2.3 Physical and biological processes over land surfaces

Laboratories : CESBIO, CETP, CIRAD, EEF, ENS-Ecologie, ESE, GEOVAST, HSM, LA, LMD, LSCE, LTHE, Sisyphe
Coordinator: E. Mougin

General objectives

This Work-Package (WP) aims to study the physical and biological surface processes over West-Africa and is split into three interrelated sub-WPs which will specialize on the local- and meso-scales of surface processes. The two first sub-WPs focus on the hydrological and biophysical processes occurring at the local scale (**WP 2.3.1** and **WP 2.3.2**) while the third one (**WP 2.3.3**) focuses on the water and energy balance and vegetation dynamics at the mesoscale. Upscaling methodology to the regional scale is also investigated.
Among the surface processes under consideration, emphasis is put on *evapotranspiration* which is the most important process coupling the physical, biological and hydrological processes occurring at the continental surface. It is also the term of the water budget responsible of the surface retroaction to the atmosphere, since evapotranspired water then enters the regional atmospheric circulation. It is also the most poorly measured and understood term of the water budget. **The main scientific objective of this WP is therefore to better understand, model and predict temporal and spatial variations of evapotranspiration in a bottom up approach integrating all the physical, biological and hydrological processes involved.** The water output of land surfaces (vegetation and soil) to the atmosphere through evapotranspiration depends on the main pathway of water circulation within the soil. In West Africa, two major systems exist: In Sahel, the aquifer is disconnected from the topsoil because of its depth, and two kinds of plants coexist: a) plants relying on surface water, active only during the wet season; and b) plants able to uptake deep water from the water table and possibly active during the dry season. The study of these 'disconnected' water table systems constitutes **WP 2.3.1**. In the Sudanian and Guinean zones, the water table directly interacts with the unsaturated topsoil, and sometimes reaches the ground level. In these systems, various plant phenological types can coexist and produce complex transpiration patterns along the year. Particularly, plants able to extract deep water could be responsible of the observed '*memory effects*'. The study of these 'connected' systems constitutes **WP 2.3.2**. The extrapolation of the hydrological, physical and biological process studies to a larger scale, where important feedback to the atmosphere can be computed, will constitute **WP 2.3.3**.

- **WP 2.3.1 : Process studies at the Sahelian local intensive sites and super-sites :** the main objective is to understand coupled biological and hydrological processes at a local scale in sahelian pastoral (Mali) and agro-pastoral (Niger) zones.
- **WP 2.3.2 : Process studies at the Sudanian local intensive sites and super-sites :** the main objective is to understand key processes of the water balance for selected catchments and to understand the response of vegetation to environment constraints in a sudanian environment (Benin).
- **WP 2.3.3** : **Land-Surface Processes at the Mesoscale, with a View to Regional Upscaling :** the main objective is to understand vegetation phenology, water and energy fluxes at the meso-scale through the analysis of data collected over the different sites and modelling.

Understanding, modelling and predicting plant phenology (i.e. the seasonal cycle of LAI and biomass) is the key issue of the study of these systems to correctly predict the evapotranspiration cycle along the year. **Most process studies will focus on integrating the numerous ecological processes (carbon assimilation, water uptake and release, vegetation growth and decay,**

coupled C/H2O/N cycles,…) responsible for the phenological cycle. Moreover, water transpiration is closely linked to CO2 assimilation through the stomatal control by plants. This coupling is simulated in most current SVAT models. The water extraction strategy and the phenological cycle of plants will be used to define major plant functional groups and water fluxes will be simulated for each group.
Besides, west-african ecosystems contribute a significant fraction to global biogeochemical C and N cycling. Biogenic emissions of NOx by soils, Biogenic Volatile Organic Compounds (BVOC) by woody vegetation, as well as wet and dry surface deposition control tropospheric ozone, particle formation (aerosols) and gas concentrations. Biogenic emissions are linked to meteorological and surface characteristics such as soil moisture and temperature (NOx), phenology and plant water stress (BVOC) whereas dry deposition fluxes are largely dependant on land use covers. This **WP aims to provide a better parameterization linking biogenic emissions and surface characteristics at local and meso scale.** As well, **this WP aims to investigate key processes that regulate deposition in connection with surface parameters**.

The following scientific questions will be addressed in this WP:

- What are the diurnal/seasonal/interannual variations of water and energy fluxes from local to meso-scale?
- How do physical and biological surface processes control water and energy fluxes?
- What is the role of land heterogeneity on water and energy fluxes?
- How does the vegetation control water and energy fluxes?
- What is the role of vegetation on the 'memory effects'?
- How are biogeochemical cycles controlled by land surface processes, and what are the feedbacks of surface processes on these cycles (water, CO2, nitrogen, tropospheric chemistry, aerosols)?

Work content

To reach these objectives, field measurements must be performed and coupled hydrological, vegetation dynamic and biogenic emission models developed and tested. Communication between data providers and modellers will be organised and common data standards defined in connection with ***WP 4.1.2***. Furthermore, development of up-scaling algorithms is essential for going from local scale models to meso-scale and regional scale models.

Observation Strategy

Field observations are conducted over the 3 meso-scale sites identified by the '*ORE-CATCH*' in Benin, Mali and Niger and monitored since 2002 within the frame of the LOP activities (**WP 4.2.3**). WP 2.3 will focus on understanding various processes leading to the generation of water, carbon, NOx, COVB and energy fluxes at the catchment scale (in the order of 1-10 km^2) and investigate how it relates key processes at the meso scale (in the order of 10,000 km^2). Investigation of key processes of vegetation functioning and dynamics and partly also for stream flow (or runoff) generation will focus, in Mali, on the Agoufou local intensive site (1 km^2) and Hombori supersite (25 x 25 km^2), in Niger, on the Wankama catchment (2 km^2) and in Benin, on the Ara catchment (15 km^2). Processes involved in water surface redistribution strongly depend on the rainfall regime. Direct runoff conditioned by soil surface features and rainfall intensities is preponderant in sahelian countries (Mali, Niger) whereas subsurface water and groundwater drainage supply the rivers in wetter countries (Benin). Hydrological process studies will be therefore combined with studies on vegetation dynamics for different scales and rainfall regimes. At meso-scale, the WP will rely on the monitoring of selected catchments or regions that are already under investigation, namely the upper Ouémé catchment (Benin, 14 600 km^2) with an additional focus on the Donga sub-catchment supersite (600 km^2), the Kori de Diantiandou catchment (Niger, 6000 km²) and the Niamey's square degree (Niger, 12 000 km^2), and the Gourma region (Mali, 30 000 km^2).

In south-western Niger, the lowest parts of valleys are occupied by a myriad of seasonal ponds that collect the runoff from the hillsides. Runoff is confined to small scale endoreic catchments. Pool water evaporates but most of it percolates to the regional aquifer. Due to its depth (20-60 m below ground level), groundwater return to the atmosphere is limited. Studies will be performed to identify deep infiltrations zones (gullies along hillside, bands of dense vegetation - tiger bush on plateau-) on which water is subtracted from the general surface water cycle.

In Gourma, the Agoufou local intensive site represents the landscape elementary unit for surface water cycle in arid zone (a series of dune slopes with depressions at bottom). Associated with vegetation measurements, soil water dynamics will be monitored and deep infiltration will be investigated to close the water budget.

In Sudanian regime (Upper Ouémé, Benin), river flow is provided by direct runoff (Hortonian or saturation overland flow) but also by subsurface flows (perched saturated zones or deep grounwater). Therefore, studying interactions between soil water and vegetation is fundamental. Natural vegetation can be classified at the first order according to the tree/grass ratio. Catena is the landscape elementary unit for mechanisms which govern the flow production in Sudanian zone. Three catena representatives of the main land covers over the region (young fallow, savannah and forest) are instrumented to close local water budgets.

Interaction between the water cycle and Carbon /N turnover will be assessed by measurements of C, N and water vapour exchange as well as the radiation balance. Emphasis will be put on the spatial (covering the whole latitudinal climate transect) and temporal (seasonal with a focus on the transition between dry and wet seasons) variability of these processes. Surface/atmosphere exchange will be measured by micro-meteorological methods using flux stations. Ecophysiological control parameters (CO2/H2O exchange, canopy absorbed PAR, leaf conductance, …) will be determined using a mobile leaf enclosure system. Flux spatial variability at the intensive site scale will be investigated through scintillometry measurements and related to airborne and boundary layer measurements.

Since soil moisture drives the different processes, additional emphasis will also be put on the characterization of the temporal and spatial variation of soil moisture content at different scales. Vegetation dynamics will be monitored with focus on dependency of water stress and soil moisture availability using biomass, LAI measurements and plant species distribution assessments. In addition to water vapour flux measurements, in situ transpiration (sap-flow) measurements on the main tree species will be performed. Models will be evaluated with these new data sets. Interaction between runoff and the vegetation dynamic will be analyzed. Sensitivities of runoff to vegetation growth (and vice versa) will be tested for different land covers.

Modelling Strategy

Process oriented land surface models will be possibly developed and applied for the hydrosphere-biosphere-atmosphere exchange. Biological models will be jointly run with SVAT models and distributed hydrological models. Coupled models will be tested against ground data (vegetation, surface fluxes, soil moisture,…) that will be acquired on the three local intensive sites in Benin, Mali and Niger. Water, energy and CO2 flux stations will be deployed on the different intensive local sites. Associated with micro-meteorological, field and satellite measurements, these will provide essential data for model testing from local- to meso-scale. A forcing database for the land surface models will be developed in collaboration with **WP 4.1.2**. This will imply to test the consistency of the data base at different scales. The spatialisation of local models and the control of their simulated outputs will be performed through the development of assimilation procedures of multispectral satellite data. Final outputs will be spatialised evapotransipration fields.

The following land surface models will be used at different scales in this WP:

Name	Type	Scale of applicability
ABC and abc-rwf	Hydrological model	Local to meso-scale
GR4j	Hydrological model	Local to meso-scale
POWER	Hydrological model	Local to meso-scale
REW_v4.0	Hydrological model	Local to meso-scale
IBIS	Vegetation model	Meso to regional scale
SARRA-H	Crop model	Local scale
STEP	Vegetation model	Local to meso-scale
TGPIX	Vegetation model	Supersite scale
TREEGRASS	Vegetation model	Local scale
SETHYS	SVAT	Local to regional scale
ORCHIDEE	Land surface model	Local to regional scale

Data required
Observations needed from Satellites (WP 4.3)

- Satellite derived land-surface maps for the 3 meso-scale sites
- Validated satellite derived land surface products (LAI, tree cover, surface soil moisture,…)

Observations needed from the instruments and field campaigns (WP 4.2.3)

LOP Instruments

Code	Instrument	Site	PI	Laboratory
AL.Met_G	Campbell meteorological station	Mali	F. Timouk	CESBIO
AL.Met_Nc	Campbell meteorological station	Niger	L. Descroix	LTHE
AL.Met_Od	Campbell meteorological station	Benin	S. Galle	LTHE
CL.Rain_G	Automatic rainfall gauges (8)	Mali	F. Lavenu	CESBIO
CL.Rain_N	Automatic rainfall gauges (30)	Niger	T. Lebel	LTHE
CL.Rain_O	Automatic rainfall gauges Upper Oueme (30)	Benin	C. Depraetere	LTHE
CL.Rain_Od	Automatic rainfall gauges Donga (18)	Benin	L. Le Barbe	LTHE
CL.Run_O	Flow gauging stations, Upper Oueme (12)	Benin	C. Peugeot	HSM
CL.Run_Od	Flow gauging stations Donga, (6)	Benin	L. Séguis	HSM
CL.Pond_Nc	Network of 6 level recorders on ponds	Niger	B. Cappelaere	HSM
CL.Gwat_N	Network of 178 measured wells	Niger	G. Favreau	HSM
CL.Gwat_Od	Village wells Donga (22)	Benin	L. Seguis	LTHE
CL_Depot.RW	IDAF Stations (5)	WA	C. Lacaux-Galy	LA

EOP Instruments

Code	Instrument	Site	PI	Laboratory
AE.CO2_G	Tethered balloon	Mali,Benin	L. Kergoat	CESBIO
AE.Flux_G	Flux stations (4)	Mali	F. Timouk	CESBIO
AE.Flux_Nc	Flux stations (4)	Niger	B. Cappelaere	HSM
AE.Flux_Od	Flux Stations (4)	Benin	S. Galle	LTHE
AE.Van_Od	Chemistry Laboratory Van	Benin	D. Serça	LA
CE.SW_G	Soil moisture stations (9)	Mali	P. deRosnay	CESBIO
CE.VegSoil_G	Vegetation instruments	Mali	J. Seghieri	CESBIO
CE.PAR_Ga	fPAR measurements	Mali	V. Demarez	CESBIO
CE_Sap_Ga	Sap flow stations	Mali	V. Ledantec	CESBIO
CE.Rain_Nc	Network of 50 raingauges	Niger	L. Descroix	LTHE
CE.Run_Nc	Network of 9 recording streamgauges	Niger	L. Descroix	LTHE
CE.SW_Nc	Soil moisture monitoring station	Niger	B. Cappelaere	HSM
CE.SWsan_Nc	Soil water neutron probe	Niger	L. Descroix	LTHE
CE.Veget_Ncw	LiCOR LAI 2000 and LiCOR 6400	Niger	N. Boulain	LTHE
CE.Gwat_NC	Level recorders in boreholes (aquifer)	Niger	G. Favreau	HSM
CE.Wchem_O	Water chemistry Upper Ouemé	Benin	C. Peugeot	HSM
CE.Wchem_Od	Water chemistry Donga	Benin	L. Séguis	HSM
CC.geophy_odc	Geophysical electrical surveys	Benin	H. Robain	GEOVAST
CE.Run_Odc	Gullies gauge stations (catena)	Benin	L. Séguis	HSM
CE.Gwat_Odc	Piezometers (27) (catena)	Benin	L. Séguis	HSM

CE.SW_Odc	Soil water (catena)	Benin	S. Galle	LTHE
CE.Veg_Odc	Vegetation surveys (catena)	Benin	J. Seghieri	CESBIO

Field Campaigns

Code	Instrument	Site	PI	Laboratory
C.Geophysi_Od	Superficial geophysical survey	Benin	H. Robain	GEOVAST
C.Scintil_Od	Scintillometry	Benin	J.M. Cohard	LTHE

Links to other WPs

The strong ties to other WPs are highlighted in the following table:

1.2	Water Cycle	A better understanding of land surface processes at the local and the meso-scales is essential for modelling the water cycle. Hydrological models developed in 2.3 are used to calculate surface water budget in 1.2.
1.3	Surface-atmosphere feedbacks	Feedbacks to be taken into account in order to understand persistency in rain fields, ETP fields; also for modelling. Key role of soil moisture and groundwater in these feedbacks. Pathway for possible memory effects.
2.4	Aerosols and chemical processes in the atmosphere	Links between vegetation dynamics and emission/deposits of chemical species.
3.	Impact studies	Influence of land surface processes (especially the link between vegetation and runoff) on water and food resources.
4.1.2	Model evaluation	Hydrological & vegetation modelling activities; improved land-data assimilation system
4.2.3	Field campaigns	Need EOP/LOP observations at various scales. Airborne POLDER measurements of the land surface during SPO-0 and SOP-1.
4.3	Satellite remote sensing	Need satellite products at the local, intensive and meso-scale sites as a vital middle step in the up-scaling to the regional scale.
4.4	Data base and historical data	User-friendly consistent databases to provide input and validation data for modelling.

2.3.1: Process studies at the Sahelian local intensive- & super-sites

Laboratories : CESBIO, CETP, CIRAD, EEF, ENS-Ecologie, ESE, HSM, LA, LTHE.

Coordinators: B. Cappelaere, L. Descroix

2.3.1a 5 year plan

Objectives

- Understand the key processes involved in the sahelian hydrological processes (runoff generation, unsaturated zone dynamic, groundwater dynamic and deep drainage) from local to supersite (Wankama/Tondi Kiboro, Agoufou to Kori de Diantiandou catchment) i.e. at the scale of hillslope and small catchment.
- Understand the response of vegetation to environmental constraints in terms of phenology and water extraction strategy for the main identified plant functional groups at seasonal and interannual temporal scales.
- Understand surface energy balance for a sahelian landscape through the analysis of flux station data.
- Estimation of temporal and spatial *EvapoTranspiration* variability at different scales.
- Understand the determinants of the spatial and temporal variations in BVOC and N oxides emissions and develop new parameterizations.

- Characterising the seasonal variation of atmospheric aerosols for the sahelian ecosystems.
- Develop and test coupled physical and biological models describing the coupled C/N/H2O cycles.
- Run coupled hydro/vegetation models for plausible land-use and climate scenarios to test process responses to variations in system forcings.

Work content

Observation Strategy

- Design and implementation of experimental setup at local (point and catchment scales) hydrology/vegetation monitoring sites. Particularly, this includes the deployment of water and energy flux stations.
- Field and model studies to identify aquifer recharge locations (ex.: hillside gully network or pools, alluvial fans, etc…).
- Identifying groundwater recharge zones using measurements in the unsaturated zone (solute content, subsurface geophysics) at the local scale.
- Applying geophysical methods to delineate changes in groundwater storage at the seasonal and interannual scale below infiltrating zones, and comparison with estimates based on hydrological (surface) estimates
- H2O/CO2/NOx/COVB exchange measurements at the soil and vegetation levels. Ecophysiological measurements on plants with the objectives of characterising the effects of environmental forcings on water uptake and release.
- Inferring night time CO2 flux from concentration profiles and daytime H, LE, CO2 fluxes from CBL budget at the supersite scale with a tethered balloon.
- Identify vegetation functional groups in terms of phenology, water extraction, and ecophysiology.
- Measurements of the seasonal variation of atmospheric deposition including both wet and dry processes.
- Measurements of relevant hydrological and vegetation variables within all catchments and local sites, in order to provide an overview of water and vegetation processes with various degrees of resolution and spatial coverage, and to provide reliable, consistent data for model formulation, validation, calibration, and operation.

Modelling Strategy

- Refine and test model formulations for local-scale elemental hydrological and biological processes.
- Upscale plot-scale vegetation model components to local, catchment scale and couple with distributed hydrological model.
- Modelling of BVOC and N oxides emissions versus meteorological and surface parameters.
- Analyse the seasonal variations of the deposition fluxes in relation with the surface parameters (vegetation types, soil classes, water soil content,...) using both measurements and numerical simulation.

Foreseen deliverables

- Vegetation, soil and land cover maps for the local intensive- and super-sites (Mali, Niger).
- Field measurements (vegetation, soil moisture, surface fluxes, biogenic emissions, wet and dry deposition, runoff, piezometric heads) at the Agoufou/Hombori (Mali) and Wankama (Niger) sites.

- Data base of input parameters for vegetation and hydrological models.
- Identification of interactions between water cycle, plant phenology and C/N/H2O/COVB turnover, and wet/dry deposition.
- Validated hydrological models for local-scale sites in Niger.
- Validated coupled hydrological and biological/vegetation dynamic models at the local and supersite scales (Mali, Niger).
- Validated coupled Vegetation - SVAT models.
- Evapotranspiration fields at various temporal and spatial scales (from local- to meso-scale).

2.3.1b 2004 Achievements

Observation Work

- Design of experimental set-up for observations of the physical and biological processes. Two meetings held in France and Niamey for the participants of the Niger site (**CETP, HSM, LTHE, ENS**).
- Installation and test of equipments in the field. In situ calibration of new equipments for the Niger sites and for the Malian site. This includes soil moisture and meteorological stations (**CESBIO, HSM, LTHE**)
- Erosion/Sedimentation field campaigns over the Dantiandou super site (**LTHE**).
- Field campaigns devoted to the cartography of soils and vegetation. Identification of plant functional groups for the Gourma site (**CESBIO**).
- Herbaceous vegetation (LAI, biomass, vegetation cover) and tree phenology monitoring at meso-scale during the wet season for the Gourma site, Mali. (**CESBIO**).
- H2O and CO2 gas exchange measurements at leaf level for the main plant species at the Agoufou intensive local site. Ecophysiology measurements at the leaf level. Measurements of the daily temporal variation of water potential for the main tree species (**CESBIO, ESE**).
- Soil CO2 and H2O fluxes using portable chambers at the Agoufou local site (**CESBIO, EEF**).
- Characterization of the spatial and temporal variations of surface soil moisture content using portable probes at the Agoufou local site and at meso-scale (**CESBIO**).
- Night-time CO2 concentration profiles using a tethered balloon over the Agoufou local site, Mali (**CESBIO**).
- NOx emission measurements from various soils and geomorphology features at the Hombori supersite (Mali) during the transition of the dry/wet seasons using dynamic chamber techniques (**LA**).
- Installation of the IDAF station at the Agougou local intensive site (Mali) in June (**LA**).
- Collection of the precipitation at the event scale during the wet season (July-October) to quantify the wet deposition. Weekly bulk collection of aerosols on Teflon filters (from July). Estimation of dry deposition from the inorganic and organic chemical composition of the soluble part. Monthly passive samplers of gas (NO_2, HNO_3, SO_2, NH_3, O_3) concentrations (**LA**).
- Vegetation measurements in Niger : annual grass biomass, open top by hemispherical photography, vegetation cover fraction by photography, vegetation plot cartography, neutron probe and tetraprobe measurement of soil humidity (**ENS, HSM, LTHE**).

Modelling Work

- Development of forcing databases for the Gourma and Niamey sites (**CESBIO, HSM, LTHE**).
- Analysis of geophysical and geochemical data acquired from the unsaturated zone for the Wankama site (Niger), interpretation with respect to deep infiltration processes and confrontation with simulation outputs from the abc-rwf hydrological model (**HSM**).
- Model development for the hydrological and vegetation processes with emphasis on upscaling and coupling of model components. Coupling between a hillslope hydrological model (ABC-rwf) and a plot-scale vegetation model (TREEGRASS) for the Niamey site. Scaling laws have been investigated and tested using TGPIX vegetation model. (**ENS, HSM**).
- Adaptation of the SETHYS land surface model (SVAT) and coupling to the STEP vegetation functioning model. Test over the Agoufou intensive local intensive. Tests of calibration procedures using multispectral remote sensing data (**CESBIO, CETP, LEGOS**).
- Tests of photosynthesis / conductance models based on ecophysiological measurements performed at the Agoufou local site, Mali (**CESBIO, ESE**).
- Parameterization of NOx emission using a neural network relating non linear equations between the flux and its parameters of influence (soil and air moisture and temperature, precipitation, soil texture and land use). Coupling with a SVAT model. (**LA**).

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2.3.1c 1 year plan (2005)

Observation Strategy

- Implementation of EOP instruments over the Malian site: soil moisture stations (*CE.SW_G*), rainfall gauges (*CL.Rain_G*), flux stations (*AE.Flux_G*), sap flow stations on trees (*CE_Sap_Ga*), PAR stations for vegetation canopies (*CE.PAR_Ga*). (**CESBIO, HSM, LTHE**).
- Implementation of EOP instruments over the Niamey site: soil moisture stations (*CE.SW_Nc, CE.SWsan_Nc*), rainfall gauges (*CL.Rain_N*), flux stations (*AE.Flux_Nc*), stream gauges (*CE.Run_**Nc***), vegetation instruments (*CE.Veget_Ncw*)**,** automatic weather stations (*AL.Met_Nc*), (**HSM, LTHE**).
- Hydrological LOP campaigns. Measurement of rainfall (*CL.Rain_N*), pond levels (*CL.Pond_Nc*), water table levels (*CL.Gwat_N*). (**HSM, LTHE**).
- Development of the data base for the Malian and Niamey sites (**CESBIO, CETP, HSM**).
- Vegetation field campaigns: Ecophysiology measurements (**CESBIO, EEF, ESE**), Tree phenology (**CESBIO, HSM**), Vegetation biomass and LAI (**CESBIO, HSM**), Soil moisture heterogeneity at different scales (**CESBIO, HSM, LTHE**), CO2 night time profiles, H, LE, CO2 day time flux estimations with the tethered balloon (*AE.CO2_G*). (**CESBIO, LA**).
- Analysis of flux data in relation to soil moisture and vegetation parameters (**CESBIO, CETP, CIRAD, EEF, ENS, ESE, HSM, LA, LTHE**).
- NOx and COVB emission measurements at the Agoufou local site in the middle of the rainy season (August) at the Agoufou local site, Mali (**LA**).
- Wet and dry deposition at the sahelian sites (**LA**).

Modelling Strategy

- Proceeding with hydrologic and vegetation model component development and testing, with emphasis on potential for upscaling and coupling as described in **WP4.1.2**. (**HSM**).

- Simulation studies on the effects of heterogeneity of vegetation on simulated fluxes. Incorporation of water uptake by trees from the water table in the TREEGRASS model. (**ENS, HSM**).
- Application of the coupled SETHYS and STEP models for the Malian site. Tests with the flux data (energy, CO2 and H2O), soil moisture, vegetation biomass, net radiation and surface temperature. Tests of assimilation procedures of remote sensing data into the coupled models at the local site scale (**CESBIO, CETP, LEGOS**).
- NOx and COVB modelling via a coupled SVAT - biogenic emission models. Simulation of seasonal emissions by soils and vegetation. (**LA**)

2.3.2 : Process studies at the Sudanian local intensive- & super-sites

Laboratories : CESBIO, CETP, GEOVAST, HSM, LA, LTHE, Sisyphe.
Coordinators : S. Galle, L. Séguis

2.3.2a 5 year plan

Objectives

- Understand the key processes of the water balance (runoff generation, groundwater recharge) for selected catchments at seasonal and interannual temporal scales for the catenas and the Donga super site.
- Understand the response of vegetation to environmental constraints at seasonal and interannual temporal scales.
- Understand surface energy balance for a sudanian landscape through the analysis of flux station data.
- Understand the interactions between environmental variables and vegetation phenology.
- Understand the determinants of the spatial and temporal variations in BVOC and NOx emissions and develop new parameterizations.
- Test and validate physical distributed models describing the water cycle and the vegetation biomass from the intensive local sites (catenas) to the supersite.

Work content

- Design and implementation of experimental setup on the 3 catena representatives of the dominant land covers (young fallow, savannah and forest). Particularly, this includes the deployment of water and energy flux stations, the drilling of piezometers, the setup of humidity profile stations and gully gauging stations along catenas.
- Applying geophysical method to define the aquifer thickness and its structure and to monitor the seasonal fluctuations of the water table along the catena.
- Assessment of the water budget at the point scale of the humidity profile stations and at the catena scale.
- Identify the seasonal variation of the vegetation (biomass, LAI)
- Refine and test model formulations for local-scale (catena) hydrological processes in POWER.
- Upscale local-scale hydrological model to catchment scale.
- Hydrological campaigns on the 6 nested catchments.
- Characterize the specific tracers of hydrological compartments (subsurface, deep groundwater and runoff) involved in river flow by regular geochemicals campaigns in traditional wells and at the stream-gauge stations along the Donga river.

- Calibration and validation of the POWER model according to the hydrographs separation performed with the tracers.

Observation Strategy

- Identification of the seasonal vegetation dynamics for the main vegetation covers (young fallow, savannah and forest).
- Study the unsaturated zone at specific points in local intensive sites.
- Geophysical characterisation of the groundwaters (localisation, thick, faults) and seasonal monitoring.
- Drilling of piezometers along the toposequences to study the seasonal dynamic of superficial groundwaters (sub-water flow and alterites groundwaters). This point will be performed with the geophysical studies. Geochemistry will be also used to identify relations between the different superficial groundwaters.
- Evapotranspiration study: In addition to meteorological stations and flux stations (**WP 1.2 and 4.2.3**), IR scintillometer will be set up on a toposequence during one rainy season. Measurements will be used to validate satellite evapotranspiration estimations (**WP 1.2, 1.3, 4.3**).
- Runoff studies: According to the geochemistry studies, streamflow is composed by an important part of direct runoff. Characterisation of superficial hydraulic conductivity at saturation will be made on the toposequences. To quantify hillslope runoff, gauge stations will be set up on gullies.
- H2O/CO2/NOx/COVB exchange measurements at the soil and vegetation levels.
- Measurements of the seasonal variation of atmospheric deposition including both wet and dry processes.

Modelling Strategy

At the local scale:

- Heat and mass transfer modelling: The data set gathered on each specific vegetation cover will be used to test and validate the SiSPAT (*Simple Soil Plant Atmosphere*) model. The results will be used to evaluate the simplified evapotranspiration module used in POWER at the catchment scale.
- Groundwater modelling: A 3D DEM based on drills and geophysical maps will be built on the intensive local site. Groundwater modelling (CASC3D code implemented by LSCE) will be performed to investigate the river-groundwater relationships.
- Hillsope runoff modelling: Runoff module in POWER will be improved by runoff and soil characteristics measurements.
- Modelling of BVOC and N oxides emissions versus meteorological and surface parameters.
- Analyse the seasonal variations of the deposition fluxes in relation with the surface parameters (vegetation types, soil classes, water soil content,...) using both measurements and numerical simulation.

At the supersite scale:

- Testing and validate the *POWER* (*Planner Oriented Watershed model for Environmental and socio-economic Responses*) hydrological model. Based on a new concept of distributed hydrological model, it explicitly represents surface heterogeneity, the branching structure of the river network, and the surface energy budget. It will be tested at the different sub-catchments of the Super site. Groundwater simulated contributions to streamflow will be compared to those deduced from geochemistry studies.

__Foreseen deliverables__

- Water budgets from the station scale (humidity profile station) to the catena scale (intensive local scale).
- Assessment of the hydrological functioning scheme at the intensive local scale.
- Water budgets (runoff, groundwater recharge and drainage) for the sub-catchments of the supersite.
- Field measurements (vegetation, soil moisture, surface fluxes, biogenic emissions, wet and dry deposition, runoff, piezometric heads) at the Agoufou/Hombori (Mali) and Wankama (Niger) sites.
- Validation of the water cycle mechanistic modeling at the intensive local scale.
- Validation of POWER at the Donga supersite scale.
- Assimilation and validation data (biomass, soil humidity) for satellital studies (**WP 4.3**).

2.3.2b 2004 Achievements

__Observation Work__

- Design of experimental set-up for observations of the physical and biological processes. One meeting held in France (**CETP, HSM, LTHE, CESBIO, GEOVAST**).
- Installation of 2 soil humidity profile stations in the "young fallow" and "forest" catena.
- Drilling of 18 piezometers along the catenas.
- Installation of a Parshall gauging station on a gully along the "young fallow" catena.
- Identify the vegetation species (grass and tree) and characterize phenology along the 2 above-mentioned catenas and on a savannah catena during the 8 months of the rainy season.
- Characterize the infiltration capacity of the soil surface and its eventual fluctuation during the rainy season according to the vegetation development.
- Superficial electrical geophysical survey on the "young fallow" and "forest" catena
- Hydrological campaigns.
- Geochemistry campaigns.

__Modelling Work__

- Continuation of the POWER development.

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2.3.2c 1 year plan (2005)

Observation Strategy

- Implementation of EOP instruments over the Benin site: soil moisture stations (*CE.SW_Odc*), piezometers (*CE.GWat_Odc*), flux stations (*AE.Flux_Odc*), gully gauge stations (*CE.Run_Odc*). (**HSM, LTHE**).
- Temporal electrical geophysical survey to identify the water table fluctuations during the rainy season along the catena (**GEOVAST**)
- Hydrological campaigns (**HSM, LTHE**)
- Geochemistry campaigns on streamflow and groundwaters (**HSM**)
- Vegetation field campaigns (**CESBIO, HSM**)
- NOx and COVB emission measurements from April to July at the Djougou site (**LA**).

Modelling Strategy

- Continuation of the POWER development (**LTHE**)
- First test of SiSPAT (*Simple Soil Plant Atmosphere*) model. The results will be used to evaluate the simplified evapotranspiration module used in POWER at the catchment scale (**HSM, LTHE**)
- First test POWER on the 6 nested catchments (**HSM, LTHE**).
- NOx and COVB modelling via a coupled SVAT - biogenic emission models. Simulation of seasonal emissions by soils and vegetation. (**LA**)

Foreseen Deliverables

- First estimation of the runoff and the groundwater drainage to river along the catena.
- First estimation of the water budget at the soil moisture profile stations.

- Improving of POWER according to the groundwater and runoff characterisations.

2.3.3 : Land-surface processes at the mesoscale with a view to regional upscaling

Laboratories : CESBIO, CETP, HSM, LA, LMD, LSCE, LTHE.
Coordinator: L. Kergoat

2.3.3a : 5 year plan

Objectives

The WP 2.3.3 aims at documenting the following themes:

Objectives of WP 2.3.3	**Relevant Integrative WP**
- Document the spatial variability of soil moisture and surface fluxes. - Estimate surface fluxes through observation and modelling to address interactions between land surface and the atmosphere at the meso-scale. - Provide data sets and functional understanding of land surface to validate large-scale models. - Investigate land surface memory effect.	**WP 1.3**
- Assess the contribution of land surface to water budgets, with emphasis on the meso-scale window.	**WP 1.2**
- Document the meridian gradient of surface fluxes, their variability in space and time, in order to constrain regional simulations of the WAM.	**WP 1.1**

Such objectives require a good understanding of water redistribution, both lateral and vertical, as well as water extraction by plants and evaporation. These processes depends on a variety of mechanisms, which are studied in details within **WP 2.3.1** and **WP 2.3.2**, based on intensive instrumentation installed for the SOP, EOP or LOP.
Main issues for **WP 2.3.3** are to document how these processes and properties are organised in space, at which scales such organisations are pre-eminent, to identify the non-linear responses, and to establish methods and models to scale these responses up to the meso-scale window which is an important scale for atmospheric studies.

Work content

Overall Set-up

The objectives of the **WP 2.3.3** require a dense network of instruments which can not be installed over the whole gradient. However, the 3 selected meso-scale sites in Benin, Mali and Niger document the meridian gradient, spanning a large range of ecosystems, hydrological systems, land use, and climate conditions typical of the WA monsoon. Within each meso-scale site, dedicated instrumentation documents the spatial variability of surface fluxes, soil moisture and their drivers.

Up-scaling Strategy

a) *Bottom-up* (**CESBIO, CETP, HSM, LA, LMD, LTHE, LSCE**)

This is the core of **WP 2.3.3**. Bottom-up approach is organised in successive steps.

- Modelling processes at the local or patch scale, inferring the drivers of spatial variability. Models coupling SVAT - hydrology - vegetation are available or being develop, providing a hierarchy of scales and approaches (3D, 2D, 1D), with different degrees of coupling (see **WP 4.1.2**).
- For each site, at least one surface model will be run at the meso-scale: POWER for Benin, STEP for Mali and ABC for Niger. **WP 2.3.1** and **WP 2.3.2** will provide test and validation with field data (e.g. tower fluxes). Meso-scale forcings will be provided by **WP 4.1.2** and remote sensing. In parallel, simple functional responses will be identified: e.g. response of evaporative fraction to soil moisture, vegetation type, with a focus on non-linearities.
- Aggregation methods will be tested: from simple sums of vertical fluxes, to approaches accounting for lateral interactions (e.g. hill-slope modelling) and satellite data assimilation in surface models.
- Comparison of up-scaled fluxes with relevant measurements will be performed (scintillometer, Boundary Layer budgets, airborne fluxes, river discharge, pond and water table monitoring).
- Up-scaling results will be analysed according to the objectives of **WP 1.1, 1.2 and 1.3**.

b) *Top-down* (**LA, LMD, LSCE**)

- Direct tests of large-scale models will be performed with datasets at the local, patch and meso-scales. Especially, a co-ordinated processing of the tower fluxes will provide unique datasets of canopy gas exchange and energy balance (LE, H, RN, G, CO2) together with LAI, biomass and soil moisture. Data at larger scale (discharge, water table) and output of up-scaling exercise will help documenting the role of sub-grid variability for large-scale models. Large-scale models include ORCHIDEE, Meso-NH "Chimie" (NOx emissions).

Both *Bottom-up* and *Top-down* approaches will provide surface simulations and benchmarks relevant to surface/atmosphere coupled simulations of **WP 1.1 and 1.3**.

Modelling strategy

The modelling strategy is design to reach the two following objectives: 1) to provide meso-scale estimate and understanding of surface fluxes with coupled vegetation/SVAT/hydrology model for every meso-scale window. 2) To represent at best the surface processes severely impaired by scaling issues (caused by soil moisture heterogeneity, water redistribution, water extraction differences between plants, vegetation heterogeneity, presence of crusts, etc.).

For the first objective, the vegetation/SVAT/hydrology coupling has already started for the Niger and Mali sites (coupled TREEGRASS/ABC and STEP/SETHYS). Further work is planned for the three sites (including POWER development). These coupled models aim at integrating the conclusions of **WP2.3.1** and **WP2.3.2**, and they will use maximum remote sensing data through forcing of boundary conditions or through data assimilation.

For the second objective, we need to identify the scaling issues. This relies on measurement at different scales but also on modelling at different scales. Indeed, detailed 3D, 2D, 1D models are necessary complement to observations. This is the reason why detailed modelling experiments are scheduled. Among them, we plan to simulate hill-slope situations to address the importance of lateral water redistribution and topography on surface fluxes (including effects mediated by vegetation growth, ponds, watertables…). Simulations will be performed also for scales corresponding to integrated measurements: scintillometer, aeroplanes transects, CBL studies (UHF, balloon). Again, the focus will be on 'meso-scale' models, as well as large-scale models, but detailed models (2D, 3D) can be used to some extent in this situation. Finally, we plan to simulate surface fluxes for each flux station with detailed models, but also the 3 coupled models which simulate meso-scale windows, and some large scale models (as mentioned in the top down approach).

Compared to previous modelling exercises (Hapex, Sebex), we have a unique opportunity to address the whole gradient of surface conditions, as well as the patch-to-landscape-to-meso-scale for the 3 windows.

Integration into WP 1.x (integrative work packages)

All the objectives of **WP2.3.3** (see table above) are addressed through the up-scaling / modelling / observation framework, except the memory effects. Indeed, such 'memory' mechanisms are diverse and deserve explanations.

First of all, land surface memory is short term, medium term and long term.
- **Short term effects** : These effects include land surface processes impacts on PBL, convection (triggering and preferred development of cell within a squall line). **WP 2.3.3** contribute to document the role surface fluxes: response to past rainfall, water redistribution, water extraction by plant, intensity of turbulent exchanges and radiation balance. Spatial scales from 100 m to 300 km are considered, time scale of 10 minutes to several days for case studies of surface/atmosphere simulations, as well as 1 season to look at statistical effects of local reinforcement of precipitation patterns or climate predictability. The modelling and observation strategy, focused on the meso-scale window is appropriate for such investigations (see also **WP 1.3**). The role of land surface in climate predictability will also benefits from **WP2.3**, based on a good sampling of the meridian gradient of surface conditions during 3 years of EOP.
- **Medium term effects**: These effects include the different mechanisms, which can **spread information over periods greater than one season**. Typically, the possible effect of surface fluxes in the guinean zone on monsoon development, in response to previous autumn precipitation fells in this category. Other important effects can be mediated by vegetation change (change in tree leaf area, changes in the dynamics of trees and grasses in response to previous year climate condition). In addition, effect of previous year land surface processes on dust and aerosol production might have an impact on the WAM development through WA radiation balance.
These effects require a good understanding of surface processes, which are addressed in **WP 2.3** mostly at the EOP/LOP timescale, using instrumentation funded by ORE (CATCH, PHOTON). Long-term monitoring of surface conditions (biomass, phenology, tree cover and water balance,) but also the essential drivers of such of long term variability are needed: Why and how land surfaces behave as they do!
- **Long term effects:** These effects encompass the effects of land-use/land cover change on the WAM. A proper representation of land surface processes in GCM is required, as well as a high consistency between land surface simulation and long term satellite series (e.g. realistic albedo changes, vegetation cover, tree cover, phenology, soil erosion, cultivation practice, surface radiation balance and fluxes). Benchmarks provided by **WP 2.3**, over the north-south gradient are important in this respect. Mechanistic bases for model projection are also required.

Data requirement

- *At the local scale*, process studies and results of **WP 2.3.1** and **WP 2.3.2** will be used in **WP 2.3.3** to test/develop models. Dedicated field campaigns are planned to test/develop remote

sensing algorithms for vegetation types and phenology, LAI, soil moisture, soil properties in connection with **WP 4.3**.
- *At the local to super-site scale* (100 m to 50 km), specific observations provide important dataset: flux towers, small watershed (pond monitoring or discharge), water table, scintillometer, Boundary Layer budget and fluxes (plane, balloon). The **flux towers** play a central role in this context: the instrumentation plan aims at documenting the large-scale meridian gradient and the meso-scale spatial variability, with 4 stations for each meso-scale window. This task is performed in close connection with AMMA-IP teams (especially CEH).
- At the *meso-scale*, up-scaling methods rely on remote sensing (**WP 4.3**) and integrative observations such as river discharge data. A number of forcings are crucial to **WP 2.3.3**: First of all, **precipitation fields**, mostly from LOP instrumentation, also EOP radars and remote sensing. Second, radiation, air humidity, wind, data to be provided by **WP 4.1.2**.

<u>Foreseen deliverables</u>

- Spatial variability and scaling laws for soil moisture and evapotranspiration., from the local to meso-scale.
- Variability in time of soil moisture and surface fluxes. Functional response of land surfaces, from minutes to years.
- Meso-scale fields of surface fluxes through bottom-up and top-down modelling approaches, including coupled simulations of soil moisture and evapo-transpiration with Vegetation/SVAT/Hydrology.
- Meso-scale surface fluxes, vegetation phenology, soil moisture and water budget through assimilation of remote sensing data into coupled vegetation/SVAT/Hydrology models.

2.3.3b 2004 Achievements

This work package has been designed in 2004, to start in 2005. In 2004, important actions were completed.

- Set-up of flux towers. Since funding was secured in 2004, CEH (C. Lloyd) with teams involved in **WP.2.3.1** and **WP 2.3.2** were able to design an instrumentation plan for the 12 flux stations. Field trips to select the tower sites have taken place (Gourma) or will be competed in 2004 (Niger, Ouémé).
- Meetings before and during Dijon make it possible to design a consistent work plan, to perform a detailed review of the participants, as well as to define the links with the other WPs.
- Within each meso-scale windows, models and modellers have been identified (see achievements of **WP 4.1.2**/Models).
- Implementation and test of assimilation procedure of microwave and optical satellite data into the STEP mode for the Gourma site.

2.3.3c 1 year plan (2005)

Being mostly an integrative subWP, **WP 2.3.3** interacts with and partly designs instrumentation and model developments detailed in **WP 2.3.1** and **WP2.3.2**. In 2005, specific tasks are:
- Participation to the definition of required data: forcings (**WP 4.1.2**) and remote sensing (**WP4.3**).
- Identification of scales, time period of land surface simulations (and relevant data requirements).

- New 'integrative' field measurements (tower fluxes, ponds/river/table monitoring, tethered balloon, transects for LAI/biomass, soil moisture); Also finalise links with SOP instruments and SOP planes.
- Development of models to be scaled-up (at least STEP, ABC, POWER).
- Classification of land surface according to vegetation, soil, hydrological units in connection with **WP4.3**.