

# Exchanges

## African Monsoon Multidisciplinary Analysis (AMMA)

From Parker et al, page 4: Overview of the AMMA observing campaigns

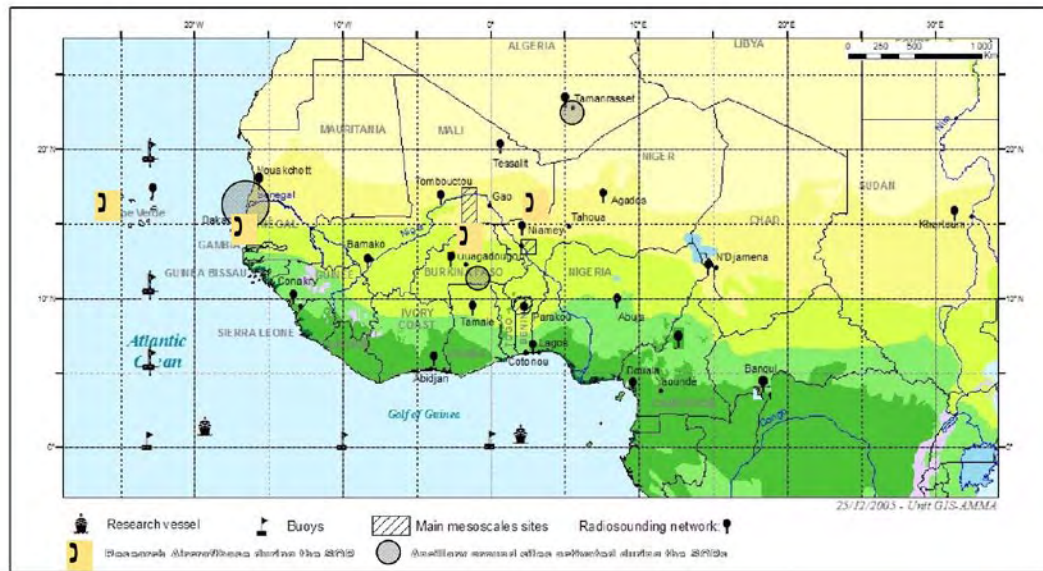


Figure 1. The regional AMMA domain; the three mesoscale sites are shown as hatched domains. The three ancillary ground sites activated during the SOPs around Dakar, and at Tamanrasset and Dano (South Burkina Faso) are shown as grey shaded circles.

### Editorial

I'm pleased indeed that this edition of Exchanges focuses on AMMA and thus on key aspects of the West African Monsoon. Many thanks to Chris Thorncroft for helping to draw the contributions together and for his help in editing. The CLIVAR Scientific Steering Group endorsed AMMA as one of its key contributing projects in March 2003. AMMA was also approved by the GEWEX SSG as one of its contributing Continental-Scale Experiments in February 2005. Overall AMMA is very much both an international research programme and multi-year field campaign with societal need as a key driver (see the article by Redelsperger et al on page 2). 2006 was a year of marked success for AMMA as it moved through the various phases of its Special Observing Period (SOP) and the articles here both reflect that and set the SOP in the context of AMMA's long-term and enhanced observing periods.

This edition has been timed to provide additional input to this year's meeting of the Joint Scientific Committee (JSC) of WCRP which this year meets in Zanzibar. The meeting will include a one-day "African Climate Research Networking Workshop for Young Scientists" organized in conjunction with the global change System for Analysis, Research and Training (START). AMMA will be one of the topics presented, as will wider aspects of the work of the CLIVAR Variability of the African Climate System (VACS) Panel (to be presented by the VACS co-chair, Chris Reason). Topics range from the IPCC 4th Assessment WG1 findings for Africa to climate change-related vulnerability and will include an invited lecture on "Mainstreaming Climate Information in National Development Plans and Strategies" by the Hon. Minister M Mwandosya, Tanzania. A panel discussion will seek to address "Challenges of coordinating existing and emerging initiatives in Africa" and enhancement of WCRP-related research on the continent. In a CLIVAR context, it will be important for VACS to review the outcomes of the workshop and to build on the conclusions, links and contacts that it will provide.

Howard Cattle

**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). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

## African Monsoon Multidisciplinary Analysis (AMMA) : An International Research Project and Multi-Year Field Campaign

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African Monsoon Multidisciplinary Analysis (AMMA) is an international project to improve our knowledge and understanding of the West African monsoon (WAM) and its variability with an emphasis on daily-to-interannual timescales (Redelsperger et al., 2006). AMMA is motivated by an interest in fundamental scientific issues and by the societal need for improved prediction of the WAM and its impacts on West African nations. AMMA promotes international coordination of ongoing activities, basic research and a multi-year field campaign over West Africa and the tropical Atlantic. Close partnerships are developed between those involved in basic research of the WAM, operational forecasting and decision making, and such partnerships are establishing blended training and education activities for Africans.

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 variability of the WAM to issues of health, water resources, food security and demography for West African nations and defining and implementing relevant monitoring and prediction strategies.
- (3) To ensure that the multidisciplinary research carried out in AMMA is effectively integrated with prediction and decision making activity.

A review of the present state of knowledge on the West African Monsoon and the related scientific questions to be addressed by AMMA are described in the International Science Plan (ISP, 2005). The ISP also includes a description of the strategy proposed to tackle these questions.

### Motivation and Major Issues

The interannual and interdecadal variability of the West African monsoon (WAM) is well documented and has motivated considerable research. 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 in recent decades have resulted in extremely dry years with devastating environmental and socio-economic impacts. Such variability has raised important issues related to sustainability, land degradation, and food and water security in the region.

Unfortunately, we are hindered in providing skilful predictions of WAM variability and its impacts. There are still fundamental gaps in our knowledge of the coupled atmosphere-land-ocean system at least partly arising from lack of appropriate observational datasets but also because of the complex scale interactions between the

atmosphere, biosphere and hydrosphere that ultimately determine the nature of the WAM. The monitoring system for the WAM and its variability is inadequate with many gaps in the standard routine network and lack of routine monitoring of some key variables. While the next generation of satellites will undoubtedly help with routine monitoring and prediction efforts, more research is required to validate and exploit these data streams. Dynamical models used for prediction suffer from large systematic errors in the West African and tropical Atlantic regions. Finally, there has been a lack of integrative science linking the work on WAM variability with work on food, water and health impacts.

### A Multiscale Approach

To address the multiple scales that characterize the WAM the AMMA program is structured around 4 interacting spatial scales (Figure 1, page 13): (i) Global scale; the scale at which the WAM interacts with the rest of the globe; emphasis is given to improving our understanding of the role of global SST patterns on WAM variability; seasonal-to-decadal variability are the main time scales of interest (ii) Regional scale; the scale at which we consider monsoon processes and scale interactions; emphasis is given to improving our understanding of the interactions between the atmosphere, land and tropical Atlantic ocean (especially the Gulf of Guinea). The annual cycle and seasonal-to-interannual variability are the main time scales of interest. (iii) Mesoscale; the scale of the typical rain-producing weather systems. This scale is central to the understanding of scale interactions in the WAM system (e.g. through interactions with synoptic easterly waves and the African easterly jet), and the coupling between hydrology and the atmosphere at the catchment scale. (iv) Local scale or sub-meso scale. It is the convective rain scale which is central to the hydrology of the Sahel and of small watersheds to the south; it is the main scale of interest for agriculture and for human impact studies in general.

AMMA emphasizes the importance of improved understanding of how these scales interact and combine to characterize the WAM and its variability, including how these interactions impact sources and transport of water vapour, aerosol and key chemical species (e.g. key greenhouse gases, ozone and aerosol precursors) in the West African region and globally.

### Integrative Science

While it is convenient and appropriate to describe the research plans in terms of the different spatial scales, it is essential, for an improved understanding, to study the scale and process interactions. The implementation of AMMA is designed in this spirit. The AMMA project integrates the scales at which the geophysical and human

processes interact. Furthermore the various disciplines involved in the study of the WAM need to be integrated to achieve the three overarching aims (Figure 2, page 13). This approach has guided the structuring of the scientific objectives.

From the geophysical perspective, the fundamental science underpinning the AMMA project can be viewed as the various disciplines coming together within broader integrative science topics: i) the interactions between the WAM and global climate, ii) the water cycle of the WAM from the regional to the local scale and iii) the coupled atmosphere-land-ocean system and its multiple scales. To feed these integrative topics with sound disciplinary knowledge of the processes and their scale dependence detailed studies of the processes are needed: i) atmospheric processes with a focus on the convective processes, ii) oceanic processes which contribute to the WAM, iii) biophysical processes over the continent and iv) aerosol and chemical atmospheric processes.

To study the human dimension of the variability and possible trends in the West African Monsoon AMMA aims to address the direct impact of the environmental conditions mainly on three limiting conditions for African societies: i) Land productivity, ii) water resources and iii) health impacts. Transversal tools (models and data assimilation; field campaigns, satellite remote sensing and long-term data collection, data base) are promoted and particularly used to transfer knowledge from the geophysical community to the activities in the human dimension.

#### **An international project**

Based on a French initiative, AMMA was built by an international scientific group and is currently funded by a large number of agencies, especially from France, UK, US and Africa. It has been the beneficiary of a major financial contribution from the European Community's Sixth Framework Research Programme. Detailed information on scientific coordination and funding is available on the AMMA International web site <http://www.amma-international.org>

AMMA aims to strengthen the international framework needed to facilitate interactions between researchers working in the different national and pan-national projects and ensure that the field campaigns are well coordinated to optimize the scientific impact of the observations. An international structure has been established to oversee and coordinate these efforts. The International Scientific Steering Committee (ISSC) ensures the scientific integrity and coherency of the scientific objectives of AMMA and the fulfillment of the three overarching aims.

The ISSC is structured by 5 integrative science working groups (WGs) which take up 5 topics central to the aims of AMMA. WG1: West African Monsoon and Global Climate is concerned with the 2-way interactions between the WAM and the rest of the globe, especially as they influence the variability of the WAM and its global impacts. It includes aerosol and chemistry aspects. WG2: Water cycle is concerned with the processes involved in

the water budget occurring through all scales (Figure 1). WG3: Surface-Atmosphere feedbacks is concerned with providing increased knowledge and understanding of the coupling between atmosphere and continental surfaces at regional and mesoscale and, separately, the coupling between the atmosphere and ocean (the coupled atmosphere-land-ocean system being addressed in WG1). WG4: Prediction of climate impacts is concerned with the 2nd major aim of AMMA and will provide strong linkages between the work taking place on impacts and that taking place on observed variability and predictability of the WAM in WG1. WG5: High impact weather prediction and predictability is a joint WG with THORPEX and is concerned with improving our knowledge and understanding of high impact weather over the West African continent, and its impacts on the tropical Atlantic and extratropics. Operational activities will be promoted including tailoring of forecast products for users, and data impact and targeting studies.

AMMA is endorsed by the World Climate Research Programme (WCRP) and continues to develop in association with CLIVAR and GEWEX. AMMA is also endorsed by IGAC and ILEAPS (components of IGBP) and is working with other international projects and programmes including GCOS, GOOS and THORPEX.

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## Overview of the AMMA observing campaigns

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### Introduction

The great challenge in designing the AMMA observing strategy has been to deal with the very wide range of timescales and spatial scales dictated by the monsoon system (Redelsperger et al, this issue). Our approach has been to divide the programme into three nested periods associated with characteristic scientific and operational issues:

- The Long-term Observing Period (LOP; 2001-2010) is designed to deal with scientific issues related to variability in the system over a number of seasons. Operationally, this relies on the maintenance of a manageable number of established monitoring systems, on the land, in the atmosphere and on the ocean (including sea surface temperature and salinity, ground water balance, vegetation dynamics, anthropogenic forcing, and atmospheric state). The LOP actions also include the recovery and archiving of historical data.
- The Extended Observing Period (EOP; 2005-2007) aims at providing a detailed analysis of the monsoon system over at least 2 complete annual cycles. This has involved the reinforcement of the LOP sites, including the radiosonde network; the installation of new, relatively high-maintenance sensors, such as flux stations; and oceanic measurements carried out by a research vessel during two annual cruises in the Gulf of Guinea.
- The Special Observing Periods (SOPs; 2006) were shorter periods of activity in which every effort was made to achieve the best possible intensive analysis of certain elements of the monsoon system. Four SOPs were conducted at key stages of the annual cycle: (i) the dry season (SOP0; 10 January- 20 February), (ii) Monsoon onset (SOP1; 15 May-30 June), (iii) Peak monsoon (SOP2; 1 July – 30 August) and (iv) Late monsoon, defined here as the period when the downstream impact of the WAM onto the formation of cyclones over the tropical Atlantic is at its peak (SOP3; 15 August- 30 September). In 2006, the extremely late onset of the monsoon, in mid-July, therefore occurred during SOP2 (Janicot et al. this issue). Seven research aircraft and three research vessels, as well as an estimated 800 scientists and technicians were active in the field during the various SOPs of 2006.

More details can be obtained from (<http://www.amma-international.org/>), and Bourlès et al. this issue.

### Long-term networks, the EOPs and enhanced monitoring

The foundation of the AMMA long term strategy has been the pre-existing network of mesoscale sites and ocean observations (Figure 1, front cover). In particular, the three mesoscale "super-sites" of Gourma, Niamey and

Ouémé were defined in 2001 as a regrouping of existing programmes on which aerosol, chemistry, hydrology and vegetation measurements were performed in a similar way by similar instruments. These three sites provide a nice sampling of the diversity of the land surface conditions over West Africa. In recent years, the PHOTONS/AERONET network has been widely used to establish climatologies of aerosol properties while IDAF is monitoring the chemistry of wet and dry deposits and emissions at 5 stations over West Africa (Figure 2). Over the tropical Atlantic, the PIRATA Observing system (<http://www.pmel.noaa.gov/pirata/>) was initiated in 1997 and now supports 16 buoys making operational oceanic and atmospheric measurements. A meteorological station has also been installed on Sao Tome Island in 2003, where a tide gauge has also been maintained for many years in the framework of PIRATA.

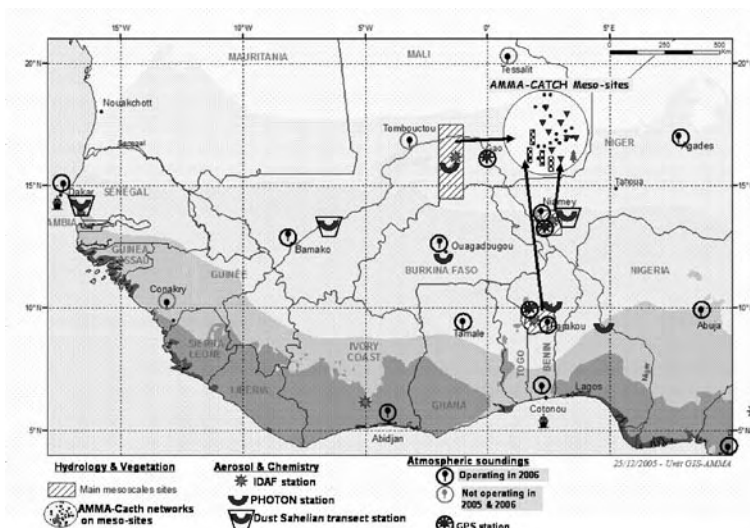
Each of these facilities has supported a network of instrumentation over several years addressing key elements of the monsoon system. For the AMMA EOP they have been enhanced by additional instrumentation and dedicated missions.

The main effort of the land surface EOP programme was on the super-sites, since it is at the smaller meso-scale that a better understanding of the hydrological processes and of their coupling with the vegetation dynamics is needed for improving the parametrisations of land surface models. The observations over these mesoscale sites were enhanced both by the intensification of existing networks, and the introduction of new sensors for limited periods.

Surface fluxes (latent and sensible heat, CO<sub>2</sub>) and soil moisture are key variables that were not monitored prior to the EOP, but should remain for the post-EOP LOP years (at least 2008 and 2009). The series of 17 flux stations deployed on the mesoscale sites from 7°N (Pobè, Bénin) to 17°N (Bamba, Mali) constitutes a unique meridional transect to document surface-atmosphere exchanges in a region where virtually no such measurements existed before AMMA. Surface fluxes are also documented using two scintillometers (one in Niger, one in Bénin) providing a spatially integrated measurement of the sensible heat flux over an area of a few km<sup>2</sup>. Another key EOP water balance instrument is the XPORT X-band Doppler and polarized weather radar installed on the Ouémé site. It has provided a fine resolution observation of the rainfields at high time-sampling frequency (typically one volume scan every 10 minutes) over the Donga catchment.

The land surface LOP-EOP program is certainly the first such program carried out in West Africa on at least two accounts: i) joint and coherent monitoring of three sites over several years, covering a range of different

Figure 2. The LOP and EOP regional scale observing systems over the continental AMMA domain. Radiosonde stations marked with a red circle did not achieve comprehensive EOP measurements: Tessalit was not operational, Tombouctou was active intermittently, and Conakry was only operated during SOP3.



surface conditions; ii) deployment of new sensors never previously used in this region of the world. The three meso-sites have acted as “field schools” that are used to train a new generation of young African scientists to new instruments and methods in hydrometeorology.

The radiosonde network of West Africa has been in decline for many years. It has therefore been essential to invest in improvements and extensions to the network: 23 stations have been identified as significant for AMMA science (Figure 1). A number of existing stations have been refurbished, where needed, with special attention to their data communication facilities. This has included reactivation of the important climate station at Abidjan, and improvements in communications across the network. On the existing stations, the data acquisition on the Global Telecommunication System (GTS) improved from 64% in 2005 to 73% in the period March-December 2006 – further improvements are expected in 2007. Central to AMMA’s strategy has been the provision of a network of 5 stations in the Guinean zone including 4 new stations, at Tamale, Parakou, Abuja and Cotonou (Figure 1). These have been operating since early 2006 and provide climatic, as well as more intensive measurements of the monsoon circulation, filling a conspicuous gap (which had persisted for nearly 5 years) in the atmospheric data from the monsoon inflow. In addition to the radiosonde network, three GPS water vapour stations were installed for the EOP (Figure 2), and a further three more in the SOP year of 2006 (Figure 3, page 13), providing two north-south transects of 3 stations. Weekly ozone sondes have been released from Cotonou throughout the EOP, with two per week during the SOP year.

The LOP aerosol monitoring has been enhanced by a Sahelian Dust Transect made of three stations (Figure 2) located in M’Bour (Senegal, 16.96°W), Cinzana (Mali, 5.93°W) and Banizoumbou (Niger, 2.66°W). Each of these sites is equipped with a TEOM, measuring the concentration at ground level (particle size resolved), an automated collector monitoring the wet and dry deposits, a micro-lidar and a photometer.

The EOP programme on the ocean has consisted of two annual cruises (see Bourlès et al., (2007) for more

details); one during the establishment of the cold tongue and the monsoon onset (June), and one at the end of the equatorial upwelling corresponding to the retreat of the ITCZ to the south (September). These French cruises acquired a large amount of observations in the upper ocean, principally along two meridional sections, at 10°W and 2°50’E, south of the “AMMA-CATCH” continental observations (see Bourlès et al. this issue). These cruises have also been the opportunity for training colleagues from African countries involved in AMMA: at the time of writing, 16 scientists from Benin, Togo, Nigeria, Congo, Ivory Coast, Ghana and Senegal have contributed to data acquisition, XBTs and ARGO profiler deployment and sea water sampling.

### Special Observing Periods

The regional coverage on the continent was enhanced by establishing three additional meso-sites (Figure 1): the Dakar site, equipped with the US radar N-POL, is a land-ocean transition site, which was further developed in August-September 2006 by the installation of the TOGA C-band radar at Praia in the Cape Verde Islands; at Dano (Burkina Faso), a surface layer monitoring and a mobile radiosonde station were installed; to the extreme north, at Tamanrasset, the Transportable Remote Sensing Station (TReSS) was deployed to measure aerosol and cloud radiative properties through a synergy of backscatter lidar, radiometry and in situ sampling within the Sahara.

Two of the EOP meso-sites became “super meso-sites” (Figure 3). The Niamey meso-site was expanded for aerosol/radiation measurements with the ARM Mobile Facility (Miller and Slingo 2007) (AMF) installed at the Niamey airport for the whole of 2006, and the Banizoumbou super-site was equipped with an impressive and unique set of instruments dedicated to a high resolution and high frequency sampling of the aerosol loading and optical properties. Also at the Niamey airport was the C-Band MIT Doppler weather radar, for fine resolution precipitation measurements and to study the dynamics of convective systems. On the Ouémé méso-site, the Donga super-site was equipped with two Doppler and polarised weather radars

(including the RONSARD C-band radar), two profilers, and various other vertically pointing instruments, as well as a lightning detection network, providing a detailed sampling of the atmospheric variables conditioning the water and energy budgets at the mesoscale. Aerosol and chemistry measurements were also enhanced at Djougou to provide an ancillary aerosol (of predominant biomass-burning origin) site in a more humid environment.

During the weeks leading up to the monsoon onset, centred on the month of June, three research vessels (the French *Atalante*, the German *Meteor* and the US Ronald H. Brown) were deployed simultaneously in the tropical Atlantic (Figure 4 (page 13) – see also Bourles et al. this issue). In particular, intensive high frequency measurements of the turbulent fluxes at the air-sea interface have been acquired that will allow us to assess the relative importance of different parameters and processes driving the air-sea exchanges in the tropical Atlantic during the monsoon onset.

6-hourly radiosoundings were made on six stations (Figure 3) with two periods of 3-hourly soundings during 20-29 June and 1-15 August. During the months of June to September 2006, around 7000 radiosondes were released on the network. Through the partnership between AMMA and SCOUT ([http://www.ozone-sec.ch.cam.ac.uk/scout\\_o3/](http://www.ozone-sec.ch.cam.ac.uk/scout_o3/)), a suite of 35 large balloons, with a variety of payloads devoted to water vapour, chemistry, aerosols and cloud measurements in the tropical tropopause layer (TTL), were also launched from Niamey in SOP2. In total, 251 radiosondes were released from the 3 research vessels in the Atlantic, and 510 dropsondes were released from research aircraft over the continent and the adjacent ocean, with the majority of these being transmitted to the GTS. During SOP3, 6 driftsonde gondolas were successfully launched from Zinder (Niger) and these deployed a total of 129 dropsondes as they moved westward over the continent and the tropical Atlantic. Finally, 15 boundary layer pressurized balloons were launched from Cotonou, to move generally north-eastward in the monsoon flow, between 15 June and 15 July 2006.

Aircraft operations were coordinated into particular scientific themes. In SOP0, flights with the UK BAe146 and a French (LSCE/CNES) lidar-equipped microlight aircraft targeted patterns of mineral dust and biogenic aerosol. During SOP1 and SOP2, five research aircraft – the French Falcon and ATR42, the German Falcon, the British BAe146 and the European Geophysica – were operated from bases at Niamey and Ouagadougou. The majority of flights were aimed at exploring the physics and chemistry of land-ocean-atmosphere interactions, including surveys over the Sahara and the ITF (Inter-tropical front), through the Sahel and the Guinean zone and over the whole Atlantic Ocean, in coordination with ship measurements during SOP1. Other flights explored the dynamics and chemistry of MCSs (Mesoscale Convective Systems), long-range transport, and cloud microphysics, coordinated with the radars, as well as

with CALIPSO and CLOUDSAT overpasses. During SOP3, operations moved to Dakar, where the UK BAe146, the French Falcon and the NASA DC-8 made observations of the dynamics and composition of circulations leaving the coast. 7 African Easterly Waves were sampled, of which 4 became named storms (Thorncroft et al., 2007).

The headquarters of the AMMA Operational Centre (AOC) was located in Niamey at a refurbished villa of the Niger Direction de la Meteorologie Nationale (DMN). Operational weather forecasting was conducted at the African Centre of Meteorological Application for Development (ACMAD), by a team of forecasters from several West African countries. Developing new forecasting techniques and training were two important aspects of this activity which will have long term benefits for the West African community of meteorologists.

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## African Monsoon Multidisciplinary Analysis (AMMA) : Special measurements in the Tropical Atlantic

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## Introduction

Oceanographic and maritime atmospheric observations complement the land surface and continental atmospheric measurements made during the three observing periods of AMMA (see also Parker et al., this issue): Long term Observing Period (LOP; 2001-2010), Enhanced Observing Period (EOP; 2005-2007), and Special Observing Period (SOP, in 2006). Detailed scientific rationale for these data is given in both international and national AMMA documents (see <http://amma-international.org/science/>). The principal aims of these observations are:

- the study of processes that determine seasonal to interannual variability of observed sea surface temperature (SST), sea surface salinity (SSS), mixed layer depth and heat content, in the Tropical Atlantic and in the Gulf of Guinea (GG), and their linkage with the West African Monsoon (WAM);
- the study of processes that determine the seasonal evolution of the cold tongue - Inter Tropical Convergence Zone (ITCZ) - WAM system.
- the study of both ocean and atmosphere boundary layers and air-sea exchanges;
- the validation of models, satellite data and products.

The overall sampling strategy is mainly based on (1) the acquisition of *in situ* measurements in the eastern Tropical Atlantic and the GG and (2) the integration of these data to characterize the air-land-sea monsoon system during the three observing periods of AMMA (and thereby resolving different timescales ranging from annual to interannual).

## Ocean measurements

## LOP measurements:

Long-term measurements in this region are facilitated through existing sustained observing networks and acquisition programs, such as the Pilot Research moored Array in the Tropical Atlantic (PIRATA) ATLAS buoy network<sup>1</sup>. The moorings within this multi-national network consist of longitudinal arrays along 38°W/35°W, 23°W, 10°W, as well one at 0°N, 0°W in the GG and a newly-deployed site at 6°S, 8°E near the Congo Plume. Additional data coverage in the tropical Atlantic is provided by a French "Observatoire de Recherche pour l'Environnement" (ORE) for sea surface salinity, the Voluntary Observatory Ship (VOS) expendable bathythermograph (XBT) lines, a large number of surface drifters provided by the US Global Drifter Program, Argo, and the French CORIOLIS operational programs. This vast autonomous measurement network is enhanced by repeat surveys by oceanographic research vessels, and

data collected at coastal stations, by tide gauges, and at a meteorological station on São Tomé Island (Equator-6°E), which was installed within the framework of AMMA/France.

## EOP measurements:

In addition to these LOP measurements, observations are carried out in the scientific framework of the French EGEE project ("Etude de la circulation océanique et des échanges océan-atmosphère dans le Golfe de Guinée") during the EOP. To assess interannual and seasonal variability, six EGEE cruises in the GG are being conducted from Cotonou, Benin, with two cruises per year during the three EOP years (2005-2007). Cruises were scheduled to coincide with the monsoon onset and development of equatorial upwelling in the GG in boreal spring and summer (end of May to July), and again during the mature phase of the monsoon (September-October), when the cold tongue is still well developed in the GG and the ITCZ begins its southward migration. Seasonal and interannual variability is measured along several meridional sections (Figure 1 page 14). Primary focus is given to the 10°W section, which was occupied several times prior to EGEE by PIRATA and EQUALANT cruises, and to the 3°E line, directly south of Benin and the "AMMA-Catch" continental observations area (see Lebel et al., this issue).

The first four EOP cruises were successfully completed in June-July and September 2005, and in May-July and November 2006. The most recent EGEE cruise in November 2006 (EGEE-4), was carried out onboard a refitted research catamaran (R/V L'ANTEA), and was limited to the 10°W and 3°E sections, north of 6°S. The two last EGEE cruises are scheduled for June and September 2007. During each cruise, hydrological (CTD-O2) and current (ADCP) profiles of the upper ocean are made above 500m along each meridional section with a  $\frac{1}{2}^\circ$  resolution in latitude/longitude, which increased to  $\frac{1}{3}^\circ$  in the equatorial band, between 2°S and 2°N. During the CTD casts, seawater samples are collected for determination of salinity, dissolved oxygen and nutrient profiles. XBTs provide additional temperature profile information between CTD profiles and every  $\frac{1}{2}^\circ$  in latitude/longitude along the transits. Ocean turbulence measurements using microstructure shear and temperature sensors are conducted in tandem with CTD measurements along 10°W, 2°50'E and 6°E since September 2005. The dataset will allow studies on upper ocean mixing processes and diapycnal heat flux. Along-track measurements of a wide range of meteorological parameters, upper layer currents (VM-ADCP), sea surface temperature and salinity, CO<sub>2</sub>, nutrients, and

<sup>1</sup>a list of web sites for each of the autonomous measurement networks is provided at the end of the article

Helium (coll. Univ. of Bremen) made to support the station measurements. The cruises also provide the opportunity to service the PIRATA buoys in the GG, to deploy Surface Velocity Profilers (SVP) surface drifting buoys, and to deploy Argo profilers (35 Argo profilers in 2005 and 2006), which profile temperature and salinity down to 2000m depth every 10 days.

#### *SOP measurements:*

In 2006, for the SOP AMMA process studies, an even broader range of oceanic and meteorological measurements were successfully collected, thanks to a very efficient collaboration between US, German and French partners. Through this international research network, three quasi-simultaneous cruises were conducted during the SOP 1 period, from May to July, onboard the French R/V *Atalante* in the GG, and onboard the US R/V *Ronald H. Brown* and German R/V *Meteor* in the west and central tropical Atlantic. The overarching goal of these three campaigns was to assess the monsoon onset initial conditions and the processes that drive the air-sea exchanges, from both sides of the ITCZ. From the R/Vs *Atalante* and *Ronald H. Brown* measurements, turbulent fluxes were estimated by inertial dissipation, correlation and bulk methods. Flux measurements were supported by redundant solar and infrared radiation sensors and precipitation measurement arrays on each ship. From the R/V *Atalante*, turbulent fluxes were also measured during 6 long duration stations (24h to 48h) when the ship was close to the PIRATA ATLAS buoys and again south of the São Tomé Island, the site of an autonomous meteorological station. Aerosol optical depth from multi-frequency shadowband radiometers on both vessels and backscatter and chemistry from lidar and the MOUDI on the R/V *Ron Brown* helped to characterize the atmospheric composition and any intrusions of dust or pollution aerosol from Africa. Radiosoundings (RS) were performed twice a day from the three vessels, with real-time data transmission by GTS for ingestion into various mid-range forecast models and to complement the improved African upper air network installed as part of AMMA. Two aircraft surveys over the GG on June 14 (ATR 42 and F20 *Léandre*) and July 4 (ATR 42 only) provided additional air-sea sampling over the R/V *Atalante* cruise-track. Flight paths were along 2°50'E, from the coast (Cotonou) to 2°N, during which time the R/V *Atalante* released radiosondes every 3h. Instrumentation onboard the ATR42 measured atmospheric turbulence, SST, and in situ measurements while the F20 *Léandre* was equipped with 2 Lidar and launched dropsondes. Radiometric measurements of sea surface skin and air temperature on both the RVs *Atalante* and *Ron Brown* provided high accuracy measurements for calculation of heat exchange across the air-sea interface. Ocean mixed layer temperature was profiled from the R/V *Atalante* through the deployment of 12 drifting thermistor chains ("Marisonde" drifters) and several SVP which measured temperature profiles in the upper 70m. In the framework of the German project "North Atlantic" an array of four current meter

moorings was installed around 23°W, 0°N during R/V *Meteor* cruise to observe the equatorial supply routes toward the eastern Atlantic upwelling regions, and two current meter moorings were also deployed at 23°W, 5°N and 10°W, 0°N. Taken together, the three cruises thus maintained or deployed a total of 8 PIRATA Atlas buoys, 6 subsurface moorings, 45 Argo profilers, 34 SVP surface drifters, 251 radiosoundings, 20 atmospheric ozone profiles (from the R/Vs *Meteor* and *Ron Brown* R/Vs), 258 XBTs and 17 XCTDs, and carried out a total of 292 CTD and 540 microstructure profiles across the entire tropical Atlantic.

#### **Perspectives:**

The various measurement strategies (lagrangian, eulerian, synoptic, surface and subsurface, high frequency acquisition etc...) and the wide range of measured parameters (currents, hydrology, tracers) provide a rich dataset for studying oceanic processes in the tropical Atlantic, both in relation to seasonal features such as the WAM and observed interannual variability. Furthermore, the collection of a high quality turbulent flux dataset over various time and length scales will help determine the relative importance of different air-sea parameters and processes in the tropical Atlantic (e.g. Brut et al., 2005) such as skin SST effect and cooling due to precipitation. Gridded flux fields over the ocean will be produced from the combined surface data, including satellite retrievals and atmospheric parameters calculated from bulk flux algorithms. The PIRATA array, ship-based data and drifters will provide an unprecedented dataset for these comparisons. A key issue regarding these gridded fields is to determine the surface heat and water budget in the GG during the monsoon season, in order (1) to realistically force oceanic models, (2) to evaluate the amount of northward heat and moisture flux from the ocean to the continent during monsoon development and maturation and (3) to test concepts concerning the importance of meridional temperature gradients associated with the formation of the equatorial cold-tongue during the WAM. Specific efforts are needed to evaluate such surface flux fields in atmospheric NWP models, which generally fail to close oceanic budgets. A wide range of oceanic and air-sea products from MERCATOR and research models CLIPPER and ROMS will also be evaluated with EGEE data, focusing on their assimilation schemes and realization of oceanic currents and SST patterns. At a regional level, the modelling effort will be on upper layer heat budgets, and on factors that drive the formation and maintenance of the "cold tongue" in the GG. On smaller scales, process studies using data suited to defining fine-scale features and short-duration processes in the ocean, upper mixed layer, and marine atmospheric boundary layer will be conducted. In the short term, efforts are focused on providing the best possible quality data to the AMMA database including quality-controlled and inter-compared time series from all three ships. The combined LOP, EOP, and SOP data streams, will provide an ample test set for evaluating recent variability in the tropical Atlantic Ocean, such



as the large interannual SST differences noted in June 2005 and 2006 (Figure 1), as well as provide a worthy complement to the continental datasets for improved interpretation and forecasting of the WAM.

#### Websites:

PIRATA: <http://www.pmel.noaa.gov/pirata/>;

CORIOLIS : <http://www.coriolis.eu.org/cdc/default.htm>;

SEA SURFACE SALINITY: <http://www.legos.obs-mip.fr/en/observations/sss>;

XBT NETWORKS: <http://www.brest.ird.fr/us025/observatoire/reseaux.htm>;

SURFACE DRIFTERS : <http://www.aoml.noaa.gov/phod/dac/>;

#### Reference:

Brut, A., A. Butet, P. Durand, G. Caniaux, and S. Planton, 2005: Estimations of turbulent air-sea fluxes and their parameterizations including airflow distortion corrections from the EQUALANT99 dataset. *Quart. J. Roy. Meteor. Soc.*, **131**, 2497-2538.

### Aerosol studies during AMMA

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#### 1. Introduction

The North African continent is one of the largest global sources of mineral dust and anthropogenic biomass-burning aerosols. These aerosols have a significant influence on the radiative energy budget of the West African region, by both scattering and absorbing atmospheric radiation. These effects reduce the net radiative flux at the surface but can significantly increase radiative absorption in the atmosphere and may thereby influence synoptic-scale atmospheric dynamics prior to the monsoon development. High aerosol burdens and chemical emissions associated with biomass-burning activities are also a concern to human health and the quality of life in the West African region.

Agricultural burning activity is most intense during the dry season in West Africa (December-February) leading to high concentrations of biomass-burning aerosol across the Sahel region. Saharan dust is also transported far south into the Sahel during the dry season when the ITCZ shifts south towards the West African coastline. The dry season Special Observing Period (SOP-0) was established within the AMMA program to focus on aerosol and meteorological measurements that were carried out during January and February 2006.

The first phase of SOP-0 concentrated on the Central West African region around Niger, Benin and Nigeria and was in co-ordination with the UK Met Office Dust and Biomass Experiment (DABEX). This involved the Facility for Airborne Atmospheric Measurements (FAAM BAe 146), which operated from Niamey, Niger. Ground sites at Niamey and Banizoumbou (Niger), Ilorin (Nigeria), and Djougou (Benin) hosted a variety of Lidars, aerosol-sampling instruments and radiometers. The Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) was also deployed at Niamey throughout 2006 hosting a more detailed and comprehensive suite of radiometric instruments.

The second phase of SOP-0 involved FAAM aircraft activities along the Atlantic coast of Senegal, and Mauritania as part of the Dust Outflow and Deposition

to the Ocean (DODO) experiment. Aircraft measurements were also taken to characterise aged biomass-burning aerosols that had been transported off the coast to the South of Senegal. Ground-based measurements were also made at M'Bour (Senegal) during the second phase of SOP-0.

The overall objective of these activities was to characterise the properties of dust and biomass-burning aerosols in West Africa and develop an understanding of how these aerosols were mixed and transported over time. A further objective was to provide quality observations for the validation of remote sensing techniques, including satellite retrievals and retrievals from ground-based Aerosol Robotic Network (AERONET) sunphotometers. Such observations are also vital for the ongoing development of global, regional and process-level aerosol models.

#### 2. Satellite observations

Satellites are an indispensable tool for identifying aerosol plumes and mapping their horizontal distribution. Figure 1 (page 14) shows the January 2006 mean aerosol optical depth, estimated from the Multi-angle Imaging SpectroRadiometer (MISR) on-board the NASA TERRA satellite. This highlights the high aerosol loadings associated with both biomass-burning activity in the Sahel, and dust production over certain areas of the Saharan desert (e.g. north-east Niger and Chad). MISR aerosol optical depths were generally well correlated with AERONET and aircraft measurements during DABEX, confirming the strength of the MISR instrument in measuring aerosol properties over land (e.g. Abdou et al. 2005). However, retrievals of aerosol size distributions and single scattering albedo seemed less successful. MISR is limited by its narrow swath (360km), which means that global coverage is only possible every 9 days.

The Moderate resolution Imaging Spectroradiometer (MODIS), on-board both TERRA and AQUA, has good spatial coverage and provides daily images from which cloud and aerosol plumes can be identified (<http://rapidfire.sci.gsfc.nasa.gov/>). These images were crucial

in planning which areas to investigate during aircraft exercises. Another specific utility of MODIS is its ability to pin-point individual large fires and map their spatial distribution over time. The monthly mean map of fire-count density (Figure 2 page 14) identifies a huge belt of intensive agricultural burning activity across Africa between the latitudes of 5°N and 12°N. MODIS images, and products from other satellites such as PARASOL and CALIPSO, have also been of particular use for post-event analysis of aerosol emissions and transport. The Spinning Enhanced Visible and Infra-Red Imager (SEVIRI instrument), operating from a geostationary METEOSAT platform, has also been an excellent tool for identifying and tracking dust outbreaks over the North African continent.

### 3. Airborne observations

The FAAM BAe 146 aircraft is fitted with a large range of meteorological, cloud, aerosol and radiometric instruments. The aircraft made 13 dedicated flights during DABEX, Jan 13-Feb 3, and 7 flights during DODO, Feb 7-16. The aircraft measured aerosol size distributions, optical properties (scattering and absorption coefficients) and aerosol chemical composition from an Aerosol Mass Spectrometer. Aerosol samples collected on filters have also been analyzed for chemical signatures. These *in situ* measurements are complemented by broadband and spectrally-resolved radiometers bringing together a comprehensive characterization of aerosol properties, vertical distributions and optical depths. Six flights were made to the south over the intense regions of biomass-burning activity (as directed by MODIS images). Two of these specifically targeted fresh smoke plumes rising from active fires. Four flights were made in the immediate vicinity of Niamey and encountered mixtures of dust and more aged biomass aerosol. Three flights were flown to the northeast to investigate plumes of Saharan dust that had been identified from MODIS images. During DODO flights investigated localised dust storms forming over Mauritania and advecting out over the Atlantic.

An ultra-light aircraft equipped with active remote sensing, by the Laboratoire des Sciences du Climat et de l'Environnement (LSCE/IPSL/CEA-CNRS) and Air Creation, allowed a range of resolved measurements to characterise aerosol scattering on the vertical over the Niamey and Banizoumbou area in the south Niger. This involved a total of 30 hours of flying, on some occasions strategically co-ordinated with the FAAM aircraft.

Throughout DABEX and DODO elevated layers of aged biomass-burning aerosol were consistently observed at altitudes up to 4km and often several hundred kilometers north from major biomass-burning emission sources. Furthermore, high concentrations of dust were often observed, typically below 1.5km, over both the semi-arid regions to the north of Niamey and the more highly vegetated regions to the south. Here smoke mixed with the dust creating mixtures of fresh biomass-burning aerosol and dust. These aerosols were transported vertically by convective mixing creating layers of aerosols at various

altitudes. A transition of aerosol size distributions has been noted between fresh smoke aerosols and elevated aged aerosol layers.

### 4. Ground-based observations

Ground-based observations were made from super-sites (Banizoumbou in Niger, Djougou in Benin, and M'Bour in Senegal) operated only during the AMMA SOP 0, or continuously as the ARM mobile facility (AMF) in Niamey, Niger. All super-site stations were fully equipped by European and US partners, and coincided geographically with AERONET/PHOTON stations. The super-sites provided high-quality, high temporal resolution aerosol and radiation measurements specific to the SOP 0 observational strategy. The AMF was installed by US teams at Niamey airport for the full year of 2006. A particular goal of the AMF deployment was to generate estimates of the divergence of radiation across the atmosphere by comparing surface measurements with data from the Geostationary Earth Radiation Budget (GERB) satellite instrument (Slingo et al. 2006).

These ground sites have created a complete set of physical, chemical and optical measurements, made near the surface, including size distributions, size-segregated sampling for chemical and mineralogical analysis, spectral scattering and absorption coefficients, remotely-sensed column-integrated properties, spectral and broadband radiation fluxes, and aerosol vertical distributions from LIDAR backscattering profiles.

### 5. Modelling activities

Various models have been used to forecast the occurrence of dust outbreaks, and the transport and dispersion of smoke plumes. For example, trajectory analyses have been used to assess the origin of aerosol layers that were observed at different altitudes. Modelling studies will also investigate the emission, transport and evolution of dust and biomass-burning aerosols at local and regional scales. This will help to better quantify aerosol sources and their effects on the radiation budget.

### 6. Preliminary Conclusions

High concentrations of mineral dust and biomass-burning aerosol were observed over the West African region, during January-February 2006, as part of dry season AMMA Special Observing Period (SOP-0). This involved a variety of *in situ* sampling and remote sensing measurements, satellite data and model simulations. The primary focus has been on understanding how mineral dust and biomass-burning properties vary within the West African region, and how these properties relate to emission, mixing and transport processes.

MISR and AERONET show monthly mean optical depths in excess of 0.5 across some parts of the region where biomass-burning activity was most intense. A large contribution to the aerosol optical depth also comes from Saharan dust. This was transported into the Sahel by low-levels convergent winds and was typically found below 1.5km. In general, the dust loading was higher further north, whereas biomass-burning aerosol was dominant to the south. Biomass-burning aerosols were consistently

found in elevated layers distributed up to 4km that often extended several hundred kilometres north of major fire sources. Aircraft measurements and LIDAR backscatter profiles reveal complex vertical structure within aerosol layers. Associated back-trajectory analyses often show different origins for aerosols at different altitudes.

Aircraft and ground-based *in situ* sampling measurements have shown huge variability of aerosol physical, chemical and optical properties with space and time. For example, the single scattering albedo, a parameter of key importance for radiative forcing and climate impacts, was found to vary from around 0.98 at 550nm for dust that absorbed very little solar radiation, to anywhere in the range 0.75-0.9 (at 550nm) for biomass-burning aerosols that were more highly absorbing. AERONET retrievals from sites in the biomass-burning zone (e.g. Djougou in Nigeria) confirm single scattering albedos often down to 0.8 or 0.85 at 550nm for columns dominated by biomass-burning aerosol.

Satellite estimates of optical depth from MISR, AERONET and the FAAM aircraft are generally in good agreement increasing confidence in the use of MISR to map the spatial distribution of aerosol over land. A newly developed Deep Blue algorithm is also anticipated to bring improvements in MODIS estimates of aerosol optical depth over bright land surfaces (Hsu et al. 2004). Ground-based and airborne measurements also coincided with AERONET sunphotometer sites allowing useful comparisons. Validations are generally encouraging, supporting further use of AERONET data for the development of global and regional aerosol models.

These understandings gained from AMMA SOP-0 aerosol studies need to be brought together by regional modelling studies to generate more quantitative assessments of aerosol radiative impacts. This will be crucial in determining the possible influence of regional aerosols on large-scale atmospheric dynamics and the hydrological cycle, prior to the onset of the monsoon.

#### Acknowledgements

The FAAM is jointly funded by the Met Office and the Natural Environment Research Council. Figures 1 and 2 were provided by Christopher Sundar, University of Alabama, Huntsville.

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### The large-scale context on the West African Monsoon in 2006

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#### Introduction

Within the framework of the project AMMA (African Monsoon Multidisciplinary Analysis), an intensive field campaign was organized during the summer 2006 to better document the set-up and the development of the African monsoon. In parallel, regional and large-scale monitoring has been carried out through the production of 21 weekly bulletins (available at the address <http://aoc-paris.polytechnique.fr/> in the bulletin section) in order to provide regularly an integrated view of the evolution of this monsoon system in a larger context. The main results are presented shortly here and will be more extensively described elsewhere.

#### Interannual variability

Figure 1(over page) displays the anomaly field of OLR (out-going longwave radiation; Liebmann and Smith 1996) in July-September 2006 relative to the period 1990-2005. In the climatological ITCZ (Inter-Tropical Convergence Zone) area which is located along 10°N in

summer, a meridional dipole of OLR anomalies is evident in summer 2006 with moderate lower (higher) values north (south) of the ITCZ meaning a slight northward location of the ITCZ relative to the 1990-2005 average. This is associated with moderate positive SST (sea surface temperature) anomalies in the tropical Atlantic with no significant SST anomalies being present in the other basins. Thus the monsoon season of 2006 appears as a near normal season relative to the last 15 years. It is interesting to notice the negative OLR anomalies over Northwest India and Saudi Arabia whose possible extension westward linked to low-level Rossby cyclonic circulation (not shown) might explain the enhancement of convection over the northern part of the African ITCZ as suggested by Mounier and Janicot, (2007).

#### The monsoon onset

The onset stage of the African summer monsoon is linked to an abrupt latitudinal shift of the ITCZ from a quasi-stationary location at 5°N in May-June to a second quasi-

stationary location at 10°N in July-August. This leads to major changes in the atmospheric circulation over West Africa (Sultan and Janicot 2003).

Over the 1968-2005 period, the mean date of the monsoon onset was 24th June with a standard deviation of 8 days. Figure 2 (page 17) depicts the latitude-time cross-section of the OLR field in 2006 averaged between 10°W and 10°E. After weak convective activity in winter, the first rainy season over the Guinean Coast (the coast line is located at 5°N) begins around mid-April with a high increase of convective activity during the second half of April and most of May, followed by a temporary weakening around the end of May (whereas we can notice a northward peak of the ITCZ at the same time) and a recovery of convective activity in June. Convection weakens again from approximately 25th June and 10th July, which corresponds to the typical transition phase of the monsoon onset (Sultan and Janicot 2003), followed by the installation of the monsoon and convection over the Sahelian latitudes with the gravity center of the ITCZ located between 10°N-12°N during the whole summer. An approximate date for the onset transition (that is the centered date of the minimum of convective activity period) can be fixed at 3rd July but the convective activity is increasing significantly over the Sahel from 10th July.

In order to monitor operationally the seasonal progression towards the onset stage of the African monsoon, an Onset Index (OI) has been defined that is able to detect the northward migration of the ITCZ from the Guinean Coast to the Sahelian latitudes. To do so, two standardized OLR indices have been computed using a 5-day mean over 10°W-10°E: a Northern Index (NI) between 7.5°N and 20°N, and a Southern Index (SI) between 0°N and 7.5°N. These indexes have been filtered to remove variability shorter than 15 days. The OI is defined as the difference between NI and SI. It is presented on Figure 3 (page 17) with a reversed sign in order to be interpreted as a rainfall signal (positive values when the ITCZ is in its northern location et vice-versa). The onset date probability function is represented by the shaded vertical bars on Figure 3, the more probable onset dates corresponding to the higher density of the shading. This x-axis labels are expressed in pentads from the beginning of the year. The thick line

depicts the mean index over the period 1979-2000 and the thin line the index in 2006.

The curve of the mean index shows a smooth transition from negative values (when the ITCZ is located over the Guinean Coast) to positive values (when the ITCZ is located over the Sahelian latitudes) except for a northward acceleration from the pentad number 36 (that is just after the onset date of 24th June). The curve for 2006 shows an evolution similar to the mean except being more noisy. The index peaks first to a positive value at pentad 29 (that is 20th-25th May) but retreats quickly to negative ones. This event, being short and located outside of the onset occurrence probability period (represented by the vertical bars), can be considered as a bogus onset. It can be detected on Figure 2 as a temporary northward extension of the ITCZ during the second half of May. The causes of this bogus onset will be analyzed elsewhere. The onset index reaches positive values again on pentad 35 (19th-23rd June) and remains weak until pentad 38 (5th-9th July) when it increases drastically. We can then consider that the convective activity over the Sahel begins really around 10th July at the regional scale, that is with a mean delay of 10 days relative to the mean installation of the African summer monsoon (see also the article of Thorncroft et al., this issue). The last part of the 2006 index during the summer remains higher than the mean values confirming the somewhat higher than average convective activity of the 2006 summer monsoon. The NCEP operational analyses show that from 1st July the low-levels atmospheric fields (zonal wind component, relative vorticity, top of the monsoon layer, integrated water vapor content, Saharan heat low activity, latitude of the Inter-Tropical Front -ITF-) have moved to the north while the deep convection has not developed before 10th July. An explanation for such contradictory evolution is suggested in the next section.

The annual cycle of the 2006 African monsoon has been also very different from the 2005 monsoon cycle where a high tropical Atlantic SST dipole (negative SST anomalies in the Guinea Gulf and positive SST anomalies northward) during spring and the beginning of the summer has induced an ITCZ located more to the north and an earlier monsoon onset. This could involve the

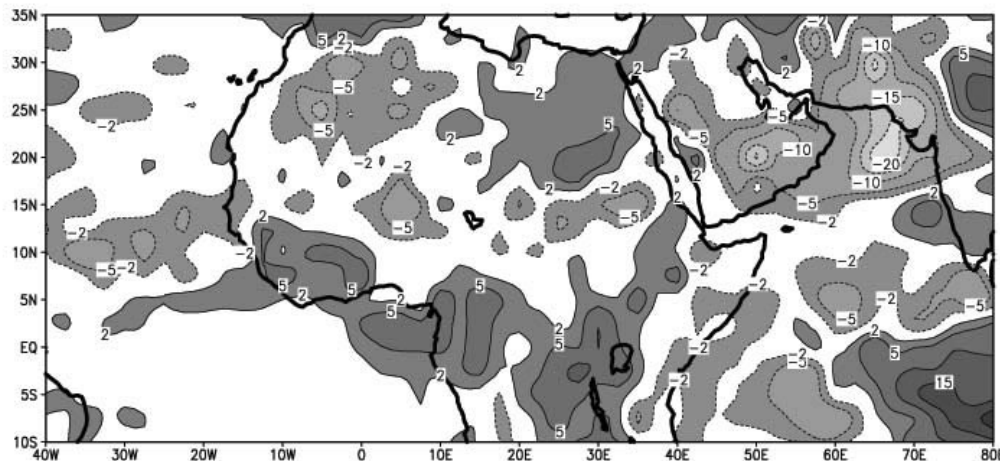


Figure 1: July-September 2006 OLR anomalies relative to 1990-2005. Negative (positive) values in the ITCZ area means enhanced (weakened) convection.

continued on page 17

From Redelsperger et al, page 2: African Monsoon Multidisciplinary Analysis (AMMA) : An International Research Project and Multi-Year Field Campaign,

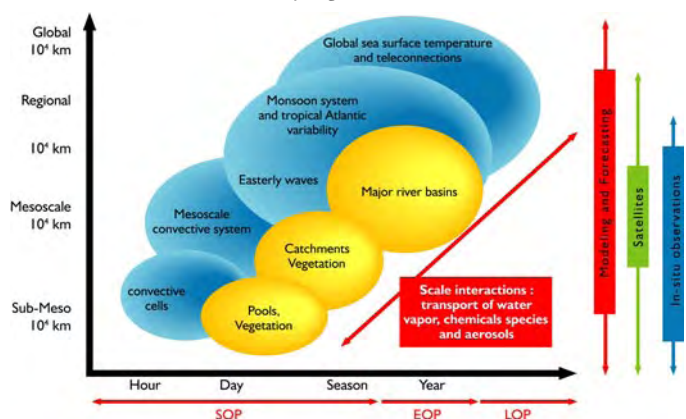


Figure 1 Simplified schematic of key phenomena together with their associated space and time scales. The arrow is included to highlight the importance of scale interactions and transport processes in the WAM.

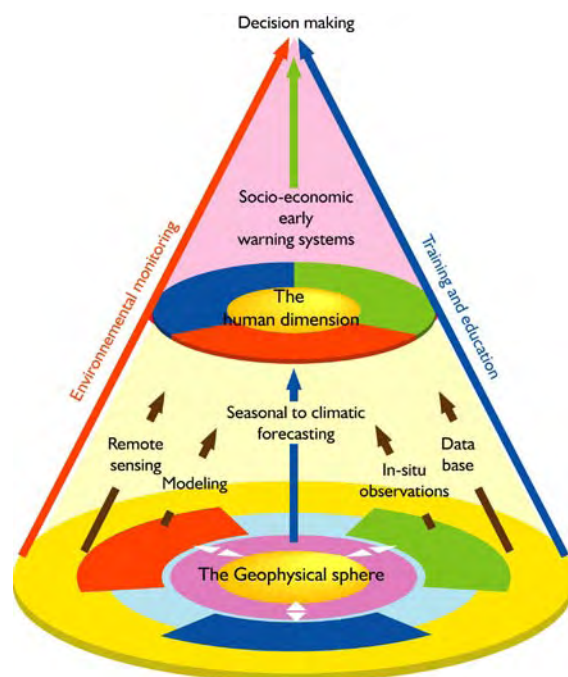


Figure 2 Implementation of AMMA: Integrative science for the geophysical (a) and human dimension (b) Integration from this knowledge through various tools and for the exploitation by impact studies (c)

Parker et al, page 4: Overview of the AMMA observing campaigns

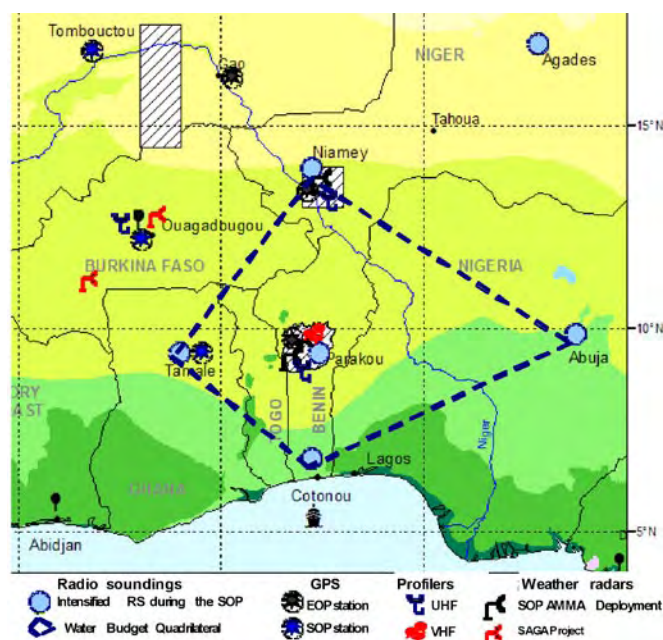


Figure 3. The SOP ground instruments over the central part of the study domain.

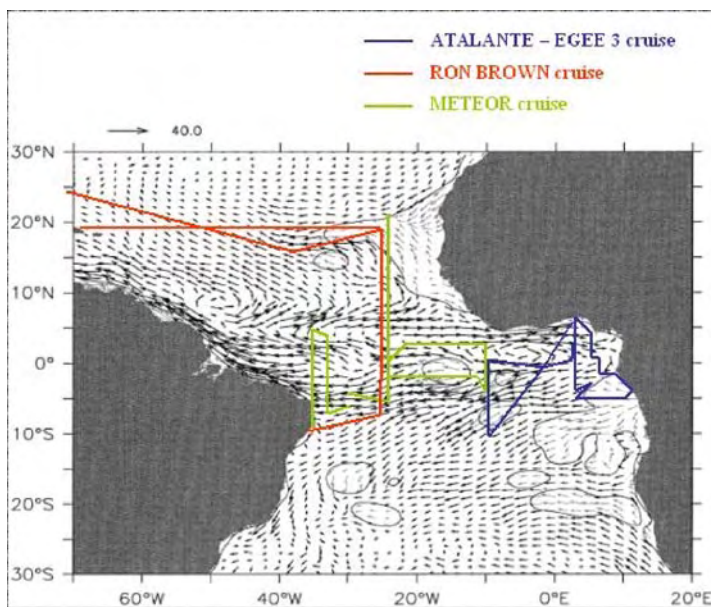


Figure 4. SOP monsoon onset cruise tracks.



From Bourles et al, Page 7: Special measurements in the Tropical Atlantic

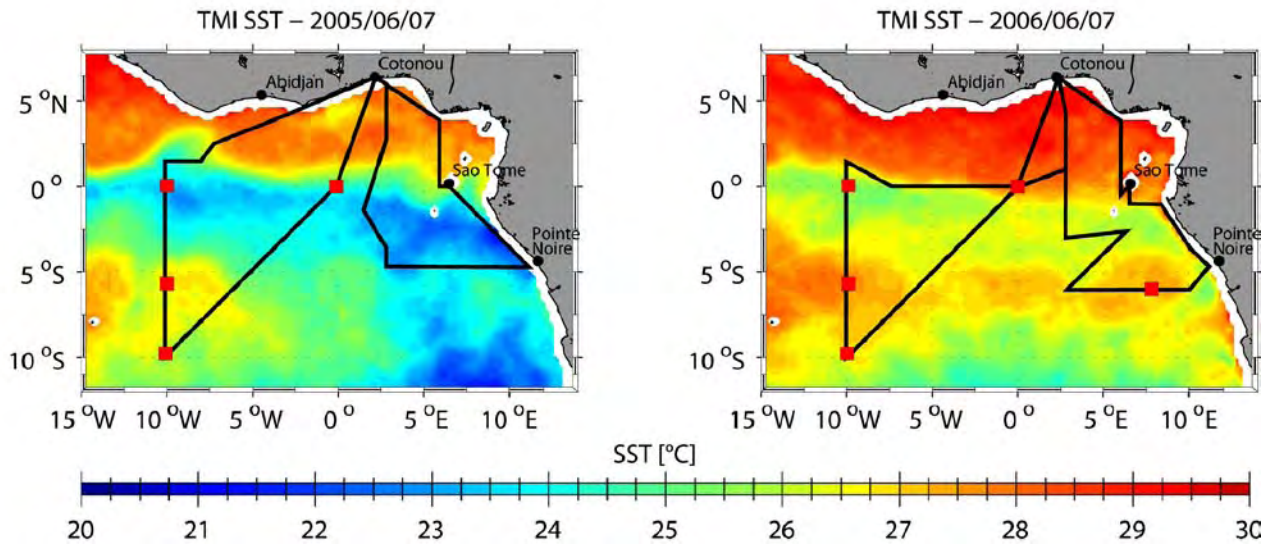


Figure 1: Typical trackline of the French EGEE cruises in the Gulf of Guinea (left: EGEE 1 in June 2005; right: EGEE 3 in May-July 2006). Repeat observations are carried out along the 10°W, 3°E and 6°E sections, and when possible along the 6°S section. Also shown are the PIRATA ATLAS buoys location (red squares), that are serviced during the EGEE cruises. Cruises trackline are superimposed on maps of the sea surface temperature as measured by TRMM/TMI sensor, on June 7, 2005 (top) and June 7, 2006 (down).

From Johnson et al, page 9: Aerosol studies during AMMA

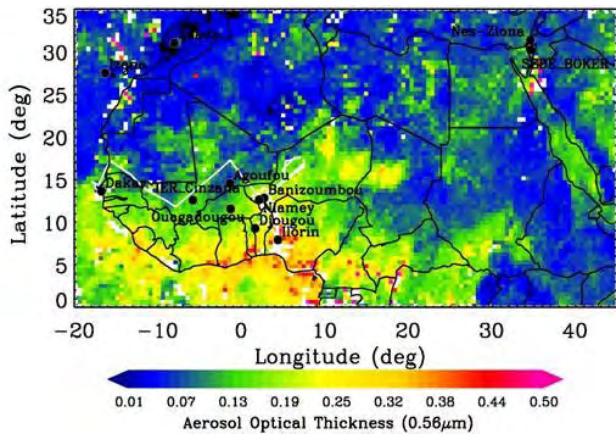


Figure 1. January 2006 monthly mean aerosol optical depth from Multi-angle Imaging SpectroRadiometer (MISR) with surface measurement sites indicated and FAAM aircraft tracks is over-plotted in white.

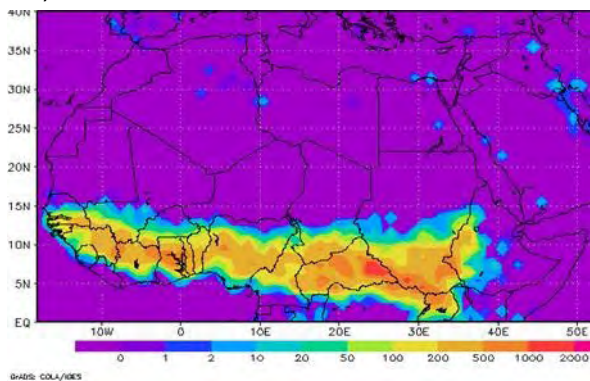


Figure 2. January 2006 monthly mean fire count density from MODIS.

From Janicot et al, page 11: The large-scale context on the West African Monsoon in 2006

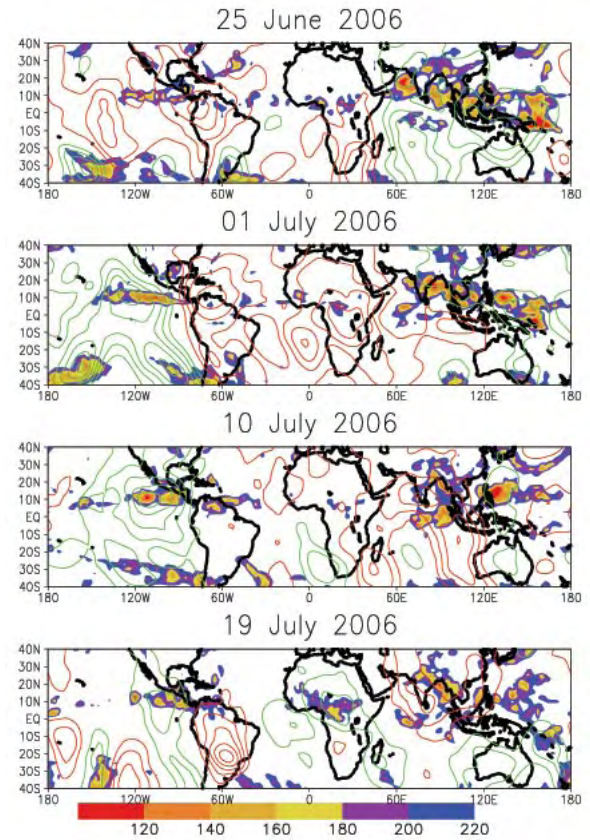


Figure 4: Daily OLR values (shaded) and 200 hPa NCEP velocity potential anomalies (relative the period 1979-1999) on 25th June, 1st July, 10th and 19th July 2006. Green (red) contours means upper-level large-scale divergence (convergence), by step of  $2 \times 10^6 \text{ m}^2 \cdot \text{s}^{-2}$  (the zero isolines are not displayed).



From Thorncroft et al, page 18: Overview of African weather systems during the summer 2006

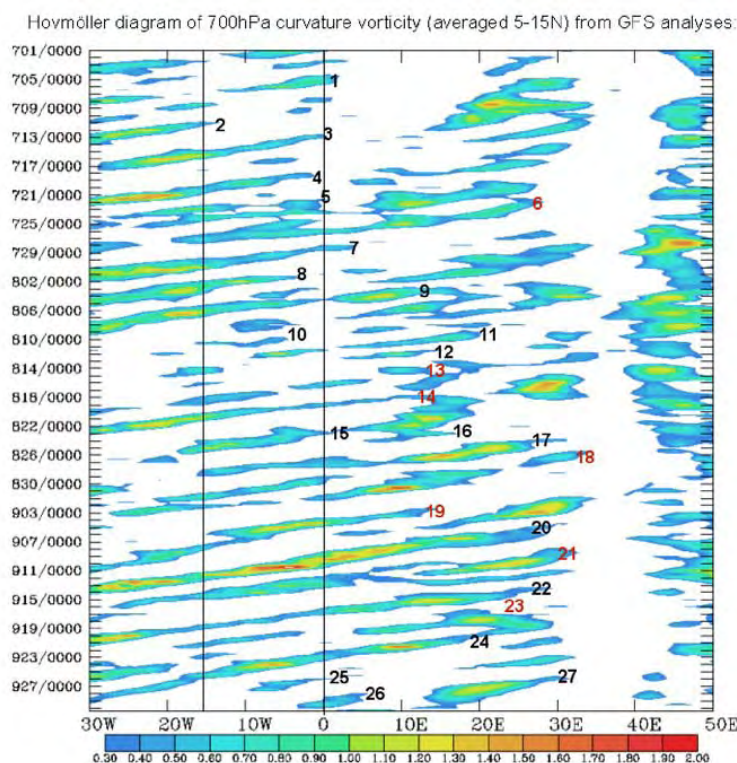


Figure 3: Hovmöller space-time diagram of 700hPa curvature vorticity averaged between 5 and 15N, based on the GFS analysis. The numbers refer to synoptic systems that meet the tracking criteria used by Berry et al (2007). Those in red became tropical cyclones in the Atlantic basin. These were 6: Chris, 13: Ernesto, 14: Debby, 18: Florence, 19: Gordon, 21: Helene, 23: Isaac

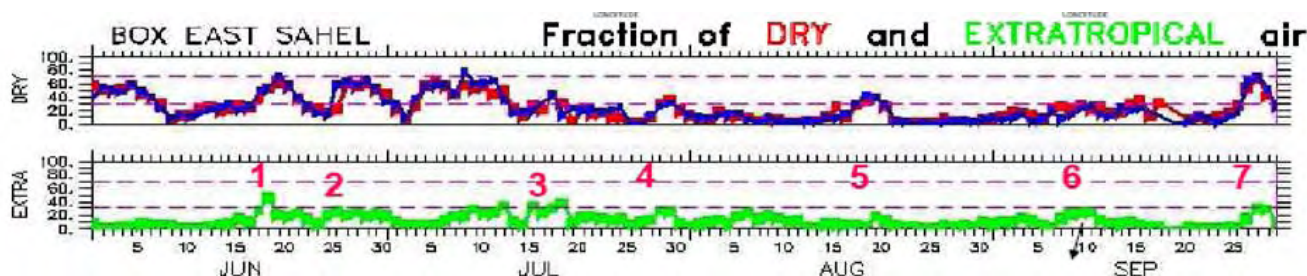


Figure 4: Evolution of the dry air characteristics at 500 hPa in the East Sahel box [0-10°E; 10-15°N] as provided by the back trajectory analysis, for the areal fraction with RH below 5% and the areal fraction with latitude origin greater than 40°N.

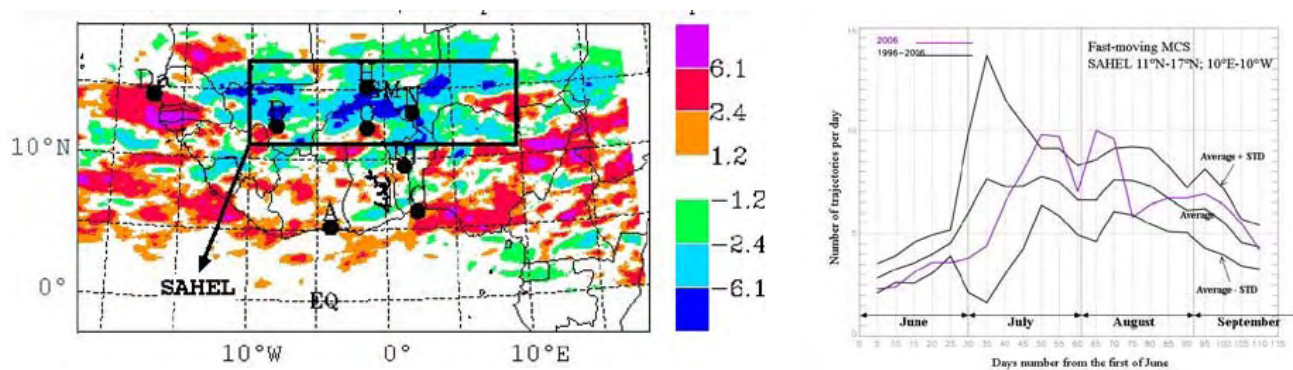


Figure 5: Anomaly (a) of nebulosity distribution (hr/month) of fast-moving MCS (C3+C4) for JJAS 2006 relative to a 10-yr mean. Seasonal evolution (b) of their number over the Sahel box (outlined on a) during 10 days, for the 10 yr climatology ( $\pm$  standard deviation) in black and 2006 (purple).

From Taylor et al, page 20: Atmosphere interactions during the AMMA SOP

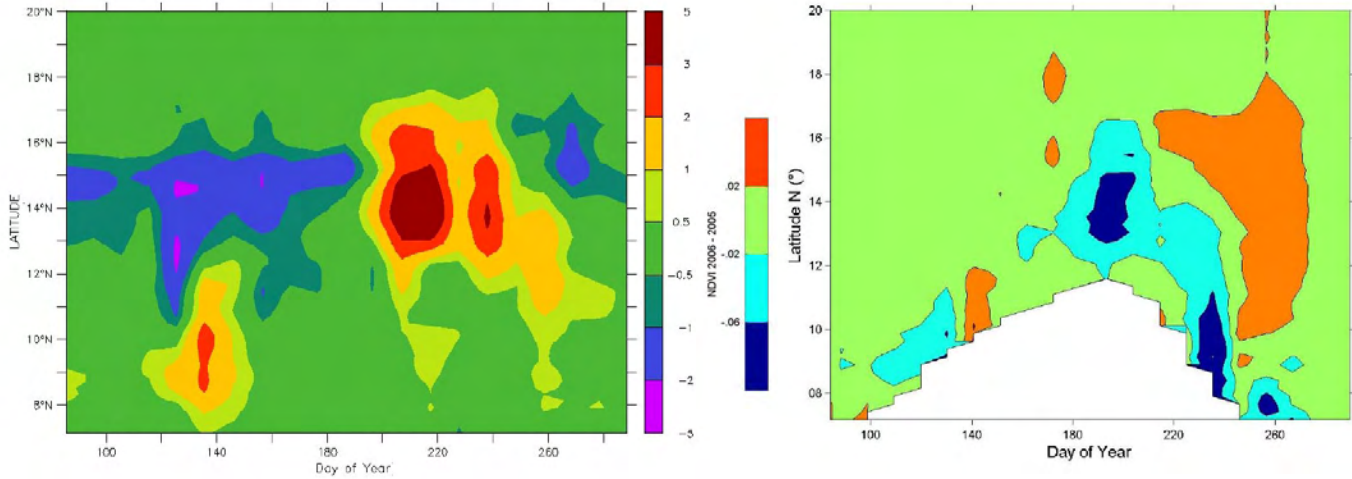


Figure 1 Time-latitude plots of (left) surface soil moisture (m<sup>3</sup>/m<sup>3</sup>) and (right) NDVI. The data shown are averaged between 10W and 10E and indicate the difference between 2006 and 2005. The soil moisture data is derived from AMSR microwave passive measurements (Njoku, 2004) and is averaged over 10 days, and the NDVI is computed from SPOT-VGT data. Regions of persistent cloud cover are shown in white on the NDVI plot.

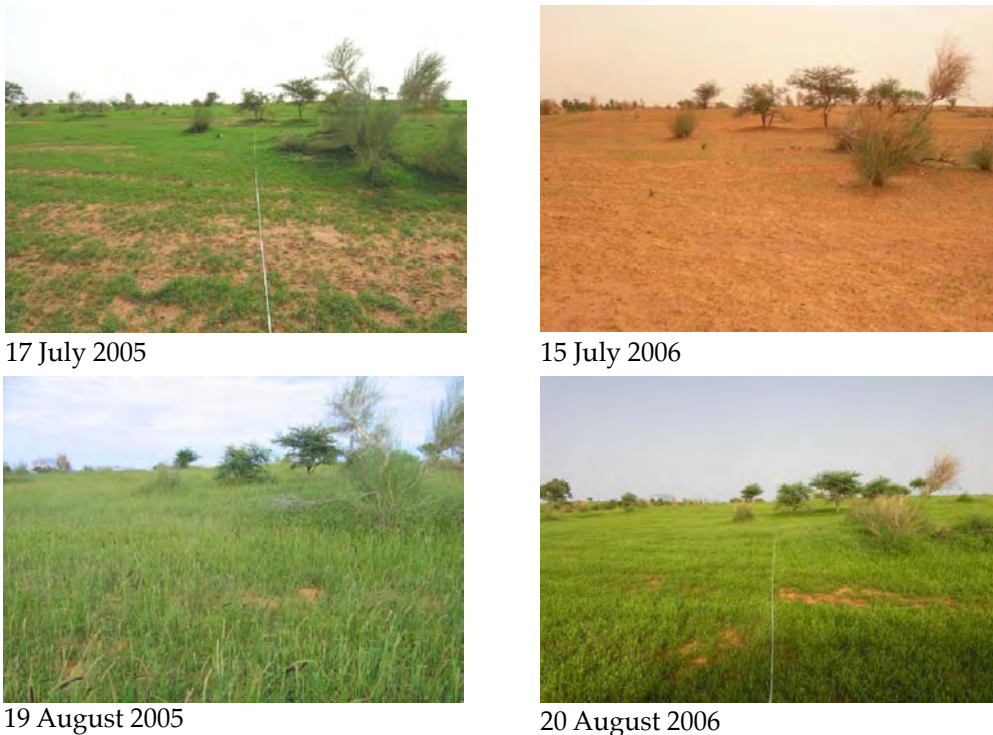


Figure 2 Contrasting vegetation conditions at the Agoufou field site during July and August 2005 and 2006 (courtesy E. Mougin).



continued from page 12

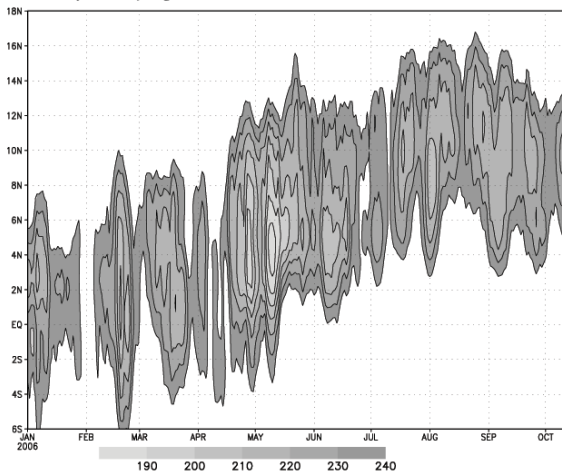


Figure 2: Time-latitude cross-section of the OLR field averaged on 10°W-10°E from 1st January to 11th October 2006. A moving average on +/-3 days have been applied to smooth the signal. The coastline is located approximately at 5°N.

impact of ocean-atmosphere interactions in the Guinea Gulf on the monsoon development (see the article of Bourles et al., this issue). The 2006 monsoon season has also been characterized by a more zonal component of the low-levels monsoon winds especially off the coast of West Africa over the northeastern tropical Atlantic.

**Intraseasonal variability**

Matthews (2004), then Mounier and Janicot (2007) considered the impact of intraseasonal variability and especially in the 40-day periodicity, linked to the MJO (Madden-Julian Oscillation) activity over the Indian sector, on the West African monsoon. This was the case in 2006 during the monsoon onset and could explain its delay. Figure 4 (page14) depicts the combined OLR fields (shaded) and 200 hPa NCEP/NCAR (Kalnay et al. 1996) velocity potential anomaly fields on 25th June, 1st, 10th and 19th July 2006. On 25th June convective activity is enhanced over the Indian sector and the west Pacific through a pattern similar to the ones associated with MJO events. It is associated with a wave-number one pattern of the velocity potential anomaly with upper-level large-scale divergence in this sector and convergence over the central and eastern Pacific. On 1st July the convective activity is sustained and the wave pattern has moved eastward (possibly associated with an equatorial Kelvin wave dynamics); the subsidence area is now located from Central America to Africa preventing the development of convective activity in this domain. On 10th July the

MJO structure has disaggregated as well as the velocity potential wave pattern and nothing prevents convection over Africa where the low-levels fields are favorable for the monsoon development. Finally 19th July corresponds to the first peak of the African monsoon activity (see also Figure 2).

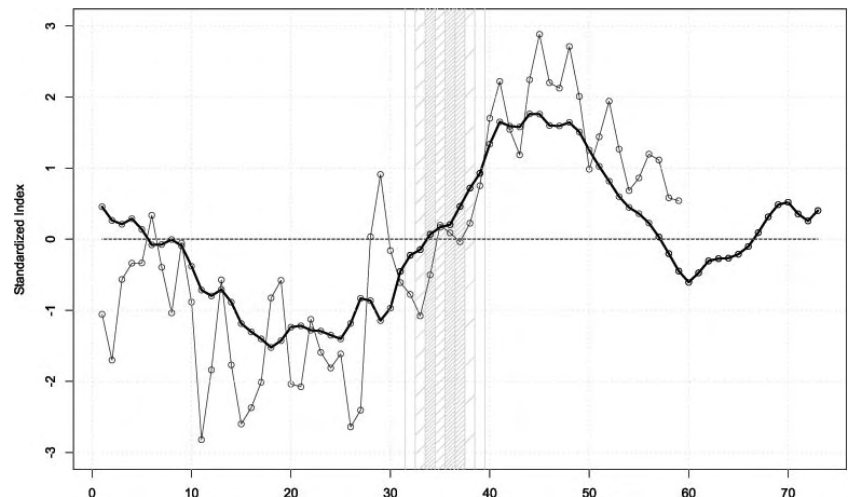
**Conclusion**

The 2006 African summer monsoon has been characterized by a near-normal convective activity despite a delayed onset, may be due to the occurrence of a MJO event.

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Figure 3: Time series of the 5-day monsoon index (see text for more details). The thick (thin) line represents the averaged index over the period 1979-2000 (the 2006 index). Vertical bars represent the probability function defined in Sultan and Janicot (2003). The x-axis labels are expressed in pentad.



**Overview of African weather systems during the summer 2006**Thorncroft, C.D.<sup>1</sup>, J-P Lafore<sup>2</sup>, G Berry<sup>1</sup>, R Roca<sup>3</sup>, F Guichard<sup>2</sup>, M Tomasini<sup>2</sup>, N Asencio<sup>2</sup><sup>1</sup>University at Albany, SUNY, NY, USA; <sup>2</sup>CNRM/GAME, Météo-France & CNRS, Toulouse, France; <sup>3</sup>LMD/IPSL, Paris, France

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**1 Introduction**

The African easterly jet (AEJ) supports the development of African easterly waves and mesoscale convective systems and, in general, both types of weather system coexist and interact. African easterly waves (AEWs) are synoptic-scale weather systems that characterize the West African monsoon (WAM) and the downstream tropical Atlantic during boreal summer (see schematic in Figure 1 for orientation). Mesoscale convective systems (MCSs) are cumulonimbus cloud systems that produce a contiguous precipitation area ~100 km or more in at least one direction (Houze 1993).

AEWs are important systems to study because of their association with daily rainfall over tropical Africa (e.g. Reed et al, 1977) and because they can serve as precursors for tropical cyclones (e.g. Avila and Pasch, 1992). Despite their importance, there are still fundamental gaps in our understanding of the dynamics and evolution of AEWs as they move across Africa and the Atlantic including how they interact with convection and MCSs. The observations made during the SOP, combined with satellite and modeling studies will be used to address these gaps. It should also be noted that we have very little knowledge or understanding of the nature of the variability of AEWs on intraseasonal-to-interannual timescales including if and how this impacts the WAM and tropical Atlantic variability.

Since MCSs provide a majority of the rainfall over West Africa (e.g. Mathon et al., 2002) it may be argued that the variability in the WAM is linked to variability in the MCS statistics. In this context it is important that we improve our understanding of the 2-way interactions between the MCSs and the synoptic environment in which they develop including the AEWs, the jets, low-level monsoon, Saharan air flow and surface conditions. The extent to which MCSs can become organized, the processes that lead to this and the consequences for the 2-way interactions with the synoptic environment require investigation.

Recent investigations have highlighted the important role of mid-tropospheric dry air plumes for convectively active Sahelian region (Roca et al., 2005). These "dry intrusions" have been shown to originate from the upper-levels in mid-latitudes (Figure 1), in a similar way to that seen over the tropical oceans (e.g. Parsons et al, 2000), where they were shown to inhibit convection. The extent to which these dry intrusions modulate convective activity over the Sahel as well as tropical cyclogenesis downstream will be investigated in AMMA.

As background for ongoing and future studies of these weather systems we provide here a brief overview of the AEW, dry intrusions and MCS activity that characterized the West African monsoon in summer 2006.

**2. African easterly waves in 2006**

The crudest and most commonly used diagnostic to describe AEW activity is based on the variance of the time-filtered meridional wind, or eddy kinetic energy (EKE) at some pressure level close to the level of the AEJ (around 700hPa) or just below it (around 850hPa). The time-series of the 2-6 day filtered EKE at 850hPa for the West African region is shown in Figure 2. Based on this diagnostic it would seem that the summer 2006 season was characterized by relatively strong AEW-activity compared to the mean. However, as shown below, seasonal averaging obscures the marked intraseasonal variations in AEW-activity that characterized this season.

Berry et al (2007) have recently proposed an objective method for diagnosing AEWs. Troughs are diagnosed based on advection of curvature vorticity by the rotational flow. This diagnostic was designed to be used in real-time, and to help distinguish the synoptic scale trough from embedded mesoscale features that often "contaminate" the analysis. Motivated by this, we present here a Hovmoller diagram of the 700hPa curvature vorticity (averaged between 5-15N), and based on the operational NCEP GFS model (Figure 3, page 15). A sequence of vorticity "tracks" can be seen on the diagram moving from east to west. The numbers mark the initial locations of objectively analysed AEW-troughs, with red numbers denoting AEWs that were later associated with named tropical cyclones in the tropical Atlantic. During the July-September period, a total of 27 AEWs were objectively analysed (compared with 31 in 2004 and 28 in 2005). What is most striking about the season however is the marked variations within the season.

July was very different to the later months with six out of seven of the first waves forming close to the longitude of Niamey or west of it. In August the AEWs were initiated further west, between 10-20E, but AEWs over Niamey were still weak. Starting at the end of August and going into September the AEWs became more coherent, with stronger amplitudes over most of tropical North Africa. Interestingly, several AEWs also appeared to start further east, between 20-30E at this time. Variability in the nature and variability of AEW initiation is a topic that will be investigated during AMMA (see Mekonnen et al, 2006, Hall et al, 2006). It should also be noted that all seven of the AEWs that became named tropical cyclones were initiated east of Niamey and six of these occurred after the middle of August. Whether such variability in AEW-activity can impact variability in tropical cyclone activity remains an important area of research (see Hopsch et al, 2007), and will be a key part of the NASA-AMMA research project.

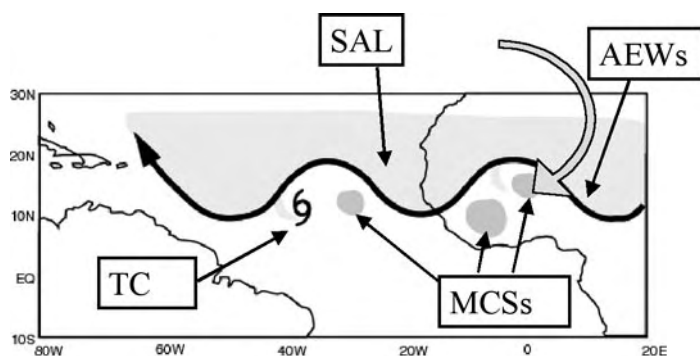


Figure 1: Key weather systems in the West African and Tropical Atlantic regions. Solid line represents a streamline at the level of the AEJ around 600hPa. Dark shading represents embedded MCSs and light shading indicates the location of the Saharan Air Layer (SAL). The large arrow represents the mean dry intrusions track seen in 2006.

**3. Extratropical dry intrusions and other synoptic features**

Figure 4 (page 15) illustrates a product setup during the SOP to monitor and forecast the mid-tropospheric humidity using a back trajectory technique. Compared with other years (Roca et al. 2005), the extra-tropical dry intrusions were less frequent in 2006, with about 50% fewer events than for instance in 1992. Seven clearly identifiable events have been detected, with some suppressing convection and some appearing to aid the organization of convection. In mid-September we noticed that dry intrusion 6 coincided with intense AEW 20 (c.f. Figure 3). Such links will need to be studied in more detail in the SOP case studies.

The corresponding evolution of the vertical profile of relative humidity in the same region (Niamey) supports the identification of 4 distinctive periods for the Sahel in 2006.

- Pre-onset period I: In June the atmosphere was very dry with 2 layers separated by a thin layer of moister air (~70%) at 5 km altitude. The upper troposphere was much drier than after the onset and exhibits strong intra-seasonal variability with several dry intrusion events ( $RH \leq 10\%$ ).
- Sahel dry spell period II: Between the dynamical WAM onset (~25 of June) and the the start of the active monsoon precipitation (mid-July), the convection was suppressed in the Niamey region possibly due to the passage of the suppressed phase of an MJO. Layers below 3 km stayed dry and warm consistent with the lack of convective events in this period.
- The monsoon active period III over central Sahel (mid-July to mid-September): A continuous series of convective events went over the Niamey super site associated with moist and colder air up to 5 km. Often convective events were preceded by dry air intrusions in the mid-troposphere. Three of them have an extra-tropical origin (labelled 4, 5 and 6 in Figure 4).
- Monsoon retreat period IV end of September: Progressively the lower troposphere returned to warmer and dryer conditions. Some dry intrusions

were still detected in the mid-troposphere.

**4. Mesoscale convective systems in 2006**

Using an automatic tracking algorithm based on Meteosat infrared imagery (Morel and Senesi, 2002), an MCS classification scheme based on their mean propagation speed (V) and their life duration (D) has been used. Based on this, the following 4 MCS classes have been defined:

- C1 class [ $D < 9$  hr;  $V < 10$  m.s<sup>-1</sup>] for small numerous diurnal and slow-moving MCSs located between 3°N and 13°N mainly over mountains and the ocean.
- C2 class [ $D > 9$  hr;  $V < 10$  m.s<sup>-1</sup>] for long-lived slow-moving MCSs located more over the coasts and ocean and less on relief in contrast to the C1 class.
- C3 class [ $D < 9$  hr;  $V > 10$  m.s<sup>-1</sup>] for fast-moving systems dissipating in the evening. They are few and located over continent.
- C4 class [ $D > 9$  hr;  $V > 10$  m.s<sup>-1</sup>] for fast-moving long-lived squall line type systems. They are less numerous but the largest (typically 30000 km<sup>2</sup>). Their track coincides with the Sahel band.

An important feature of this classification that should be noted, is that fast-moving MCSs (C3+C4) coincide with the MCS subpopulation introduced by Mathon et al. (2002), accounting for 90 % of the total rainfall in the Central Sahel region. The above classification scheme of 4-classes has been applied to a 10-year period (1997 to 2006) to provide a mean with which to compare the 2006 season with.

The most dramatic change in convective activity in 2006 concerned the fast-moving MCSs C3+C4 (Figure 5a, page 15), with a significant deficit (up to 30% relative to the 10-year mean) over the Sahel. In contrast, fast-moving systems were more active to the South, in particular East Nigeria and South of Dakar. A local maximum of C4 activity can be seen along the Niger-Nigeria border. The seasonal evolution of the number of fast-moving systems over the Sahel provides much more information. The extreme interannual variability in late June to mid-July (indicated by the upper and lower black lines)

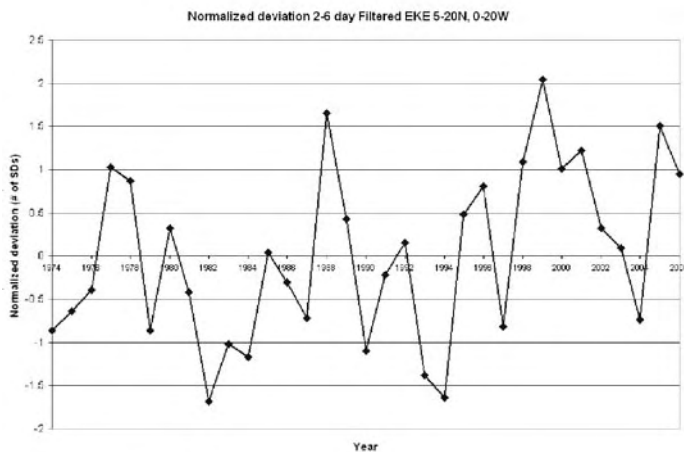


Figure 2 Normalized deviation of 2-6 day filtered eddy kinetic energy, averaged over the region between 5-20N and 0-20W.

corresponds to the start of the wet season over Sahel. The 2006-year is unusual with a late arrival of the MCS activity. Nevertheless the activity is well above the normal during the mid-July to mid-August period. The end of the season is closer to the normal with a weak positive anomaly in September. In short, the precipitation arrived late but due to more activity after mid-July and a lack of any significant dry spell after that, the season was normal overall.

### 5. Final Comments

It should be recognized that this is only a preliminary analysis of the AEWs, dry intrusions and MCSs, and also that there are other methodologies for analyzing these systems, some of which were presented at the AMMA workshop that took place in Toulouse in November 2006. What is particularly striking already in this analysis though is the need to better understand the intraseasonal variations in the rainfall, AEW- and MCS-activity along with the variability in dry intrusions including how these features interact with each other and the basic state (especially the African easterly jet). The huge dataset collected during the 4-months of the SOP is an invaluable resource to investigate these interactions.

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## Land Surface – Atmosphere Interactions During the AMMA SOP

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### Introduction

Rainfall in the West African Monsoon (WAM) region exhibits strong variability on time scales ranging from the diurnal to the decadal, and space scales from a few kilometres up to the regional. This variability produces a strong response in land surface properties (soil moisture and vegetation) which may persist long after the initial atmospheric perturbation. The fluxes of heat and water vapour into the atmosphere are strongly dependent on these surface properties, and are thought to play an important role in subsequent convection (e.g. Taylor and Ellis 2006) and atmospheric dynamics (e.g. Eltahir and Gong 1996). The strong sensitivity of the land and atmosphere to each other in West Africa make this region a “hotspot” of land-atmosphere feedback, a coupling which is not well-represented by large scale models (Koster et al 2004).

Observations are a critical component to gain a better understanding of how the coupled system functions. We need to test our models of how the land surface

responds to rainfall across the broad range of climatic and land cover conditions within the WAM region. To this end, soil moisture, leaf area and surface fluxes of heat and water vapour are being monitored at supersites across the region, and over the course of the Extended Observation Period (EOP; 2005-2007). The evolution of the land surface at the larger scale is being monitored through analysis of remote sensing data, which can be validated against *in situ* data. A major effort is going into running a variety of land surface models (LSM) in the AMMA LSM Inter-comparison Project (ALMIP) at spatial scales from local to regional. This will provide improved estimates of the surface state and fluxes based on the best available meteorological forcing. These models will also provide realistic surface boundary conditions for the atmospheric simulations required to unravel the complex processes involved in land-atmosphere interaction. These simulations are complemented by atmospheric observations made during the Special Observation Period (SOP) of summer 2006, to ascertain how the atmosphere



responds to the land surface. In the following, we present some preliminary results from the SOP focused on land-atmosphere interaction.

#### Evolution of land surface properties during 2006

Although there is no such a thing as an average monsoon season, 2006 was notable because of the very late arrival of wet conditions in the Sahel zone (12° -18° N), and a rainfall deficit in the Soudanian and Guinean zones. In these respects, 2005 was closer to the average situation. The impact of these features on land surface properties is illustrated in Figure 1 (page 16), which compares both satellite-derived surface moisture and vegetation index (NDVI) between 2006 and 2005.

The relatively dry conditions in the Sahel during the early stage of the monsoon (May to mid-July, days 120-200) are indicated by the negative large-scale soil moisture anomaly (relative to 2005) during that period. The early season rainfall deficit severely affected plant growth, leading to a delayed greening up of the surface in 2006 across much of the Sahel. This is apparent from the negative NDVI anomaly in July (days 180-210). By contrast, August and September were wetter in 2006 than 2005 across the Sahel, and are characterized by positive soil moisture anomalies between 12° and 17° N. The impact of the wetter conditions, with more regular rain events, can be seen from the positive NDVI anomalies developing in early August (day 220), lagging the soil moisture anomalies by typically 10-20 days. However, plant development south of 10° N remained relatively weak in 2006.

An illustration of the contrasting vegetation conditions between 2005 and 2006 is provided in Figure 2 (page 16), which presents photographs from the Agoufou field site in Mali (15.3° N, 1.5°W). The development of the herb layer during late July and August 2006 was very rapid, and similar biomass levels were reached in both years.

#### The atmospheric response to land surface variability

The SOP provided the opportunity to make measurements of the atmospheric response to surface fluxes using a variety of platforms. Figure 3 provides an example of such data taken onboard an aircraft in a region of heterogeneous surface characteristics in north-eastern

Mali. The BAe146 aircraft operated by the UK Facility for Airborne Atmospheric Measurements performed a series of flights targeting regions of heterogeneous soil moisture from recent rain events. The wetted regions were anticipated to produce high rates of surface evaporation direct from the soil, and low sensible heat fluxes. The regions were identified using land surface temperature data derived from Meteosat Second Generation by the LandSAF in near real time. In this example, storms on the evening of 20 July 2006 wetted the soil on the aircraft transect between 15.3° and 15.6° N, and to the north of 15.9° N, and can be identified by the strong negative surface temperature anomalies (grey shading). The impact on the boundary layer at the time of the flight some 18 hours later is evident; above the wet soil, the mixed layer was typically 1 K cooler and 2 g/kg moister than above adjacent dry regions. Such atmospheric anomalies have a significant effect on the stability of the atmosphere to subsequent convection, and hence illustrate the potential for feedbacks between rainfall and soil moisture.

Through the incorporation of *in situ* and satellite observations into improved models of the coupled system, it is hoped that the AMMA program will reduce uncertainty in our predictions of weather and climate in the WAM region. A better representation of land-atmosphere coupling based on knowledge gleaned in the West African "hotpot" should also feed into improved climate simulations across the world.

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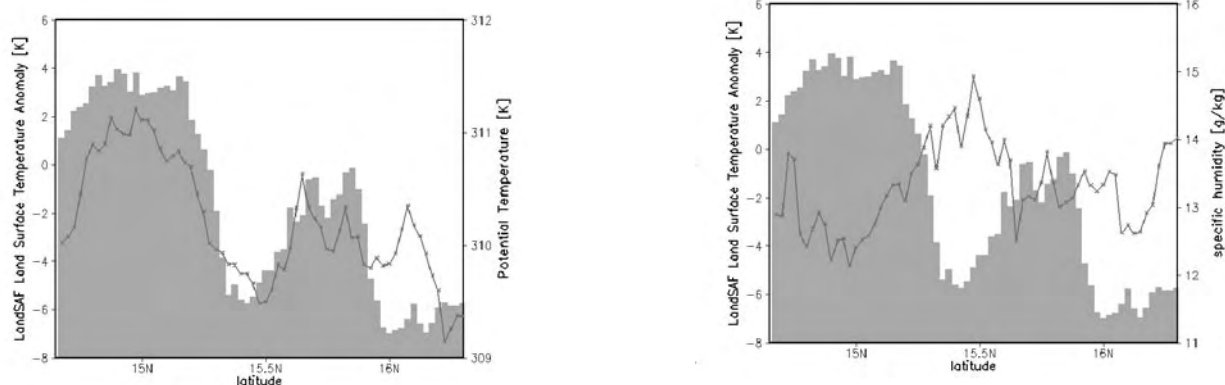


Figure 3 Potential temperature (left) and specific humidity (right) on a flight leg at 250 m above the ground on 21 July 2006. The grey shading in both plots is the satellite-derived land surface temperature on the flight track on that day, expressed as an anomaly from the mean diurnal cycle over 3 weeks.

## Climate modelling in AMMA

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The African Monsoon Multidisciplinary Analysis (AMMA) is an opportunity for the climate modeling community to analyse model skill at different space and time scales, mostly considering interactions between the atmospheric dynamics and physical parameterizations. The multiscale approach of the AMMA project provides us with an opportunity to improve physical schemes and to evaluate the reliability of climate change predictions in terms of regional climate.

### Motivation and Major Issues

West Africa is characterized by well defined and strong meridional surface gradients of albedo and vegetation from the Guinean Gulf to the Sahara. These surface features are coupled to well defined atmospheric circulations such as the African easterly jet (AEJ), which develops over West Africa during the monsoon season typically between 10°N and 15°N. The location of the AEJ itself is strongly correlated with meridional gradients of surface air temperature, soil moisture, and moist static energy (Cook 1999, Thorncroft and Blackburn 1999). More generally, interannual variability of the monsoon is accompanied by changes in these basic structures. Synoptic variability over West Africa during the monsoon season, in turn, is dominated by African easterly waves (AEWs), which may be linked to the AEJ (Burpee 1972, Hsieh and Cook 2005, Kiladis et al. 2006; Thorncroft et al., 2007). As a consequence, the structure and variability of these basic large-scale features involve strong and complex interactions with the soil as well as surface, turbulent and convective processes that occur on different space and time scales (Diongue et al., 2002; Taylor and Lebel, 1998). Finally, the West African monsoon exhibits specific seasonal variations, with in particular an onset characterized by an abrupt latitudinal shift from the Guinean coast to the Sahel occurring typically at the end of June (Sultan and Janicot, 2003; Janicot and Sultan, 2007), to be compared to a more progressive latitudinal retreat in the fall.

The different space and time scales involved in the West African Monsoon system need to be well simulated to adequately forecast the mean and the higher statistical moments of the system. Models aimed at both medium-range forecasting and climate simulation should reproduce the main physical mechanisms of the system in order to correctly represent the higher-order statistical moments. So, the first issue we want to address is how well the current models simulate not only the mean state, but its variability and related mechanisms.

To address issues related to the multiple scales that characterize the West African Monsoon (WAM), the AMMA program is structured around 4 interacting spatial scales: global scale, regional scale, mesoscale, and

local scale (see Jean-Luc Redelsperger et al., this issue). Typically, the resolution of climate models allows for the representation of physical processes ranging from global-scale to regional scale. The mesoscale is almost absent, while the local scale is not represented. This fact raises some problems regarding both the physical mechanisms to be simulated and the usefulness of the climate "forecast". Interactions between AEWs and mesoscale convective systems is key, characterizing rainfall at both the mesoscale and the local scale. The absence of this interaction is a severe limitation of state-of-the-art climate models, and it affects the usefulness of the simulated precipitations for impact studies.

The multiple scale approach of the AMMA program should allow us to improve our understanding of how these scales interact and to define the intrinsic limit of the climate models. Specifically, the AMMA program can supply the essential information needed to help us understand if the processes not active in the present climate models can be parameterized, or if they need to be explicitly resolved (i.e., is there any gap in the spectral domain of the physical processes?).

### How well do the climate models simulate the WAM?

Although several papers focus on how well climate models simulate the WAM, few intercomparison projects address this issue considering both a large number of models and different key physical processes.

The West African Monsoon Project (WAMP) - funded by the European Union in the Fourth Framework (1997-2000) - has increased the knowledge of the processes characterizing the WAM variability. Special emphasis was on the seasonal cycle, interannual variability and spatial-scale interactions. The results and the caveats produced by the WAMP are summarized as follows: Seasonal cycle - typically, the GCMs do not capture the seasonal cycle of rainfall, producing an early onset of the monsoon. Moreover, the Saharan heat low, which plays an important role in determining the meridional temperature gradient, is typically overestimated in GCM simulations, and the models simulate too many intense rainfall events. On the interannual time scale, it has been suggested that the WAM area is influenced by ENSO forcing through equatorial waves (Kelvin and Rossby waves). The ability of GCMs to reproduce the wave dynamics seems to be weak but should be analyzed in detail. Synoptic and Mesoscale Weather Systems - multi-scale interactions have been studied by analyzing observational data sets and using a hierarchy of models (from regional climate models to single column models). The relevance of the AEJ-AEW link has been highlighted. Moreover, interactions between convection and AEWs have been analyzed: while the convection propagates

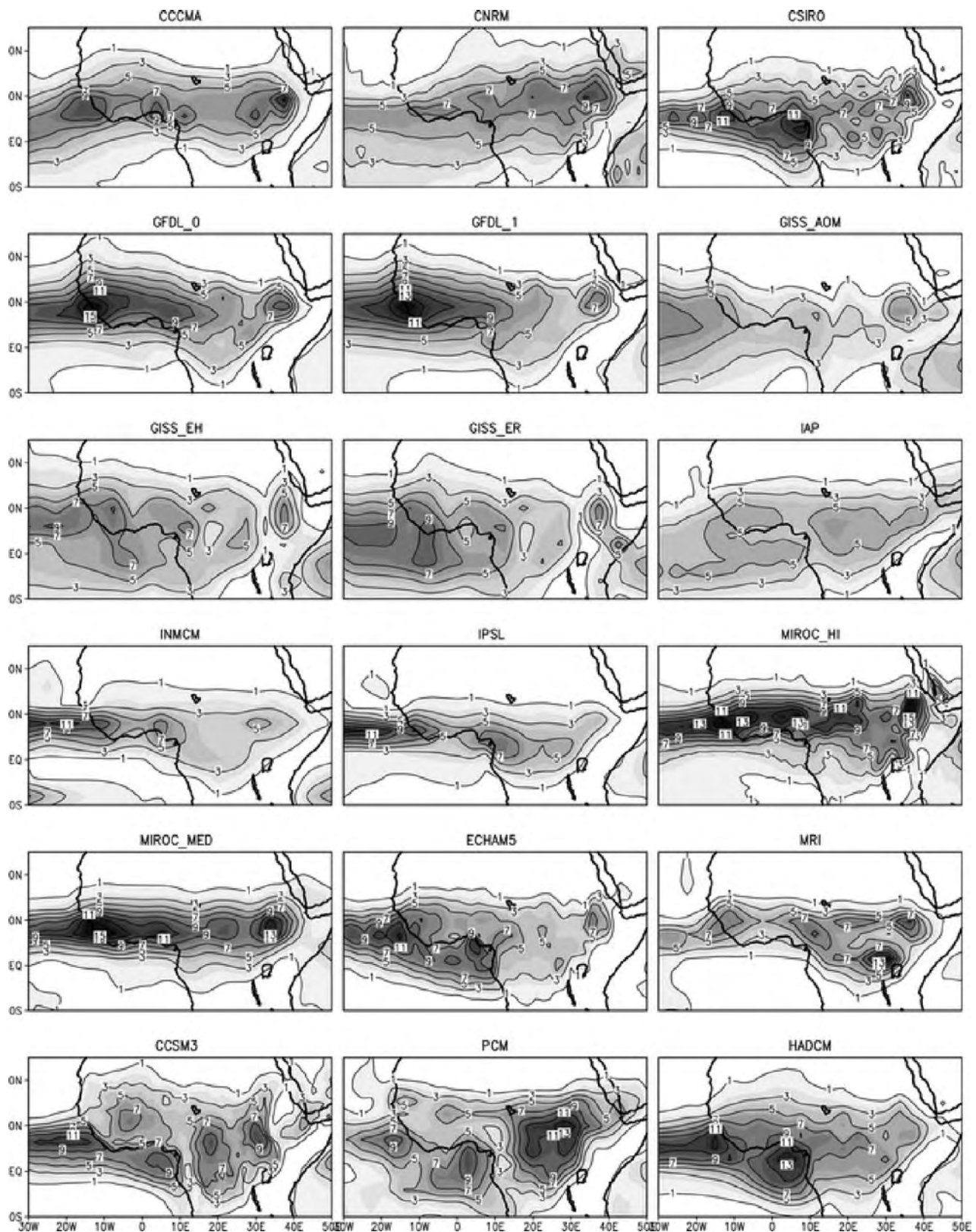


Figure 1 Simulated 1949-2000 JJAS precipitation rates (mm day<sup>-1</sup>) over northern Africa from some coupled GCMs. Contours start at 1 mm day<sup>-1</sup> and are every 2 mm day<sup>-1</sup>, shading intervals are every 1 mm day<sup>-1</sup>. (by the courtesy of AMS)

through the AEW in observations, the convection in a GCM tends to be tied to the trough of the wave.

More recently, the simulations performed for the IPCC- Fourth Assessment Report have been gathered by the Project for Climate Model Diagnostics and Intercomparison (PCMDI: <http://www-pcmdi.llnl.gov>) to form the WCRP/CLIVER IPCC AR4 archive. Several models with different physical schemes and different climate components (atmosphere, ocean, biosphere) are available for diagnostic analysis. Several subprojects are dealing with African Climate and the African Monsoon. Here, as an example of the ability of coupled GCMs to correctly simulate the WAM climatology, we report the analysis from Cook and Vizzy (2006). Figure 1 shows the simulated 1949-2000 JJAS precipitation distribution from 18 coupled GCMs. Overall, the current generation of coupled GCMs fails to capture the right precipitation patterns, and the twentieth-century drying trend in the Sahel, at least in their ensemble mean.

#### International initiatives

In this context, and thanks to past experience, two main intercomparison initiatives have been developed with the aim of getting a more precise view of the ability of large-scale and regional models to simulate the fundamental features of the West African monsoon (see below for short details): the USA WAMME (West African Monsoon Modeling and Evaluation)<sup>1</sup> and the European AMMA-MIP (AMMA-Modeling Intercomparison)<sup>2</sup>.

The comparison of bulk thermodynamic and dynamic quantities defining the climate state, such as the tropospheric average temperature, tropospheric average wind speeds, and the variance of geopotential height, allows the definition of global metrics which are robust diagnostic tools. Nevertheless, such an approach does not allow for the disentanglement of the role of each one of the vast range of distinct physical processes contributing to the global balances. In order to capture the differences in the representation of specific physical processes, it is necessary to use specialized diagnostic tools – i.e., process-oriented metrics – as indices for model reliability.

Such an approach is the common feature between the two initiatives. By introducing process-oriented metrics,

it will be possible to identify the models' weaknesses (dynamics or physics schemes) and to understand the degree to which parameterization can replace resolving processes in the next generation of models.

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<sup>1</sup>WAMME (<http://wamme.geog.ucla.edu/>) uses GCMs and regional climate models (RCMs) to address issues regarding the role of land-ocean-atmosphere interaction, land-use and water-use change, vegetation dynamics, as well as aerosols, particularly dust, on WAM development. The WAMME project plans to (1) evaluate the performance of current GCMs and RCMs in simulating WAM precipitation and relevant processes at diurnal, intraseasonal, to interannual scales, as well as its onset and withdrawal, (2) identify common discrepancies and provide better understanding of fundamental physical processes in WAM; (3) conduct sensitivity experiments to isolate important key physical processes for interannual and interdecadal variations of WAM, (4) demonstrate the utility and synergy of CEOP and AMMA field data in providing a pathway for model physics evaluation and improvement, and (5) evaluate the nested RCMs' ability to simulate West African regional climate.

<sup>2</sup>The AMMA-MIP (<http://amma-mip.lmd.jussieu.fr/>) will focus on hydrological parameters and convection at seasonal and intraseasonal time scales. Because of the relative zonality of the WAM system, a first cross section analysis consisting of zonal averages of model outputs taken from 10°W to 10°E will be on the latitudinal extent of the WAM system. The idea of the cross-section is inherited from the EUROCS cross-section over Eastern Pacific (Siebesma et al., 2004). The study of synoptic dynamics (waves, monsoon breaks, ...) and longitudinal structures (influence of orography, ...) will be performed using latitude-longitude maps for few key fields. A specific part of the inter-comparison will be devoted to the chemical/aerosols models and to their interaction with dynamical models.

## Climate impact studies in AMMA-EU

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### Relevance

West Africa is characterized by a large fraction of the population living in rural areas and with an economy and livelihoods based mainly on rain fed agriculture. A range of factors, including climatic variability, demographic pressure and limited water resources, contribute to making West Africa the most food insecure region of the world. This implies that a great number of people depend critically on the West African Monsoon (WAM) as a major factor determining the success and failure of their subsistence production as well their incomes from cash crops. This has been so for centuries, yet global climatic change is likely to influence the WAM and its variability significantly, requiring that traditional coping and adaptive strategies are modified or renewed. At the same time, new technologies, including new crop variants and management practices, potentially allow skilful seasonal forecasts to be used as a basis for making optimal use of the limited rainfall. Thus a combination of better chosen and eventually improved crop varieties, improved seasonal and even intraseasonal forecasts together with a more efficient dissemination of information have a potential of increasing agricultural productivity. Traditional adaptation strategies are embedded in social structures, and thus they cannot easily be modified without considering them within these contexts. AMMA-EU includes five work packages addressing issues related to impacts of and vulnerability to WAM change and variability, coping and adaptive strategies, and measures to forecast crop failure. The impacts dealt with include both direct effects on crop production and natural vegetation growth, broader studies of vulnerability and adaptation strategies, both traditional and new, and effects on availability of water resources, including the hydrology of the major river basins and dams, which play a great role as a source of water for irrigation and urban water supply. Health impacts of changes in WAM are addressed concentrating on malaria, meningococcal meningitis and Rift Valley Fever. Among the 'outreach activities' of AMMA-EU is to translate the scientific results of the project into improvements to existing 'early warning systems for food security' and operational seasonal forecasting. While the following description refers to "AMMA" research on impacts it should be recognized that this text is mainly describing the contributions to this from AMMA-EU.

### Objectives of the AMMA impact work packages

One overarching goal of AMMA is to assist in the achievement of the UN Millenium Development Goals in Africa and the implementation of the EU Strategy for Africa (Commission of the European Communities, 2005), which includes "action to counter the effects of

climate change" and "the development of local capabilities to generate reliable information on the location, condition and evolution of environmental resources, food availability and crisis situations." Also, AMMA addresses issues dealt with by the three 'Rio-conventions' on climate change, biological diversity and desertification, which all deal with climate change related topics, not least when seen in a West African perspective. Within these overall AMMA objectives, the impact work packages focus particularly on the direct and indirect implications of climate change and variability on production and livelihoods and on strategies and policies. They take into consideration all levels from the international to the household, seeking to minimize adverse and maximize positive effects. In addition the impact work packages have as an objective to place African researchers and research institutions centrally in the activities. The translation of the outputs of the geophysical research on WAM to make it useful in environmental, water and agricultural management is a special challenge to AMMA, and to the impact work packages in particular.

To help meet these high level objectives, the specific objectives of the AMMA impact work packages are:

- To identify short and longer term impacts changes in the WAM that are likely to have on agriculture and land productivity, land use, water resources, health and food security
- To investigate the options for adaptation to the above impacts
- To improve the ability of operational centres to forecast seasonal variation in the WAM
- To compile the results of this research and communicate them to the user communities.
- To develop operational scientifically-based tools for managers and decision makers

### Project activities

In order to meet the above objectives, the impact work packages of AMMA have initiated a range of different activities to achieve the following:

- Application of results of AMMA's geophysical research to investigate the impacts and options for adaptation to changes in the WAM
- Provision of funding to strengthen the African participation in, and ownership of, AMMA research activities
- Initiatives strengthening the linkages, today and beyond AMMA between European research institutions and African universities and research centres
- Promotion of multidisciplinary approaches to WAM research through joint research activities involving European and African partners and integrating

geophysical research on bio-physical processes with broader-based impact research

- Activities providing regional and national operational centres with better tools and knowledge, allowing the services provided to decision makers to be improved
- Initiatives ensuring that the further development of national expertise is maintained beyond the AMMA project.

#### Research questions

In concrete terms the research questions of the AMMA impact work packages include the following:

- How can better short, medium and seasonal forecasts be used to improve farmers' as well as national strategies and decision making?
- What are the climate change adaptation options and strategies available to farmers and pastoralists?
- What are the impacts of climate change on water resources availability and hydrosystem vulnerability at the river basin scale in West Africa?
- What is the impact of climate variability on disease transmission and then the consequences of climate change on the epidemiological patterns of malaria, meningococcal meningitis and Rift Valley Fever in West Africa?
- How can AMMA results be integrated into improved early warning systems for food security?

#### The AMMA extension

Recently, AMMA has been extended to include 17 new African partners by an additional grant from EU. The main aim of this extension, which focuses on AMMA's impact work packages, is to reinforce the participation of African AMMA researchers and research institutions. We see this as a particularly important step towards fulfilling AMMA's overall objectives, which goes beyond the mere

improvement of our understanding of the geophysics of WAM change. At a meeting in Bamako in February 2007 the first steps were taken to initiate research on climate change and variability impacts and adaptation strategies, involving the many new partners. We foresee that the AMMA extension will add to the original AMMA activities within this field in the following areas:

- expanding research into adaptive strategies acknowledging that farmers and pastoralists are constantly adapting to change and that climate change has in the past and will in the future influence agricultural land use and rural livelihood strategies in a variety of ways.
- improving the possibilities of AMMA results becoming useful in agricultural decision making at village and household level. Also, the African participation will facilitate information being fed into national food security assessments and early warning systems of crop failure.
- extending the impacts of climate change to groundwater in some large aquifers in West Africa (Senegal, Niger and Ouémé) and building seasonal and real-time hydrological forecasting models for the management of water resources.
- extending the studies of climate impact on health in Niger, Senegal and Ghana to other countries of West Africa and improve our understanding of the role of climate and the environmental typology in the evolution of public health issues. New data will be gathered in two very different climatic regions. Analyzing this data according to space and time scales will help to improve the climate link within the tools used in public health services for surveillance and early warning systems.

#### Call for contributions:

We would like to invite the CLIVAR community to submit papers to CLIVAR Exchanges for the next issue. This will be on Ocean Model Development and Validation and the guest editor will be Professor Peter Killworth. The deadline for submissions will be Friday 18th May 2007.

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



## From the CLIVAR Calendar

please see [http://www.clivar.org/calendar/calendar\\_all.php](http://www.clivar.org/calendar/calendar_all.php) for full details and web sites

When	Where	Meeting	Attendance	Contact	email
15 - 20 April 2007	Vienna, Austria	EGU General Assembly 2007	Open		
21 - 26 April 2007	Florianopolis, Brazil	13th Brazilian Symposium on Remote Sensing (SBSR)	Open		sbsr@dsr.inpe.br
23 - 27 April 2007	Brazzaville, Republic of Congo	ETCCDI workshop on indices for climate extremes in Central Africa	Invitation	Omar Baddour	
23 - 25 April 2007	Pretoria, South Africa	CLIVAR/GOOS Indian Ocean Panel Meeting	Invitation	Roberta Boscolo	rbos@iim.csic.es
23 - 28 April 2007	Geneva, Switzerland	Atmospheric Observation Panel for Climate (AOPC)	Invitation		
23 - 27 April 2007	Montreux, Switzerland	ENVISAT Symposium 2007	Open		ESA. Conference. Bureau@esa.int
30 April - 3 May 2007	Waikoloa Village, Hawaii, USA	7th Workshop on Decadal Climate Variability	Open	Vikram M. Mehta	vikram@crces.org
02 - 05 May 2007	Paris, France	OOPC-12	Invitation	Albert Fischer	
07 - 09 May 2007	Buenos Aires, Argentina	South Atlantic Workshop	Invitation	Alberto Piola	apiola@hidro.gov.ar
19 - 24 May 2007	Obergurgel, Austria	ESF Research Conference on Ocean Controls in Abrupt Climate Change	Limited	Rachid Adghoughi	
22 - 25 May 2007	Acapulco, Mexico	AGU 2007 Joint Assembly - Session A15 Climate processes in the tropical Atlantic and their role in regional and global variability: past present and future	Open	Yochanan Kushnir, Ping Change, Chidong Zhang	kushnir@ldeo.columbia.edu, ping@tamu.edu, czhang@rsmas.miami.edu
24 - 26 May 2007	Hiroshima, Japan	XII GLOBEC SSC meeting	Invitation	GLOBEC IPO	globec@pml.ac.uk
24 - 26 May 2007	Amsterdam, The Netherlands	2007 Amsterdam Conference on the Human Dimensions of Global Environmental Change - "Earth System Governance: Theories and Strategies for Sustainability"	Open		
27 May - 6 June	Crete, Greece	1st International Summit on Hurricanes and Climate Change	Open		
29 - 31 May 2007	Hong Kong, China	International Conference on Climate Change	Open		
04 - 06 June 2007	Barcelona, Spain	WCRP Workshop on Seasonal Prediction	Open	Dr Anna Pirani	Anna.Pirani@noc.soton.ac.uk

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