered design	• ……………………………..	•	
Trademark applications	• ……………………………..	•	
Copyrights	• ……………………………..	•	
Secret know-how	• ………………………………………	•	
other – please specify :	• ……………………………..	•	

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors				

1.4 Description of each single result *(one form per result)*

No. & TITLE OF RESULT *(as in section 1.2)*

3	Development and assessment of anthropogenic climate change scenarios, including land use, for monsoon climates.

SUMMARY *(200 words maximum)*

Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

Model results have indicated an intensification of the Indian and West African summer monsoons in a future warmer climate due to the enhanced land-sea contrast and a northward displacement of the intertropical convergence zone. Whereas an increase in the atmospheric transport of water vapour by the strengthened monsoon flow is important for Indian monsoon rainfall, precipitation recycling through local land surface evaporation is a major contributor to changes in rainfall over West Africa. Again the importance of land surface processes in terms of soil water balance, vegetation cover and land use changes has been demonstrated. Positive feedbacks between the circulation and vegetation have been shown to contribute to vegetation die-back particularly over Amazonia. Scenarios for future land use in Africa are being developed where climate sensitivity to past land use changes has already been demonstrated.

PROMISE has focused specifically on high-resolution global and regional simulations to provide a more complete picture of potential changes in monsoon climates under the influence of enhanced greenhouse gases. For Africa, in particular, where the latitudinal gradients in precipitation are very pronounced, the use of higher resolution has been shown to improve the simulations. In general, the scenarios indicate an increase in monsoon precipitation over the Sahel and India throughout the next century. However, there can be significant decadal variability within this trend, with several decades of reduced or unchanged precipitation. A detailed analysis of the temporal behaviour of the monsoon rains has also shown that the trend towards stronger monsoons is also accompanied by more extreme daily and monthly rainfall amounts.

Changes in land-use will be a key aspect of the human response to increasing population numbers as well as to a changing climate. PROMISE has developed new scenarios of future land use for West Africa, which have been used to show that the direct feedback of land use on climate at the regional scale is likely to be weaker than the effect of increased global CO_2 levels. However, at the local/national scale, extensive deforestation may contribute to a substantial reduction in precipitation, and therefore impact negatively on water resources.

One of the responses to climate change with regard to food security is to increase the level of irrigation. This will have a significant impact on soil water, vegetation and river run-off. As part of an important step towards an integrated approach to climate change prediction, a sophisticated land surface model, which predicts levels of irrigation and its consequent effects, has been developed.

Please categorise the result using codes from Annex 1

Subject descriptor	272	274	271	37

CURRENT STAGE OF DEVELOPMENT

Please tick one category only 🗐

Scientific and/or Technical knowledge (Basic research)	☐ X
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	**Details(Title, ref. number, general description, language)**	**Status:** ***PU*=Public** ***CO*=Confidential**

INTELLECTUAL PROPERTY RIGHTS

Indicate all generated knowledge and possible pre-existing know-how (background or sideground) being exploited

Type of IPR	**Tick a box and give the corresponding details (reference numbers, etc.) if appropriate.**		**Knowledge *(K)*/ Pre-existing know-how *(P)***
	Current	**Foresee**	
Patent applied for	• ……………………………..	•	
Patent search carried out	• ……………………………..	•	
Patent granted	• ……………………………..	•	
Registered design	• ……………………………..	•	
Trademark applications	• ……………………………..	•	
Copyrights	• ……………………………..	•	
Secret know-how	• ………………………………………	•	
other – please specify :	• ……………………………..	•	

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors				

1.4 Description of each single result *(one form per result)*

No. & TITLE OF RESULT *(as in section 1.2)*

4	Development of a water resource model for West Africa that will provide an improved methodology for the assessment of water resources in relation to water demand.

SUMMARY *(200 words maximum)*

Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

The availability of adequate water resources may be the most serious problem humanity will face in the coming decades, particularly in seasonally arid regions. As the demands for water increase, an important issue is the evaluation of changes of the hydrological budget that countries experience, not only due to climatic change but also due to human disturbances through reservoir construction and water use by agriculture. PROMISE has pioneered a new approach to assessing future availability of water for West Africa which will allow policy makers and others to make better informed resource allocation decisions, and will facilitate the assessment of impacts of human activities – such as climate change and land use change – on water availability in relation to people's needs for water for all purposes.

PROMISE results clearly indicate the likelihood of increasing water shortages in the semi-arid Sahel zone where population densities are high and water is already scarce. This region is one that already suffers from high levels of poverty and water stress, and the results reinforce the pressing need to promote and fund adaptation strategies for improved water resources provision and management in this area.

Increasingly, seasonally arid regions use irrigation to enable crop production in the dry season and to support crop development in the rainy season. PROMISE has enabled the development of an integrated land surface and hydrology scheme that includes the effects of irrigation in the fully coupled climate model. This has provided one of the first estimates of the effects water extraction for irrigation on river flows for the major rivers of India under future climate scenarios.

Please categorise the result using codes from Annex 1

Subject descriptor	666	669	580	271

CURRENT STAGE OF DEVELOPMENT

Please tick one category only

Scientific and/or Technical knowledge (Basic research)	☐ X
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	**Details(Title, ref. number, general description, language)**	**Status:** ***PU*=Public** ***CO*=Confidential**

INTELLECTUAL PROPERTY RIGHTS

Indicate all generated knowledge and possible pre-existing know-how (background or sideground) being exploited

Type of IPR	**Tick a box and give the corresponding details (reference numbers, etc.) if appropriate.**		**Knowledge *(K)*/ Pre-existing know-how *(P)***
	Current	**Foresee**	
Patent applied for	• ……………………………..	•	
Patent search carried out	• ……………………………..	•	
Patent granted	• ……………………………..	•	
Registered design	• ……………………………..	•	
Trademark applications	• ……………………………..	•	
Copyrights	• ……………………………..	•	
Secret know-how	• ………………………………………	•	
other – please specify :	• ……………………………..	•	

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors				

1.4 Description of each single result *(one form per result)*

No. & TITLE OF RESULT *(as in section 1.2)*

5	Development of crop models and the methodology required to link crop models with seasonal weather and climate prediction models.

SUMMARY *(200 words maximum)*

Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

A major effort in linking the disciplines of crop modelling and climate prediction has been undertaken in PROMISE. Considerable progress has been made in developing crop models and the methodology required to link crop models with seasonal and climate prediction models. Comprehensive crop models have been deemed too complex for using at regional and larger scales because of the detailed input required, for example, soil characteristics, crop genotype. Simpler models are therefore being developed which are based on these complex models but will still provide information on yield, biomass growth, harvest index and phenology. The feasibility of up-scaling crop models to a spatial scale commensurate with that used in seasonal and climate prediction models has been demonstrated for the case of Indian groundnut yields. This has enabled a methodology to be developed which links crop and seasonal prediction models, and which will provide probabilistic information on potential crop development and yields at the regional level.

However, PROMISE research with crop models has also raised a number of important issues, particularly those related to biases within climate models, and has highlighted again the need for significant improvements in climate model simulations, particularly with respect to precipitation. A key recommendation from PROMISE is that, given the great importance of the space/time distribution of rainfall for crop and soil water balance, future work on climate applications for agriculture should place more emphasis on the intra-seasonal variability of weather. Lastly, we restate the importance, at least for semi-arid environments, of reliable and timely predictions of the onset of the rainy season.

Please categorise the result using codes from Annex 1

Subject descriptor	142	639	14	

CURRENT STAGE OF DEVELOPMENT

Please tick one category only 🗐

Scientific and/or Technical knowledge (Basic research)	☐ X
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	**Details(Title, ref. number, general description, language)**	**Status:** ***PU*=Public** ***CO*=Confidential**

INTELLECTUAL PROPERTY RIGHTS

Indicate all generated knowledge and possible pre-existing know-how (background or sideground) being exploited

Type of IPR	**Tick a box and give the corresponding details (reference numbers, etc.) if appropriate.**		**Knowledge *(K)*/ Pre-existing know-how *(P)***
	Current	**Foresee**	
Patent applied for	• ……………………………..	•	
Patent search carried out	• ……………………………..	•	
Patent granted	• ……………………………..	•	
Registered design	• ……………………………..	•	
Trademark applications	• ……………………………..	•	
Copyrights	• ……………………………..	•	
Secret know-how	•	•	
other – please specify :	• ……………………………..	•	

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors				

1.4 Description of each single result *(one form per result)*

No. & TITLE OF RESULT *(as in section 1.2)*

6	Establishment of a web-based data archive, website, network to develop active links with, and support for scientists in monsoon-affected countries

SUMMARY *(200 words maximum)*

Provide an overview of the result which gives the reader an immediate impression of the nature of the result, its relevance and its potential; Briefly describe the current status/applications of the result (if appropriate) with non confidential information on entities potentially involved.

The PROMISE Data Archive has a web-based interface allowing both data retrieval and direct visualization of a subset of the archived fields. The PROMISE archive includes observed and simulated datasets on meteorology, hydrology and agriculture, with a specific focus on regions affected by monsoon climates. It has been set up with the aim of improving the collaboration and exchange of results between research institutions in European and extra-European nations (particularly in developing countries), and between scientists with expertise on climatology, hydrology and agricultural resources. The PROMISE data archive has been established at CINECA with a web-based interface, allowing both data retrieval and direct visualization of a subset of the archived fields (see: http://www.cineca.it/promise/).

The PROMISE website (http://ugamp.nerc.ac.uk/PROMISE/) was created at the start of the project and development has continued throughout the project. The site now contains detailed sections on all aspects of PROMISE, including highlights of the project's achievements. The PROMISE website is complemented by the educational information included on the Monsoon Online site (http://www.met.rdg.ac.uk/cag/MOL/). Monsoon Online has undergone major revision in the course of PROMISE and now includes more detail about the evolution of the monsoon (updated every week during the Asian monsoon season).

Two brochures outlining the aims of PROMISE and summarizing current progress have been produced and distributed widely both within the EU and internationally.

During the project, PROMISE sponsored two major activities aimed at engaging scientists from monsoon-affected countries in PROMISE research. 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' were held at ICTP with the co-sponsorship of PROMISE. The end of PROMISE was marked by an international conference held at ICTP entitled 'Monsoon Environments: Agricultural and Hydrological variability of seasonal variability and climate change'. The meeting provided an excellent opportunity to disseminate PROMISE work to the European and American scientific communities as well as to scientists from monsoon-affected countries. The Powerpoint presentations from the meeting have been made available from the PROMISE website. To facilitate the dissemination of PROMISE results to researchers with slow internet connections, the presentations are also being distributed to participants on a CDROM.

Please categorise the result using codes from Annex 1

Subject descriptor	150	183		

CURRENT STAGE OF DEVELOPMENT

Please tick one category only

Scientific and/or Technical knowledge (Basic research)	☐ X
Guidelines, methodologies, technical drawings	☐
Software code	☐
Experimental development stage (laboratory prototype)	☐
Prototype/demonstrator available for testing	☐
Results of demonstration trials available	☐
Other (please specify.):	☐

DOCUMENTATION AND INFORMATION ON THE RESULT

List main information and documentation, stating whether public or confidential.

Documentation type	**Details(Title, ref. number, general description, language)**	**Status:** ***PU*=Public** ***CO*=Confidential**

INTELLECTUAL PROPERTY RIGHTS

Indicate all generated knowledge and possible pre-existing know-how (background or sideground) being exploited

Type of IPR	**Tick a box and give the corresponding details (reference numbers, etc.) if appropriate.**		**Knowledge *(K)*/ Pre-existing know-how *(P)***
	Current	**Foresee**	
Patent applied for	• ……………………………..	•	
Patent search carried out	• ……………………………..	•	
Patent granted	• ……………………………..	•	
Registered design	• ……………………………..	•	
Trademark applications	• ……………………………..	•	
Copyrights	• ……………………………..	•	
Secret know-how	• ………………………………………	•	
other – please specify :	• ……………………………..	•	

MARKET APPLICATION SECTORS

Please describe the possible sectors for application using the NACE classification in Annex 2.

Market application sectors				

1.5 Quantified data about the result (one form per result)

Items (about the results)	**Actual current quantity** [a]	**Estimated (or future) quantity** [b]
Time to application / market (in months from the end of the research project)		
Number of (public or private) entities potentially involved in the implementation of the result :		
of which : number of SMEs :		
of which : number of entities in third countries (outside EU) :		
Targeted user audience: # of reachable people		
# of S&T publications (referenced publications only)	44	17
# of publications addressing general public (e.g. CD-ROMs, WEB sites)	4	
# of publications addressing decision takers / public authorities / etc.		
Visibility for the general public	Yes	

[a] *Actual current quantity = the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve within the next 3 years.*

I, **project co-ordinator**, confirm the publishable information contained in this part 1 (sections 1.1 to 1.5) of the Technological Implementation Plan.

Signature:	**Name: Prof. Julia Slingo**
Date:	**Organisation: University of Reading**

Part 2 Description of the intentions by each partner

This part 2 must be completed by each partner who is essential for the dissemination and use (i.e. result owners and/or major project contributors and/or major dissemination and use contributors). Each will detail its own use and dissemination intentions concerning the result(s) they are involved with. This description must be made result by result.

These different parts may be transmitted to the Commission either assembled at the consortium level, or individually by each partner to safeguard confidential matters if necessary (through any appropriate media). Obviously, when all partners are implementing a single dissemination and use scheme all together, a single part 2 is needed.

PARTS 2 WILL ALWAYS BE KEPT CONFIDENTIAL BY THE COMMISSION

2.1.1 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**UREADMY**
PARTNER's WEB SITE (if any) :	

CONTACT PERSON(S):

Name	Julia Slingo
Position/Title	Professor and Deputy Director
Organisation	Centre for Global Atmospheric Modelling
Address	Department of Meteorology, University of Reading, Earley Gate, Reading RG6 6BB
Telephone	+44 (0) 118 931 8424
Fax	+44 (0) 118 931 8316
E-mail	J.M.Slingo@reading.ac.uk

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	**Improved understanding of the natural variability and predictability of current monsoon climates** The influence of Indian Ocean on East African rainfall and the Asian Summer Monsoon has been clarified. The inter-relationship between ENSO, Indian Ocean variability and the Asian Summer Monsoon has been studied.
2	**Development of sophisticated land surface schemes** Seasonally varying vegetation phenology has been developed and implemented in a state-of-the-art climate model. The impact of seasonally varying vegetation is most marked during the dry season. The sensitivity of the climate to the specification of soil parameters has also been demonstrated.
5	**Development of crop models and the methodology required to link crop models with seasonal weather and climate prediction models.** A methodology for providing probabilistic predictions of crop development and yield on both the seasonal timescale and for future climate change has been developed. An appropriate working space scale for linking crop and climate models has been identified. A new general large area model for annual crops has been developed and tested.
6	**Establishment of a web-based data archive, website, network to develop active links with, and support for scientists in monsoon-affected countries** The PROMISE website (http://ugamp.nerc.ac.uk/PROMISE/) was created at the start of the project and development has continued throughout the project. The PROMISE website is complemented by the educational information included on the Monsoon Online site (http://www.met.rdg.ac.uk/cag/MOL/). A workshop and final conference have been organized at ICTP with sponsorship for scientists from developing countries.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale		
Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**
Publications	Papers arising from PROMISE research will continue to be submitted for publication in the refereed literature	12- 24
Website	The PROMISE website will continue to be maintained with additional material added as appropriate.	Continuous
CDROM	A CDROM containing the Powerpoint presentations from the final conference and other documents from the PROMISE website will be prepared for dissemination to developing countries with limited internet access	1

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ X	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.1 : Quantified data for each partner's main result

Items	**Currently achieved quantity [a]**	**Estimated future quantity [b]**
Economic impacts (in EURO)	....	....
# of licenses issued (within EU)	....	....
# of licenses issued (outside EU)	....	....
Total value of licenses (in EURO)	....	....
# of entrepreneurial actions (start-up company, joint ventures…)	....	....
# of direct jobs created [c]	....	....
# of direct jobs safeguarded [c]	....	....
# of direct jobs lost	....	....

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Prof. Julia Slingo**

Date:

2.1.2 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)**
PARTNER's WEB SITE (if any) :	www.cirad.fr

CONTACT PERSON(S):

Name	Florent Maraux
Position/Title	Dr, Head of Agronomy Program
Organisation	CIRAD-Amis
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Telephone	+33-467 61 56 45
Fax	+33-467 61 71 19
E-mail	Maraux@cirad.fr

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	**Provision of the crop model SARRAH to assess the impact of climate scenarios on growth and yield of annual crops in dry environments in West Africa and elsewhere.** This model has been validated for millet with on-station and on-farm, agronomic observations in Senegal. It is sensitive to hydrological and classical agro-meteorological variables and enables taking into account certain adaptive responses of the simulated system to climate variation, such as sowing date, choice of variety and some agricultural practices.
2	**Assessment of errors occurring when climate data aggregated at different spatial scales (pixel sizes) are used for crop modelling, and provision of a methodology to control such errors** (collaboration with IRD Grenoble). In particular, the crop and field water balances are extremely sensitive to spatial aggregation of rainfall data, typically resulting in over-estimation of yield potential. The proposed solution is based on a model re-introducing temporal variability lost during aggregation.
3	**Evaluation of decision criteria for sowing dates using local, rainfall based and regional, meteorology based parameters** (collaboration with LMD Paris). GCMs may in the future be used to guide agricultural decisions, but this requires solid concepts for the translation of climatic information into action. One such concept was developed and applied to climatic scenarios.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).	Timescale (months)
Increasing the range of crops simulated with SARRAH	SARRAH will be modified to simulate a larger range of tropical crops, including aquatic rice and perennials	24
Improvement of the up/down-scaling tool and initiation of training courses	A refined methodology for simulations of climatic impacts will be developed on the basis of SARRAH and the up/down-scaling tool for climatic data. Students and professionals from Africa and elswhere will be trained in using the tool.	24

FOREEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ X	**FIN**	Financial support	☐
LIC	Licence agreement	☐ X	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐ X
JV	Joint venture	☐	**CONS**	Available for consultancy	☐ X
			Other	(please specify)	☐

2.2.6 : Quantified data for each partner's main result

Items	**Currently achieved quantity** [a]	**Estimated future quantity** [b]
Economic impacts (in EURO)	0	0
# of licenses issued (within EU)	0	0
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	0	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Florent Maraux**

Date: 23 May 2003

2.1.3 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**Meteo-France Centre National de Recherches Météorologiques**
PARTNER's WEB SITE (if any) :	**http://www.cnrm.meteo.fr/**

CONTACT PERSON(S):

Name	Jean-François Royer
Position/Title	Ingénieur en Chef
Organisation	Meteo-France, Centre National de Recherches Météorologiques
Address	CNRM/GMGEC , 42 Avenue G Coriolis 31057 Toulouse Cedex 1, France
Telephone	+33 561 079377
Fax	+33 561079610
E-mail	Jean-Francois.Royer@meteo.fr

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	**Improved understanding of the natural variability and predictability of current monsoon climates:** Ensembles of global seasonal atmospheric simulations from March to September have been performed with either free-running (control case) or prescribed soil moisture. The results show that, even in the tropics and during a strong phase of the ENSO, soil moisture may some impact on the interannual precipitation variability and on seasonal forecasts.
2	**Development of sophisticated land surface schemes:** The description of current land-surface distribution over the globe has been improved by using a high resolution database derived from satellite observations. An integrated impact assessment model has been used to obtain realistic projections of future land use changes. Sensitivity experiments have been performed to assess the surface climate response to the specification of land surface properties
3	**Development and assessment of anthropogenic climate change scenarios:** A scenario of climate change for the 21-st century has been performed with a coupled atmosphere-ocean model. The results of the simulation have been sent for inclusion in the PROMISE database. A detailed analysis of the response has been performed over Africa and India. Simulations with an increased spatial resolution over Africa have been performed. The impact of greenhouse gas forcing and anthropic land-use changes for 2050 have been compared

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**
Datasets	Provision of the results of the simulations to the Promise database, or provision of selected results upon request to other scientific users.	12
Publications	Submission of the results for publication in peer-reviewed scientific journals Revision of the submitted papers	12 24

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ X	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.3 : Quantified data for each partner's main result

Items	Currently achieved quantity [a]	Estimated future quantity [b]
Economic impacts (in EURO)	 0	0
# of licenses issued (within EU)	0	0
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	0	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: JF Royer **Name: Jean-Francois Royer**

Date: 30/04/2003

2.1.4 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**Danish Meteorological Institute**
PARTNER's WEB SITE (if any) :	**www.dmi.dk**

CONTACT PERSON(S):

Name	Wilhelm May
Position/Title	Dr.
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Telephone	+45 3915 7462
Fax	+45 3915 7460
E-mail	may@dmi.dk

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	Evaluation of the simulation of the mean Indian summer monsoon and its sub-seasonal variability: Very good simulation of the monsoon climate and of the sub-seasonal variability by the high-resolution AGCM. Assessment of future monsoon climate in response to anthropogenic climate change: Intensification of the Indian summer monsoon when considering the monsoon rainfall and other parameters of the hydrological cycle as a consequence of the general warming.
2	Evaluation of the simulation of extreme daily rainfall events during the Indian summer monsoon and the assessment of their future change: Quite good simulation of the day-to-day variability and of extreme daily rainfall events. Generally, enhancement (reduction) of extreme rainfall in accordance with an enhancement (reduction) of the mean monsoon rainfall, but up to one order of magnitude stronger.
3	Evaluation of the predictions from the DEMETER multi-model ensemble seasonal forecasting system: Some forecast skill by combining the anomalies predicted by the different models also for the monsoon rainfall. Potential for further improved prediction of the Indian summer monsoon by combing the predictions by the individual models in an "optimal" way.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).	Timescale (months)
Evaluation of the AGCM's ability to simulate the mean Indian summer monsoon and its sub-seasonal variability	Evaluation of the simulation of the mean Indian summer monsoon and its sub-seasonal variability: Very good simulation of the monsoon climate as well as of the sub-seasonal variability by the high-resolution AGCM, indicating the value of the high resolution. One article is published in a scientific journal.	4
Assessment of the future Indian summer monsoon climate in response to anthropogenic climate change	Assessment of the possible changes in the Indian summer monsoon due to global warming on the basis of a time-slice experiment with a high-resolution AGCM: Intensification of the Indian summer monsoon when considering the monsoon rainfall and other parameters of the hydrological but a weakening when considering the large-scale circulation. The publication of two articles in a scientific journal is envisaged, one is published.	12
Evaluation of the AGCM's ability to simulate extreme rainfall events during the Indian summer monsoon and the assessment of the future characteristics of extreme daily rainfall events in response to anthropogenic climate change	The high-resolution AGCM simulates the day-to-day variability of the monsoon rain fall and the characteristics of extreme daily rainfall events in quite good agreement with observations. For the future, the extremes of the monsoon rainfall are typically enhanced (reduced) in those areas where the mean monsoon rainfall is enhanced (reduced). But there are also regions, where the future changes in the extreme and the mean rainfall go into the opposite direction. Furthermore, the local changes in the extreme rainfall can exceed the changes in the mean rainfall by up to one order of magnitude. The publication of one article in a scientific journal is envisaged.	6
Evaluation of the predictions from the DEMETER multi-model ensemble seasonal forecasting system (7 models and 9 ensemble members) with respect to the Indian summer monsoon	A combination of the anomalies predicted by the various models lead to some skill for predicting changes of various indices describing the intensity of the Indian summer monsoon. The forecast skills for local changes of both the large-scale flow and the rainfall are somewhat lower but not at all negligible. The varying forecast skill of the individual models suggests a good potential for improving the prediction of the intensity of the Indian summer monsoon by combining the predictions by the different models in an "optimal" way, taking the strength and the weakness of the individual models into account. A continuation of this work is desirable.	8

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (□) corresponding to your most probable follow-up.

R&D	Further research or development	☐ x	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing agreement/Franchising	☐	**INFO**	Information exchange, training courses	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify) ____________________	☐

2.2.4 : Quantified data for each partner's main result

Items	**Currently achieved quantity** [a]	**Estimated future quantity** [b]
Economic impacts (in EURO)	....	....
# of licenses issued (within EU)	....	....
# of licenses issued (outside EU)	....	....
Total value of licenses (in EURO)	....	....
# of entrepreneurial actions (start-up company, joint ventures…)	....	....
# of direct jobs created [c]	....	....
# of direct jobs safeguarded [c]	....	....
# of direct jobs lost	....	....

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Wilhelm May**

Date: 29 April 2003

2.1.6 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**Natural Environment Research Council – Centre for Ecology & Hydrology, Wallingford**
PARTNER's WEB SITE (if any) :	**www.ceh.ac.uk**

CONTACT PERSON(S):

Name	Christopher Taylor
Position/Title	Senior Scientific Officer
Organisation	Centre for Ecology & Hydrology – Wallingford
Address	Maclean Building, Wallingford, Oxfordshire OX10 8BB, UK
Telephone	+44-1491-838800
Fax	+44-1491-692238
E-mail	cmt@ceh.ac.uk

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	**Provision of a detailed hydrological model for application to West Africa.** The work made use of the Global Water AVailability Assessment method (GWAVA) which provides an improved methodology for the assessment of water resources in relation to water demand for application at the global scale, based on a 0.5 by 0.5 degree latitude-longitude grid. The main output of GWAVA is the comparison of water availability and demand at the scale of the grid cell, enabling the variability and complexity of the water resources situation to be appreciated.
2	**Assessment of climate change and land use change impacts on water resources.** Using the GWAVA model, a variety of scenarios of future change was examined in order to identify the particular locations within the study region which are expected to come under increasing water stress over the next 25 to 50 years. This revealed that there is expected to be a marked increase in water stress in the Sahel zone, the part of the region where population densities are high and water is already scarce. The impact of land use change was found to be largest in the high rainfall areas of the region. However, in the highly stressed Sahel zone, the anticipated changes in population and water demands, combined with climate change, are expected to be dominant, and land use factors are less significant.
3	**Assessment of land use change on climate in West Africa.** Studies using the Met Office/Hadley Centre General Circulation Model were made examining the climatic response to past and predicted future changes in land use in the region. Realistic and use scenarios were generated from a variety of sources, and predictions of future land use made, based on key socio-economic factors. The scenarios show the heterogeneity of the region in terms of land use change, with deforestation hotspots evident even at the national scale. The model suggests that historic and future land use change leads a modest reduction in regional rainfall. However, in hotspot regions, the decrease can account for 10% of the mean annual rainfall.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).	Timescale (months)
Further development and application	We plan to try to set up collaborations with a number of organisations to further develop and test the GWAVA method in different situations around the world, with the eventual aim of making realistic assessments of the balance of water resources and demand under climate and other change scenarios.	36

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ X	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐ X
JV	Joint venture	☐	**CONS**	Available for consultancy	☐ X
			Other	(please specify)	☐

2.2.6 : Quantified data for each partner's main result

Items	**Currently achieved quantity** [a]	**Estimated future quantity** [b]
Economic impacts (in EURO)	0	0
# of licenses issued (within EU)	0	0
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	0	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Christopher Taylor**

Date: 29 April 2003

2.1.7 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**Laboratoire de Météorologie Dynamique - CNRS**
PARTNER's WEB SITE (if any) :	**http ://www.lmd.jussieu.fr**

CONTACT PERSON(S):

Name	LAVAL Katia
Position/Title	Professor
Organisation	CNRS - LMD
Address	4 Place Jussieu, Boîte 99 75252 Paris Cedex 05
Telephone	01.44.27.50.15
Fax	01.44.27.62.72
E-mail	laval@lmd.jussieu.fr

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	A Global Land Surface Scheme ORCHIDEE has been achieved and implemented in the GCM.
2	**Irrigation Assessment** A sheme has been developed to compute irrigation by defining water requirement and an equilibrium between water demand and water supply.
3	**Impact of doubling CO2** Atmospheric simulations have been performed with 1CO2 (control) and 2CO2 concentrations. The influence of doubling CO2 on river flows and irrigation is being assessed.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).	Timescale (months)
Development of a Global Land Surface Scheme Orchidee	- Presentation of the model at Scientific Meetings - Publication of a scientific paper - Use of Orchidee to predict the river flows over large scale basins.	6 12 12
Irrigation Assessment	- Presentation of the module at Scientifc Meetings - Publication of a scientific paper - Assessment of the impact of irrigation on surface energy budget	6 6 12
Impact of doubling CO2	The influence of doubling CO2 on water budget is evaluated	12

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ ✓	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.7 : Quantified data for each partner's main result

Items	**Currently achieved quantity** [a]	**Estimated future quantity** [b]
Economic impacts (in EURO)	0	0
# of licenses issued (within EU)	0	0
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	0	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] The added value or the number of items already achieved to date.
[b] Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).
[c] "Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Pr. LAVAL Katia**

Date: 05/2003

2.1.8 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**MPG.IMET**
PARTNER's WEB SITE (if any) :	**www.mpimet.mpg.de**

CONTACT PERSON(S):

Name	Prof. Dr. Mojib Latif
Position/Title	Professor
Organisation	Institute for Marine Research, University of Kiel
Address	Düsternbrooker Weg 20 24105 Kiel, Germany
Telephone	+49 431 600-4050
Fax	+49 431 600-4052
E-mail	mlatif@ifm.uni-kiel.de

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	**Natural variability of monsoonal systems** Description of the interannual variability of sea surface temperature (SST) in the tropical Indian Ocean and its relationship with monsoon systems and ENSO
2	**Influence of SST anomalies on monsoon climates** Description of the impact of regional SST anomalies on West African summer monsoon
3	**Role of land surface processes for monsoon climates** Implementation of a simple dynamic vegetation model into the ECHAM GCM and description of the impact of dynamic vegetation on variability of Sahelian rainfall during the last five decades. Description of the relative roles of vegetation and orbital parameters for the regime change from the mid-Holocene "green" Sahara to todays climate.
4	**Impact of anthropogenic climate change on monsoon climates** Description of the impact of anthropogenic climate change on Indian summer monsoon. Description of the impact of changes in sulphate aerosol concentrations on West African summer monsoon. The results of the ECHAM4/OPYC3 climate change simulations with greenhouse gas-only and greenhouse gas plus sulphate aerosol and ozone forcings have been made available to the PROMISE database for use by other partners and other impact-related research.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**
(For all results) Publication	Dissemination of results through publication in peer-reviewed scientific journals	12
Further development and application	The implementation of a full dynamic vegetation and improved surface hydrology scheme in the ECHAM GCM is in progress and will be used to further study the role of land surface processes for monsoon climates.	24

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ X	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.8 : Quantified data for each partner's main result

Items	Currently achieved quantity [a]	Estimated future quantity [b]
Economic impacts (in EURO)	........0.......	.........0......
# of licenses issued (within EU)	........0.......	.........0......
# of licenses issued (outside EU)	........0.......	.........0......
Total value of licenses (in EURO)	........0.......	.........0......
# of entrepreneurial actions (start-up company, joint ventures…)	........0.......	.........0......
# of direct jobs created [c]	........0.......	.........0......
# of direct jobs safeguarded [c]	........0.......	.........0......
# of direct jobs lost	........0.......	.........0......

[a] The added value or the number of items already achieved to date.
[b] Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).
[c] "Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Mojib Latif**

Date: May 13, 2003

2.1 9: Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT99-00022**
PARTNER's NAME :	**Met Office**
PARTNER's WEB SITE (if any) :	**www.metoffice.com**

CONTACT PERSON(S):

Name	Mr Roy Kershaw
Position/Title	Group Leader
Organisation	Met Office
Address	Hadley Centre London Rd Bracknell RG12 2SY UK
Telephone	+44(0)1344 856204
Fax	+44(0)1344 854898
E-mail	Roy.kershaw@metoffice.com

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1 Publications	The results of our contribution to the project will be increased understanding of atmosphere and land processes which will be freely available through publication in scientific journals.
2 Data	As part of our contribution we are making atmospheric simulations available to other partners so that crop models can be driven by them.

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale

Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**
1 Publication	We would expect to publish all relevant papers within 2 years post project	24
2 Data	Data will be made available through the PROMISE data archive for at least the duration of the project and probably for several years afterwards	60?

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☒) corresponding to your most probable follow-up.

R&D	Further research or development	yes	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.9: Quantified data for each partner's main result

Items	**Currently achieved quantity** [a]	**Estimated future quantity** [b]
Economic impacts (in EURO)	0	0
# of licenses issued (within EU)	0	..............0.
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	..............0.	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name:Roy Kershaw**

Date:30 April 2003

2.1.10 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT99-00022**
PARTNER's NAME :	**UREADAG**
PARTNER's WEB SITE (if any) :	www.reading.ac.uk/~aaspel

CONTACT PERSON(S):

Name	Dr Tim Wheeler
Position/Title	Lecturer and Director
Organisation	Plant Environment Laboratory
Address	Department of Agriculture, The University of Reading Cutbush Lane, Shinfield, Reading, RG2 9AD, UK
Telephone	+44(0)118 9883000
Fax	+44(0)118 9885491
E-mail	t.r.wheeler@rdg.ac.uk

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1 Publications	The results of our contribution to the project will be to provide a method for development of a combined weather and crop forecasting system. This methodology has been published in scientific journals. We have also compiled the responses of scientists worldwide who identified potential applications of seasonal forecasts in agriculture.
2 Data	Model simulation runs for groundnut crops across India have been performed and made available to project collaborators.
3	

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale		
Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**
1 Publication	One journal article has been published. Others should be published within the next 18 months	18
2 Data	Data from crop model simulation runs will continue to be available to project collaborators	24+

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	yes	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.10 : Quantified data for each partner's main result

Items	**Currently achieved quantity [a]**	**Estimated future quantity [b]**
Economic impacts (in EURO)	0	0
# of licenses issued (within EU)	0	..............0.
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	...............0.	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Dr Tim Wheeler**

Date: 11 May 2003

2.1.11 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT-1999-00022**
PARTNER's NAME :	**European Centre for Medium Range Weather Forecasts**
PARTNER's WEB SITE (if any) :	**www.ecmwf.int**

CONTACT PERSON(S):

Name	Laura Ferranti
Position/Title	Dr.
Organisation	ECMWF
Address	Shinfield Park RG2 9AX Berkshire Reading U.K.
Telephone	+44 118 949 9601
Fax	+44 118 986 9450
E-mail	LauraFerranti@ecmwf.int

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	Assessment of monsoon long term forecasts produced operationally by ECMWF.
2	
3	

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale		
Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	☐ x	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.11 : Quantified data for each partner's main result

Items	**Currently achieved quantity** [a]	**Estimated future quantity** [b]
Economic impacts (in EURO)	....	....
# of licenses issued (within EU)	....	....
# of licenses issued (outside EU)	....	....
Total value of licenses (in EURO)	....	....
# of entrepreneurial actions (start-up company, joint ventures…)	....	....
# of direct jobs created [c]	....	....
# of direct jobs safeguarded [c]	....	....
# of direct jobs lost	....	....

[a] *The added value or the number of items already achieved to date.*
[b] *Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).*
[c] *"Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation*
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Laura Ferranti**

Date:2nd May 2003

2.1.12 : Description of the use and the dissemination of result(s), partner per partner

MANDATORY INFORMATION :

CONTRACT NUMBER :	**EVK2-CT99-00022**
PARTNER's NAME :	**Centre de Recherches de Climatologie – Univ. Bourgogne (UB)**
PARTNER's WEB SITE (if any) :	**www.u-bourgogne.fr/climatologie/**

CONTACT PERSON(S):

Name	Dr Sylwia TRZASKA
Position/Title	
Organisation	Universite de Bourgogne, Centre de Recherches de Climatologie
Address	6, bd Gabriel 21000 Dijon France
Telephone	+33(0)3 80 39 38 22
Fax	+33(0)3 80 39 57 41
E-mail	Sylwia.Trzaska@u-bourgogne.fr

No, TITLE *(as in section 1.2)* **AND BRIEF DESCRIPTION OF MAIN RESULT(S)**

1	**Seasonal forecasts of West African Monsoon** Development of simple statistical forecasts schemes for West African Rainy season based on regional and global predictors derived from NCEP reanalyzes. Real-time seasonal forecasts for 2001 and 2002 seasons.
2	**Land surface sensitivity studies** Description and Atmospheric General Circulation Model sensitivity study of the interannual changes in vegetation characteristics on West African Monsoon.
3	

FOR EACH MAIN RESULT, TIMETABLE OF THE USE AND DISSEMINATION ACTIVITIES WITHIN THE NEXT 3 YEARS AFTER THE END OF THE PROJECT

Mention the use and dissemination related activities, the main associated partners, the related milestones and give an indicative timescale		
Activity	**Brief description of the activity, including main milestones and deliverables (and how it relates to data in sections 1.5 and 2.2).**	**Timescale (months)**
1	Real time forecasts presentation at regional forecast forum (PRESAO), published in the 'Long-Lead Forecast Bulletin' and available on the web site	12
2	Peer-reviewed publication of the results	24

FORESEEN COLLABORATIONS WITH OTHER ENTITIES

Please tick appropriate boxes (☐) corresponding to your most probable follow-up.

R&D	Further research or development	yes	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange, training	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

2.2.12 : Quantified data for each partner's main result

Items	Currently achieved quantity [a]	Estimated future quantity [b]
Economic impacts (in EURO)	0	0
# of licenses issued (within EU)	0	..............0.
# of licenses issued (outside EU)	0	0
Total value of licenses (in EURO)	0	0
# of entrepreneurial actions (start-up company, joint ventures…)	..............0.	0
# of direct jobs created [c]	0	0
# of direct jobs safeguarded [c]	0	0
# of direct jobs lost	0	0

[a] The added value or the number of items already achieved to date.
[b] Estimated quantity = estimation of the quantity of the corresponding item or the number of items that you foresee to achieve in the future (i.e. expectations within the next 3 years following the end of the project).
[c] "Direct jobs" means jobs within the partner involved. Research posts are to be excluded from the jobs calculation
 # = number of ...

I confirm the information contained in part 2 of this Technological Implementation Plan and I certify that these are our exploitation intentions

Signature: **Name: Sylwia Trzaska**

Date: May 12, 2003

Part 3 Search for Collaboration through Commission services (Optional)

A separate part 3 might be completed by each partner willing to set up new collaborations, and seeking dissemination support from the CORDIS services.

The part 3 must be consolidated at the consortium level and transmitted to the Commission by the co-ordinator.

PARTS 3 WILL BE DISSEMINATED BY THE COMMISSION

CONTACT PERSON FOR THIS EXPLOITABLE RESULT

Name	
Position	
Organisation	
Address	
Telephone	
Fax	
E-mail	

COLLABORATIONS SOUGHT

Please tick appropriate boxes () corresponding to your needs.

R&D	Further research or development	☐	**FIN**	Financial support	☐
LIC	Licence agreement	☐	**VC**	Venture capital/spin-off funding	☐
MAN	Manufacturing agreement	☐	**PPP**	Private-public partnership	☐
MKT	Marketing	☐	**INFO**	Information exchange	☐
JV	Joint venture	☐	**CONS**	Available for consultancy	☐
			Other	(please specify)	☐

POTENTIAL OFFERED FOR FURTHER DISSEMINATION AND USE

Please, clearly describe your input, the value and interest of the applications and the dissemination and use opportunities that you can offer to your potential partner.

PROFILE OF ADDITIONAL PARTNER(S) FOR FURTHER DISSEMINATION AND USE

Please, clearly describe the profile and the expected input from the external partner(s).

I confirm the information contained in part 3 of this Technological Implementation Plan and I authorise its dissemination to assist this search for collaboration.	
Signature:	**Name:**
Date:	**Organisation:**

Part 4 Comment on European Interest

All projects are expected to meet European interests. This section should provide an appraisal of your project in terms of European added value and support to the implementation of European Union policies.

1. Community added value and contribution to EU policies

1.1 European dimension of the problem

(The extent to which the project has contributed to solve problems at European level)

By increasing the knowledge and awareness of the feedbacks between regional climate and anthropogenic changes in land use, PROMISE has contributed to improvements in the scientific basis for the construction and development of scenarios for the future sustainable development of tropical regions, particularly with respect to agriculture, forestry and water resources. This is relevant to the EU’s *Environment Policy* concerning the protection of land, the conservation and management of natural resources. In addition, PROMISE has promoted active collaboration with scientists and institutes in monsoon-affected countries with the aim of creating a trust-building relationship to ensure that EU *Environmental Policy* on global issues, such as control of greenhouse gas emissions and ecosystem conservation, are perceived by these countries as based on unbiased scientific advice.

1.2 Contribution to developing S&T co-operation at international level. European added value

(Development of critical mass in human and financial terms; combination of complementary expertise and resources available Europe-wide)

PROMISE has brought together state-of-the-art climate and seasonal prediction models with sophisticated models of ground hydrology, water balance for large river catchments, crop development and productivity. No single country has all these tools available, nor the expertise in their application to monsoon climates. By bringing together these various models and expertise, PROMISE has provided considerably more breadth and added-value to the research than could be achieved at the national level, in line with the EU’s policy on *Research and Technological Development*. PROMISE has also engaged scientists and users from monsoon-affected countries. It has therefore promoted EU scientific leadership and the *International Role of Community Research* by contributing to global international cooperation on environmental issues, in this case those of weather and climate with hydrology and agriculture. It has also developed links with, and promotes technology transfer to those countries within the EU’s policy on *External Relations*.

1.3 Contribution to policy design or implementation

(Contribution to one or more EU policies; RTD connected with standardisation and regulation at Community and/or national levels)

The cross-disciplinary nature of the proposed research has enabled PROMISE to bridge the gap between those who provide seasonal and climate change predictions and those who apply these predictions to the areas which have direct societal and economic implications, in this case water resources and food. As such, PROMISE has direct relevance to the EU's *Common Commercial Policy* and *Development Policy*.

The EU and its Member States are at the centre of global efforts to promote aid and development in the ‘Third World’ in order to alleviate poverty in these regions. Improvements in our ability to predict potential droughts, crop failures and food shortages would be of enormous value in mitigating these humanitarian disasters, improving livelihoods and in reducing the costs of food aid. PROMISE has developed the potential within the EU research community to provide scientific advice of relevance to the development of short-term and long-term strategies within the EU’s humanitarian aid programmes. This would be particularly relevant to the Commission's *European Office for Emergency Humanitarian Aid (ECHO)*. In the longer term, advice on the potential impacts of climate change on water resources and agriculture in highly vulnerable monsoon countries, and on potential measures to mitigate against such impacts will be crucially important for future policy and funding levels for the EUÕs *Development Policy*.

2. Contribution to Community social objectives

2.1 Improving the quality of life in the Community :
Not applicable

2.2 Provision of appropriate incentives for monitoring and creating jobs in the Community (including use and development of skills) :
Not applicable

2.3 Supporting sustainable development, preserving and/or enhancing the environment (including use/conservation of resources) :

Climate change brought about by anthropogenic release of greenhouse gases and transformation of the land surface natural cover should be more precisely evaluated in order for it to be incorporated in cost benefit analysis. This can be particularly relevant for the implementation of carbon sequestration policies based on either preservation or extension of forest resources. A more precise evaluation of the possible beneficial or detrimental impact of changes in tropical forests and land management on the regional or global climate, as incorporated in PROMISE research, is a prerequisite for a proper evaluation of the strategic objectives and economic policies aimed at preserving or restoring sustainable forest resources in developing countries. This could have an interest for nature conservation policies supported by the EU program.

PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

(Contract number: EVK2-CT-1999-00022)

Sections 5 & 6: Final Report

SECTION 5:

Contract n°	**EVK2-CT-1999-00022**	Project Duration:	Feb. 2000-Mar. 2003
Title	Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change: PROMISE		

Objectives:

- Assessment of the natural variability and predictability of monsoon climates on seasonal, interannual and interdecadal timescales.
- Development of sophisticated land surface schemes which incorporate (i) a detailed treatment of soil water including the effects of irrigation and (ii) changes in vegetation and land use based on satellite-derived, high-resolution observations of vegetation cover.
- Development and assessment of anthropogenic climate change scenarios, including land use, for monsoon climates.
- Development of integrated system for linking crop yield and seasonal weather prediction models
- Assessment of impact of natural and anthropogenic climate change on ground hydrology, water resource management and crop systems.
- Development of pro-active links with scientists from monsoon-affected countries through establishment of data archive, web site and network.

Scientific achievements: PROMISE has made significant advances in our ability to understand, simulate and predict monsoon climates, their mean behaviour and their variability on intraseasonal and interannual timescales, and how these will change in the future due to anthropogenic influences. PROMISE has shown that the land surface is a crucial driver in monsoon variability on timescales from days to decades and that the influence of vegetation and soil hydrology must be well represented in climate models.

PROMISE has provided new assessments of climate change for India and West Africa. It has been shown that the intensification of the Indian and Sahelian summer monsoon in a future warmer climate is due to enhanced land-sea contrast, a northward displacement of the inter-tropical convergence zone, and increased levels of precipitable water in a warmer atmosphere. PROMISE has demonstrated that improved projections of future monsoon climates, in particular for extreme precipitation events and surface hydrology, require higher resolution for the impact assessment of anthropogenic climate change on the Asian and African monsoon regions.

Land use and natural resource management policy at the national level need to take account of predicted changes in climate, as well as satisfying the demands of a growing population and economic development. PROMISE has developed new scenarios of future land use for West Africa and shown that the direct feedback of land use on climate at the regional scale is likely to be weaker than the effect of increased global CO_2 levels. However, at the local/national scale, extensive deforestation may contribute to a substantial reduction in precipitation, and therefore impact negatively on water resources.

PROMISE has pioneered a new approach to assessing future availability of water for West Africa which will allow policy makers and others to make better informed resource allocation decisions, and will facilitate the assessment of impacts of human activities – such as climate change and land use change – on water availability in relation to people's needs for water for all purposes. PROMISE results clearly indicate the likelihood of increasing water shortages in the semi-arid Sahel zone where population densities are high and water is already scarce. This region is one that already suffers from high levels of poverty and water stress, and the results reinforce the pressing need to promote and fund adaptation strategies for improved water resources provision and management in this area.

Increasingly, seasonally arid regions use irrigation to enable crop production in the dry season and to support crop development in the rainy season. PROMISE has enabled the development of an integrated land surface and hydrology scheme that includes the effects of irrigation in the fully coupled climate model. This has provided one of the first estimates of the effects water extraction for irrigation on river flows for the major rivers of India under future climate scenarios.

A major effort in linking the disciplines of crop modelling and climate prediction has been undertaken in PROMISE. Significant progress has been made towards establishing a toolbox for evaluating the impact of climate variability and change on crops in semi-arid environments. A new approach to crop modelling has been pioneered, which provides an upscaling of a phenology-based model to spatial scales closer to those of the regional climate models. This then reduces the need for statistical downscaling using weather generators that are not necessarily transferable to future climate states.

However, PROMISE research with crop models has also raised a number of important issues, particularly those related to biases within climate models, and has highlighted again the need for significant improvements in climate model simulations, particularly with respect to precipitation. A key recommendation from PROMISE is that, given the great importance of the space/time distribution of rainfall for crop and soil water balance, future work on climate applications for agriculture should place more emphasis on the intra-seasonal variability of weather. Lastly, we restate the importance, at least for semi-arid environments, of reliable and timely predictions of the onset of the rainy season.

Main Deliverables:

- Advances in our ability to understand, simulate and predict monsoon climates, their mean behaviour and their variability on intraseasonal and interannual timescales, and how these will change in the future due to anthropogenic influences.
- Improved assessments of climate change for India and West Africa, including high-resolution scenarios, which can be used by impacts modellers and policy makers.
- Development of improved land surface schemes for climate models, including the effects of irrigation and flood plains on soil hydrology and river discharge.
- New estimates of future water availability for West Africa, which include the effects of changes in land use, human consumption.
- Major advances in linking the disciplines of crop modelling and climate prediction for monsoon environments.
- Effective measures for disseminating the results of PROMISE to scientists and users in monsoon-affected countries.

Socio-economic relevance and policy implications: Understanding the natural variability of monsoon climates is a prerequisite for understanding and quantifying climate change in these sensitive regions and for making seasonal predictions. The land surface is key to providing more accurate climate simulations that will be of significant value for regional climate change forecasting and for impact assessment. The assessment of the impact of climate change due to anthropogenic causes on monsoon areas has obviously a direct economic implication for these regions. The needs for water resources are increasing with the growth of population and the intensification of agriculture. A good understanding and prediction of monsoon variability is of paramount importance to plan ahead and limit climate induced socio-economic problems.

The problem of water resources may be the most serious problem society will face in the coming decades. As the demand for water increases, an important issue is the evaluation of changes of the hydrological budget, not only due to climatic change related to CO_2 increase, but also due to human disturbances through reservoir construction and water use by agriculture. The water resource modelling developed in PROMISE can be applied worldwide, allowing policy makers and others to make better informed resource allocation decisions, and facilitating the assessment of impacts of human activities (such as climate change) on global water distributions.

Food production in seasonally arid areas is inherently risky. PROMISE has initiated an important collaboration between climate and crop modellers. The final goal of the collaboration is to achieve substantial progress towards the development of an integrated system for the interpretation of seasonal forecasts and climate change predictions in terms of their agricultural impacts.

Conclusions: As a result of PROMISE, significant progress has been achieved in understanding, simulating and predicting monsoon variability and change. Important developments in modelling the land surface, particularly vegetation and soil hydrology, have been achieved, and new future land use scenarios have been constructed. Both have enabled new assessments of the influence of the land surface on climate variability and change. Important new links between the climate, crop and water resource modelling communities have been established, which have laid the foundations for collaboration beyond the lifetime of PROMISE. The interaction between these various disciplines has emphasised the barriers to progress presented by climate model systematic errors and set priorities for future research.

Dissemination of results: The transfer of technology to developing countries is essential if EU research is to be properly exploited. Consequently PROMISE has placed a particular emphasis on the dissemination of results and the engagement and training of scientists from monsoon-affected countries. Several mechanisms have been used to ensure that PROMISE research is disseminated and exploited to maximum effect. These include (i) the development and maintenance of the PROMISE website (http://ugamp.nerc.ac.uk/promise); (ii) publication of two brochures promoting PROMISE research and a CDROM containing presentations from the final conference; (iii) the establishment of the PROMISE Data Archive; (iv) organization of a Workshop and two International Conferences at ICTP with sponsorship for scientists from developing countries; and (v) a series of fact-finding visits to agricultural centers in the semi-arid tropics.

Keywords: monsoons, climate change, seasonal prediction, crop modelling, water resources

SECTION 6

6.1 Background

The majority of the world's population lives in countries, which rely on the regular return of the monsoon rains. It is in these countries that future increases in population, with their accompanying stresses on the environment, are most likely to occur. These countries have semi-arid climates that are highly vulnerable to climate change. Of particular relevance to agriculture and hydrology will be the change in the incidence of extreme events on interannual (flood vs. drought) and subseasonal (wet vs. dry spells) timescales.

PROMISE is an interdisciplinary project that has developed further the atmospheric science base in seasonal and climate change prediction for monsoon-affected countries, and has established new links between atmospheric science and the impacts communities related to hydrology and agriculture. This has been achieved by bringing together state-of-the-art climate and seasonal prediction models with sophisticated models of ground hydrology, water balance for large river catchments, and crop development and productivity.

PROMISE has addressed the variability, predictability and climate change impacts for all the major monsoons since common processes and methodologies apply. There have been real benefits for the development of the research by considering the range of scenarios offered by the various monsoon systems. Similarly PROMISE has addressed the key issues of both seasonal prediction and climate change. Each has required the basic underpinning research into the natural variability of the current climate, specifically what factors influence that variability and how well current climate models represent it.

The potential for seasonal prediction is greatest in the tropics where the climate is closely tied to the ocean temperatures. Although El Nino dominates tropical interannual variability, other factors need to be investigated, particularly land surface conditions and changes in land use. The effects of El Nino can often be exacerbated by changes in land use (e.g. deforestation of tropical rain forests leading to floods/mudslides) or agricultural practices (e.g. change from natural to farmed vegetation and the balance between crops and livestock). In this regard, PROMISE has advanced the state of the art in seasonal and climate change prediction for monsoon-affected countries by focusing on the influence of land surface processes and of anomalies in land surface conditions.

PROMISE was organized around three main science themes:

(i) Natural variability and predictability of monsoon climates on seasonal, interannual and interdecadal timescales.

(ii) Assessment of anthropogenic climate change scenarios for monsoon climates.

(iii) Impact of natural and anthropogenic climate change on ground hydrology and agricultural systems.

In addition, a key element of PROMISE has been the development of pro-active links with scientists from monsoon-affected countries. Collaboration with research institutions in monsoon-affected non-European nations has been an important component of this project and was explicitly planned as an additional workpackages. Training and dissemination activities have been an important part of PROMISE, facilitated by the developing countries' programme at the UNESCO International Centre for Theoretical Physics (ICTP).

To cover the various science areas, PROMISE involved partners from the seasonal prediction and climate modelling communities, as well as specialists in modelling ground hydrology, river flows and crop productivity and who have particular expertise in the semi-arid tropics. PROMISE has built on the world leading expertise in Europe on modelling monsoon climates, developed, in part, through the EU FP4 projects, 'Studies of the Hydrology, Influence and Variability of the Asian Summer Monsoon (SHIVA)' and the 'West African Monsoon Project (WAMP)'. Whilst SHIVA answered many questions, it also identified priorities for future research. These included the need to continually improve the basic simulation of the monsoon with the recognition that coupled ocean-atmosphere processes may have an important influence on monsoon variability on timescales from days to decades. SHIVA also identified land surface processes as major players in monsoon variability and change with the requirement for greater understanding of the ways in which the land surface hydrology and land use change affect monsoon systems. Finally, SHIVA concluded that the goal of providing skilful seasonal forecasts for the monsoon still eludes us. We do not yet have a clear idea of how predictable the system is likely to be, or how much the apparently chaotic behaviour of the intraseasonal variability may limit that predictability. PROMISE was designed to address these issues as well as establishing the links between the climate and impacts modeling communities.

6.2 Scientific/technological and socio-economic objectives

The overall research objectives of PROMISE have been to advance the science of seasonal and climate change prediction for monsoon environments, and to develop the methodologies for translating these predictions into the impacts of climate variability and change on water resources and crop productivity. PROMISE had the additional objective of linking with scientists in monsoon-affected countries in order to achieve improved involvement in, and dissemination of PROMISE research.

The specific objectives of PROMISE were:

(1) Description of the natural variability of monsoon systems for the current climate, and assessment of the skill of climate models to represent this variability.

(2) Assessment of the seasonal predictability of monsoon systems using ensemble integrations, and development of advanced statistical techniques for evaluating the skill of seasonal forecasts.

(3) Assessment of the sensitivity of monsoon variability to regional anomalies in SST and land surface conditions, including vegetation.

(4) Documentation of the impacts of anthropogenic climate change on the characteristics of monsoon climates.

(5) Development of future scenarios of land use changes and assessment of the impact of these changes on monsoon climates.

(6) Development of methods for assessing the impact of natural and anthropogenic climate change on water resources, in particular the water balance of major river basins.

(7) Progress towards the development of an integrated system for the interpretation of probabilistic seasonal forecasts in terms of the crop development and yields.

(8) Assessment of anthropogenic climate change on crop productivity for selected regions.

(9) Provision of a web-accessible data archive, open to EU and non-EU institutions, containing data for selected surface climate variables from (a) global and regional simulations of the present day and future climates, (b) seasonal prediction ensembles, as well as relevant observational datasets for impact studies.

(10) Establishment of active links with climate scientists in monsoon-affected countries and with international hydrological and agricultural research centres.

(11) Organization of a workshop at ICTP during the second year of the project, especially focused on the collaborative aspects of model validation and hydrological/agricultural impact studies, and a final, international conference to disseminate the results of PROMISE to scientists from monsoon countries.

6.3 Applied methodology, scientific achievements and main deliverables

6.3.1 Methodology

PROMISE has exploited existing or new numerical simulations on seasonal and climate timescales, such as seasonal prediction ensembles, current climate simulations forced with observed sea surface temperatures for the 20th century, and climate change scenario simulations for the 21st century. In addition to the existing standard control and transient climate change integrations of the modeling centers, higher-resolution model integrations have been performed to study changes in the characteristics of monsoon climates, in particular extreme events, and to provide the higher spatial resolution needed for the impact studies involving agriculture and hydrology. These higher-resolution simulations were performed using regional models and/or time-slice experiments with global AGCMs. In the 'time-slice' setup, the output from standard transient simulations has been used as boundary conditions for high-resolution atmospheric GCMs that are run for relatively short present-day and future time periods.

PROMISE has undertaken process studies and sensitivity experiments through numerical experimentation with global and high-resolution regional models. The influence of sea surface temperature (SST) anomalies in the various ocean basins on the interannual variability and predictability of monsoons has been studied. The land surface is the link through to the agricultural and hydrological applications; land surface processes and the impacts of changes in land use have therefore been particular foci for PROMISE.

PROMISE has used existing or developed new models of crop development/productivity, ground hydrology and water balance in large river catchments, to investigate the seasonal predictability of crop yields and the effects of climate change on water resources and crop productivity.

New statistical techniques have been developed to aid in the analysis of the model integrations and to address issues such as the change in return period for extreme events and the characteristics of sub-seasonal variability. A set of statistical procedures, designed for the analysis of intraseasonal variability in climate simulations has been made available. The statistical package includes a sequence of spectral techniques, classical and complex empirical orthogonal function (CEOF) analysis. A graphical output of the results has been provided based on GrADS and XMGrace software. Some idealised examples of simple propagating signals have been developed for validation of the scripts, and for allowing the users to become familiar with the programs, the methods of analysis, and their interpretation. These scripts have been delivered to the PROMISE Internet site for testing by the other participants.

In order to improve the exchange of results between research institutions in European and extra-European countries, and between scientists with expertise on climatology, hydrology and agricultural resources, PROMISE has established an easily accessible database with selected results from numerical simulations and observational datasets.

6.3.2 Scientific Achievements

A: Natural variability and predictability of current monsoon climates on seasonal, interannual and interdecadal timescales.

PROMISE research on understanding the natural variability and predictability of monsoon climates has built on the strong foundations provided by the EU FP4 projects, 'Studies of the Hydrology, Influence and Variability of the Asian Summer Monsoon (SHIVA)' and the 'West African Monsoon Project (WAMP)'. These projects already provided a good understanding of the modes of interannual variability and their association with ENSO, in particular. Here we focus on the major new results from PROMISE in the following specific areas: (i) Influence of the Indian Ocean; (ii) Influence of land surface processes on monsoon variability and predictability; (iii) New perspectives on the intraseasonal variability of the West African Monsoon; and (iv) Understanding decadal variability in the Sahel.

(i) Influence of the Indian Ocean on monsoon variability in Africa

In the last few years, since the identification of the Indian Ocean Zonal or Dipole Mode in 1999, there has been increasing interest in the variability of the Indian Ocean, the factors that give rise to it and its influence on the climate of the surrounding regions. It is well known that the atmospheric circulation anomalies generated by the El Niño/Southern Oscillation (ENSO) can produce remote responses in the global oceans and land surface. However it is not clear to what degree these remote changes contribute to the memory and hence the predictability of the global circulation during and following ENSO. A series of idealised experiments with the Hadley Centre atmospheric GCM, HadAM3, have been designed to investigate these questions (Spencer et al. 2003). The model is forced with a 4-year cycle of SSTs, typical of a fairly strong El Niño/La Niña, based on composites of many events from the observed SSTs for 1871 to 1999. These SST anomaly cycles are imposed either regionally in the tropical Pacific, or globally, and each experiment is run for 40 years, i.e. 10 cycles of El Nino/La Nina.

Several months after the peak in ENSO forcing, the remote, lagged response by the global oceans substantially affects the Asian Summer Monsoon (Figure 1). This suggests that the basin wide warming of the Indian Ocean, which occurs during the summer after El Niño, has an important influence on the behaviour of the monsoon. The model results show a damping of the precipitation anomalies associated with El Niño once the global SST anomalies are included. It is interesting to note the non-linearity of the response of the model to the Indian Ocean SST anomalies associated with El Niño/La Niña. Whilst the Indian Ocean warming in response to El Niño influences the monsoon, the corresponding cooling of the Indian Ocean in response to La Niña appears to have little effect (not shown).

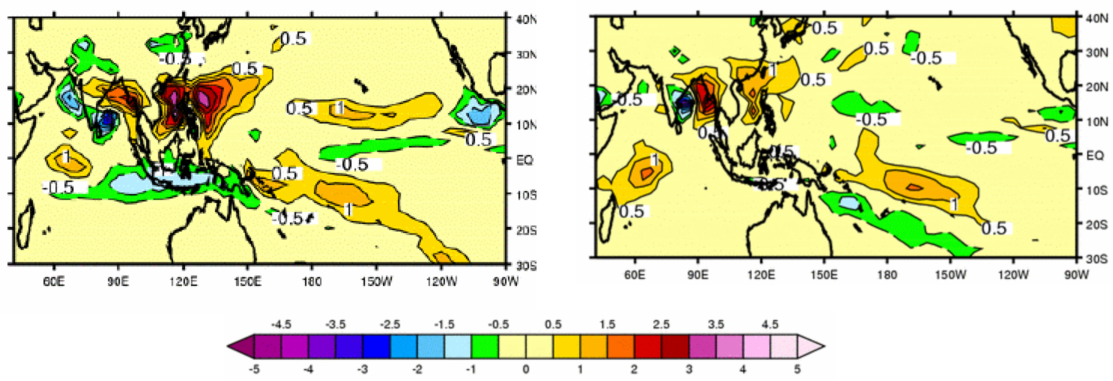


Figure 1: *Precipitation anomalies simulated by HadAM3 for JJAS following the peak of El Nino from tropical Pacific-only SST forcing (left panel) and global SST forcing (right panel).*

Although the above research suggests that ENSO influences the Indian Ocean and thus the Indian monsoon, the existence of a coupled ocean-atmosphere mode independent from ENSO that originates in the Indian Ocean climate system and may induce anomalous rainfall over eastern Africa and Indonesia has also been identified. This Indian Ocean Zonal or Dipole Mode is characterised by SST anomalies of one sign in the south-eastern and anomalies of the opposite sign in the western tropical Indian Ocean. The relationship between the seasonal cycle of a developing El Nino and the onset of an IOZM event has been analysed using SST and low-level wind data. The dynamics of ENSO cause a cooling of the Indian Ocean off the north Australian and Sumatran coasts. Comparison of the evolution of IOZM and ENSO events suggests that when the ENSO forcing is strong during boreal autumn, the season in which the zonal gradient of SST in the Indian Ocean is weakest, the cooling in the Eastern Indian Ocean may be sufficient to reverse the zonal SST gradient in the Indian Ocean and trigger an IOZM.

The identification of the IOZM has raised questions about how Indian Ocean processes affect the climate of the surrounding continents. During IOZM events, the SST gradient in the Indian Ocean is reversed and the low level winds perturbed, with easterly anomalies in the central northern Indian Ocean weakening the climatological westerly flow. Observational and reanalysis data have been used to analyse the impact of the Indian Ocean Zonal Mode (IOZM) on the boreal autumn rainy season (the short rains) in coastal equatorial East Africa (Black et al. 2003).

It has been found that strong IOZM events are associated with high rainfall in tropical, coastal East Africa, with the two strongest IOZMs of the last century (1961 and 1997) coinciding with the two rainiest autumns. Reanalysis wind and humidity data have been used to construct a dynamic scenario, in which sustained suppression of the climatological westerly winds in the northern, central Indian Ocean results in less moisture than usual being advected away from the African continent, and hence anomalously high rainfall in coastal East Africa.

The results of this study suggest that the relationship between Indian Ocean SST gradient and East African rainfall is, to some degree, non-linear. This conclusion is supported by two observations. Firstly, East African rainfall is only stronger than usual during the strongest IOZM events. Weaker events (moderate IOZMs), are not systematically associated with any rainfall anomalies at all. Secondly, during negative IOZM years, i.e. when the western Indian Ocean is anomalously cold and the Eastern Indian Ocean is anomalously warm, there is no significant effect on East African rainfall. If the system were linear, the positive rainfall anomalies observed in strong positive IOZM years would be matched by conversely strong negative anomalies during strongly negative IOZM years.

(ii) Influence of land surface processes on monsoon variability and predictability

Since the early studies in 1980's, dynamical seasonal forecasting still shows very limited skill in many areas. Even the upper limit of predictability, derived from atmospheric seasonal hindcasts forced by observed sea surface temperatures (SSTs), seems to be relatively low so that dynamical forecast systems do not necessarily perform better than empirical statistical schemes (Garric, Douville and Déqué, 2002). It is therefore important to take advantage of all possible sources of climate predictability in such dynamical forecasts. Besides SST, the land surface hydrology - snow depth and soil moisture (SM) - also shows some regional anomalies that could persist long enough to affect the atmosphere over several weeks or months. Their potential impact on seasonal predictability is however difficult to assess due to the lack of reliable multi-year climatologies on the global scale.

Recently, the Global Soil Wetness Project (GSWP) has investigated the feasibility of producing global soil moisture climatologies by driving land surface models (including the ISBA model of CNRM) with an observed atmospheric forcing. Though limited to a 2-year period (1987-88), this GSWP monthly dataset can be used to relax the deep soil moisture in ensembles of seasonal hindcasts based on the ARPEGE-Climat atmospheric GCM. Such experiments have been first conducted over two boreal summer seasons (1987-88) and have shown that this relaxation not only improves the ARPEGE model's climatology, but also its ability to reproduce some differences between the two seasons (Douville, 2002).

More recently, other ensembles of boreal summer atmospheric hindcasts, spanning a 15-year period (1979-1993), have been analysed (Douville, 2003a). Each ensemble is made up of ten 4-month integrations from June to September (results are averaged only over the last three months) for each season of the 15-year period. The 15-year ECMWF reanalyses (ERA15) are used to initialize both the atmospheric and land surface variables on 27 May. For each season, the ten members are generated by adding a weak random perturbation to the ERA15 reanalyses through a simple Monte Carlo method. Only the atmospheric prognostic variables are perturbed so that all members of a given season share the same land surface initial conditions.

Besides a control experiment using interactive soil moisture (SM) boundary conditions computed by the ISBA land-surface scheme, two sensitivity experiments have been performed with a relaxation of deep SM toward different monthly mean datasets: the ARPEGE climatology (based on the 15 years of the control experiment) and a presumably more realistic climatology (based on the 2 years available from GSWP). The aim is not to capture the observed patterns of interannual variability, but rather to investigate if the reproducibility of seasonal climate anomalies (perfect model approach) is sensitive to different treatments of soil moisture. Both sensitivity experiments indicate that damping the SM variability leads to a clear and robust reduction in surface evaporation and low-level temperature variability over most areas in the tropics and the summer extratropics.

Generally speaking, soil moisture seems to have a limited impact on seasonal predictability, especially in the tropics. Moreover, changes in predictability are less homogeneous than changes in variability. For example, SM anomalies appear as a source of predictability over North America, but not over India. Several reasons can be proposed for such a contrast in the regional responses, including the stronger evaporation-precipitation feedback in the interior of the North American continent than over the Indian peninsula. Generally speaking, few tropical areas show a possible influence of SM on predictability at the seasonal timescale. The main exception is the impact found on the predictability of the low-level temperature during the dry season in the southern tropics.

Our sensitivity experiments do not allow us to distinguish between the role of initial conditions and boundary conditions of SM, since both are set to climatological values. For this reason, a third ensemble of seasonal hindcasts has been conducted, in which the relaxation is implemented only during the month of June (Douville, 2003b). The results suggest that, in the regions where SM appears as a source of predictability, a large fraction of this extra predictability originates from the initial conditions of SM. Nevertheless, additional experiments based on other GCMs and on more reliable soil moisture analyses than ERA15 (for example the forthcoming ERA40 or GSWP2 datasets) are necessary to confirm these preliminary results.

As well as soil moisture, vegetation plays a controlling factor on evapotranspiration and potentially on the local climate in the tropics. As part of PROMISE research on climate change in monsoon environments, issues of land use change have been studied. To underpin this research a better understanding and representation of vegetation in climate models is needed. As part of this, a representation of the seasonal cycle in vegetation phenology has been developed from observational data and incorporated in the land surface scheme of the Unified Model, MOSES-2 (Lawrence and Slingo 2003a, 2003b). The seasonal phenology of vegetation can influence the lower atmosphere through changes in Leaf Area Index (LAI), roughness length, and albedo, and in seasonally arid monsoon climates may be an important factor in determining the onset and evolution of the monsoon. Results from a series of integrations with the Hadley Centre atmosphere-only model (HadAM3) indicate that the surface temperatures and soil water budgets are most significantly impacted in semi-arid and continental regions where the climate system is dominated less by moisture supply from the adjacent oceans. The effects of vegetation phenology on monsoon climatologies are seen primarily outside the rainy season, when the upper level soil moisture is not saturated (Figure 2).

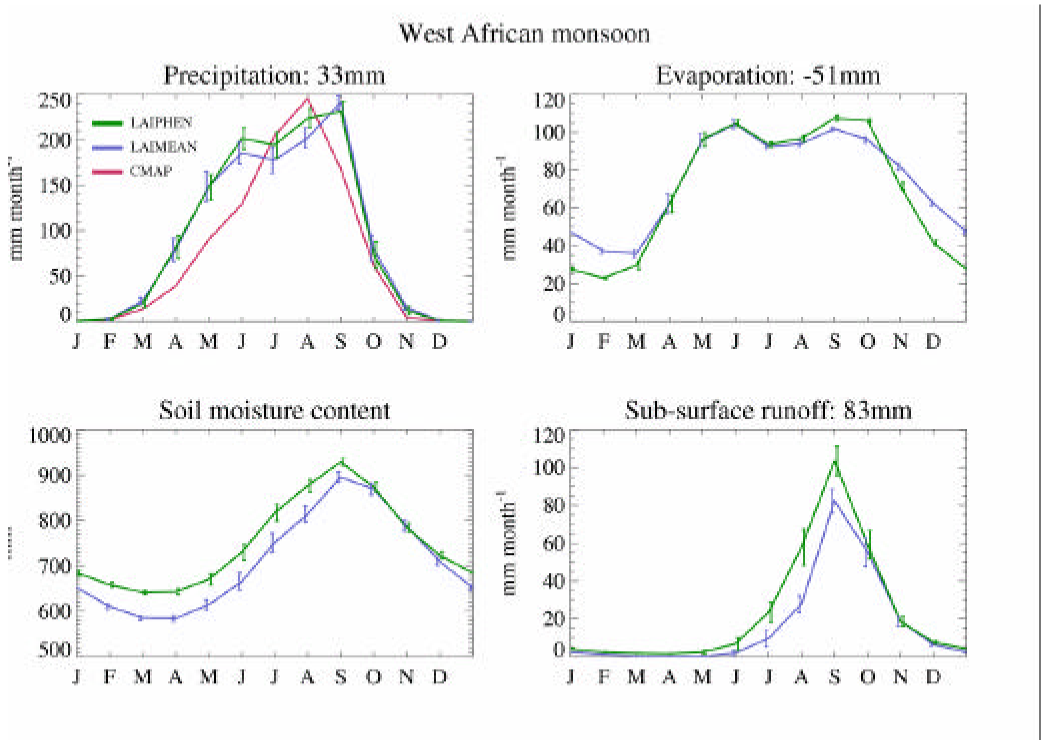


***Figure 2**: Seasonal cycle in surface variables over West Africa simulated by HadAM3 with mean and seasonally varying vegetation. Note that the onset of the monsoon occurs much earlier than observed.*

In a related study, the dependence of climate sensitivity to vegetation on the specification of soil hydraulic parameters has been studied (Osborne et al. 2003). A different, but equally realistic set of soil parameters from the IGBP dataset has been incorporated in the land surface scheme of HadAM3. The results have shown that the climatic effects of changes in vegetation cover (e.g. deforestation) are highly dependent on the soil specification. In addition, there are large geographical variations in the climate sensitivity with the various monsoon climates responding differently. For example, India is largely insensitive to vegetation-climate interactions because the moisture supply for the monsoon rains comes primarily from the oceans through large-scale atmospheric convergence. On the other hand, China and Africa are much more sensitive since more of the moisture comes from local recycling of soil water.

(iii) Understanding decadal variability in the Sahel

The Sahelian region has a decadal variability being among the most pronounced identified in the historical climate records of the 20th century. The rainfall over the West Sahel shows a multidecadal drying trend from the 1950s (wet mode) to the beginning of the 1990s (dry mode), with a slight recovery in recent years. There is scientific agreement that this multidecadal trend is primarily induced by sea surface temperature anomalies (SSTA) and amplified and prolonged by local feedbacks, e.g. vegetation and soil moisture.

We investigated the impact of tropical decadal-scale SST forcing on West Sahelian rainfall using the ECHAM4 general circulation model. Two sets of sensitivity experiments with prescribed SST fields have been performed. In the first series, climatological SST was artificially enhanced or decreased by one Kelvin in different ocean basins to study the importance of the different regions for Sahelian rainfall. In the second set, more realistic SSTA composite fields were used to focus on the transition between the wet and the dry mode by perturbing the climatological AMIP2 SST from 1979-1995 ('dry control') with observed Reynolds SST from 1951-1960 ('wet') in all or certain ocean basins.

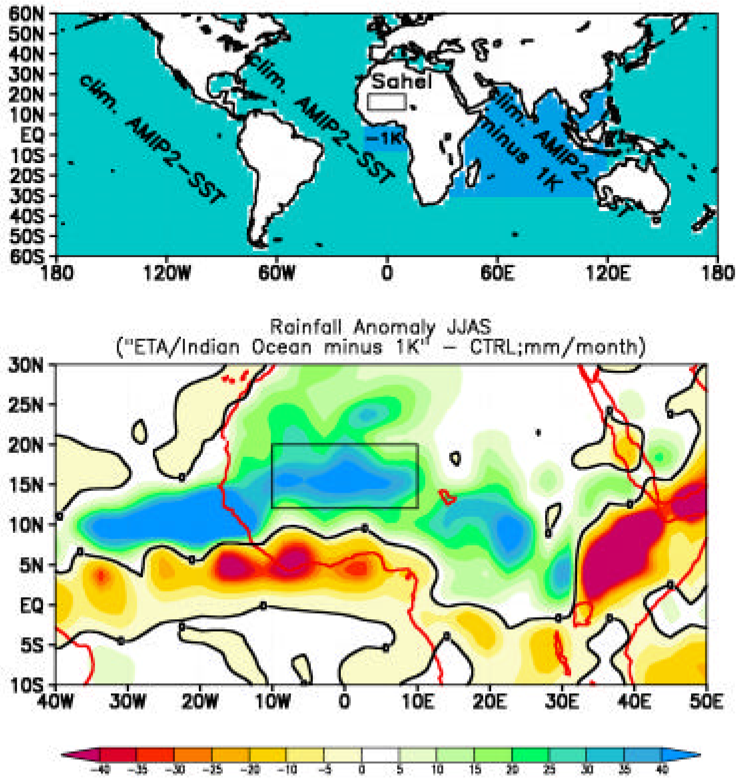


***Figure** 3: Combined effect of warming Indian Ocean and eastern tropical Atlantic SST on West African rainfall: a decrease of the climatological AMIP2 SST (1979-1995, representing the "dry" mode) by 1 K in these two regions (top panel) leads to a significant increase in West Sahel rainfall and is able to reproduce the dipole between Guinea Coast and Sahelian rainfall (bottom panel).*

The results (Figure 3) show that decadal changes in tropical SST are able to produce a dry and wet mode in the Sahel. The tropical Atlantic is not responsible for the recent decadal change in West Sahelian rainfall; in particular, the inter-hemispheric Atlantic SST gradient is not the cause of the decadal drying trend over the West Sahel. These experiments indicate that the warming of the tropical Indian Ocean that has been observed during recent decades seems to be most important for the recent decadal drying trend in West Sahelian rainfall (Figure 3). One of the leading modes of rainfall variability over West Africa is a dipole between Sahelian and Guinea Coast rainfall. The experiments show that this Guinea-Sahel rainfall dipole can be induced by simultaneous SST anomalies in the tropical Indian Ocean and in the eastern tropical Atlantic (Figure 3). This mechanism also explains why there is no significant anti-correlation between Guinea Coast and West Sahel rainfall. The SSTs in the tropical Indian Ocean and in the eastern tropical Atlantic evolve more or less independently.

Various studies have shown that dry conditions in West Africa are related to the interhemispheric SST gradient in the Atlantic Ocean. The observed SST in the North Atlantic has decreased during 1950 and 1975, and increased again thereafter, whereas the SST trend in the South Atlantic has been consistently positive. This pattern of change represents a decrease of the North-to-South Atlantic SST gradient during the period of the Sahelian drought. We investigated possible causes for this change of SST gradient and suggest that it might, in fact, be partly due to anthropogenic aerosol emissions. The increasing SSTs in the South Atlantic are consistent with an overall greenhouse gas warming, whereas this positive trend might have been overshadowed in the North Atlantic by a cooling due to sulphur emissions from North America and Europe, which have increased since 1945 and underwent a rapid reduction since about 1990.

To test this hypothesis, two 50-year experiments with ECHAM4 (T30) coupled to a mixed-layer ocean and a thermodynamic sea-ice model and including a fully interactive aerosol model (direct, semi-direct, first and second indirect aerosol effect) were performed: one run used only natural aerosol emissions while the second simulation considered natural plus anthropogenic emissions. Both experiments used fixed present-day greenhouse gas concentrations. The mean difference between the two runs represents the effect of aerosols on climate and indeed shows a decrease of up to 60% in precipitation over North Africa during the wet season, July to September. This decrease in precipitation can be explained by a change in the interhemispheric SST gradient in the Atlantic, which is similar between this sensitivity experiment and the observations. So, although natural variability cannot be excluded, one plausible additional explanation for the Sahelian drought during the 1970's and 1980's is a combination of greenhouse gas warming, dominant in the southern hemisphere, and aerosol cooling masking the greenhouse gas warming in the northern hemisphere. The control of sulphur emissions in the northern hemisphere after the 1990's might have contributed to the recovery from this dry period.

The role of vegetation feedbacks for the multidecadal Sahelian rainfall variability during the last five decades has been investigated using the ECHAM4 atmospheric general circulation model (AGCM) coupled to the simple dynamic vegetation model SVEGE. The feedback processes in the coupled model include changes in albedo, evapotranspiration and surface vegetation cover due to leaf area index changes. Four different ensemble integrations with prescribed observed SSTs were performed: a "control" ensemble using fixed annual climatological vegetation and albedo; an ensemble with interactive vegetation; an ensemble of integrations with a fixed but updated annual mean vegetation and albedo derived from the ensemble mean of the interactive vegetation integrations; and finally integrations with a fixed monthly mean vegetation and albedo also derived from the dynamic vegetation ensemble.

The control simulation forced with observed SST alone is unable to reproduce the amplitude of the Sahelian drying trend from the 1950's to the 1980's. Using the updated vegetation and albedo distribution leads to an improvement over the control run in the simulation of the spatial rainfall pattern in the Sahel and Sahara regions, but still underestimates the amplitude of the multidecadal variability (Figure 4, top). An even better spatial rainfall pattern and a realistic amplitude of multidecadal variability are obtained with the fully interactive vegetation model (Figure 4, middle), which includes three mechanisms not contained in the "fixed vegetation" runs: a variable amplitude of the albedo annual cycle, the interdecadal trend of albedo and the variation of transpiration area (leaf area index). The combination of these processes enhances the SST-induced multidecadal signal by weakening precipitation at the beginning of the monsoon season during dry years through the effects of increased albedo and by enhancing rainfall at the end of the season during wet years through stronger evapotranspiration and convective precipitation related to higher leaf area index. Thus, vegetation responding dynamically to precipitation changes acts as an amplifier for a low-frequency (i.e. interdecadal) signal of SST anomalies.

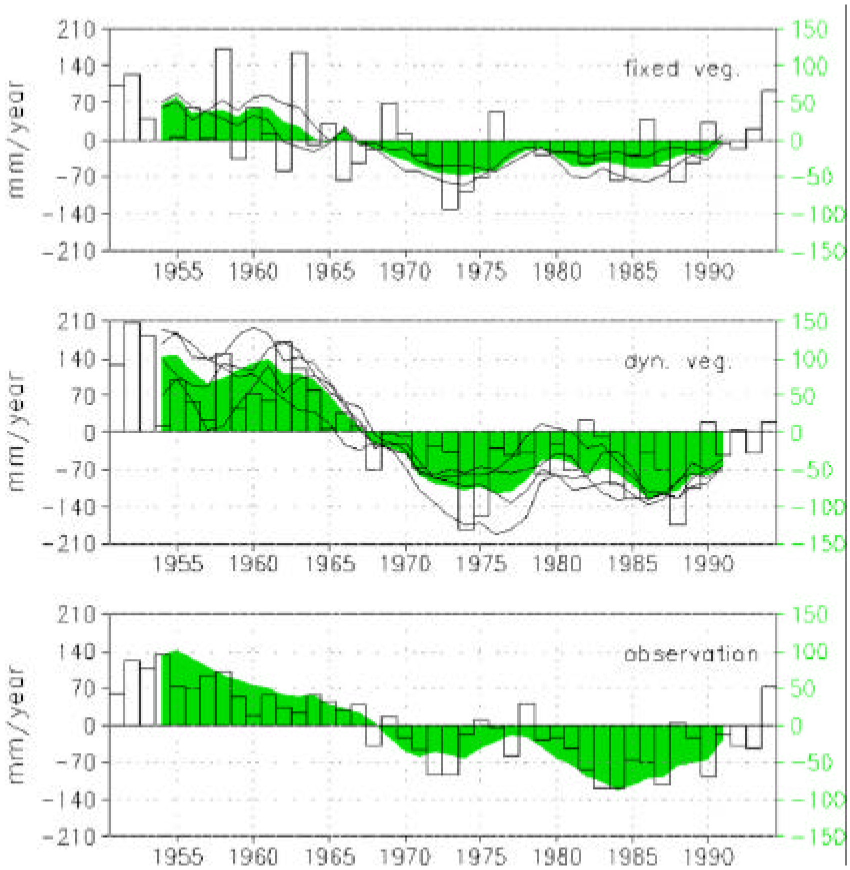


Figure 4: *Sahel rainfall anomalies relative to the 1951-1994 mean for experiments using fixed (top) and dynamic vegetation (middle), and observations (bottom). Bars: ensemble average of annual means (left axis); solid lines: 7-year running means of single ensemble realizations (right axis); shaded curve: ensemble average of 7-year*

(iv) New perspectives on the intraseasonal variability of the West African Monsoons

Although intraseasonal variability is known to dominate the seasonal evolution of the Asian Summer Monsoon, previous research on the West African Monsoon has focused on the role of the synoptic scale African Easterly Waves (AEW) that operate on shorter timescales. New research in PROMISE has highlighted the intraseasonal behaviour of the West African Monsoon and identified potential mechanisms that influence this variability and its scale interactions with AEWs.

Spectral analysis applied each year to daily Sahelian rainfall indexes has provided evidence of rainfall fluctuations at intra-seasonal time-scales, between 10 and 60 days, coherent with an intra-seasonal wind field pattern at 925hPa and at 700hPa. This intra-seasonal signal, strongest in the 10-25 days spectral window, is associated, during enhanced (weakened) phases in the West African monsoon, with a westward propagation of positive (negative) rainfall anomalies with a westward travelling cyclonic (anticyclonic) anomaly over the northern part of the Sahelian region (Janicot and Sultan, 2001). Because of the high intermittency of the intra-seasonal signal and in order to isolate and to study these atmospheric fluctuations, we have begun to use the Local Mode Analysis (LMA) on the wind field at 925hPa and 700hPa from the NCEP and the ERA-15 reanalysis. This new method (Goulet and Duvel, 2000) is fitted to characterize intermittent atmospheric oscillations by making it possible to extract locally the most persistent oscillations that characterize the spatial and temporal structures of any field. To complete the documentation of this intra-seasonal signal over West Africa, we have also begun cases studies based on the year 1998. Composite and spectral analyses have been performed to wind fields from NCEP reanalyses, rainfall from IRD and also to convective systems from the Meteosat-7 IR channel, to better characterize theses enhanced and weakened phases in the West African monsoon in 1998.

A more precise study on the intra-seasonal variability has been done over the 1968-1990 period. We have shown that rainfall and convection over West Africa are significantly modulated at two intra-seasonal time scales, 10-

25-day and 25-60-day, leading to recurrent variations of plus or minus 30% of the seasonal amplitude. A composite analysis based on a regional rainfall index has pointed out a main quasi-periodic signal of about 15 days. We have shown that during an intra-seasonal wet sequence, convection in ITCZ is enhanced and its northern boundary moves to the north, while the speed of the AEJ decreases and the monsoon flow becomes stronger. This modulation of convection at intra-seasonal time scales is not limited to West Africa but corresponds to a westward propagating signal from eastern Africa to the western tropical Atlantic (Figure 5). The enhanced (weakened) phases of the West African monsoon are associated with a stronger cyclonic (anticyclonic) activity over the Sahel controlling a stronger (weaker) moisture advection over West Africa (Figure 6). We have also shown that the activity of African Easterly Waves between 3 and 10 days is significantly modulated at this intra-seasonal time scale around 15 days.

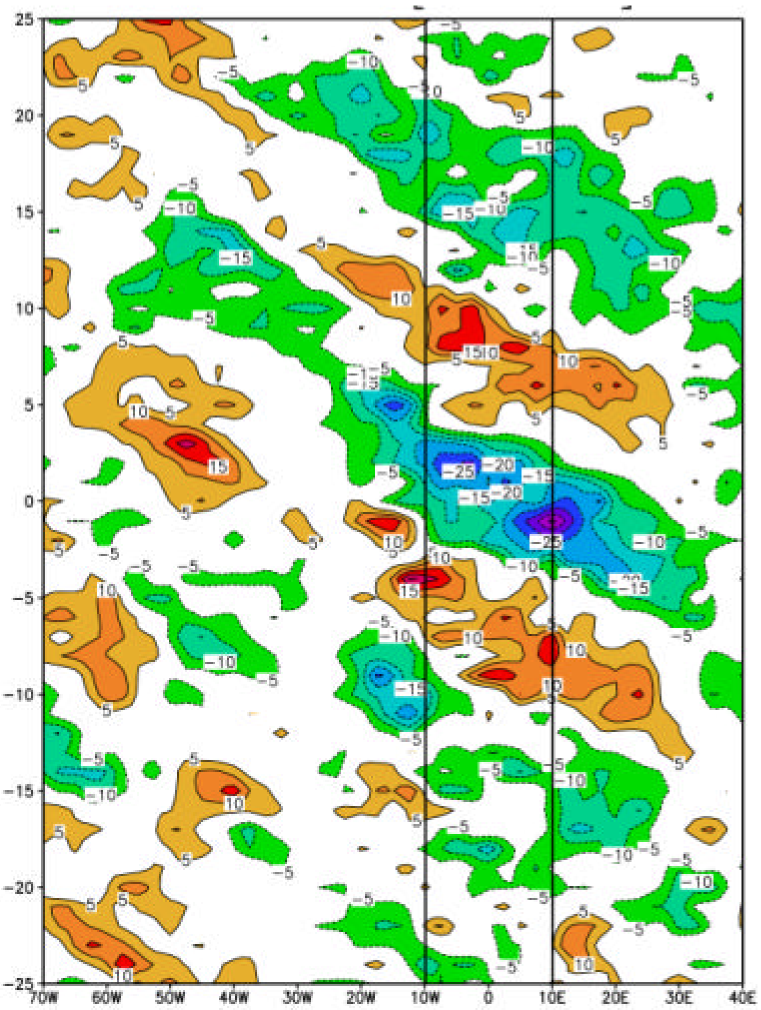


Figure 5: *Evolution along 12.5^0-15^{0}N of the OLR anomaly field (Wm^{-2}) through a composite wet cycle based on a convective maximum between 10^{0}E and 10^{0}W. Note the westward propagation of the wet cycles and the typical timescale of 15 days between events.*

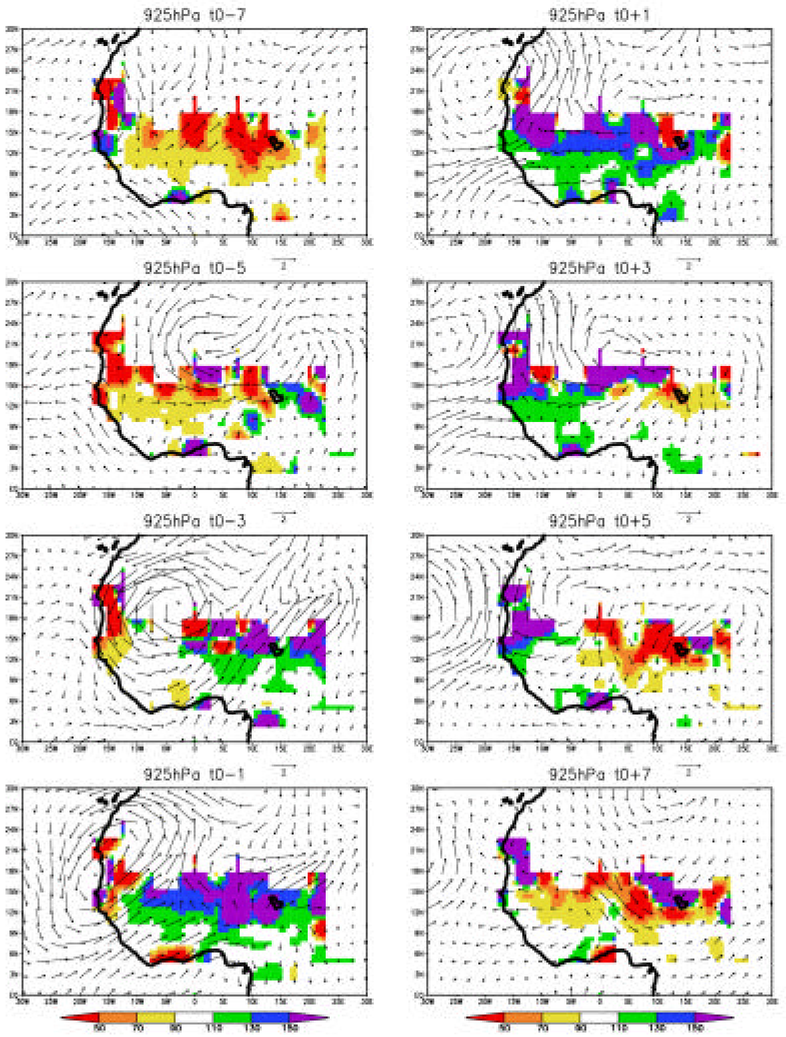


***Figure 6**: Evolution of the rainfall and 925hPa wind anomalies through the life cycle (15 days) of a wet event that peaks at Day 0.*

B. Climate model skill and assessments of the reproducibility/predictability of monsoon variability

Model systematic error remains a serious problem for simulations of monsoon climates and there is a need to continually improve the basic simulation of the monsoon with the recognition that coupled ocean-atmosphere processes may have an important role to play. Thus the evaluation and improvement of climate models has remained a key area of research for PROMISE.

(i) Progress in simulating the mean climate and interannual varaibility

The simulation of the mean and interannual variability of monsoon climates by the Hadley Centre atmosphere-only GCM (HadAM3) at a range of horizontal and vertical resolutions has been assessed based on AMIP II integrations and multi-decadal integrations with an idealised El Nino/La Nina cycle (see Spencer et al. 2003). The model systematically overestimates the strength of the Asian Summer Monsoon with a tendency for the model to be biased towards an active monsoon regime in which the precipitation pattern is dominated by the continental tropical convergence zone (TCZ). The West African Monsoon is less well simulated by the model, with the seasonal cycle being particularly poor. The onset of the rains occurs much earlier than observed and the subsequent cooling of the land surface by increased soil moisture leads to an overall weaker monsoon.

The interannual variability of the monsoons has also been assessed and the results have shown that the model has limited skill, although the reproducibility can be quite high. For example, the model systematically simulates above normal rainfall over India during El Nino years (Figure 7), which appears to be associated with a strong response by the local Hadley circulation over the Eastern Hemisphere. Although this type of behaviour is seen in observations and dominated the monsoon response to the 1997 El Nino (Slingo and Annamalai, 2000), it is too prevalent in HadAM3. The reproducibility is generally quite high and the model displays considerable inverse symmetry in its response during the growing phases of El Niño and La Niña. However, although the precipitation anomalies over the tropical Pacific are generally well captured the model systematically simulates the wrong sign of the anomalies over India. Thus the level of skill in the predictability of the Asian summer monsoon by HadAM3 is generally low. These results suggest that improving the representation of boundary layer mixing and convection (along with increased vertical resolution) improves the links between surface forcing and the monsoon strength.

The lack of skill of the model in simulating the observed interannual variability appears to be related to systematic errors in the model's mean climate. HadAM3, in common with many models, underestimates the precipitation over the maritime continent. The results from a sensitivity experiment, which increased the heating over the maritime continent, led to significant improvements in many aspects of the global climate as far away as Eurasia (Neale and Slingo, 2003). Although there was only a slight improvement in the simulation of the mean monsoon, the interannual variability was substantially improved, stressing the non-linear relationship between model systematic error and predictability.

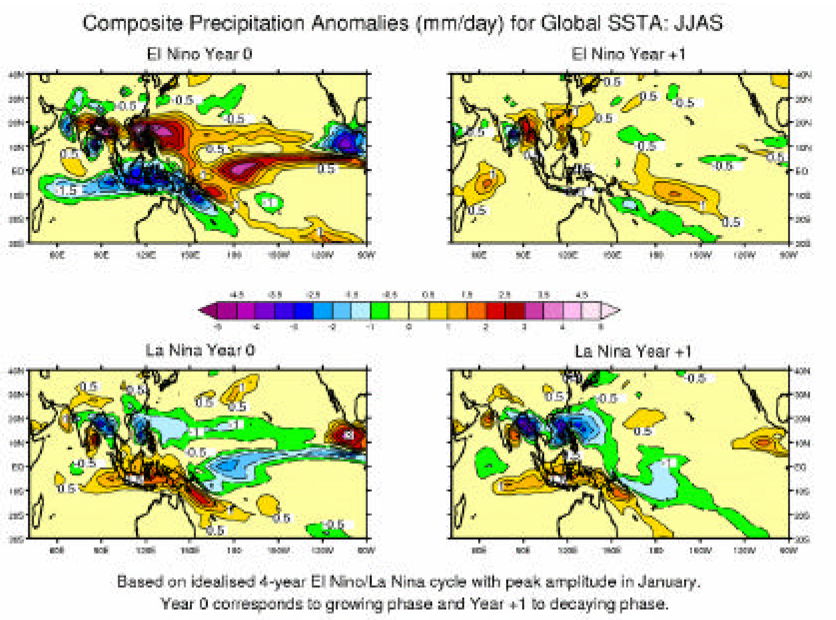


Figure 7: *Precipitation anomalies (mm/day) simulated by HadAM3 from multi-decadal integrations with an idealised El Nino/La Nina cycle. Note the invertability in the patterns for the growing phases of El Nino and La Nina. In the decaying phase of El Nino, in particular, the response is influenced by the warm SST anomalies that develop in the Indian Ocean as a remote response to El Nino forcing.*

A new semi-Lagrangian, non-hydrostatic version of the Hadley Centre model, called HadGEM, is currently under development and has provided an important comparison with the results described above. This model incorporates numerous changes to the physical parametrizations in both the atmosphere and ocean components, as well as to the model grid and vertical resolution, and includes additional processes such as the sulphur cycle and cloud aerosol effects. The aim of this work has been to assess the sensitivity of the monsoon simulation to changes in the model physics. Four-member ensembles of atmosphere-only (HadGAM) runs (each differing only in their initial conditions), covering the AMIP-II period (1979-1995) have been compared with similar runs of the standard climate version, HadAM3. A secondary aim has been to assess the impact of coupling the atmosphere and ocean models on the monsoon simulation. For this purpose, a 60-year period from an equilibrium run of HadCM3 and a 30-year test run of HadGEM have been analysed.

The monsoon climatology in HadGAM improves on HadAM3 in terms of the circulation strength, and in some aspects of the precipitation distribution (see Fig. 8), such as over the eastern equatorial Indian Ocean and over the west Pacific. However, the westerly low-level monsoon jet extends too far eastwards across East Asia, and precipitation is underestimated over India and over Indonesia. The monsoon in HadCM3 is rather different from that in HadAM3. The monsoon circulation is weaker and there is far less precipitation over and around the Indian peninsula. Instead, precipitation over Indonesia is increased. These changes are associated with errors in the sea surface temperature (SST) climatology of the coupled model, where the northern hemisphere temperatures are colder and the SSTs around Indonesia warmer than observed.

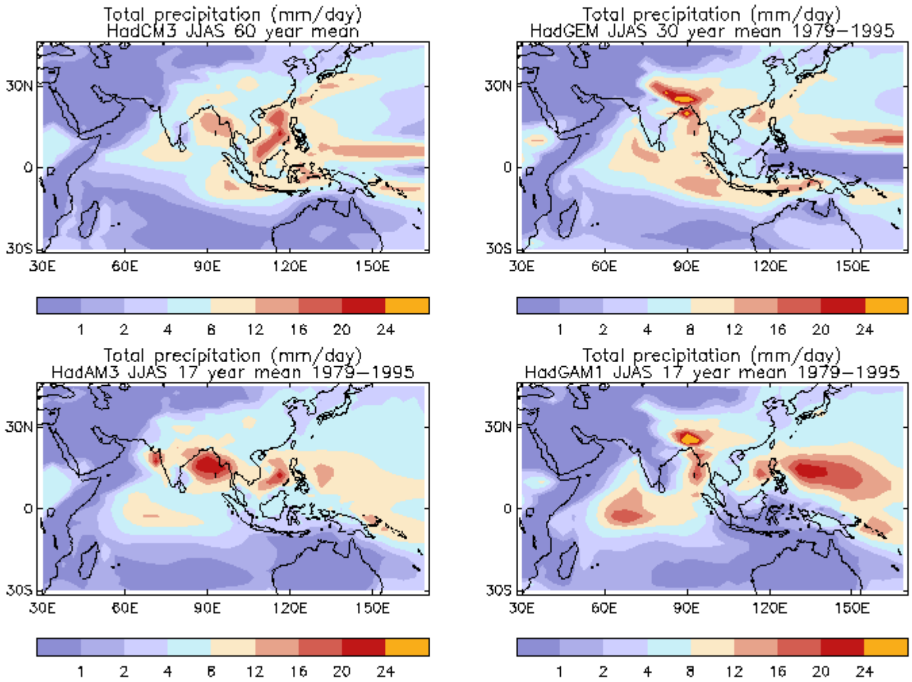


Figure 8*: Model climatologies of total precipitation (mm/day) averaged between June and September, for versions of the atmosphere-only (HadAM3, HadGAM1) and coupled (HadCM3, HadGEM1) Hadley Centre model.*

Both atmosphere-only models (HadAM3, HadGAM1) have a dominant mode of interannual variability that explains of order 40% of the variance, far higher than is observed. Despite the vast differences between the two models, their dominant modes are very similar (Figure 9). The coupled versions of the two models (HadCM3, HadGEM1) also show aspects of this mode. The dominance of this first mode in HadCM3 is rather less than in HadAM3, while in HadGEM the dominant mode is very similar to, and explains the same amount of variance as, the atmosphere-only model.

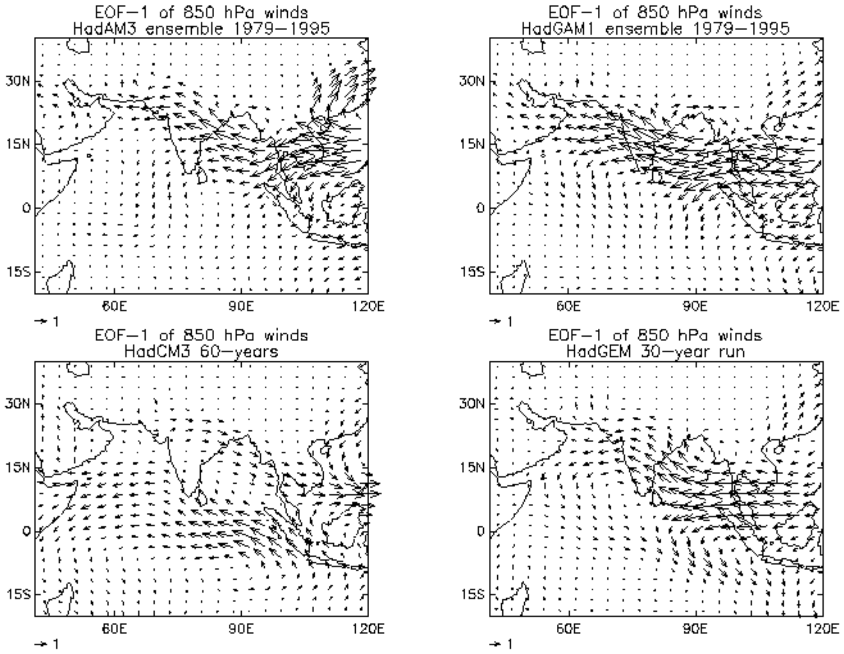


Figure 9*: First empirical orthogonal function of 850 hPa horizontal winds: (a) HadAM3 (38% of variance); (b) HadGAM (47% of variance); (c) HadCM3 (30% of variance); (d) HadGEM (48% of variance)*

Several things can be concluded from these results. Different atmosphere-only models can exhibit very similar dominant modes of interannual variability, despite having quite different monsoon climatologies. However, in the case of HadAM3, the variability is strongly linked to SST forcing, while internal variability dominates in HadGAM. In spite of this, we find that strong SST forcing can outweigh the internal variability in HadGAM on some occasions. Coupling the models appears to improve the variability associated with the Indian Ocean SST dipole, although it is possible that this is associated with SST errors over Indonesia. However, links to ENSO are not altered much by the coupling of either model version. Neither model really captures the impact of global SST changes on the monsoon. This may be a result of remaining systematic errors that are common between the models, or it may suggest that the impact of SST forcing on the atmosphere is not represented properly in either model version. Investigation of these aspects should help to inform future model development.

(ii) Seasonal predictability and the links between intraseasonal and interannual variability

The interaction between subseasonal and interannual variability and its role in predictability has been discussed by Sperber et al. (2000), and a detailed description of the observed intraseasonal variability of the Asian summer monsoon has been prepared by Annamalai et al. (2001). The intraseasonal variability in the Hadley Centre models has also been studied and comparison with these observational studies has shown that the model has some difficulty in capturing basic characteristics of monsoon active/break cycles. Further, a detailed study of a number of models by Sperber et al. (2001) has suggested that deficiencies in the simulation of subseasonal modes contribute directly to poor seasonal predictability and to systematic error of the mean state.

Preliminary analysis of the intraseasonal variability in the models shows a strong similarity between the second mode of intraseasonal variability and the dominant interannual mode in HadAM3. A bias towards positive/negative phases of this intraseasonal mode in El Nino/La Nina years is also apparent, consistent with the tendency of the model to simulate above normal rainfall over India in El Nino years (Figure 7). Conversely, there is little similarity between the intraseasonal and interannual modes in HadGAM, suggesting once again that internal variability dominates.

An analysis has also been completed of the variability and predictability of the Asian summer monsoon, as represented by numerical simulations with observed SST performed in the context of the PRISM project (Predictability experiments for the Asian summer monsoon). The PRISM experiments consisted of a set of nine 10-member ensemble integrations performed with the ECMWF atmospheric GCM (cycle 16r2), with spectral truncation T63 and 31 vertical levels, using data from the ECMWF re-analysis (ERA) as initial and boundary conditions.

As in the Hadley Centre model (Figure 9), the dominant mode of interannual variability of the Asian summer monsoon consists of a zonally coherent pattern, associated with a meridional shift of the Tropical Convergence Zone (TCZ) from the equatorial Indian Ocean to the Bay of Bengal and South East Asia. Again, the ECMWF model overestimates the fraction of variance explained by this mode but unlike the Hadley Centre model, the association between this mode and SST anomalies is rather weak leading to poor predictability on interannual timescales. The second mode of variability on the other hand has a good correspondence with observed patterns of variability and shows a clear relationship to the ENSO cycle, indicating a high level of potential predictability.

An EOF analysis of 5-day-mean rainfall revealed a strong similarity between the dominant patterns of rainfall variability on the interannual and intraseasonal scale. Although seasonal-mean values of the PC associated with the leading rainfall pattern shows no significant correlation with the ENSO index, the probability distribution of the leading 5-day-mean PC indices is turned from unimodal in the warm phase of ENSO to bimodal in the cold ENSO phase. These changes are suggestive of some sort of bifurcation in the monsoon properties, with a multiple-regime behaviour being established only when the zonal asymmetries in equatorial Pacific SST exceed a threshold value. Although an observational verification of this hypothesis is still to be achieved, the detection of regime-like behaviour in simulations by a complex numerical model gives a stronger support to this dynamical framework than simple qualitative arguments based on the analogy with low-order non-linear systems.

(iv) Dynamical methods for seasonal prediction.

The previous sections described PROMISE research on assessing the model simulations of the mean monsoon and its interannual variability, with particular reference to the role of intraseasonal variability. This research was required to underpin the assessment of the DEMETER multi-model ensemble system for seasonal prediction as originally planned, but the delays in the production of ERA-40 and, hence, in the DEMETER predictions, has meant that only a limited analysis has been possible. The seasonal predictions of the Indian summer monsoon have been verified against the CMAP data set for precipitation and against ERA-40 for the other atmospheric variables. Both large-scale indices describing the strength of the monsoon, and the local values of the rainfall and the winds have been considered. Preliminary results suggest a potential for improving the forecasts of the Indian summer monsoon by weighting the forecasts of the individual models in an optimal way.

In addition to the DEMETER system, ECMWF has been performing operational seasonal forecasts for several years and its performance with respect to the Asian summer monsoon is monitored routinely. The ensemble forecasts, initiated in May at forecast range 2-5 months, consist of 40 members, and span the period 1987-2002. Dynamical indices (the vertical shear of the zonal and of the meridional wind component) and spatial averages of rainfall anomalies (India and Indonesia) are used to estimate the observed interannual variability and the skill of the seasonal forecast predictions. GPCP data are used to verify precipitation, while the other atmospheric variables are verified against a combination of ERA-40 and the operational analyses (Figure 10).

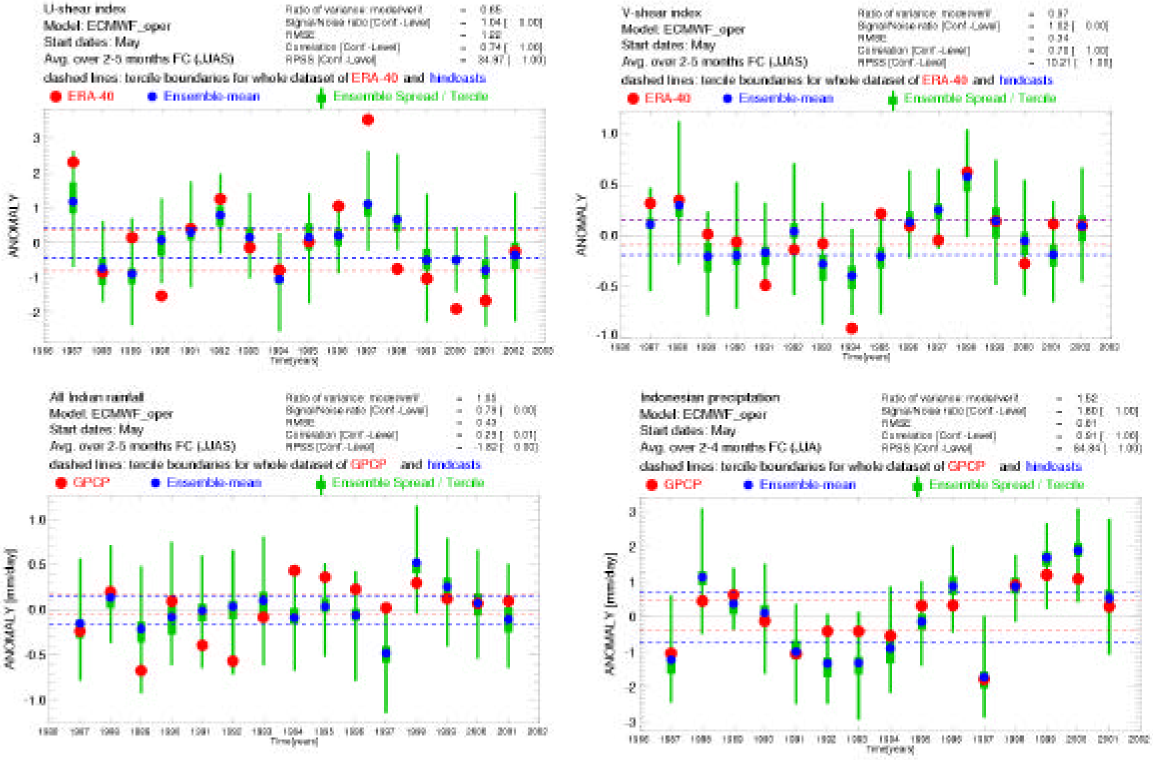


***Figure 10**: Various measures of the skill in forecasting the Asian Summer Monsoon from the ECMWF operational seasonal forecasting system based on a 40-member ensemble initialised in May.*

In general, interannual fluctuations in the strength of the monsoon circulation are predicted with some skill. Forecasts of rainfall anomalies over Indonesia are also successful, but rainfall predictions for India show very little skill.

(iii) Statistical methods for seasonal prediction

As noted in the previous section, dynamical methods for seasonal prediction have limited success and statistical methods still have a very important role to play. They also provide a benchmark against which the dynamical systems can be judged. However, statistical methods can be limited by the non-stationarity in the predictors. For example, the statistical relationships between traditional SST predictors and rainfall in Africa seem to be unstable on decadal time scales and to depend greatly on the state of the global ocean.

On interannual time-scales better statistical forecasts are obtained using more localized low-level atmospheric predictors merging global and regional influences. For West Africa low level Moist Static Energy content (MSE) seems to form a relevant framework. April-to-June meridional patterns of the near surface MSE south of 10°N control the amplitude and timing of the Sahelian July-to-September rainy season (Fontaine and Philippon, 2000). Wetter than normal Sahelian season are usually preceded by stronger than normal MSE gradients during boreal spring. For East Africa useful predictors are related to atmospheric dynamics signals: Indian monsoon and Walker-type circulation for the short rains, Congo basin air mass intrusion and MSE gradient between East Sahel and Ethiopian Mounts for the long rains. For both seasons, significant signals are observed within subtropical stationary waves (Camberlin and Philippon, 2001, 2002). For both regions the NCEP-NCAR Reanalysis atmospheric data were found to be useful for deriving predictors and statistical forecasts with a lead of one season. The real-time statistical forecasts for the 2000 and 2001 Sahelian rainy season were correct. Moreover zonal dynamics and moisture convergence in the reanalyses bear some potential for further improvements of the statistical rainfall forecasts for West Africa (Fontaine et al., 2003).

As far as the continental conditions are concerned, the strong relationship found between Sahelian July-to-September rainfall and the previous September-to-November rainfall amounts over the Guinean Region is of particular interest (Figure 11).

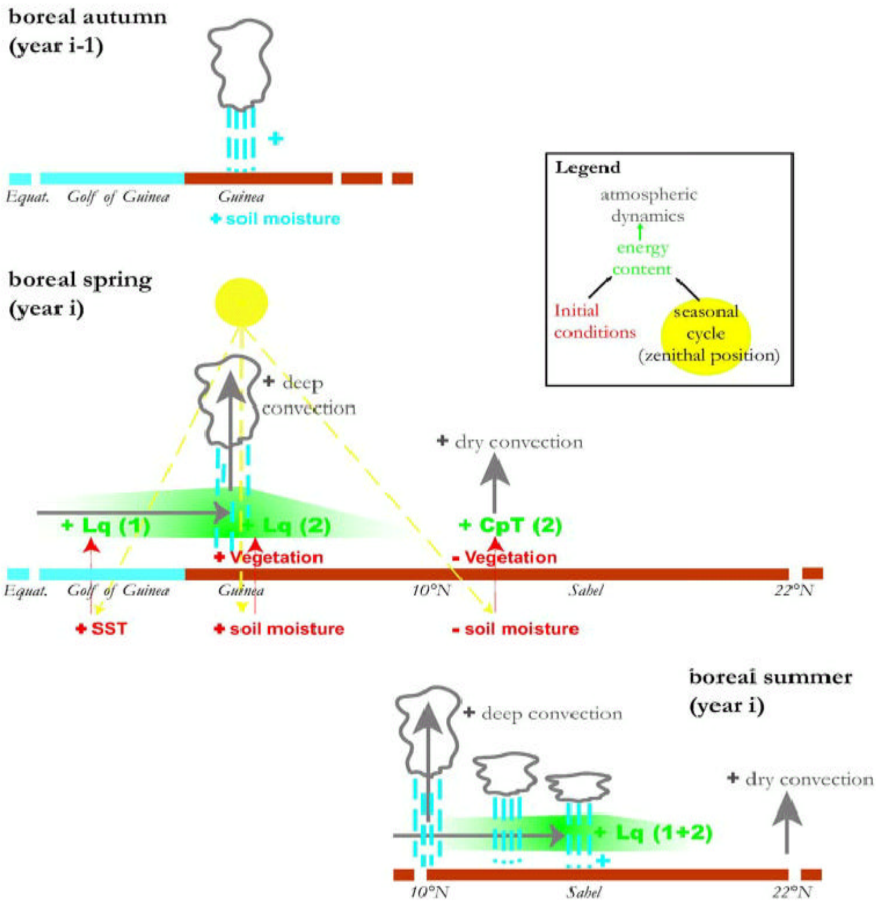


Figure 11*: Schematic view of the mechanisms influencing regional meridional low level gradients of MSE (green shadings) over Atlantic and West Africa with focus on interseasonal persistence (Lq and C_pT denote standard latent and sensible energy fluxes). An abnormally high precipitation during autumn over Guinea region leads to stronger MSE gradients between Guinea and Sahel in the next spring, and thus to stronger monsoon over the Sahel in summer.*

The hypothesized mechanism for this interseasonal teleconnection involves soil moisture (Philippon and Fontaine, 2002) and is also supported by the rather strong relationship between the development of the vegetation prior to the onset of the monsoon and Sahelian rainfall found in the independent NDVI dataset. The role of the vegetation development on the dynamics of the monsoon has been tested through sensitivity experiments with ARPEGE-Climat (Meteo-France). The modification of the seasonal cycle of the model vegetation in the Guinean region led to significant changes in the West African monsoon timing and amounts, although these were less important than global SST impacts.

C. Monsoons and anthropogenic climate change

The change of the hydrological cycle in anthropogenic climate change is of paramount importance for monsoonal climates and the water resources in monsoon regions. In a warmer climate, the evaporation rate during summer will be enhanced with consequences for the storage of soil moisture. But the most important and difficult effect to assess is precipitation response. Many studies have suggested that, in an enhanced CO_2 atmosphere, rainfall could be more intense because the land-sea temperature contrast increases and induces a strong monsoon flow. Significant advances in assessing the impacts of anthropogenic climate change have been achieved under PROMISE.

(i) Climate change over India

Possible future changes of the monsoon climate have been analyzed in transient climate simulations performed with the coupled atmosphere-ocean-sea ice version of the ARPEGE-Climat atmospheric model at a T63 (~2.8°) horizontal resolution. Two new 150-year simulations starting in 1950 have been used: a control simulation in which the greenhouse gas concentrations and aerosols are kept fixed at their 1950 observed value, and a scenario simulation in which the greenhouse gas concentrations are changed annually according to the IPCC scenario SRES-B2. No flux adjustment is used. The control simulation gives a realistic representation of the current climate with only a small drift.

The climate anomalies for the second half of the 21st century, when compared to the second half of the 20th century, show a significant increase in the mean annual surface air temperature over India of 2K with a maximum in winter, and of about 9-10% in monsoon rainfall due to increased moisture convergence. A northward shift of the westerly monsoon flow over the Arabian Sea and India, along with a relative weakening of the zonal monsoon circulation is simulated, together with a strengthening of the regional meridional Hadley circulation.

The simulated change of the hydrological cycle has been analysed in detail. As expected, a general increase of precipitable water was found to be associated with the atmospheric warming. This positive feedback to the greenhouse effect also contributes to the global hydrological cycle by increasing the water holding capacity of the atmosphere and providing more water vapour to precipitating systems. The stronger warming of the upper atmosphere by convection leads to a strengthening of the Hadley circulation, with a corresponding increase of subsidence and drying on the winter hemisphere subtropics. This is accompanied by a northward shift of the ITCZ. The annual cycle of precipitation over the monsoon areas is thus amplified with higher precipitation during the wet season. The increase in rainfall over India is particularly strong. Since the soil reservoirs are saturated during the monsoon season, this increase of rainfall leads to a larger runoff and only to a small change in evaporation.

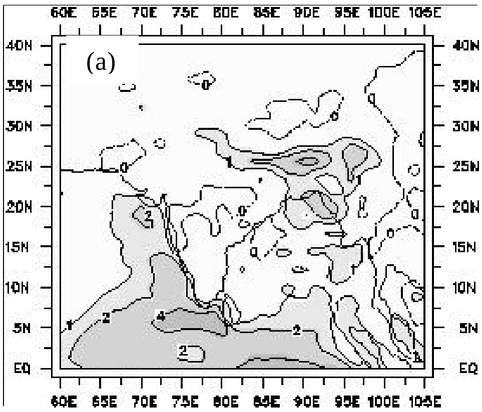
Large multi-decadal fluctuations are found in addition to the long-term increase in simulated precipitation. The simulations show a Nino-like warming in summer, but no systematic change in SST variability in the Pacific. A strong correlation of Indian monsoon rainfall with east equatorial Pacific SST is found during summer and fall. The simulated ENSO-monsoon teleconnections have a strong modulation at the multi-decadal time scale but no systematic weakening in response to global warming.

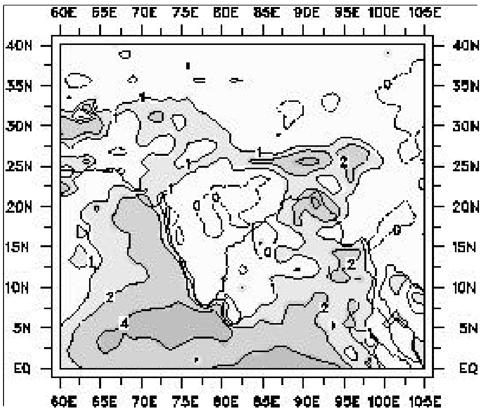
The response of the Asian summer monsoon, including the mean monsoon and its variability, to global warming has also been studied by analysing a control and a transient greenhouse gas warming integration with the ECHAM4/OPYC3 AOGCM. In the transient greenhouse gas experiment, the atmospheric concentrations of greenhouse gases were prescribed as observed from 1860 to 1990, and according to IPCC scenario IS92a from 1990 onwards. The results show that increases of greenhouse gas concentrations lead to an intensification of the Asian summer monsoon and its variability. The intensified monsoon precipitation is confined to the Indian peninsula and its vicinity and results mainly from an enhanced land-sea contrast, a northward shift of the convergence zone and a westward shift of the ascending branch of the Walker circulation, as the land heats up more rapidly than the ocean. In addition to this enhanced mean monsoon precipitation, a gradual increase of the monsoon variability was simulated from year 2030 onwards. It seems to be connected with the corresponding increase of the sea surface temperature variability (ENSO) over the tropical Pacific.

A particular focus for PROMISE research has been in the use of higher resolution in the assessments of regional climate change. Control (pre-industrial) and increased-CO_2 experiments (2041-2060) have been completed for both regional (RCM) and global (GCM) models. The models' intraseasonal variability has been investigated via the active and break cycles of the summer monsoon, and the mechanisms which give rise to the distinctive precipitation anomalies associated with these events have been seen to be more realistically represented in the RCM compared to the GCM. In the warmer future climate, the change in particular intraseasonal precipitation anomalies can be attributed to the change in the frequency of cyclones, originating in the Bay of Bengal, which track over southern India, as opposed to along the normal position of the monsoon trough. These changes to the cyclone frequency, however, do not appear to be significant due to the limited length (twenty years) from each period.

Global time-slice experiments with the ECHAM4 atmospheric GCM at a high horizontal resolution of T106 have also been performed for two periods: the present-day climate (1970-1999) and the future climate (2060-2089). The investigation includes aspects of the large-scale flow as well as of the hydrological cycle, in particular the day-to-day variation and the extremes of daily rainfall during the monsoon season. The time-slice experiment (period 1970-1999) simulates many aspects of the Indian summer monsoon very well, and due to the fine horizontal resolution of about 120 km many regional details of the rainfall pattern are well captured.

Despite a weakening of the large-scale monsoon flow in the future, the time-slice experiment predicts an increase of the mean rainfall during the Indian summer monsoon over most of the Indian region (Fig. 12, upper left). The regional pattern of the monsoon rainfall is more pronounced in the future, due to an intensification of the atmospheric moisture transport into the Indian region in the future.





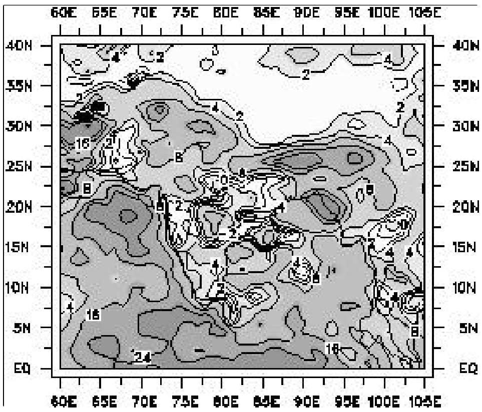


***Figure 12**: Climatic change, defined as the difference between the time-slice for the future climate and the time-slice for the present-day climate, for (upper left) the seasonal mean rainfall (June to September), (upper right) the intensity of rainfall, defined as the mean rainfall on wet days (days with precipitation exceeding 0.1 mm), and (lower left) the 95%-percentile of rainfall on wet days. Units are [mm/d].*

The future changes in the mean monsoon rainfall are only to a small extent due to changes in the frequency of days with rainfall, the so-called wet days, defined as days with precipitation exceeding 0.1mm. There is, however, a general tendency of wet days occurring more often over the Indian Ocean and the Indian peninsula and occurring less frequently elsewhere. As a consequence, the future changes in the intensity of daily rainfall (Figure 12, upper right) mainly account for the changes in the mean monsoon rainfall.

One way to capture the heavy monsoon rainfall is by the 95%-percentile of the precipitation on wet days. That is, more precisely, the average amount of precipitation occurring on the 5% of the wet days with the strongest rainfall. For the future, the time-slice experiment predicts an increase in the intensity of the heavy rainfall in most of the area (Figure 12, lower left). The comparison with the future changes in the rainfall intensity reveals a number of differences. The changes in the 95%-percentile are considerably stronger than the corresponding changes in the rainfall intensity. In some regions, such as over the centre of the Indian peninsula, and in Indochina, the change in the 95%-percentile is up to 20 times as strong as for the intensity.

(ii) Climate Change over Africa

The transient climate simulations performed with the coupled atmosphere-ocean-sea ice version of the ARPEGE-Climat atmospheric model at a T63 (~2.8°) horizontal resolution have also been analysed over Africa. Maximum warming is stronger over land than over ocean with an increase in precipitation is over Sudan and Sahel, corresponding to a northward shift of the summer monsoon system. The increase in the summer monsoon rainfall is particularly strong over Sahel and a comparison of the relative contributions of moisture transport and surface evaporation to precipitation has been made. The increase in summer monsoon rainfall over Sudan-Sahel is due to stronger moisture advection, combined with larger precipitation efficiency in July, and is reinforced by surface evaporation showing the importance of precipitation recycling in the region. The increase in the African summer monsoon leads to positive soil moisture anomalies in JJA, and the anomalies tend to persist during the dry season due to slower evaporation in the absence of vegetation and to stronger water recycling.

A strengthening and northward displacement of the Hadley circulation is found over Africa, and is consistent with the intensification of the hydrological cycle. The zonal wind response shows a decrease of the intensity of the AEJ and a northward and upward displacement of its core. This is due to the response of the meridional temperature gradient, which shows a reduction of the positive temperature gradient in the lower troposphere and an increase in the middle troposphere over the continent.

The scenarios over Africa have been improved by performing complementary simulations in 'time slice' mode with the variable resolution version of ARPEGE-Climat (T106, with stretching factor of 2.5) with the pole of stretching over the Gulf of Guinea, in which the grid stretching produces a resolution of about 100 km over Africa. A control simulation for the period 1970-1990 and a time-slice simulation for the period 2040-2060 have been performed. The future scenario used the greenhouse gases concentrations averaged over the period and the computed SSTs from the coupled scenario, but with a correction of the bias of the coupled model. The description of the land surface has also been improved by updating the land-surface fields used in the soil-vegetation model ISBA on the basis the ECOCLIMAP database.

The greenhouse gas response in African temperature and precipitation for the coupled, uniform T63 and variable-resolution T106 models are compared in Figure 13.

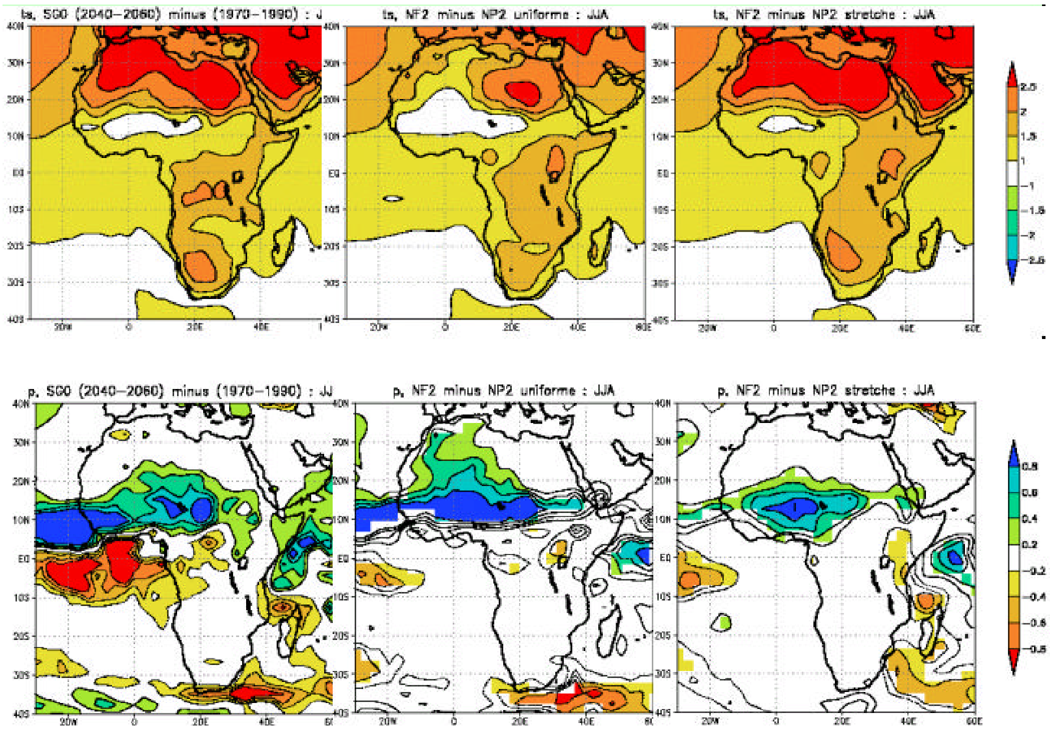


Figure 13:
Response of summer (June to August) 2m-temperature in °C (top) and precipitation in mm/day (bottom) for 2040-2060 with respect to 1970-1990 in scenario B2 simulated by ARPEGE-Climat in the coupled mode (left), and in time-slice simulations without the SST bias at the same uniform resolution T63 (middle), and with the variable resolution T106 with a stretching factor of 2.5 (right).

D. Monsoons and land-use/water-use changes

(i) African Deforestation

Different possibilities for choosing realistic deforestation scenarios for the period 2030-2050 have been considered. What appears the more consistent approach is to rely on scenarios produced by integrated assessment models, which have been used to produce the greenhouse gas emission scenarios for the IPCC Third Assessment Report. Among the 6 models used for the formulations of the new SRES scenarios, the model IMAGE 2.2 seems to have the most detailed land-surface scheme and produced land-surface maps at a resolution of 0.5 degrees. IMAGE 2.2 is a dynamic integrated assessment model for global change developed by the National Institute for Public Health and the Environment (RIVM) in the Netherlands. The overall objective of the IMAGE 2 model is to simulate, on the basis of political and socio-economic scenarios, plausible future trends of GHG concentrations in the atmosphere, and to determine their impacts on physical, biogeochemical and human systems. The model has been extensively reviewed and frequently used for IPCC assessment. More information about IMAGE is available at http://www.rivm.nl/image/.

A time slice simulation to study the sensitivity to future anthropogenic vegetation change has been made with the stretched-grid version of ARPEGE-Climat with high resolution over Africa. This experiment is similar to the simulation described in Section C using the SST anomalies and greenhouse gas concentration from the coupled scenario SRES-B2 averaged over 2040-2060, with in addition a change in the land cover specified from the results of the impact assessment model IMAGE 2.2. In the control simulations the geographical distribution of the vegetation and of its properties from the ECOCLIMAP land-cover database. In the future climate simulation the land surface changes from the IMAGE 2.2 scenario take into account a reduction of the tropical forest over Africa due to the expansion of agricultural land to feed a growing population. 30-year simulations have been performed in order to obtain stable climate statistics, and the analysis has been made on the last 25 years of the simulations.

The response to the future vegetation changes over Africa has been compared to the response due to greenhouse forcing alone (Maynard and Royer, 2002a). The response to African deforestation has been found to be generally smaller than in previously published deforestation experiments (Figure 14). Annual mean precipitation is reduced significantly only in equatorial Africa. A relatively small evaporation reduction is also found to be significant. The change is small because transpiration, as computed by the model, is affected only slightly by deforestation, and can partly compensate the reduced interception loss over the deforested areas.

A detailed analysis has been made to outline the role of different land surface parameters in the overall response, in particular the interactive role of soil wetness, and of stomatal resistance variations due to changes in the vegetation cover. Changes in stomatal resistance are found to modulate significantly the surface latent heat fluxes. Evapotranspiration generally increases with decreasing stomatal resistance, and the impact of changes in stomatal resistance is higher wherever soil moisture is not a limiting factor, such as in African tropical forests. With high soil moisture availability, lower stomatal resistance allows larger water vapor release, leading to higher evapotranspiration fluxes. The study thus indicates that the evapotranspiration control is more via soil moisture availability, than directly via vegetation cover changes.

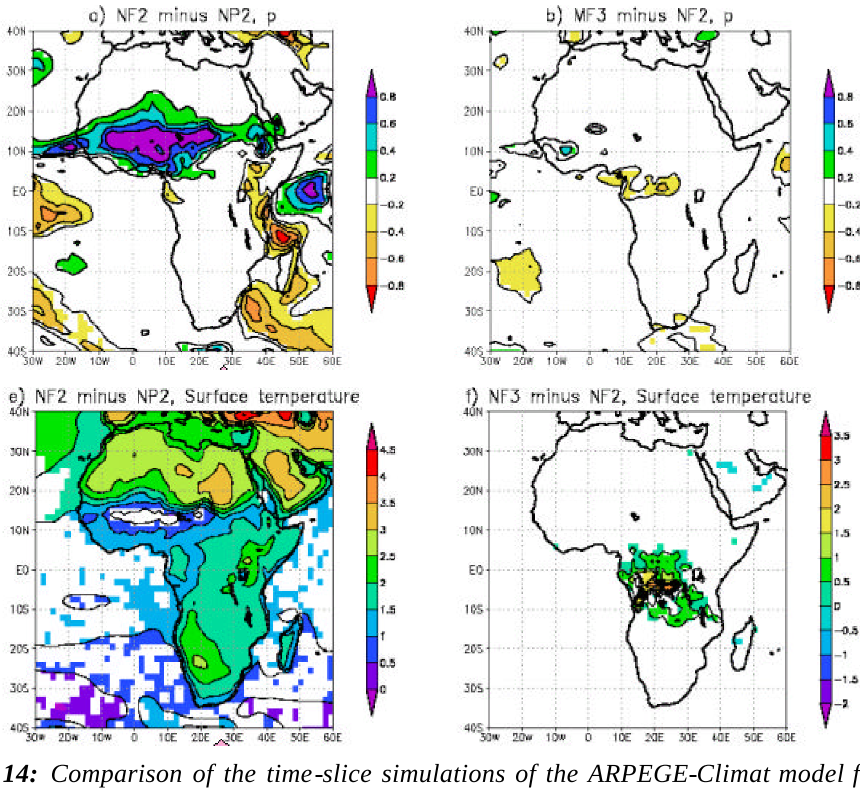


Figure 14: *Comparison of the time-slice simulations of the ARPEGE-Climat model for 2040-2060 in scenario B2 with respect to 1970-1990, giving the response of 2m temperature in °C (top) and precipitation in mm/day (bottom) in summer (JJA), to the greenhouse gases forcing only (left column), and to the land-surface changes from the IMAGE 2.2 model (right column).*

Additional sensitivity experiments have been made to separate the influence of the different land surface parameters in the response to tropical vegetation changes (Maynard and Royer, 2002b). A simulation has been performed with a scenario of large-scale reforestation over Africa by using the potential vegetation map produced by the IMAGE model for 2050. However the impact was found to be sensitive to changes in the computation of some land surface parameters in ISBA, such as the inclusion of subgrid-scale orography in the computation of the surface roughness length (Maynard and Royer, 2003)

Past studies have used idealised changes in vegetation to illustrate climate sensitivity in West Africa, studies which have been used to argue that vegetation changes may have played a key role in the Sahelian drought since the 1960s. However, these scenarios may exaggerate both the intensity and extent of changes in vegetation that have actually occurred. There is no accurate historical record of regional vegetation changes extending back to before the drought began. One important driver of vegetation change is land use practice. Therefore an important aspect of the work has been an assessment of historical land use changes in the region from a variety of data sources.

To quantify land use change in the sparsely vegetated countries of the Sahel, results of a detailed land use model developed specifically for that region, and run at the national scale, forced by population statistics, rainfall and other factors have been exploited. In the moist tropical region of West and Central Africa, a variety of sources have been used to estimate current rates of deforestation at the national scale, and simple scenarios for future deforestation (such as 'business as usual' and population-forced models) have been explored. Rates of land use and land cover change have varied widely across the region in recent decades. For example, countries such as Burkina Faso and Niger have undergone rapid agricultural extensification, whilst large-scale deforestation in the tropical belt has been limited to the Ivory Coast and, to a lesser extent, Togo. In the coming decades, the most dramatic changes in vegetation are likely in the relatively undisturbed tropical forests of the Congo Basin.

To explore the climatic effects of past and future land use changes, the Hadley Centre model was run with three scenarios, based on land use estimates for 1961, 1996 and 2030. Simulations using mean sea surface temperatures (SSTs) showed a small but consistent reduction in precipitation throughout the region as a result of vegetation land use changes. The largest changes occurred in regions with the greatest deforestation (e.g. Ivory Coast, Congo Basin), with reductions of up to 10% annual rainfall at individual grid points. Interestingly, the precipitation in the West African monsoon region increased with the change from 1996 to 2030 land use, in spite of regional losses in vegetation. An additional simulation was performed to investigate the impact of the remote deforestation occurring during this period in the Congo Basin. The model suggests that the anticipated deforestation in that region may produce enhanced precipitation in the Sudan and southern Sahel, offsetting any local effect.

The importance of land use change for understanding the historical record of Sahel rainfall was examined with further simulations adopting alternative SST scenarios from extreme years. The sensitivity of summer rainfall to SST is an order of magnitude larger than the sensitivity to land use change. This suggests that the impact of land use change on climate in the region is second order compared to the natural climate variability of the region. Additional runs with imposed leaf area index anomalies were performed to examine the role of biophysical feedbacks on rainfall in extreme years. The runs support the suggestion that the natural response of the vegetation to rainfall amplifies the external (SST) forcing. In addition, the results suggest that this feedback may become more important with the loss of natural vegetation.

(ii) Effects of Irrigation

As part of PROMISE, a new version of the LMD GCM atmospheric model with an integrated vegetation/land surface and hydrological model (ORCHIDEE) has been developed which includes river routeing and irrigation schemes. This has provided an opportunity to simulate the re-evaporation of water in the streams within the flood-plains or through irrigation.

The irrigation scheme includes three components. First the irrigation water requirement is computed, based on the FAO formulation. Second, the actual irrigation is computed according to the relative equilibrium between water demand and supply of each grid cell. The resulting actual irrigation is withdrawn from the river system and aquifer reservoirs. Third, the computed irrigation is added to the land covered surfaces of each irrigated grid boxes of the model. The model is shown to capture the main features of the geographical and temporal variations of the irrigation over India. As expected the intensive irrigation over the Indian Peninsula leads to increases in the annual mean value of the latent heat fluxes.

Based on the successful implementation of the ORCHIDEE scheme, further numerical experiments have been performed to study the interactions and feedbacks between irrigation and climate, from regional to global scales. The preliminary results show that climate change has a substantial effect on irrigation. The doubling of CO_2 induces a decrease of precipitation over Indus and Ganges basins and an increase over the Brahmaputra basin. Consequently, a decrease of river flow is simulated over the Indus and Ganges basins, and the water supply to irrigation is reduced over these region (Figure 15).

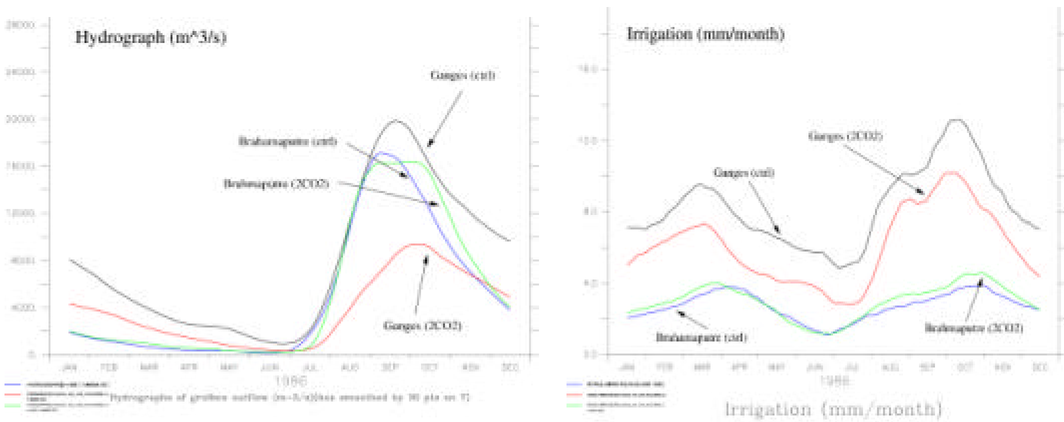


***Figure 15**: Simulations of the river flows (left panel) and irrigation (right panel) from the three major rivers of India for the control and double CO2 climates.*

E. Exploring the impacts of climate variability and change on water resources

(i) Assessment of water resources in relation to water demand for West Africa

The Global Water AVailability Assessment method (GWAVA) has been exploited to provide an assessment of future water availability in West Africa, one of the most vulnerable regions of the world. GWAVA has been developed by the NERC Centre for Ecology & Hydrology and the British Geological Survey in order to provide an improved methodology for the assessment of water resources in relation to water demand for application at the global scale. The approach is based on a 0.5 by 0.5 degree latitude-longitude grid, and it attempts to improve on previous work by:

- adequately representing the spatial and temporal variation in both water availability and water demands, thus avoiding the distortions of national averages;
- simulating the effects of natural features (lakes and wetlands) and human-made features (reservoirs, abstractions and long-distance transfers) which have major effects on the availability and flow of water;
- accounting for the full range of demands, including domestic use, industry, irrigation and livestock;
- treating the problems of international river basins in a realistic manner; and
- providing for the assessment of future scenarios of the balance between water availability and demand due to climate change, population growth, urbanisation and increasing per capita consumption.

The main output of GWAVA is the comparison of water availability and demand at the scale of the grid cell, enabling the variability and complexity of the water resources situation to be appreciated.

Within the PROMISE project, GWAVA was set up to model the West African region, and the necessary input data on current baseline conditions have been assembled, as well as scenarios of change in climate, population, water demands and land use. The modelling area covered the whole of the West African region, a box of approximately 17°W to 24°E and 0°N to 23°N. This area comprises 22 countries, having a wide range of hydrological regimes and climates. Topographic maps of the whole region were used to identify the river network so that flow routing within the model could be made to mimic the natural drainage system (Figure 16). Information on lakes, reservoirs, wetlands, soil types and vegetation cover was assembled from a variety of sources and set up for input to the model on a gridded basis.

Grid-based data on the baseline climate for the region were acquired from the Climatic Research Unit at the University of East Anglia. Observed flow data at key sites in the region were assembled to be used as calibration data. Using this information, the model was set up and run to simulate baseline conditions across the region. A reasonable degree of calibration against observed flows was attained. For the many areas for which no observed flow data were available, model parameters were determined based on the general similarity with neighbouring areas that did have data.

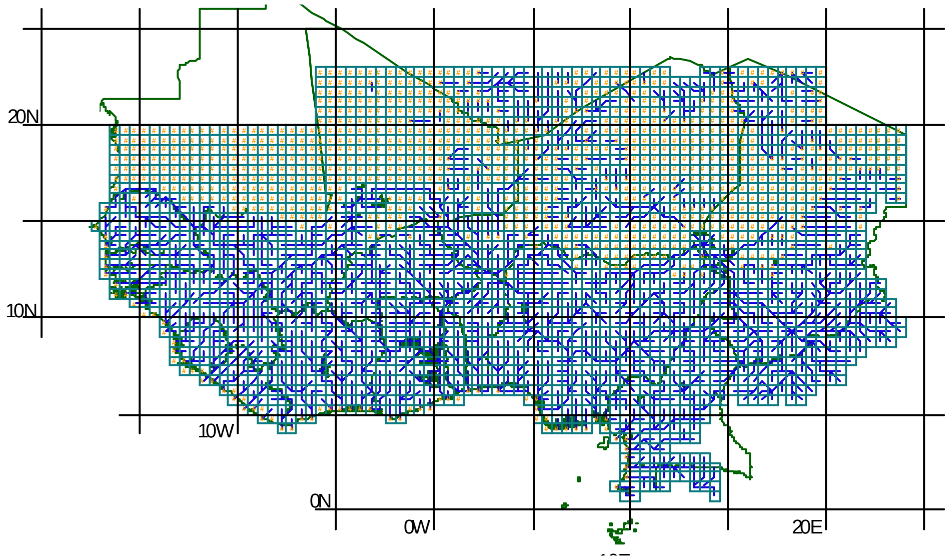


Figure 16: *River network, modelling grid and cell linkages for the West African study region.*

The main controlling factors on the parameters of the GWAVA model are the soil type and land cover type. Because the West African region has experienced very extensive changes in land cover due to forest and woodland clearance and livestock grazing, and these changes are expected to continue into the future, the modelling system was modified and tested to enable a wider range of land cover types to be accommodated. Sample catchments were identified to test the modified land cover data, and to test the sensitivity of the model to those inputs. Scenarios of future land cover at the national level were taken from those described in Section D(i).

Using the modified GWAVA model, the expected changes in water stress over the study range for a variety of scenarios, including climate, population, water demand and land use changes were estimated. The climate scenarios used were the Hadley Centre's HadCM3 (with low and high emissions assumptions) and the ARPEGE-Climat model of Meteo France. There were some marked differences between the models, but these were mainly in areas of high rainfall where water availability is good, so the final results, when looked at in terms of water resources, are reasonably similar. Overall they indicate a marked increase in the areas suffering high water stress in the Sahel zone (Figure 17).

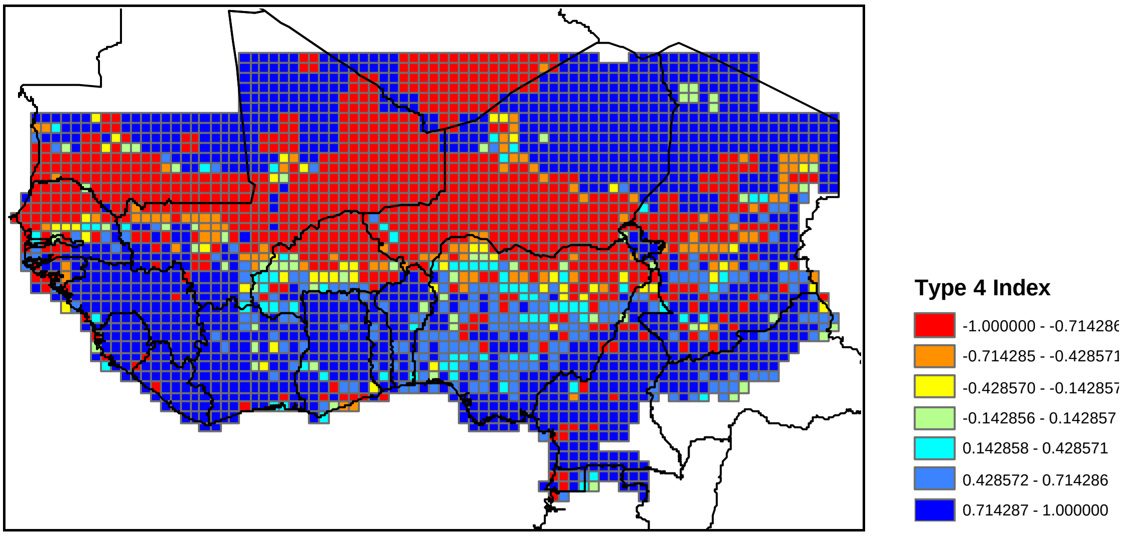


Figure 17: *Water stress estimates for West Africa for the 2050s using HadCM3 (high emissions assumption). Red areas indicate cells with high water stress (low water availability in relation to demand), and blue low water stress.*

The effects of land use change were also studied in isolation from the other changes included in the future scenarios. This showed that, while quite significant changes in river flows are to be expected, these changes are concentrated in the areas with high rainfall and low water stress and so are of little significance. In the highly stressed Sahel zone, the effects of land use change are relatively minor, and it is the anticipated changes in population and in water demands (for domestic use as well as irrigation needs for food production, and for industrial production), combined with climate change, that are expected to be the dominant factors in the worsening water situation in this area.

(ii) Developing a method for estimating large scale changes in river flows

The Global Land Surface ORCHIDEE model described in Section D(ii) has been used to study the effect of climate fluctuations on water resources and the impact of changes in water management on climate. By including the scheme in the LMD GCM, it is possible to diagnose during a climate change simulation the regions in which water resources are critically affected and to suggest to the hydrological community regions where more detailed off-line studies might be helpful.

The river routeing scheme within ORCHIDEE is defined to close the water balance and to transport the water from the continents to the oceans. The routeing scheme is able to take into account a number of different rivers in the same grid box with different percentages of occupation of the mesh. Another original aspect of this routeing scheme is that it is fully integrated in the land-surface scheme and can thus interact with the soil moisture scheme. This allows us to simulate floodplains and anthropogenic irrigation, which are important processes in tropical regions.

Figure 18 shows an example of the performance of the river routeing method when coupled to the land surface scheme within the atmospheric model. The comparison is for the gauging station of Koulikoro on the river Niger. The black line represents the hydrograph simulated when the land-surface model is coupled to the GCM at a quite low resolution (2 by 2 degrees). The red line gives the average of the results for the years 1987 and 1988 when the model is forced by the atmospheric conditions provided by the ISLSCP project at a resolution of 1 by 1 degree. These results can be compared to the observed hydrograph (green line) (covering most of the 20th century) and the results are very encouraging. The timing of the maximum flow is correct but the amplitude is underestimated in the off-line and coupled integrations. This might be expected as the years simulated are among the driest of the century.

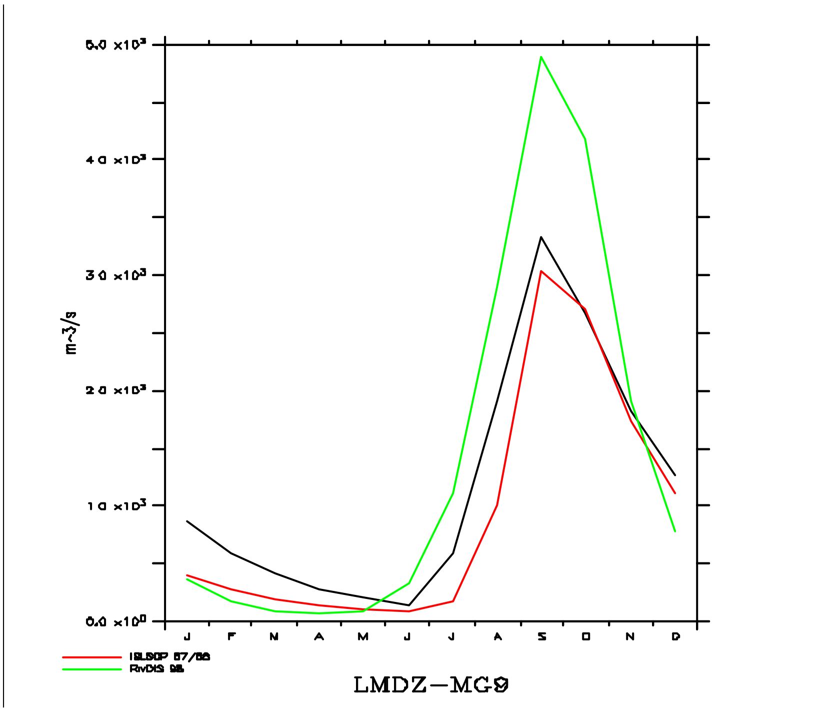


Figure 18: *Evaluation of the routing scheme: hydrographs for the gauging station of Koulikoro on the river Niger (for explanation see text above).*

The final part of the development of the river routeing scheme was the inclusion of a representation of floodplains in the model and the evaluation of the simulated water cycle in the fully coupled system. For this analysis the annual cycle and the inter-annual variability of the discharge of the Parana and the Niger rivers were studied. The comparison of these two basins is interesting in many aspects. First they both are under the influence of tropical climates and have within their catchment major floodplains. The precipitation simulated by the atmospheric model is quite realistic in both areas except for a systematic underestimation of the annual mean rainfall. For the Parana this has the consequence that in the coupled model the river nearly dries up in October and November at the station of Corrientes. Introducing the floodplains of the Pantanal improves the annual cycle of the discharge but does not correct the systematic bias that results from the low precipitation.

For the Niger, however, the impact of the floodplain on the hydrograph is not reproduced in the coupled mode. A more detailed analysis of this result has shown that the synoptic variability of the precipitation in the GCM is much too low. This results in very small fluctuations in the flow of the river and thus no generation of floods in the inner delta of the Niger. For the model to reproduce correctly the discharge of the river at Niamey it is thus paramount to improve the daily variability of the convective systems that generate the largest fraction of the rainfall.

It is a remarkable feature of the hydrological cycle of the West African region that the relative inter-annual variability of the discharge of the Niger is nearly twice as large as that of the precipitation (Table 1). It was thus tempting to see if this new model could reproduce this result.

Table 1: Interannual variations as a percentage of the annual mean in the observed and simulated (with and without floodplains) river discharges from the Parana and Niger during 1979-1995.

Std Variation of anomalies (%)	***Precipitation***	***Discharge***
Observed at Koulikoro	10.7	28.0
Koulikoro: Simulated	9.9	31.2
Koulikoro: Simulated + floodplains	11.2	35.3
Observed at Niamey	9.9	26.6
Niamey: Simulated	11.1	31.2
Niamey: Simulated + floodplains	12.2	35.3

F. Crop modelling for seasonal and climate change prediction.

A major effort in linking the disciplines of crop modelling and climate prediction has been undertaken in PROMISE. This research has raised a number of important issues, particularly those related to spatial scale and the biases within climate models. In the following sections two approaches have been used to address the issue of spatial scale, one in which upscaling of the crop model is advocated and the other in which downscaling of the climate data is used. Although significant progress has been made towards establishing a toolbox for evaluating the impact of GCM output scenarios on crops in semiarid environments, it was not possible to use the new tools to measure the impact of specific GCM scenarios, because climate simulations of satisfactory quality could not yet be provided. PROMISE research has highlighted again the need for significant improvements in climate model simulations, particularly with respect to precipitation.

(i) A protocol for integrating information from seasonal forecasts of monsoon climates with impact assessments of crop productivity in India and Africa.

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.

As part of PROMISE an overall methodology for integrating crop and climate prediction has been developed. This involves using known relationships to develop models that can be combined optimally to produce results of known accuracy. An important part of this methodology is to take advantage of the probabilistic methods used in seasonal weather forecasting to both optimise and quantify accuracy. Figure 19 presents a schematic of the various stages in the development of the combined system, and the progression from the application and evaluation of the system for seasonal forecasting in current climates to the probabilistic assessment of the impacts of future climate change.

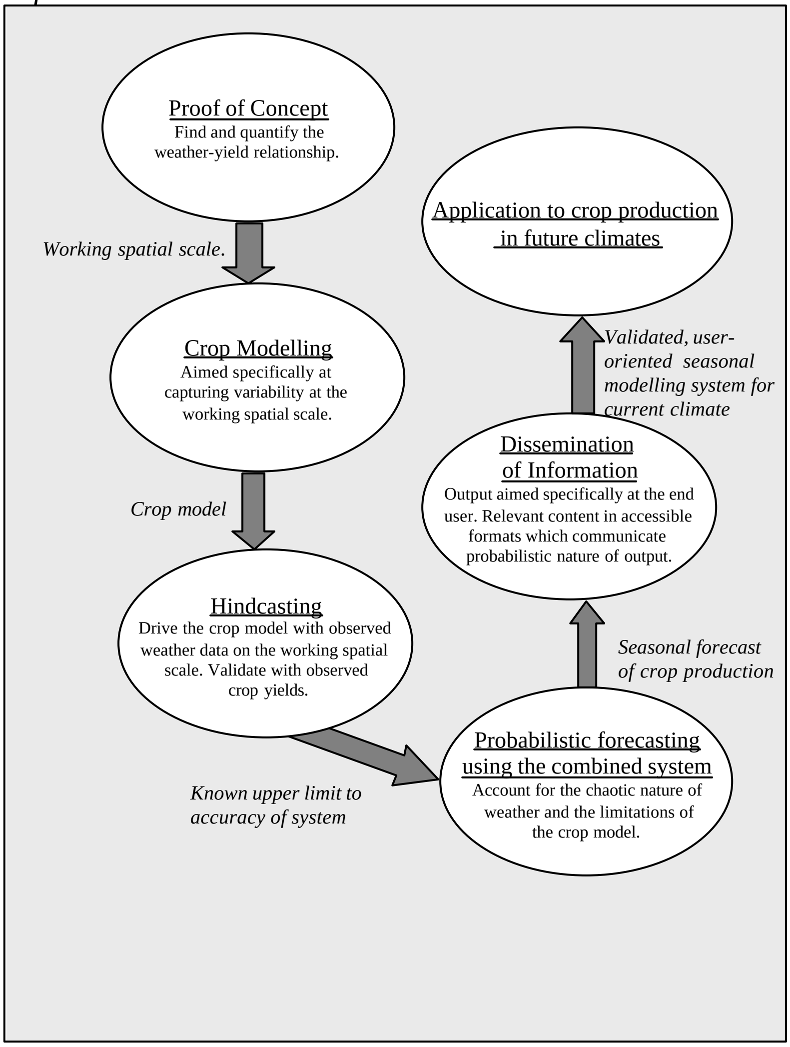


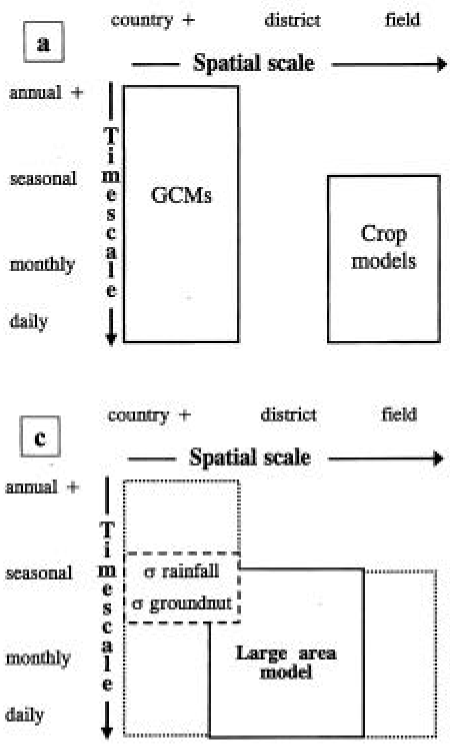
__Figure 19:__ The development of a seasonal crop productivity forecasting system. Italicised text illustrates links between the various stages.

Firstly, a link must be established between weather and crop yield or crop quality on a spatial scale appropriate for the combined crop/weather prediction system. 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.

(ii) Development of a general large area model for tropical annual crops

In order to combine weather and crop forecasting techniques, a common spatial scale must be identified, and there must be a proven correlation between weather variables and yield on this common scale in order for modelling work to have any chance of success. During PROMISE, the development of the methodology proposed in Figure 19 has been based on groundnut yields for India since good records of yield at high spatial resolution and over many years are available.

Rainfall is the dominant climatic determinant of groundnut yield in India, but correlations between rainfall and yield vary from region to region. In order to identify any existing coherent pattern in this relationship, a mathematical technique that takes account of both spatial and temporal variability is needed. This variability has been explored using empirical orthogonal function (EOF) analysis. A coherent, large-scale pattern emerges for both rainfall and yield. On the subdivisional scale, the first Principal Component (PC) of rainfall is well correlated with the first PC of yield (r^2=0.53, p<10^{-4}), demonstrating that the large-scale patterns picked out by the EOFs are correlated. Further, district-level EOFs of the yield data demonstrate the validity of upscaling these data to the subdivisional scale. Similar patterns are produced using data on both these scales, and the first PCs are very highly correlated (r^2=0.96). Hence a common spatial scale (the subdivisional scale, ~ 300 km) has been identified (Figure 20), typical of that used in seasonal weather forecasting, which can form the basis of crop modelling work for the case of groundnut production in India. Details of this work can be found in Challinor et al (2003a).



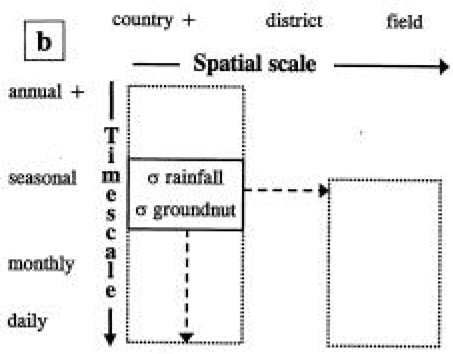


Figure 20: *Schematic representation of the scaling issues relevant to combined crop and weather forecasting systems: a) scales of current GCM and crop simulation models; b) common scale for response of groundnut yield to rainfall identified by Challinor et al (2003); c) proposed scale of large area crop model*

It is large area models, then, as opposed to point models, which are the appropriate choice for GCM-driven groundnut modelling in India (Figure 20). Such large area models would incorporate a point-wise phenology model, with inputs and outputs designed to be representative of an intermediate spatial scale (between the single point or plot and the common spatial scale identified above). Further upscaling of crop model output could be achieved by running the model using a distribution of inputs that is representative of the spatial variability within the subdivision. In the case of India, districts or agro-meteorological zones are ideal for this purpose.

Another distribution can be developed from the GCM ensembles to represent uncertainty in the weather forecasts. The output of the system will then be a distribution of district-level potential yields (since pests and diseases are not modelled). By comparing model output with measured distributions of district yield, a distribution function representative of the yield gapcan be obtained. By assuming that this function is constant in time, or by identifying different functions for different pest/disease scenarios, the system can then be used to predict yield on the subdivisional scale.

The overall structure of the model system is shown in Figure 21. This includes spatial representation of soils, mathematical distributions that capture the uncertainties in the crop model, and a novel method of deriving the patterns of actual crop yields from those of potential (model output) yields. The format and parameters for the central crop model (GLAM, General Large Area Model for annual crops) have been finalised and coded.

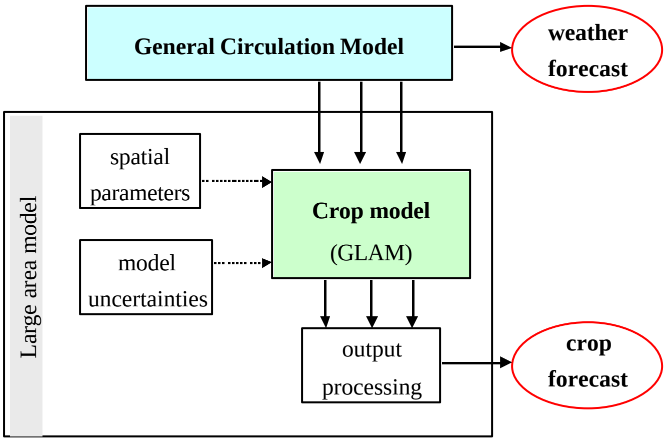


Figure 21: *Diagram of the combined seasonal weather/crop forecasting system.*

The large area model (GLAM) represents a new approach to crop modelling. Whilst still using a process-based approach, the model is designed to work at the larger spatial scale with fewer input parameters than is typical for phenology-based models. A full description of the development and testing of GLAM is given in Challinor et al. (2003b).

GLAM has been tested for groundnut yield across India in deterministic mode by using observed daily rainfall and monthly data for temperature and sunshine hours. Three sites have been examined in detail - grid cells from Gujarat in the west, Andhra Pradesh towards the south, and Uttah Pradesh in the north. Agreement between observed and modelled yield was variable, with correlation coefficients of 0.74, 0.42 and 0, respectively. Skill is highest where the climate signal is greatest, the interannual variability in crop yields is large, and correlations are comparable to, or greater than, simple correlations with seasonal mean rainfall. In regions such as Uttah Pradesh, where the crop is not water limited and variations in climate have little impact, the interannual variability in crop yields is probably associated with other factors such as crop management, which GLAM does not currently represent.

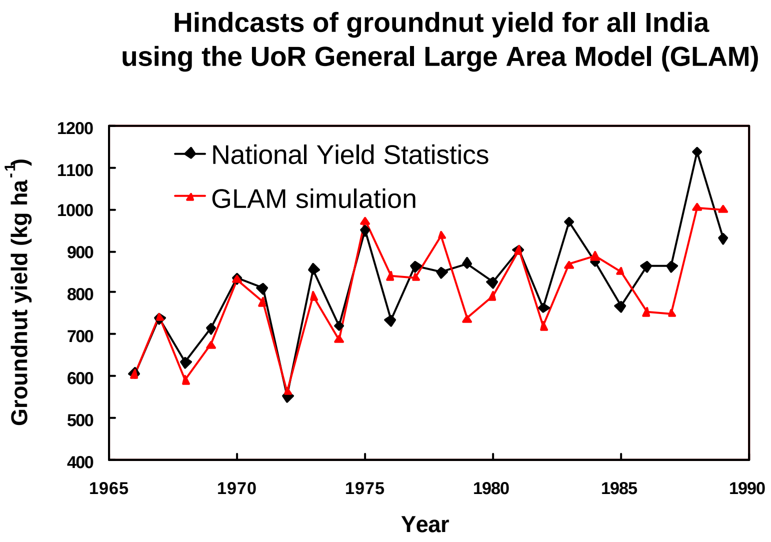


Figure 22: *Comparison of simulated and observed crop yields for India*

Yield from all 35 cells have been aggregated to simulate all-India yield (Figure 22). The correlation coefficient between observed and simulated yields is 0.76, and the root mean square error is 8.4% of the mean yield. This is considerably higher than a simple empirical relationship between seasonal mean rainfall and crop yield, and shows the additional skill provided by the process-based model and the use of daily rainfall data. So far the model has not been run with daily temperature data and it is expected that further improvements in skill are possible because groundnuts are sensitive to heat stress at particular phonological stages. In addition, one of the key factors in crop development under climate change may be the exceedance of critical temperature thresholds, which GLAM has been designed to represent.

(iii) Development of a local scale crop model for West Africa.

Future agricultural forecasting systems for the Sahel should be able to use both seasonal weather forecasts and climate change scenarios such as those simulated with global circulation models (GCM). The simple crop water balance model for West Africa, called SARRA (Samba et al. 2001), has been developed further under PROMISE into a full crop model (SARRA-H) that continues to operate at the plot level with daily time-steps, but includes the following additional features:

- Radiation driven carbon assimilation, limited by a physiological drought function ("P-factor", FAO system based on fraction of transpirable soil water (FTSW) in the root zone)
- Calculation of ground cover from biomass allocated to form leaf area, and of available soil water using a dynamic root front
- Separation of evapotranspiration (ET) into E and T components using fraction ground cover as weighting criterion, and PET as driving force
- Introduction of photoperiod and thermal time to set the pace of phenological development
- Stress dependent conversion of biomass into grain yield
- Model sensitivity to crop population density

Versions of SARRA-H have been developed for dry-land cereals and groundnut. Written in Delphi language, the model is object based and features an extensive graphic interface. The model was developed in close collaboration with regional partners in West Africa (CERAAS in Senegal and Agrhymet in Rep. Niger), and in consultation with crop physiologists of Reading University.

A GIS tool developed at Cirad called 'Almanach', developed in the same programming environment as SARRA-H (Delphi), has been adapted to suit the objectives of PROMISE (Lo Seen et al., 2001; Baleux et al., 2001). 'Almanach' is a single executable program that uses a standard Microsoft Windows user interface. This permits inexperienced computer users to access the data, run the model and view the results. The tool allows the user to display on a map the input and output variables of the crop model. Some GIS specific functions are included in this tool to create printed maps, as well as a query tool that allows the user to extract data from the data set to use in another software.

For the on-station calibration and validation of SARRA-H, detailed datasets on millet were provided by CERAAS, permitting growth analyses for 3 years and several water regimes at the Bambey site in Senegal.

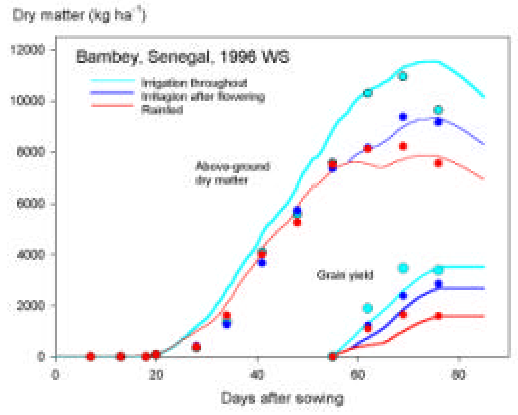


Figure 23*: Simulated (lines) and observed (points) biomass and yield of a millet crop in summer 1996 in Bambey, Senegal.*

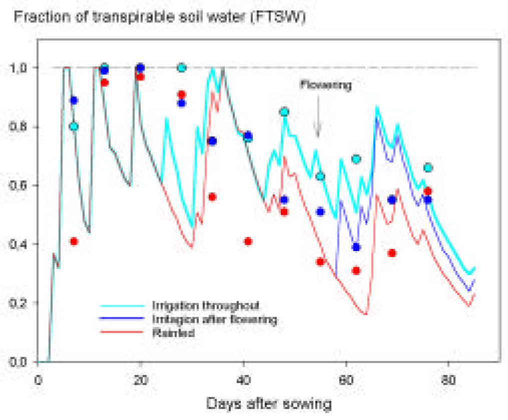


Figure 24: *Simulated (lines) and observed (points) fraction of transpirable soil water (FTSW) in the field for the same crops as in Figure 23. Simulations take into account drought dependent progress of the root front.*

The model represents realistically the dynamics of dry matter, yield (Figure 23) and water use (Figure 24) of the crop in various stress situations, with attainable yields of up to 11 t/ha (above-ground biomass) and 4 t/ha (grain). By contrast, the model over-estimated 3-4 fold farmers' millet yields surveyed for 2001 in various regions of Senegal (data aggregated for groups of villages), covering 200-650 mm rainfall (cumulative during crop growth), and 13.8° to 15.7°N latitude (Figure 25). Indeed, according to practitioners' experience, farmers' yields are usually between 0.2 and 1.0 t/ha depending on rainfall, but may reach 4 t/ha occasionally. Importantly, the crop model explained 78% of yield variation among sites, indicating that climate explains most of the variation of yield, whereas the low absolute level of yields compared to the attainable level must be due to other factors.

A comparison between potential (water unlimited), attainable (water limited) and actual farmers' yields (Figure 26) indicated that with increasing latitude, potential yield increases due to increased radiation, and attainable and farmers' yields decrease due to water limitation. Above-ground biomass production was thereby more sensitive to solar radiation, and grain yield was more sensitive to water limitation.

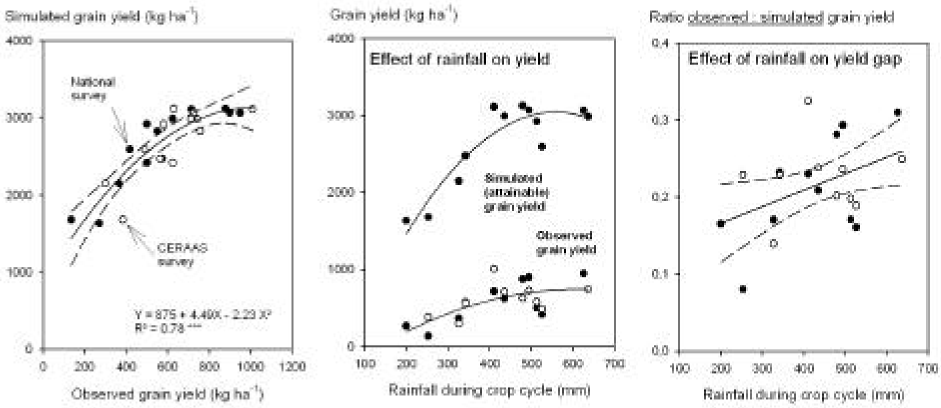


***Figure 25**: On-farm validation of the SARRA-H crop model in Senegal, 2001. Left: relationship between simulated (attainable) and observed grain yield for millet. Centre: Simulated and observed grain yield as a function of rainfall received during the season. Right: Relationship between the fraction observed: simulated grain yield and seasonal rainfall, indicating that the yield gap increases as rains decrease.*

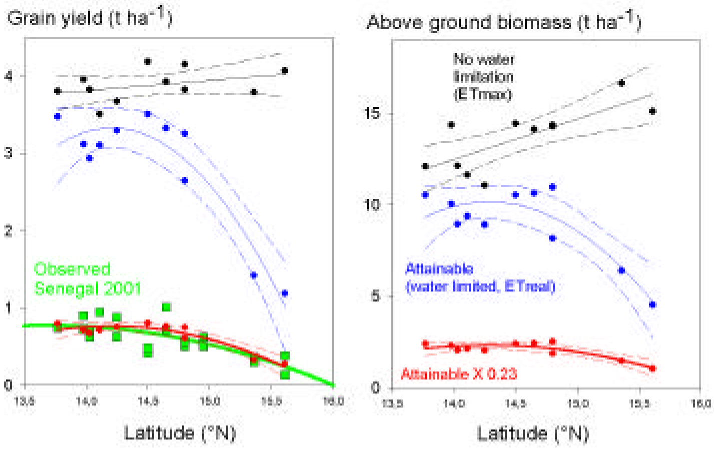


***Figure 26**: Simulated potential, attainable and farmers' yield levels as a function of latitude in Senegal. Broken lines indicate 5%-confidence*

(iv) Pilot study of the crop model performance using simulated climate scenarios

A pilot study was conducted on the impact of simulated climate change scenarios on groundnut yields in Senegal, using a preliminary version of SARRA-H and high resolution, time-slice simulations for 1950-79 and 2010-39 using the ARPEGE atmospheric model (Syahbuddin 2001). Although the predictions of crop yield have little validity due to flaws in the preliminary version of the crop model and in the climate simulations (significant latitudinal shift of iso-lines for weather variables), this study raised important methodological issues related to spatial and temporal scales.

The main problem is related to differences in intensity distribution of daily rain totals between plot level (synoptic stations) and simulations (200 x 200 km grid) for the same period and geographical area (Figure 27: case of Koudougou). The ARPEGE climate model under-estimates the number of dry days (<1 mm) and the number of days with heavy rains (> 25 mm), while over-estimating the frequency of small rains (1 < X < 25 mm), mainly because of the grid size. Crop yie lds respond to local weather, and regional yield means are therefore not a linear function of regional weather means. Yields are very sensitive to intensity distribution and frequency of rainfall events because event size determines the fraction of water running off, evaporating, infiltrating and percolating. This is critical in arid environments where the season begins with a dried-out soil and a superficial wetting front that gradually descends as a function of percolation (which can be a large or small fraction of rainfall). SARRA-H is sensitive to these processes. Furthermore, the crop model simulates farmers' decision when to sow, which depends on rain event size. In fact, rainfall distribution is as important as quantity for achieving favourable seedbed conditions.

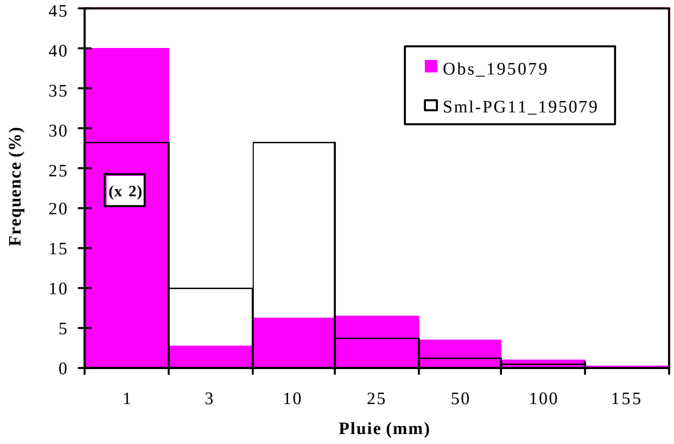


Figure 27*: Frequency distribution of daily rainfall for 1950-79 observed at Koudougou in Senegal and simulated with ARPEGE for a pixel that includes the same site.*

In this pilot study using ARPEGE climate data for 1950-79, yields were under-estimated because simulated sowing was generally late and the root system shallow, owing to inaccurate simulation of rainfall distribution. The time-slice for 2010-39 gave a further yield decrease due partly to lower solar radiation, and partly to higher temperatures resulting in shorter crop duration. However, it has been shown that an improved definition of the onset of summer monsoon can improve the potential yield through a better choice of the sowing date. A strong impact of the intra-seasonal dry sequences around 40 days on the potential yield has been demonstrated, particularly when these dry sequences appear during the flowering and the grain ripening phases of the crop.

The impact of disparate spatial sampling scales on the rainfall distribution and hence on the simulated crop yields is a serious issue which has been explored further in a series of sensitivity experiments with the plot-scale crop simulations to aggregating and disaggregating available rainfall data for an area in Senegal centered on 14.5°N 15°E. The study area covered 7 weather stations (1° pixel square) or 17 stations (2.8° pixel) and analyses were done for 31 years (1950-1980). Aggregation (up-scaling) of yield and rainfall data for the pixels using simple or weighted averages by kriging gave the same results. However, running the crop model for points (plot scale) and large aggregated pixels gave very different partitioning of water (Figure 28) and yield levels for millet (Figure 29). On average, the "useful" fraction of rains (transpiration) was much greater when aggregated data were used, reflecting an under-estimation of runoff and deep drainage due to the 'smoothed' rainfall distribution. This led to an over-estimation of yield by 63% for the 2.8° pixel (c.f. 50% for 1°).

The results of scaling studies showed clearly that plot level water balances could not be predicted with spatially aggregated rainfall data. On the other hand, it was shown that plot level intensity distribution of rains is a major determinant of crop water use and thus, yield. A disggregation (down-scaling) tool was therefore used to reconstitute point (plot) data from large pixels using a probabilistic method calibrated for Sahel environments (Niamey, Rep. Niger). The method essentially creates a user-defines number of virtual locations within the pixel at which rainfall is distributed according the passage of virtual rain fields.

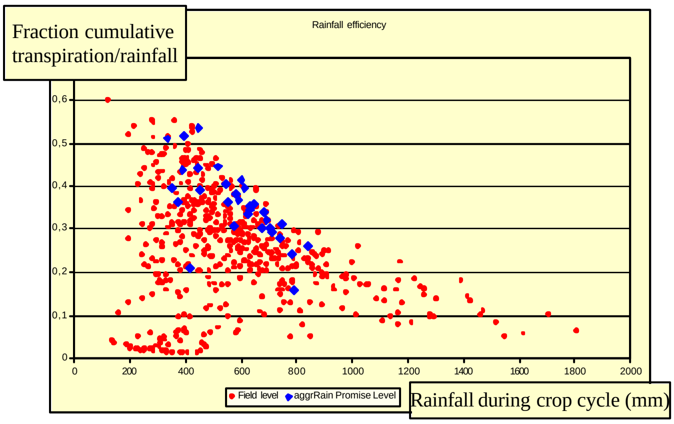


Figure 28*: Simulated fraction of useful rainfall (seasonal transpiration over rainfall during crop cycle) for 31 years on individual locations (red) and an aggregated, 2.8° pixel (blue). Simulations with SARRA-H.*

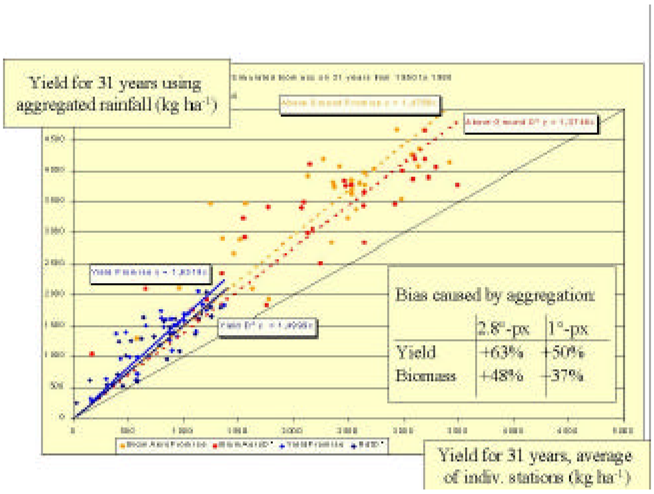


Figure 29*: Relationship between yield (blue) and biomass (red) simulated with aggregated rains (2.8° and 1° pixels) and plot level rain distribution using SARRA-H.*

Figure 30 shows the disaggregation results for the extreme example of 1972, a disastrous drought year in the Sahel. The combination of SARRA-H and the down-scaling model gives a reasonable accuracy of case distributions on the yield-rainfall scatter, and can therefore be used for agronomic impact simulations on large pixels. Further research is needed, however, to calibrate and validate this method for different types of climate and different seasons, and to improve handling of the combined tool, which at this stage is still quite cumbersome. Lastly, it must be noted that climate change may affect the values of down-scaling parameters in an unknown fashion.

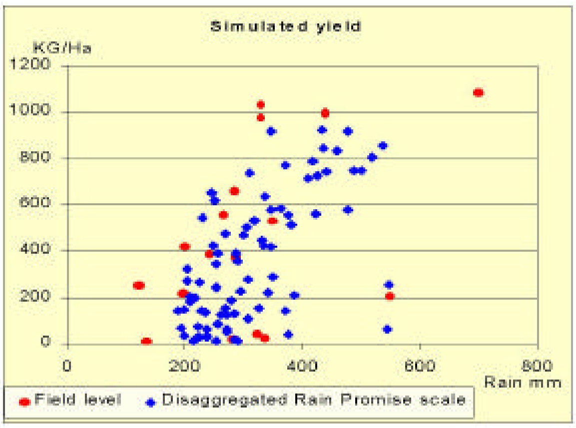


Figure 30*: Millet yields simulated with SARRA-H on a 2.8°-pixel in Senegal for 1972, using observed climate for 17 locations, and 82 hypothetical locations reconstituted from the aggregated pixel with a down-scaling model.*

Significant progress has been made towards establishing a toolbox for evaluating the impact of climate change on crops in semiarid environments in West Africa. This toolbox comprises a generic, plot-level crop model suited for West African grain crops (e.g., millet, sorghum, maize, peanut) and a down-scaling tool translating aggregated "pixel" weather into local "point" weather. The limited spatial resolution of GCM outputs leads to systematic errors in the plot-level water balance, particularly with respect to the fraction of water effectively used for transpiration and growth. These errors are particularly large in semi-arid environments, where the rainfall distribution is comparatively erratic and where, because of high evapo-transpiration, only relatively large rains are able to replenish the soil water reserve.

The crop models used in this study are sensitive to effects of temperature (including effects on phenology and respiration), solar radiation, the evaporative demand of the atmosphere, and rainfall. By contrast, it was deemed necessary to simulate not just the impact of climate on crops as they behave now, but also to be able to simulate short-term, tactical adjustments, such as sowing dates, choice of varietal type and crop population density, all of which the farmer would try to optimise when faced with changing conditions. Strategic adjustments, however, such as change of cropping system, land use or the introduction of irrigation, were not considered.

Unfortunately, it was not possible to use the new tools to measure the impact of specific GCM scenarios, because climate simulations of satisfactory quality could not yet be provided. We suggest that given the great importance of rainfall size distribution for the crop and field-level water balance, further work on GCM applications for agriculture should put more emphasis on the intra-seasonal variability of weather, particularly rainfall, both in terms of short-term predictions and climate change. Lastly, we restate the importance, at least for semi-arid environments, of reliable and timely predictions of the onset of the rainy season. This information is crucial for sowing dates and the choice of crop and crop variety, unless a modified cropping system is developed that uses less variable sowing dates associated with the regional onset of monsoons. In this hypothetical case, nitrogen catch crops and/or weed suppressive crops may be necessary to occupy the land between the first major rains and the ”true” onset of the monsoon, from when on the crop can be safely sown. This vision, as it were, is one of the many add-on results generated by PROMISE, and deserves to be further explored.

6.3.3 Deliverables

The scientific achievements described in the previous section are only a sample of the wide range of results from PROMISE. A detailed report on each of the PROMISE Work Packages (WP) is provided on the PROMISE website: http://ugamp.nerc.ac.uk/PROMISE/. Due to the delays in the production of the ECMWF 40-year Reanalysis (ERA40) and the subsequent impact on the EU DEMETER project, the work planned on the assessment of the seasonal predictability of monsoon climates has not been completed. The following specific deliverables were completed for each science WP:

WP1: Natural variability and predictability of current monsoon climates on seasonal, interannual and interdecadal timescales

- D1001: Description of the natural variability of monsoon systems for the current climate, including the interaction between decadal, interannual and intraseasonal timescales
- D1002: Assessment of the skill of current climate models to represent the natural variability of the monsoon climates
- D1003: Development of advanced statistical techniques for extracting signals of monsoon variability
- D1101: Assessment of the seasonal predictability of monsoon systems using ensemble techniques
- D1103: Assessment of the origins of monsoon predictability (particularly in the Sahel)
- D1201: Assessment of the sensitivity of monsoon variability/predictability to regional SST anomalies
- D1301: Understanding the relationship between Eurasian snow anomalies and monsoon variability
- D1302: Assessment of the sensitivity of monsoon variability to anomalies in land surface/vegetation conditions

WP2: Assessment of anthropogenic climate change scenarios for monsoon climates.

- D2001: Documentation of the impacts of anthropogenic climate change on the characteristics of monsoon climates
- D2002: Assessment of the value of high resolution regional model simulations for use in climate change impact studies
- D2101: Development of future scenarios of land use changes
- D2102: Assessment of the impact of land use changes on monsoon climates

WP3:Impact of natural and anthropogenic climate change on ground hydrology and agricultural systems.

- D3001: Provision of a detailed hydrological model for application to West Africa
- D3002: Assessment of the impact of climate change on water resources and on the water balance in large river catchments
- D3101: Identification of the important meteorological parameters for crop models; assessment of the potential shortcomings in seasonal prediction and crop models
- D3102: Progress towards the development of an integrated system which applies probabilistic methods for the interpretation of seasonal forecasts in terms of crop development and yields, as well as recommendations to farmers.
- D3103: Assessment of the impacts of future CO_2 emissions and land use scenarios on crop productivity

In addition to the science WPs, PROMISE also placed great importance on the active engagement of non-EU scientists and international agricultural and hydrological research institutes (e.g. CGIAR, AGRHYMET). Consequently, PROMISE included two further cross cutting work packages to support the research and to develop pro-active links with scientists and institutes in monsoon-affected countries. The following deliverables were achieved in these WPs:

WP4: Development of a database of observed and simulated data on meteorology, hydrology and agriculture for monsoon climates.

- D4001: Web-accessible database with a public domain component and a protected-access component open to the European and extra-European partners
- D4002: Provision of model data for selected surface climate variables

Due to staffing difficulties at CINECA the development of the PROMISE data archive was delayed and the caching of observational datasets (D4003) was not completed at the end of the project. However, the PROMISE data archive will be maintained beyond the end of PROMISE and

WP5: Establishment of active links with climate scientists in monsoon affected countries and with international hydrological and agricultural research centres.

- 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 with impact assessments of crop productivity

Finally, with such a diverse project that involves three major disciplines and covers a wide range of timescales from seasonal to interdecadal, proper coordination has been vital for the success of PROMISE. A separate work package, devoted to the coordinating activities, has achieved the following deliverables:

WP6: Coordination and promotion of the aims, activities and achievements of the PROMISE project.

- D6001: Development and maintenance of PROMISE web site.
- D6002: Annual meetings. Publication of final report (submission of a paper based on the final report to the Bulletin of the American Meteorological society is planned).
- D6003: General dissemination of the aims and achievements of PROMISE. This was achieved through the final, international conference on '*Monsoon Environments: Agricultural and Hydrological variability of seasonal variability and climate change*' held at ICTP.

6.4 Conclusions including socio-economic relevance, strategic aspects and policy implications

PROMISE is an interdisciplinary project that has developed further the atmospheric science base in seasonal and climate change prediction for monsoon-affected countries, and has established new links between atmospheric science and the impacts communities related to hydrology and agriculture. This has been achieved by bringing together state-of-the-art climate and seasonal prediction models with sophisticated models of ground hydrology, water balance for large river catchments, and crop development and productivity.

PROMISE has made significant advances in our ability to understand, simulate and predict monsoon climates, their mean behaviour and their variability on intraseasonal and interannual timescales, and how these will change in the future due to anthropogenic influences. PROMISE has shown that the land surface is a crucial driver in monsoon variability on timescales from days to decades and that the influence of vegetation and soil hydrology must be well represented in climate models.

PROMISE has provided new assessments of climate change for India and West Africa, which can be used by impacts modellers and policy makers. It has been shown that the intensification of the Indian and Sahelian summer monsoon in a future warmer climate is due to enhanced land-sea contrast, a northward displacement of the inter-tropical convergence zone, and increased levels of precipitable water in a warmer atmosphere.

Land use and natural resource management policy at the national level need to take account of predicted changes in climate in West Africa, as well as satisfying the demands of a growing population and economic development. PROMISE has developed new scenarios of future land use for West Africa, which have been used to show that the direct feedback of land use on climate at the regional scale is likely to be weaker than the effect of increased global CO_2 levels. However, at the local/national scale, extensive deforestation may contribute to a substantial reduction in precipitation, and therefore impact negatively on water resources.

PROMISE has demonstrated that improved projections of future monsoon climates, in particular for extreme precipitation events and surface hydrology, require higher resolution for the impact assessment of anthropogenic climate change on the Asian and African monsoon regions.

The availability of adequate water resources may be the most serious problem humanity will face in the coming decades, particularly in seasonally arid regions. As the demands for water increase, an important issue is the evaluation of changes of the hydrological budget that countries experience, not only due to climatic change but also due to human disturbances through reservoir construction and water use by agriculture. PROMISE has pioneered a new approach to assessing future availability of water for West Africa which will allow policy makers and others to make better informed resource allocation decisions, and will facilitate the assessment of impacts of human activities – such as climate change and land use change – on water availability in relation to people's needs for water for all purposes.

PROMISE results clearly indicate the likelihood of increasing water shortages in the semi-arid Sahel zone where population densities are high and water is already scarce. This region is one that already suffers from high levels of poverty and water stress, and the results reinforce the pressing need to promote and fund adaptation strategies for improved water resources provision and management in this area.

Increasingly, seasonally arid regions use irrigation to enable crop production in the dry season and to support crop development in the rainy season. PROMISE has enabled the development of an integrated land surface and hydrology scheme that includes the effects of irrigation in the fully coupled climate model. This has provided one of the first estimates of the effects water extraction for irrigation on river flows for the major rivers of India under future climate scenarios.

A major effort in linking the disciplines of crop modelling and climate prediction has been undertaken in PROMISE. The socio-economic impact of this research is potentially very high, provided that yield predictions are made available to decision makers in a timely fashion.

Significant progress has been made in PROMISE towards establishing a toolbox for evaluating the impact of climate variability and change on crops in semi-arid environments. A new approach to crop modelling has been pioneered within PROMISE, which provides an upscaling of phenology-based models to spatial scales closer to those of the regional climate models. This then reduces the need for statistical downscaling using weather generators that are not necessarily transferable to future climate states.

However, PROMISE research with crop models has also raised a number of important issues, particularly those related to biases within climate models, and has highlighted again the need for significant improvements in climate model simulations, particularly with respect to precipitation.

A key recommendation from PROMISE is that, given the great importance of the space/time distribution of rainfall for crop and soil water balance, future work on climate applications for agriculture should place more emphasis on the intra-seasonal variability of weather. Lastly, we restate the importance, at least for semi-arid environments, of reliable and timely predictions of the onset of the rainy season.

6.5 Dissemination and exploitation of results

The transfer of technology to developing countries is essential if EU research is to be properly exploited. Consequently PROMISE has placed a particular emphasis on the dissemination of results and the engagement and training of scientists from nonsoon-affected countries. Several mechanisms have been used to ensure that PROMISE research is disseminated and exploited to maximum effect.

(i) PROMISE web site

The PROMISE website (http://ugamp.nerc.ac.uk/PROMISE/) was created at the start of the project and development has continued throughout the project. The site now contains detailed sections on all aspects of PROMISE, including highlights of the project's achievements.

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 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.

The PROMISE website is complemented by the educational information included on the Monsoon Online site (http://www.met.rdg.ac.uk/cag/MOL/). This is linked closely to the PROMISE site and is maintained by David Stephenson (UREADMY), Rupa Kumar Kolli (IITM, Pune, India) and Emily Black (UREADMY), all of whom are associated with PROMISE. Monsoon Online has undergone major revision in the course of PROMISE and now includes more detail about the evolution of the monsoon (updated every week during the Asian monsoon season).

(ii) PROMISE Data Archive

The PROMISE Data Archive, implemented by the CINECA Inter-University Consortium in Bologna and designed in collaboration with the University of Reading and the Abdus Salam International Centre for Theoretical Physics in Trieste, has a web-based interface allowing both data retrieval and direct visualization of a subset of the archived fields. The PROMISE archive includes observed and simulated datasets on meteorology, hydrology and agriculture, with a specific focus on regions affected by monsoon climates. It has been set up with the aim of improving the collaboration and exchange of results between research institutions in European and extra-European nations (particularly in developing countries), and between scientists with expertise on climatology, hydrology and agricultural resources.

In addition, a specific software protocol (DODS) allows users to access remote data over the internet using data analysis and visualisation packages such as Matlab, Ferrat, IDL, and GrADS. Processing of data by DODS-enabled packages is actually performed on the remote data server, with results sent to the “client” in numerical form; therefore users can process a large amount of data without being limited by the memory capacity of their local machines or the speed of their internet connections.

The PROMISE data archive will be maintained (and possibly expanded) in the next years through an agreement between CINECA and the Abdus Salam International Centre for Theoretical Physics.

(iii) Interactions with scientists from monsoon-affected countries

During the project, PROMISE sponsored two major activities aimed at engaging scientists from monsoon-affected countries in PROMISE research.

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’ were 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 end of PROMISE was marked by an international conference held at ICTP entitled ‘Monsoon Environments: Agricultural and Hydrological variability of seasonal variability and climate change’. The conference was hosted by ICTP and sponsored by PROMISE, ICTP, START/CLIMAG and the WCRP. The sponsorship enabled 60 researchers from developing countries to participate. In total, there were 125 participants, most of whom made either poster or oral presentations. All the PROMISE partners were represented at the conference, and several made keynote talks. The meeting provided an excellent opportunity to disseminate PROMISE work to the European and American scientific communities as well as to scientists from monsoon-affected countries. The Powerpoint presentations from the meeting have been made available from the PROMISE website. To facilitate the dissemination of PROMISE results to researchers with slow internet connections, the presentations are also being distributed to participants on a CDROM. For further details of the conference see: http://ugamp.nerc.ac.uk/promise/research/conference2003 .

A presentation on PROMISE was given to the inter-departmental committee for climate change at the FAO in Rome, which 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 conference being publicized widely within the FAO and subsequently to several of FAO employees attending the meeting.

PROMISE also enabled important links with international scientists working within agriculture to be established through a series of visits. 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 2). 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. In recognition of the quality of PROMISE research, partners have also been invited to participate in the UK-China meeting on food security issues, with participation funded by the UK Government.

Table 2. 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 Philippines)	Rice
Sept. 2002	Royal Meteorological Society Conference on 'Quantitative Precipitation Forecasting'	Poster presented in the impacts session
Sept. 2002	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

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 that this research area presents.

An important issue is the matching of 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 PROMISE website contains detailed reports on each of the visits with suggestions for possible applications of PROMISE research and future direction for further research. Table 3 provides an example of the type of information gathered during these visits.

Table 3: 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 fertilisers 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

6.6 Publications (See Section 2).

The full list of papers in the refereed literature, enabled by PROMISE is provided in Section 2. These can be found on the PROMISE website, as well as Powerpoint presentations and conference posters. A CDROM containing the presentations from the PROMISE Final Conference has also been produced.

In addition, 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.

ANNEX 1

Table of all participants in the PROMISE project

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