WP1000: Final Report

UREADMY

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 1), 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.

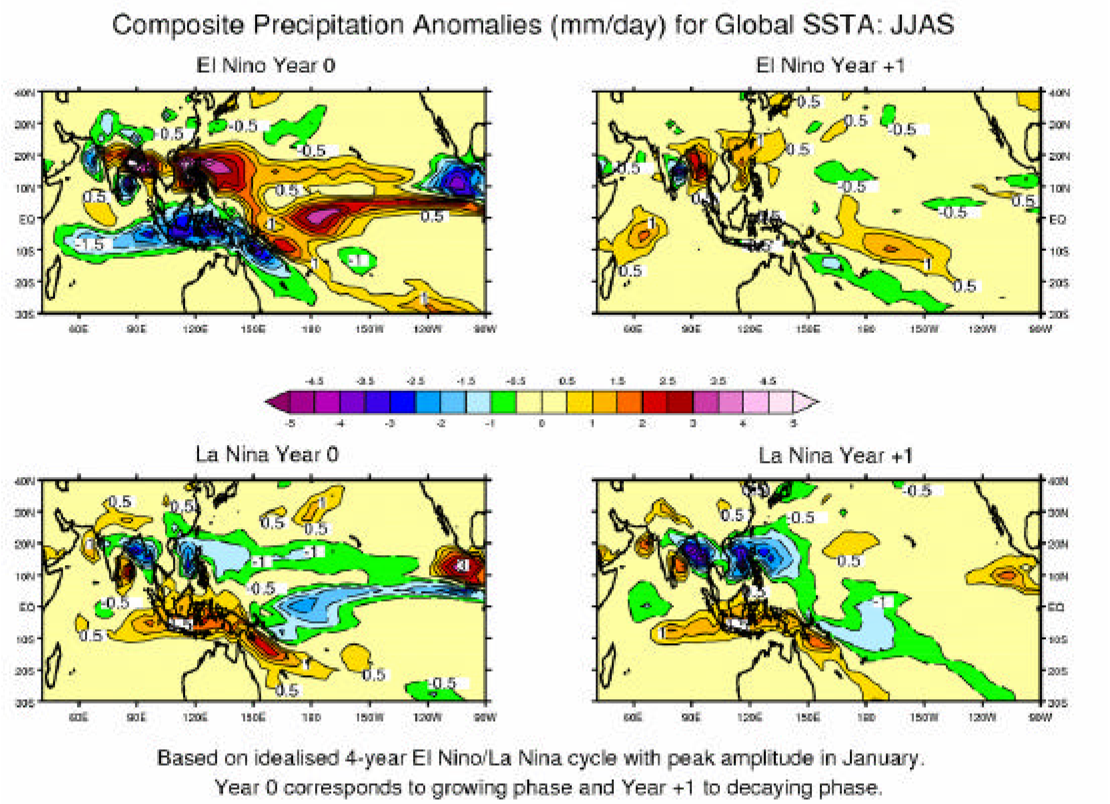

Figure 1: Precipitation anomalies (mm/day) simulated by HadAM3 from multi-decadal integrations with an idealised El Nino/La Nina cycle. Note the invertibility in the patterns for the growing phases of El Nino and La Nina. In the decaying phase of El Nino, in particular, the response is influenced by the warm SST anomalies that develop in the Indian Ocean as a remote response to El Nino forcing.

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.

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 later stages of the work plan for WP1000 with a greater emphasis being placed on vegetation-climate interactions. In collaboration with the Met Office, 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 (Lawrence et al. 2003a, 2003b). The seasonal phenology of vegetation can influence the lower atmosphere through changes in Leaf Area Index (LAI), roughness length, and albedo. Results 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).

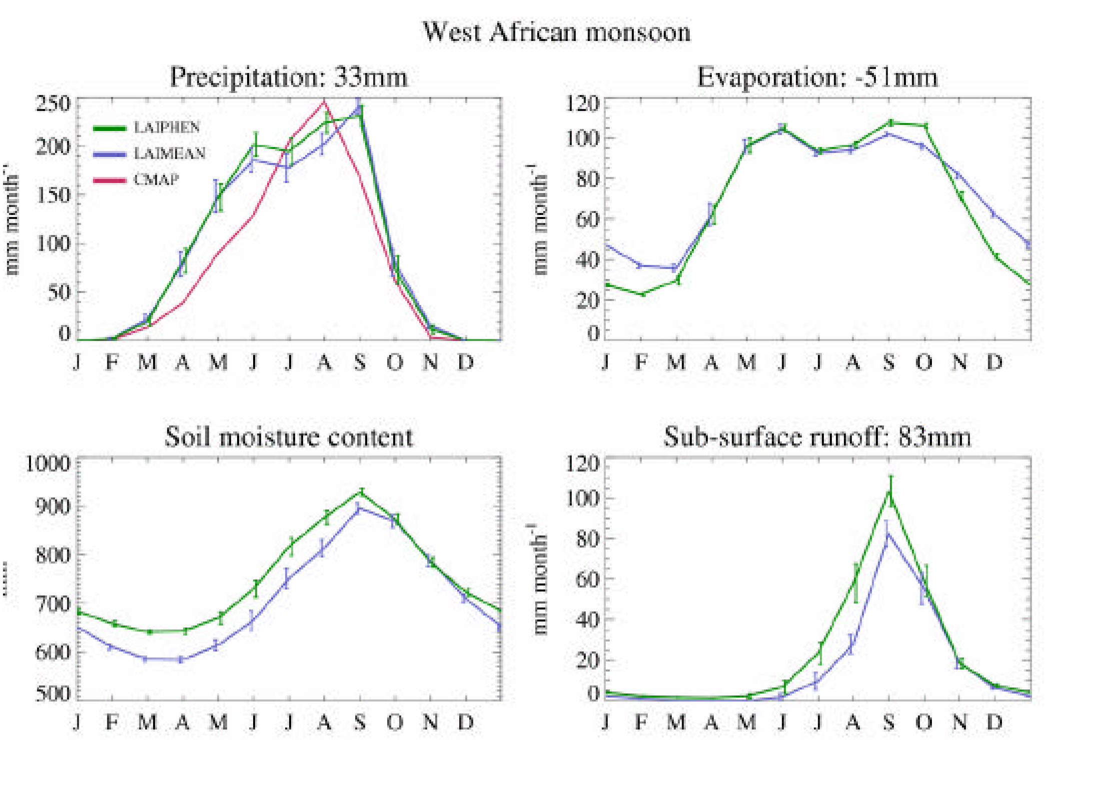

Figure 2: Seasonal cycle in surface variables over West Africa simulated by HadAM3 with mean and seasonally varying vegetation. Note that the onset of the monsoon occurs much earlier than observed.

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). 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.

New statistical methods have been developed for extracting climate signals, particularly changes in seasonality, from timeseries of observed and modelled data. This is based on the recursive linear filtering technique (X11) for decomposing data into the sum of interannual, seasonal and intraseasonal terms. This method has been used to study variations in the seasons and how they are linked, for example, to ENSO.

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Met Office (Gill Martin)

During PROMISE, we have assessed the mean monsoon climate and interannual variability in development versions of the Met Office Unified Model. A new semi-Lagrangian, non-hydrostatic version of the Unified Model called HadGEM is currently under development. 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. We have compared four-member ensembles of atmosphere-only (HadGAM) runs (each differing only in their initial conditions), covering the AMIP-II period (1979-1995) 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, we use a 60-year period from an equilibrium run of HadCM3 and a 30-year test run of HadGEM.

The monsoon climatology in HadGAM improves on HadAM3 in terms of the circulation strength, and in some aspects of the precipitation distribution (see Fig. 1), 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. 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 (Fig. 2). 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.

Work done under WP1200 suggests 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.

Figures

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Fig. 1: Model climatologies of total precipitation (mm/day) averaged between June and September: (a) HadCM3; (b) HadGEM; (c) HadAM3; (d) HadGAM

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other types of printers.

Fig. 2: 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)

Meteo France/ CNRM (Fabrice Chauvin, Hervé Douville and Jean-François Royer)

Objectives

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

Methodology and scientific achievements

MF-CNRM has made available a set of statistical procedures, based on the work of Guérémy and Céron (1999, J of Climate, 12, 2831-2855) designed for the analysis of intraseasonal variability in climate simulations. This task has needed a translation of the original procedures, written in the PV-WAVE language into a package of Unix scripts and FORTRAN 77 programs, so that they can be able to run on a wide range of workstations, and be applied more widely. A graphical output of the results is 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 be put on the PROMISE Internet site for testing by the other participants. Thus the statistical package based on the work of Céron and Guérémy is now available from the PROMISE web page.

The statistical package includes a sequence of spectral techniques, classical and complex empirical orthogonal function (CEOF) analysis. The analysis method is based on the Space-Time Spectral Analysis (STSA) of Hayashi (1977, 1979, 1982) for decomposition of the total spatio-temporal spectrum into stationary and propagating components. It consists in performing first a spectral Fourier decomposition of a spatio-temporal field. Calculation of the quadrature spectrum between real and imaginary parts of the space spectral coefficients gives the squared amplitude of travelling waves, its sign giving the direction of propagation of the waves. It also allows to partition the space-time power spectra into standing and travelling waves. Then, power spectra can be visualised in the spectral domain. Another interest of the method is the possibility to visualise the 2D temporal variance for the different kinds of waves (total, stationary, propagating, progressive and retrogressive waves). Once determined the spatio-temporal window in which the waves of interest occur, the initial raw data can be filtered in the time domain, so as to isolate the phenomena by removing most of the residual energy outside the chosen window, allowing to retain only a selected spatio-temporal window for the subsequent analysis of the propagating components. After this windowing a classical EOF, or its dual, can be applied to retain only the components explaining a large part of the variance. Finally, a complex EOF is performed to separate the amplitude and phase of the eigenvectors. The Complex Empirical Orthogonal Function techniques is be used to decompose the temporal variance into different modes. Complex EOF is a method which allows introduction of a temporal dimension in the classical EOF for studying travelling phenomena. The method consists in transforming the real space-time signal into a complex signal by introducing an imaginary component representative of the time evolution of the space patterns. Then, the variance can be decomposed into different modes, as for a classical EOF, but the modes are no longer associated with only static variability but with dynamic one, taking into account the time evolution of the variability. A complete description of these methods is given in Céron and Guérémy (1999), as well as an application for the study of African Easterly Waves.

As an application of the methods and a contribution to both WP1000 and WP1300 workpackages, 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 (Douville, 2003). 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. Thus, predictability of the AEWs activity has been assessed in the ARPEGE/climat GCM, as well as the influence of soil moisture on this predictability. After a selection of the appropriate space-time spectral window by the STSA method, the raw data was filtered (filter was not included in the statistical package) 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 Guinea 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 Guanine/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 behaviour 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).

Finally a new long-term simulation forced by observed monthly mean SSTs over the period 1950-2000 has been performed with the same version of ARPEGE-Climat which was used for the transient climate scenarios of WP2000. This simulation is being used to validate the simulated interannual variability and teleconnections by comparison with NCEP and ECMWF reanalyses, and for comparison between the forced and coupled climate simulations, in particular the impact of ENSO over the Indian and African monsoons.

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.

Publications

Garric G., H. Douville, M. Déqué, 2002: Prospects for improved seasonal predictions of monsoon precipitation over Sahel. International J Climatol , 22 (3), 331-345.

MPG.IMET (Mojib Latif, Astrid Baquero-Bernal, Reiner Schnur, Erich Röckner)

Our studies focused on two areas: (1) the interannual variability of sea surface temperature (SST) in the tropical Indian ocean and its relationship with monsoon systems and ENSO and (2) the interdecadal variability of Sahelian rainfall.

Several studies suggest that ENSO influences the Indian Ocean and thus the Indian monsoon, while others have proposed 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. This latter mode, referred to as "Dipole Mode" and characterised by SST anomalies of one sign in the southeastern and anomalies of the opposite sign in the western tropical Indian Ocean, has been re-examined in this study using Principal Oscillation Pattern and simple (cross-) correlation analyses. The results show that the Indian Ocean SST exhibits a strong ENSO-related interannual variability which accounts for most of the variance in the Indian Ocean. The study concludes that the dipole mode between the western and eastern Indian Ocean does only exist in the boreal fall season and only as an ENSO response structure. If all seasons are taken into account the ENSO signal in the Indian Ocean is governed by a large-scale monopole. Independently from ENSO, only a weak dipole between the eastern and central Indian Ocean could be identified.

The interdecadal variability of Sahelian rainfall during the last century is dominated by a drying trend in the Sahel since the 1950's and its subsequent recovery since the 1990's. Various mechanisms for these dry conditions in the Sahel have been proposed, mainly interaction with sea surface temperatures and land surface processes. Results from our study on the importance of dynamic vegetation for the realistic simulation of the interdecadal Sahelian rainfall variability during the last five decades using the ECHAM4 general circulation model is contained in the report for WP1300. They show that coupling a simple dynamic vegetation model to ECHAM4 leads to a much better agreement with observations. Results related to the sensitivity of African monsoon climate to SST anomalies are described in WP1200.

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.

LMD (Polytechnique) : Benjamin SULTAN & Serge JANICOT

Our investigation of the West African monsoon dynamics has been done 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.

The monsoon onset

The African monsoon onset has been studied through the recurrent abrupt shift of the ITCZ which has been pointed out in regard to the daily rainfall dataset (from the IRD, Institut de Recherches pour le Développement) for each year between 1968 et 1990. Composite analyses based on the shift dates applied to the NCEP and the ERA-15 reanalysis have shown that this northward shift of the ITCZ is associated with a westward travelling atmospheric circulation pattern in the monsoon layer, persistent up to 600 hPa, at intra-seasonal scale. This work has been presented at the first PROMISE meeting and at the American Meteorological Society for the 24th Conference on Hurricanes and Tropical Meteorology (Janicot and Sultan, 2000). The main results have been published in *GRL* (Sultan and Janicot, 2000).

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*.

Intra-seasonal variability in West Africa

Spectral analysis applied each year to daily Sahelian rainfall indexes have allowed us to highlight some evidence of rainfall fluctuations at intra-seasonal time-scale, between 10 and 60 days, coherent with an intra-seasonal wind field pattern at 925hPa and at 700hPa. This intra-seasonal signal, stronger in the 10-25 days spectral window, associate, during enhanced (weakened) phases in the West African monsoon, a westward propagation of positive (negative) rainfall anomalies with a westward travelling cyclonic (anticyclonic) anomaly over the northern part of the Sahelian region. This work has been recently published in *GRL* (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. 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*.

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.

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Summary

The deliverables of the work package have all been achieved. Because of slower than expected progress with ERA40 the precise details of what has been achieved have not been as originally planned. However, the project has delivered as complete a description as possible of natural variability of monsoons and the present state of the art of numerical simulation given the data available.