Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges

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CLIVAR-Africa

Latest CLIVAR News

- This issue of CLIVAR Exchanges was sponsored by the Canadian Centre for Climate Modelling and Analysis
- The second circular for the CLIVAR Conference available soon. Check out **www.clivar2004.org**
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CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

CLIVAR is a component of the World Climate Research Programme (WCRP).

African Monsoon Multidisciplinary Analysis (AMMA): An International Research Project and Field Campaign

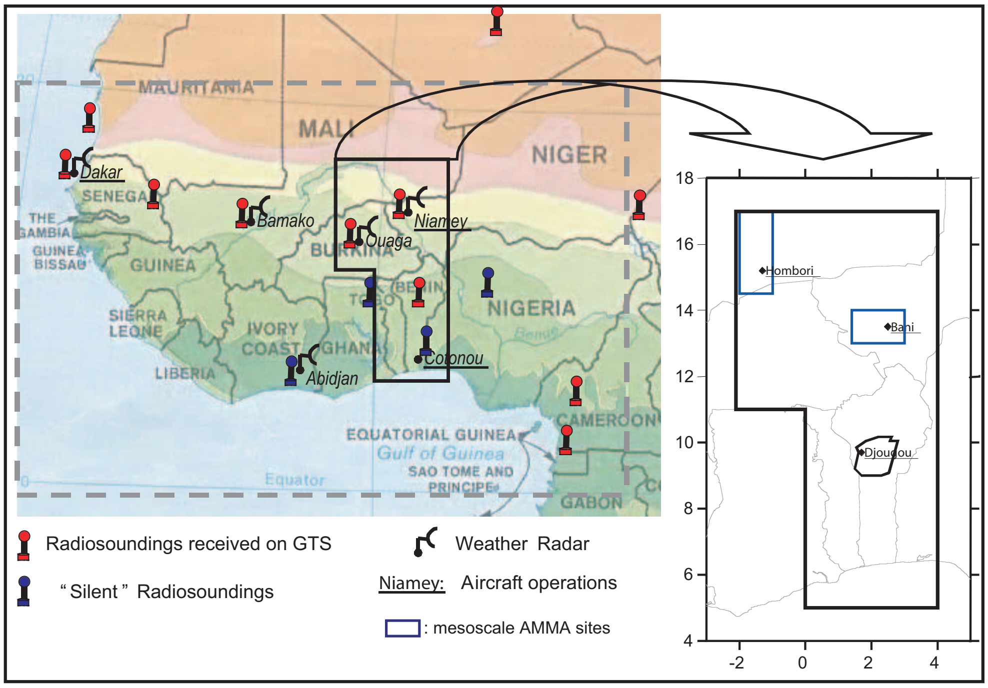

Figure 1 from Lebel et al. (page 52):
The AMMA observing region over West Africa with the location of radiosounding stations (including examples of key stations that need reactivating for AMMA), operational radar and possible airports for aircraft operations. Also indicated in the figure is the region where surface and atmospheric observations will be enhanced along a climatic transect (right), that includes three mesoscale sites that form part of the CATCH hydrological project (http://www.lthe.hmg.inpg.fr/catch).

Call for Contributions

We would like to invite the CLIVAR community to submit papers to CLIVAR Exchanges for the next issue. The overarching topic will be on science related to **Global Modelling.** The deadline for this issue is **October 31, 2003**.

Guidelines for the submission of papers for CLIVAR Exchanges can be found under: http://www.clivar.org/publications/exchanges/guidel.htm

Sponsored by the Canadian Centre for Climate Modelling and Analysis

Editorial

Dear CLIVAR community,

CLIVAR – Africa – When we thought about a research programme for Africa as a component of CLIVAR about 5 years ago, some colleagues had serious doubts that such an endeavour would ever get off the ground. Coordinated climate research in Africa is of course more complicated and much harder to fund than in areas like Europe or the equatorial Pacific. Thus, as we expected, it took a bit more time to pave the way for a climate research programme for Africa, but with the hard work of the initial CLIVAR Africa Task Team and the present VACS (Variability of the African Climate System) Panel and many other interested scientists, the first coordinated projects, like AMMA, are now starting. The development of the CLIVAR Africa component has shown that there is a) need for internationally coordinated climate research for Africa and b) a critical mass of interested scientists to drive this endeavour. These two components are needed to develop concise research plans and exciting proposals in order to convince the funding agencies to support this research.

Climate research in Africa is different to other parts of the world. Not only because of the infrastructure which in most areas is not on the same level as in Europe or North America but also because of a much closer relationship to applications and impacts. Studying rainfall variability in Africa does not only mean seeking for a better understanding of process and phenomena with potential improvement in seasonal forecasts, it also means looking into the impacts of this variability (e.g. food production, water supply, etc). Climate impacts are much more obvious and stronger within Africa than elsewhere in the world. This is also a challenge for a physically driven research programme like CLIVAR which has to cooperate much closer with application programmes, such as START, in this context.

Given the progress that we have seen over the past 5 years, time is clearly ripe for a special issue on CLIVAR Africa in our newsletter Exchanges. The response to call for papers has been overwhelming, with more than 30 scientific contributions submitted, covering a wide range of climate research in Africa. That was a) many more than we expected and b) more than we can handle in a single issue of Exchanges. Thus, we agreed to produce another double issue as we did last year for CLIVAR Atlantic. Nevertheless, even this solution has not enabled us to publish all papers in the printed version of this newsletter. In the selection process for the papers for the printed issue we took a number of criteria into account including topic, quality, length and we also gave preference to papers with African authorship. We tried hard to achieve the best compromise possible. Nevertheless, it is a compromise and we are sorry that we cannot print all of those that were submitted. Those papers not included in the printed version, as well as those which are, can be downloaded from our website. A listing of all articles can be found on pages 63 & 64. Please visit http://www.clivar.org/publications/exchanges/ex27/ex27_cont. htm to download these papers.

As pointed out in the last issue, the increasing interest along with a steadily increasing number of subscribers, means that it requires more and more resources to produce the newsletter. We had to find new sponsors and we are very grateful to our SSG member Dr. Francis Zwiers from CCCma, Canada who kindly offered financial support for Exchanges for this issue. As a consequence, this issue of Exchanges is printed in and distributed from Canada.

Overall, we hope to continue to further develop Exchanges as a lively and integral part of CLIVAR and climate research in general and to maintain the present rate of publication of 4 issues per year.

In about 9 months the First International CLIVAR Conference will take place in Baltimore, USA. The pace of the preparations for the meeting is accelerating. A second circular with call contributions and meetings details will be distributed soon. We are looking forward to a very successful review the first phase of CLIVAR during this meeting which will hopefully be documented and supported through a wide and active participation of our community in that meeting.

In addition, for 2004, a number of important and interesting workshops are currently being planned under the auspices of CLIVAR, such as the CLIVAR WGOMD workshop on 'Evaluating the ocean component of IPCC-class climate models', the CLIVAR Workshop on 'Atlantic Thermohaline Circulation Variability' Kiel, Germany in September and a WGSIP/WGNE/WGCM Workshop on Ensemble Methods, in Exeter, UK in October. Visit the CLIVAR Website for more details about these interesting meetings and make them a success through your active participation.

Andreas Villwock and Howard Cattle

The annual review of CLIVAR by the SSG

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Over the course of the past 12 months, CLIVAR has made significant strides towards meeting its near-term implementation objectives as the largest and most encompassing project within the World Climate Research Programme (WCRP). From May 5-9, 2003 the CLIVAR Scientific Steering Group (SSG) was hosted by Dr. Francis Zwiers in Victoria, Canada. The SSG used this opportunity to take stock of the status of CLIVAR going into next year's first International CLIVAR Science Conference "Understanding and Predicting Our Climate System" to be held in Baltimore, USA from June 21-25, 2004 (see http://www.clivar2004.org/ for details).

As the CLIVAR panels and working groups grow in maturity, links and common activities between them are emerging. This is particularly noticeable in terms of observational activities, but is also reflected in continual progress in modelling of the coupled climate system. A considerable amount of the discussion at the SSG was devoted to the best means to scale up from, and bring together, the various components of the programme in the context of a global synthesis. The SSG also considered means of enhancing the applications aspect of CLIVAR's climate research.

A key component of the strategy for a global synthesis is the reanalysis of past observations into global fields. Atmospheric reanalyses, such as ERA40, are, of course, well established. The resulting gridded products have proved to be a key tool for CLIVAR empirical, diagnostic and modelling studies on global and regional scales. However the need is not only for atmospheric reanalyses, but also for ocean reanalyses, high resolution land surface reanalyses and reanalyses using coupled systems. As a matter of high priority, CLIVAR is seeking to promote and develop wider activity on ocean reanalyses or synthesis in support of ocean climate problems as a complement to the Global Ocean Data Assimilation Experiment. Establishment by CLIVAR of a global re-analysis data base of ocean observations will be a key to any ocean reanalysis activity.

The implementation of ocean observational systems in support of CLIVAR research continues to progress. In recent years, an unprecedented number of satellites with ocean observing missions have been launched, e.g. Jason (radar altimetry), ENVISAT (altimetry, ocean colour, radiometry), and others. New missions with ocean relevance have also been selected, e.g. GOCE (geoid and gravity measurements) and Aquarius (sea surface salinity). *In situ* networks have been making progress, most notably Argo (with more than 620 floats operating - see http://argo.ucsd.edu/) The first Argo science workshop will be held in November 2003 to review scientific and operational use of the data. The TAO/TRITON array in the Pacific continues to underpin much of CLIVAR research on ENSO and related variability in the tropical Pacific. The data are widely used: some 43 refereed publications in 2002 used TAO/TRITON data. The existence of TAO/TRITON has also made possible programmes such as PACS/EPIC (http://tao.atmos.washington.edu/pacs/) and other studies. PIRATA, the Atlantic complement of the TAO/TRITON array has a growing user community. Vandalism continues to be a problem in the Atlantic. For the future, the SSG agreed that the CLIVAR Ocean Observations Panel (COOP) will be reconstituted with a focus on global ocean data synthesis/reanalysis, air-sea fluxes, and broad-scale ocean observations, while leaving observing system implementation issues pertaining to sustained observations to OOPC, JCOMM, etc.

Among the CLIVAR basin panels, the greatest progress to date has been in the Atlantic. CLIVAR implementation in the Atlantic sector, under the leadership of Martin Visbeck focuses primarily on issues of tropical Atlantic variability, the meridional overturning circulation and basin-wide implementation of sustained observations. A new key activity is the encouragement of sustained observations in the South Atlantic. A summary of the implementation activities of CLIVAR in the Atlantic can be found at http://www.clivar.org/organization/atlantic/IMPL/index.htm. and in the report of the most recent panel meeting on page 59.

Implementation in the Pacific has lagged the Atlantic. Two events have dominated the Pacific sector in 2002. The first is the 2002/03 ENSO event, early indications of which were picked up by routine observations. The second is a continuation since 1998/99 of anomalously high SSTs in the central and eastern subtropical gyre and cooler waters along the North American seaboard. Though the field phase of EPIC has come to an end, VEPIC, a VAMOS extension of EPIC is under consideration and the Kuroshio Extension System Study (KESS – http://www.po.gso.uri.edu/kess/) has now been granted funding. A progress report for the Pacific panel will be published in the next issue of Exchanges.

The Southern Ocean (SO) panel under the direction of Steve Rintoul and Eberhard Fahrbach held its first meeting in March 2002 in Hobart, Tasmania. The observational strategy for the Southern Ocean builds largely on the Argo programme which is the only method for repeated in situ measurements in this remote region. A new initiative (GOODHOPE) aims to cover the important "choke point" section south of Africa, which is something of a gap (see ftp://ftp.soc.soton.ac.uk/pub/woceipo/SO/goodhope0303.pdf for more details).

Turning to the CLIVAR monsoon panels, the Variability of the American Monsoon System (VAMOS) Panel continues to make excellent progress. VAMOS is made up of a number of projects, the North American Monsoon Experiment (NAME), the Monsoon Experiment in South America (MESA), VEPIC and a project study on the South American Low Level Jet Experiment (SALLJEX). Each of these has reached a different state of implementation under the overall guidance of Roberto Mechoso. A key achievement this past year has been the realisation of SALLJEX which was focused on the moisture corridor east of the Andes. More details can be found in the report from the most recent VAMOS panel meeting (page 61).

The most recent meeting of the Asian-Australian Monsoon Panel (AAMP) took place in Atlanta February 25-27, 2003, chaired by Julia Slingo and Peter Webster. Important progress has been made in the planning of the joint GEWEX/CLIVAR CEOP Inter-monsoon Model Study (CIMS)(http://monsoon.t.u-tokyo.ac.jp/ceop/overview1.html). The AAMP also considered advances in monsoon modelling studies, especially intra-seasonal variability, in order to better understand and predict the monsoon. The Asian-Australian sector is one of the domains within CLIVAR with obvious links into applications studies. The Climate Forecasting Applications in Bangladesh (CFAB), which Peter Webster helped to set up, and which aims to make forecasts available within Bangladesh, is one possible avenue. An AAMP proposal for the formation of an Indian Ocean Panel for CLIVAR received strong support from the CLIVAR SSG. They recommended it be set up jointly with IOC in the framework of the recently established IOGOOS.

Within the Variability of the African Climate System (VACS) Panel, considerable energy has been devoted by the chair Chris Thorncroft to continue the development of the African Monsoon Multidisciplinary Analysis (AMMA) project (see page 52), which is clearly viewed by its participants as a joint CLIVAR-GEWEX project. Another project is the production of an Atlas of African Climate Variability to stimulate and promote research activity on this topic. It will achieve this by providing global and regional diagnostics along with text that highlights key scientific issues.

The CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP) has initiated a number of important projects to assess the present capabilities of modelling systems used for seasonal prediction. Among others, progress has been made with the Seasonal Prediction Model Intercomparison Project (SMIP-2) (http://www-pcmdi.llnl.gov/smip/), and the new model experimentation and output standards experiment. In response to a request from the CLIVAR SSG, WGSIP developed a new definition a continuous numerical oceanic El Niño index (OENX) based on the NIÑO 3.4 index. It is intended to characterize the state of the tropical Pacific as it relates to ENSO, but avoids categories and does not attempt to directly imply local and remote climatic impacts.

Modelling of the global climate system lies at the heart of CLIVAR activities. While the work of WGSIP encompasses CLIVAR's work on short time-scales, modelling efforts on longer time-scales are coordinated through the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) chaired by John Mitchell. Of particular interest to CLIVAR is the ability of coupled GCMs to reproduce the climate's natural variability as well as the coupled system's response to anthropogenic influences. Amongst WGCM's activities, the Coupled Model Intercomparison Project (CMIP) is one of the most important and long-standing initiatives. A CMIP Workshop is planned back to back to the WGCM/GAIM Conference on Earth System Modelling in Hamburg, September 22 – 23, 2003 to review the past CMIP phase and to coordinate future activities for the next assessment report of IPCC. In addition, WGCM has endorsed a proposal for systematic intercomparison of cloud feedbacks in climate models and has also recommended initiation of a pilot project on Coupled Model Climate of the 20th Century experiments, to be announced through CMIP.

The Working Group on Ocean Model Development (WGOMD) chaired by Claus Böning has now, after the end of WOCE become a joint WGCM/CLIVAR activity. WGOMD has established a Pilot Ocean Model Intercomparison Project (P-OMIP). During a workshop planned for March 2004, WGOMD will review the pilot phase of OMIP and assess the state of ocean models used in the next IPCC assessment. More details can be found in the summary of the last WGOMD meeting on page 57.

A major task still facing CLIVAR is the definition of an appropriate data structure that is capable of delivering ocean and atmospheric data and products to CLIVAR researchers in a timely and simple manner. Given the wide range of CLIVAR and CLIVAR–relevant datasets and the existing range of data archiving systems and procedures the decision as to what is, and what is not, relevant to CLIVAR is problematic. The key issue here is to identify the relevant data centres which act or are willing to act as the repository for

CLIVAR data and to provide a data management and information interface between the range of data centres and users.

Planning is well underway for the first International CLIVAR Conference, June 21-25, 2004 in Baltimore, USA: Subsequent announcements about the conference will be available at http://www.clivar2004.org/. As this science conference will be five and a half years after the international CLIVAR "Commitments" Conference held in Paris during December of 1998, it will serve as an opportune basis for assessing progress to date within the programme. Since CLIVAR was designed and approved at the outset to be a 15 year programme, the SSG discussed making the year 2013 the sunset date for the programme. This recommendation will be forwarded for consideration at the next meeting of the WCRP Joint Scientific Committee.

☞ **A more detailed report can be found under under:**
http://www.clivar.org/publications/exchanges/ex27/pdf_files/s27_ssg.pdf

Variability of the African Climate System (VACS): A CLIVAR-Panel for Africa / An Africa-Panel for CLIVAR

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1. Background

The VACS panel is concerned with implementation of CLIVAR in the African region. A major goal of the panel is to recommend and facilitate a sustained observing network that will support research and prediction of the African climate system and its impacts. This must be achieved through international collaboration between scientists doing basic research and prediction along with focused field programmes aimed at improving our understanding of the African climate.

Many regions of Africa experience marked interannual-to-decadal variability of seasonal rainfall often resulting in devastating impacts on local populations, ecosystems and economies. Intraseasonal variability is also of vital importance, since agricultural systems can be enhanced and optimized with reliable information about growing season length and monsoon onset times. The prospect of improving our fundamental understanding of African rainfall systems, with the goal of improving our ability to predict climate variability, is a strong motivating factor for VACS.

From a larger-scale perspective, it is important to understand the role of Africa within the global climate. For example, Africa provides a major heat source for the atmosphere that can have significant remote impacts. The relationship between West African rainfall and Atlantic tropical cyclones is well known example of such an impact (e.g. Landsea and Gray, 1992). North Africa is also the world's major source of mineral dust aerosol. In general though, the role of Africa in the global context has received little attention and the need for more research in this area is a further strong motivating factor for VACS.

The CLIVAR-Africa Implementation Plan (ICPO, 2000), working from the CLIVAR Africa report (ICPO, 1999), recognizes the strong need to promote basic research of the African climate system including more evaluation of models used for climate prediction. It focuses on answering the following broad questions:

I. What are the causes of African climate variability and how is this related to other parts of the globe?

II. How well do current dynamical models simulate African climate variability and its relationship with the global climate?

III. Which deficiencies do dynamical models have that can account for known inadequacies in the simulation of African climate variability and its relationship with the global climate?

Answering these questions will require a combination of diagnostic, modeling and process studies including regional field campaigns. The Implementation Plan emphasizes the need to address these questions on different interacting timescales. These are (i) the annual cycle, (ii) interannual variability, (iii) intraseasonal variability (including synoptic and mesoscale weather systems) and (iv) decadal variability. The Implementation Plan discusses the key research issues and datasets available for investigating these different timescales.

In promoting research projects, VACS recognizes the substantial impacts that African climate variability has on food security, water resources and health. It is therefore important to ensure strong linkages between the research on climate variability and these impacts. Several papers in this issue reflect this need.

Finally, VACS recognizes the importance of building the capacity of the continent. VACS will contribute to this by establishing and promoting workshops that have a training

The VACS panel and guests at its 3rd meeting at the University of Cape Town, South Africa, January 2003.

component and by encouraging and establishing strong research links with African scientists. Also, the AMMA project (see page 52 and below) in West Africa is being developed in partnership with African scientists and has a capacity building component.

Motivated by strong societal needs for improved predictions of African climate variability, the VACS panel will continue to encourage and develop projects that will contribute to this. Research efforts will also be promoted to provide a continuous update on the characterization of the continental and regional climate variability needed to support assessments of climate change and its impacts. More detailed information about VACS-activities including the Implementation Plan, current membership, contact details and the status of current projects can be obtained from the VACS web-pages (http://www.clivar.org/organization/africa/vacs.htm).

2. VACS Activities

Since the establishment of the panel in 2000, VACS has had meetings every January. These have taken place in Nairobi (2001), Niamey (2002) (immediately following an international AMMA workshop (see below)) and Cape Town (2003) (see photo). VACS is currently promoting and developing several projects to support the implementation of CLIVAR in Africa and these are discussed briefly in the summary of the Cape Town meeting in this issue (page 56).

One project in particular that has gained considerable momentum in the last 12 months is the African Monsoon Multidisciplinary Analysis (AMMA) project. This project is discussed in more detail on page 52. One early success of the AMMA project is the establishment of an international community of collaborators that includes a substantial contribution from Africa. For example, the AMMA workshop held in Niamey in 2001 was attended by 44 African scientists from 9 countries and led to the creation of a network of African scientists coordinating efforts to contribute to AMMA (see the article on AMMANET on page 55). Although the AMMA project is focused on the West African monsoon it is hoped that its approach and lessons learned from establishing the project will be helpful for establishing similar collaborative research projects in other regions of the African continent.

One area of research that is emphasized in the AMMA project and is relevant to other regions is the annual cycle. Study of the annual cycle of rainfall and associated regional circulations provides us with a test of our understanding of the coupled atmosphere-land-ocean system and of the ability of dynamical models to simulate it. As indicated in the following discussion of the annual cycle of the West African monsoon we have yet to pass this test.

3. Annual Cycle of the West African Monsoon

The annual cycle of rainfall in the West African region is characterized by a poleward migration of peak rainfall up to about August followed by a more rapid retreat (see Fig. 2 on page 30 and Fig. 1 on page 11). It also includes an apparent "jump" in the location of peak rainfall at the end of June from the coastal region around 5°N to about 10°N (Sultan and Janicot, 2000; Le Barbé et al., 2002). As shown in the CLIVAR-Africa Implementation Plan (2000), state-of-the-art GCMs used for climate prediction have difficulty simulating the annual cycle of rainfall and associated regional circulations. This raises serious concerns about whether these models can realistically represent the key interactions between the WAM and the rest of the globe that are important for determining interannual-to-decadal variability of West African and regional climates. It is fundamentally important that we improve our understanding of the annual cycle of West African rainfall and the associated regional circulations including in particular the processes that influence rainfall intensity, its meridional migration, onset, the apparent "jump" and rapid retreat.

Mechanisms have been proposed to explain various aspects of monsoons and their evolution and need to be investigated in the context of the WAM. These include the role of changes in boundary layer equivalent potential temperature gradients and inertial instability on the establishment of direct circulations and the location of rainfall (e.g. Emanuel, 1995; Zheng et al., 1999; Tomas and Webster, 1997), the role of dry intrusions from higher latitudes on the associated intensity and meridional extent of the rainfall (e.g. Parsons et al., 2000; Chou et al., 2001), the role of surface processes including soil moisture and vegetation feedbacks and atmosphere-ocean interactions (e.g. Taylor and Lebel, 1998; Chou et al., 2001, Zheng et al., 1999) and the role of remotely forced circulations including those associated with the Asian Monsoon (e.g. Rodwell and Hoskins, 1996).

Central to any investigation of these mechanisms are the annually varying surface conditions over the continent and ocean. Over the continent we rely heavily on remote sensing and off-line models to give us an analysis of the land-surface conditions based on indirect observations through projects such as GLDAS (http://ldas.gsfc.nasa.gov/GLDAS/docs/GLDASoverview.shtml). There is a need for more *in situ* data for evaluation of these products over the African continent and more investigation of the coupled processes that determine them and their impact on the WAM. Over the ocean there are still gaps in our understanding of processes that determine the annual cycle of SSTs in the tropical Atlantic and their interactions with the WAM. The evolution of the SSTs in the Gulf of Guinea (see paper by Bourles, page 15) and in particular the evolution of the cold tongue are particularly important in this regard (e.g. Grodsky and Carton, 2003).

The nature of the interactions between surface conditions and the atmosphere must be investigated through an analysis of surface energy and water budgets, atmospheric convection (moist and dry) and radiation. The associated regional circulations and jets need to be analysed, including their impact on transport of water vapour and their role in influencing the weather systems.

The AMMA project seeks to coordinate observations of the coupled atmosphere-land-ocean system that will allow us to improve our understanding of the WAM and investigate the scientific issues raised above. This will take advantage of the long-term observations already in place over the land through the CATCH project (http://www.lthe.hmg.inpg.fr/catch) and in the tropical Atlantic through PIRATA, ARGO and XBTs (see http://www.clivar.org/organization/atlantic/IMPL/index.htm).

4. Final comments and introduction to the special issue

Although major challenges still exist, through the AMMA project in particular we are making steady progress towards implementation of CLIVAR in West Africa. It needs to be made clear that VACS is also making efforts to implement CLIVAR in other regions of the African continent. In this regard, a project concerned with East African climate variability including the contrasting roles of the Indian Ocean and regional lakes is in its early stages of development.

This special issue of Exchanges illustrates the considerable interest in African climate variability and the wide-ranging studies that are currently taking place. The papers highlight the multiple interacting timescales that characterize climate in different regions of the continent. Along with this, another common message that these articles illustrate is the need to highlight the relative roles of ENSO and regional oceans on African climate variability and, as discussed above, the land surface conditions. Several articles are included that are concerned with the impacts of African climate variability - a reminder of the strong societal motivation for VACS-research.

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North African dust production: Source areas and variability

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Introduction

Mineral dust has an important impact on the earth's climate system, influencing chemical processes (Schwartz et al., 1995) and modifying heating by direct radiative effects of scattering and absorption (Tegen et al., 1996) and through indirect radiative effects via their influence on cloud microphysics (Rosenfeld, 1999). The total radiative forcing of dust remains a large uncertainty in the prediction of future climate.

The primacy of the Sahara as the planet's largest source of mineral dust has long been known as is well illustrated by the annual mean TOMS Aerosol Index (AI) values (Figure 1). A large component of this dust is transported over the oceans, some reaching the Caribbean and the USA. As such, dust is one of the crucial components by which Africa influences the global climate system.

In this paper we investigate the source regions of North African dust and relate these sources to features of the circulation. We focus on the Bodélé Depression in Chad, the world's single most productive source region, offering a circulation based explanation for its productivity before going on to examine dust transport via a fourth order trajectory model driven by 3 dimensional reanalysis winds for two extreme years of dust output.

North African Dust Sources

Sources of North African dust have, until recently, been determined from surface meteorological observations of current weather codes and visibility. Since observing stations are often remote from dust sources, a full picture of dust generation and distribution has been elusive. The release of the satellite based TOMS AI data over the period 1979-1993 (Herman et al., 1997), while featuring new problems relating to the retrieval process, has helped to fill gaps in previously data sparse areas. Using the TOMS AI data, Washington et al. (2003) have used eigenvector based techniques on the covariance matrix of monthly AI anomalies to determine objectively key North African source regions. These turn out to be 1) The Bodélé Depression in Chad, 2) the Djouf region spanning the northern border of Mali and Mauritania, 3) the Chotts of eastern Algeria and Tunisia and 4) a broad region of central Libya.

The Bodélé Depression is the world's single largest source. Emissions peak in the March to May period and reach a minimum (consistent with North African dust output as a whole) during October to December. The Djouf region peaks between June and August. The importance of palaeo lakes as modern dust sources has been stressed elsewhere (e.g. Prospero et al., 2002; Washington et al., 2003). Such regions are supply unlimited because of the rich deposits of fine materials, in the case of the Sahara dating to the humid period of the mid Holocene. The Bodélé Depression

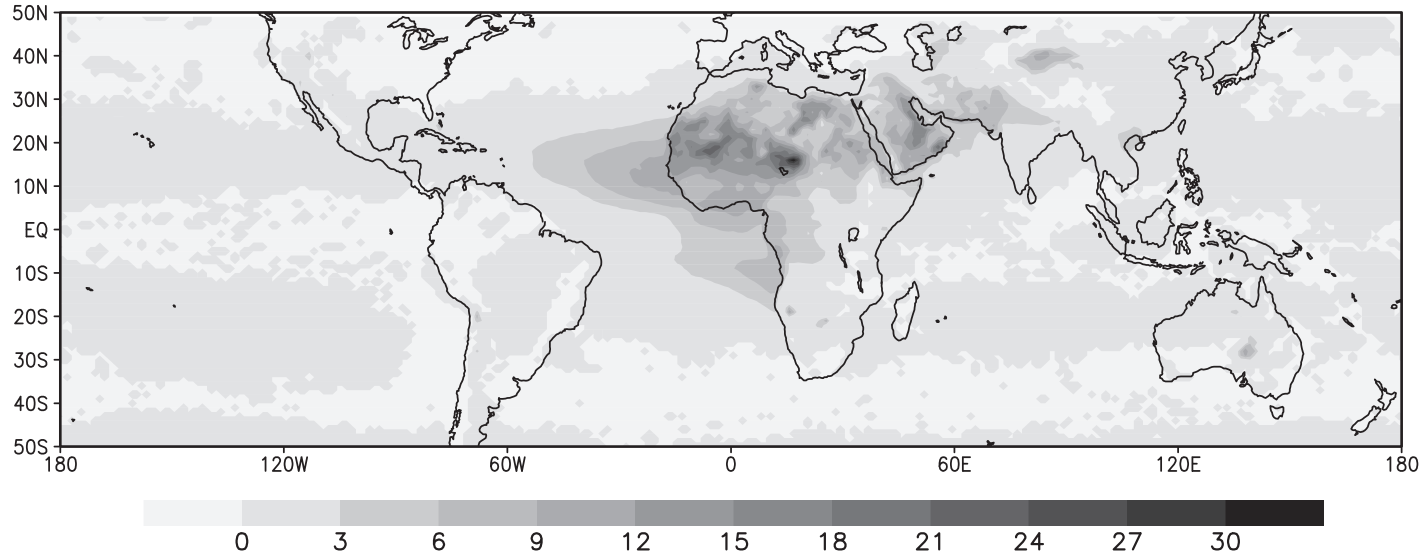

Fig. 1: World map of annual mean Aerosol Index (AI) values (x 10) determined by TOMS.

seems unique in the combination of unlimited sediment and the near surface circulation. Using 6 hourly surface wind data from the NCEP/NCAR reanalysis project, potential sand flux

$$q = 2.61\, U_*^3\, p g^{-1}\, (1-U_{*t}/U_*)(1+U_{*t}/U_*)^2$$

(where, q = potential sand flux, g = acceleration due to gravity, *p* = fluid density and U_{*t}=threshold shear stress and U_* = surface shear velocity given) was calculated for the world's land areas. In the case of the Bodélé Depression, the coincidence of the peak dust emissions, the maximum in potential sand flux and the minimum in topography is remarkable (Figure 2). The coincidence of these fields in North Africa occurs only in the Bodélé Depression.

The large scale structure of the wind in the Sahel and central Sahara, although complicated, is reasonably well described (Burpee, 1972; Cook, 1999). The African Easterly Jet (AEJ) is a prominent feature of the wind with a width of 5 to 10 degrees in most data sets and a jet core near 10°N on the west coast of Africa. Figure 3 shows a latitude-height section along 22°E of the long term mean of the zonal wind for May from the NCEP/NCAR data. The core of the AEJ is

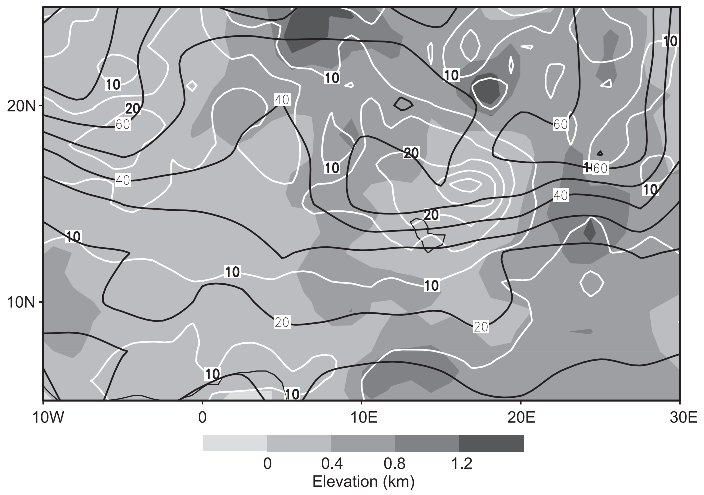

Fig. 2: TOMS AI values (white contours), potential sand flux (black contours) and elevation (shading) in km for the Sahara, long term means, April-June.

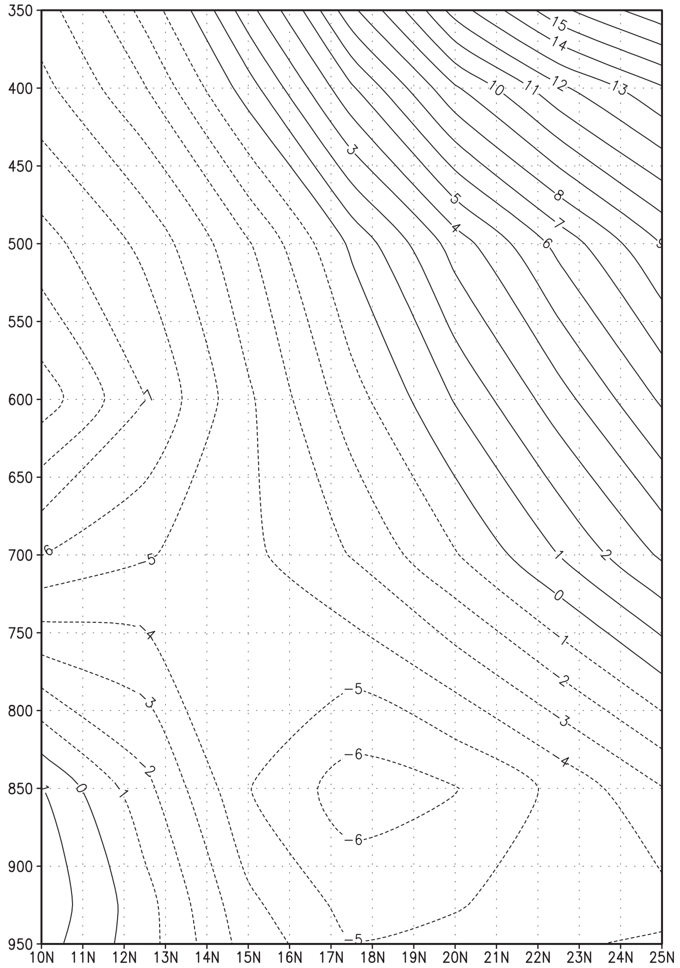

Fig. 3: Latitude-height section along 22°E of the long term mean of the zonal wind (m/s) for May from the NCEP/NCAR data.

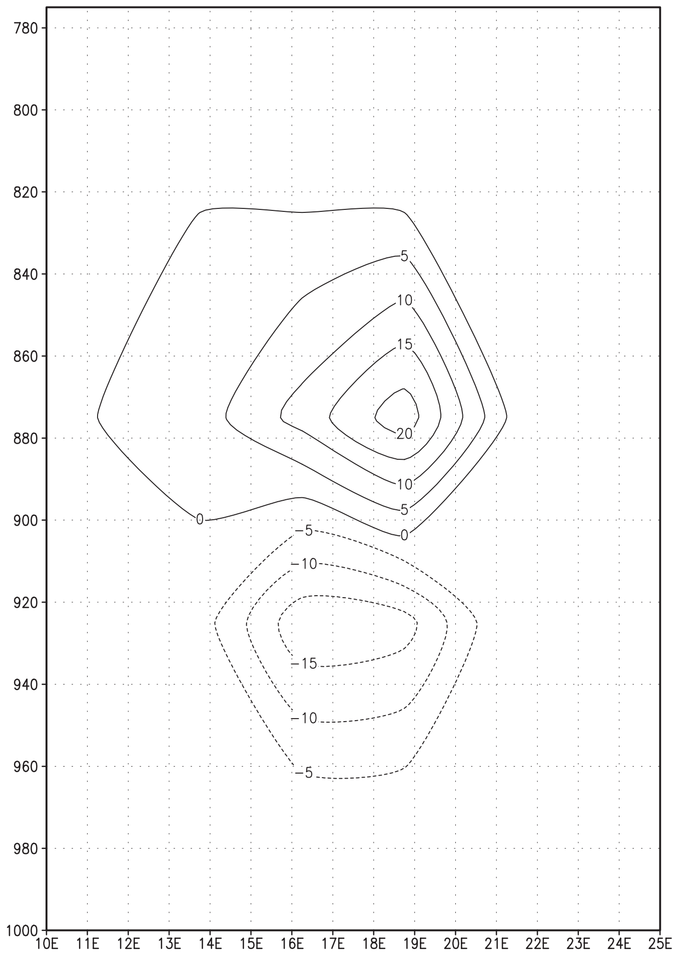

Fig. 4: Longitude-height section of trajectory densities differences between May 1991 and May 1989 at 12 hours following release from the Bodélé Depression. The section is averaged between 10°N and 27° N.

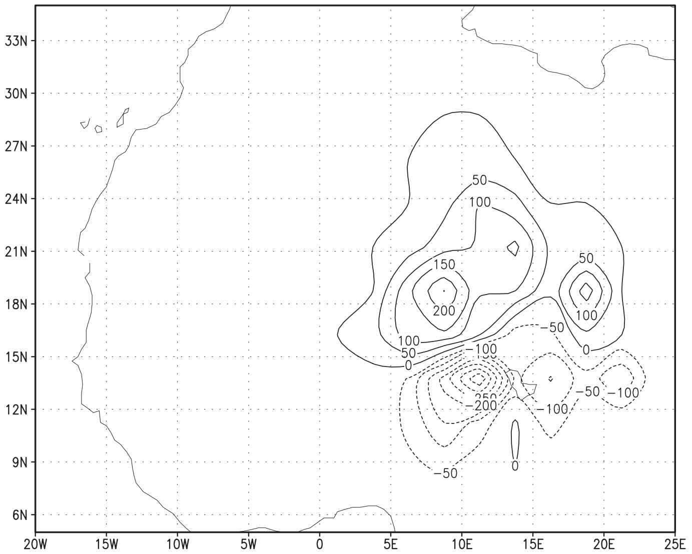

Fig. 5: Trajectory density differences between May 1991 and May 1989 at 48 hours following release from the Bodélé Depression.

clearly evident near 600 hPa, but at this longitude, a secondary maximum extends from 16 to 22^{o}N at a height of 900 hPa. A similar maximum is evident in the meridional wind profile (not shown). This region corresponds to the entry point of low level winds into the extended Bodélé Depression where the zonal wind is concentrated to the south of the Tibesti Mountains and to the north of the Enedi Massif. It is remarkable that the coarse resolution data set captures this channelling so well.

Variability of Dust Emissions and the Atmospheric Circulation

Over the period of the TOMS record, the time series of TOMS AI anomalies reach a peak in May 1991 and a minimum in May 1989. The TOMS record agrees well with surface based met records from Bilma (18.6^{o}N, 12.9^{o}E, in Niger) which is downwind of the Bodélé Depression. Bilma recorded a record 14 sand storms during May 1991 compared with 3 in May 1989. Together, these time series offer a convenient opportunity to study the difference in the circulation for these two months.

During May 1991, the topographically confined low level jet maximum (identified in Figure 3) at the entrance to the Bodélé Depression was accelerated and the vertical velocity profiles showed considerably more ascent in a broad band across the southern edge of the Sahara. In order to quantify the likely effect on dust emissions, we ran a fourth-order, three dimensional trajectory model initialised by 6 hourly NCEP/NCAR winds for the period 1979 to 1990. Trajectories in packets of 20 were released from the Bodélé Depression with the position calculated at 15 minute intervals. We show the difference in the trajectory densities for May 1991 and May 1989 at 12 hours following release in Figure 4. Enhanced convection has led to a higher density of trajectories at 870 hPa in May 1991 whereas in May 1989 trajectories remained much closer to the surface. Two days following release, the trajectories in May 1991 were transported westwards near 20^{o}N, while in May 1989, southward transport in the low level winds led to a clearer atmosphere over the Sahara. (Figure 5).

Summary

Dust is an important unknown in the climate system. North Africa is the leading source of global dust emissions and within North Africa, the Bodélé Depression is the world's single largest source of dust. This is a major example of the way in which African climate influences the global climate system. Understanding the circulation mechanisms which generate dust is clearly important for reducing uncertainty in climate change predictions.

We have shown that the Bodélé Depression is characterised by a remarkable co-location of maximum near surface wind transport potential, a minimum in topography and a maximum in the TOMS AI loadings. Variability of the dust output is also subject to large scale adjustments to the low level winds and convective environment suggesting that dust sources may be represented with the current available resolutions in GCMs.

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Seasonal rainfall variability within the West African Monsoon system

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Introduction

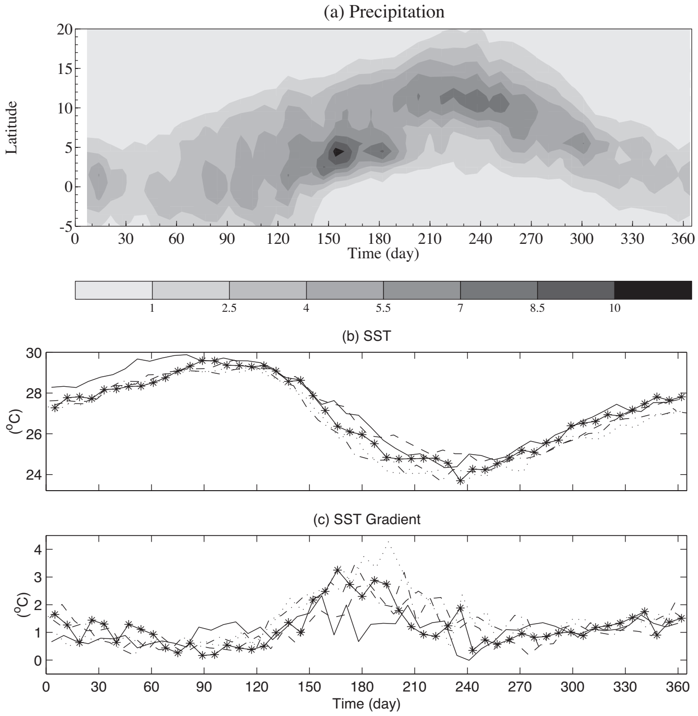
A marked seasonal cycle exists in both the surface rainfall and the large-scale environment over West Africa (Nicholson and Grist, 2003). Major intense rainfall events appear in the Gulf of Guinea from April, move to the latitudes of about 10°N during the boreal summer, and then retreat back south after mid-September-October, manifesting the seasonal march of the ITCZ. Time-latitude diagrams of mean rainfall indicate that this seasonal migration is characterized surprisingly by an abrupt shift of major rain zone during June-July (Figs. 1a and 3a; e.g., Sultan and Janicot, 2000).

A detailed examination of surface rainfall on the weekly time scale shows that the abrupt shift or "jump" of major rain belts is actually a manifestation of the onset of intense convection and rainfall along 10°N and a simultaneous, sudden termination of intense convection and rainfall near the Gulf of Guinea (5°N) during the time period June-July (Fig. 1a). This seems to suggest that two different processes are active near the latitudes of 5°N and 10°N, respectively, and the peak rainfall seasons favoured by these two processes are different due to different seasonal evolutions in the large-scale environment (Lebel et al., 2003). In this study, a detailed description of seasonal variations of various variables within the West African Monsoon system are provided by means of currently available, high-quality TRMM satellite observations (Adler et al., 2000). The study is concentrated on the variability in surface rainfall, sea surface temperature (SST) in the tropical eastern Atlantic, and large-scale circulation patterns, e.g., the African easterly jet (AEJ) tropical easterly jet (TEJ), etc. Based on these observational evidences, we argue that seasonal variations in surface rainfall near the Gulf of Guinea, where the rainfall peaks during May-June, are primarily modulated by seasonal forcing from the ocean; In contrast, rainfall and variability within the interior West Africa primarily result from the interactions among various dynamic components.

Sea Surface Variations

Weekly products from the TRMM satellite are applied to examine seasonal cycles in various variables and their relationships in the Gulf of Guinea (Figs. 1 and 2). The SST forcing is evident (Figs. 1a and b). Higher (lower) SST generally corresponds to more (less) rainfall. Intense rainfall is observed at two different seasons and two different regions (Fig. 1a). A sharp reduction of rainfall south of 5°N occurs at the day 190-200 period (Mid-July), resulting from the cold SST damping. Warmer SST generally corresponds to the rainfall events south of 5°N within the Gulf of Guinea before day 190. However, a lag-phase (about one month) is evident between the maximum rainfall and warmest SST. It is also interesting to note that the most intense rainfall zone in the region actually comes with the appearance of strong meridional SST gradients (Fig. 1c), despite that the mean SST has to be above a certain threshold (at least 26°C) (Fig. 1b). This suggests the importance of both direct SST forcing and its related dynamic (gradient) forcing in organizing surface convergence, tropical convection and rainfall, generally consistent with previous studies (Lindzen and Nigam, 1987).

Weekly surface wind components from the QuickScat satellite (Liu, 2002) averaged in the tropical eastern Atlantic are shown in Fig. 2. Surface wind changes direction from southwesterly to southeasterly around day 120. Particularly,


(a) Precipitation

(b) SST

(c) SST Gradient

Fig. 1: Seasonal cycles in (a) weekly rainfall (mm day^{-1}) between 9.5°W-9.5°E, (b) weekly SST from TRMM Microwave Imager (TMI) [°C; 4.125°S - 4.125°N, 10.125°W - 5.125°E], and (c) weekly TMI SST differences between 2.125°N and 0.125°S, averaged along 10.125°W - 5.125°E. In (b) and (c), solid lines are for 1998, dashed line for 1999, dashdot lines for 2000, dotted lines for 2001, and star lines for 2002.

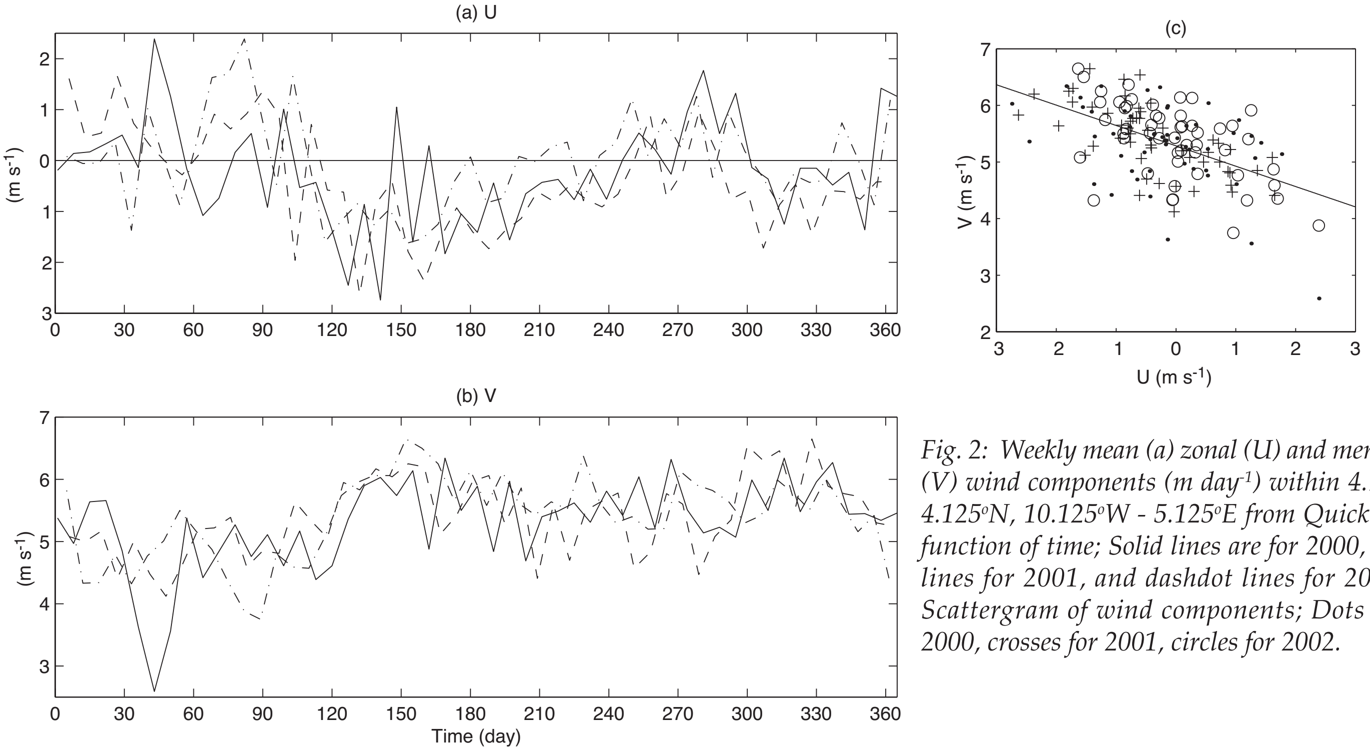
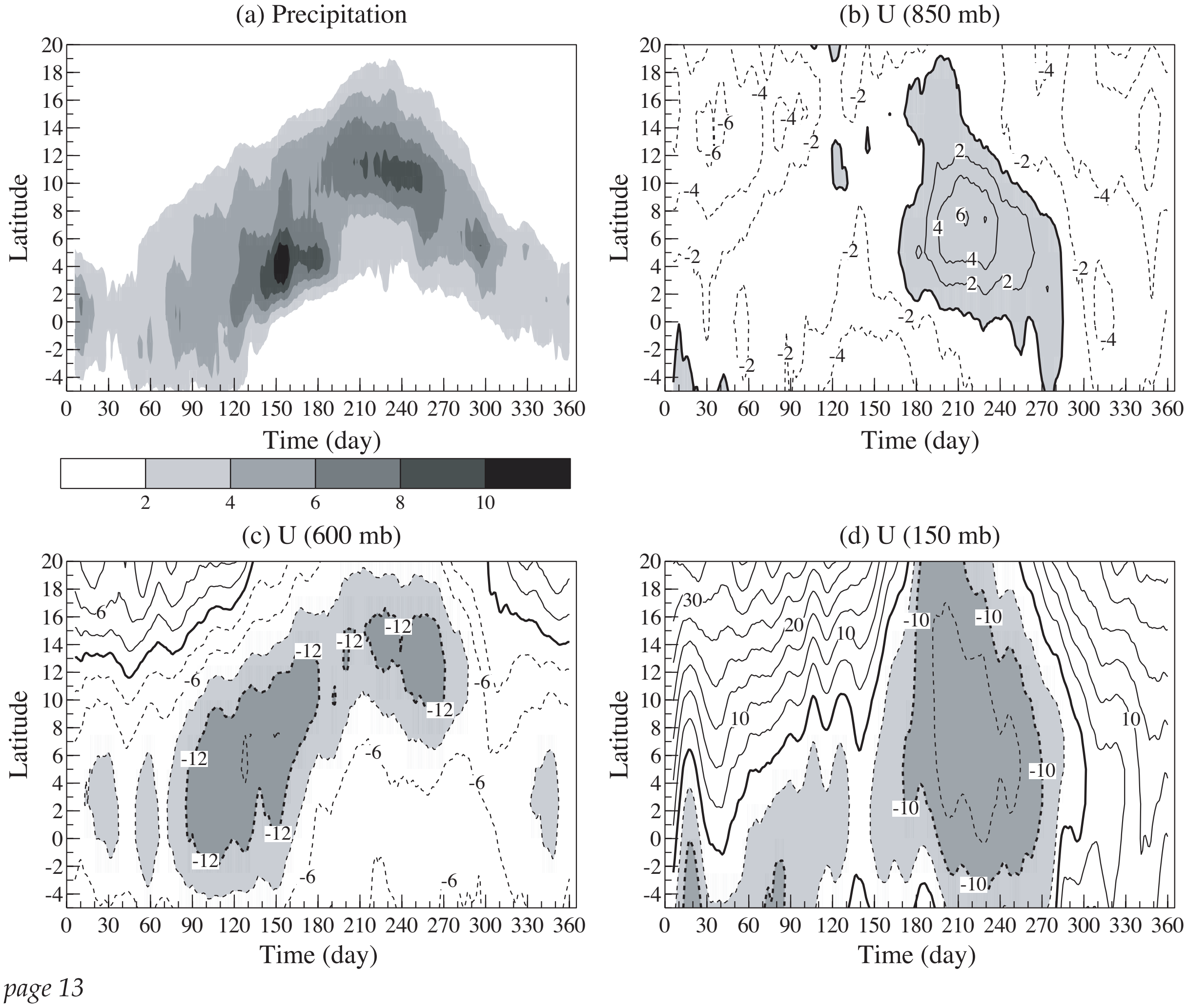


Fig. 2: Weekly mean (a) zonal (U) and meridional (V) wind components (m day^{-1}) within 4.125°S - 4.125°N, 10.125°W - 5.125°E from QuickScat as function of time; Solid lines are for 2000, dashed lines for 2001, and dashdot lines for 2002. (c) Scattergram of wind components; Dots are for 2000, crosses for 2001, circles for 2002.



Caption on page 13

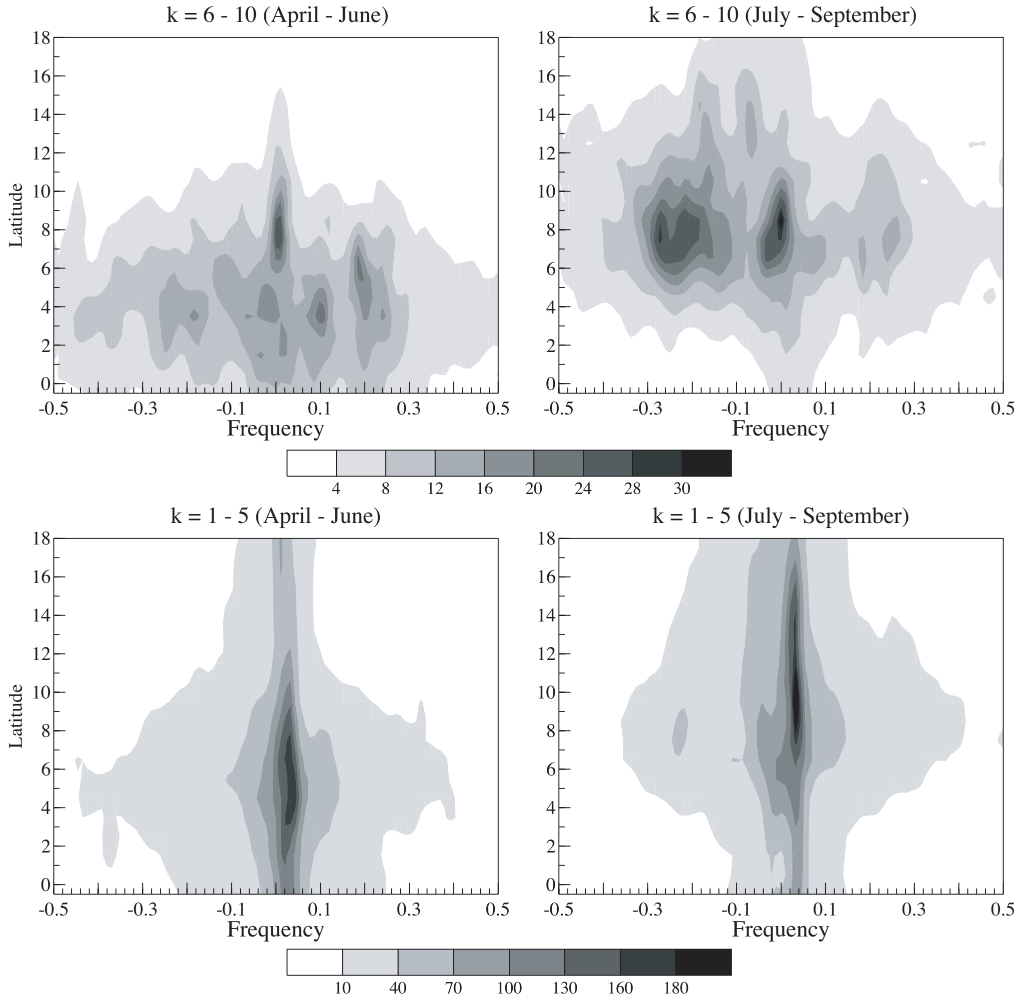


Fig. 4: Mean spectral power (mm^2 day^{-2}) of rainfall between 9.5^{o}W - 9.5^{o}E as function of frequency (cycles day^{-1}) and latitude. Positive (negative) frequencies represent eastward (westward) components.

an abrupt increase in the meridional wind component occurs during the day 120-150 period, consistent with the monthly results (not shown), which is instrumental to equatorial upwelling. Despite high-frequency variabilities in surface wind components on the weekly time scale, coherent relations between zonal and meridional winds can be discerned, especially clear in Fig. 2c. Within this region, the surface trade wind vectors always shift from southwesterly to southeasterly, or vice versa.

Mean zonal wind field

Previous studies indicate that summer rainfall variability over West Africa is closely associated with the variabilities in the large-scale environment on both interannual and seasonal time scales (e.g., Nicholson and Grist, 2003). By using the zonal wind component from the NCEP/NCAR reanalysis project (Kalnay et al., 1996), we emphasize the seasonal variations in several dynamic features, e.g., the AEJ, TEJ and low-level flow, etc.

Fig. 3 depicts the seasonal cycles in daily surface rainfall, and zonal wind components at 850 mb, 600 mb, and 150 mb between 10^{o}W-10^{o}E. As in Fig. 1a, surface rainfall (Fig. 3a) shows a significant break during the day 180-200 period (or June-July). There is an abrupt development in the low-level westerly flow, quantified by the zonal wind at 850 mb (Fig. 3b), which is concomitant with the onset of the rain events along 10^{o}N. The AEJ moves northward and becomes stronger in the spring (Fig. 3c). It becomes weaker during the day 180-200 period, possibly related to the appearance of the intense African easterly waves (AEWs) which tend to weaken the AEJ. As for the low-level westerly flow, a sudden development of the TEJ is also seen approximately at the same time period, i.e., around day 180 (Fig. 3d). These concurrent transition features in various fields implies their close association.

Rainfall-related perturbations

Surface daily rainfall patterns over the tropical eastern Atlantic and West Africa are further decomposed into various perturbation signals, particularly within the synoptic-scale domain (here referred to wavenumber *k*=6-10). This enables us to explore whether any season- and/or latitude-dependent wave modes exist in surface rainfall variability. A 2-d wavelet spectrum analysis is applied to extract the regional spectral power of perturbations within the wavenumber-frequency space (Gu and Zhang, 2001).

Evident seasonal variations are seen in both the strength and preferred frequency of spectral signals within a wavenumber range of *k*= 6-10 (Fig. 4). Most of the spectral signals move to the north from April to August, following

Fig. 3 (left): Seasonal cycles in (a) daily rainfall (mm day^{-1}; 10-day running mean) from the TRMM level-3 daily rainfall product (3B42) between 9.5^{o}W-9.5^{o}E, and daily zonal wind components (m s^{-1}; 10-day running mean) from NCEP/NCAR Reanalysis Project at (b) 850 mb, (c) 600 mb and (d) 150 mb between 10^{o}W-10^{o}E.

the seasonal migration of major rain events. During April-June, most propagating signals appear with frequencies *f*>0, i.e., eastward-propagating, and along 2°N-6°N; Two major power peaks are located roughly at *f*=0.1 and *f*=0.18 *cycles day*$^{-1}$, respectively; Thus, within the synoptic-scale domain, the rain events at the latitudes of 5°N shown in Figs. 1a and 3a are primarily composed of eastward-propagating perturbations which may be associated with the Kelvin-type tropical waves forced by the warmer SST (e.g., Wheeler and Kiladis, 1999). In contrast, during July-September, westward-propagating signals are dominant within a frequency band of -0.1 to -0.3 *cycles day*$^{-1}$, corresponding to the intense AEW activity and major rain events along 10°N.

The mean spectral power for those smaller-wavenumber perturbations (*k*=1-5) is also shown in Fig. 4. An evident power peak is seen at a frequency range of *f*=0.02 - 0.04 *cycles day*$^{-1}$, though the 92-day running window used here may not be good enough to resolve the lower-frequency part of these signals. In contrast to their synoptic-scale counterparts, these wave signals are always propagating eastward, though there is a seasonal migration in their preferred latitudes roughly following the seasonal march in surface rainfall. We speculate that these wave signals might be related to the classic tropical intraseasonal variability, i.e., the Madden-Julian Oscillation (MJO). Since the MJO-related convective signals are considered to be primarily confined in the Indian and western Pacific oceans and very little work has been done in the Atlantic-West African sector, detailed properties and mechanisms behind these rainfall perturbations need to be quantified in the future. It also needs to be mentioned that the 2-d wavelet spectrum analysis has shown no evidence for the westward-propagating intraseasonal signals as proposed by Sultan and Janicot (2000) possibly because they are weak and/or can only be observed during a relatively short time period.

Conclusion

Surface rainfall and seasonal variability over West Africa seem to be associated with two different processes. Near the Gulf of Guinea (about 5°N), intense rainfall begins in April, apparently following the occurrence of warm SST in the tropical eastern Atlantic. Meridional SST gradients also play an essential role in forcing convection and rainfall during the day 120-190 period (approximately from May to mid-July). Low-level southerly flow accelerates, possibly a direct response to the convection and rainfall, which induces the decrease in SST through an enhanced equatorial upwelling. Besides enhancing the southerly flow, the formed cold SST zone quickly begins to suppress the convection and rainfall when the mean SST is less than about 27°C, though the strong meridional SST gradients still exist till about day 250. That the major deep convective zone fails to move northward across the land may also be due to the unfavourable surface land conditions. Consequently the major surface rainfall events near the Gulf of Guinea disappear due to the formation of an oceanic cold tongue complex in the tropical eastern Atlantic. During the course of this evolution, surface rainfall is shown to be both a passive and an active member in the entire coupled system. Other large-scale factors such as AEJ and TEJ, however, have not shown any significant impact in this region.

Along the 10°N within the interior West Africa, a second rain belt begins to develop from July and remains there during the later summer season. This belt seems to be independent of the first one to the south. The onset of rainfall events within this belt is concomitant with a northward-movement of the AEJ and accompanying horizonal and vertical shear zones (not shown), the appearance and strengthening of the TEJ and a strong low-level westerly flow, and the appearance of intense westward-propagating synoptic-scale wave signals. Thus, the rainfall and variability within the western African continents are primarily modulated by these large-scale features such as the AEJ, TEJ and low-level southwesterly flow (e.g., Grist and Nicholson, 2001). However, the indirect dynamic effect of SST may not be neglected. Significant negative correlation between the SST in the tropical eastern Atlantic and the mean rainfall along 10°N is found (not shown) as in Opoku-Ankomah and Cordery (1994). Additionally, intense surface meridional SST gradients during the day 190-250 period might be favorable for the surface convergence zone and rainfall along 10°N.

A 2-d wavelet spectrum analysis further provides a detailed decomposition of surface rainfall variability. Most eastward-propagating (intraseasonal and synoptic-scale) wave signals are observed within the first peak zone during May-June. During July-September, in contrast, AEWs dominate the variability in the synoptic-scale domain within the second peak zone, even though eastward-propagating intraseasonal signals are still seen. This wave mode decomposition enhances our argument on the seasonal variations of rainfall patterns over West Africa.

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On the Gulf of Guinea and the West African Monsoon

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Framework

Recent studies have clearly confirmed that the Gulf of Guinea (hereafter GG) may play a key role on the West African Monsoon (hereafter WAM; e.g. Janicot et al., 2001). There, the atmospheric circulation of the layers in contact with the ocean is mostly northward: the dominant trade winds vary from southeast south of the equator to southwest along the coasts of the GG, so contributing to the WAM phenomenon. The GG is thus a large source of the water vapour which feeds most of the precipitation falling on this region of the continent (Wauthy, 1983). The sea surface temperature (hereafter SST), that conditions the heat and vapor exchanges between the ocean and the atmosphere, is consequently a key parameter in the GG in regard to the WAM (e.g. Camberlin et al., 2001; Kouadio et al., 2003). Understanding of the mechanisms controlling SST variability in the GG deserves to be improved potentially alllowing significant progress in the forecasting of climate on seasonal and interannual time scales. For example, if the equatorial and coastal upwellings, vary primarily seasonally (Gouriou and Reverdin, 1992), their existence and their amplitude are also variable from one year to another, partly due to the equatorial mode of variability that, along with the meridional mode, controls the climate and the SST in the tropical Atlantic (Servain et al., 2000). Such SST variability consequently influences the release and the intensity of the monsoon observed in West Africa (Fontaine et al., 1999). SST variability depends also upon many other factors, as fluxes at the interface, vertical and horizontal mixing and advection, etc. Actually, the circulation in the GG, characterized by many zonal surface and subsurface zonal currents (Figure 1), is rather complex and poorly documented, and needs to be better described to get a more precise understanding of the variability of surface and near-surface conditions (SST, but also sea surface salinity and mixed layer depth).

A few results and prospective

We briefly present here some new results obtained during the Equalant 1999 and 2000 cruises, both carried out in boreal summer (Bourlès et al., 2002; see also http://nansen.ipsl.jussieu.fr/EQUALANT/ for further explanations about these

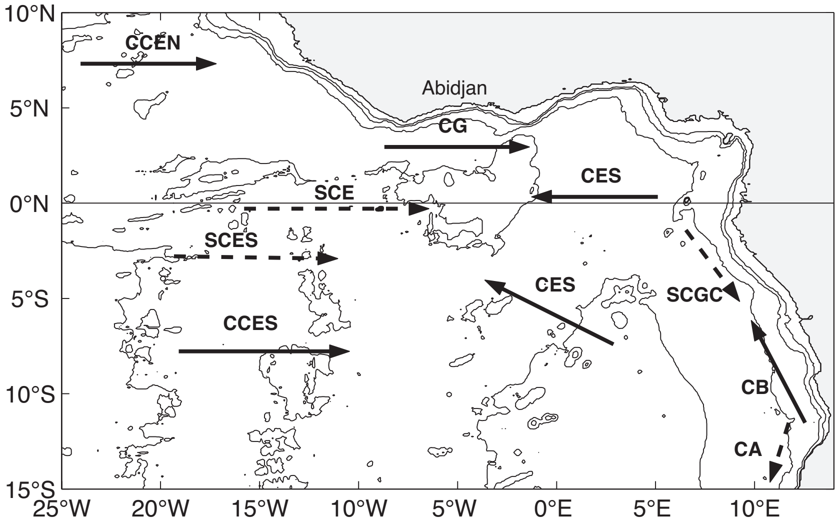

Fig. 1: Schematic of the surface and subsurface circulation in the east equatorial Atlantic and the Gulf of Guinea. Surface currents (full arrows): North Equatorial CounterCurrent (CCEN); Guinea Current (CG); South Equatorial CounterCurrent (CCES); South Equatorial Current (CES); Benguela Current (CB). Subsurface Currents (dashed arrows): North Equatorial UnderCurrent (CSEN); Equatorial UnderCurrent (SCE); South Equatorial UnderCurrent (SCES); Gabon-Congo UnderCurrent (SCGC); Angola Current (CA).

cruises). One of the interests of these cruises consisted in the repetition at a one year interval of the 10°W meridional section. As shown by Bourlès et al. (2002), the surface and subsurface currents exhibited very strong differences. For example, the eastward flow associated with the Equatorial Undercurrent (SCE) reached larger depths and was located farther south in 1999 than in 2000. Further, the northern branch of the westward South Equatorial Current (CES), observed around 2°N at 10°W, was very much weaker in 1999 than in 2000, and the eastward Current of Guinea (hereafter CG), located between around 3°N and the African coasts, exhibited a larger meridional extent but weaker surface velocity (see Bourlès et al., 2002, their Plate 1).

Such differences observed in the current patterns at a one year interval have to be compared and associated with those observed in the hydrographic parameters, such as the temperature (Figure 2, page 30) salinity and oxygen (not shown). The SSTs were warmer in 1999 than in 2000. The equatorial upwelling was accordingly weaker in 1999, with temperature differences between the two sets of observations larger than 1°C. The amount of warm water with temperature higher than 26°C (in the north) and 24°C (in the south) was also consequently larger in 1999 than in 2000. At depth, the thermocline appears, in contrast to 2000, well marked in 1999 at the depth of the SCE around 50m and relatively flat. In the region of the equator, the warmer surface and thermocline waters present in 1999 are always associated with weaker salt and oxygen concentrations (not shown). These observations suggest the signature of a large scale warm Atlantic event in 1999, as suggested also by other kinds of measurements and recent analysis of SST, winds (with weakening of the strength of the zonal component of the wind in the west of the basin) and fluxes, (the reader can refer to the SST/wind stress monthly analysis and climatology at http://www.brest.ird.fr/WOCE/html/atlmonyr.html for illustration).

In order to improve our knowledge of the circulation in the GG and, among others, on the processes responsible for the variability in the surface and near-surface conditions (i.e. SST, salinity and mixed layer depth conditioning the turbulent fluxes at the air-sea interface) in this particular region, the EGGE (*Etude de la circulation océanique et de sa variabilité dans le Golfe de Guinée*) oceanic and climatic programme has been funded and started. The EGGE programme will span the period from 2002 to 2007 in the framework of the AMMA programme (see http://medias.obs-mip.fr/amma/ for complete information about this programme). EGGE has complementary parts, including numerical and process studies. The field component of EGGE will consist of: 1) Oceanographic cruises providing measurements of hydrography, currents and tracers, along the same sections carried out in two opposite seasons during three years (2005-2007). More specific cruises, comprising additional atmospheric and fluxes measurements, will be carried out in 2006 in the framework of the Special Observation Period of AMMA. These cruises will also provide measurements needed for calibration/validation of new satellite measurements (*e.g.* TRMM, MSG, SMOS); EGGE cruises will be carried out in close relationship with the PIRATA programme, and could also be used to maintain some of the PIRATA "Atlas" buoys (refer to http://www.ifremer.fr/ird/pirata/piratafr.html for details); 2) Extension of meteorological measurements available along the equator from the PIRATA buoys network, by the implementation of an additional meteorological station at the São Tomé Island (0°N-6°E), associated with a tide-gauge already maintained there from many years; 3) Use and instrumentation of any R/V transit and VOS cruises, through XBTs, SVP and "PROVOR" T/S profilers, in the framework of the ARGO/CORIOLIS international programme (see for example: http://www.ifremer.fr/coriolis/). The contribution of African scientists and laboratories to such an effort will be particularly fruitful.

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The role of tropical SSTs in forcing Sahelian rainfall variations

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Summary

Rainfall over the West Sahel shows a multidecadal drying trend from the 1950s (wet-mode) to the beginning of the 1990s (dry-mode). Our study examines the decadal-scale response of the atmospheric general circulation model (AGCM) ECHAM4.5 to the observed tropical SST anomaly field representing the difference between the dry and wet mode. The model response to the total SST forcing, its individual components in the different ocean basins and combinations of these is analysed. Our results suggest that the warming trend in the Indian Ocean plays a crucial role for the drying over the West Sahel.

Figure 1 (page 32) shows the tropical (30ºS-30ºN) June to September (JJAS) SST difference field contrasting the situations between the dry and wet mode in the Sahel. The wet and dry modes cover the periods from January 1951 to December 1960 and from January 1979 to February 1996, respectively. For the dry mode the climatological AMIP2-SST (Taylor et al., 2000) dataset is used, while for the wet mode the climatological monthly means are computed from the Reynolds SSTs[¶]. Results are obtained from a set of 21-year SST sensitivity experiments with the AGCM ECHAM4.5 (Roeckner et al., 1996). The results are averaged over the last twenty years and only the mean response (sensitivity run minus control integration) is shown here.

The integrations are: The control integration which is driven with the climatological AMIP2-SST (dry mode). The integration "Global Tropics", in which the full SST anomaly field of Figure 1 is added to these values. The integrations "Atlantic", "Pacific", and "Indic" only in which the SST anomalies in Figure 1 from the respective ocean basins are added to the climatological values of the control run.

In the experiment "Global Tropics", the tropical SST anomalies representing the wet mode produce a precipitation increase in the whole sub-Saharan Sahel region (Fig. 2a). A two-sided t-test reveals a significant (at the 95%-confidence-level) rainfall enhancement over the West Sahel (indicated by the box). Over the tropical Atlantic, the model simulates a northward shift of the intertropical convergence zone (ITCZ), with more rainfall in the north and less in the south.

In the "Atlantic" integration, the rainfall response is primarily characterised by a rainfall decrease over southern West Africa and the eastern tropical Atlantic (Figure 2b). In the "Pacific" experiment, a positive rainfall response is simulated over the eastern Sahel. From the maximum – located in the area of the Red Sea – the precipitation increase extends to the west (Figure 2c). In the "Indic" experiment, the rainfall is enhanced over West Africa, the ITCZ is intensified over the tropical Atlantic Ocean, and the rainfall is reduced over East Africa (Figure 2d). The results of considering the SST forcing of two ocean basins together (not shown) indicate that the impact of the tropical Indian and Pacific Ocean on the decadal rainfall change over the Sahel is dominant: the tropical Atlantic Ocean with either the tropical Pacific or Indian Ocean produces nearly the same rainfall anomalies over North Africa as the Pacific or Indian Ocean alone. The main influence of the tropical Atlantic Ocean is on the Atlantic coastal regions and over the Atlantic Ocean itself. The "Pacific/Indic" experiment produces a similar rainfall response as the "Global Tropics" experiment over the Sahel.

Thus, our SST sensitivity experiments indicate that the tropical Indian Ocean is the most important agent in producing the decadal rainfall reduction over the West Sahel. The SST in the Indian Ocean shows a pronounced warming since the 1950s. In order to further investigate the role of the Indian Ocean SST, the tropical Indian Ocean SST is simply reduced by one Kelvin in the region (see Fig. 3a) in an additional sensitivity experiment. A significant JJAS rainfall enhancement over West Africa is simulated (Fig. 3b) confirming our hypothesis that the tropical Indian Ocean plays an important role in forcing Sahelian rainfall anomalies. Reduced SSTs in the tropical Indian Ocean lead to less convection/precipitation over most of the tropical Indian Ocean. This results in an anomalous downward motion, reduced latent heat release, and upper tropospheric convergence. The anomalous inflow results in anomalous westerly winds over Africa. This anomalous east-west circulation in the upper atmosphere links the region of anomalous convergence over the Indian Ocean to the region of anomalous divergence centred over West Africa. The latter is connected with upward motion over West Africa, and the enhanced convection is amplified by enhanced moisture convergence and convective heating.

In summary, the tropical Indo/Pacific SSTs are most important for the recent decadal rainfall trend over the Sahel. Our experiments indicate that the warming of the Indian Ocean is of paramount importance for the decadal rainfall reduction over the West Sahel. This is supported by high

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[¶] Reynolds SST data were provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Website at http://www.cdc.noaa.gov/.

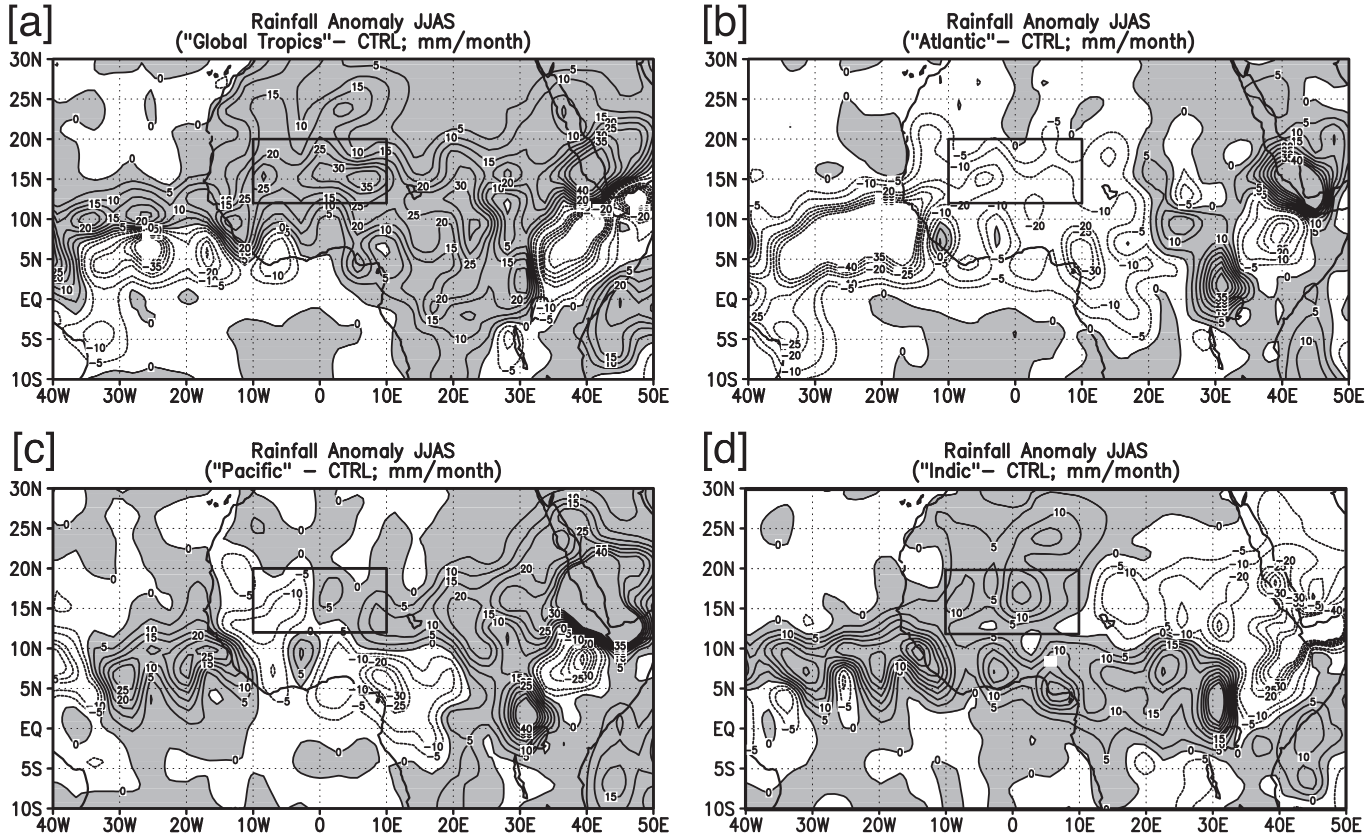

Fig. 2: Simulated JJAS rainfall anomaly (relative to control integration) for experiment with: 2a, Full SST anomaly of Fig. 1 (page 33) („Global Tropics"); 2b, Atlantic portion of Fig. 1 („Atlantic"); 2c, Pacific portion of Fig. 1 („Pacific"); 2d, Indian Ocean portion of Fig. 1 („Indic"); units: mm/month. The box indicates the West Sahel.

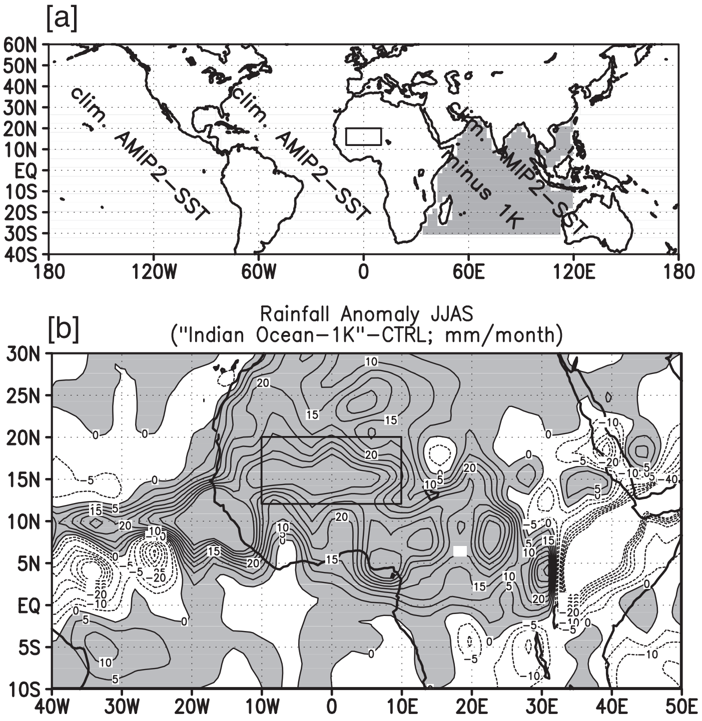

Fig. 3: Simulated JJAS rainfall anomaly (Fig. 3b; relative to control integration) for experiment with tropical Indian Ocean sea surface temperature reduced by one Kelvin (Fig. 3a); units: mm/month. The box indicates the West Sahel.

anti-correlations between the observed low-pass-filtered rainfall over the West Sahel and tropical Indian Ocean SSTs and by an observational study of Shinoda and Kawamura, 1994. The tropical Pacific seems to be more important for the East Sahel. The tropical Atlantic impacts the decadal rainfall change over the Atlantic itself and along its coasts, e.g. the Guinea Coast.

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The role of the Indian Ocean in modulation of ENSO impacts on the West African Monsoon

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Introduction

The major hypotheses for explaining the long lasting dry conditions since the late 1960's in West Africa, and more particularly in the Sahel, that led to profound societal and environmental changes, involve sea surface temperature (SST) and land surface modifications.

Numerous diagnostic and modelling studies have highlighted possible roles of the tropical Atlantic, ENSO and interhemispheric SST anomaly (SSTA) gradients in the climate variability over West Africa. The location of this area and a relative narrowness of the Atlantic Ocean make it prone to influences from different, adjacent and remote oceanic areas and the exact mechanisms for the SST impacts in this region have still to be better understood. The differences between some SST-related results could arise from changes in the observed relationships on decadal time-scales, and thus a strong dependence on the period considered. For example there is evidence of higher impacts of El Niño events on the Sahel during recent, drier decades than during the previous, wetter period (Janicot et al., 2001). This could be partly due to the increased amplitude of interannual SST anomalies in the equatorial Pacific since late 1970's. However, there are also indications that interdecadal SST modifications - particularly over the Indian Ocean - may change the nature of the observed ENSO teleconnections.

Methodology

We use idealized SST Anomalies (SSTA) to force the Météo-France Atmospheric General Circulation Model (AGCM) ARPEGE-Climat to investigate the role of different basins and modes of SST variability on the West African climate.

The SSTA patterns are defined using a combination of the main modes of SST variability extracted with a basic rotated EOF analysis of global SST. The EOF modes show well known structures associated with interannual-to-decadal climate variability. In this work, focusing on ENSO, only the results of forcings combining the EOF1 with the EOF3, viewed as a global, slowly evolving background, are presented

- EOF1 (Fig. 1a) reflects ENSO-type variability with strongest loadings in the eastern tropical Pacific and major time variability around 36-60 months. The major El Niño/La Niña events are easily identified in the time series. Note also the associated variability in the tropical Indian Ocean, in phase with the eastern Pacific anomalies.
- EOF3 (Fig. 1b) is a global, more extratropical interhemispheric gradient with strong loadings in the tropical Indian Ocean and low frequency/trend characteristics.

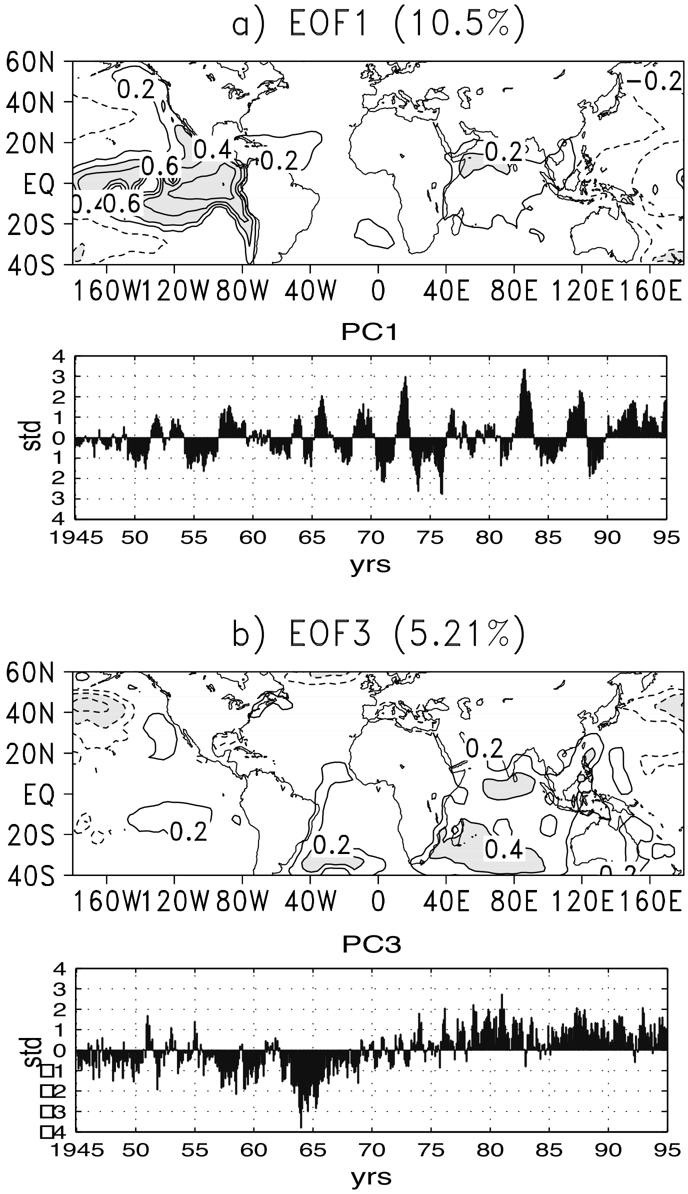

Fig. 1: EOF analysis of the global SST 1945-94 (MOHSST4 dataset); a) EOF1, loading pattern and time series; b) same as a but for EOF3.

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El Niño coinciding with the negative phase of the EOF3, reflecting the conditions during the wetter Sahelian period (before ca. 1970) is referred to as the TE+ experiment. El Niño together with the positive phase of EOF3, prevailing during more recent dry epoch is named TE-. Additional sensitivity experiments with SSTAs extracted from an EOF composition but confined only to the Pacific (PAC) and Indian Ocean (IND) allow the role of each of these basins to be further investigated. The SSTAs reach 2.8K in the eastern Pacific in TE- and PAC, where they are the warmest and up to 1.2K in the tropical Indian Ocean in TE- and IND. For each SSTA the simulations were centred on the Sahelian rainy season and 3 runs with different initial conditions were performed in order to assess the reproducibility of the results (cf. Trzaska et al. (1996) and Trzaska (2002) for the structure definition, maps and the experimental set up). Monthly mean anomalies in wind and precipitation relative to the control in August, the month of maximum of precipitation over the Sahel are discussed below.

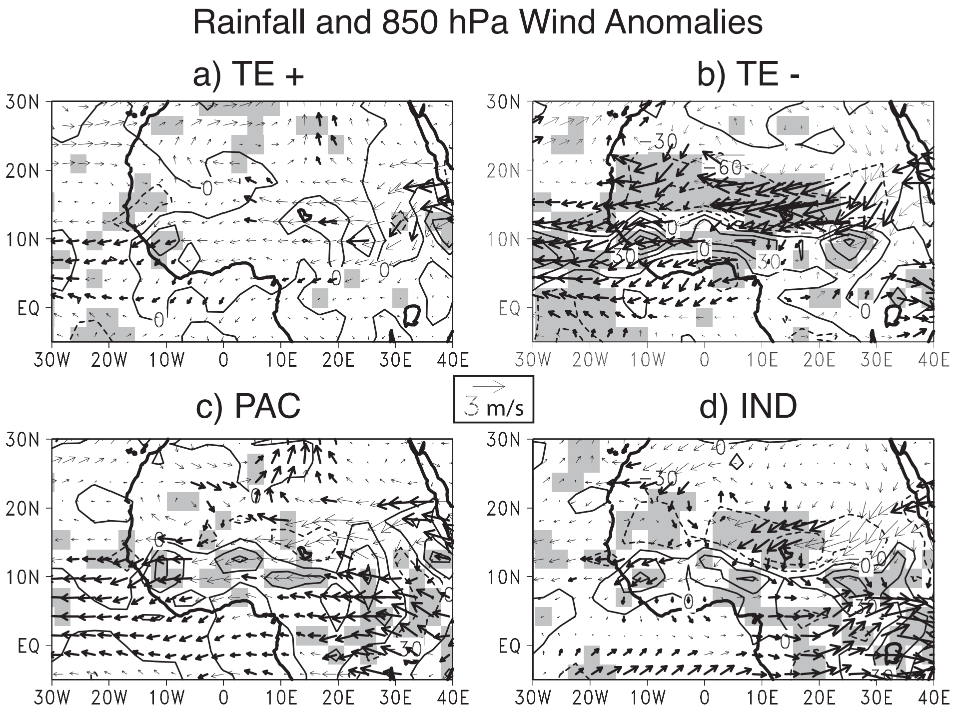


Fig. 2: Simulated monthly mean anomalies (August) for total rainfall (contours, in mm/month) and total wind at 850 hPa (vectors) for the different SSTA : a) TE+, b) TE-, c) PAC, d) IND. Shadings for the significant rainfall anomalies at p=0.05 according to the Student's t=test; bold vectors for significant zonal and meridional wind components at p=0.05 according to the Hotelling test.

Results

The main spatial and temporal characteristics of West African monsoon are correctly simulated by ARPEGE-Climat and the maxima of the precipitation correspond to maxima of low-level moisture convergence (Trzaska, 2002). Still the location of the main modelled rainbelt in August is slightly northward compared to the observations and the analyses are made relative to this model climatology.

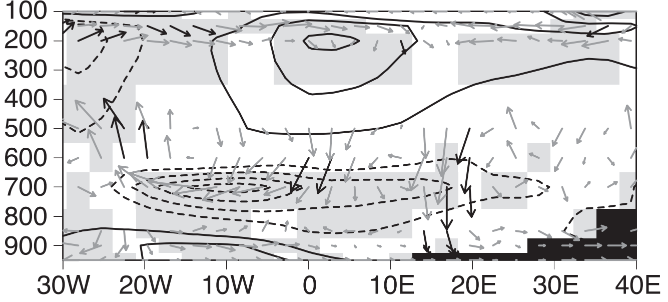
The simulated El Niño impacts over West Africa were found to depend strongly on the polarity of EOF3 and particularly on the warming of the Indian Ocean. Fig. 2 shows monthly rainfall and low-level (850 hPa) wind anomalies in August when forcing with global SSTA (top panels) and individual basin SSTA (lower panels)

- Global TE+ SSTAs (Fig. 2a) do not produce significant rainfall anomalies except over the western coastal area and the low level wind reduction is important only over the NW tropical Atlantic. In contrast, TE- SSTAs (Fig. 2b) lead to strongest rainfall and wind anomalies, consistent throughout the whole Sahelian band, with significant reduction of precipitation and monsoon penetration in central and eastern parts.
- The comparison with the basin-only forcings shows that TE+ seems to be a somewhat weaker case of PAC anomalies (Fig. 2c) where a southward shift of rainfall and a reduction of westerly monsoon component south of 10°N are generated. The western part of the Sahel in the TE- case shows rainfall and circulation anomalies similar to the PAC experiment whereas the strong rainfall and wind anomalies in the Central and Eastern Sahel are consistent with the IND anomalies (Fig. 2d).

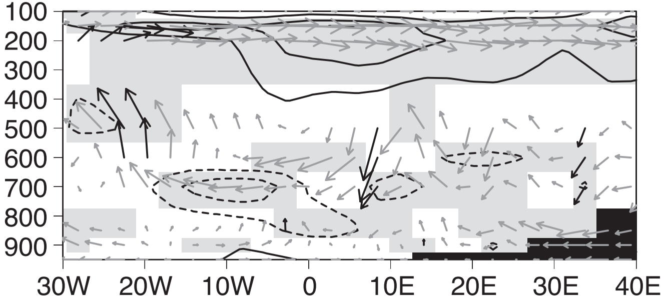
Thus the TE- case seems to be a combination of the PAC and IND generated anomalies which suggests the potential role of the tropical Indian Ocean warming in the generation of widespread anomalies over the Sahel during recent El Niño events in 70's-80's. This is further confirmed by the inspection of other variables at different atmospheric levels and particularly evidenced in divergent circulation-related fields such as velocity potential (not shown).

The emerging hypothesis is the following: the warming in the tropical Indian Ocean which usually accompanies El Niño events, when occurring with a warmer Indian Ocean basic state, may trigger deep convection and upper level divergent anomalies that are competitive in magnitude with those triggered by the warming of the eastern Pacific. This appears to lead to upper level convergence and subsidence over the Atlantic-African region with the western part influenced by the Pacific-related and eastern part by the Indian Ocean-related anomalies as illustrated in the divergent circulation at the equator in Fig. 3 (compare panels a to b and c).

Divergent Circulation
Cross - Section 5ºS - 5ºN
a) TE - anomalies



b) PAC anomalies



c) IND anomalies

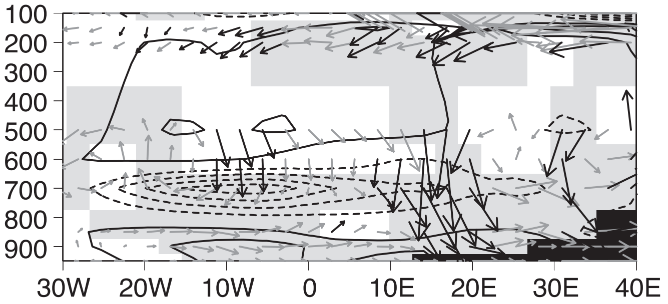


Fig. 3: Simulated monthly mean anomalies (August) for horizontal divergent component of the atmospheric circulation and vertical velocity averaged between 5ºS and 5ºN. a) TE-, b) PAC, c) IND experiments. Contours for the meridional component, vectors for the zonal and vertical components (scaling arbitrary); Shading for significant anomalies at p=0.05 in horizontal components according to the Student's t-test; bold vectors for significant changes in the averaged vertical velocity according to the Student's t-test.

On the contrary when ENSO occurs in a cooler Indian Ocean context (TE+, not shown) only upper/lower level westerly/easterly anomalies are generated as in PAC case, in agreement with the results of Fig. 2a.

The competition between anomalies generated in the Pacific and Indian basins over the West Africa is even more evident away from the equator, with a flow convergence over the Sahara and significant upper level vertical motion anomalies above the main rainfall deficits (Fig. 4), extending consistently to the low levels (not shown). No such subsidence is observed in PAC and TE+ cases (not shown).

Divergent Wind at 200hPa
TE - anomalies

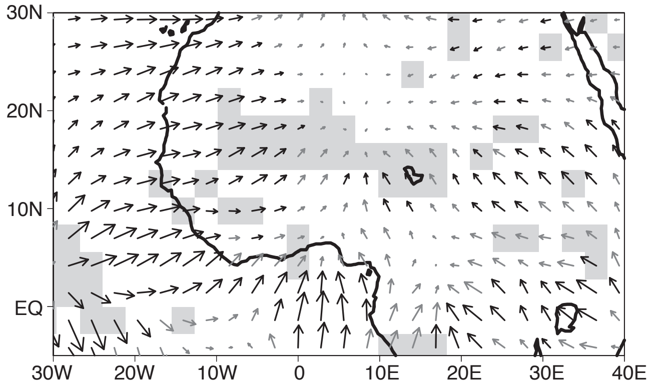


Fig. 4: Simulated monthly mean anomalies (August) for horizontal divergent component of the atmospheric circulation at 200hPa for TE-. Shadings for the vertical velocity anomalies significant at p=0.05 according to the Student's t-test, bold vectors for horizontal components significance.

Conclusions

The above results suggest the mechanisms by which the state of the global ocean and particularly of the tropical Indian Ocean may affect the teleconnections between ENSO and West African rainfall leading to stronger and broader deficits in a warmer Southern Hemisphere/tropical Indian Ocean context. The role of the Indian Ocean for the simulation of the ENSO impacts over West Africa has been shown by Rowell (2001) but this work did not study the differences in the impacts in the context of the long-term evolution of the Indian Ocean. Further results (not shown) show also that the state of the Indian Ocean might be more important than that of the Atlantic Ocean in agreement with the findings by Bader at al., 2003 (this issue).

The amplitude and structure of the SSTAs in the different basins appear to be crucial. In particular, the recent 1997-98 ENSO, although of large magnitude in the Pacific was less felt over West Africa because of the zonally asymmetric state of the Indian Ocean (Saji et al., 1999; Webster et al., 1999). Such structures seem to have been weaker and/or aborted in the 1970's and 80's (Annamalai et al., 2003) when the El Niño signal was strongly felt over West Africa.

The above results may be model-dependent but give some indications of the role of the Indian Ocean which has been seldom associated with the West African climate. Further studies on the association between the long-term evolution of the Indian Ocean SST and Sahelian rainfall and the involved mechanisms as well as on the decadal changes in the variability and co-variability with eastern Pacific and/or Southern and equatorial Atlantic are needed.

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The pre-onset and the onset of the Monsoon system over West Africa

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1. Introduction

Agriculture in the Sudano-Sahelian zone is heavily dependent on the seasonal characteristics of rainfall. The onset of "useful" rains, that is the first rains sufficient to ensure enough moisture in the soil at the time of the planting and not followed by prolonged dry spells which could prevent the survival of seedlings after sowing, is certainly the major point for agriculturists. However there is not a unique definition for the date of the onset of the rainy season (Ati et al., 2002). The objective of this study is to characterize at a regional scale two main steps in the seasonal evolution of the monsoon over West Africa, that is, (1) what we call the "pre-onset" of the summer monsoon, defining the beginning of the rainy season over the Sudano-Sahelian zone based on the northward migration of the northern limit of the south-westerly winds of the monsoon (called the Inter-Tropical Front - ITF -), (2) the real "onset" of the summer monsoon characterized by an abrupt northward shift of the ITCZ from 5°N to 10°N (Sultan and Janicot, 2000; Le Barbé et al., 2002), and leading to major changes in the atmospheric circulation over West Africa (Sultan and Janicot, 2003).

2. The pre-onset of the summer monsoon

By using daily gridded rainfall data from IRD (Institut de Recherche pour le Développement) we computed (Fig. 1) a regional rainfall index over the Sudano-Sahelian region, by averaging the rainfall values for the grid points located between 10°W and 10°E along 15°N, that is over the longitude band where the meridional land-sea contrast exists. This index clearly shows the progressive rainfall increase between April and August. It is however possible to detect two different steps in this mean seasonal cycle, a first one around mid-May with a first increase of the positive rainfall slope, and a second one around late June with a second acceleration of the seasonal cycle leading to the rainfall maxima of August.

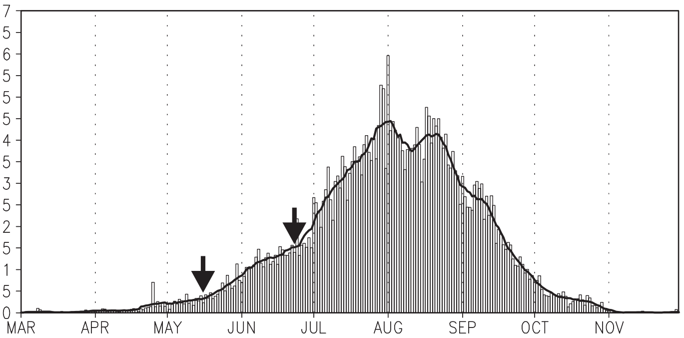

Fig. 1: Mean 1968-1990 rainfall time series (mm day^{-1}) computed on grid points located between 10°W and 10°E, along 15°N. The line represents the time series filtered to remove variability lower than 10 days. The two arrows localize the breaks in the positive rainfall slope.

The first step is connected to the ITF crossing 15°N, and to the arrival of the monsoon winds advecting moist air on the Sahelian latitudes. We will then consider this step as the "pre-onset" of the summer monsoon because it corresponds to the beginning of the rainy season on the Sudano-Sahelian region, a rainfall regime with a significant amount at the regional scale while the ITCZ is still located at 5°N. To define the "pre-onset" date, we based our approach on the idea that local convection will begin to be initiated more or less regularly when moisture advected by the southwesterly monsoon winds will be present over the Sahel with a sufficient amount. At the regional scale considered here, the latitude of the ITF, represented by the northern boundary of the 925 hPa zonal wind zero-isoline, by using NCEP/NCAR reanalyses (Kalnay et al., 1996), could be a good indicator of the real "onset" of the summer monsoon characterized by an abrupt northward shift of the Intertropical Convergence Zone (ITCZ) from 5ºN to 10ºN (Sultan and Janicot, 2000; Le Barbé et al., 2002), leading to major changes in the atmospheric circulation over West Africa (Sultan and Janicot, 2003). We then define for each year between 1968 and 1990 the date when the 925 hPa zonal wind component averaged over 10°W-10°E equals zero at 15°N, going from negative to positive values.

The average “pre-onset” date is the 14 May and the standard deviation on the period 1968-1990 is 9.5 days. The corresponding rainfall time series (not shown) depicts now a very clear break at this date with a strong increase of the positive rainfall slope, meaning that the arrival of the ITF at 15°N can be considered as a meaningful signal for the beginning of the rainy season over the Sudano-Sahelian zone.

3. The onset of the summer monsoon

The second step can be clearly associated with the abrupt northward shift of the ITCZ from 5°N to 10°N and with major changes in the atmospheric circulation over West Africa signing at this time the development of the meteorological summer monsoon system over West Africa. This is the reason why we will call this second step the summer monsoon “onset”.

A similar approach has been used to highlight the meteorological signal associated with the summer monsoon onset corresponding to the abrupt northward transition of the ITCZ. This transition is highlighted when computing time-latitude diagrams of daily rainfall values averaged over the longitudes 10°W-10°E. Figure 2a (page 30) depicts such an example for the year 1978. This rapid shift of the ITCZ is clearly identifiable on this type of diagram. It leads to a sharp reversal of the meridional rainfall gradient over West Africa, which is also evident on Fig. 2b by the crossing of the rainfall time series at 5°N and 10°N.

As for the detection of the monsoon pre-onset, a quasi-objective method can be built up to define a date for the ITCZ latitudinal shift for each year between 1968 and 1990. An Empirical Orthogonal Function analysis (EOF; Richman, 1986) has been performed on time-latitude diagrams of daily rainfall values averaged over 10°W-10°E, for each year from 1 March to 30 November. Most of the rainfall variance decomposed by the EOF analysis is explained by the two first components. The first one (about 91% of the variance on 1968-1990) is highly correlated with the rainfall time series at 10°N (correlation of 0.9 on 1968-1990) and the second one (about 9% of the variance on 1968-1990) is highly correlated with the rainfall time series at 5°N (correlation of 0.75 on 1968-1990). The rainfall indexes (i.e. the rainfall integrated from 10°W to 10°E) at 10°N and at 5°N can then be used to sum up rainfall variability over West Africa and to define a date for the ITCZ shift. The time series of the rainfall indexes at 5°N and 10°N for 1978 are shown on Fig. 2b. A rainfall maximum occurs during May-June when the ITCZ is located at 5°N. The abrupt shift of the ITCZ from 5°N to 10°N can be defined by simultaneously, a decrease of the 5°N rainfall index and an increase of the positive slope of the 10°N rainfall index. For 1978 the date of 17 June has been selected (see vertical line on Fig. 2b). This method has been used to define a date of the ITCZ shift for each year from 1968 and 1990. The mean date t_0 found for this shift over the period 1968-1990 is 24 June and the standard deviation is 8.0 days.

Fig. 2c shows the composite of the mean 10°W-10°E daily rainfall values averaged over the period 1968-1990 by using the ITCZ shift date for each year as the respective reference date. This figure gives latitude-time rainfall variations between t_0 (the shift date) minus 90 days and t_0 plus 140 days. Figure 2d shows the corresponding rainfall indexes at 5°N, 10°N and 15°N. The rainfall maximum at 5°N, also evident at 10°N and at 15°N, occurs about 10 days before t_0. Then rainfall decreases slightly but over all of West Africa to a relative minimum value at the beginning of the ITCZ shift. At t_0, the shift is detected by a new positive slope of the rainfall index at 10°N and at 15°N. The ITCZ reaches the latitude 10°N about 10 to 20 days after t_0 where rainfall increases until mid-August. The abruptness of the northward progression of the ITCZ is in sharp contrast to its withdrawal, which appears as a more orderly southward progression. It is in contrast also with the northern limit of the ITCZ (see the 1 to 4 mm day^{-1} isolines) which has a more gradual latitudinal variation during the onset than during the withdrawal.

4. Conclusions

Two steps have been characterized through a composite approach: the “pre-onset” and the onset of the summer monsoon.

The “pre-onset” stage around the 14 May corresponds to the arrival in the Inter-Tropical Front (ITF) at 15°N, that is the confluence line between moist southwesterly monsoon winds and dry northeasterly Harmattan, bringing sufficient moisture for isolated convective systems to develop in the Sudano-Sahelian zone while the Inter-Tropical Convergence Zone (ITCZ) is centred at 5°N. The onset stage around the 24 June is linked to an abrupt latitudinal shift of the ITCZ from a quasi-stationary location at 5°N in May-June to another quasi-stationary location at 10°N in July-August.

The origin of this abrupt shift is unknown. The associated atmospheric circulation has been described by Sultan and Janicot (2003) and a possible role of the heat low dynamics has been proposed as a major feature in the origin of the onset of the West African monsoon.

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Multiscale View of the Sahelian Rainfall Regimes

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1. Introduction

Rainfall in the Sahel displays a large degree of variability over a range of time scales. This variability is rarely characterized at relevant scales from a hydrological point of view despite the often dramatic consequences of intraseasonal dry spells and pluri-annual droughts on the water cycle of these regions. Rain events are a key element of the rainfall regime of semi-arid regions (D'Amato and Lebel, 1998). They are associated with convective systems that could interact with synoptic disturbances.

Characterizing the Sahelian rainfall regime at different scales allows to link the seasonal cycle with the interannual variability. Three complementary data sets were used to this end, covering 40 years for the regional daily raingauge network, and 10 years for a full resolution meteosat data set and a high-resolution recording raingauge network. One is composed of around three hundred daily raingauges covering a 1,700,000 km^2 area for the period 1951-1990. The second is a set of full resolution Meteosat images covering the years 1989-1999, allowing for a systematic tracking of the mesoscale convective systems (MCSs). The third data set was produced from an experimental network of recording raingauges covering 16,000 km^2 in the region of Niamey, Niger, during the years 1990-2000.

2. The convective systems

Combining ground data from the EPSAT-Niger network and Meteosat data, Laurent et al. (1997) found that, over the region of Niamey, most of the intense rain events producing 80% of the annual rainfall were associated with large cloud clusters well identified from IR imagery. A more comprehensive study carried out by Mathon and Laurent (2001) on a 1989-1998 Meteosat data set has later shown that, for the period extending from July to mid-September, there is a region of maximum occurrences of Mesoscale Convective Complexes (MCCs) – defined following the criteria of Maddox (1980). This region is precisely centred on 11-13°N, spreading in longitude between 10°W and 15°E.

According to Laing et al. (1999), these MCCs produce 22% of Sahelian rainfall. This proportion is not sufficiently large to account for the year-to-year variability of Sahelian rainfall. Mathon and Laurent (2001), on the other hand, have shown that long lived MCSs defined at 233K account for 60% of the Sahelian deep convective coverage at 213 K. In their study, MCSs are defined as cloud clusters larger than 5000 km^2 at the 233K temperature threshold and long-lived MCS are those lasting for more than 24 hours. During July-September (JAS), the total number of MCSs recorded this region is a little less than 20,000 for the years 1990-1999. A very small number of this total population accounts for most of the cloud coverage. In fact, 80% of the total cloud coverage at 233K is produced by the 240 largest systems, that is little more than 12% of the MCSs. The minimum size of these 240 largest MCSs is greater than 50,000 km^2. They include 23 MCCs. In order to quantify the rainfall produced by these large systems, only those which covered at least 80% of the 16,000 km^2 EPSAT-Niger study area were retained. Since the raingauges of the EPSAT-Niger network record 5-minute rainfalls, it is possible to compute precisely the rain produced by each system during its passage over the study area.

The calculation of Mathon and Laurent (2001) gave the following results: i) the largest 12% of the systems produce 93% of the July-September (JAS) rainfall in this part of the Sahel with an average event rainfall of 14.7 mm and ii) the MCC's (that are all included in the largest 12% of the systems) represent only 1% of the total number of systems, producing 20% of the JAS rainfall. The calculation also confirmed that, even though MCCs are by far the most rain efficient systems – producing on average 19 mm per event, they account for a relatively small share of the JAS rainfall because they are few in number.

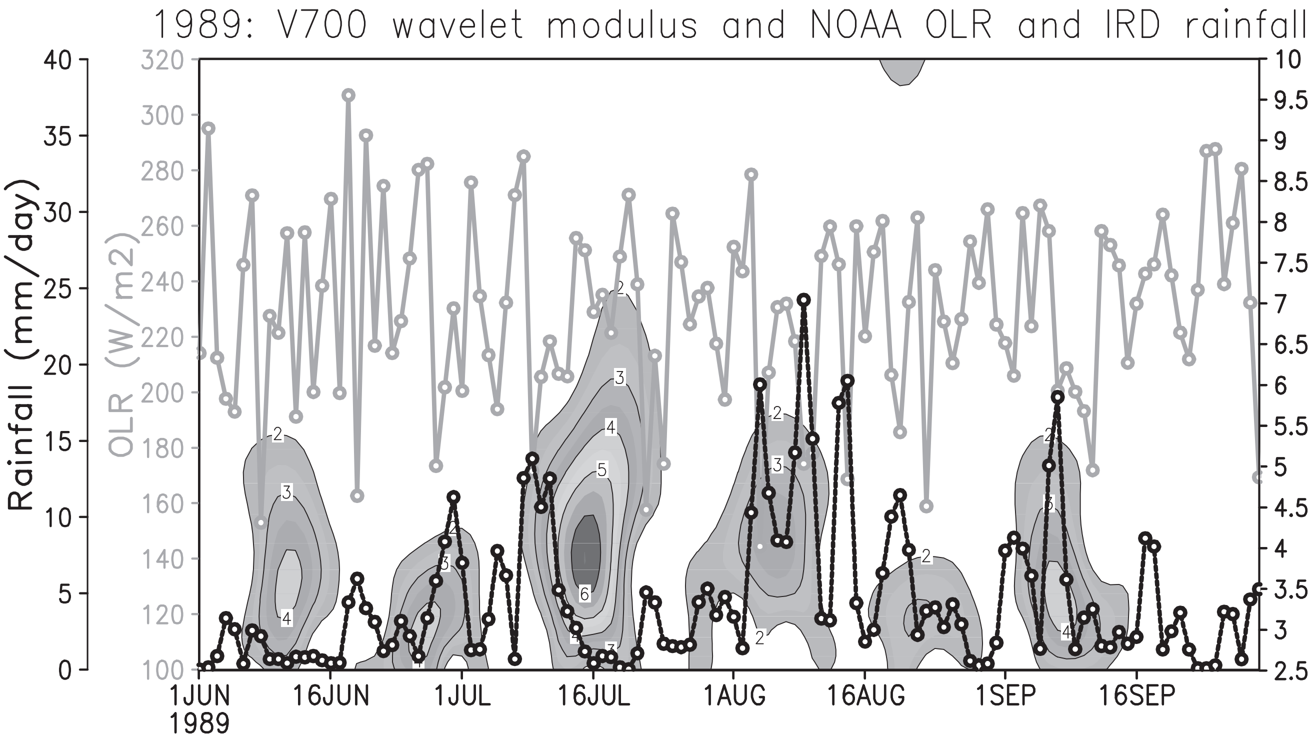

Fig. 1: Evolution from June to September 1989 of the different wave regimes (wavelet modulus on the meridional wind at 700 hPa, shaded), the OLR (light grey line) and the observed daily rainfall (black line).

Since the subpopulation of MCCs is too small for climatological analysis, it is necessary to select a larger population of MCSs – objectively defined – that account for a more significant share of the JAS rainfall. A detailed analysis of the most efficient systems revealed that they all include at least one 213 K cluster, embedded in a larger 233 K cluster and lasting for more than 3 hours. By selecting among these systems those moving at a speed greater than 10 ms^{-1} when passing over the ground validation area, Mathon and Laurent (2001) obtained a subpopulation of rain efficient systems very similar to the subpopulation of the largest 12% of the systems in the selected Sahelian region. It similarly accounts for more than 90% of the JAS rainfall in the region of Niamey.

3. The Synoptic Weather Systems

Easterly waves have been identified as key synoptic features modulating convection and rainfall over the Sahel (Burpee, 1972; Reed et al. 1977; Thorncroft and Blackburn, 1999; Diedhiou et al., 1999). Combining the NCEP/NCAR reanalyses, satellite measurement of the Outgoing Longwave Radiation (OLR) and the observed daily rainfall, it is possible to analyse the seasonal cycle of rainfall and convection and its interaction with easterly waves. Figure 1 shows the evolution of the OLR and of the observed rainfall for the Niamey grid point from June to September 1989 superimposed on the wave regime characterised by a Morlet-wavelet analysis of the meridional wind at 700 hPa. Wavelet analysis (shaded) confirms that most of the disturbances over the Sahel have a period lying between 3 and 5 days, the maximum in the 6-9-day band period occurring mainly in the beginning and at the end of the rainy season.

Analysing the association between waves and rain reveals a rather complete pattern. From 1 to 10 August and around 7 September, waves are associated with cold clouds and high rainfall heights (wet waves). The waves observed during the second week of June and around 21 August are associated with dry events and cold clouds (OLR between 180 and 200 W/m^2 for the first case and less than 160 W/m^2 for the second) and almost no observed rainfall at the surface (dry waves). There is also a wave observed around 16 July, which is not associated with either convection or rain at the surface. Finally, on 14 August, a strong convection (OLR less than 170 W/m^2) and a high rainfall (up to 15 mm) are recorded without any wave. As the modulus of the wavelet is positively correlated to the variance of the wave, all this indicates that the variance of the wave, considered only from the fluctuations of the meridional wind, is not a good indicator of the rainfall variability. Convection and rainfall can occur without any easterly waves present and not all easterly waves are associated with rainfall.

4. The interannual variability

Figure 2 shows that rainfall deficit during July-September is associated with a lower number of the large rain-efficient convective systems identified previously. By comparison, the mean event rainfall produced by these large sys-

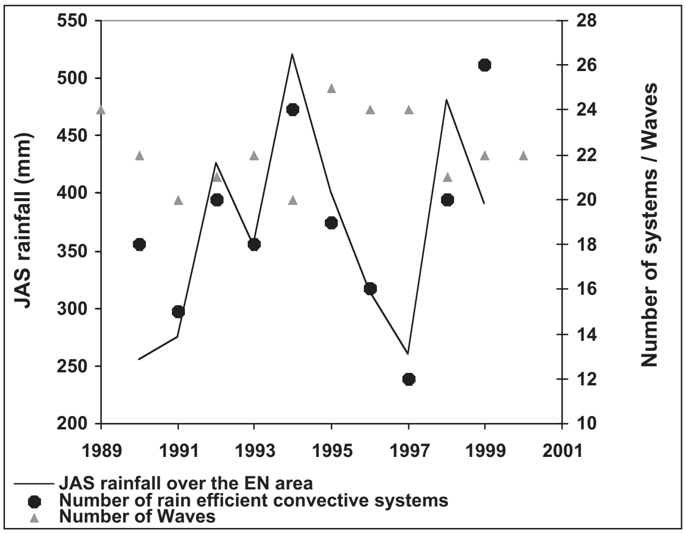

Fig. 2: Rainfall recorded over the EPSAT-Niger study area for July-September, versus the number of large convective systems and the number of easterly waves.

tems does not vary significantly from year to year (not shown). Figure 2 also shows that the number of easterly waves recorded for a given year is not significantly correlated to the rainfall of that year. This has two consequences. First, monitoring the convective systems from IR images of geostationary satellites provides a simple tool for drought monitoring over an entire region such as the Sahel. It should be kept in mind however, that strong local gradients may exist and that ground data are a necessary complement to these satellite data. Secondly, it remains elusive to explain the year to year variation in the number of rain-efficient convective systems by simply looking at the synoptic weather patterns. It is therefore important to better understand at the intraseasonal scale the links between the life cycle of Sahelian convective systems and synoptic weather patterns, in order to improve our comprehension of the interannual variability.

5. Conclusion

The interannual variability of Sahelian rainfall is largely controlled by the annual fluctuations in the number of the rain efficient convective systems. Also, the mean event rainfall of the large convective systems characterizing the continental regime does not display significant differences between wet and dry years. These results are important in a hydrological perspective because runoff is affected differently by a decrease in the number of large rain events or by a decrease in the overall mean event rainfall.

It was also shown that the raw number of 3-5-day waves is not a good indicator of the number of rain efficient convective systems recorded over the Sahel for a given year. This suggests the distinction between "wet" waves and "dry" waves. This tends to assume the existence of an intraseasonal signal modulating the rainfall during JAS. This modulation is currently being analysed using the NCEP/NCAR reanalyses. Phases of stronger African Easterly Jet / weaker Tropical Easterly Jet - which have been identified in previous studies - might be connected to the existence of dry waves (deep convection but no rainfall at the surface). The question is then to determine the nature of this intraseasonal signal and how it is linked to the interannual variability. Is it dominantly a modulation of the cyclonic activity of the waves or is it related to two different regimes of convection? Improving our understanding of the links between the interannual variability of Sahelian rainfall and its seasonal cycle is thus an important issue for future work on the WAM and its hydrological impact.

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Mesoscale modelling of the African Humid Period

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During the last glacial period, dry conditions prevailed over Saharan and Sahelian Africa, somewhat drier than today. But beginning around 14,500 years ago (14.5 kyr), the region became progressively more moist. Numerous large lakes dotted the landscape of what is now the Sahel until about 5.5 kyr (Gasse, 2000). Being able to capture this signal in a climate model, and to explain it, will strengthen our understanding of African climate variability and our confidence for predicting future climate.

The African Humid Period occurred at a time of higher summertime insolation in the Northern Hemisphere. Due primarily to changes in the precession component of the orbital forcing, solar insolation at the top of the atmosphere at 15ºN in summer was approximately 5% greater than today. This forcing is the external cause of the African Humid Period (Joussaume et al., 1999). However, GCM simulations suggest that a consideration of additional factors and/or feedbacks within the climate system is required to understand the African Humid Period. For example, there is strong evidence that SSTs off the west coast of Africa were considerably cooler than today, perhaps 5 K cooler, in conjunction with enhanced upwelling (deMeocal et al., 2000). There is weaker evidence that the Gulf of Guinea was somewhat (~1 K) cooler near the equator, although this cooling may have been confined to the winter season. Certainly land surface attributes over large regions of northern Africa were different, with grasslands extending about 5º of latitude farther north than today. And, of course, atmospheric CO_2 concentrations were at their pre-industrial value of about 280 ppmv.

We have developed a regional climate model (RCM) based on MM5 (Vizy and Cook, 2002) and applied it to the African Humid Period to distinguish the roles of the various factors in establishing the wetter climate. By modelling climate on smaller space scales (10's of kilometres) than is possible with a GCM, the space scale of the modelling is brought close to that of the geological record. This provides a better opportunity for model validation, and for modelling to aid in the interpretation of geological evidence. Also, the RCM provides an improved simulation of the present day climate of northern Africa, since the physical parameterizations can be optimized for the region and the strong surface moisture, wind, and temperature gradients that characterize this region are resolved. The model domain, topography and present-day SSTs are shown in Figure 1 (page 31).

A series of RCM integrations has been used to compare the African climate of 6 kyr with today's climate, and to explore the sensitivity to various assumptions about surface boundary conditions. Solar forcing alone causes increases in precipitation, and a northward retreat of the desert by about 2º latitude, significantly less than that indicated by the geological record. Similarly, imposing changes in surface vegetation alone, guided by observations, moistens the region, but not sufficiently. Reasonable increases in precipitation occur only when both solar forcing and vegetation differences are applied together.

Figure 2a (page 31) shows differences in precipitation from a present day simulation when 6 kyr insolation, vegetation, and CO_2 differences are applied. In contrast to GCM simulations of the African Humid Period, the RCM produces excessive rainfall over the present-day Sahel and Sahara regions in the 6 kyr case. (GCM simulations uniformly underpredict precipitation for the African Humid Period, although some improvement occurs with interactive ocean and/or land surface models.) The addition of colder sea surface temperatures off the west coast and in the Gulf of Guinea improves the RCM's agreement with geological reconstructions for the Sahel, as indicated by the reduction in the precipitation enhancement north of 15ºN in Fig. 2b as compared with Fig. 2a. But the simulation along the Guinea Coast degrades, since the model simulates drying over Ghana where there is evidence of a modest increase in lake levels. Without Gulf of Guinea SSTAs, the RCM simulation produces the simulation of precipitation changes that is most consistent with the geological record. This supports the geological evidence of cooling of the west coast, and suggests that either the Gulf of Guinea was not cooler during the African Humid Period, or that the cooling was confined to the non-monsoon season, or that the region of cooling was too narrow to influence the large-scale monsoon circulation.

These simulations of the African Humid Period climate provide an opportunity for in-depth analysis of how a different climate regime works. For example, despite the increase in insolation at the top of the atmosphere, the net solar heat input to the surface is *smaller* over most of Sahelian Africa and the southern Sahara during the African Humid Period due to the increase in cloud cover, and the surface temperature is slightly cooler. Enhanced warming of the lower atmosphere is accomplished primarily through increases in latent heating from the wetter surface.

The African Humid Period provides an example of a different climate state and, most importantly, it is a different climate state that can be validated independently of climate models. In addition, the African Humid Period provides a wonderful opportunity to study climate transitions, since the moist period ended quite rapidly as if some threshold were reached at a certain value of the solar forcing. Future work with the RCM will focus on the time-dependent signal, and the results will be brought to bear on understanding the all-important decadal-scale signals, whether natural or anthropogenic, over northern Africa.

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Climate variability in Central Equatorial Africa: Evidence of extra-tropical influence

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Introduction

Central Equatorial Africa (CEA) is the third most extensive region of convection, globally, after the West Pacific warm pool region and Amazonia, and as such is likely to represent a primary driver of the tropical general circulation. However, our understanding of the climate processes in CEA is limited and the literature on African climate variability is strongly biased towards West Africa, the Sahelian zone, East Africa and Southern Africa. Thus, despite the importance of CEA to the global climate system the region represents a notable gap in our understanding.

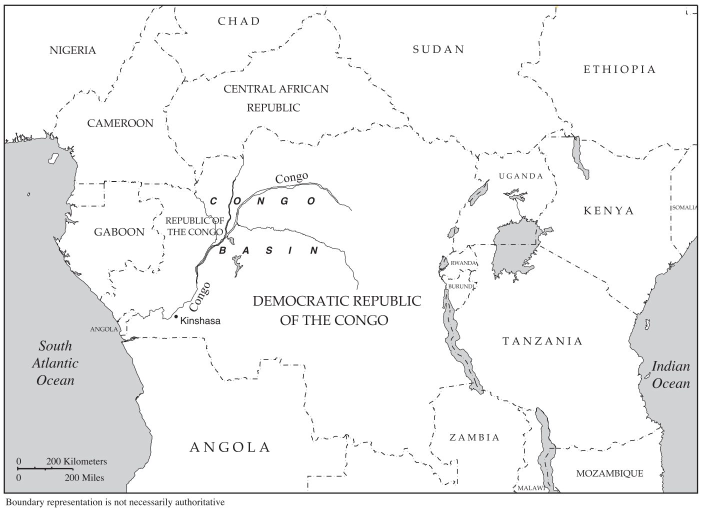

Fig. 1: Central Equatorial Africa and the Congo River basin

Very few studies have attempted to characterise either the meso-synoptic scale processes that produce rainfall in the CEA region, nor the larger scale structures that influence variability at longer timescales. There is, however, evidence of a positive association between rainfall over parts of western CEA and tropical southern Atlantic SSTs (Hirst and Hastenrath, 1983; Nicholson and Entekhabi, 1987; Camberlin et al., 2001). Camberlin et al. (2001) further identify a significant negative association between rainfall in central CEA and SSTs in the northern tropical Atlantic, associated with the broader north/south dipole in West African rainfall. Evidence for the impact of ENSO on CEA is rather limited. Kazadi and Kaoru (1996) document a correlation of Zaire rainfall with ENSO whilst Ameraskera et al. (1997) note a weak negative correlation between annual Congo River discharge and ENSO.

A major reason for the lack of detailed studies of CEA climate variability is a paucity of high quality long-term datasets. In this study, we utilise a long-term record (1903-89) of monthly discharge data from the River Congo (Q) observed at Kinshasa (4.3ºS, 15.3ºE) as the primary climate index of the region. The Congo river is the world's second largest in terms of both discharge (mean annual discharge = 40,000 m^3s^{-1}) and basin area (approximately 3.8M km^2) and drains most of the CEA region (roughly 12ºS-7ºN, 15-30ºE) (Figure 1). The Congo discharge data, therefore, represents an integrated measure of effective precipitation over most of CEA. We also use the observed rainfall data of Hulme (1992) averaged over CEA and NCEP reanalysis data (Kalnay et al., 1996). This short paper presents results indicating substantial influence of the North Atlantic Oscillation (NAO) on CEA climate, selected from a more comprehensive study recently completed by the authors involving both empirical analysis and model simulations (Todd and Washington, 2003).

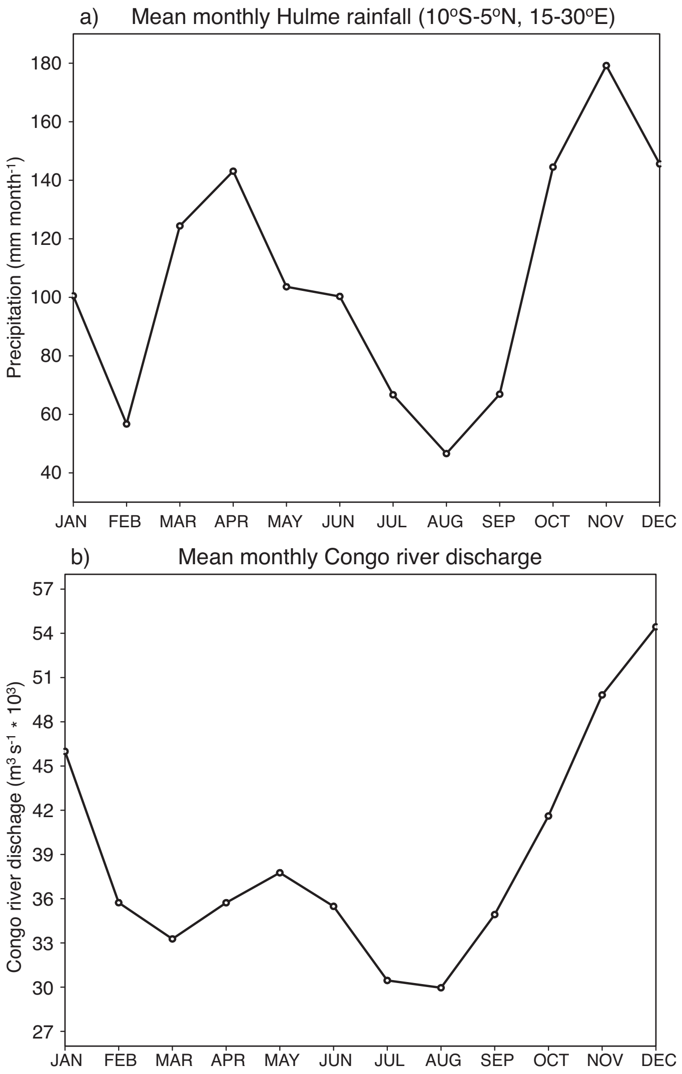

*Fig. 2: Mean monthly values (1903-89) for (a) Hulme precipitation for the region 10ºS-5ºN, 15-30ºE (mm month^{-1}) (b) Congo river discharge m^{3}s^{-1} *10^3).*

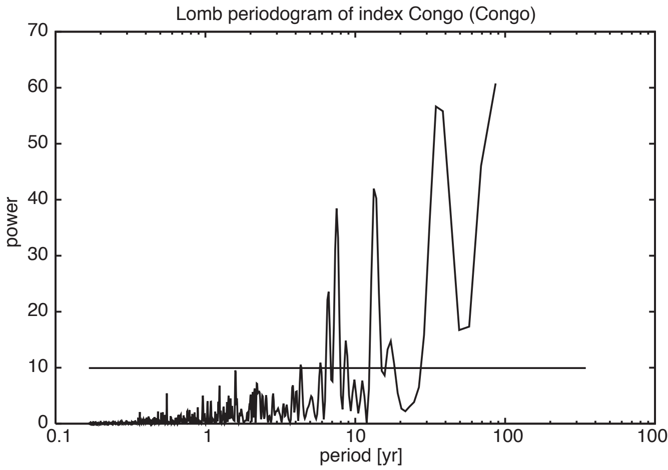

Fig. 3: Periodogram of monthly Congo River discharge. The horizontal line denotes the 0.05 probability of any peak exceeding this value in a white-noise spectrum.

Table 1: Correlation of AMJ and annual (Aug-July) Congo River discharge (Q) and JFM NAO index (1903-89)

	Unfiltered	HF	LF
AMJ Q vs JFM NAO	-0.49	-0.37	-0.56
Annual Q vs JFM NAO	-0.4	-0.37	-0.43

Results and discussion

The mean annual cycle of observed rainfall averaged over CEA (Figure 2a) shows a clear semi-annual cycle with peaks in the transition months (OND and MAM) and minima in the high season months (JAS, JF). This is basically associated with the north/south movement of the ITCZ across tropical Africa. Congo river discharge (Figure 2b) shows a similar semi-annual cycle with peaks in the AMJ and NDJ seasons indicating a lag in the surface hydrological system of 1-2 months. This paper focuses solely on the AMJ (MAM) discharge (rainfall) season.

The power spectrum of monthly discharge (Q) (Figure 3) shows dominant power at multi-annual (around 6-8 years) and decadal timescales (around 14 years). Wavelet analysis shows that the 6-8 year periodicity dominates from around 1950 onwards (not shown). On the basis of the spectral power of Q, we refer to the HF component of all data series as that filtered to retain variability in the interannual band (<4 years), and the LF component as that which retain variability at multi-annual to decadal timescales (> 4 years). For AMJ Q the LF component contains the majority of total

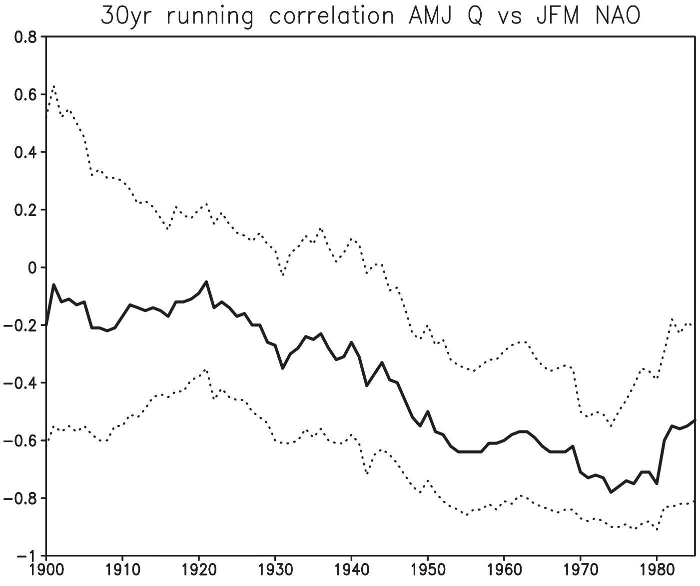

Fig. 4: 30 year running correlation of AMJ Q_{LF} and JFM NAO_{LF} (solid line). Dotted lines indicate upper and lower 95% confidence intervals as determined by 1000 sample randomised Monte Carlo simulation.

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From Bourles: On the Gulf of Guinea and the West African Monsoon (page 15)

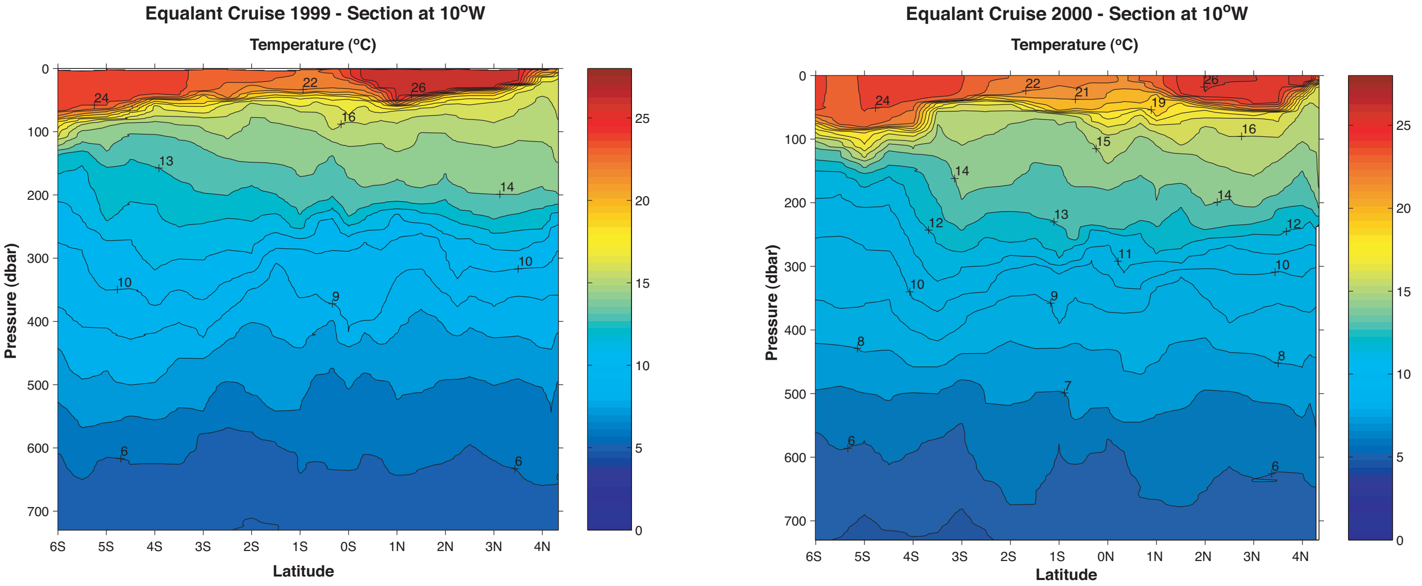
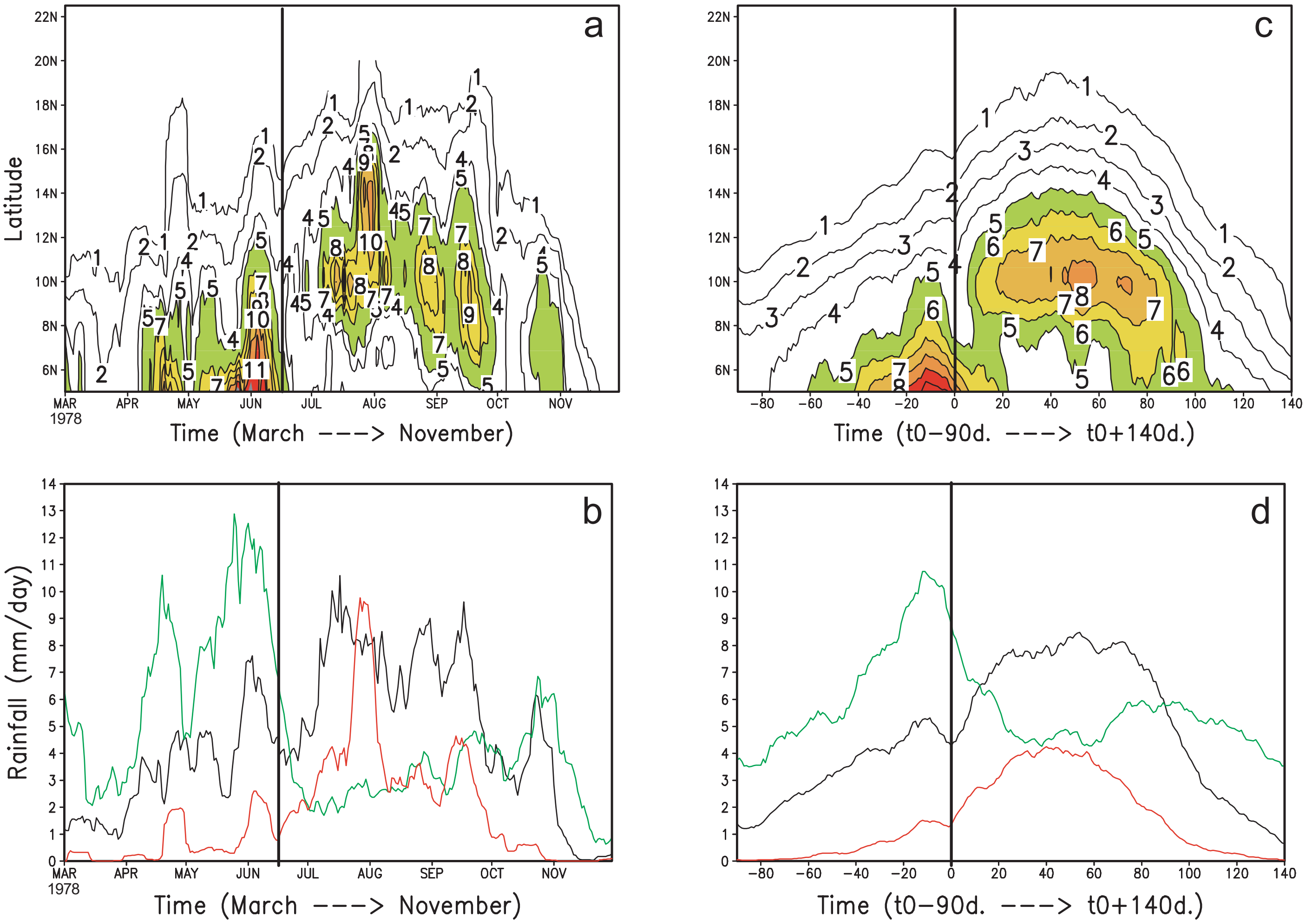


Fig. 2: Latitude-depth sections of temperature (°C) along 10°W, from 6°S to the African coast and for the first 700m depth, during August 1999 (left) and July 2000 (right).

From Sultan and Janicot: The pre-onset and the onset of the Monsoon system over West Africa (page 22)



Caption on page 31

From Cook et al.: Mesoscale modelling of the African Humid Period (page 27)

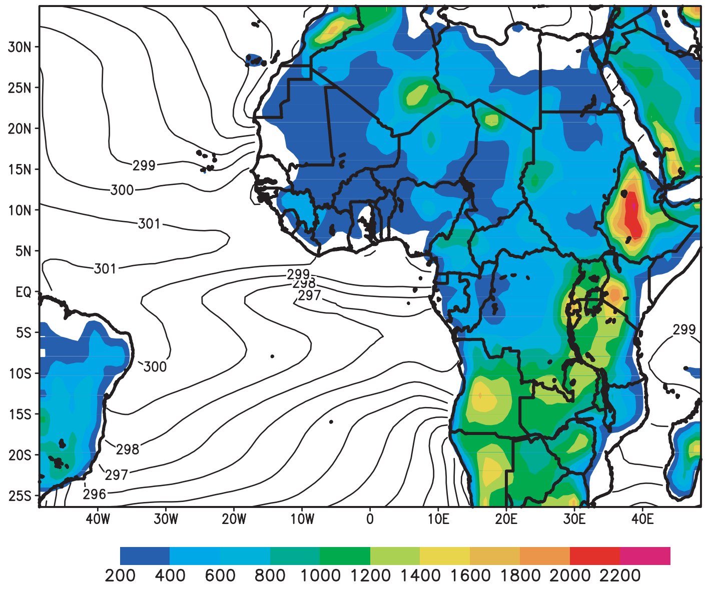


Fig. 1: Regional climate model domain for the African Humid Period simulations. Shading on Africa denotes topography, with the elevation scale in meters indicated in the color bar. Contours are present day SSTs as resolved in the model.

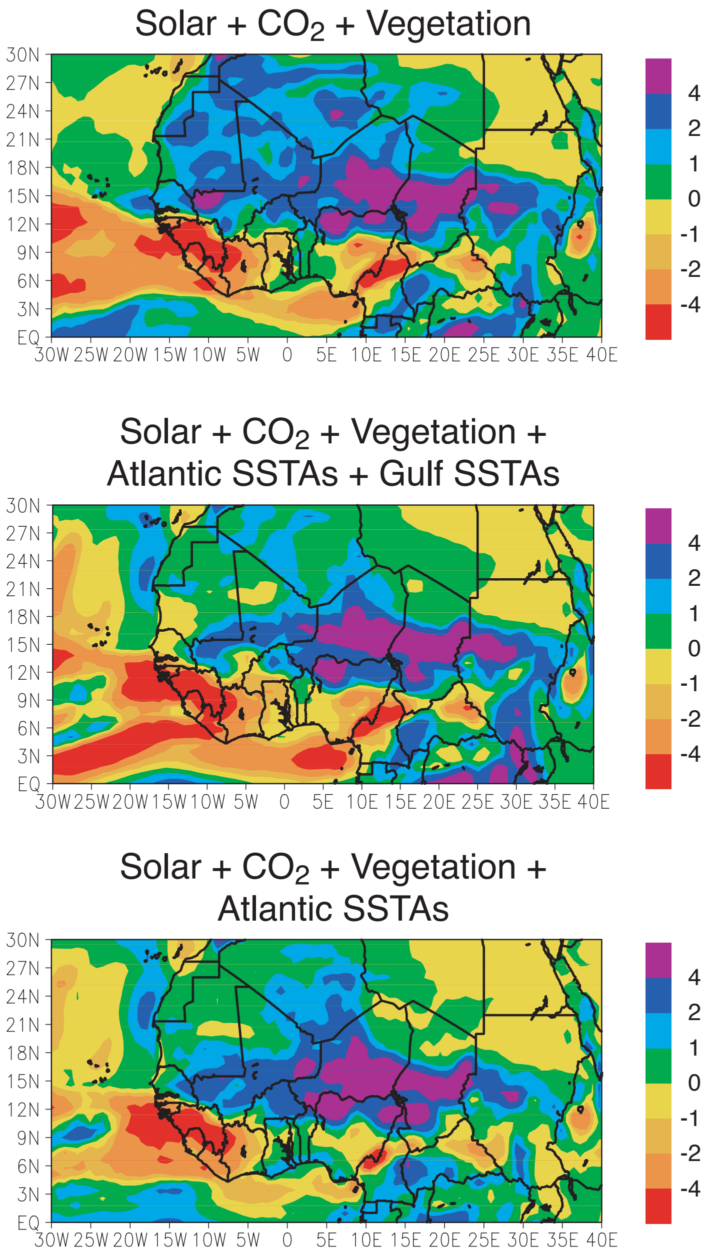


Fig. 2 (right): Precipitation differences from present day in the RCM with African Humid Period values of (a) solar forcing, vegetation, and atmospheric CO_2 concentrations; (b) SSTAs in the eastern Atlantic and Gulf of Guinea in addition to solar forcing, vegetation, and atmospheric CO_2 concentrations; and (c) SSTAs in the eastern Atlantic only plus to solar forcing, vegetation, and atmospheric CO_2 concentrations. Contour units are mm/day.

Fig. 2 (left): (a) Time-latitude diagram from 1 March to 30 November 1978 of daily rainfall (mm day^{-1}), averaged over 10°W-10°E and filtered to remove variability lower than 10 days. Values greater than 5 mm.day^{-1} are shaded. (b) Time sections of diagram (a) at 5°N (green curve), 10°N (black curve) and 15°N (red curve). On the two panels, the vertical line localizes the date selected for the ITCZ shift (17 June). (c) Composite time-latitude diagram of daily rainfall (mm.day^{-1}) averaged over 10°W-10°E, filtered to remove rainfall variability lower than 10 days, and averaged over the period 1968-1990 by using as the reference date the shift date of the ITCZ for each year. Values are presented from t_0 (the shift date) minus 90 days to t_0 plus 140 days. Values greater than 5 mm.day^{-1} are shaded. (d) Time sections of diagram (c) at 5°N (green curve), 10°N (black curve) and 15°N (red curve). On the two panels the vertical line localizes the date of the ITCZ shift at t_0 (the mean date over the period 1968-1990 is 24 June).

From Bader et al.: The role of tropical SSTs in forcing Sahelian rainfall variations (page 17)

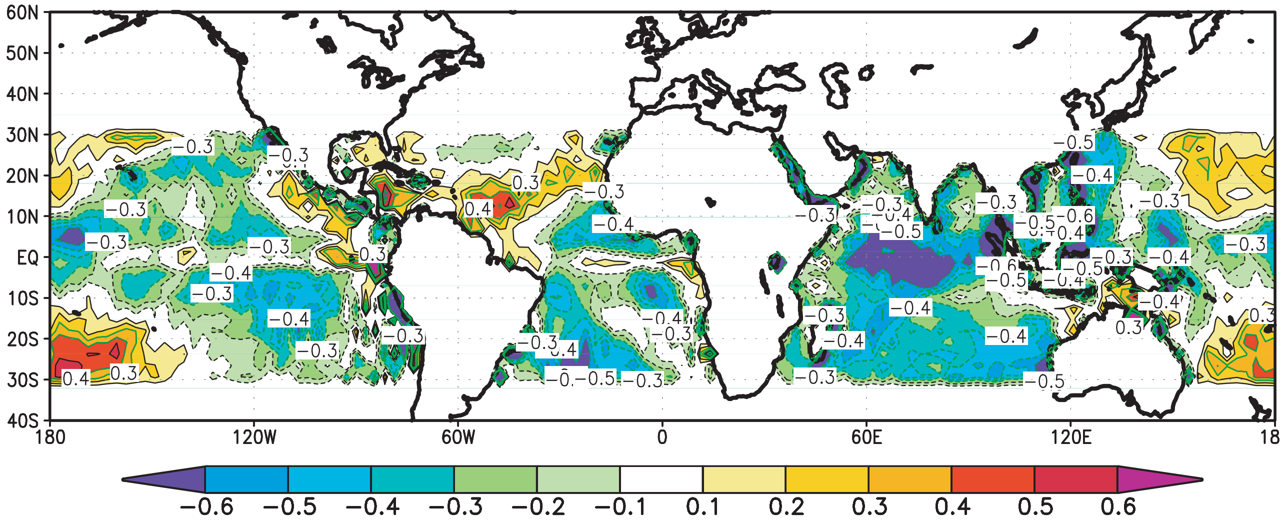


Fig. 1: JJAS SST anomaly in the tropics (Wet-Mode (1951-1960) minus Dry-Mode (1979-1995)); units: Kelvin.

From Black: The impact of Indian and Pacific Ocean processes on the East African short rains (page 40)

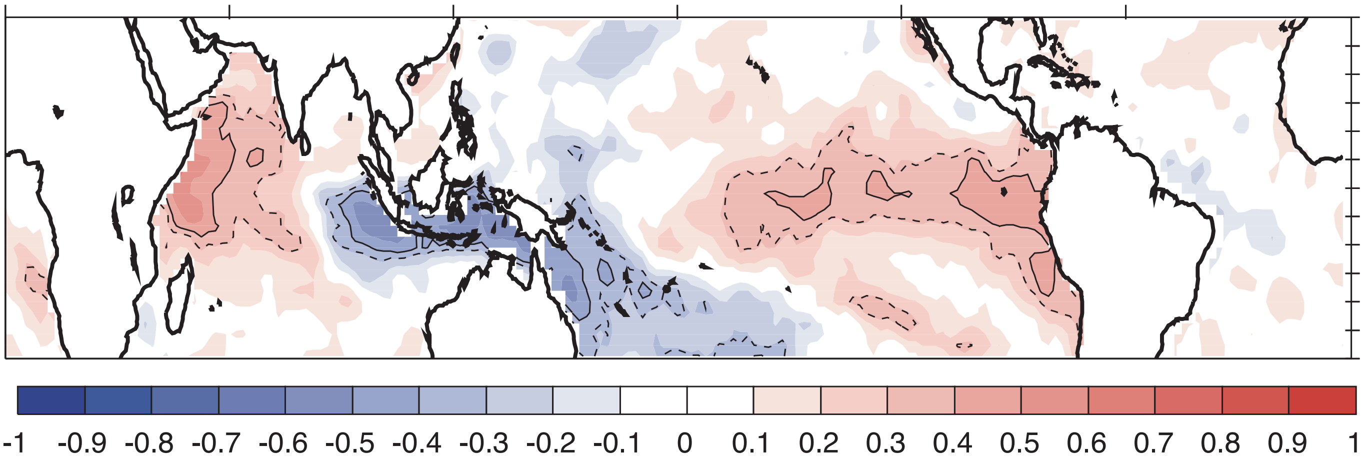


Fig. 2 (above): Correlation between October rainfall in coastal, equatorial East Africa and October SST at every point on the globe for 1958-1997 (dashed lines denote 95% significance and solid lines denote 99% significance). The rainfall data are taken from the CRU dataset and the SST is taken from the GISST dataset.

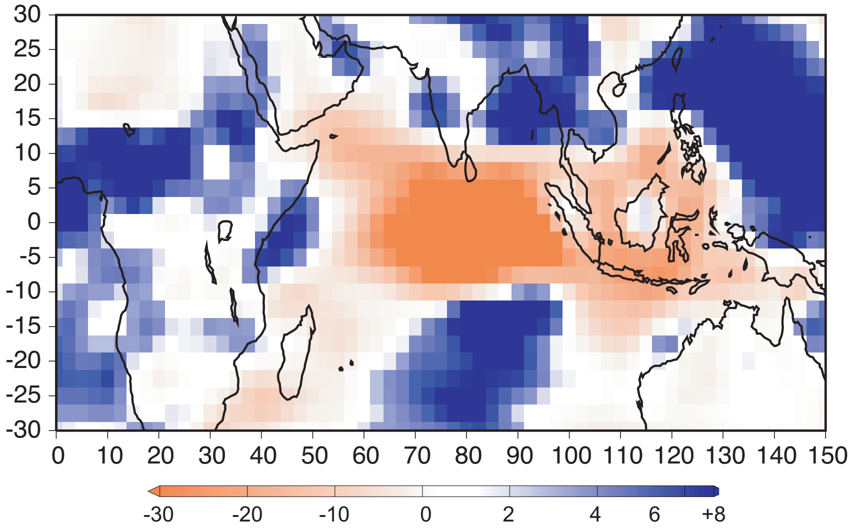


Fig. 6: Composite of October westward moisture flux anomaly during dipole years in the Indian Ocean basin.

From Behera et al.: Impact of the Indian Ocean Dipole on the East African Short Rains: A CGCM Study (page 43)

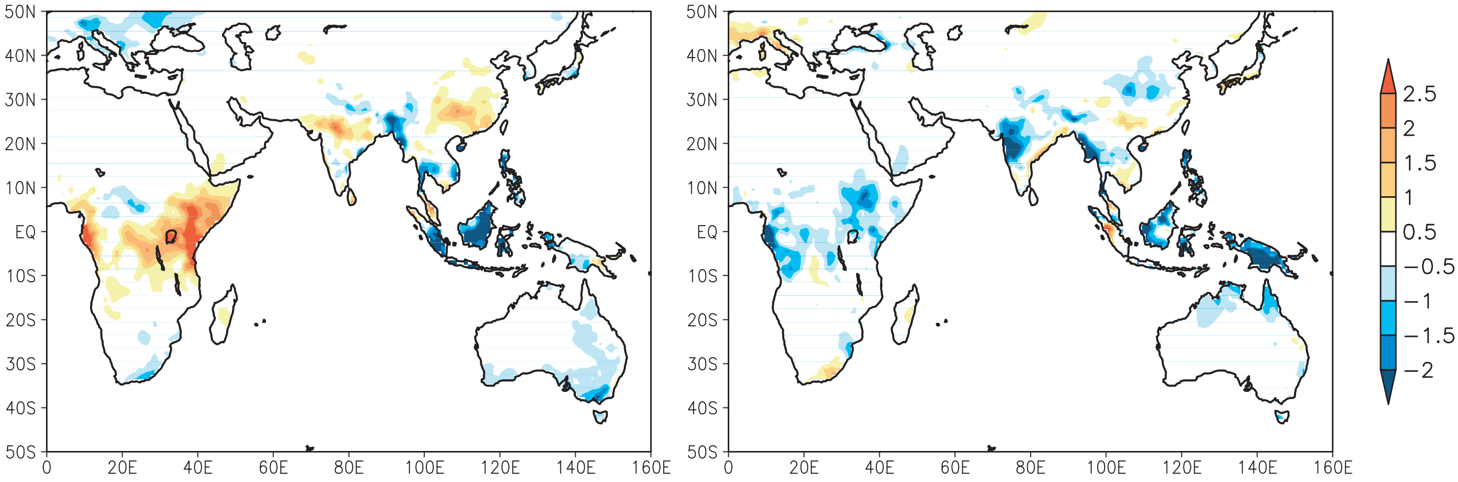


Fig. 1: Composite rainfall anomalies (mm/day) for September-November during pure IOD (left panel) and pure ENSO (right panel) events. The years considered in the composite are given in Yamagata et al. (2002). The original rainfall data are from Willmott and Matsuura (1995).

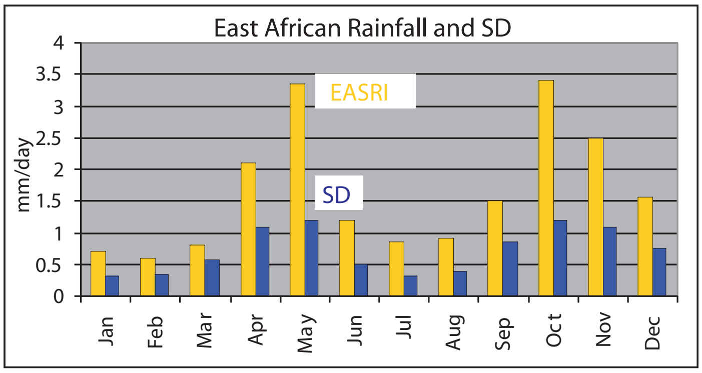


Fig. 2: Modeled seasonal distribution of East African rainfall (yellow) and its standard deviation (blue).

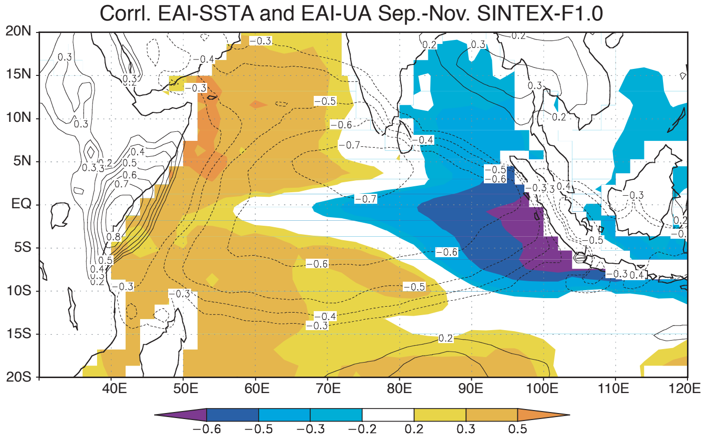


Fig. 3: Correlation of EASRI with the anomalies of SST (shaded) and zonal wind (contour) during September-November.

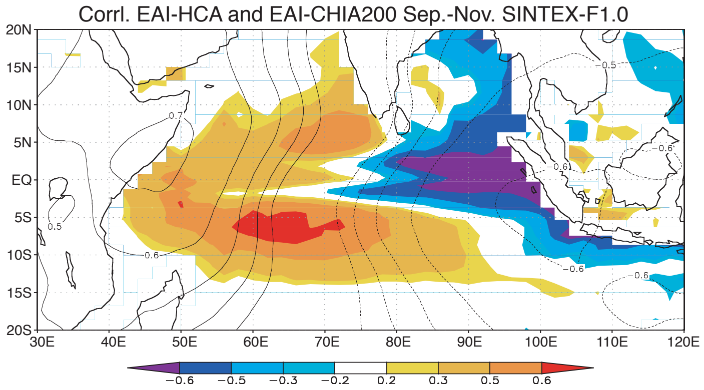


Fig. 4: Correlation of EASRI with the anomalies of heat content of the upper 300m (shaded) and the 200 hPa velocity potential during September-November.

From Tadross et al.: Calculating the onset of the maize growing season over southern Africa using GTS and CMAP data (page 48)

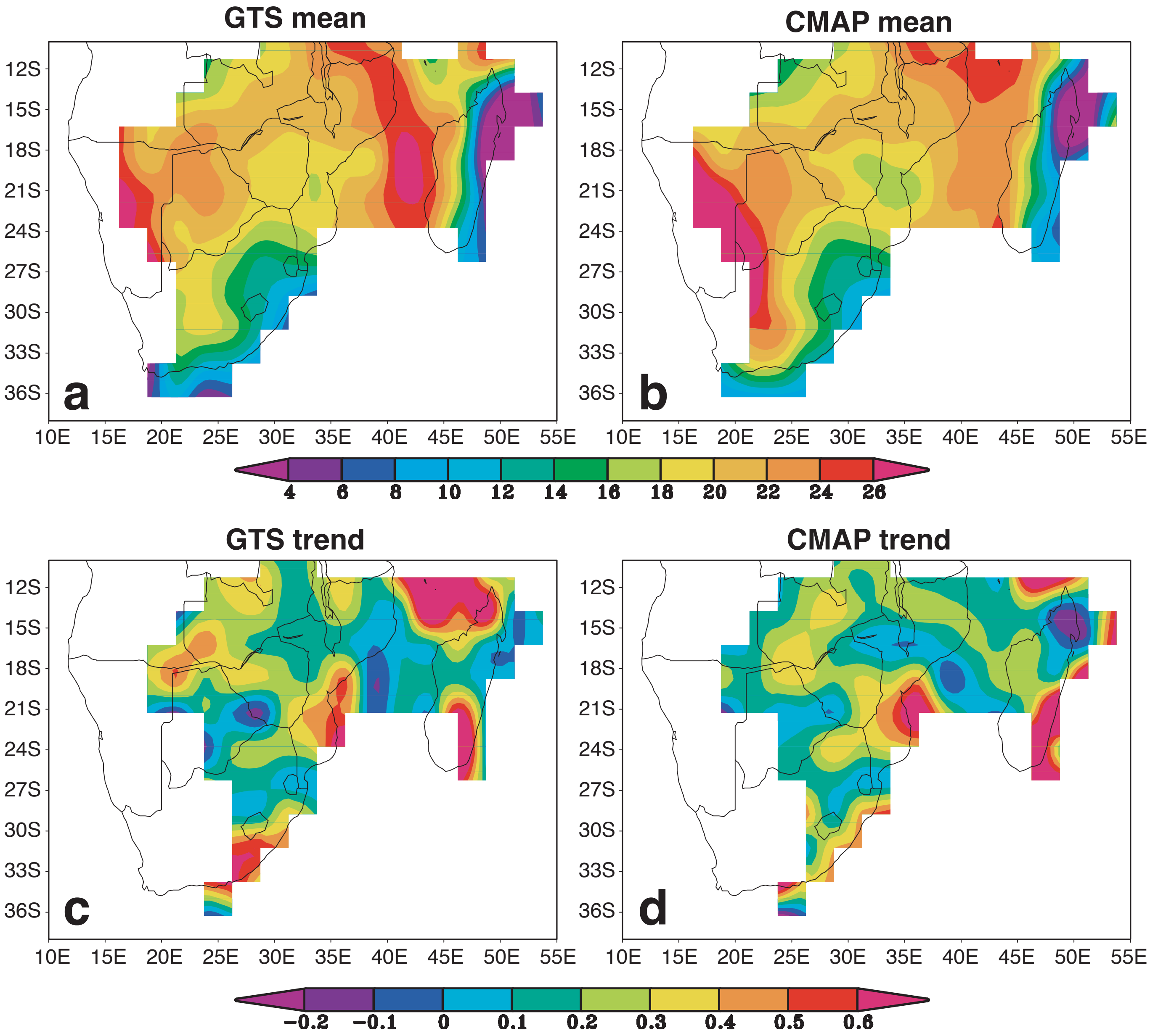


Fig. 3: Mean onset (number of pentads after August 3rd) for a) GTS and b) CMAP. Onset trend (pentads/year) for c) GTS and d) CMAP for the period 1979-1999.

continued from page 29

variance (67%) with the HF component contributing less (30%).

A notable finding of our analysis is the strong negative association between AMJ Q and the NAO during the boreal winter/spring (DJF-MAM) (Table 1). Indeed, winter/spring NAO has a significant negative correlation with *annual* Congo River discharge (Table 1). The correlation with the NAO has been stronger in recent decades compared to that in the first half of the 20th century (Figure 4), indicative of some kind of climatic shift around 1950, coincident with the emergence of the 6-8 year multi-annual power in Q. This multi-annual spectral peak in Congo River discharge is broadly similar to the dominant periodicities in found in various indices of the NAO (Hurrell and van Loon, 1997). However, the correlation of AMJ Q and winter NAO is significant for both the HF and LF components, indicating that the association does not simply result from a relatively few multi-annual 'events' post-1950. McHugh and Rogers (2001) document a similarly strong association between DJF rainfall over southeast African rainfall (0-16ºS, 25-40ºE) and the NAO. It is appears, therefore, that the NAO exerts a substantial influence on the climate of an extensive region of tropical Africa from the Atlantic to the Indian Ocean.

The nature of this teleconnection linking CEA climate with the North Atlantic is demonstrated through the analysis of the large-scale zonal wind field. AMJ Q_{LF} is strongly positively correlated with JFM 500hPa zonal winds over CEA (Figure 5a), part of a coherent structure of five bands of alternating sign extending from the polar North Atlantic to equatorial Africa, strongly characteristic of the NAO (Figure 5b). The structure is very similar for the HF component (not shown). Correlations of AMJ Q_{LF} and JFM zonal wind (LF) over CEA are positive throughout the troposphere but peak near 550hPa in a broad band either side of the equator (Fig-

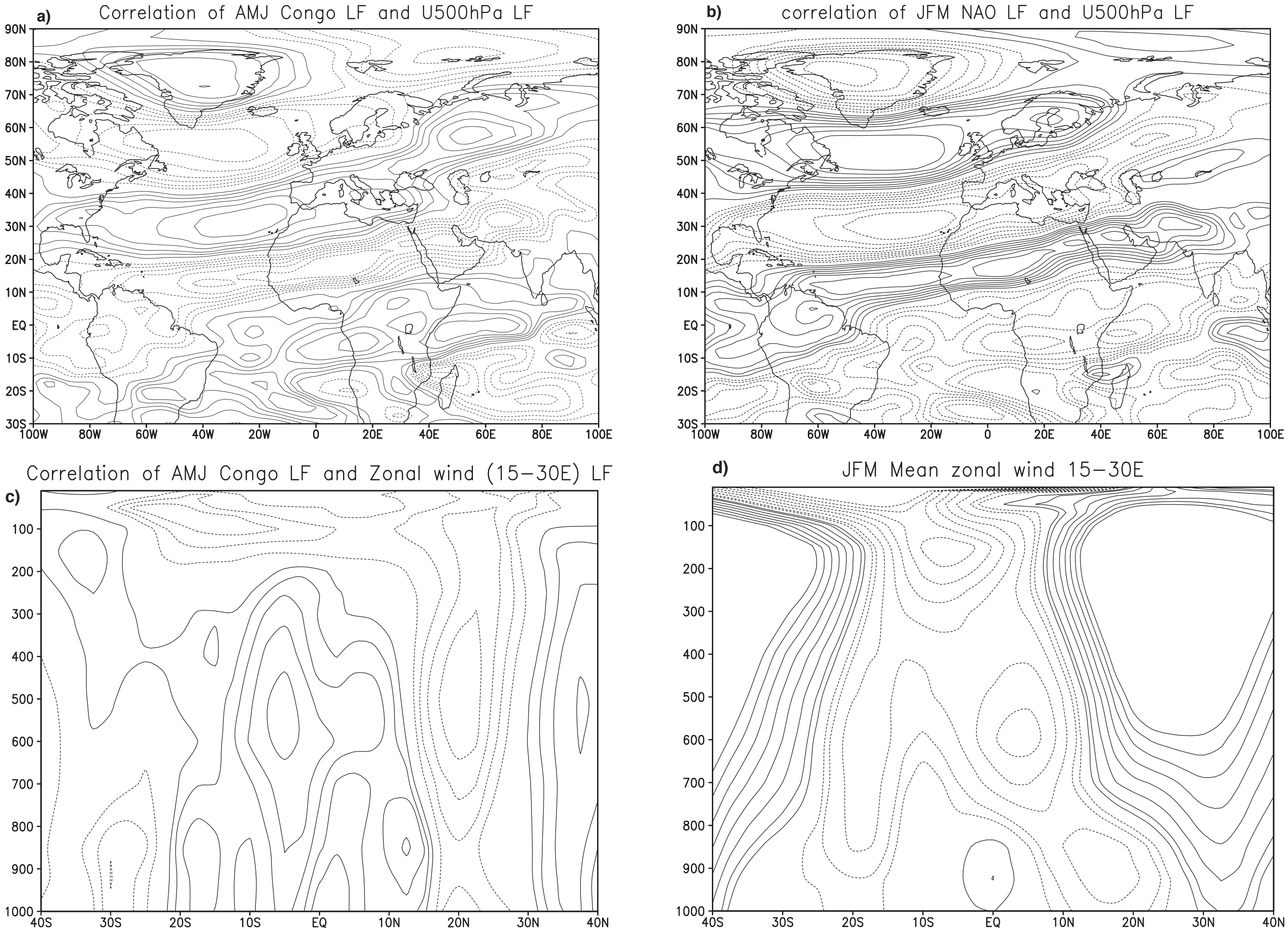


Fig. 5: (a) Correlation of Q_{LF} and LF component of 500hPa zonal wind, (b) correlation of NAO_{LF} and LF component of 500hPa zonal wind, (c) Latitude/height plot of correlation of Q_{LF} and LF component of zonal wind averaged over 15-30ºE, (d) Latitude/height plot of mean zonal wind averaged over 15-30ºE (ms^{-1}). For correlations, positive (negative) contour values are solid (dotted), contour interval is 0.1, zero contour is omitted.

ure 5c). This response is the proximity of the mean position in JFM of the Africa Easterly Jets, located north (AEJ-N, near 4ºN) and south (AEJ-S, near 17ºS) of the equator (Figure 5d). Thus, anomalously wet (dry) events over CEA during the boreal spring season are associated with an anomalously weak (strong) AEJ-N and AEJ-S during the winter/spring.

Conclusions

Our understanding of the climate of Central Equatorial African region is arguably weaker than that of any other tropical continental region. During AMJ, the weaker of the two main Congo River discharge seasons, we document a strong association with the large-scale mid-tropospheric zonal flow in the CEA region, which appears part of a coherent structure of zonal wind anomalies associated with the NAO pattern. That an important control on equatorial African climate should be a dominant pattern of winter/spring extra-tropical circulation in the northern hemisphere is all the more interesting given the relatively weak forcing from tropical SSTs, including ENSO, in this season.

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Interannual variability of growing season over drought-prone areas of Ethiopia

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During the 1970s and 1980s, the words “drought”, “famine”, and “Ethiopia” unfortunately were highly synonymous. Such dire conditions returned to Ethiopia in some of the intervening years, and prevail in mid-2003. Most devastating Ethiopian droughts are associated with failure of summer (Kiremt) rains that account for up to 95% of total annual rainfall (Fig. 1). Despite this situation, fundamental understanding of the patterns and causes of the seasonal-to-interannual variability of Kiremt rainfall has remained conspicuously absent. The most drought-prone areas are located over eastern/northeastern Ethiopia (Fig. 1), where annual rainfall averages between 100-1000 mm and exhibits marked interannual variability (coefficient of variation for individual stations ranges from 30-60%). Here, for the first time we examine the interannual variability of Kiremt over the drought-prone areas during 1965-99 in terms of its onset, cessation, and growing season duration, all of which are crucially important for Ethiopia’s food supply, and identify some preliminary associations with ENSO events.

Kiremt onset and cessation dates, dry spell lengths, and total and effective growing season durations were determined for individual stations in Fig. 1 from their daily rainfall totals, and then averaged across all stations. For most stations, Kiremt was taken as the first day receiving at least 10 mm of rain, provided no continuous dry period of eight days (totalling ≤ 0.1 mm) or more occurred in the subsequent 30 days. This onset definition was varied slightly for a few stations in the extreme north. Kiremt cessation was taken as the first day of a dry spell of at least 20 days that occurred after onset. Intra-Kiremt dry spells were defined as periods of at least five days when rainfall totaled no more than 5 mm. Complete growing season duration was the difference between onset and cessation, from which the cumulative number of dry spell days was subtracted to give the effective growing season duration.

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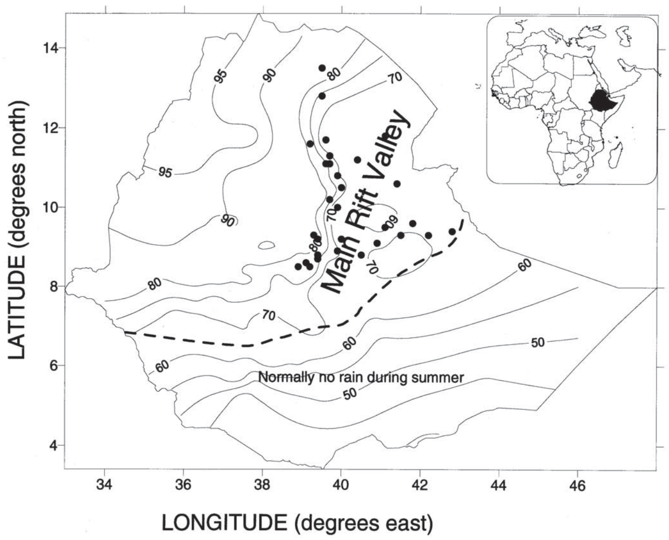

Fig. 1: Orientation Map locating rainfall stations used (dots, which delimit study area) and giving average percentage of annual rainfall occurring during May-October (isopleths). North of bold broken line, the main (Kiremt) rainy season occurs during June-September; area south of line has rainfall maxima in April and October and normally no rain in summer.

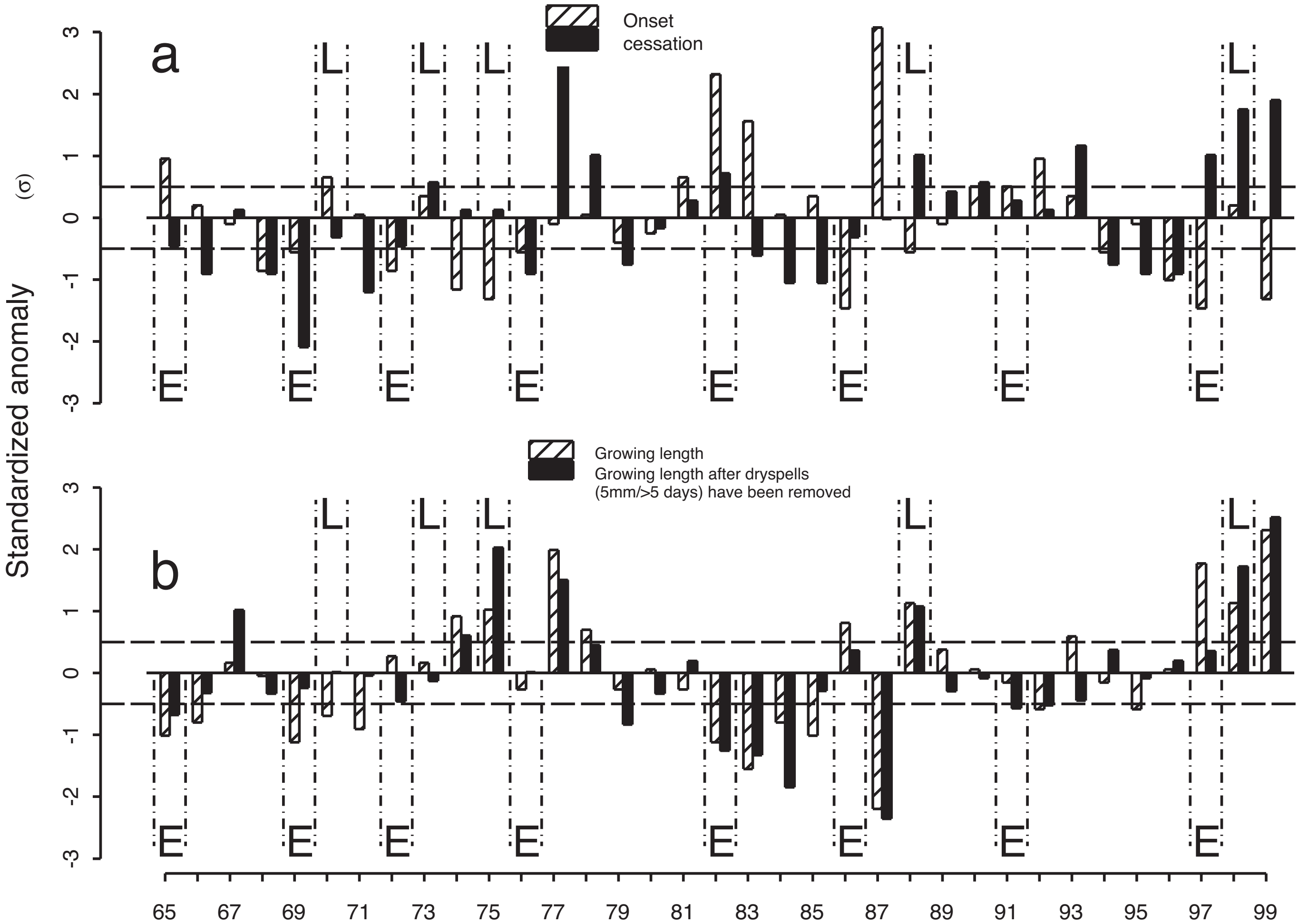

Fig. 2: 1965-99 time series of standardized anomalies (σ) of Kiremt (a) onset and cessation and (b) total and effective growing season duration averaged over eastern and northeastern Ethiopian stations in Fig. 1. See text for definitions of onset, cessation, and growing season durations. In (a) positive (negative) anomalies indicate late (early) onset and cessation, and in (b) positive (negative) anomalies indicate long (short) growing seasons. E and L denote onset years (Year 0) of warm and cold Tropical Pacific ENSO events, respectively (Smith and Ropelewski, 1997; Montroy et al., 1998).

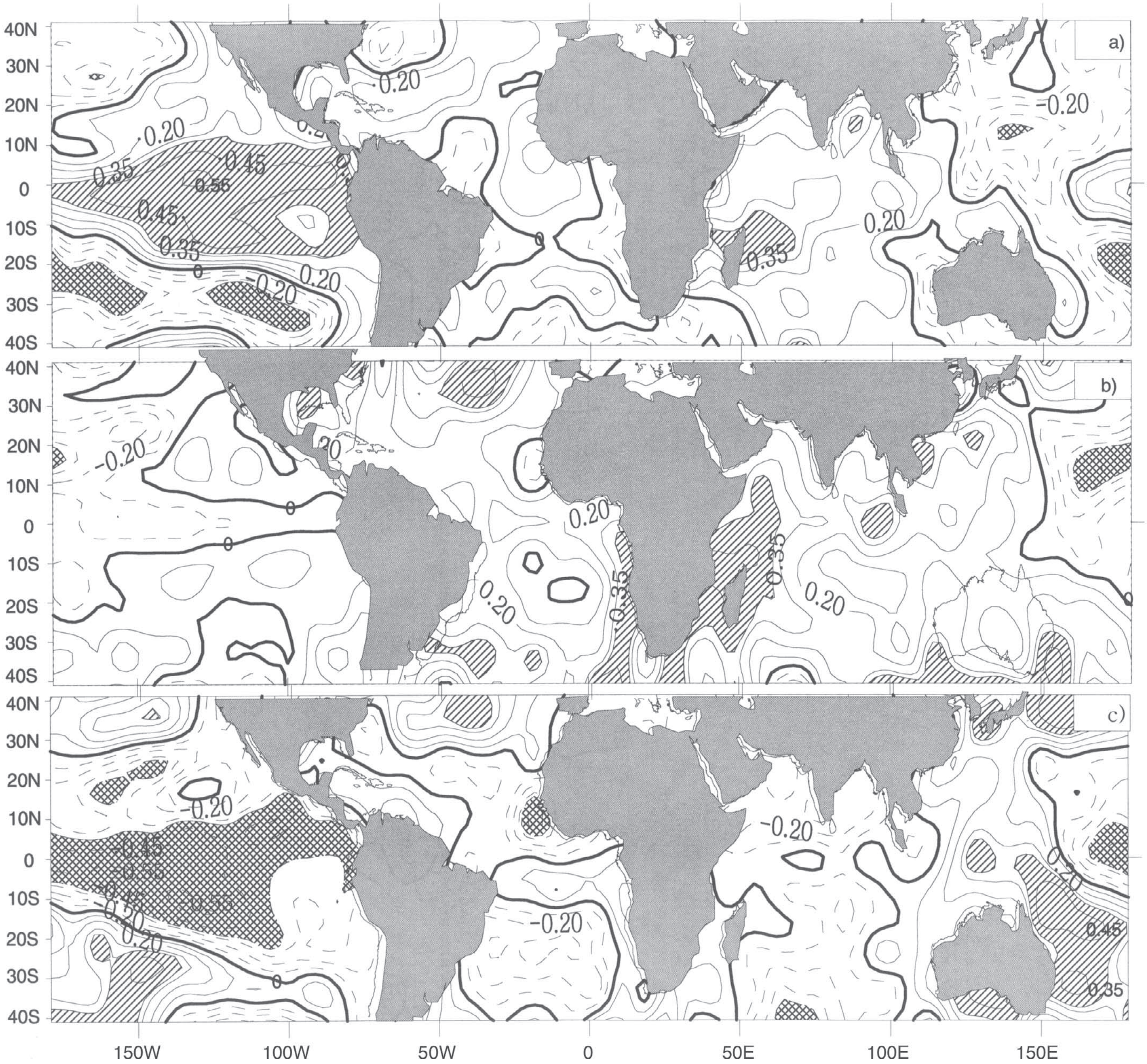

Fig. 3: Representative correlation patterns between key Kiremt parameters and seasonal sea surface temperature (SST) anomaly fields for tropics-subtropics for 1965-99. (a) Kiremt onset versus December-February SST, (b) Kiremt cessation versus July-September SST, and (c) effective Kiremt growing length versus July-September SST. Positive (negative) correlations are denoted by solid (broken) isopleths. Areas of positive (negative) correlations significant at 95% confidence level are hatched (cross-hatched).

There is significant interannual variability in the onset, cessation, and growing length of Kiremt that reflects some associations with ENSO events (Fig. 2). Averaged over eastern and northeastern Ethiopia, Kiremt onset was earlier (≤-0.5 σ)/later (≥+0.5 σ) than normal in 34%/26% of years (Fig. 2a). 42% of earlier than normal Kiremt onsets occurred in the onset year (Year 0) of a warm ENSO phase; this involved five of the eight warm ENSO phases. Interestingly, in the remaining three warm ENSO phases (especially 1982-83) Kiremt onset was later than normal, which constituted one-third of delayed Kiremts during 1965-99. In contrast, none of the near-normal Kiremt onsets (between ±0.5 σ; 40% of years) occurred during Year 0 of a warm ENSO phase, and only two were in Year 0 of a cold ENSO phase. It is striking that the remaining 12 of the 14 near-normal Kiremt onsets occurred in years that did not include El Niño or La Niña onsets. Few large departures in cessation dates occurred during Year 0 of El Niño or La Niña events; half of El Niño events coincided with near-normal Kiremt onsets. Instead, most large departures in Kiremt cessation occurred during neutral ENSO phases, most notably 10 of 12 late Kiremt onsets.

Growing length also shows some association with ENSO events when the cumulative dry spell length is removed (Fig. 2b). Averaged over eastern and northeastern Ethiopia (Fig. 1), 23%/20% of effective Kiremt growing lengths were shorter (≤-0.5 σ)/longer (≥+0.5 σ) than normal. There is a tendency for short/long effective Kiremts to accompany El Niño/La Niña events. Three of 8 short Kiremts occurred among the 8 El Niño events and no short Kiremts coincided with La Niñas. Conversely, 3 of 7 long Kiremts were in La Niña years, and no long Kiremts coincided with El Niños. A majority of Kiremts (57%) were of near-normal effective length (between ±0.5 σ); 13 of the 20 occurred during neutral ENSO phases.

The above results were complemented by correlation analyses linking the three key Kiremt parameters (onset, cessation, effective growing length) to three-month tropical-subtropical sea surface temperature (SST) anomaly fields for December-February, April-June, July-September, September-November, and October-December for the 1965-99 study period. Fig. 3 presents one representative global correlation map for each Kiremt parameter. Kiremt onset is positively correlated with preceding December-February SST over the equatorial central and eastern Pacific Ocean (Fig. 3a); the pattern persists through April-June but significantly diminishes during July-September (not shown). This result gives greater emphasis to the above tendency for some El Niño events to be associated with late Kiremt onsets, as opposed to other El Niño events coinciding with early starts to Kiremt. It likely reflects the extended delays in Kiremt onset during the 1982-83 El Niño, and waning of the 1986 event through early 1987 (Fig. 2a). Kiremt cessation correlates poorly with SST in the tropical Atlantic and Pacific basins, but more strongly (positively) with SST in the western Indian Ocean and Arabian Sea. This Indian Ocean-Arabian Sea linkage maximizes during July-September (Fig. 3b), but similar statistically significant correlations occur earlier during April-June and persist through the September-November and October-December periods (not shown). This positive relation indicates that warm SSTs in the Indian Ocean and Arabian Sea are likely to be associated with delayed Kiremt cessation and hence prolonged rain, perhaps in association with an increase in tropical storms/depressions over the Arabian Sea near the end of Kiremt (Lee et al., 1989; Tadesse, 1994; Lander and Guard, 1998).

Effective Kiremt growing length is significantly correlated with Tropical Pacific SST; the pattern is best developed in July-September (Fig. 3c) after originating during April-June (not shown). The correlation pattern includes two major features - negative linkages with central and eastern equatorial Pacific SST that confirm the above tendency for short/long effective Kiremts to accompany El Niño/La Niña events; and positive associations with SST in a large north-south oriented area immediately east of New Guinea and Australia. Fig. 3c does not suggest any strong relations between effective Kiremt length and SST in the Atlantic and Indian Oceans.

The teleconnection processes contributing to the foregoing statistical relations now are being investigated using a coupled GCM-regional modelling approach.

Acknowledgement

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The impact of Indian and Pacific Ocean processes on the East African short rains

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Introduction

Widespread poverty and the dependence of much of the population on rain-fed agriculture make East Africa particularly vulnerable to the effects of climate variability. Knowledge of the processes controlling rainfall is essential to the development of seasonal forecasting systems, which could be used to mitigate the effects of drought and flood. Moreover, understanding the climate of East Africa is not only important for the assessment of regional impacts. Recent work has highlighted the role that East African convection plays in modulating the circulation within the Indian Ocean basin (see for example Webster et al. (1999)). The nature of the relationship between East African rainfall and Indian and Pacific Ocean sea surface temperature (SST) is therefore relevant to the dynamics of the Indo-Pacific region as a whole. The following article summarises the results of a study that used observational data to unravel the complex relationship between the boreal autumn rainfall in equatorial East Africa, Indian Ocean processes (in particular the Indian Ocean Dipole (IOD)) and the El Niño-Southern Oscillation (ENSO).

The relationship between the Indian Ocean dipole and East African rainfall

The seasonal cycle of rainfall in coastal, equatorial East Africa is given in Figure 1, which also shows the location of all the regions referred to in the text. It can be seen that there are two main rainy seasons, the long rains, which occur between March and May, and the short rains, which peak in October and November. Although they are not as strong as the long rains, the short rains exhibit greater interannual variability. This study will focus on the short rains.

Figure 2 (page 32) shows the contemporaneous correlation between the short rains in the study area and SST at every point within the tropics. Three regions of strong, geographically coherent correlations are evident: positive correlations in the tropical western Indian Ocean and eastern tropical Pacific and negative correlation in the tropical eastern Indian Ocean. This implies that anomalously strong short rains are associated with warming in the western Indian Ocean and eastern Pacific, and cooling in the eastern Indian Ocean - a pattern of SST that is characteristic of the build up to an El Niño. This is consistent with the time series shown in Figure 3, which illustrates that during the three strongest El Niños (1972, 1982 and 1997), rainfall was well above average. However, it can also be seen that during some other weaker El Niños, (1969, 1976, 1986, 1987 and 1991), rainfall was below average, suggesting that the response of the East African short rains to ENSO is modulated by other factors.

Although the relationship between ENSO and interannual variability in East African rainfall has been examined extensively (see for example Hastenrath et al. (1993) and Mutai et al. (1998)), the role of the Indian Ocean has received relatively little attention. Recently, however, there has been increased interest in this issue, following the description of the Indian Ocean dipole - an interannual mode of variability in Indian Ocean SST that is characterised by a perturbed zonal gradient in SST and anomalous low level winds (see Saji et al. (1999)). The strength of the dipole is measured by the dipole mode index (DMI), which is defined as the difference in SST anomaly between the western and eastern Indian Ocean (see Figure 1 for the location of these regions). Figure 3 shows that rainfall in the region of interest is above average during every dipole year and that the five highest rainfall seasons occurred when the dipole was active, implying that the Indian Ocean dipole exerts some control on strong rainfall in East Africa. The fact that rainfall is above average during *every* IOD event but only during *some* El

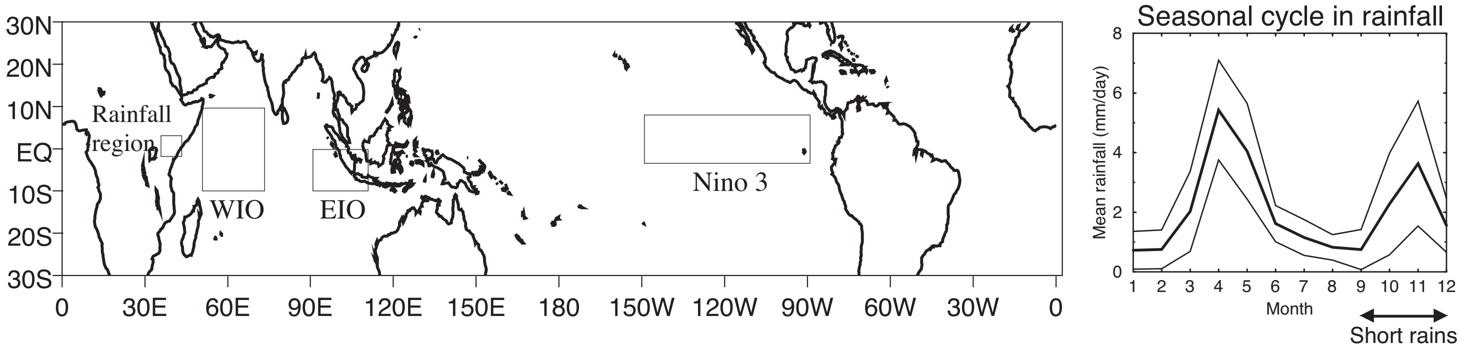


Fig. 1: (a) Location of the regions referred to in the text. (b) Seasonal cycle in rainfall in coastal, equatorial East Africa.

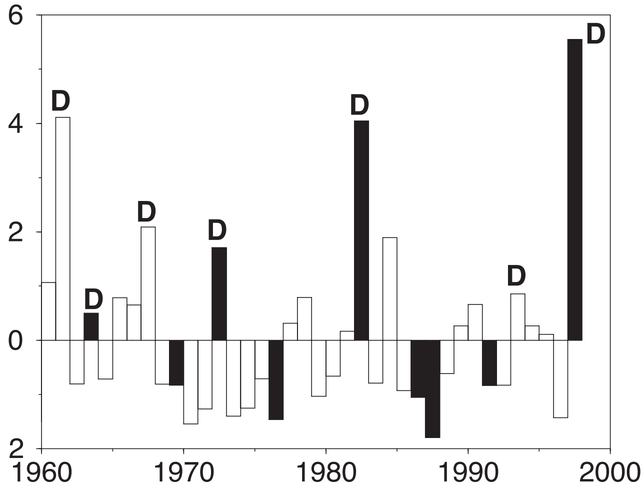


Fig. 3: A time series of September-November mean daily rainfall for 1960 – 1997. El Niño years are filled black and IOD years are indicated by 'D'.

Niños suggests that the short rains' link with the IOD is stronger than their link with El Niño.

The association apparent from the time series plotted in Figure 3 is not, in itself, convincing evidence that the IOD drives strong rainfall in East Africa. The SST in the western and eastern Indian Ocean, the eastern Pacific Ocean and the DMI are strongly cross-correlated with each other. This means that the apparent association between dipole events and strong East African rainfall could be an indirect effect of a causal relationship with SST anomalies in either the western or eastern Indian Ocean or even the Niño 3 region of the Pacific. Further analysis, however, shows that this is not the case. For each of the regions in question, the rainfall time series was divided into four sets: (i) dipoles with high SST, (ii) dipoles with low SST, (iii) non-dipoles with high SST and (iv) non-dipoles with low SST. Figure 4 shows three plots (one for each region) of the mean SST plotted against the mean Sep.-Nov. seasonal rainfall for each of the four groups (with the error bars denoting standard deviation). It is evident that rainfall during dipole years is consistently higher than rainfall during non-dipole years regardless of the SST in any of regions analysed. This confirms that the link between East African rainfall and SST in the tropical Pacific is weaker than its link with the IOD. It is also clear that the link with the IOD as a whole is stronger than the link with the SST in either of the regions forming the poles of the dipole.

A dynamic scenario for the link between the Indian Ocean dipole and strong short rains

Black et al. (2003) proposed a dynamic scenario by which the Indian Ocean dipole could cause excessively strong short rains in East Africa. Figure 5 compares the zonal 850hPa wind during dipole events with the mean climatology. It can be seen that the mean wind field is dominated by easterly flow across the southern Indian Ocean, which delivers moisture to coastal East Africa. It is important to note, however, that much of the moisture carried by the easterly flow over the southern Indian Ocean is returned back across the northern Indian Ocean by a westerly flow. During all dipole years, this flow is severely weakened (although it was only actually reversed during 1997). It is postulated that it is the weakening of this westerly flow, which normally returns moisture to the Indian Ocean, that leads to heavier than usual rain on the African continent. This idea is supported by Fig. 6 (page 32), which shows that the westward moisture flux during dipole years is enhanced around the African coast and markedly reduced in the Indian Ocean. Following the ideas of Lindzen and Nigam (1987), it is suggested that the anomalous winds during dipole years are a direct result

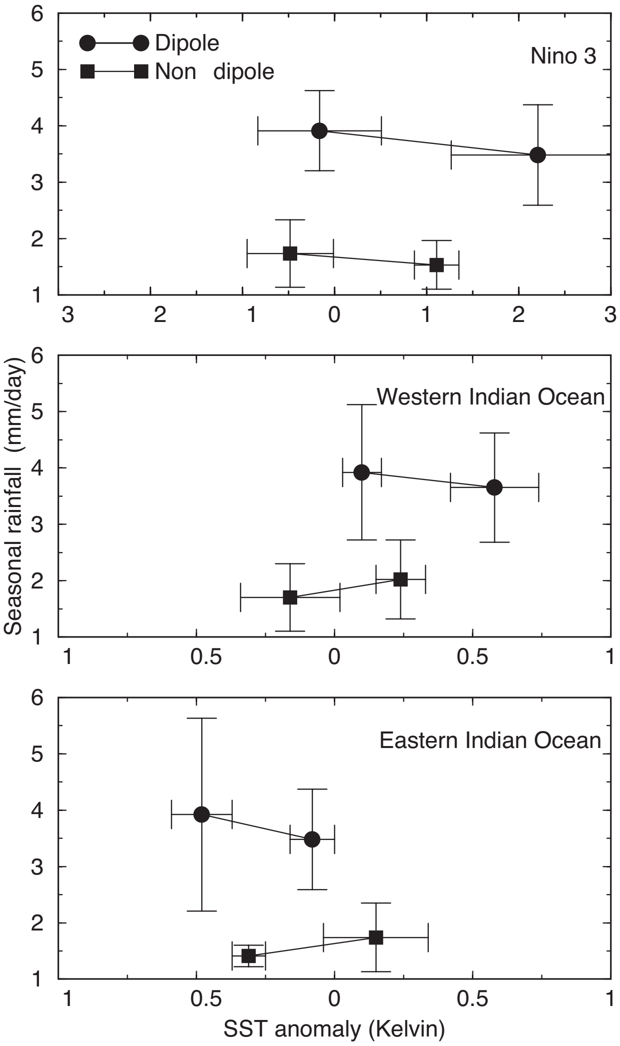
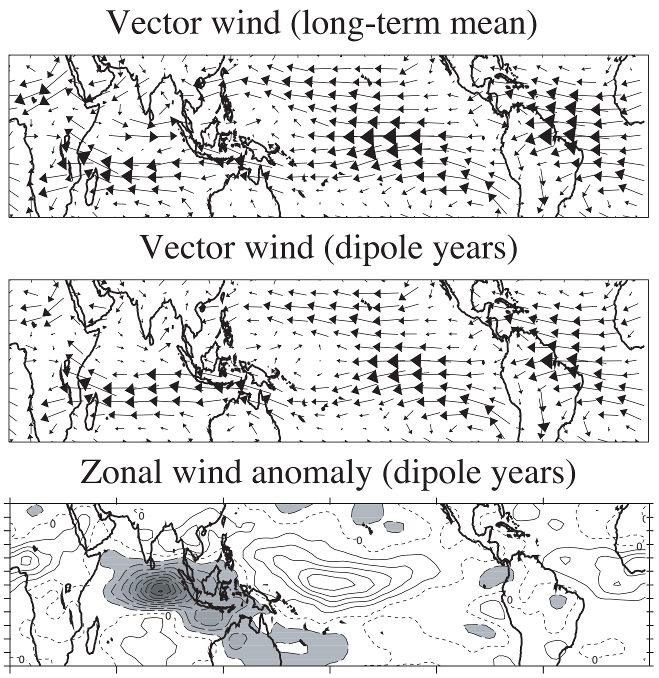


Fig. 4: Mean Sep.-Nov. seasonal rainfall in East Africa plotted against mean SST for (a) Niño3, (b) Western Indian Ocean SST, (c) Eastern Indian Ocean SST. The points on the graph represent the mean and standard deviation in SST and rainfall for four groups of years: (i) dipoles with warmer SST (ii) dipoles with colder SST (iii) non-dipoles with warmer SST (iv) dipoles with colder SST.


Vector wind (long-term mean)

Vector wind (dipole years)

Zonal wind anomaly (dipole years)

Fig. 5: (a) Long-term mean 850hPa wind for October;
(b) a composite of October 850hPa wind during dipole years;
(c) a composite of October zonal wind anomaly during dipole years (negative values shaded, contour interval 1 m/s).

of the perturbation of the east-west gradient in SST across the Indian Ocean. This would explain the previous observation that it is the dipole as a whole, rather than the SST at either of the poles, that is associated with high rainfall in East Africa.

The teleconnection between East African rainfall and El Niño

Figure 3 shows that each of the four El Niños associated with high rainfall in East Africa, (1963, 1972, 1982 and 1997), coincided with a dipole event. Moreover, there is a significant correlation (R=0.57) between the DMI and Niño 3 SST. This evidence is consistent with the observed teleconnection between East African rainfall and ENSO being the result of a link between ENSO and the Indian Ocean Dipole. However, Figure 3 shows that the relationship between the IOD and El Niño is complex. In some IOD years, such as 1961, there is no El Niño; in other years, such as 1986, there is an El Niño but no IOD. Closer analysis, however, reveals that an IOD only ensues if the El Niño is strong during autumn. For example, in 1986-1987, (the strongest El Niño not associated with an IOD), the event peaked in the summer of 1986 and was weak during autumn of both 1986 and 1987. The occurrence of IOD events when there is no El Niño (most notably during 1961) suggests that the IOD can be triggered by factors other than ENSO.

A link between El Niño and the IOD is physically plausible. El Niño events are associated with a general warming of the Indian Ocean. However, in the east, there are localised regions of cooling along the Sumatran coast and off Australia, in the region of the Indonesian through-flow. In the south, the cooling may be caused by ENSO related anomalies in water transport via the Indonesian throughflow (see Meyers, 1996). The anomalies near the Sumatran coast could be a response to anomalous along-shore southerly winds. In autumn, the season during which the IOD peaks, the climatological zonal SST gradient in the Indian Ocean is near zero. Therefore, strong El Niño forcing during the boreal autumn would be likely to cause sufficient cooling in the western Indian Ocean to trigger an IOD event, and subsequently high rainfall in coastal, equatorial East Africa.

Conclusions

- The anomalous zonal wind field that develops as a result of the perturbation in zonal SST gradient that characterises the Indian Ocean dipole causes excessive rainfall in coastal, equatorial East Africa.
- The observed teleconnection between El Niño and East African boreal autumn rainfall is a manifestation of the dynamic link between El Niño and the Indian Ocean dipole.

Acknowledgements

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Impact of the Indian Ocean Dipole on the East African Short Rains: A CGCM Study

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Introduction

The seasonal rainfall in equatorial eastern Africa is characterized by double peaks. This semiannual signal in the rainfall of the region is mainly attributed to the north-south migration of the intertropical convergence zone (ITCZ). The atmospheric convergence over East Africa becomes stronger during the two transition seasons of the monsoon winds when the ITCZ is closer to the equator. Rainfall is higher during the first peak (April-May) compared to the second peak (October-November) (e.g., Hastenrath et al., 1993). The latter is known as the season of short rains. These short rains show higher interannual variability compared to the rainfall of the first season (Hastenrath et al., 1993; Black et al., 2003). Understanding causes of such interannual variability will immensely contribute to regional issues of water management and disease control.

Several previous studies investigated the statistical relationship between the short rains and the SST variability related to the El Niño/Southern Oscillation (ENSO) in the Pacific Ocean (Ropelewski and Halpert, 1987; Ogallo, 1989; Hastenrath et al., 1993; Mutai and Ward, 2000). These studies suggest the existence of a weak relation, i.e. an enhanced rainfall during warm ENSO events. The influence of the Indian Ocean on East African rainfall variability has drawn attention recently (e.g. Goddard and Graham, 1999). In particular, the recent discovery of the Indian Ocean Dipole (IOD) mode has shed new light on this neighbourhood relationship (Saji et al., 1999; Yamagata et al., 2002; Saji and Yamagata, 2003b; Black et al., 2003).

Saji et al. (1999) showed an east-west dipole mode in the Indian Ocean sea surface temperature (SST) anomalies that is coupled to the atmospheric zonal circulation. They also showed that the IOD has a significant correlation with the East African rains; the rainfall is increased (decreased) during a positive (negative) event. Unlike the basin-wide surface warming (cooling) that is related to warm (cold) ENSO, the dipole mode associated with subsurface equatorial ocean dynamics is shown to be independent of the Pacific phenomenon (e.g., Rao et al., 2002; Shinoda et al., 2003). However, about 35% of the dipole events co-occur with ENSO and this raised a debate whether the Indian Ocean could generate its own coupled dipole mode. Several recent studies showed the independent existence of the IOD (e.g. Yamagata et al., 2002; Yamagata et al., 2003; Saji and Yamagata, 2003a). In Fig. 1 (page 33), we show the rainfall anomalies associated with pure IOD and pure ENSO events during boreal fall as described in Yamagata et al. (2002). It is very clear that the independent IOD has a significant influence on the East African Short Rains (EASR). Notice that the ENSO influence is quite different from the conventional view when we remove the co-occurring IOD influence. We address this topic here based on the simulation results using the SINTEX-F1 CGCM adapted for the Earth Simulator.

Model and data

The model results used in the study are obtained from an ocean-atmosphere-land coupled general circulation model (CGCM) simulation. The CGCM known as SINTEX-F1 (SINTEX-FRSGC) is an upgraded version (Masson et al., 2003; Luo et al., 2003) of the SINTEX (Scale Interaction Experiment, a European Commission funded project) model described in Gualdi et al. (2003). The model has been also modified for integration on the Earth Simulator. In this model, the atmospheric component ECHAM-4 (Roeckner et al., 1996) is coupled to the ocean component ORCA (also known as OPA8.2) (Madec et al., 1998) through the coupler OASIS 2.4 (Valcke et al., 2000). The atmosphere model has a spectral triangular truncation of T106 with 19 vertical levels. The details of the coupling strategy are reported in Guilyardi et al. (2001); the model details and its skill to reproduce the Indian Ocean variability can be found in Gualdi et al., (2003). We note that the ocean component OPA8.2 of the ORCA R2 grid uses the Arakawa C grid with a finite mesh of 2^ox1.5^o. The meridional resolution is enhanced equatorward from 1.5^o to 0.5^o. The model's finite mesh is designed in a way that the North Pole is replaced by two node points over land regions, one on North America and the other on Asia. The model has 31 levels in the vertical.

The monthly data from the last 200 years of the total 220 years model simulation is used in the analysis of the present study. The low frequency variabilities of periods longer than 7 years are removed from the dataset.

Model IOD and its impact on the EASR

The SINTEX-F1 has shown very good skill in simulating the IOD and ENSO as in the SINTEX model simulations reported in Gualdi et al. (2003). We have calculated the standard deviations for the model Dipole Mode index (DMI) and for the Niño3 SST index. We note here that the western

Table 1

	EASR-DMI	EASR-Niño3
Correlation (whole year)	0.45	0.08
Correlation (Sep.-Nov.)	0.65	0.28

box (40°-60°E, 10°S-10°N) used in deriving the model DMI is slightly different from the one usually used for calculating the DMI from the observed data (50°-70°E, 10°S-10°N) (Saji et al., 1999). This is because the eastern pole anomalies in the model are seen to spread far more into the central Indian Ocean as compared to observation. The model captures the amplitude of the eastern Pacific variability quite well with a SST standard deviation of 0.8°C. The model SST standard deviation of the DMI is 0.5°C and is slightly higher compared to the observed data as reported in Saji et al. (1999). The correlation between the DMI and Niño3 (0.4 for the whole year and 0.54 for the boreal fall season) is also quite realistic. The high September-November correlation between the two indices shows the non-orthogonal nature of the two phenomena; this is consistent with the simulation result showing about 31% of the total IOD events associated with warm ENSO events just as seen in the observations. This provides us with further confidence that the current model has the essential capability to reproduce the Indo-Pacific climate variability.

We thus check the model seasonal variability of the EASR and compare the results with earlier observations (e.g. Hastenrath et al., 1993; Black et al., 2003). Fig. 2 (page 33) shows the seasonal variability of the EASR index (EASRI) obtained after averaging the model rainfall anomalies over the eastern African region (35°-46°E, 5°S-5°N). The model simulation of the seasonal short rains and its variability is quite realistic. Although the amplitude of the long rains is less compared to the observation, this model bias may be neglected here as the main aim of the present study is to discuss the short rains. In the following, we focus on the interannual variability of the EASR.

Fig. 3 (page 33) shows the simultaneous correlation of EASRI with the anomalies of SST (SSTA) and zonal wind in the Indian Ocean during September-November. The figure shows an east-west asymmetry in the EASRI-SSTA correlation, which clearly demonstrates the influence of IOD on the model short rains. The simultaneous high correlation of the zonal wind anomalies also emphasizes the existence of air-sea coupling during the IOD's influence on the EASR. This anomalous Walker circulation (also see 200 hPa velocity potential correlation in Fig. 4 (page 33) during pure IOD events is already reported by Yamagata et al. (2002) using reanalysis data. The anomalous zonal circulation increases the moisture transport to the western Indian Ocean and induces higher atmospheric convection there. This, in turn, gives rise to above normal rainfall. The EASRI is also highly correlated with the upper ocean heat content anomalies (Fig. 4) providing a positive feedback to the equatorial SST anomalies (e.g. Rao et al. 2002). Thus the model is successful in simulating the influence of the IOD on the EASR. Table 1 shows the relative influence of the IOD and ENSO on the EASR. As seen from the values, the IOD has a far more influence on the model EASR as compared to that from the ENSO. This result is further confirmed by a partial correlation analysis.

The long time series of the model simulation has provided us with greater confidence on the reported IOD impact on the East African short rains. We therefore conclude that more attention is needed to understand the IOD phenomenon and its impact on the surrounding climate system for the societal benefits. The high skill of the SINTEX-F1 for capturing the EASR-IOD relation is very encouraging; it provides an effective tool for our understanding of the IOD phenomenon.

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Sensitivity of southern African climate to soil-moisture

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Introduction

Feedbacks from the land surface have long been suggested to play a role in regional climate (e.g. Charney, 1975; Nicholson, 2000). Recently, a number of climate model studies have provided evidence that soil moisture can play an important role in modulating larger-scale forcing of regional climate, particularly in the interior of continental regions of North America (Hong and Kalnay, 2000; Oglesby et al., 2002), North Africa (e.g. Cook, 1999; Douville, 2002; Douville et al., 2001; Nicholson, 2000), and Australia (e.g. Timbal et al., 2002).

Mechanisms driving soil moisture feedbacks on regional climate are related to local moisture cycling, where the land surface can supply a considerable proportion of precipitable water to the lower troposphere, and through alterations of atmospheric thermodynamics and dynamics. For example, Cook (1999), has shown that the African Easterly Jet (AEJ) is primarily a function of temperature gradients magnified by meridional soil moisture gradients in Tropical North Africa; variations in these gradients affect the position and strength of the AEJ and its interactions with precipitation generating mechanisms.

Here we describe preliminary results from a study of the sensitivity of regional climate processes, especially precipitation, to soil moisture perturbations over Southern Africa (SA), using the fifth-generation Pennsylvania State University-National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model (MM5) (Grell et al., 1994).

Methods and data

We use MM5 coupled with the Oregon State University Land Surface Model (OSU-LSM) (Chen and Dudhia, 2001a; 2001b). MM5 was applied at 60km resolution, running at 120-second time steps, and forced with boundary conditions from NCEP reanalyses for the austral summer 1998/9 (Nov-Feb). This year was unusual in that the evolving Pacific El Niño did not markedly affect precipitation over the Southern Africa (SA) region: rainfall was close to the long term average (Curtis et al., 2001). This was at least partly due to SST conditions in the SW Indian Ocean favouring above-average rainfall.

Three main experiments were performed. In a control experiment, MM5 was run with a "normal" soil moisture that was allowed to vary in response to simulated precipitation. In a second "dry" run, soil moisture in MM5 was fixed at a level 10% above wilting point, effectively preventing moisture fluxes back into the atmosphere. A third "wet" experiment maintained soil moisture at 10% below field capacity, thereby permitting unlimited evaporation to occur.

In all experiments the vegetation and soil parameters were standard to the OSU-LSM; the PX (Pleim and Xiu, 1995; Xiu and Pleim, 2001) planetary boundary layer and Grell (Grell et al., 1994) convective schemes were used. Additional experiments using these same soil moisture conditions, but with alternative convective schemes were also performed, but are not described here. Results were not dependent on the convective precipitation scheme used.

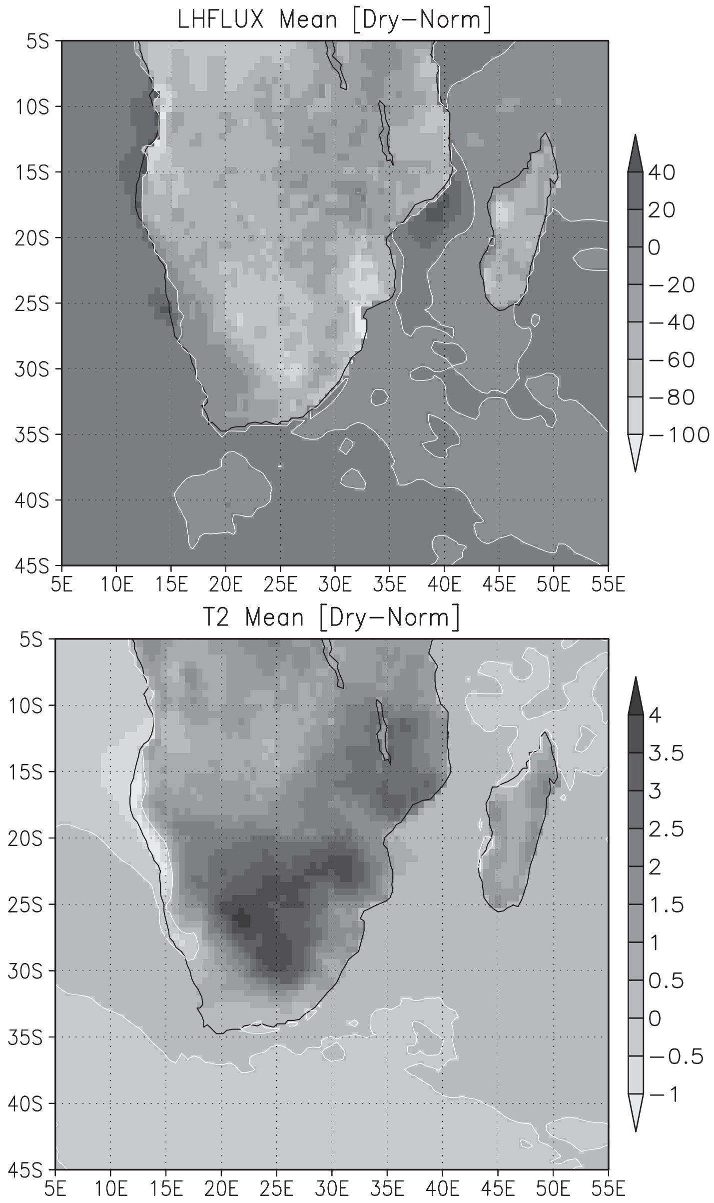

Fig. 1: Nov-Feb mean latent heat flux (upper panel) and surface temperature anomalies(lower panel) forced by a "dry" soil (anomalies relative to the "normal" run).

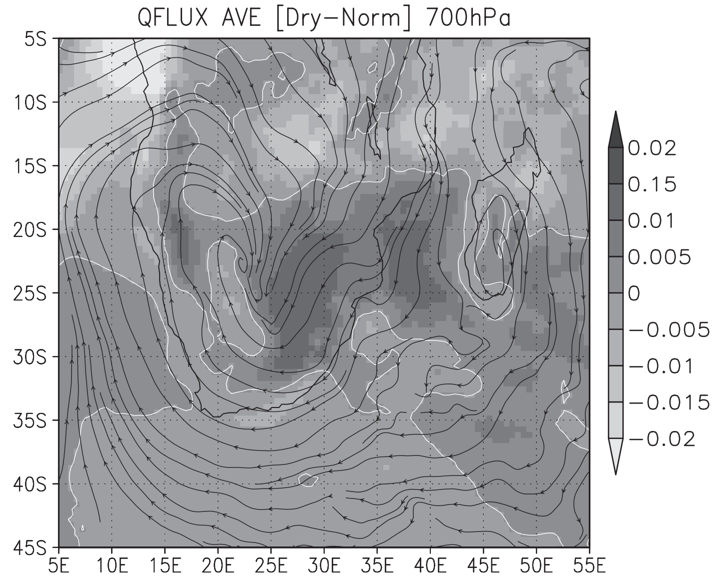

Fig. 2: Nov-Feb 700hPa Q-flux (shaded) and wind-stream anomalies forced by a "dry" soil.

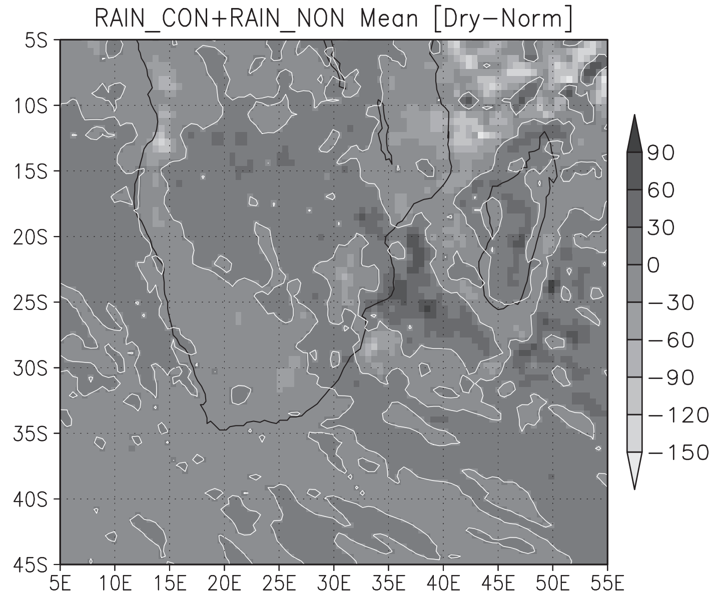

Fig. 3: Nov-Feb rainfall anomalies forced by a dry soil.

Results

We present results from the "dry" versus "normal" runs only. The differences between "wet" and "normal" runs are generally of opposite sign. Simulations with a permanently dry soil produce the expected differences in surface energy fluxes and temperature. In the dry run, latent heat fluxes over the entire subcontinent are reduced in favour of sensible heating of the ground and near surface atmosphere. The anomalies are largest over the interior of the southern part of the sub-continent. Anomalies of opposite sign occur in a narrow strip along the west coast (Figure 1).

The surface heating over the interior produces a low-mid level heat anomaly of up to 3K and a cool anomaly above about 500hPa. The mixing ratio is generally reduced near the surface, but is increased at higher levels, driven by an enhanced low level moisture flux from the N and E associated with an anomalous cyclonic circulation around the core of the surface heating anomaly (Figure 2). This enhanced Q-flux produces increased horizontal moisture convergence over the areas where rainfall has increased.

Positive rainfall anomalies occur in a broad NW-SE band stretching from the north of the interior heating anomaly into the SE Indian ocean (Figure 3). Rainfall is reduced to the west of the area of heating, along the entire west coast, in the Mozambique channel, and to the north of Madagascar. The anomalies over land are predominantly due to changes in convective rainfall, while over the ocean they are from a combination of convective and non-convective rainfall. Areas with enhanced rainfall are associated with a change in the probability distribution of rainfall towards larger totals.

Processes producing enhanced precipitation

Despite effectively shutting-off local soil moisture recycling over southern Africa, rainfall is enhanced over a large part of the region. This appears to be for at least two reasons. First, the surface heating increases the environmental lapse rate, and hence the chance of instability and convective rainfall; this is confirmed through analysis of total static energy profiles (not shown). Second, the anomalous moisture convergence arising from the low level cyclonic circulation anomaly feeds the conditional instability, particularly to the N and E of the heat low.

The rainfall response indicates an enhanced Hadley circulation and increased frequency of tropical-temperate cloud bands, which are the dominant mode of poleward energy and momentum transfer in the southern African sector. (Todd and Washington, 1999).

These results suggest that there is potentially a negative feedback operating in soil-moisture–atmosphere interactions over the region. Rather than causing drought conditions to persist as has been noted for the US (Hong and Kalnay, 2000), the proximity of southern Africa to moist maritime air means that surface heating and reduced local recycling of moisture are compensated by advection of moisture from the NE. This moisture is then available for convection in conditions that favour instability. These processes may be enhanced by a shift or phase-locking of tropical-temperate cloud bands over the continent, in preference to their preferred position further east.

This leads us to speculate that the observed location of tropical convection and tropical-temperate cloud bands depends on the distribution of heating resulting from land-surface conditions, which in turn is derived from feedbacks from the basic state of the regional climate.

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Calculating the onset of the maize growing season over southern Africa using GTS and CMAP data

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Introduction

The start of the growing season is a seasonal characteristic that has important consequences for agriculture and the production of cereals. In southern Africa the dominant cultivar is maize and many subsistence farmers rely on this crop to both feed themselves and generate income. However many farmers are resource poor and therefore vulnerable to climate variability and extremes. This is particularly true of extremes in the onset of the growing season. A cereal such as maize requires consistent water during its germination phase and if a farmer plants early (when he sees the first rains) he may find that the rains are not consistent and do not provide moisture for germination over the coming weeks. If he plants late and the rains are heavy he may find that his seed has no time to gain purchase in the soil and consequently will be washed away. Many subsistence farmers do not have the resources for a second planting should the first fail. Therefore planting at the right time becomes the first choice in a critical array of decisions that these farmers face.

In an effort to establish the patterns of onset and measure its inter-annual variability we compare its characteristics calculated using two datasets: daily station data communicated over the Global Telecommunication System (GTS) and pentad CPC Merged Analysis of Precipitation (CMAP) (Xie and Arkin, 1997). The two datasets are not independent as the CMAP data uses the GTS station data to fix the magnitude of the precipitation field, with satellite-based estimates providing the field shape and magnitude where station data are absent. Since the station data are often reported irregularly it is unclear to what extent the satellite estimates influence the data. The purpose of the comparison presented here is to see how the inclusion of the satellite data affects the calculation of the onset of the maize growing season. The similarities and differences are important and allow us to gauge the usefulness of the CMAP data for this type of study over southern Africa.

Data and method

The daily station data taken off the GTS were first interpolated to a 2.5 X 2.5 degree grid using a Cressman interpolation (Cressman, 1959) and then averaged to produce pentad (5 day) means. These spatial and temporal scales correspond to those on which the CMAP pentad data are distributed, thus facilitating comparisons between the two datasets. A third dataset, which may be used for comparison, is produced by the Climatic Research Unit (CRU) at the University of East Anglia, UK. This dataset is monthly mean, station only, rainfall at 0.5 degree resolution and utilises a more comprehensive archive of station data than that found on the GTS (New et al., 2000).

Figure 1 shows the October-December (OND) climatological biases of CMAP and GTS data with respect to the CRU data for the 1979-1999 period. It can be seen that both the CMAP and GTS data are positively biased over most of the southern sub-continent, with the GTS station data less so. The CMAP bias was found to increase as the season progressed (not shown). This is likely due to bias in the OLR and IR satellite precipitation estimates, which in the absence of station data contribute more to the precipitation estimates. This contribution will increase with increased convective activity later in the season. An examination of the timeseries of GTS-CRU over Zimbabwe (not shown) also indicates that differences between the two datasets are greater during ENSO years. Although no definitive reason can be given for this observation, it may arise because of the way the CRU dataset is constructed; percentage anomalies are interpolated and added to the climatology which has the effect of smoothing extremes. This is an important consideration when deciding which datasets are to be regarded as ‘truth’ in any comparison.

The results presented in Figure 1 are derived from a limited number of stations found in the GTS dataset. Figure 2 shows the average number of stations to be found in each 2.5 x 2.5 degree grid cell and it can be seen that the highest concentrations are found in South Africa and over the border in Zimbabwe. This picture however reflects a dynamical situation. During the 1980’s the highest concentrations of station data were found in South Africa and during the 1990’s this changed, with decreasing concentrations over South Africa and increasing concentrations over Zimbabwe. These changes in reporting stations are also reflected in the error estimates distributed with the CMAP data (not shown). Where station concentration is high the CMAP error is low and vice versa. Although most of South Africa and Zimbabwe have concentrations of 3-5 stations on average per grid box, the rest of the sub-continent has concentrations mostly between 0 and 2.

Having shown that CMAP and GTS exhibit different biases (Figure 1) we now calculate the onset of the growing season using both datasets. Our criteria for judging the on-

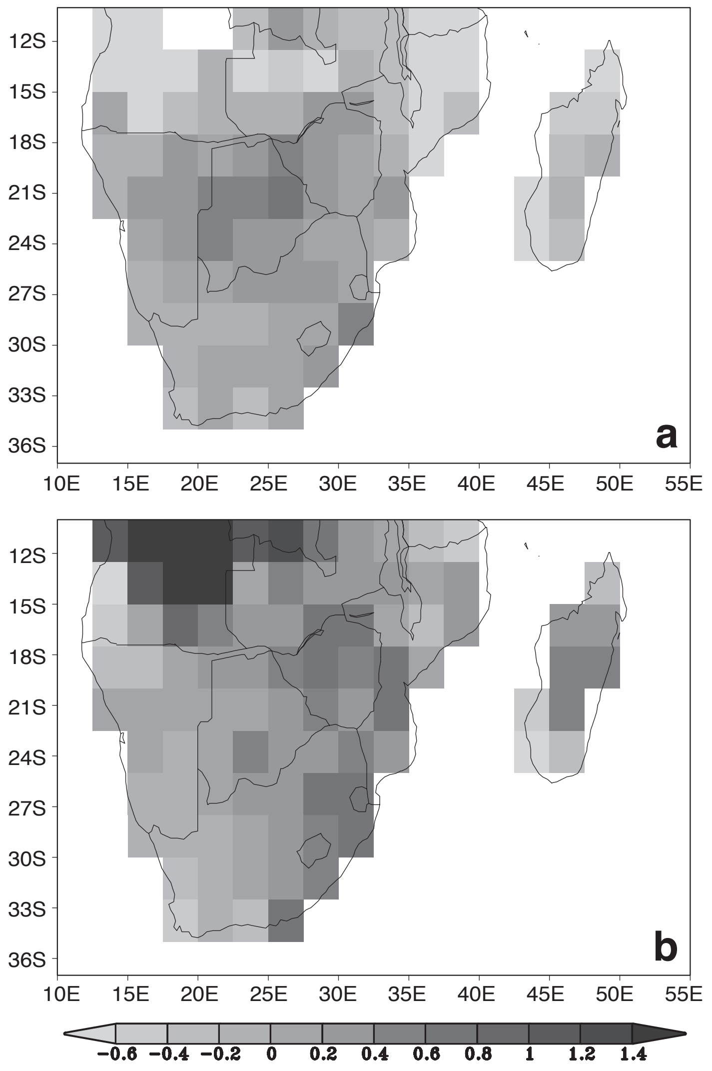

Fig. 1: Difference in October-December (OND) precipitation (mm/day): a) GTS-CRU, b) CMAP-CRU.

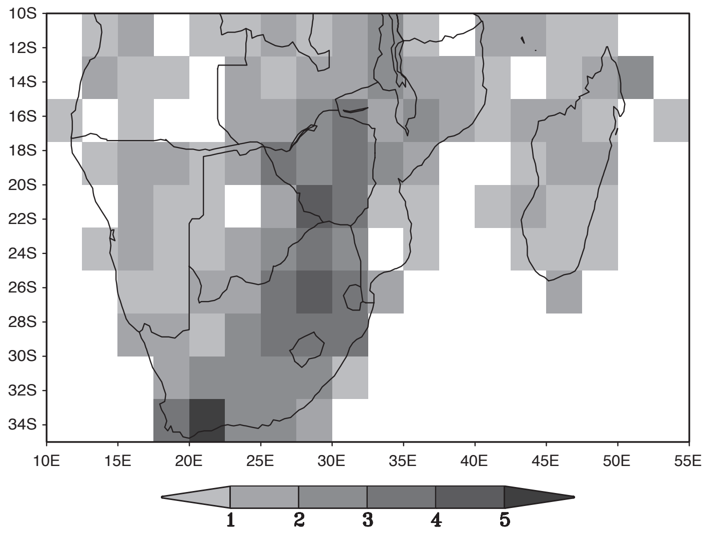

Fig. 2: Average number of stations per 2.5 degree grid box (1979-1999).

set of the maize growing season is that given by AGRHYMET (1996); one dekad with at least 25mm of rain is followed by two consecutive dekads where at least 20mm of rain falls. These criteria are based on the moisture required to ensure the successful germination of maize in the first month after planting. Hence the onset shown here is specific to the cultivation of maize, though it is noted that other cereals also require consistent moisture during the early phases of cultivation. This onset definition is calculated using one month of rainfall data, hence errors due to missing or incorrect data at the daily or pentad timescales are smoothed.

Mean onset and trends

Mean onset (number of pentads after August 3rd) for the years 1979-2000, was calculated using the criteria above and is given for both GTS and CMAP data in Figure 3 (a & b) (page 34). To aid comparison of the two datasets the CMAP data has been masked so that only the area covered by GTS data is displayed. The trend of onset for the 1979-1999 period is also displayed in Figure 3 (c & d). It can be seen that regions covered by data are found mostly to the east of the sub-continent. Except to the west over southern Botswana and Namibia (CMAP later than GTS), and north-western parts of Zambia (CMAP earlier than GTS) the two datasets mostly agree on the mean onset pentad. Discrepancies in these extreme regions of the GTS defined onset are not surprising as station data are sparse and the number of years with defined onsets contributing to the mean value are less.

One aspect of onset on which farmers in particular would like information is whether there is a trend for later or earlier onset. This was estimated using both a linear least squares method and a robust regression technique. The latter uses iterative methods to minimise the effect of extreme samples that may unduly influence the result. Both techniques produced similar results which are shown for the robust regression in Figure 3c and 3d. It is apparent from the figure that there is a trend for later onset over the region as a whole. Both datasets tend to agree on the magnitude and pattern of the trend over northern South Africa, Zimbabwe, Botswana and parts of southern Zambia. The trend for later onset over southern Zambia is also confirmed in interviews with farmers in the region (P. Mushove, *pers. Comm.,* 2003).

Summary

We have compared calculations of the onset of the maize growing season over southern Africa using GTS and CMAP data. The results indicate that over the 21 years from 1979-1999 both datasets produce similar estimates of the mean onset pentad and trend. Further research is required to ascertain differences in the inter-annual variability of the two datasets, though in this regard it is worth noting that correlations with Niño 3.4 SSTs show similar patterns. Over areas with little or no station data the CMAP estimates must be treated with caution. These conclusions are perhaps surprising given the positive seasonal bias of the CMAP data with respect to both CRU and GTS data. However most of the OND CMAP bias occurs in December and mean onset over most regions occurs before then.

Acknowledgments

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Towards forecasting epidemics in Africa - the use of seasonal forecasting

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Background

Malaria kills over 2,000,000 people per year with the majority of these deaths occurring in children in sub-Saharan Africa (Breman et al., 2001). In areas of low and unstable transmission epidemics may occur and these years are often associated with anomalous weather conditions due to the variability in the African climate system. These areas of unstable malaria transmission cover a population of 100,000,000 people. The World Health Organisation advocates the development of a malaria early warning system (MEWS) which may incorporate vulnerability assessment, seasonal forecasting, weather and environmental monitoring and clinical case surveillance. A dynamic malaria model integrated into a probabilistic seasonal forecasting system could provide a component of an operational MEWS in areas where seasonal forecasts are skilful. Through the DEMETER project, we have developed a dynamic malaria model. This model is designed to run with daily observed or modelled weather data and with multi-model seasonal forecast ensembles.

Unlike previous malaria models that are rules based or statistical in nature (e.g., MARA http://www.mara.org.za), or else are weather independent in their dynamic approach (e.g. Anderson and May, 1989), the malaria model we have developed is weather-dynamical in that it can form an outcome based upon a varying weather time series and thus can be used to predict the timing of the onset and peak of epidemics in years with predicted anomalous seasonal climate patterns. Our model, (Hoshen et al., 2003) simulates the key stages in the development cycle of the principal life-threatening parasite species *Plasmodium falciparum* within the human host and the *Anopheles gambiae s.l.* mosquito which is the vector of this disease. The model includes both adult and larval life stages of the vector. The female mosquito requires a blood meal to produce eggs, and whilst feeding from their human host they may become infected with the malaria parasite. The parasite completes part of its lifecycle within the vector and then may be transmitted to the next unfortunate human prey. Once the conditions are wet enough to provide both pools for mosquito breeding sites and to raise the humidity of the air thus reducing the desiccation of the mosquitoes, the two principal cycles that control the disease and potential epidemic will commence. These cycles are the egg production within the female mosquito and the development of the parasite also within the mosquito. The environmental temperature drives both processes.

The EU funded DEMETER (http://www.ecmwf.int/research/demeter) project is a multi-model ensemble seasonal forecasting system (Palmer et al., 2003). The system comprises of seven fully coupled atmosphere ocean general circulation models, with each model running nine times from slightly different perturbed initial conditions making a 63 member ensemble. Each forecast is run out to six months with four start dates per year produced respectively over the last 40 years. See also announcement on page 62 and the article by Palmer et al. in the electronic supplement to this newsletter: http:/www.clivar.org/publications/exchanges/ex27/pdf_files/s27_demeter.pdf.

As malaria epidemic peaks generally lag the seasonal rainfall peaks by at least two months a skilful seasonal forecast, in the two to four month range, of anomalous rainfall, for areas where unstable malaria transmission is rainfall controlled, could provide early warning of a malaria epidemic with up to a six month lead time.

Results

The burden of the disease is greatest in Africa and our research has been focussed on producing malaria model data output for the continent. Meteorological station data are sparse in Africa, and therefore we developed the malaria model using ERA-40 (http://www.ecmwf.int/research/era) reanalysis data. The malaria model can, however, run with time series derived from any source.

The malaria model has been run for an initial assessment with the most recent 14 years of ERA-40 reanalysis data across all of Africa. We are using the ERA-40 data as a 'perfect forecast'. Clinical time series malaria data are available through the health information systems of many African countries but there are often problems associated with misdiagnosis in the absence of laboratory facilities and record keeping. Changes in apparent malaria incidence may result from factors such as population movement, changes in diagnosis or referral, treatment policy etc. all of which may undermine the rigour of a climate malaria analysis. However major epidemics are frequently reported and may be investigated in detail. The malaria model is being assessed in a number of ways. Firstly, by producing annual and seasonal anomaly maps we can identify where the malaria model is retrospectively forecasting epidemics; secondly by constructing an average risk map and average length of the malaria season we are making comparisons with those produced with a rules-based model used by MARA, and finally, where we have access to clinical time series, the output from our model driven by the reanalysis data is compared with the clinical record. Initial results are promising (Hoshen et al. 2003), given that the malaria model is not tuned for any region as the same code, with constant parameter values, runs for all grid points. Furthermore, there are no landscape parameters e.g. rivers, lakes or topography at present within the malaria model.

Table 1: Single grid point (35°E at the Equator) seasonal modelled malaria incidence skill scores for single-model and multimodel ensemble hindcasts for the period 1987-2001 a) with seasonal modelled malaria incidence cycle included (all values significantly different from zero with 95% confidence), b) with mean seasonal malaria incidence cycle removed (multimodel values significantly different from zero with 95% confidence). The skill scores are correlation and ranked probability skill scores. Skill scores for individual models have been averaged. Seasonal malaria incidence values have been computed using geometric averages of monthly values.

	Mean of single models	Multimodel
a.		
Correlation	0.83	0.89
RPSS	0.51	0.62
b.		
Correlation	0.29	0.45
RPSS	0.02	0.26

The next stage towards the development of a dynamic malaria forecast model within a MEWS is the integration of the malaria model within a probabilistic seasonal forecast system, in our case within DEMETER. We have used bias corrected seasonal forecasts for each of the 63 ensemble members as the input to the malaria model for some selected grid points in Africa. This of course produces 63 malaria forecasts and thus we produce not a single deterministic malaria forecast but a probabilistic malaria forecast. Early results from selected grid points show that in years where the ERA-40 driven malaria forecast shows a significant epidemic the ERA-40 'perfect forecast' data point is within the interquartile range of the seasonal forecast. This shows that there is skill within the seasonal malaria retrospective forecast when compared with the ERA 'perfect forecast'. The malaria model when driven by the multimodel DEMETER system exhibits greater skill especially when the average seasonal cycle is removed (see Table 1) than when driven by any of the single model system that is part of DEMETER.

Conclusions and further work

The dynamical malaria model discussed above shows great potential as part of an integrated probabilistic seasonal weather forecasting and malaria prediction system. Once fully developed it is anticipated that the malaria model will be integrated into an operational seasonal forecasting system and malaria predictions, after expert interpretation, will be made publicly available as part of a MEWS.

The malaria model needs a further period of development, sensitivity testing and careful validation. The use of other gridded data sets e.g. CMAP rainfall analysis will be assessed. A realistic land surface will be integrated into the model using environmental databases, parameters derived from the land surface will be used to set key variables within the malaria model. Research needs to be undertaken to bias correct and downscale data from the ensemble prediction system for use with the malaria model.

An important task is to evaluate the level of skill required in the seasonal weather forecasts to produce skilful seasonal malaria forecasts; it is possible that this will vary from region to region in Africa. The skilful prediction of the seasonal cycles of rainfall, particularly its onset and cessation and the accompanying seasonal cycle in temperature, along with the interannual variability will be crucial in making a skilful malaria epidemic forecast. Inter-strain variation must be modelled as changes in parameter values. The potential impact of interventions and their cost-effectiveness should be evaluated to allow in theory an economic benefit of the seasonal forecasts to be established.

Finally, the impacts of climate change scenarios need to be assessed with the malaria model as the areas of unstable transmission could shift in a changing, perhaps more variable climate.

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African Monsoon Multidisciplinary Analysis (AMMA): An international research project and field campaign

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1. Introduction

The interannual and interdecadal variability of the West African monsoon (WAM) is well documented and has motivated considerable research in this area (e.g. Nicholson, 1981; Lamb, 1983; Folland et al., 1986; Fontaine and Janicot, 1996; Le Barbé et al., 2002). The dramatic change from wet conditions in the 50s and 60s to much drier conditions in the 70s, 80s and 90s over the whole region represents one of the strongest interdecadal signals on the planet in the 20th century. Superimposed on this, marked interannual variations have resulted in extremely dry years with devastating environmental and socio-economic impacts. Vulnerability of West African societies to climate variability is likely to increase in the next decades as demands on resources increase in association with one of the World's most rapidly growing populations. Vulnerability may be further increased in association with the effects of climate change (IPCC, 1997).

Further motivation for a research concerned with the WAM and its variability comes from recognizing the role of Africa on the rest of the world. Latent heat release in deep cumulonimbus clouds in the ITCZ over Africa represents one of the major heat sources on the planet. Its annual migration and associated regional circulations impact other tropical regions, as exemplified by the known correlation between Sahelian rainfall and Atlantic hurricane frequency (e.g. Landsea and Gray, 1992).

Recognising the societal need to develop strategies that reduce the socioeconomic impacts of the variability of the WAM, AMMA will facilitate the multidisciplinary research required to provide improved predictions of the WAM and its impacts on daily-to-decadal timescales. It will promote international coordination of relevant ongoing activities, necessary basic research and a multi-year field campaign over West Africa (Fig. 1, page 1) and the tropical Atlantic to support this research.

AMMA will develop close partnerships between those involved in basic research of the WAM and its impacts, operational forecasting centres and decision makers. It will promote the development of blended training and education activities for African research and technical institutions.

A summary of the AMMA project now follows. More detailed information can be found on the websites and through the contacts given at the end of this article.

2. The AMMA Project

2.1 International Planning and links to WCRP

During 2001 the French community interested in the West African monsoon and its various aspects produced a 5-year research plan that included a comprehensive description of scientific objectives. The main French funding agencies (CNES, CNRS/INSU, IFREMER, IRD, Meteo France) declared their support for this effort. Workshops in the UK (June 2001), US (November 2001, November 2002), Niger (February 2002) and Cologne (July 2003) have taken place to develop the AMMA programme in an international context and to encourage international collaboration. National efforts have begun and continue to develop in Germany, UK and US. West African scientists including representation from universities and national meteorological and hydrological services have formed a collaboration known as AMMANET that is described in this issue.

During 2003 AMMA received endorsement from both CLIVAR and GEWEX. AMMA continues to develop in association with these programmes interacting with the VACS and CLIVAR-Atlantic panels. AMMA has also been awarded the status of *associated project* to the GEWEX-CLIVAR Coordinated Enhanced Observing Period (CEOP), even though its timing will prevent it from fully participating in this effort. AMMA is also expected to make a significant contribution to IGBP.

2.2 Science Areas

The AMMA project will promote research in the following key interacting science areas important for improving our understanding of the WAM and its impacts:

Monsoon dynamics and scale interactions: The processes that influence variability and predictability of the West African monsoon on seasonal-to-decadal timescales are a central part of the AMMA programme. This will include consideration of the key global teleconnections that impact the WAM along with the different roles played by land surface processes and ocean processes in the tropical Atlantic. AMMA will also strive to provide an improved understanding of the nature and variability of individual weather systems that comprise the WAM focusing on the mesoscale convective systems and African easterly waves over the continent including their association with tropical cyclones downstream.

Land surface processes: Since climate variability strongly interacts with changes in the land cover, one focus of AMMA will be on improving our knowledge and understanding of the interactions between the atmosphere and the land surface with particular emphasis on the roles played by vegetation and soil moisture feedbacks. Included in this will be an investigation of how the WAM variability determines fluctuations in the water balance from the regional down to the local scale.

Ocean processes: Since tropical Atlantic SSTs are an important influence on the WAM and its variability, it is very important to improve our knowledge and understanding of the processes that determine the SSTs in this region, in particular the Gulf of Guinea. It is important to assess the extent to which the SSTs and upper ocean heat content can be understood in terms of the local heat balance, and to investigate the relative roles of ocean dynamics, atmospheric circulations (including those that are remotely forced) and land processes in determining the SSTs and their variability.

Aerosols: North Africa is the world's major source of mineral dust aerosol. Given the great uncertainties regarding the impact of dust on weather and climate, there is an important opportunity to address aerosol issues within the AMMA project. Issues related to the mobilization, transport and impacts of aerosol on weather and climate in West African and Atlantic regions are included.

Atmospheric Chemistry: Tropical Africa is significant source of natural and anthropogenic precursors of key greenhouse gases (e.g. ozone, aerosols). To date, there is extremely limited information about the chemical composition over West Africa. The extent to which the regional and global radiative forcing and the oxidizing capacity are being perturbed by emissions from West Africa is unknown.

Applications: The variability of the WAM impacts on almost every component of the regional socio-economy including water resources, food security, health and energy. Most of these impacts are strongly determined by local processes and sub-seasonal variability of the WAM both of which are a challenge to monitor and predict. It is important to assess the variability and predictability of those aspects of the WAM that are relevant to impacts and to develop strategies for predicting them.

2.3 Aims

Motivated by the science and societal issues the AMMA project has three overarching aims:

(1) To improve our understanding of the WAM and its influence on the physical, chemical and biological environment regionally and globally.

(2) To provide the underpinning science that relates climate variability to issues of health, water resources and food security for West African nations and defining relevant monitoring strategies.

(3) To ensure that the multidisciplinary research is effectively integrated with prediction and decision making activity

2.4 A Multiscale Approach

To achieve these aims a multiscale approach to the study of the WAM is required (c.f. Fig. 1). AMMA will promote research on the WAM around 4 interacting spatial scales: (i) global scale where consideration is given to how the WAM interacts with the globe, (ii) regional scale where monsoon processes are emphasized including scale interactions and the coupled land-ocean-atmosphere system, (iii) mesoscale where mesoscale convective systems and processes operating at the catchment scale are emphasized and (iv) local scale where hydrology and links with applications including agriculture are emphasized.

2.5 Observational Strategy

AMMA is planned to be a multi-year project and will involve 3 observing periods. It should be underlined here that the enhancement of observations during these different periods will provide a unique opportunity to determine future operational monitoring necessary to improve weather and climate forecasts over the West African region.

The Long term Observing Period (LOP) is concerned with observations of two types: (i) unarchived historical observations to study interannual-to-decadal variability of the WAM and (ii) additional long term observations (2002-2010) to document and analyse the interannual variability of the WAM.

The Enhanced Observing Period (EOP) is designed to serve as a link between the LOP and the SOP (below). Its main objective is to document over a climatic transect the annual cycle of the surface conditions and atmosphere and to study the surface memory effects at the seasonal scale. The EOP will be of 2-3 year duration (2004-2006), and hopefully longer.

The Special Observing Period (SOP) will focus on detailed observations of specific processes and weather systems at various key stages of the rainy season during three periods in the summer of 2006: (i) Monsoon onset (15 May-30 June), (ii) Peak monsoon (1 July – 14 August) and (iii) Late monsoon (15 August-15 Sepember). This will include a detailed analysis of the key weather systems and their interactions with the regional scale circulations and convection including African easterly waves, mesoscale convective systems and downstream tropical cyclones.

Satellite observations will strongly contribute to the objectives of the project by providing key variables of the surface – atmosphere system (e.g. Meteosat/MSG, ENVISAT, TRMM, AURA, AQUA-Train, TERRA, SMOS). It is a major challenge to exploit this huge amount of data (20 years for Meteosat, for example) by optimising the retrievals and data analysis for monitoring as well as validation of models and assimilation. The project will provide a unique set of integrated ground observations for validation of the satellites. It will also provide the framework to build a reliable monitoring strategy combining satellite and in situ network, to make up for the low density of routine observations in Africa.

3. Final Comments and Contacts

Motivated by the strong societal and science issues national and international efforts are underway to help mobilise the extra funding needed to achieve all the AMMA aims. The AMMA webpages below will provide more information about the AMMA project and how it is progressing nationally and internationally. Contact e-mails in Africa, Europe and the US are also included below.

AMMA website: http://medias.obs-mip.fr/amma/
AMMA-USwebsite: http://www.joss.ucar/amma.edu/

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Call for papers: 9th International Meeting on Statistical Climatology
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A multi-disciplinary conference for climatologists, statisticians, and scientists in related disciplines. The conference seeks to address issues related to the climate system and to introduce recent advances in analysis techniques – together advancing the methodical basis of climatology while providing a relevant context for statisticians.

Online details and registration at
http://www.csag.uct.ac.za/IMSC
Email: imsc@egs.uct.ac.za

AMMANET: Building the African Participation to AMMA

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The necessity to create a network of African scientists is linked to the objectives of AMMA. In fact, in addition to the planned field campaign, AMMA has two long-term aspects related to "training" and "applications".

This is because the partnership with African scientists along with the multidisciplinary element are fundamental to the project. This will rely on the strong involvement of African institutions and scientists. Following the AMMA workshop in Niamey (2002) a group of African scientists initiated a discussion to establish the African interests and participation in the AMMA project.

A letter from this group was distributed to more than 400 researchers from different African institutions. This led, in February 2002, to the formal creation of a network of scientists from national meteorological and hydrological services, universities and regional centres including ACMAD (African Center for Meteorology Applied to Development) and AGRHYMET (Regional Center on Agriculture, Hydrology and Meteorology).

Baptised AMMANET, this network now consists of more than 200 participants. AMMANET is headed by a Committee of Survey, a group of 7 people who are the authors of this text. Also, each country has a national contact point for distribution of information. The network has a web page.

AMMANET is a network of African researchers from different countries, different disciplines, from national operational services, regional institutions, and from universities that wish to participate in the AMMA program. AMMANET is thus a framework where researchers have the opportunity

a) to consolidate existing collaborations;

b) to propose and develop existing projects in the framework of AMMA;

c) to coordinate the initiatives and individual suggestions for better efficiency;

d) to find or develop collaborations between African researchers or with researchers worldwide;

e) to offer assistance in replying to the different calls for proposals to finance their research projects;

f) to exchange information, data and tools (software, methods, etc.).

The objective of AMMANET is to establish local structures and teams that are able to take advantage of the available financing mechanisms available to African researchers including for example those available through START/PACOM and IRD (French Research Institute for Development). Besides, the national committees are supported by the international cooperation agencies established in the different countries (through funded proposals submitted to the cultural services of the embassies etc.). The availability of a web page where all the calls for proposals will be held constitutes a mechanism that will allow the different teams to work in an autonomous way. By doing that, AMMANET will contribute to the reinforcement of the capacities of the different national or regional institutions and universities.

The national committees organise meetings to discuss scientific aspects and coordination between the different teams. Simultaneously, summer schools will be organised each year (the first will be held in September 2003 in France) with the objective of presenting the current state of knowledge to about thirty participants and to discuss with them issues of research and development as perceived by African scientists.

More generally, AMMANET has the ambition to promote research in the science of climate and environment for applications and development. The partnership looks to the creation of a true "scientific community" competent in climate variability and its impacts in Africa. It will contribute to construction of strong links between the research and applications, another important objective of AMMA. The models and databases that will be developed in AMMA will be distributed to and evaluated by African organisations. This will support the ongoing work on adaptation strategies to environmental change.

CLIVAR Panel on Variability of the African Climate System - 3rd Session

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The CLIVAR Panel on the Variability of the African Climate System held its 3rd session at the University of Cape Town (UCT), South Africa, on 15-17 January 2003. Chris Reason from UCT acted as the local host. The meeting was co-chaired by Chris Thorncroft and Laban Ogallo. The aims of the meeting were:

- Review/update knowledge of African climate variability
- Update on developments of regional activities
- Discuss the observing networks over land and ocean
- Discuss the implementation plan and its development

Key activities that were discussed and are currently being developed and promoted by VACS are:

Atlas of African Climate Variability

A working group has been established to oversee the production of the African climate atlas. The atlas aims to promote research on African climate variability by providing a useful resource for researchers in both climate and applied communities. It will initially focus on the annual cycle and the interactions between the continent and the rest of the world by providing global and regional diagnostics along with text that highlights key scientific issues. Its initial content has been agreed and includes: observed data (*in situ* and space borne), reanalysis and model outputs of key variables including rainfall, temperature, dust, wind and pressure. This atlas is currently being developed on the web but plans are also being made to make this available on CD-ROMs and as a hard copy. The African Climate Variability Atlas will eventually link to pre-existing regional efforts/atlases.

Interannual Variability: Case Study for the 1997-2003 Period

The 1997-98 El Niño heightened awareness in many parts of Africa to the role climate can play in human well-being, and to the existence of a relatively new body of scientific knowledge claiming an ability to foresee some aspects of seasonal climate patterns with a lead-time of months. The interest continued with the prevailing La Niña conditions 1998-2000, and further significant climate anomalies in many parts, notably the extended drought in Eastern Africa and abundant rains experienced across the Sahel and at times in Southern Africa, leading to most tragic consequences of excess rainfall in Mozambique and northeastern South Africa in early 2000. The VACS panel has adopted this period for intensive study.

The primary aspect considered is whether, during 1997-2000, the large-scale modes of atmospheric variation typically triggered by El Niño /La Niña were indeed triggered – and then if they were modified by regional sea surface temperature (SST) anomalies surrounding Africa during this period - either enhancing or modifying the expected regional climate patterns in Africa. For example, the expected wet conditions in eastern Africa during Oct.-Dec. 1997 were likely amplified by prevailing warm conditions in the western Indian Ocean, and perhaps also in the tropical southeastern Atlantic, a region capable of impacting Equatorial African climate anomalies. This juxtaposition of Atlantic and Indian Ocean anomalies continued into Jan.-Mar. 1998. The climate anomalies observed in Southern Africa were not consistent with the typical El Niño / Southern Oscillation (ENSO) signature and they need to be explained. Communication of ENSO effects into a region could also be modulated by internal atmospheric variability, including interactions with mid-latitudes, and this aspect also requires consideration. A further consideration is whether the modes were influenced by longer timescale background changes to the climate state, especially those associated with global warming.

Following on from the Niamey panel meeting in 2002 and the recent Cape Town meeting in 2003 it is clear that a large community of African scientists is interested in contributing to the analysis and investigation of the 1997-present period. To take advantage of this and to promote the case study issues more widely, the VACS panel is planning a workshop with a focus on Eastern and Southern Africa.

African Monsoon Multidisciplinary Analysis (AMMA)

The AMMA project has continued to develop well during 2002/2003. An international science plan is nearly complete and will incorporate the interests of the international community keen to contribute to AMMA. A colloquium held in Niamey with the participation of ACMAD and AGRHYMET in February 2002 resulted in setting up of a network called AMMANET (described in this issue) consisting of over 200 African scientists from various disciplines and from various Universities and NMHs. FIRMA, a meteorological research fund for Africa setup at ACMAD with the support of the French Ministry of Cooperation, has already helped to initiate several projects in Africa aimed at contributing to AMMA In Europe efforts are underway to help mobilize EU funding as well as national funding in

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CLIVAR/WGCM Working Group on Ocean Model Development (WGOMD) - 4th Session

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1. Introduction

The fourth session of WGOMD was held at the Citadel Conference Centre in Villefranche-sur-mer, France, April 13-15, 2003. The chairman, C. Böning welcomed 17 participants from major climate, ocean, and ocean-ice modelling groups, to discuss the status and ongoing efforts in the development and assessment of the ocean component models used in climate studies. In response to a request of the CLIVAR SSG and the CLIVAR Atlantic Panel, one session of this meeting was held jointly with the CLIVAR Atlantic panel to facilitate and foster co-operations between these two groups.

The main goal of the session was to review an initial test phase of the Ocean Model Intercomparison Experiment and to develop a strategy for future expansion of this project.

2. Summary of OMIP status and plans

The goal of the P-OMIP (Pilot Ocean Model Intercomparison Project) is to demonstrate the feasibility and merit of a coordinated investigation of global ocean-ice model performance. WGOMD has formulated and agreed on a protocol, (basically following the example of a previous German 'mini-OMIP' (between two ocean models: MOM and HOPE)). A revised version of the OMIP forcing has been developed in order to address some problems with the previous version currently used in the P-OMIP study. Because some groups participating in the present test phase had problems to keep strictly to the protocol, the group agreed that modest modifications to the OMIP protocol should be allowed but have to be well documented.

Currently there are 6 contributors (U. Miami/LANL with MICOM/HYCOM, CCSR, MRI, LODYC, MPI and GFDL/IARC) to P-OMIP. The participating models have very similar spatial resolution (generally 2° in longitude with refinements). In the present phase, the analysis of the results is done decentralised by every participating group. A wider participation in a full-blown OMIP would require a more coordinated and centralized effort. The participating groups presented some of the results of the P-OMIP study in more detail and discussed a future strategy. A number of issues were identified such as:

- Scientific questions addressed through OMIP to generate interest (e.g. THC variability)
- Funding for experiments and analysis
- Forcing (restrictive vs. open protocol).

The group agreed that the preliminary results available at the meeting already demonstrate that P-OMIP has shown some merit and feasibility and hence it is worthwhile to continue. Nevertheless, a more comprehensive and in-depth analysis is required before enlarging the number of participants. In addition, a full OMIP does require additional resources to perform common data analysis and interpretation. The group agreed to build the future planning on a scientific review of P-OMIP results, as part of the workshop in 2004 (see below). In preparation for this event, participants will conduct analysis of P-OMIP output with respect to various themes and processes of interest in the context of the ocean's role in climate.

3. Joint Session with the Atlantic Panel

The participants were welcomed by the chairmen of both groups, Martin Visbeck (Atlantic) and Claus Böning (WGOMD) who briefly introduced the tasks of the individual panels.

The aim was to exchange information about common working areas and interest, specifically the Atlantic panel was asked to provide inputs on metrics and indices of climate variability in the Atlantic sector to be used for model-model and model-data intercomparison studies. The Atlantic panel expressed interest to access output from model experiments (e.g. OMIP) for intercomparison with observations. The initial focus was to identify jointly a metric and develop model experiments to explore the responses and sensitivity of the Meridional Overturning Circulation (MOC).

The following topics were discussed in more detail through the joint session:

Ocean Data Reanalysis and Assimilation: The panels were briefed on methods for rigorous data assimilation. Amongst the efforts contributing to GODAE (Global Ocean Data Assimilation Experiment) the ECCO ("Estimating the Circulation and Climate of the Ocean") project was highlighted. ECCO is a US consortium between scientist at JPL, MIT and SIO. See http://www.ecco-group.org for details.

Two workshops are currently being planned which are mainly focussing on ocean reanalysis but will also address atmospheric reanalysis and coupled efforts. The first one is a NSF-ONR sponsored US Workshop on "Progress and Prospects of Data Assimilation in Ocean Research" to be held in Williamburg, VA, September 9-11, 2003. The second workshop is an international CLIVAR Workshop on Ocean

Participants of the CLIVAR Atlantic Panel and Working Group on Ocean Model Development meetings in the Citadel of Villefranche - sur-mer, France.

Reanalyses, date to be decided.

CMIP (Coupled Model Intercomparison Project) Themohaline Circulation (THC) response studies: The aim of this coordinated CMIP experiment is to establish a benchmark for the sensitivity of the Thermohaline Circulation (THC) to an imposed surface freshwater flux. It was pointed out that such experiments are difficult to conduct with ocean-only models because of the usual restoring boundary condition on surface salinity which damps the salinity anomaly and misrepresents the sensitivity of the oceanic circulation. Solutions to this problem are currently under investigation.

OMIP status and plans: see section 2

Data sets for testing models, particularly with respect to the THC: The Meridional Overturning Circulation (MOC) is believed to be the most important aspect of NA ocean circulation for climate variability. The Atlantic panel prepared for WGOMD a list of observations suitable to test model representations of the Atlantic MOC together with several suggestions on model experiments to explore MOC responses and sensitivity. In this context joint activities on model-data intercomparison with WGOMD were strongly encouraged.

CLIVAR Workshop on North Atlantic Thermohaline Circulation Variability: This workshop with high relevance to both groups will take place in Kiel, Germany, September 13-16, 2004. More information is available under http://www.ifm.uni-kiel.de/allgemein/news/nawshp_04.htm.

4. Workshop on Ocean Climate Modelling

During the latter part of 2003, major climate modeling centres will be freezing their coupled models used to address IPCC 2007 questions.Additionally, US CLIVAR has announced the formation of two Climate Process Teams (CPT) starting Oct 2003. One CPT is focusing on gravity current entrainment and the other on interactions between mesoscale eddies and the mixed layer. Their goal is to, within 2-3 years, enhance the physical integrity and robustness of the IPCC-class of global ocean models. WGOMD hence considers early 2004 to be an opportune time to organize a scientific workshop to evaluate the ocean component for climate studies.

The goal for this workshop is to bring together leading ocean scientists who focus on issues related to global climate as well as high resolution models, process physics, and large-scale observations and to foster a candid and critical evaluation of the state-of-the-art in the ocean models used in the IPCC class of climate models, and to discuss strategies for improving the physical integrity of these models.

A particular challenge is how coupled ocean-ice model simulations can be systematically compared addressing questions like: Can the community coalesce around a protocol, and associated dataset, for running the models, such as within the context of an Ocean Model Intercomparison Project (OMIP)? How valuable will an OMIP be for evaluating the ocean and sea ice components of coupled climate models? Does OMIP provide a useful venue for comparing model sensitivities to parameterizations arising from the CPTs?

In preparation for the workshop, various groups expressed interest in performing analysis of OMIP output, aiming at the representation of key processes and phenomena in comparison with observed behaviours and insight from process studies. A preliminary announcement can be found under: http://www.clivar.org/recent/wgomd_wksp.htm

The full report of the WGOMD meeting will be published soon and will become available through the CLIVAR website.

CLIVAR Atlantic Implementation Panel - 5th Session

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The Atlantic Implementation Panel held its 5th session at the Citadel Conference Centre in Villefranche-sur-mer, France, April 13-14, 2003. The meeting followed the AGU/EGS Joint Assembly held in Nice, France (7-11 April) and benefited from the presence of the Working Group on Ocean Model Development (WGOMD) that was holding its 4th session simultaneously in the same Conference Centre. The chairman of the panel, Martin Visbeck, thus scheduled some specific topics of the agenda for a joint session with the CLIVAR WGOMD. A summary on these agenda items can be found in the WGOMD report at page 57.

1. Addressing Data Products, Reanalysis and Synthesis

The CLIVAR Atlantic panel plays an important role in coordinating the large number of process studies / programmes that address different aspects of climate variability and predictability in the Atlantic sector, most of them not directly initiated under CLIVAR (http://www.clivar.org/organization/atlantic/IMPL/proc-stud.html). However a burning issue of CLIVAR as whole is the design and implementation of a strategy on data integration and archiving, and the hierarchy of synthesis systems. For this reason it was decided that part of the meeting should focus on data products, reanalysis, predictability and synthesis.

Together with the several contributions on GODAE (Global Ocean Data Assimilation Experiment), there was a specific highlight on ECCO (Estimating the Circulation and Climate of the Ocean), the US effort on ocean data assimilation led by D. Stammer (see http://www.ecco-group.org). ECCO products (and those of similar efforts) have several applications in climate studies: ocean state estimation, reanalysis, surface fluxes and initialisation of coupled models.

It is of fundamental importance that the data products to be assimilated are robust and reliable, thus the data assembly centres play an important role in the synthesis process. The CORIOLIS approach to data assembly and management was explored as a potential system for serving CLIVAR purposes. CORIOLIS (http://www.coriolis.eu.org/) is a French project managing real-time *in situ* data either acquired during oceanographic cruises or available from the GTS. The observing system includes: profiling floats, XBT, CTD, thermosalinographs, moored buoys (PIRATA, TAO) and German moorings. The data are quality controlled according to internationally agreed procedures and products such as mean temperature and salinity fields are distributed through ftp/WWW.

Within the existing system for data assembly and assimilation CLIVAR needs to ensure that current datasets and products are updated with continuity and that data are available to the community in a timely fashion.

2. Addressing Predictability

An Atlantic ITCZ workshop sponsored by US CLIVAR was organized at IRI, Palisades, USA, on 18-20 September 2002. The workshop helped to identify the community interested in pursuing ITCZ studies with expertise in the disciplines of large-scale tropical meteorology and oceanography, convection, land surface interactions, climate predictions and climate impacts and applications.

Statistical schemes to predict the anomalies in the Atlantic marine ITCZ location and strength have limited success. The difficulties appear to emerge from the sensitivity of the Atlantic marine ITCZ intensity and location to relatively small changes in surface and upper air conditions and the unique blend between local and external mechanisms that affect these conditions. Models do not capture the cold seasonal anomaly in e.g. the east Atlantic but do better over the northern subtropics, though with low predictive skill. Skill is highest over the southern subtropics. Poor SST prediction results in large errors in the tropical Atlantic ITCZ rainfall. Critical issues are:

- Understanding the mechanisms and relative roles of local atmosphere-ocean interaction, adjacent land effects, and remote influences from other ocean basins (e.g., ENSO, NAO) in determining the position and intensity of the ITCZ throughout the year, with particular emphasis on the seasons when maximum societal impact is experienced, i.e., boreal spring and boreal summer.
- Overcoming model biases and developing modelling strategies (atmosphere, ocean, and land-surface interactions) to study the dynamics of, to accurately simulate, and to predict the seasonal and interannual variability of the ITCZ and its regional impacts.
- Defining sustained observations and field programmes in support of the improved, reliable monitoring and prediction of the ITCZ variability and its regional influences.

Recent years have also seen considerable research progress in understanding the causes and predictability of Atlantic climate variability. This progress has been discussed at various meetings, but the Atlantic panel felt the need to ensure that the progress in understanding could be more rapidly translated into progress in climate prediction. For this reason a workshop on Atlantic Predictability has been proposed. It has since been endorsed by the CLIVAR SSG and will be held in Reading during spring 2004.

3. Improving the Observational Network

Following the SACOS (South Atlantic Climate Observing System) workshop, held in Brazil on February 2003, a group of participants led by Alberto Piola (member of the Atlantic panel) is addressing the needs of the observational network in the South Atlantic (SA) region for climate studies. The sparse observational network there limits our ability to understand the SA impact and role. The southeast and southwest regions of the SA are the gateways for entrainment of upper layer water from neighbouring oceans and for their modification through mixing and water mass conversion. Time series transport measurements and regional modelling are necessary in these regions. In order to better understand the role of the SA on the merdional overturning circulation (MOC) it is necessary to reduce the uncertainty on the meridional heat flux through the subtropical band. The SST anomalies in the SA influence South America and African climate on several timescales, and have potentially predictable components.

Though parts of the tropical Atlantic are currently montitored by the PIRATA array, additional observations in the tropical-subtropical region appear to be necessary in order to monitor the area of extra-tropical upwelling and the bifurcation of the south equatorial current (SEC). Diagnostic studies from observations and numerical simulations shows that there is a combined pattern of SST and SLP variability in the central South Atlantic that explains the largest fraction of variance. North-south transects through the subtropical high (around 10°W) were also suggested. The panel expects a full workshop report later in the year.

Given the funded and planned proposals for current and new observations in the tropical Atlantic, and the development of the West African Monsoon dynamics studies (AMMA), we have tasked a subset of the panel to outline elements of a climate program in the tropical Atlantic that connects the marine ITZC and the role of ocean dynamics to issue over land (AMMA) in the prediction of interannal climate variability. Plans will be developed by Atlantic CLIVAR in collaboration with CLIVAR's VACS panel.

VACS Panel 3rd session, continued from page 56

France, Germany and the UK. In the US a scientific steering group that represents US interests in AMMA has been formed and a US science plan is in preparation. More details of the AMMA project and its current planning are included in this issue.

East African Research Initiative

The VACS panel has initiated plans for a research initiative in Eastern Africa. The climate of Eastern Africa is strongly modulated by the presence of the three of largest lakes in the world (Malawi, Tanganyika and Victoria); lake-atmosphere interactions have an impact in the regional climate system. The regions surrounding the three lakes are home for over 80-100 million inhabitants and it is economically among the most productive regions in Eastern Africa. A recent study indicates that the hydrodynamics of Lake Victoria play an important role in determining the coupled variability of the lake and the regional climate. These results show that by adopting the traditional modeling approach in which the lake hydrodynamics are neglected and the formulation is entirely based on thermodynamics alone is not satisfactory for Eastern Africa. Such a strategy precludes the ability of coupled regional climate models to transport heat realistically within the lake and thereby results in degraded simulation of the climate downstream over the rest of the lake and the surrounding land regions. It is currently envisaged that along with the Indian Ocean the role of these lakes on the regional climate will be emphasized strongly along with their impacts. A provisional planning document is in preparation and will be available during summer 2003. This initiative will be discussed in detail at the next VACS meeting.

Outreach

It was agreed that greater emphasis needs to be given to highlighting research on African climate variability including VACS projects. Outreach material such as a poster and a powerpoint presentation are in preparation for this purpose and will be made available on the newly updated VACS webpages (http://www.clivar.org/science/vacs.htm). More special sessions at international meetings will be sought. The panel suggested we contact the CLIVAR Exchanges editor to propose a special issue on Africa to be published within 2003, a suggestion which has been realised in this issue.

CLIVAR VAMOS Panel - 6th Session

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1. Introduction

The sixth session of the WCRP/CLIVAR VAMOS Panel (VPM6) was held in Miami, Florida, USA, from 23–26 April 2003, attended by 55 participants from 11 countries. The meeting was hosted by the Rosenstiel School of Marine & Atmospheric Science (RSMAS), the University of Miami, and the Atlantic Oceanographic and Meteorological Laboratory (AOML) of the US National Oceanic and Atmospheric Administration (NOAA).

VPM6 had three principal objectives:

- Define an implementation strategy for the initiative known at the time as VEPIC (VAMOS Eastern Pacific Implementation of Climate). Formulate science objectives, methodologies for research, timeline of field programmes, and possible interactions with other CLIVAR components
- Discuss the desirability of restructuring the Monsoon Experiment South America (MESA) component of VAMOS as a unified programme in a way similar to NAME. MESA was at the time an aggregate of three components: South American Low Level Jet (SALLJ), Plata Basin (PLATIN), and VEPIC, while NAME is a single programme.
- Define a climate modelling component for VAMOS. Identify the unique contributions of VAMOS to climate modeling, taking into account activities of other WCRP modelling programmes.

Another objective was to review possible new topics for VAMOS projects.

The plenary session of the meeting began with reports from the CLIVARs Scientific Steering Group (SSG) (Dr. Anthony Busalacchi), the International CLIVAR Project Office (Dr. Carlos Ereño), and US CLIVAR (Dr. Robert. Weller).

Prof. Roberto Mechoso, chair of the VAMOS panel, reviewed outstanding activities of the various VAMOS components during the past year, in particular the field phase of SALLJEX during early 2003, science findings of VEPIC, and plans for the NAME field campaign in 2004.

Dr. Gus Emmanuel, UCAR-JOSS, director of the VAMOS Field Program Office, described office activities since its creation. The office played a crucial role in SALLJEX and will support the NAME field campaign as well. Dr. Steve Williams and José Meitín reported on the VAMOS database, which is handled through the VAMOS Data Information Server located at the UCAR/Joint Office for Science Support (JOSS).

Another CLIVAR related activity was a Workshop on the South Atlantic Climate Observing System (SACOS), which took place in Brazil, in February 2003. Dr. Silvia Garzoli, NOAA AOML, presented the accomplishment of this meeting with respect to VAMOS activities.

Dr. Carolina Vera, U. of Buenos Aires highlighted the great success of the SALLJEX that took place between 15 Nov 2002 and 15 Feb 2003 in Bolivia, Paraguay, central and northern Argentina, and western Brazil, with the participation of scientists, students and local volunteers from Argentina, Brazil, Bolivia, Paraguay, Chile, Uruguay and USA. SALLJEX had three major components: i) enhanced upper air observations; ii) enhanced raingauge daily observations; and iii) NOAA/P-3 aircraft missions. During the experiment, numerical modelling groups contributing to SALLJEX provided a diversity of forecast products from operational centres and research institutions. Detailed information on the experiment is available at http://www.salljex.at.fcen.uba.ar.

Dr. Chris Bretherton, U. Washington, gave an update on the plans of VEPIC, including goals and methods, targeted extended time observations, and EPIC/DYCOMS-II (Dynamics and Chemistry of Marine Stratocumulus - Phase II: Entrainment Studies) developments.

Dr. Wayne Higgins (Climate Prediction Center, NOAA/NWS/NCEP) gave a report on the status and plans of NAME, emphasizing the programme's scientific rationale, linkages (to agencies and other programmes), modelling and data assimilation activities, and the NAME 2004 field campaign.

Dr. Rafael. Terra, U. de la Republica, Uruguay, introduced the project "Climate Variability and its Societal Impacts in South America" (CLARIS). This project is planned as a co-operation between European and South-American climate and applications scientists.

2. SALLJ Working Group

The first objective of this working group was to evaluate and prepare a report of the SALLJEX field experiment including a summary of the observations collected in the field as well as preliminary evaluations of data quality.

The second objective was to examine the desirability of a reorganization of MESA. It was agreed that a unified approach to the different components of MESA was necessary in order to facilitate the comprehensive understanding of the different elements in the South American Monsoon System and its variability.

3. VEPIC Working Group

This working group decided that the initiative previously known as VEPIC should be renamed VOCAL (VAMOS Ocean – Cloud – Atmosphere - Land study). The group reviewed the scientific issues and strategies for VOCAL. A set of recommendations on future diagnostic efforts, sensitivity, and parameterization studies was drafted. Recommendations were also made in regard to observational requirements for terrestrial and island stations, buoys, sea cruises and remote sensing. Coordination of activities with the US CLIVAR CPTs to feed into coupled model development was also recommended.

4. PLATIN Working Group

The major outcome of this working group was the agreement for the "straw man" conceptual design for a PLATIN Field experiment (PLATEX). The group provided the motivations and scientific reasons for planning such an experiment and produced details on the PLATEX conceptual design.

5. Summary

VAMOS reorganization: It was decided that the VAMOS programme will be organized in three components: NAME, MESA and VOCAL, with MESA absorbing SALLJ and PLATIN. Components chairs will be W. Higgins, C. Vera, and C. Bretherton, respectively. A PLATIN group will continue as the link between VAMOS and the GEF framework project with C.R. Mechoso and P. Silva-Dias as co-chairs.

VAMOS modelling. It was decided to convene an *ad hoc* working group with Prof. Mechoso acting as chair and Dr. Ben Kirtman (COLA) as vice-chair, and including representatives from the three principal VAMOS components (NAME, MESA, VOCAL) in order to review the status of modelling relevant to VAMOS research and to organize a special session on selected monsoon modelling aspects at VPM7.

SALLJEX Workshop: The panel warmly endorsed the idea of a workshop on SALLJEX data and follow-up activities planned for December 2003 in Buenos Aires, Argentina.

PLATIN and GEWEX. It was decided to renew the VAMOS request for "Continental Scale Experiment" status for the Plata Basin at the coming meeting of GEWEX Hydrometeorology Panel (GHP) in September.

Acknowledgements

The VAMOS panel is very grateful to Dr. Bruce Albrecht and Dr. David Enfield for their excellent contribution to the local organization of VPM6. Thanks are also due to RSMAS and AOML for their support. Funds were generously provided by WCRP and NOAA's Office of Global Programs.

A more detailed report of this meeting can be found under: http://www.clivar.org/publications/exchanges/ex27/pdf_files/s27_vpm6.pdf.

DEMETER: Multi-model seasonal predictions in a public domain

A unique state-of-the-art data set for studying seasonal to interannual predictability on both global and regional scales has been made available on the European Centre for Medium-Range Weather Forecast's (ECMWF) public web site: http://data.ecmwf.int/data/. This data set is based on output from the European-Union funded project DEMETER ("Development of a European Multi-model Ensemble System for Seasonal to Interannual Prediction"). In this project, six global coupled ocean-atmosphere models have been installed at ECMWF and run in hindcast mode over a substantial portion of the ECMWF 40-year re-analysis period. A seventh model was run remotely and the hindcasts integrated into the database. Each model has itself been run in ensemble mode, over 6-month integration periods, from nine separate initial conditions for each start date. An analysis of the DEMETER data set is presented on the DEMETER web site: http://www.ecmwf.int/research/demeter/verification.

The data available for downloading comprises a variety of gridded monthly mean fields from all ensemble members together with the corresponding verification from the reanalysis dataset. A tool to plot these fields before retrieving them in gridded form is also provided. The data can be retrieved in both GRIB and NetCDF format.

This data set is the first one of this kind made publicly available to scientists worlwide. It should prove useful for scientists and potential users of seasonal forecasts wishing to assess seasonal predictability using a truly state-of-the-art multi-model ensemble system, for regions and variables of interest. As well of being of intrinsic value as a research tool, this data set will also be valuable for training and education purposes.

More detailed information can be found at http://www.ecmwf.int/research/demeter and in the full article by Palmer et al. in the elcetronic supplement to this newsletter: http:/www.clivar.org/publications/exchanges/ex27/pdf_files/s27_demeter.pdf.

Supplementary Papers: Contents

continued from the back cover:

Supplementary (electronic) papers available under:
http://www.clivar.org/publications/exchanges/ex27/ex27_cont.htm

CLIVAR Calendar

2003	Meeting	Location	Attendance
Oct. 11-16	2nd Euroconference "Achieving Climate Predictability using Paleoclimate Data"	S. Feliu de Guixols, Spain	Open
Nov. 3-7	COPE Workshop on Seasonal Prediction & WGSIP-8	Honolulu, USA	Invitation
Nov. 5-7	NAME Special Session and SWG-5 Meeting	PuertoVallarta, MX	Limited
Nov. 12-14	First ARGO Science Workshop	Tokyo, Japan	Open
Nov. 18-21	CLIVAR/PAGES/IPCC Drought Implications Workshop	Tucson, USA	Limited
Nov. 24-26	CLIVAR/CCl Expert Team of Climate Change Detection Monitoring and Indices - 1st Session	Norwich, UK	Invitation
Dec. 8-12	AGU Fall Meeting	San Francisco, USA	Open
Dec. 10-12	VAMOS SALLJEX Data Workshop	Buenos Aires, Argentina	Limited

Check out our Calendar under: ***http://www.clivar.org/calendar/index.htm*** *for additional information*

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