Overview of the West African Monsoon (WAM) system and how it might be impacted by global warming

- The WAM system is controlled by :
  - Regional scale sea-land surface conditions and associated surface-atmosphere interactions ;
  - Large scale forcings from atmospheric teleconnections partly linked to sea surface temperatures ;
  - Regional and large scale gas/aerosols concentrations ;
  - Local atmospheric processes.

- This induces high natural intraseasonal to decadal scales variability that can prevail over emerging anthropogenic global warming forcing and other human-made regional forcings (land-use changes, urban aerosols).

- Triggering factors of extreme events occurrences (heavy rainfall and dry sequences, heat waves).

- Parts of variability and predictability from local interactions *versus* remote forcings.

- Skills / gaps in global and regional climate modelling.

- An integrated detection-attribution-projection approach is needed to evaluate present and future climate changes over sub-Saharan Africa as well as their associated uncertainty level.

Climate projections
IPCC Report 2013

FINAL DRAFT **IPCC WGII AR5 Chapter 22**

Do Not Cite, Quote, or Distribute Prior to Public Release on 31 March 2014

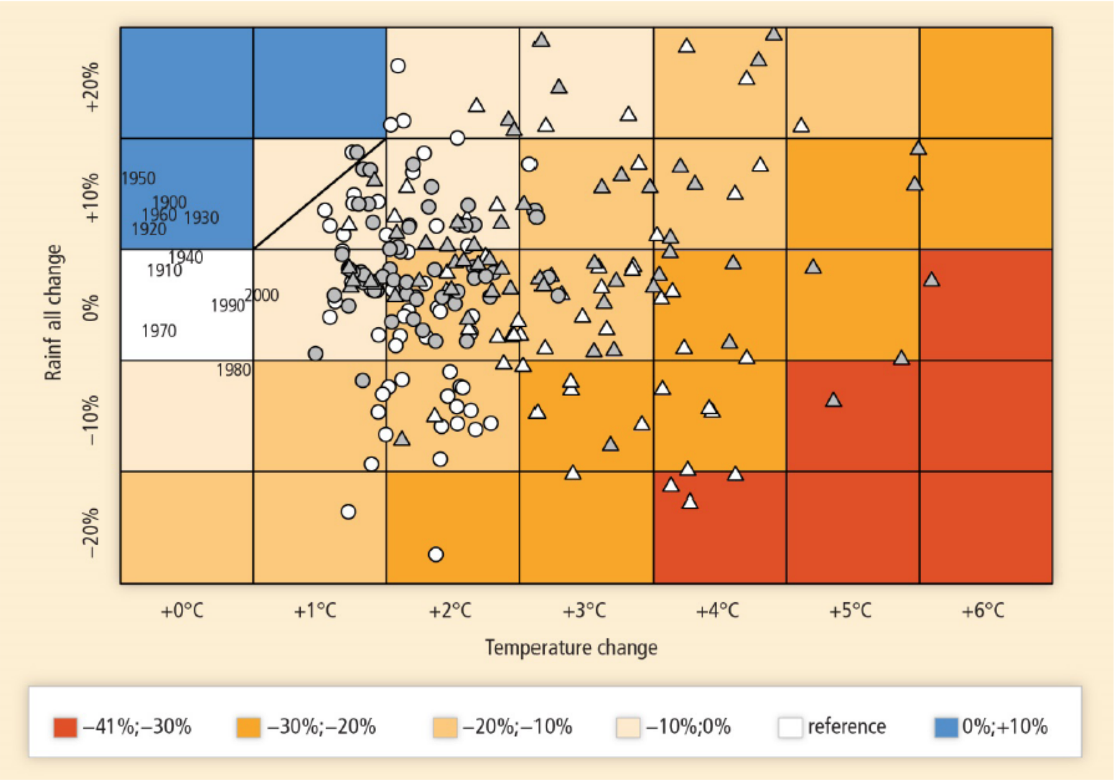
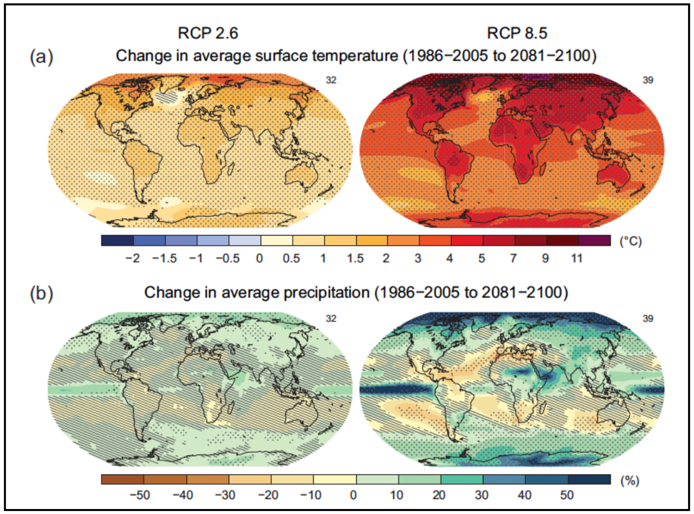


Figure 22-5: The effect of rainfall and temperature changes on mean crop yield. Mean crop yield change (%) relative to the 1961–90 baseline for 7 temperatures (x-axis) and 5 rainfall (y-axis) scenarios. Results are shown as the average over the 35 stations across West Africa and the 6 cultivars of sorghum and millet. White triangles and circles are the projected anomalies computed by several CMIP3 GCMs and three IPCC emission scenarios (B1, A1B, A2) for 2071–90 and 2031–50, respectively. Projections from CMIP5 GCMs and three RCPs (4.5, 6.0 and 8.5) are represented by grey triangles and circles. Models and scenarios names are displayed in figure S2 (available at stacks.iop.org/ERL/8/014040/mmedia). Past observed climate anomalies from CRU data are also projected by computing 10-year averages (e.g. '1940' is for 1941–50). All mean yield changes are significant at a 5% level except boxes with a diagonal line. Source: Sultan et al., 2013.

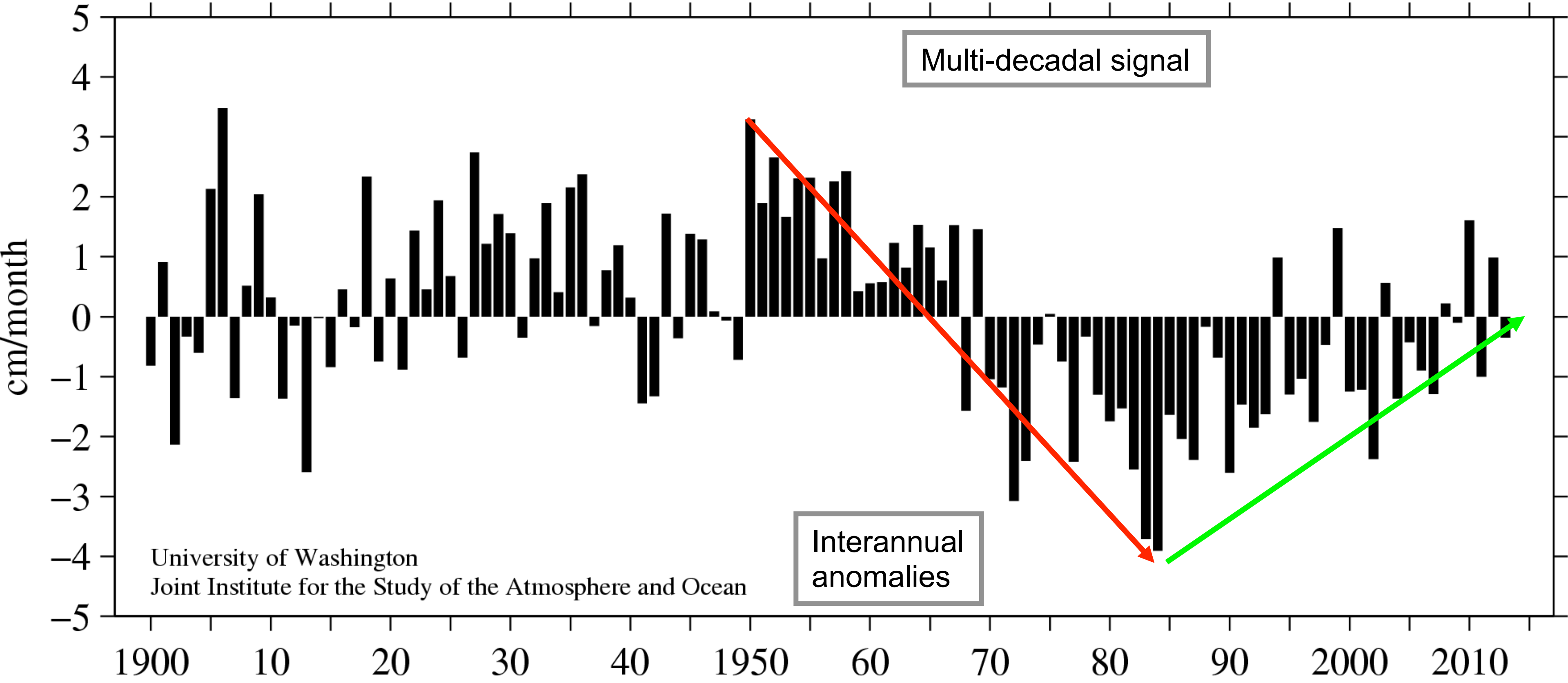


Temperature & precipitation over West Africa

Observations 1900-2010
&
Climate projections

Sorghum-millet yields evolution

Sahel rainfall anomalies June-October (1900-2013)
10°N-20°N / 20°W-10°E



University of Washington
Joint Institute for the Study of the Atmosphere and Ocean

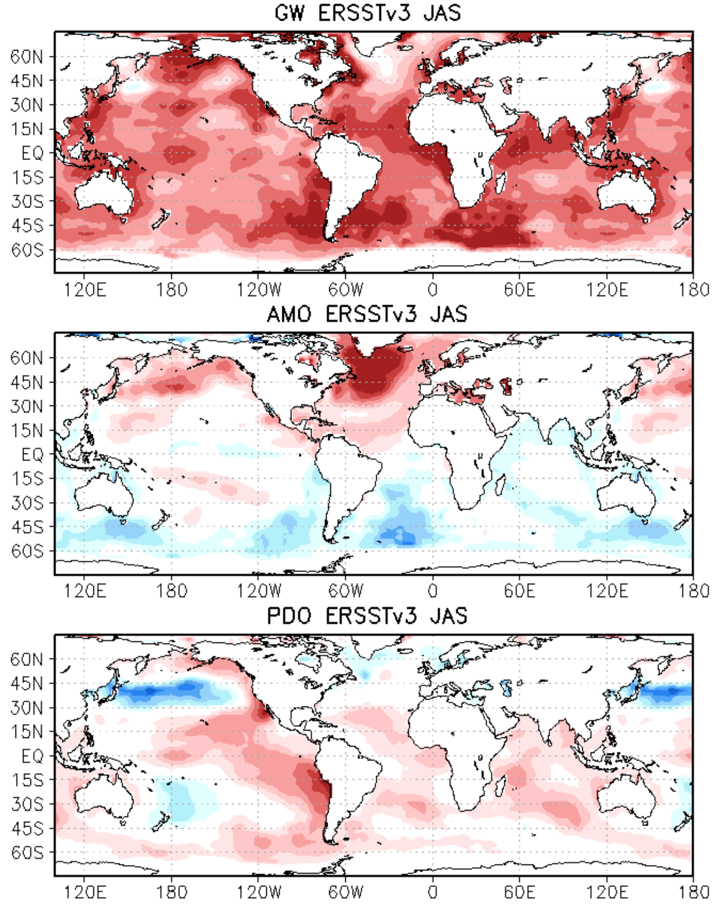
Sea surface temperature anomalies forcing ?

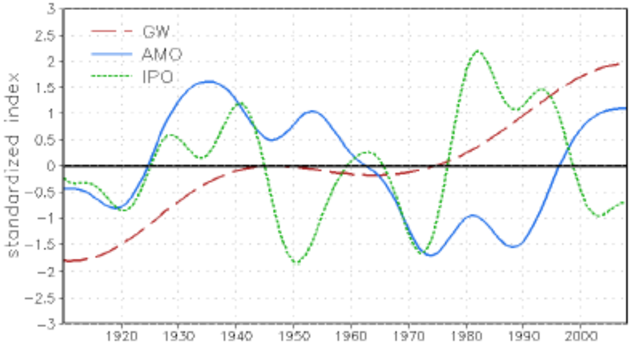
Land surface feedbacks ?

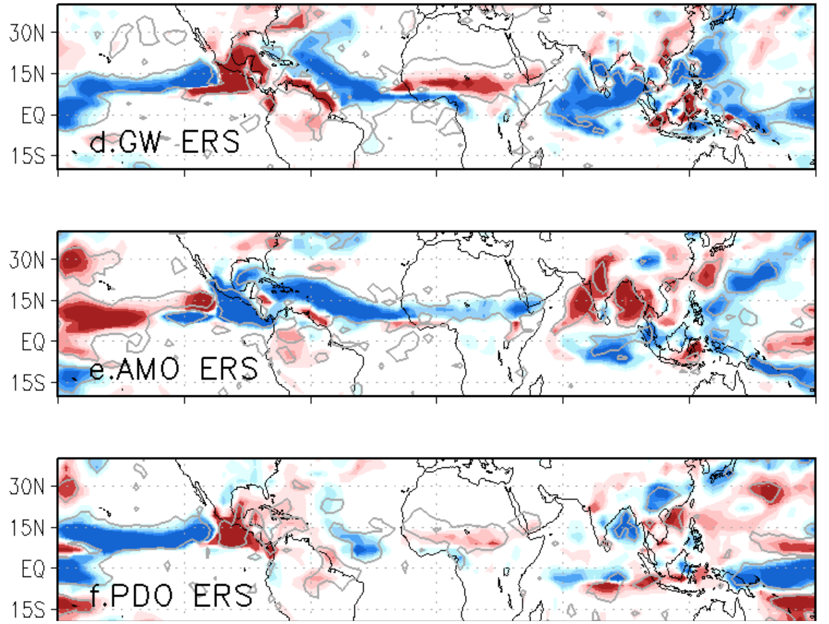
Global warming ?

Research conducted at IRD

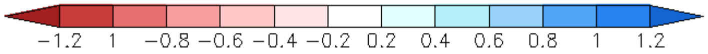
1. Decadal scale variability / SST

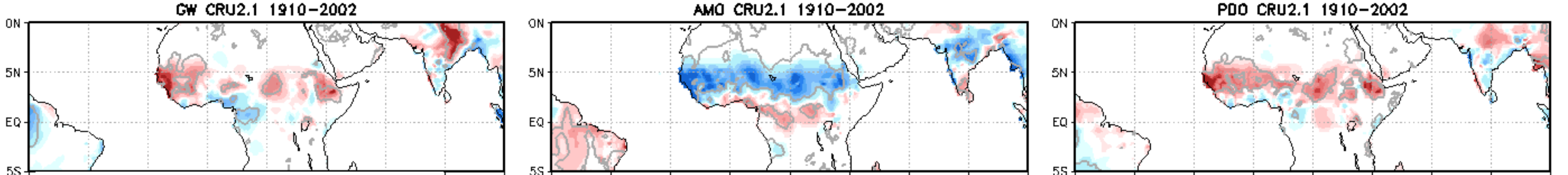




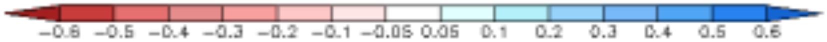


Rainfall anomalies from climate model runs



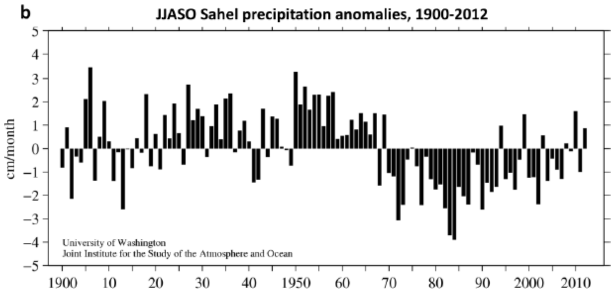


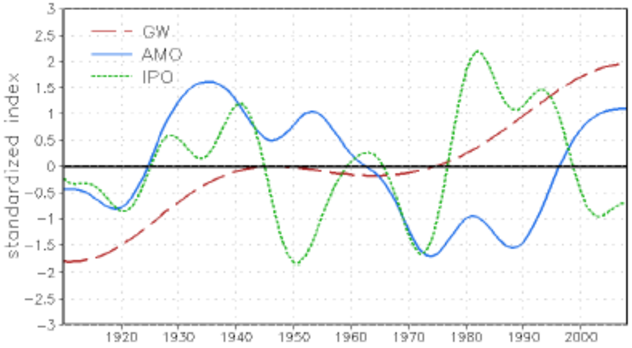
Rainfall anomalies
from observations



Research conducted at IRD

1. Decadal scale variability / SST





Q. Which impact of greenhouse gas versus SST forcing ?

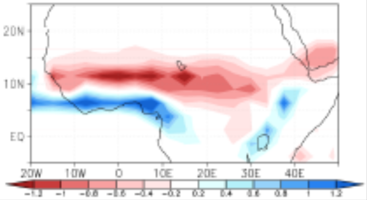
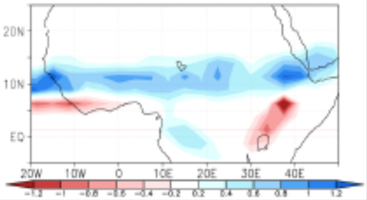
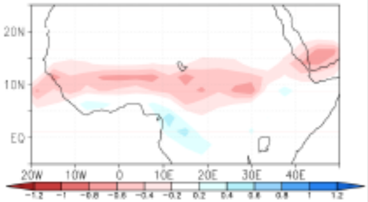
Q. Are AMO & PDO impacts on West Africa specific of XXth century or are they robust over the past ?

Q. How AMO & PDO are predictable and at which range ?

Q. Which evolution of AMO and PDO under climate change scenarios ?

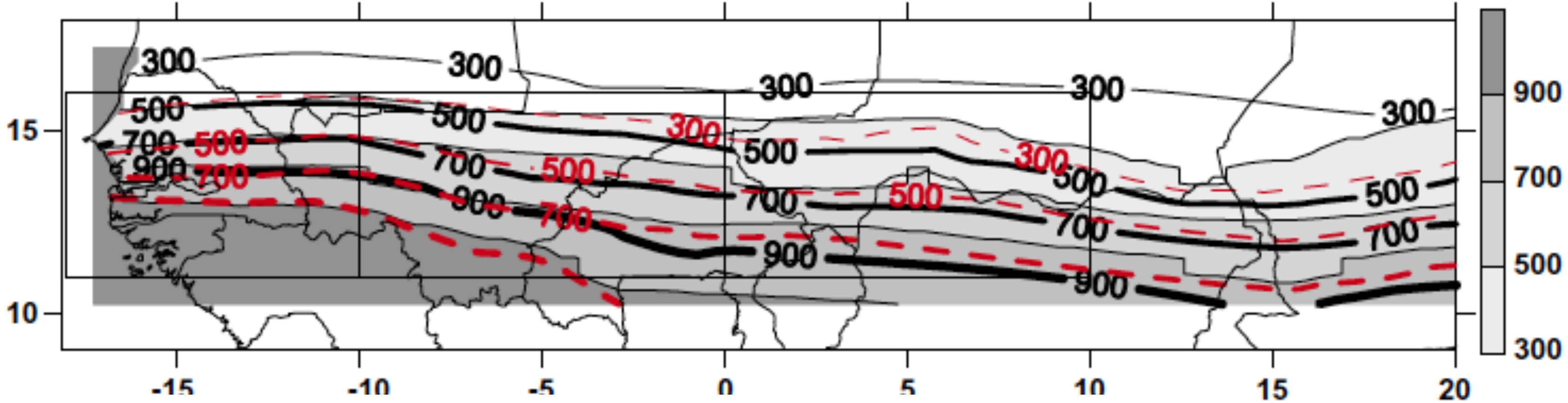
Q. How climate models simulate this kind of variability ?

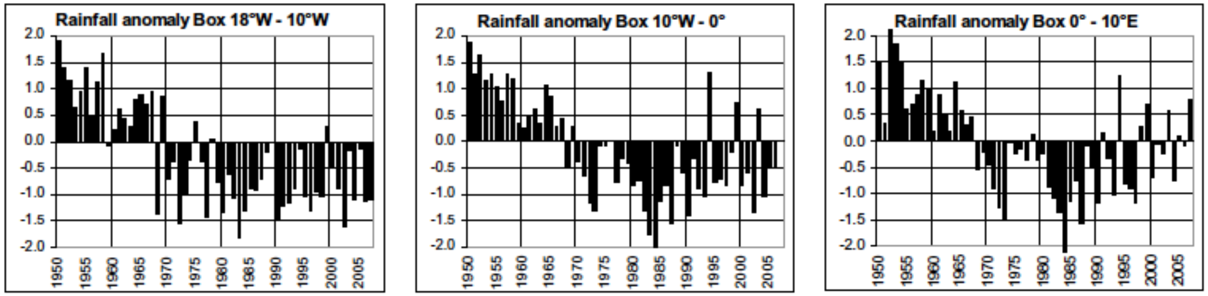
Sea surface temperature - only forcings

Component	Impact on West Africa	SST key areas	Mechanism	Contribution to 1980s Drought	Contribution to mid-1990s recovery
GW		Tropical Indo-Pacific Tropical Atlantic	Enhanced subsidence over West Africa Increased humidity fluxes into Guinea Gulf	10%	-20%
AMO		Atlantic + Mediterranean + Tropical Indian + Maritime Continent	Northward shift of the ITCZ	50%	80%
IPO		Tropics	Enhanced subsidence over West Africa	40%	40%

Research conducted at IRD
1. Decadal scale variability

T. Lebel, A. Ali / Journal of Hydrology 375 (2009) 52–64



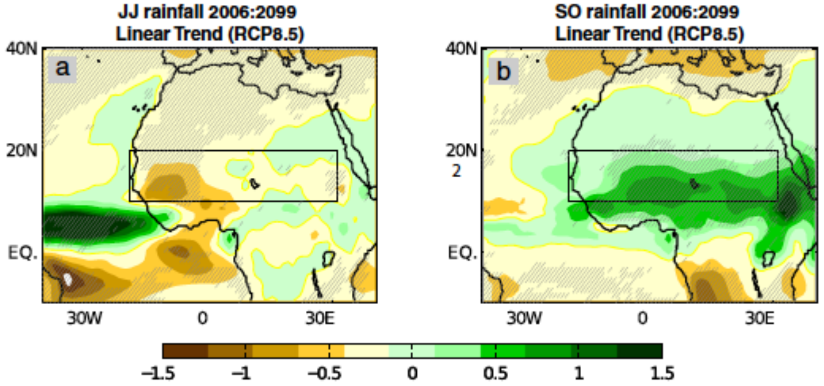


Time series of rainfall anomalies 1950-2007 averaged over three boxes from west to east

Q. Which processes can explain this Sahel rainfall dipole ?

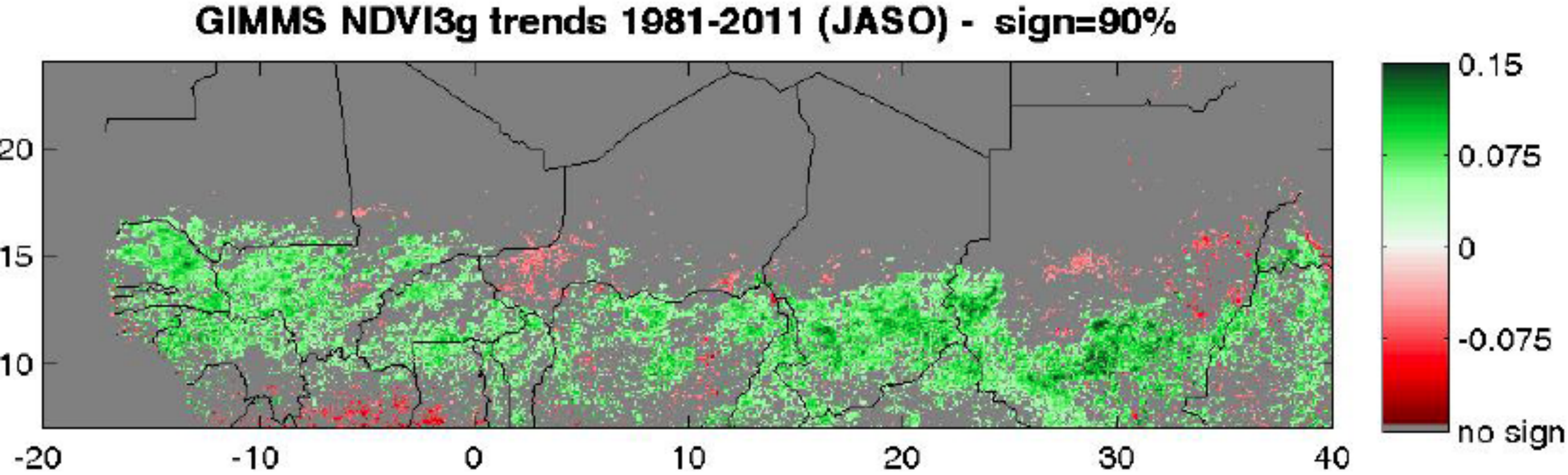
Q. Is this already a fingerprint of greenhouse gas concentration increase ?

BIASUTTI: FORCED RAINFALL TRENDS IN THE SAHEL



Rainfall anomaly pattern in climate change scenario *RCP8.5 at 2100*

NDVI growing season trends in Sahel



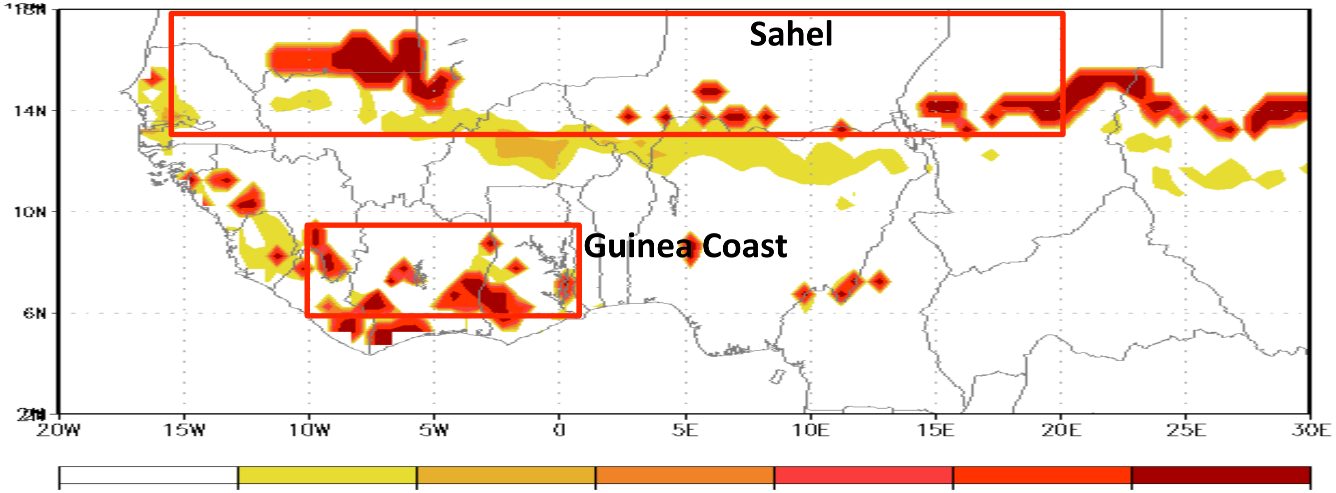
Re-greening trends are observed over most parts of the Sahel, except for western Niger and center Soudan, where negative trends are observed.

Research conducted at IRD

1. Decadal scale variability / Land surface

Which impacts of land-use changes on African monsoon dynamics ?

a. Crop and pasture fractions (1992–1870)

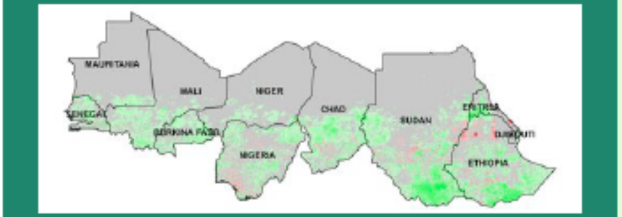


Absolute changes in crop and pasture fraction between the Preindustrial period (1870) and Present Day period (1992)

Increase of cultivated areas between 1870 and nowadays

Great Green Wall

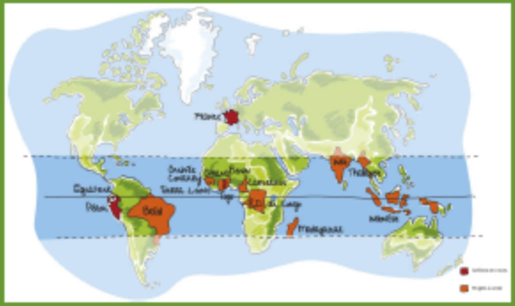
political pan-African project



> Regional scale (7000 x 15 km2)

KINOME, "social enterprise"

improving quality of life



> World-spread village-scale initiatives

Several projects of regreening / reforestation

Research conducted at IRD

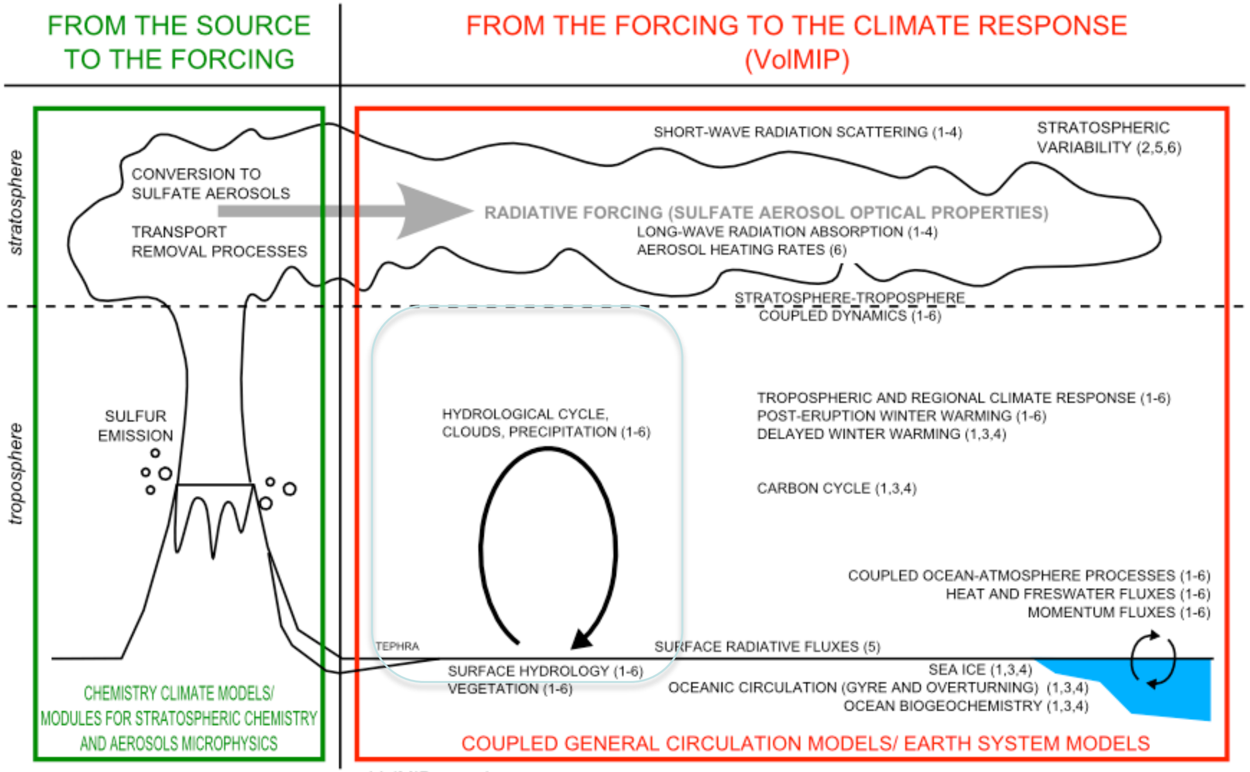
2. Natural variability over the last 2000 years

VolMIP

Model Intercomparison Project on the climatic response to Volcanic forcing

(World Climate Research Program for CMIP6 endorsement)

Davide Zanchettin (Univ. Venice), Claudia Timmreck (MPI-M Hamburg), Myriam Khodri, (IRD,Paris)



VolMIP experiments:
1: Tambora-like tropical eruption [VolLongS100EQ]
2: Pinatubo-like tropical eruption [VolShortt20EQfull]
3: Laki-like high-latitude eruption [VolLongS100HL]
4: 19th century-like cluster of tropical eruptions [VolLongC19thC]
5: Pinatubo-like eruption, prescribed net surface radiative flux [VolShort20EQsurf]
6: Pinatubo-like eruption, prescribed aerosol heating rates [VolShort20EQstrat]

Collab. IRD-MPI

Zanchettin et al., 2015

Research conducted at IRD

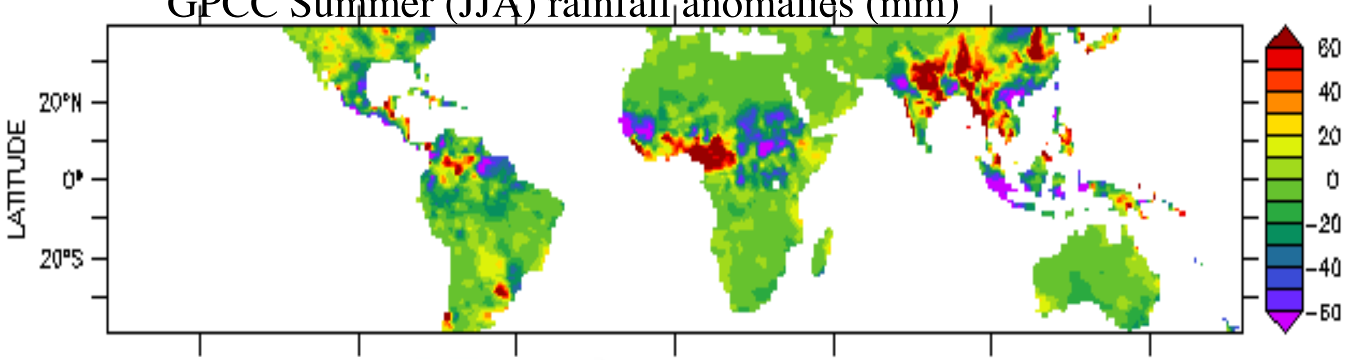
2. Natural variability over the last 2000 years

20th Century Big volcanic Eruptions impacts on Monsoon climates

Pinatubo (June 1991) El Chichon (March 1982) Mount Agung (Feb 1963) Santa Maria (Oct 1902)

Composite anomalies during the year of the eruptions

GPCC Summer (JJA) rainfall anomalies (mm)



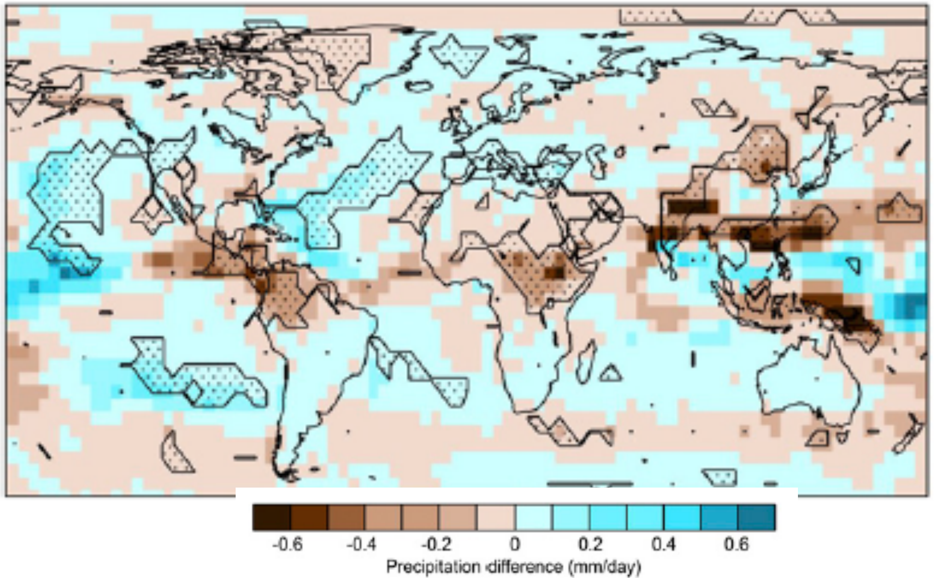
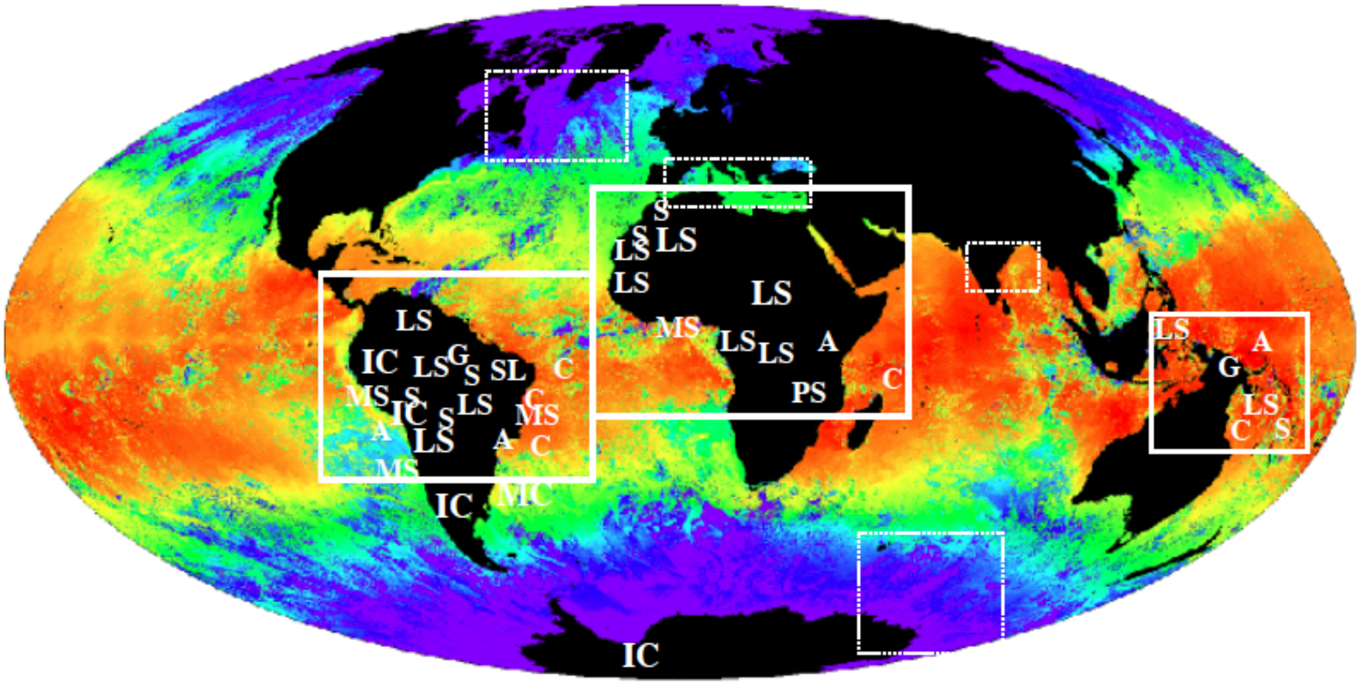


FIG. 3. Boreal summer (June–August) precipitation anomalies averaged across 14 tropical volcanic eruptions in ECHAM5.4 climate model simulations (composite of 420 simulated eruptions) for (a) ALL-REF (ensemble mean differences are calculated for each eruption relative to a reference period around each eruption, then averaged across all eruptions) and (b) ALL-NOVOLC (differ-

Wegmann et al. JCL 2014

Research conducted at IRD

2. Natural variability over the last 2000 years



MS: marine cores, LS: lake cores, C: coral/shell, S: speleothem, G: guano, A: time-series
IC: Ice Core

Q. Which role of natural forcing (solar activity, volcanic eruptions) on African climate variability for the last 2000 years ?

Q. Evaluation of decadal modes AMO & PDO

Q. Are local core data representative of regional climate ?

present day – past / ocean – continent / Multiproxy observation - modeling

Africa-France-Brazil Tripartite Project for climate reconstruction and modelling over the last 2000 years

Research conducted at IRD
3. Extreme events / rainy events

Intensification of the hydroclimatic cycle over the recent partial recovery period:

- Increased % of extreme rainfall in annual rainfall

Q. Which local/remote processes can explain this intensification ?

Q. Can it be consistent with greenhouse gas increase ? Or does it belong to natural variability ?

Q. How greenhouse gaz increase will impact extreme rain events ?

43 stations over 5°W-7°E / 9.5°N-15.5°N 1950-2010

Panthou et al. 2014

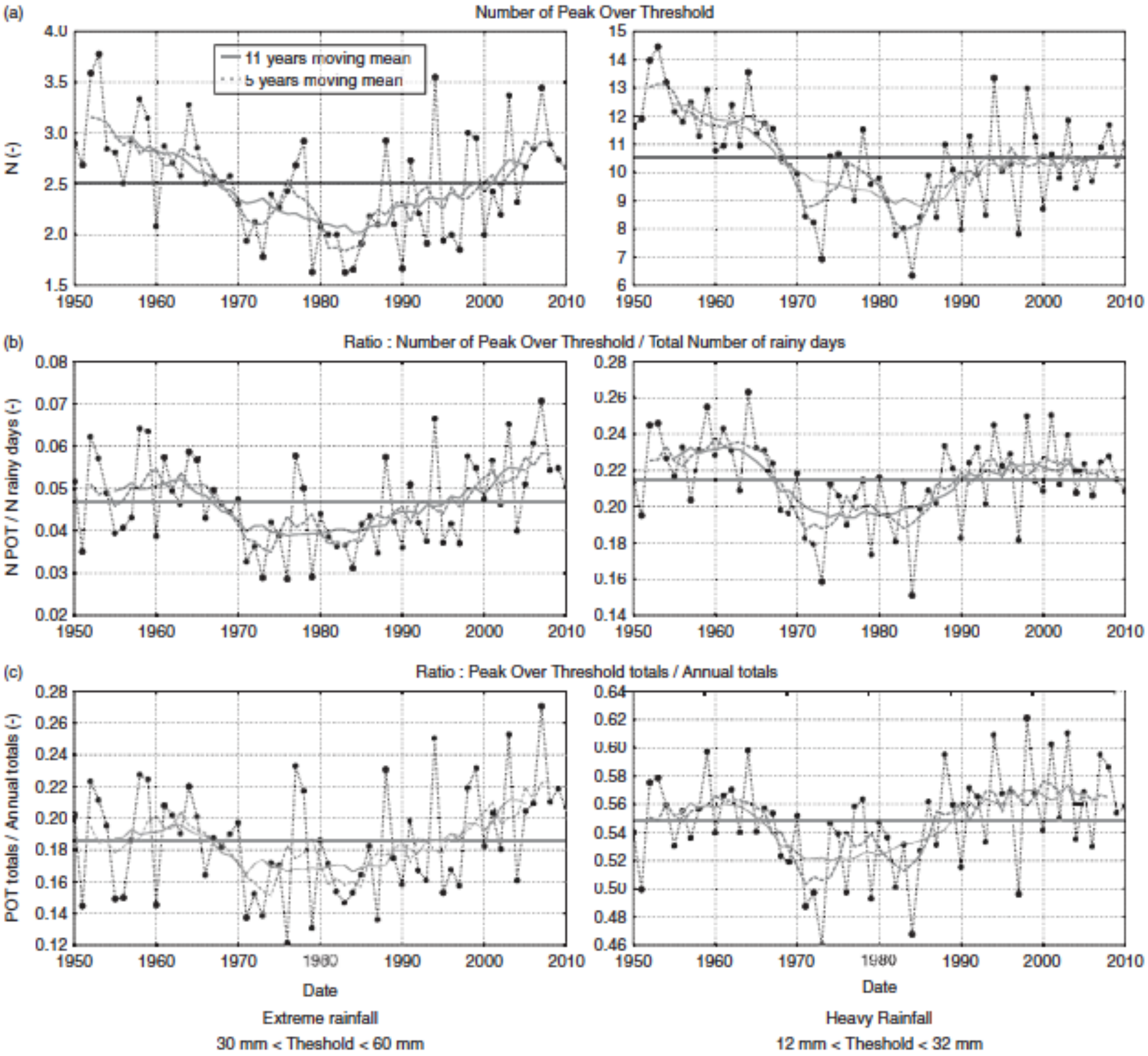
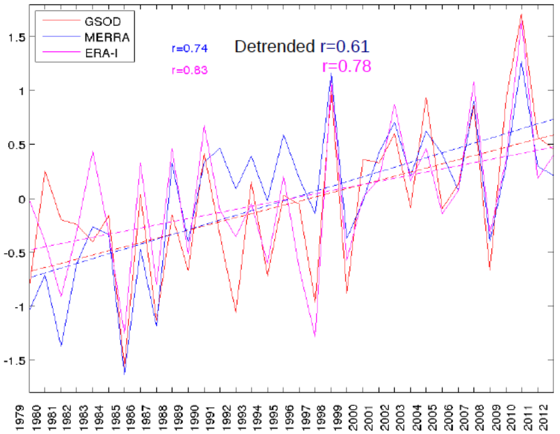


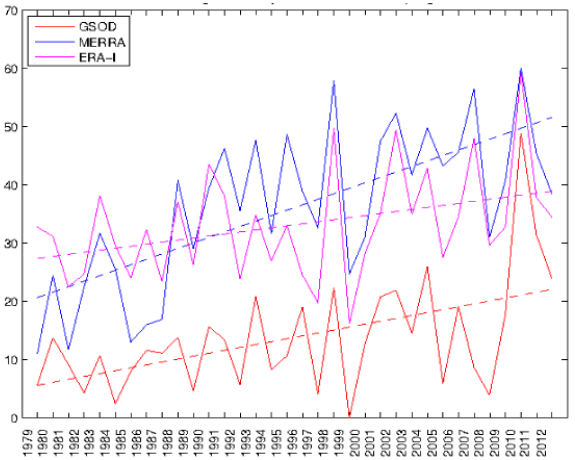
Figure 5. Evolution of the statistics of extreme (left panel) and heavy (right panel) rainfall from 1950 to 2010: (a) number of extreme (heavy) rainfall; (b) percentage of extreme (heavy) rainy days; (c) contribution of the extreme (heavy) rainy days to the annual total.

Research conducted at IRD
3. Extreme events / heat waves

Interannual evolution of Heat Index
over central Sahel; June-September 1979-2012



% of regional scale heat waves days
(Heat Index > 90% over 3 days or +)



Q. Heat waves patterns and dynamics over West Africa ?

Q. Which predictability ?

Q. Their evolution under climate change scenarios ?

Q. How climate models simulate heat waves ?

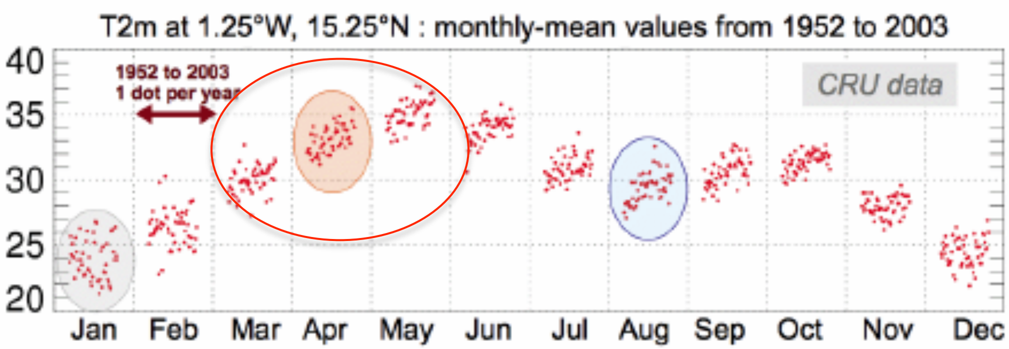
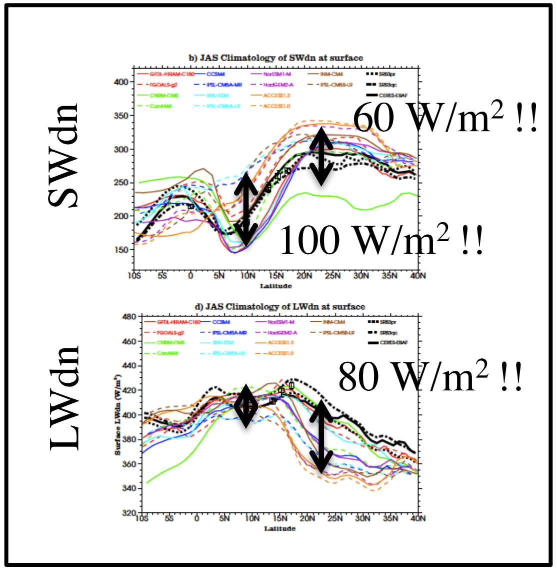
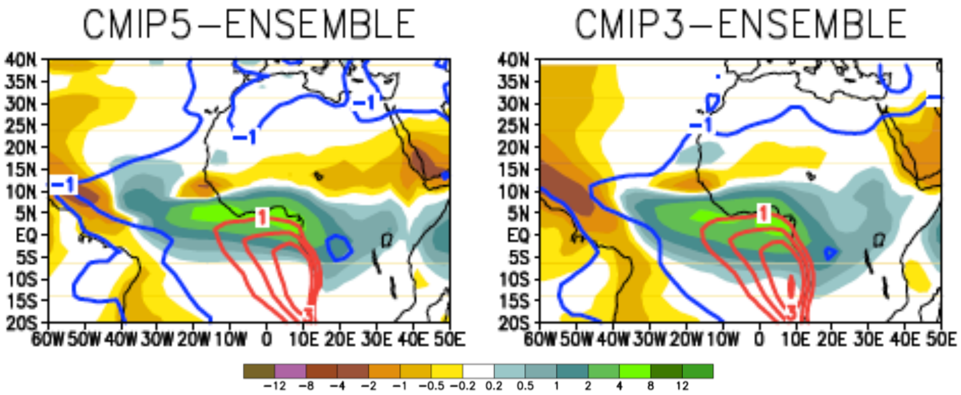


Fig.1: Annual cycle of monthly temperature over a 0.5° square degree centred on 1.25°W-15.25°N, from CRU (East Anglia). For each month, every dot represents one year from 1952 to 2003; F. Guichard (CNRM-GAME).

Research conducted at IRD
4. Climate models evaluation

- The main biases in climate models over West Africa have not been reduced from CMIP3 to CMIP5.

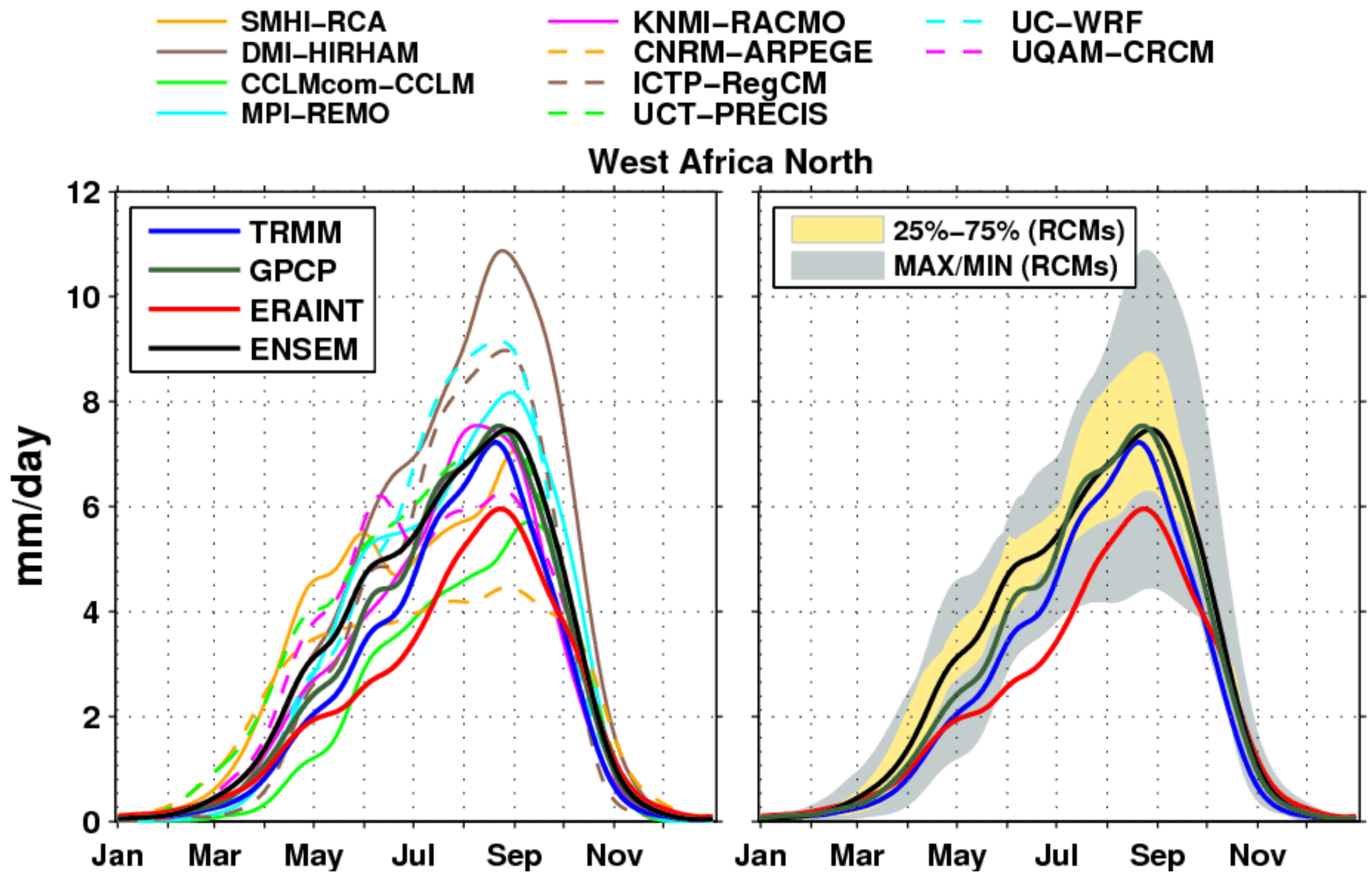




- Even in uncoupled mode, models have strong biases on rain but also on radiative fluxes.

- Biases are similar in regional climate models

Regional modeling
CORDEX-Africa



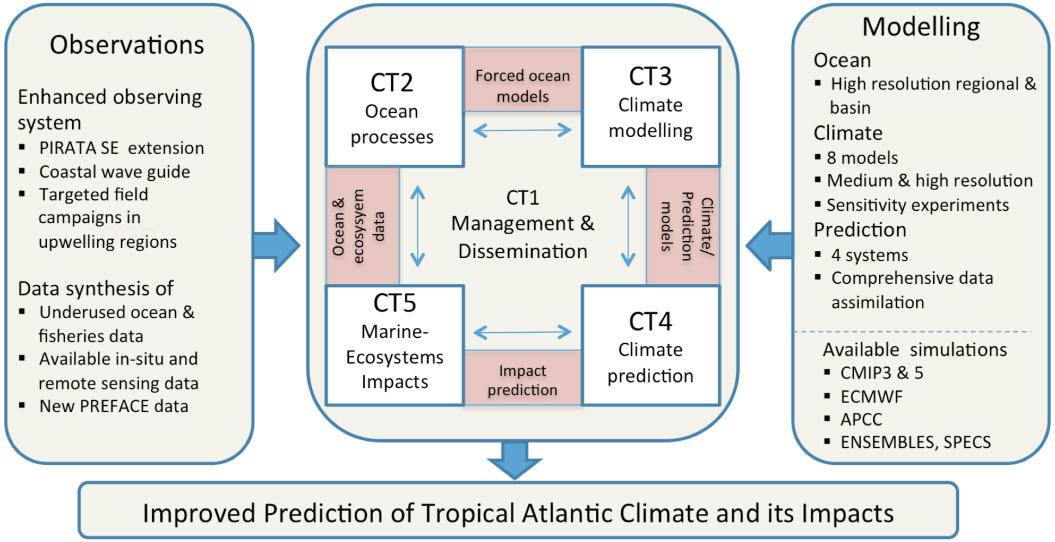
ERA-Interim underestimates precipitation in West Africa
wide spread among RCMs but the ensemble mean does a good job

Projet EU PREFACE

Enhancing PREdiction oF Tropical Atlantic ClimatE and its impacts

Objectives:

- To reduce uncertainties in our knowledge of the functioning of Tropical Atlantic climate, particularly of climate-related ocean processes (including stratification) and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability.
- To better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections.
- To improve the simulation and prediction of Tropical Atlantic climate on seasonal, and longer time scales, and contribute to better quantification of climate change impacts in the region.
- To improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the Tropical Atlantic.
- To assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.



Observations

Enhanced observing system
- PIRATA SE extension
- Coastal wave guide
- Targeted field campaigns in upwelling regions

Data synthesis of
- Underused ocean & fisheries data
- Available in-situ and remote sensing data
- New PREFACE data

CT2
Ocean processes

Forced ocean models

CT3
Climate modelling

Ocean & ecosysyem data

CT1
Management & Dissemination

Climate/ Prediction models

CT5
Marine-Ecosystems Impacts

Impact prediction

CT4
Climate prediction

Modelling

Ocean
- High resolution regional & basin

Climate
- 8 models
- Medium & high resolution
- Sensitivity experiments

Prediction
- 4 systems
- Comprehensive data assimilation

Available simulations
- CMIP3 & 5
- ECMWF
- APCC
- ENSEMBLES, SPECS

Improved Prediction of Tropical Atlantic Climate and its Impacts

African Monsoon Multi-disciplinary Analysis (AMMA) Land Surface Intercomparison Project (ALMIP) Phase 2: Local to meso Scale Processes

Boone A., Peugeot C., Demarty J, Grippa M, Benarrosh N, Brender P, Cappelaere B, Chaffard V, Charvet G., Chazarin J-P, Cloché S, Cohard J-M,
Ducharne A, Fleury L, Galle S, Getirana, A., Gosset M, Guichard F, Hiernaux P, Kaptué A., Kergoat L, Lebel T, Maignan F, Mougin E, Ottlé C,
Polcher J, Quantin G., Ramage K, Robert D, Roujean, J.-L., Séguis, L., Timouk F, Velluet C., Viarre J, and Vischel T.

ALMIP AMMA Land Surface Model Intercomparison Project **Phase 2**

Introduction

The main goal of the African Monsoon Multidisciplinary Analysis (**AMMA**) Project (Redelsperger et al., 2009, BAMS) is to obtain a better understanding of the intra-seasonal and inter-annual variability of the West-African Monsoon (WAM). The magnitude of the north-south gradient of surface fluxes (related to soil moisture and vegetation) has an influence on the position of the tropical front and the strength of the monsoon. Therefore, a high priority of AMMA is to better understand and model the influence of the spatial and temporal variability of surface processes on the atmospheric circulation patterns and the regional scale water and energy cycles. This is being addressed through a multi-scale modeling approach using an ensemble of **hydrological and land surface models** (LSMs) which rely on dedicated satellite based forcing and land surface parameter products, and data from the **AMMA observational field campaigns**. The coordination of the land surface modeling activities in AMMA is supported by the AMMA Land surface Model Intercomparison Project (ALMIP: Boone et al., 2009, BAMS). The now completed ALMIP Phase 1 dealt with surface processes at the regional scale, and results were used not only to obtain a better idea of surface processes, but also output data was used extensively by the atmospheric modeling community. In **ALMIP Phase 2**, LSMs will be forced and evaluated using observational data from three heavily instrumented supersites from the **AMMA-Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique (CATCH)** observing system (Lebel et al., 2009, JH). The AMMA-CATCH window covers a north-south transect encompassing a large eco-climatic gradient (Fig. 3).

ALMIP2 Science Questions:

1. Which processes are missing or not adequately modeled by the current generation of LSMs over this region (e.g. endorheic hydrology...)?

2. How do the various LSM respond to changing the spatial scale (three scales will be analyzed: the local, meso and regional scales)?

3. Can relatively simple LSMs simulate the vegetation response to the atmospheric forcing on seasonal time scale (for several annual cycles) for the diverse climates/vegetation covers?

4. How can LSM simulate mesoscale hydrology given their relatively simple representation of such processes?

5. What are the impacts of uncertainties/differences in the precipitation on the surface fluxes and hydrological responses of the LSM models?

In order to address these questions, **two experiments** will be performed with the first one at the **mesoscale** for each of the three super sites. A second set of experiments will be performed at the **local scale** for several selected sites within each of the mesoscale squares. The simulations will encompass the 2005-2007 Intensive Observing Period. In addition to evaluation using field data, LSM simulations will also be compared to results from detailed vegetation process and hydrological models that have already been extensively validated over this region. The results will be used in conjunction with those from ALMIP-1 in an effort to evaluate the effect of scale change on key processes. A sample of the different sites is given in the following.

Mali local scale site: Agoufou

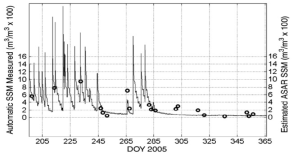


Fig.1a (top) and 1b (at left)

The Agoufou site in Mali (Mougin et al., 2009, JH) is semi arid characterized by sandy soil and widely-spaced shrubs and short seasonal grass (Fig.1a) adjacent to large areas of rocky or loamy very shallow soils. (Fig 2). Observed soil moisture (circles) are shown above (Fig.1b taken from Baup et al., 2007, Rem. Sens. Env.) compared to data derived from ASAR (satellite-based) data. Such data will be used to evaluate the LSMs.

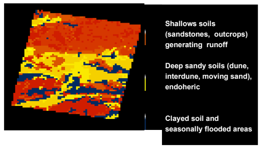
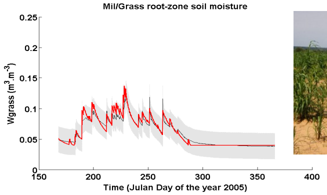


Fig.2 Detailed land cover maps have also been created for each meso-domain in addition to ECOCLIMAP2. The classification (at left) was derived from LANDSAT for the Mali meso-domain.



Millet Crops

Fig 2a (top) and 2b (left)

Niger local scale site: Wankama

The Wankama site is characterized by sandy soil, and mixed agriculture and fallows with shrubs. An example comparison (Fig 2) for the Niger site (Cappelaere et al., 2009, JH) between root zone soil moisture simulated by the SEtHys Savannah LSM model (Fig 2b: Saux-Picart, 2009, JH) compared to observed root zone soil moisture. The grey zone indicates observational uncertainty. The model is able to capture the wet season soil moisture dynamics. Such a semi-arid environment will likely challenge the LSMs, however, a robust modeling of such environments is critical to understanding and modeling the WAM. A photograph of the site (Millet) is shown in Fig.2a.

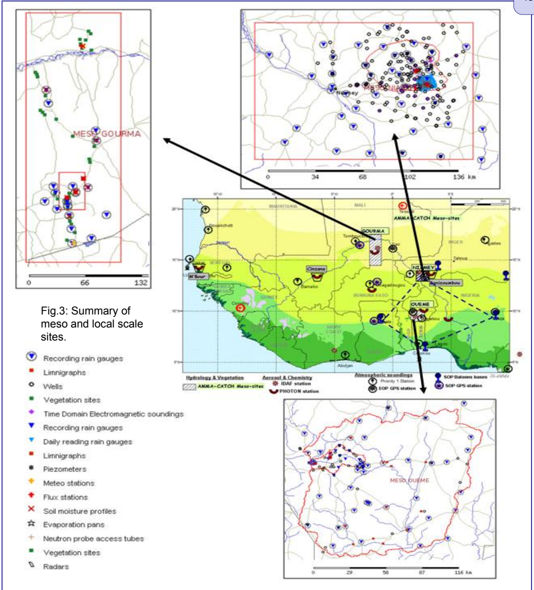
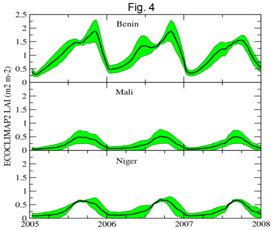


Fig.3: Summary of meso and local scale sites.

- Recording rain gauges
- Limnigraphs
- Wells
- Vegetation sites
- Time Domain Electromagnetic soundings
- Recording rain gauges
- Daily reading rain gauges
- Limnigraphs
- Piezometers
- Meteo stations
- Flux stations
- Soil moisture profiles
- Evaporation pans
- Neutron probe access tubes
- Vegetation sites
- Radars

Fig. 4



Mesoscale Forcing and Soil-Vegetation Inputs

The domain-averaged Leaf Area Index (LAI) from the **ECOCLIMAP2** database (Kaptué et a;., 2011, J Hydromet) is shown in Fig. 4. The spatial variability is indicated in green (1 std). Unlike ALMIP1, ALMIP2 includes year-to-year variability. Detailed classifications are also available (see example for Mali Fig. 2).

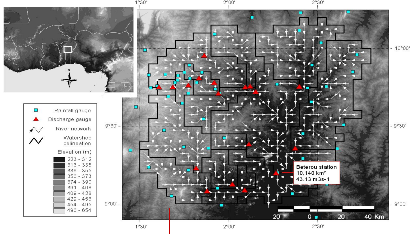
Mesoscale downwelling fluxes are form the **LAND-SAF** project. Precipitation is derived using a combined **krigged -LaGrangian** (Vichel et al., 2009, JH) methodology (nearest neighbor will also be used) based on dense rain gauge networks. Meteorological variables are from **ECMWF** operational forecast data.

Intercomparison of hydrologically based models and LSMs

Hydrological processes from conceptual hydrological models (e.g. TOPAMMA based on the TOP-Model approach) or distributed models (e.g. MIKE-SHE) will be compared to LSMs coupled to a simple Muskingum-Cunge routing algorithm (Getirana et al., 2011). A schematic of the methodology for obtaining discharge (Fig. 5b) from the for the Oueme basin (Benin). Model simulated discharge from an LSM (here ISBA) after calibration of 3 parameters during 2005 is shown compared to observations (Fig. 5c).

Production functions (such as for evapotranspiration and surface runoff) from hydrological models will be evaluated and compared to values from LSMs. It is hoped that both types of models can benefit from such a comparison.

Fig. 5a: Flow network



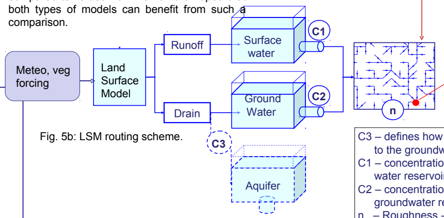
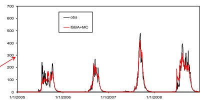


Fig. 5b: LSM routing scheme.

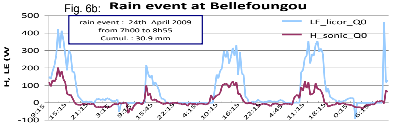
Fig. 5c: Discharge.



C3 – defines how much drainage goes to the groundwater reservoir
C1 – concentration time of the surface water reservoir
C2 – concentration time of the groundwater reservoir
n – Roughness -Manning coefficient

Benin local scale site: Bellefoungou

Fig. 6b:



Unlike the semi-arid sites in Niger and Mali, the Benin site (Guyot et al., 2009, JH) is characterized by a cleared forest. The tower (Fig. 6a) is situated in a relatively homogeneous forested area with 14m tall trees, with herbaceous under-story vegetation during the wet season. Various radiation and flux measurements have been made by both LTHE and CEH (Wallingford, UK). A sample 4 day time series (turbulent fluxes) are shown in Fig. 6b. Rain events generally take place during night time, thus limiting the impact on the retrieved fluxes.

Conclusions and Perspectives

The main goal of ALMIP2 is to obtain a better understanding and thus to improve the representation of key surface, vegetation and hydrological processes over West Africa, which can then in turn benefit the forecast and regional and global climate modeling communities, and the mesoscale, regional and global scale hydrological modeling communities. Owing to rapidly increasing population and anthropization, along with the possibility for regional changes to the climate, improved modeling is needed for applications in water resource management, disease prevention and control, and adaptive agricultural practice strategies.

Model experiments will be performed for three distinct meso-scale domains within the AMMA-CATCH window which is characterized by strong gradients in vegetation, soils and climate. Different satellite-based datasets have been assembled for evaluating models over the mesoscale regions (**LAND-SAF** products, the **Alexi Evaporation** product from the USDA: M. Anderson, etc.), along with many discharge and piezometric measurements for hydrological modeling. One to several local scale sites will also be modeled within each meso-domain. An overview sample of some of these sites is presented herein. Simulations will cover the main AMMA field campaign observational window (2005-2007) and extending into 2008.

It is hoped that ALMIP2 will be able to help bridge the gap between GEWEX Regional Hydrology Projects (RHPs) and the Global Land Atmosphere System Study (GLASS), by evaluating and comparing both hydrological and LSM models. Organization and modeling has been taking place within France over the last year: **a call to participation for the international community** is forthcoming before autumn 2011, with results due by mid-2012. A workshop will be planned for the end of 2012.

For more information (and a list of references cited in this poster), visit ➔
http://www.cnrm.meteo.fr/amma-moana/amma_surf/almip2/
If you are interested in participating, please contact A. Boone at **aaron.boone@meteo.fr** or C. Peugeot at **christophe.peugeot@ird.fr**
Funding for ALMIP2 preparations in France is currently provided by EC2CO. ALMIP2 is a sub-project of AMMA2.

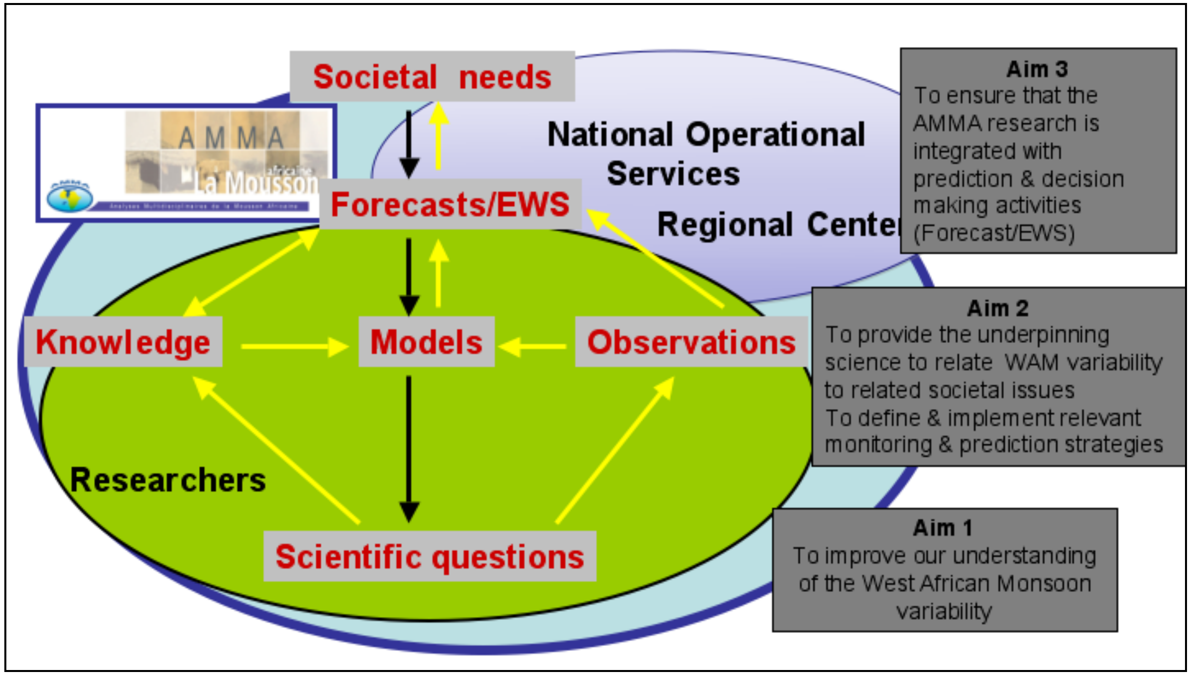
References: the references with JH herein refer to the *Journal of Hydrology CATCH Special Issue*, **375** (1–2), 2009. This issue offers a comprehensive overview of AMMA-CATCH related studies (observations and modeling).

African Monsoon Multidisciplinary Analyses

http://www.amma-international.org

AMMA is an international programme to improve our knowledge and understanding of the West African monsoon (WAM) and its variability and has emphasis on daily-to-decadal timescales including climate change. AMMA is motivated by an interest in fundamental scientific issues and societal needs for improved prediction of the WAM and its impacts on West African nations.

AMMA has been recognised as the largest multidisciplinary research program in Africa in the area of climate and environnement as well as impact research on the socio-economics of West African nations.



Aim 3
To ensure that the AMMA research is integrated with prediction & decision making activities (Forecast/EWS)

Aim 2
To provide the underpinning science to relate WAM variability to related societal issues
To define & implement relevant monitoring & prediction strategies

Aim 1
To improve our understanding of the West African Monsoon variability

Phase 2 : 2010-2020

↓

A contribution to climate services.
Upstream research towards added-value products.