## 1.2 The water cycle & the scaling issues in the West African Monsoon

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***General Objectives***

The advection of atmospheric humidity, its transformation into precipitation, and the abundance of rain water over land is one of the defining measures of the West African monsoon. The availability of water is indeed one of the most limiting parameters for life, agriculture and economic development in the Sahel. The role played by humidity advection, latent heat release and the associated energy transports and exchanges is of central importance for monsoon dynamics and its variability. A better understanding of the water cycle in the coupled oceanic, atmospheric and continental system, with the associated benefits for forecasting, is thus a major issue for AMMA.

A complete view of the water cycle is, however, a difficult task since it would require the availability of data concerning a very large number of processes at a great variety of spatial and temporal scales. Many of these processes are physical, but there is also a significant influence from biological and chemical phenomena. Most importantly, coupling between many of these processes induces complex feedbacks, which can either amplify or reduce the impact of oceanic, atmospheric or continental perturbations on water availability.

During the EOP and the SOP, AMMA will provide detailed measurements of key parameters concerning the water cycle. An exhaustive documentation of all phenomena occurring at different scales during the West African monsoon is clearly out of reach, but special observations during AMMA will concentrate on the sampling of statistically representative events at specific locations. From these data, it will be possible to evaluate the different terms of the water budget for different aspects of the monsoon for the ocean, the land surface and the atmosphere. Integrated analyses with routine observations, satellite remote sensing measurements and numerical modeling should help to generalize the local results to the regional scale.

In this work-package, the water cycle is approached through the estimation of the water budget components. Working on water balance necessarily implies improvements of the representation of the water cycle in the coupled oceanic, atmospheric and continental system, with the associated benefits for forecasting, a major issue for AMMA. It also implies direct benefits for impact studies, as, for example, water resource for domestic use or agriculture is directly linked to the storage terms of the continental water balance. The results should provide key information concerning the natural and anthropically modified processes for water resource management and for weather to climatic forecasting studies. This work package, through disciplines and scales integration, thus contributes to central objectives of AMMA.

Water budget estimations raise however a number of methodological problems. Some water balance components can be estimated directly from measurements (e.g. river outflow, rainfall), but most often the use of models is required. In most of cases, water budget estimated from models are closed, due to model construction (e.g. hydrological model), but the relative weight of each term in the balance may not be correct. An important objective here is to introduce external constraints to improve water budgets (for example for atmospheric budgets, satellite-derived rainfall fields, evapo-transpiration fields from hydrological models). In other hand, as the accuracy of water balance closure is not necessarily the same at all scales (e.g. atmospheric water balance from (re)analyses *versus* balance from ground-station fluxes measurements). Compatibility between independent estimates of water budget coming from different but connected sub-domains (e.g. rain events and watershed, oceanic surface and monsoon flow, … ) must be assessed, and closure of the associated water budgets must be verified. During the AMMA project, these evaluations will be regularly reviewed in regard to improved observations at different scales(WP4.2.1, WP4.2.2, WP4.2.3 & WP4.3), improved understanding of processes and their coupling relevant to the water cycle (WP2.1, WP2.2, WP2.3) and improved models and associated assimilation of observations (WP4.1.1, WP4.1.2, WP4.1.3).

Different components of the water budget display large spatial and temporal heterogeneities and scale interactions. Scaling issues are thus central to AMMA, and must be taken into account in water budget assessments. Methods of upscaling and downscaling need to be developed to transfer information between scales. For example, precipitation is heterogeneous on all scales down to the scale of the individual rain event; hydrological systems are very sensitive to changes not only to the amount of precipitation, but also to its distribution both in space and time; the water balance components and associated errors may vary across temporal or spatial scales, the closure may not be satisfied at all scales.

When direct measurements or reliable simulations of water budget components are lacking at hydrological scales, information at larger scales needs to be disaggregated following rules derived from field observations or models. These rules can consist of linkages between different variables, such as dynamical signatures of the flow at the large scale and statistical signatures of rainfall at the small scale. Aggregation, or upscaling of precipitation and fluxes is also necessary to evaluate the large scale water budget and to feed into work on parameterization of the land surface and associated feedbacks. The last part of this work package is dedicated to the study of the scaling properties of the geophysical fields involved in water balance, and to the development of scaling methods.

***Overall Strategy***

Facing to large uncertainties of the water cycle components specially at regional scale, the chosen approach is based on nested spatial domains with scales relevant to the important physical processes occurring in the water cycle. The WP is thus organized into 3 sub-WPs corresponding to 3 nested spatial scales and a transversal sub-WP dedicated to scaling methods. Though the methodological strategy is further detailed in the following sub-sections, a summary is given here to allow a broad view.

Sub-WP 1.2.1 concerns large scale ($>10^6$ km²) water cycle. It is one of major objective of AMMA to determine water budgets and their interannual variability at this spatial scale and for spatial and temporal resolutions of few hundred kms and 10-day to month, respectively. Studies performed in 2003 and 2004 show large uncertainties exist to these scales and with these resolutions. As outlined above, external constraints (such improved estimation of precipitation field from WP4.3 or better surface fluxes from 4.1.2) and decrease of uncertainties thanks to studies at mesoscale (sub-WP1.2.2) and improved models will be able hopefully to decrease these uncertainties during the project progress.

Sub-WP 1.2.2 concerns mesoscale water cycle ($10^3$ - $10^5$ km²). It is the preferred scale for atmosphere and surface integration, as the domain size complies with both hydrologic and atmospheric model capabilities. This Sub-WP is also the one which will beneficiate directly from progresses of WP2.1 and enhanced observations which will be gathered during EOP and SOP. In the same spirit than for Sub-WP1.2.1, decrease of uncertainties will result also from studies performed at local scale (1.2.3). In other hand, improved mesoscale budgets will be used to better assess uncertainties at large scale (1.2.1).

Sub-WP 1.2.3 deals with local scale water budget (1-10 km²). It is the scale where studies can provide directly to mesoscale model, better water cycle parametrizations which will be improved and evaluated using high resolution data on super-sites of AMMA field experiment (WPs 4.2.2 & 4.2.3).
Sub section 1.2.4 deals mainly with disaggregation of rainfall or other variables affecting water balance. Upscaling problems (mainly for fluxes or soil wetness) are addressed in WP2.3 (sub-WP 2.3.3) and a strong coordination will be maintained between these WP.

***Synergy with models and observations***

This WP will assemble data and results from other connected WPs: observations (WP 4.2 and 4.3) are used to build and validate process models (2.x and 4.1), from which the variables needed for water budget assessment are extracted. To ensure that the required data or results will be made available, this WP will pilot to a certain extent observation and modelling development. This is achieved in coordination meetings, together with the coordinators and main PI's of the concerned WPs.
This coordination task will ensure that

- the observational network (ground/ocean, airborne) and satellite products produce data at appropriate time-space scales and resolutions to be used with models
- the models produce relevant estimates of the water budget components with associated estimation errors
- the surface and atmosphere water budget produced by model and observations are compatible in terms of space-time resolution

These points are part of 2005 work programme, and the coordination of the WP thus gives recommendations to other WPs to fulfil lacking data or products. These tasks will be made easy considering that the main Observation and Model PI's are also involved in the integrative WPs, and specially 1.2.

***Summary of coordination progresses in 2004***

Significant progresses in the WP structure and methodology have been made at the Dijon meeting in Sep. 2004, mainly on details on methodology to be used at each scale (see relative sub-sections), and on the strategy of deployment of ground flux stations measurements, planned in 2005, in coordination with WP 4.23 and 2.3. Fluxes measurements and up-scaling have early been identified as key points in linking atmospheric and surface water cycle. Some adjustments on methodology are still needed (see 2005 plans), but few preliminary results related to water cycle and water balance studies have been obtained in 2004.

***Links to other WPs***

This Workpackage is central to AMMA. It thus has both-way links with other WPs.

| WP | Input to WP 1.2 | Output from WP 1.2 |
|---|---|---|
| 1.1 | Large-scale dynamical signatures associated with specific rainfall regimes are to be identified in tandem with the insight gained in this WP. | Impact and variability of the West African monsoon in terms of regional water budget |

| | | |
|---|---|---|
| 1.3 | Estimates of heat and moisture fluxes at the ocean-atmosphere and land-atmosphere interface. | Estimates (through budget closure) of poorly observed terms of the water budget: evapotranspiration, surface and underground storage.<br>Role of scaling nonlinearities in determining surface fluxes at regional scale and thence climate feedbacks. |
| 2.1 | Characteristics and (spatial and temporal) variability of large-scale humidity advection from the Atlantic and Indian oceans and from the Mediterranean sea, of the low-level monsoon flow, of drier air in the African Easterly Jet and in Saharan Air Layer;<br>Seasonal climatology of rain events and rainfall statistics;<br>3D fields of wind and precipitation and environmental characteristics (wind and humidity) associated with rain events;<br>Insight on microphysical (liquid- , ice- and mixed phase) processes occurring in the observed precipitating systems, relation with lightning as an indicator of rainfall;<br>Fine-scale characteristics of humidity in the continental boundary layer, before and after the occurrence of rain events;<br>Upper troposphere – low stratosphere interactions associated with the occurrence of precipitating systems<br>Provision of links between mesoscale convective systems and rainfall to disaggregate to the local scale. | Documentation of the dynamical, microphysical and radiative properties of the anvil clouds. Water budgets and 4D fields of wind, pressure, temperature, moisture of individual MCSs and their environment.<br>Documentation on convective cells, their 3D dimensions and life cycle. Statistics on the proportion of convective and stratiform rain, on the occurrence of rainfall evaporation.<br>Insight in rain producing physicals processes, from polarimetric data and disdrometer measurements. |
| 2.2 | Structure and evolution of SST and associated air-sea fluxes in the Gulf of Guinea before the onset and during the rainy season of West Africa | Estimation of fresh water yield to the Gulf of Guinea. |
| 2.3 | Characteristics and (spatial and temporal) variability of runoff, drainage, soil moisture, evapotranspiration and underground water storage<br>Transient hydrological features (e.g. ponds, … ) | Impact of scaling issues on land surface modelling: Identification of key scales of rainfall variability over the region; impact on watershed processes<br>Downscaling of precipitation from large-scale fields (e.g. operational analyses and reanalyses); Algorithms to produce fine-scale (e.g. watershed) rainfall structure from mesoscale observations and numerical modelling; |

| | | |
|---|---|---|
| 3 | | Multiscale atmospheric and surface processes controlling the transformation of atmospheric humidity into water available for populations<br>Disaggregated rainfall techniques for the study of hydrological systems to changing rainfall patterns<br>Disaggregated rainfall as a primary input for crop models.<br>Disaggregated hydrological and temperature fields to study the spread of vector borne diseases as a function of microclimate.<br>Quantitative estimates of water budget components at different spatial and temporal scales<br>Impact of water cycle on health (water related diseases) |
| 4.1 | Operational analyses and reanalyses to evaluate water budgets<br>Mesocale modelling results to develop analysis techniques and to compare with results from EOP and SOP data<br>Modelling of soil – vegetation – atmosphere transfer including specific data assimilation to estimate evapo-transpiration<br>Hydrological & biological modelling activities; value of improved land-data assimilation system | Assessment (including error bars) on quality of model simulations and analysis for each components of water cycle (include evaluation of evaporation and evapotranspiration) |
| 4.2 | LOP, EOP and SOP data on all the components of the water cycle<br>Need SOP/EOP/LOP observations at the mesoscale sites | |
| 4.3 | Seasonal climatology and high-resolution (spatial and temporal) characteristics of cloud clusters and precipitating events<br>Meso to regional scale estimates of precipitation, integrated water content and humidity profile, SST and air-sea fluxes over the Gulf of Guinea, surface characteristics (vegetation, soil moisture) and land-atmosphere fluxes over the continent<br>Satellite products to feed the downscaling problem.<br>Satellite products from the CALIPSO/CloudSat/Aqua mission.<br>Satellite derived surface maps (Land cover, vegetation dynamics (LAI), evaporation & evapo-transpiration, ..) | Statistics on rainfall variability, on rainfall efficiency, on vertical profiles within precipitation and their variability. Statistics on bright band characteristics, on ice and water content.<br>Validation of large scale satellite-derived soil moisture or evapotranspiration estimates using water budget estimates |
| 4.4 | | User-friendly databases to compare rainfall data at different scales using in-situ, radar and satellite sources |

***Data required (observations & modeling).***

The observation and model required are detailed in the following sub-sections

## 1.2.1 The water cycle at large scale (>$10^6$ km²)

*Coordination: F. Guichardand P. Roucou)*
*Laboratories : CETP, CNRM, CRC-Dijon, LTHE, SA*

### 1.2.1.a 5-year plan

***Objectives***

- Evaluation of the performance of operational analyses, current re-analyses and special re-analyses (AMMA EOP period) in the estimation of the various terms of the water budget at regional scale over West Africa. This objective implies extensive comparisons of (re-)analyses with independent datasets derived from observations, notably satellite products, including existing products and the new products that will be made available within the AMMA project. (CRC, CNRM)
- Identification of sources and sinks of water vapour in the region and evaluation of the contributions from large-scale transport into the region and from recycling. (CNRM, CRC)
- Identification of the connections between humidity fluxes, local dynamical phenomena and remote influences in re-analyses. (CRC, CNRM)
- Comparisons between the results obtained for wet and dry years, or wet and dry intra-seasonal periods. (CRC, CNRM)
- Estimation of the cloud component of the water budget at large-scale using satellite products (validated during the SOP using dedicated airborne in-situ and active remote sensing measurements) from the CALIPSO/CloudSat/Aqua mission. (CETP)
- Derivation of 4D fields at the scale of West Africa over limited SOP periods with MANDOPAS.(CETP)
- Estimation of fresh water yield to the Gulf of Guinea (need for WP 2.2).

***Methodology***

The water cycle observed at large scale results from the interplay of a number of distinct processes acting on a variety of scales. At this scale, analyses and re-analyses from numerical weather forecast models combined with dedicated observational products stand as the most adapted integrative tools for investigation of the atmospheric water cycle.
In a first step, we will focus mostly on the vertically integrated atmospheric water budget. This will possibly include some limited investigation of the associated vertical structures of a few parameters and/or processes, as this should help understanding further the functioning of the water cycle in (re-)analyses. Evaluation of (re-)analyses will involve extensive comparison with observational products, notably satellite-derived products. In this evaluation process, time series of selected ground-based observations from local sites will be tentatively used to provide some helpful diagnostics as well as the fields obtained at regional scale with MANDOPAS over particular periods. Observational products include a variety of satellite-derived products (rainfall, ocean-atmosphere or continent-atmosphere fluxes).
Satellite-derived products that we are planning to use (most of them directly made available from the AMMASAT database) include:

- precipitable water estimations (SSM/I,TMI), information on UTH (upper tropospheric humidity) content (Météosat & MSG water vapour channels),
- precipitation estimations (TRMM, GPCP, TAMSAT),
- moisture flux from the oceanic regions,
- cloud water estimations (SSM/I, TMI).

Moisture fluxes over continental surfaces as produced by WP4.2.1 (Land Data Assimilation) will be also key products. These products will be firstly used to evaluate the large-scale water budget obtained from the (re-)analyses. Inter-comparison of analysis and re-analyses from different NWPs (ECMWF and NCEP) will also help to identify which are the more robust features and the weaker elements of the water budgets one can derive from them.
This work will allow, in a second step, to address the scientific objectives presented above, via the combined use of (re-)analyses and observational products.
This work-package will produce evaluation products for AGCM with or without representation of large basins (collaboration with WP4.2.2 & 4.2.3). It will also produce estimates of fresh water yields to the Gulf of Guinea, to be compared to observational data (some gauging station near the major river outlets) (collaboration with WP2.2).

***Foreseen deliverables***

- Evaluation of operational analyses and reanalyses:
  - Determination of water budget and its error bars for the domains of interest over West Africa at different time scales;
  - Comparisons with existing surface data and satellite estimates of atmospheric humidity, precipitation over land and ocean, evaporation over land and ocean, evapotranspiration, soil humidity;
- Water cycle variability:
  - Diurnal cycle of the water budget, in relation with surface sensible and latent heat fluxes;
  - Better estimations of the recycling ratio and precipitation efficiency;
  - Differences in water budget (global, spatial and temporal patterns) during dry and wet years, and during dry and wet phases of the monsoon: variability of large-scale advection of water, precipitation and evaporation;
  - Role of energy fluxes at the soil-atmosphere interface in the variability

### 1.2.1.b Summary of 2004 progresses

***Contribution CNRM***

A preliminary evaluation of the ECMWF water cycle had been performed, mostly for the summer 2000 period. As an example, Fig. 1.2.1 shows a comparison of the monthly mean 3°x3° averaged precipitation for August 2000 derived from TAMSAT1 (Fig. 1.2.1a) GPCP2 (Fig. 1.2.1b) and ECMWF (Fig. 1.2.1c). The differences between GPCP and TAMSAT products, which both combine satellite and in-situ data (but not necessarily the same, and with distinct methodologies) provides some insight into the uncertainties one may expect from such products. Despite their limitations, their level of accuracy allows some evaluation of the ECMWF product. For instance, they show that ECMWF precipitation does not extend far enough to the North, and that the intensity of rainfall rates is usually too weak except for specific spots where it happens to be much too high (Fig. 1.2.1.d). In addition, we have investigated the realism of the atmospheric water budget

1 TAMSAT : tropical applications of meteorology using satellite and other data.
2 GPCP : global precipitation climatology project.

provided by the analysis. This ongoing work suggests that the tendency of the atmospheric water mass is still too strong at monthly-3°x3° scales, which at least partly results from the uncertainties in physical parametrizations.

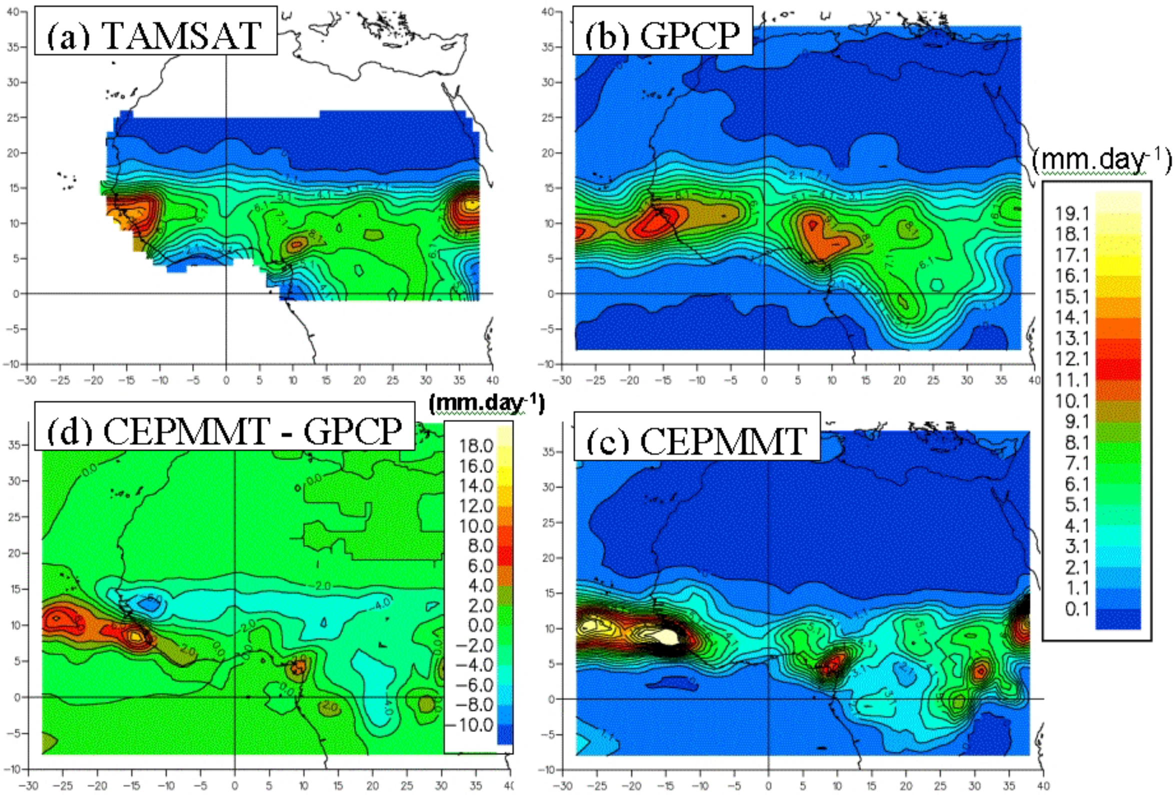


***Figure 1.2.1*** *: 3°x3° rainfall rates averaged over August 2000, from (a) TAMSAT and (b) GPCP products, from (c) the ECMWF analysis and (d) difference between CEPMMT and GPCP rainfall rates. The color table on the right is valid for to (a), (b) and (c).*

## Contribution CRC

An evaluation of water budget in NCEP reanalysis I and II is done for the period 1979-2002 (Fig 1.2.2). The analysis of the seasonal cycle at monthly time scales shows that the NCEP II are most accurate than NCEP I. For example, the first version of the reanalysis is characterized by inadequate moisture convergence in spring over the West Africa area. Three points can be noticed regarding the mean field and associated humidity sources: (i) study water transport only from a meridian point of view is not sufficient because most of the water is transported by the easterly circulation above the monsoon layer, especially by the AEJ in mid-levels, (ii) the Atlantic is not the only moisture source. Water vapor comes also from the Mediterranean basin in low and high levels and is important for the establishment of the moisture convergence; (iii) advection of humidity are not the only source of rainfall for the region because about 28% of precipitation is locally recycled.

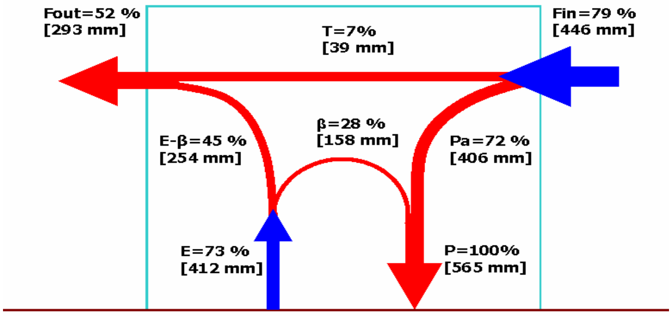


Figure 1.2.2: Estimation of the mean seasonal water cycle over the West African area in JAS for a surface area of about 3.5M.km$^2$. The values are given in percentage of the total amount of rainfall in JAS.

***Publications***

Fontaine B., Louvet S. and Roucou P., 2004 : Intra-seasonal fluctuations in the surface-atmosphere water and heat fluxes over the West African monsoon region, Jour. Geophys. Research, submitted.
Louvet, S., B. Fontaine and P. Roucou, 2004, Intra-seasonal pluviometric modulations in West-Africa : actives phases and pauses., Annual Meeting of the European Meteorological Society.

### 1.2.1.c: 2005 plan

#### *Objectives*

- To pursue ongoing work on the water budget at different space and time scales as estimated from the reanalyses and analyses and to proceed to first comparisons with new expected satellite products (WP4.3 for example better estimates of precipitation)
- To prepare numerical tools to be used for EOP and SOP (MANDOPAS).

#### *Work Content*

- Comparison of moisture convergence, precipitation and evaporation from operational analyses, at various spatial and temporal scales; for the atmospheric water budget, comparison of the accuracy of the closures obtained with the operational analyses and with ERA-40 and NCEP,
- First evaluation with observational products.

#### *Foreseen Deliverables*

- First estimate of the water budget (moisture flux convergence, precipitation, evaporation) and error bars for selected situations and periods, as provided by different analyses (joint with WP 1.1)

## 1.2.2 The water cycle at the meso-scale. ($10^3$ - $10^5$ km²)

*(Coordination: C. Peugeot, F. Guichard)*
*Laboratories : CETP, CNRM, HSM, LA, LTHE, SA*

This scale is central to the WP as it is the best scale for atmosphere and surface integration, as the domain size complies with both hydrologic and atmospheric model capabilities. This Sub-WP is also the one which will beneficiate directly from progresses of WP2.1 and enhanced observations which will be gathered during EOP and SOP.
The proposed methodology is still under discussion, and some adjustments will be brought (dedicated meetings in 2005 with the French and international partners).

### 1.2.2.a 5-year plan

***Objectives***

- Estimate the water budget components (and closure) including the surface and atmospheric parts of the water budget on meso-scale sites at intra-seasonnal to inter-annual time scales. (*CETP, CNRM, HSM, LTHE)*
- Assess the accuracy in the estimation of the terms of the water budget from observations. *(CETP, CNRM, HSM, LTHE)*
- Verify that water fluxes (rainfall, evapotranspiration) at the interface of the atmospheric and continental "boxes" are comparable. (*CETP, CNRM, HSM, LTHE)*
- Special focus on the "memory effect" possibly triggering the monsoon processes. From the intra-seasonal and interannual water budget, estimate the origins of this effect, and related processes (interannual water storage in soil or groundwater).( *HSM, LTHE)*
- Validation of precipitation estimates using instruments of different spatial coverage and model-generated products *(CETP, LTHE)*
- Provide the understanding needed for coupling an atmospheric model with a hydrological model, with adequate parametrisation to improve the representation of the water cycle.(*CNRM, HSM, LTHE)*
- Study the sensitivity of the hydrological response to the spatial and temporal variability of rainfall and to initial conditions, for a given atmospheric budget. (*HSM, LTHE)*

### Methodology

The proposed methodology is structured into three parts: i) atmospheric component of the water budget, ii) surface component, and iii) coupled approach. A preliminary step is the production of rainfall fields, considering that surface vapour fluxes will be produced by dedicated WP 4.1.2.

***Rainfall fields at mesoscale***

Rainfall estimation at mesoscale is central to water budget assessments as it constitutes a forcing field for hydrological models, and a validation or a constraint for atmospheric water budget or satellite-derived rainfall estimates.

Rainfall estimations are based on a synergy between ground observations and radar data (RONSARD, XPort in Benin, S-Pol – USA- in Niger). Raingauge networks provide reliable but punctual measurements whereas radar provides spatial and continuous rainfall estimates, affected by uncertainties due to the conversion of radar signal into rainfall. A locally denser raingauge network ("target") as in the Bénin or Niger sites, associated with disdrometers, allows to calibrate the inversion algorithms and evaluate the uncertainties and the confidence on the quantitative rainfall estimates. On the Ouémé site, synergy between the two Doppler radar Xport (X-band, LTHE) and Ronsard (C-band, CETP) will produce additional informations on rainfall microphysics and structure.

Products of radar and raingauge investigation will include:

- Radar derived high-resolution maps of rainfall for the Donga catchment during the EOP and the estimated uncertainty, to assess the sensitivity of the hydrological response to rainfall variability.
- Statistics on vertical profiles in precipitation and the occurrence of rainfall evaporation.
- Quantification of the rainfall efficiency of the event observed; of the respective role of convective and stratiform precipitation in the area.

- 3D maps of water/ice content to analyse the spatial and temporal variability of their characteristics and their evolution in the season.

Based on these results, co-kriging methods (as those developed at LTHE) using spatial information from radar to interpolate between the raingauges will be applied on the coverage area of the radars to produce reliable rainfall fields (collab with 1.2.4).

***Atmospheric component***

The methodology for this component is based on considerable experience gathered by the French and international community through European and international programmes (EUROCS and GCCS) using observational data from TOGA-COARE and ARM. This part will be also useful to setup case studies to improve water cycle parameterization in GCMs (See 4.1.3).

a) Atmospheric water budget estimates will be derived from observations with variational analysis such as used in COARE and ARM in collaboration with US (see Lin and Johnson 1996, Zhang et al. 2001) and developed at CETP (MANDOPAS). That will involve surface and hydrological components too. Namely, during the SOP, the array of high-frequency sounding data together with profiler and GPS data will allow to diagnose the time- height series of vertical and horizontal advection of water vapor for the mesoscale box, together with time-height series of water vapor tendency. We plan to estimate surface water vapor flux and precipitation from a combination of observations (direct observations, local flux measurements, satellite data) assimilated by land surface and hydrological models (See WPs 4.1.2 and 4.3). Ideally, we would like to rely on surface flux retrievals provided on scales on the order of a few hours and a few kilometers, i.e. an ALDAS (African Land Data Assimilation System) product in the same vein as the one presented by Doran et al.(1998) or Chen et al. (2004) (see also WP 1.3 and 4.1.2). A first evaluation of the water budget will be achieved through the analysis of its closure, as given by different combinations of independent estimations.

b) Cloud resolving model (CRM) simulations (Meso-NH model run at km resolution) will be performed for SOP/EOP selected periods, in using large scale advections (and directly surface heat fluxes in a first step) estimated from method described in a). The selection of periods will be based on methodological/scientific considerations (e.g. sampling of complementary situations rather than duplication of similar ones) and availability of specific data such as Doppler radar, lidar measurements, aircraft data that will be used for validation purpose. In particular, observations from the SOP will allow evaluating the realism of the simulated moisture variability at scales smaller that the mesoscale box. From these simulations, we will infer information on the water budget at smaller scales, and assess the role of acting processes. Typically, we will first concentrate on CRM simulations lasting up to a few days, and using directly observational products as inputs. This framework is particularly well suited for investigations of the mechanisms of surface-atmosphere interactions impacting the water cycle at mesoscale. In a second step to allow coupling CRM with hydrological models at an appropriated time scale, simulations over longer periods will be performed (typical on a period of month). In addition, we also plan to combine this type of simulation in starting directly from NWP analyses (global such as made at ECMWF or on limited region such scheduled with ALADIN/AROME), such as proposed in WP 4.1.3 before (and for preparation of) the SOP. Investigation of the coupling of CRM with a hydrological model is planned, but towards the second phase of the project (~2008) (See below).

c) In order to explore longer time scales, we are planning to use one-dimensional parameterised models3 (a unique GCM column, i.e. discretisation of the box along the vertical axis only). The inputs to these models are similar to the ones adopted for CRM in the paragraph b). The functioning of these 1D models will be assessed with shorter duration explicit CRM simulations, in particular with respect to their water budget. Depending on the duration of these runs, different sources of inputs will be required. Special NWP high-resolution analyses could provide useful constraints too. Despite its obvious interest, specific limitations of this methodology (linked to parameterisations in particular) should not be overlooked when analysing the results that it provides. This activity will be performed closely with work in 4.1.3 dedicated on evaluation and improvement of parameterization.

***Surface component***

Only a few components of the surface water budget can be directly estimated from observations (e.g. rainfall, river outflow), and hydrologic models are required to estimate the remaining terms (ground water and soil storage, evapo-transpiration) in a coherent framework.
The hydrologic models developed and adapted to each meso-scale site in WP 2.3 (STEP for Mali, rwf/abc for Niger, GR4 and POWER for Benin, see model description document) will be used here. They need atmospheric forcing, and produce continental water balance terms (river outflow, storage in soil or groundwater, and evapo-transpiration ETR) at hourly to yearly time scales.
Some of these models still require some developments to fully represent the impact and dynamics of vegetation, and simulate evapo-transpiration (scheduled in 2005).
Water budget closure is intrinsically included in these models, but the relative magnitude of each term has to be validated, in collab with 2.3. Independent evaluation of the resulting budgets will be made using quantities derived from observation (river outflow, ground fluxes stations, geophysical fields produced in WP 4.1.2), or sub-grid water budget simulations from sub-WP 1.2.3.

***Coupled approach***

The proposed methodology follows two complementary tracks.

a) The fast track is to use the existing fully coupled continent-atmosphere approach which has been developed in the framework of the GRID ACI, based on the abc/rwf hydrologic model, the SISVAT surface scheme and the MAR atmospheric model, for sahelian domain. This coupled simulation tool, still under test on the Sirba watershed (38 000 km² between Burkina-Faso and Niger), will be also used in WP 1.3 retro-action studies. The simulation results will be used in the present WP to evaluate the sahelian water budget components with an independent approach.
b) Assuming that the atmospheric and hydrological components as described above(atmospheric and surface components) went through well, a first step will be to compare the various estimates of fluxes at the interface. This activity will be performed during all the duration of project. In a second step, we are planning to couple a CRM (Meso-NH) and hydrological model in using experience gathered in a).

***Links***

The efforts in this sub-WP will allow producing water balance at the spatial and temporal resolution needed for sWP 1.2.1, so as to produce sub-grid validation information. This is done in interaction with sWP 1.2.4 for upscaling issues.

3 These 1D models are the ones that are designed/improved within WP 4.3.1.

**The observation data needed** for these studies include: Radiosoundings, profilers (UHF/VHF), GPS, re(analyses) for large scale advection, Ground and Airborne Doppler radars, lidar, rainfall fields (ground network, radar estimates, satellite products, in collaboration with 1.2.4), latent and heat fluxes (3-4 ground stations on each mesoscale site, airborne fluxes), runoff, water table, soil moisture and vegetation dynamics (ground networks, data from 4.2.3, or satellite products, from 4.3).

***Foreseen deliverables***

- Estimates of atmospheric water budget components with associated uncertainties from the network of enhanced radiosounding, driftsondes, profilers, lidars, radiometers and assessment of the sensitivity to the spatial and temporal sampling
- Estimates of MCS-related water budgets and relations with environmental characteristic as deduced from 2D/3D fields of wind, temperature and water contents (Doppler radars, dropsondes, ..)
- Assessment of the role of various processes on water budget: internal dynamics and microphysics, external influences of wind and humidity profiles, aerosol content
- Quantification of the efficiency of the various types of " rain producing events " in transforming atmospheric humidity into precipitation.
- Maps of soil moisture and satellite-derived evapotranspiration; insight into efficient methods for their evaluation at large scale.
- Evaluation of the continental part of the water budget (rainfall, runoff, drainage, evapotranspiration, surface and underground storage) with associated uncertainties; evaluation of interannual water storage, and impact on inter-annual water cycle ("memory effect")
- Evaluation of water budget closure for the different approaches proposed
- Insight into the impact of vegetation dynamics on the water budget

### 1.2.2.b Summary of 2004 progresses

The impact of the small scale variability of rain on radar measurement has been investigated with a radar simulator (Marielle Gosset, Eric Pascal Zahiri, LTHE). Output field from mesoNH runs over West Africa forced by reanalyses were generated and are now ready to be used as a reference data base for the radar simulator. A rain model that accounts for the stochastic aspect of drop size distribution variability was used for a first sensitivity study. The effect on the retrieval algorithms of the gate to gate variability of the rain drop size distribution has been assessed. The results are encouraging and will lead to the development of a more realistic model for DSD variability.

Mesoscale CRM simulations have been performed for some case studies over West Africa (HAPEX and Jet2000) on large domain (thanks to grid nesting techniques) in including all diagnoses to derive the full budget of water cycle.

Progresses in hydrologic model developments have been achieved (within WP 2.3) and first estimates of water budget have been computed but not yet validated for Ouémé site (Lelay et. al, see below).

A generic platform for coupling atmospheric, SVAT and hydrologic model has been achieved (ACI GRID) and applied to coupled atmosphere-surface simulations on a sahelian domain (Sirba Basin, 38700 km²) with the MAR and ABC. (Messager et al.).

***Publications***

*P. Bechtold, JP Chaboureau, A. Beljaars, A.K. Betts, M. Kohler, M. Miller and J.-L. Redelsperger 2004: The simulation of the diurnal cycle of convective precipitation over land in a global model. Q. J. R. Meteorol. Soc. In press. EUROCS special Issue*

*Guichard F., J.C. Petch, JL Redelsperger, P. Bechtold, JP Chaboureau, S. Cheinet, W. Grabowski, H. Grenier, C.J. Jones, M. Koehler, J.M. Piriou, R. Tailleux & M. Tomasini, 2004: Modelling the diurnal cycle of deep precipitating convection over land with CRMs and SCMs. Q. J. R. Meteorol. Soc. In press EUROCS special Issue*

*Gosset, M., 2004: Effect of non uniform Beam Filling on the propagation of Radar Signals at X-band frequencies. Part 2 : Examination of Differential Phase shift, J. Tech., ,21, 358-367.*

*Gosset M and J Nicol, 2004 : A physically based radar signal simulator to study radar signal statistics, International conference on hydrological applications of weather radar, fev. 2004, Melbourne, Australia.*

*Gosset M and E P Zahiri, JP Lafore and V Gouget, 2004 : Tests of polarimetric alogarithms using virtual radar scans in a mesoscale atmospheric model.Europen Conference on Radar Meteorology, ERAD, 2004.*

*Gosset M and F Cazenave, 2004 : X-port, un radar bande X polarimétrique pour des applications hydro-météorologiques, AEI 2004, Paris.*

*Le Lay, M. and S. Galle (soumis). How changing rainfall regimes may affect the water balance. A comparative approach in West Africa, Soudanian Climate. VIIth IAHS Scientific Assembly, Foz do Iguacu, Brasil, IAHS Publ.*

*Le Lay, M., S. Galle et Lebel, T. (soumis). Caractérisation des variabilités interannuelle et intrasaisonnière de la mousson africaine en zone soudanienne aux échelles hydrologiques. Subm. To Journal des Sciences Hydrologiques.*

*Messager C., Gallée, H., Brasseur O., Cappelaere B., Peugeot C., Séguis L., Vauclin M., Ramel R., Grasseau G., Girou D., Leger L. (en préparation) A fully coupled Regional Climate experiment between atmosphere and continental processes applied to the West African Monsoon. Part I: The atmospheric forcing reference experiment over West Africa and the hydrologic modelling forcing reference experiments of the SIRBA basin.*

*Roca, R., S. Louvet, L. Picon and M. Desbois, 2004, A study of convective systems, water vapor and top of the atmosphere cloud radiative forcing over the Indian Ocean using INSAT-1B and ERBE data, Meteorology and Atmospheric Physics, à paraître,.*

*Zahiri, E.P., Gouget, V. et Lafore, J.-P. 2003: Analyse à petite échelle de systèmes convectifs ouest-africains : notion de pluies évaporatives (structure et bilan d'eau), Ateliers de Modélisation de l'atmosphère, 3-5 décembre 2003, Toulouse (France), pp 223 - 226.*

### 1.2.2.c 1-year plan (2005)

#### *Objectives*

The objective of the one-year plan is to prepare and test the tools, methods and data applied to water budget assessments.

As SOP data are essential to produce water balance estimates, year 2005 and partly 2006 will be dedicated to preliminary studies and preparation. Ensure that the observations and models available allow fulfilling the WP objectives. This will be achieved in technical meetings where methodological details will be presented and discussed.

***Work content***

***Rainfall fields***

Analysis of the uncertainties in the radar derived 3D water content and rainfall estimation using output from (mesoNH) and a radar simulator will be made, as well as analysis of disdrometer (present and historic) data to pre-tune algorithm and evaluate uncertainties in radar measurement. The quality of atmospheric water budget retrieval – sensitivity analysis to measurement errors, radar positions and scanning strategy, will be assessed. Simulations such a the one done to assess XPort QPEs will be extended to analyze the usefulness of a network of 2 radars (Xport and Ronsard) and the analysis will include retrieval of the terms of the atmospheric water budget using the MANDOPAS analysis.

***Atmospheric component***

As a preparation to the SOP, we will use mesoscale CRM simulations as performed during 2004 on some case studies to derive and analyse time-height series of the moisture budget terms, including large scale advections, convective, microphysical and surface processes (link with WP 4.1.3, inputs for 1D parametrized models).

***Surface component***

The main actions will focus on

a) model developments and validation to fully simulate meso-scale water cycle processes: SVAT and groundwater module for rwf/abc, dynamical vegetation for rwf/abc and POWER, validation of STEP parametrization. These actions are shared with 1.2.3 and 2.3.
b) prepare tools to evaluate errors in model simulations : use of the radar simulator with the mesoNH fields and /or output from a stochastic rain simulator, to evaluate error bars in rain field for different time/space resolution ; propagate these errors in hydrological models and determine the impact of on the water budget, and their dependence on the scales.
c) prepare meso-scale evapotranspiration data using field and satellite observations and Land Data Assimilation (ALDAS in 4.1.2)

Based on these results, preliminary estimates of meso-scale surface water budget with the available model versions will be produced.

***Coupling approach***

Simulations with MAR/ABC will be further exploited, to produce results on water budgets. The technical framework (generic coupling technique) suggest that other applications such as coupling a CRM (Meso-NH) with a hydrologic model can be envisaged. Considerations on this point will be engaged in 2005.

***Foreseen Deliverables***

- Preliminary assessment of radar estimation expected quality for the Ouémé region rainfall.
- Determination of meso-scale rainfall and runoff data from observations,
- Determination of atmospheric water budget terms for one or two precipitating convective events as simulated from CRM on a 1 day period.
- Evaluation of storage terms (soil and groundwater) from observation data and process-based models,
- First estimates of the components of the continental water cycle on meso-scale sites for recent years
- First results on impact of vegetation on water cycle from observational data

### 1.2.3 The water cycle at the local scale (1-10 km²)

*(Coordination: C. Peugeot)*
*Laboratories : CETP, HSM, LTHE*

This Sub-WP focuses on the development, test and validation of hydrologic models or parametrizations to be used at the meso-scale, in collab. with 2.3, using high resolution data on super-sites of AMMA field experiment (WPs 4.2.2 & 4.2.3).

#### 1.2.3. a 5-year plan

***Objectives***

- Understanding of the combined effects of local processes on the hydrological budget at the small catchment scale, including interactions of land cover and vegetation dynamics and the water cycle. (HSM, LTHE)
- Test and validation of models and parametrizations developed in 2.3 to be used for meso-scale water budget studies (HSM, LTHE)
- Validation of water balance components (and error estimation) on super-sites (watershed scale), including :
  - partition between fast and delayed responses of the river, and impacts on water budget
  - storage processes possibly responsible of memory effect (ground water, unsaturated zone, vegetation)
  - assessment of deep infiltration (sink) and evaporation (feedback) terms so as to be able to close the water balance of small watersheds.
  - Evapotranspiration (comparison with flux products : ground station, airborne, satellite; links with 4.1.2, 4.2.3 and 4.3)
- Sensibility of model outputs to forcing (rainfall) and parameter uncertainties (CETP, HSM, LTHE)
- Assessment of the impact of vegetation dynamics (intra-seasonnal and inter-annual) on the water budget (HSM, LTHE)

***Methodology***

The hydrological models to be used are the same as those used at the meso-scale : STEP, rwf/abc, GR4, POWER. Some developments and tests are needed, to secure a fully simulation of the surface water cycle (in collaboration with sWP 2.3). High resolution variables are used to force (rainfall from ground network and radar), or validate/evaluate the model results (data from ground fluxes stations, river outflows, water-table levels). Three to four flux stations will be deployed on each super site as from early 2005 (collaboration with 4.2.3 and 2.3).

Assimilation of remote sensing data (surface temperature, soil moisture, evapotranspiration from MSG, SPOT or ENVISAT data) is envisaged to improve model simulations of the water balance and constrain surface variables.

The robustness of model parameter estimation and the associated uncertainties will be assessed using sensibility analysis and multi-criteria and/or Bayesian methods. Propagation of uncertainties on input data will be studied, particularly for rainfall fields for which estimation errors will be produced (radar algorithms and raingauge data).

***Foreseen delivrables***

- Evaluation of the sensitivity of the water budget to the spatial resolution of rainfall using rainfall ground and radar data set: insight into the rainfall scaling issue (link with 1.2.4).
- Characterisation of the small-scale variability of boundary layer humidity, in relation with soil humidity and vegetation.
- Characterisation of the high-resolution spatial and temporal patterns of rain fields; derive statistics on the 3D structure of rainfall events.
- Implementation of the components of the hydrologic models necessary for a coupling with the atmosphere.
- Evaluation of the degree of accuracy in the water budget closure at catchment scale; propagation of input data errors and quantification of simulation errors in hydrological models.
- Evaluation of the influence of rainfall spatial and temporal variability on the hydrological response and continental water budget.
- Estimate of evaportanspiration at local scale; Maps of soil moisture and evapotranspiration (with 4.1.2 and 4.2.3)
- Assessment of the impact of small-scale land cover and vegetation dynamics on the water budget.

## 1.2.3.b Summary of 2004 progresses

Progresses mainly concern model development (see WP 2.3) : vegetation scheme included in rwf/abc ; test and validation of a simplified version of Power. Applications to water budget have not yet been made.

## 1.2.3.c 1-year plan (2005)

***Objectives***

- Tune algorithms and assess uncertainties in radar estimation, for the targeted region. Choose best scanning strategy.
- Progresses on the development and tests on hydrological models.
- Set up of ground observation data base (recent years, i.e. LOP and pre-LOP periods) for model operation
- First -and raw- estimates of small-scale intra-seasonal and interannual water balance for recent years.
- Work content
- Analysis of the uncertainties in the radar derived 3D water content and rainfall estimation using output from a atmospheric mesoscale model (mesoNH) and a radar simulator
- Analysis of disdrometer (present and historic) data to pre-tune algorithm and evaluate uncertainties in radar measurement.
- Development of the POWER model to include new processes or processes crudely represented into the model; improvement of the lateral flow component in the POWER model; application to the Donga river basin using remote sensing data to characterize surface parameters (soil moisture, vegetation maps, LAI, surface temperature)
- For the sahelian catchments: validation of the deep infiltration scheme (aquifer recharge); validation of the vegetation-hydrology interaction scheme.
- Sensitivity and Uncertainty analysis of model outputs
- Evaluation of the simulated components of the water balance using existing data from recent years (streamflow, groundwater level, soil moisture)

***Foreseen Deliverables***

- Pre-tuned and operational algorithms for the radar rainfall estimation over the Donga basin and estimation of the uncertainties; pre-tuned and operational algorithms for the estimation of the 3D water content at local (Donga) scale and vertical profiles.
- Evaluation of the POWER model concept (Donga catchment).
- First estimation of the water balance components (evapotranspiration, streamflow, groundwater flow, soil water storage) on the pilot catchments; with quantification of uncertainties.

## 1.2.4 Scaling issues in the West African Monsoon.

*(Coordination: N. Hall)*

### 1.2.4.a 5 year Plan

***Objectives***

- Analysis of the scaling properties of rainfall and other variables playing a key role in linking the climate variability and the water cycle.
- Characterisation of the links between large scale meteorological fields and small scale rainfall properties.
- Development and validation of rainfall disaggregation algorithms.
- Cross calibration of precipitation estimates using instruments of different spatial coverage and model-generated products.
- Paramerization of hydrological processes from local scale analysis to provide tools to upscale the water budget at the meso-scale

***Work content***

At the impact scale, many physical systems, particularly hydrological systems are very sensitive to the statistics of precipitation events. Changes not only in totals but also in distributions both in space and time can have a significant effect. Downscaling and disaggregation is thus of critical importance for impacts on water resources, vegetation production and health. A complementary approach is proposed here, working with both physical and statistical models and using a variety of data and observing platforms.

Budget studies of water and energy differ greatly according to the scale considered. A basin scale hydrological budget will be governed by different processes from those controlling the continental water cycle. Continental budgets are therefore sensitive to the types of measurements used, and a consistent strategy for integrating, or upscaling local measurements of precipitation and evapotranspiration must also be found. Consistency will be sought between local scale in situ and radar measurements and the integrated estimates provided by satellites and model-generated and reanalysis products.

Data analysis: data collected on different scales by different observing systems is to be collated and analysed for its spatiotemporal properties. Basic information about the structure of rainfall will then be used in statistical disaggregators to produce simulated fields from larger scale indicators. Widely separated study areas will be used to compare properties over differing terrain.

***Methodology and sampling issues***

A variety of instruments will be used to provide information on rainfall structure at all scales, from the 1mn drop size spectra derived from disdrometer measurements to satellite imagery. Methodology to analyse and compare the characteristic time and spatial scales derived from these various instruments will be developed and assessed.

- Analysis at local scale to provide information for disaggregation: using radar, raingauge, and disdrometer data available on the Donga site during the EOP: correlation analysis of the 3D structure of precipitation from radar data to find characteristic time and space scales; cell recognition and tracking with statistics of their dimensions and life cycle; analysis of rain drop spectrum from disdrometer data in coordination with the radar imagery.
- Large scale physical/statistical downscaling: a two-step strategy is envisaged to produce local precipitation indices from large scale indicators. Analysed dynamical and thermodynamic features of the monsoon will be first linked to satellite-derived statistics of mesoscale rain-generating systems, and then further downscaled to provide statistical moments of local rainfall variability. Statistical methods to be tested include canonical correlation analysis, analogues and neural networks. However, experience shows that the correct choice of predictor and predictand variables has more influence on the result than the precise details of the statistical method. For the west African region dynamical indicators based on temperature, humidity and the large scale divergent flow will be tested in relation to discrete information on the number density and genesis density of mesoscale convective systems derived from satellite images. It is also potentially interesting to include dynamical and budgetary constraints in the statistical filter. The relation between MCS events and rainfall statistics has been the subject of previous investigations and these results need to be adapted into an appropriate empirical model, targeting the moments of the rainfall distribution that control the hydrological response.
- Small scale pure statistical disaggregation: once the relevant statistical moments of spatiotemporal variability have been produced, a purely statistical approach will be used to generate rainfall products that can be used for impact studies. This follows directly from the work that has been carried out over the last few years at LTHE on desegregation modeling of MCS-related rainfall taking into account the characteristic shape and propagation of rainfall events. Applications include hydrological, agronomic and epidemiological models.
- Rainfall measurements and hydrological budgets: assessment of controlling factors including regional variations in the integration of precipitation and evapotranspiration from local measurements to continental budgets.
- Surface fluxes and physical processes at the land surface: the representation of surface fluxes at the resolution scale of a regional or global model should take account of scale disparities and aggregation nonlinearities in state variables and surface fluxes.

**Foreseen deliverables**

- Documentation on the characteristic scales, life cycles and trajectories of rainfall ‘objects’, from the smallest convective cells to the MCS.
- Documentation of regional and seasonal variations of the scaling properties of rainfall (from Sahelian and Sudanese observations).
- Downscaling rules from statistical models to link monsoon dynamics with regional rainfall statistics.
- Disaggregated local rainfall products to be used by impact models (Water resources, Vegetation and crop models, Vector born diseases).
- Progress in disaggregation algorithms at all scales for use in further studies including interactive climate system studies.

- Cross calibration of rainfall estimates on a variety of scales.
- Coordination of hydrological budget studies between local and meso scales.
- Scaling characteristics to be used for model parametrisation and for model validation (most notably models used to close the water budgets and surface fluxes).
- Comparisons between water budgets and fluxes derived from upscaling (from individual rain events to continental budget) and from downscaling (disaggregation of large-scale modelled and observed fields).

### 1.2.4.b Summary of 2004 progresses

Preliminary steps have been taken in the analysis large scale flows over west Africa and their linkage with MCS event statistics. Multivariate analysis of a range of dynamical fields has yielded time series of indicators of the state of the WAM. These have been compared with time series of indicators of area integrated MCS statistics, including occurrence and genesis. Key areas of MCS genesis have been identified that impact rainfall over the region and some analysis has been done on the difference between wet and dry years (Abdou Ali, LTHE). This work is not yet mature and further work needs to be done to reach downscale with this analysis and settle on a statistical method. This will be pursued in a DEA study which will hopefully lead to doctorate work.

### 1.2.4.c 1-year plan (2005)

#### *Objectives*

The initial stage of the work will mainly be oriented towards the definition of methods and the collection of the necessary datasets and/or model output.

#### *Work content*

- Basic assessment of information about the structure of rainfall to be used in statistical disaggregators to produce simulated fields from larger scale forecasts.
- Large scale physical/statistical downscaling: definition of a two-step strategy to produce local precipitation indices from large scale indicators. Assessment of statistical methods to be used and most effective predictor/predictant variables between large scale flow and MCS tracking statistics (projected DEA study of Clement Suavet, LTHE).
- Small scale pure statistical disaggregation: definition of the relevant statistical moments of spatiotemporal variability needed to generate rainfall products that can be used for impact studies.
- Set up the tools for scale and structure analysis of rain from radar data. The data will be provided during the EOP in the Donga region, and SOP in the Niger and Ouémé region.
- Radar simulations will be advanced by making use of drop size distribution measurements gathered with a disdrometer in Ivory cost and Niger in recent years. These will be used to analyze the DSD variability at several scales and this information will feed the parametrization of DSD in radar simulation studies using the coupled mesoNH / radar simulator set described in1.2.2. It also represents a first step for the multisensor analysis of the scaling properties of rain.

#### *Deliverables*

- Report on choices to be made associated with possible statistical downscaling methods.
- Initial derived statistical relationships between monsoon dynamics with regional rainfall statistics.
- Advancement of parameterisations for drop size distribution variability.