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Chapter 3
EOP Surface Flux Measurements
TT2a

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1 Scientific justification and objectives

An important component of the AMMA project is the monitoring of surface conditions continuously over the course of the Extended Observation Period (EOP). Over West Africa, the seasonal evolution of the atmosphere is accompanied by pronounced changes in surface properties, driven by rainfall. These properties (notably soil moisture and leaf area) control fluxes of heat and moisture into the atmosphere and thus affect characteristics of the coupled system. We have at this time little knowledge of the evolution of these properties and associated fluxes during the annual cycle, and from one year to the next. Furthermore, their poor representation in large scale models affects the overall simulation of the monsoon system. Where we do have observations, these are for a limited period over a relatively small area (e.g. HAPEX-Sahel).

Flux observations are not representative of the areal average fluxes even at the mesoscale, due to strong heterogeneity in factors such as vegetation cover, soil characteristics, and rainfall. At the larger scale, these detailed observations by themselves provide little insight into processes occurring elsewhere on the vegetation gradient between the natural closed canopy forest in southern West Africa and the desert in the north of the region. The primary aim of the EOP surface flux monitoring in AMMA is therefore to make continuous observations from a selection of typical land covers under a broad range of climatic conditions over a minimum of 2 years. The ensemble of instruments (a network of flux stations augmented by other micrometeorological instrumentation e.g. radiation, soil physics) will provide a coherent set of observations with which to understand how the land surface typically evolves at representative points on the gradient. Crucially, the flux stations will provide ground truth to link with earth observation data, and to constrain surface models. This will feed into the land data assimilation scheme, the measurements playing a critical role in attempts to quantify the daily to interannual variability of the land surface at scales from the meso- to the monsoon scale. In addition, the systems will provide flux observations to support field/catchment scale studies.

The provision of surface fluxes, surface meteorological measurements and soil physics measurements during the EOP/SOP is required in various of the Work Packages listed in Table 1.

The location and operation of the flux systems provides, not only the time-series of regional point measurements of sensible and latent heat and carbon dioxide fluxes for the above work packages, but also the relevant long-term data to vegetation, soil moisture, energy balance and aerosol experiments at each of the supersites. There are therefore very strong links between TT2a and TT2b, TT3, TT4 and TT5.

Table 1. Stated measurement requirements by the Work Packages

WP	Rainfall	Soil Moisture	Evaporation	Sensible Heat	CO2	Radiation	Met Data
1.1	√		√	√			
1.2	√	√	√			√	√
1.3	√	√	√	√		√	√
2.1	√		√	√			
2.3	√	√	√	√	√	√	√
2.4	√				√	√	√
3.1	√	√	√		√		√
3.3	√	√					√
3.4	√	√	√				√
4.1	√	√	√	√		√	√
4.3	√	√	√			√	√
4.4	√	√	√	√	√	√	√
5.1			√			√	√
6.1	√	√	√	√	√	√	√

2 Observing strategy

2.1 Overall Strategy

The primary aim above can be met by addressing the different energy balances of the typical vegetation surfaces in the region and so the deployment of the flux stations has attempted within the overall budget constraints to encompass these differences. Of overall concern is the efficient collection of continuous data during the EOP – an effort that would be compromised by attempting a transect approach to the measurements.

The network of new equipment, expressly commissioned for the AMMA project, is enhanced through other surface flux measurement systems, currently operating within other projects but linked to AMMA. These include wide-aperture scintillometer instruments and modified Bowen Ratio systems.

The scientific need informed the design of a multi-site network of simple and robust heat flux stations capable of running with minimum maintenance throughout the EOP. This network comprises four super sites, encompassing the north-south rainfall gradient and the typical vegetation covers found within a super site. The sites are based around existing measurements and experimental infrastructure. The sites are in the Hombori-Gao region of N. Mali (5-300 mm annual rainfall), the Niamey region of Niger (550 mm), the Upper Ouémé catchment in Benin (1200 mm), and another (at present undefined) site in southern Benin (around 1400 mm, during 2 wet seasons within the year).

The success of funding bids to both NERC (UK) and the EU has provided the flexibility to convert several of the heat flux stations to full eddy correlation systems measuring water and carbon fluxes. These conversions are necessary over certain surfaces where the heterogeneity of the vegetation and soil surfaces severely limits the ability of simple heat flux stations in combination with energy balance considerations to provide believable estimates of evaporation. Even the interpretation of sensible heat flux measurements is complicated by the heterogeneity of these surfaces and an independent measure of evaporation allows better quality control of the data. Additional full eddy correlation systems have been funded from other sources (the French API-AMMA and the UK funded CLASSIC programmes).

2.2 Modelling and satellite observations

The surface flux observations will provide an important source of ground truth for land surface modelling and satellite efforts in AMMA. They will provide:

- the means to develop and calibrate land surface schemes at the point scale
- a characterisation of 'typical' land surface functioning across the vegetation gradient for comparison with surface scheme behaviour in NWP and climate models
- observations which can be compared with both remotely-sensed data and land surface schemes forced by remotely-sensed data

In the cases of (2) and (3), the spatial scales do not correspond, the flux observations being sub-grid and sub-pixel scale. On any particular day, direct comparisons might be poor, due for example to spatial variability of rainfall. However, in many cases the behaviour of the surface at the larger scale should resemble that which is observed locally when averaged over longer periods, or when account is taken of spatial variability in vegetation. Given the lack of available ground truth fluxes across the region for developing satellite and surface modelling schemes, use of the flux data will increase confidence in results from these larger scale tools.

The sites have been chosen to capture a broad range of surface conditions found in the monsoon region. The systems will produce standard forcing variables for land surface schemes (summarised in Table 2) as well as the turbulent fluxes for verification. These will be available at 30 minute resolution for the duration of the EOP. From the modelling prespective, it is crucial to have long time series of forcing data, and the more verification (flux) data that is available, the better. However, given the inherent problems of flux measurements, verification datasets will be shorter than the more routinely observed meteorological data. Additional data will be made available describing site – vegetation coverage, soil type etc.

It has been agreed that Quality Controlled data will be available 6 months after the collection from the field sites. Non quality controlled data can be made available upon request as soon as it has been added to the flux database. Quality control, in the first instance, will consist of isolation of physically unrealistic values. While gap-filling strategies based on protocols developed within the CarboEurope programme are available, these are intrinsically models and should not be used to generate "measurements" for inclusion in databases. Gap-filling is pertinent when individuals or groups are preparing period or annual budgets within reported scientific research.

Within the constraints of time (to database submission) and man-power, it will only be possible to identify physically unrealistic data in the meteorological forcing data. This is known as Level 1 quality control (QC). Within the flux data, Level 1 QC can generally be applied to scalar values (e.g. horizontal windspeed, temperature, gas concentration) and most errors will occur during rainstorms. Level 2 QC will generally apply to the fluxes themselves. With fluxes, even apparently unrealistic data (e.g. energy balance mismatch) at the 30 minute scale may be perfectly acceptable. While there are detailed analysis procedures to identify data which does not conform to the basic tenets of surface flux measurements (e.g. stationarity, advection concerns, stability), there is not the necessary critical mass of expertise within the AMMA community to be able to quality control all the flux data to this level. A measure of the daily or period energy closure, and the identification of flux measurements which fail the stability and windspeed criteria (mostly nighttime conditions) may be the best quality control on the flux data that can be achieved with the manpower and time available.

As the Level 1 QC criteria can be specified as a data range for every averaging period, the QC can be automated and performed locally at the supersites where day-to-day appreciation of the local conditions will be invaluable. Level 2 QC requires experience of flux data and a more general appreciation of longer-term and larger scale micrometeorological processes. An appreciation of the latter will be addressed at a workshop to be convened in Cotonou early in 2006.

The main aim of TT2a is to provide surface flux measurements to the AMMA community. To take advantage of this data, it is necessary to identify individuals, or groups of individuals, who have an interest in using the data to augment their other studies (plant physiology, hydrology, aerosols etc.), or are interested in the comparison of the different land covers at each supersite. The comparison of data across the mesoscale sites in terms of land surface function is an additional key area of work. This analysis will be performed in WP1.3 and WP2.3 and will be coordinated from Wallingford, working in close collaboration with the mesoscale groups.

2.3 List of sites, instruments and relevant maps

The TT2a instrument network consists of 14 flux stations and 2 scintillometer stations grouped at the following regional locations. The instrument systems and the parameters measured are described in the tables following the location descriptions.

2.3.1 Mali-Gourma Mesosite

The northernmost main site is in the region of Hombori-Gao, Mali, where a heat flux station (HFS) will be located at a largely unvegetated desert site at Bamba (50 -100mm annual precipitation, >95% sand soil). In the absence of existing AMMA activity in a completely unvegetated area, this should provide relevant ground truth for desert conditions. The area around Hombori (300 mm annual precipitation) is largely either low-intensity grazed savannah grassland or laterite areas with little vegetation. Isolated areas of open acacia forest are also present. An HFS will be established over an extensive laterite pan (common across the region) while complete CO2/evaporation/Heat flux stations (Mk4) will be installed over both a typical area of grassland and an open forest site. Instrumental details for the HFS and Mk4 flux systems are shown in Table 2a and complete instrumentation information is supplied in ANNEX 1.

2.3.2 Wankama-Banizoumbou Mesosite

A Sahelian region main site will be sited around Wankama, to the east of Niamey, Niger where the annual precipitation is around 600 mm. Here the typical surfaces consist of Millet (the local grain crop), heavily grazed fallow bush , degraded fallow bush and laterite pans, mostly covered with poor to good dense vegetation strips known as Tiger Bush. Methodological difficulties with interpreting Tiger Bush energy fluxes identified during HAPEX-Sahel have not been resolved sufficiently in the intervening period for routine data monitoring practice, and the surface will be excluded from the flux station deployment. Some insight will be gained from consideration of the laterite surface at the northern Mali site. An API funded CO2/H2O flux station (see Table 2a and ANNEX.1 for instrument details) will be installed over an area of fallow bush. Another API funded CO2/H2O system will operate over an area of Millet to characterise the heat, evaporation and carbon dioxide fluxes. An HFS system will operate over degraded fallow bush close to the API system mentioned above. This will provide a useful comparison of the energy flux differences that may occur due to climate change or farming practice. An HFS system will be used on a campaign basis alongside the tower measurements of “erosion” flux (TT2b) in an area of

Millet to provide the micrometeorological parameters that define, and help to explain, the turbulent transport of dust and aerosols.

In addition to the above, a heat and water vapour eddy correlation system will be set up at Niamey airport as part of the ARM Mobile Facility from January to December 2006.

BENIN

2.3.3 Djougou Mesosite

A Soudanian region main site will be sited around Djougou in the Ouémé catchment, northern Benin (1200mm annual precipitation). The vegetation surfaces here are typically open scrub forest and croplands with some isolated areas of forest. The small scale homogeneity of the region croplands presents difficulties in evaluating evaporation from a HFS System owing to the point nature of the radiation and soil heat flux measurements compared to the field scale of the sensible heat fluxes. In response to TT5 requests for complete latent heat and CO2 flux measurements, funds will be sought to augment one HFS with a Licor Li7500 H2O/CO2 instrument. This will be installed (augmented or not) in an area of fallow bush. Another HFS system will be deployed over a more homogeneous crop or open scrub grassland site where energy balance considerations can be adequately applied. A Mk4 System will measure CO2/H2O and Sensible Heat fluxes over a typical forest site where the heterogeneity requires direct flux measurements of water vapour and CO2 (see Table 2a and ANNEX.1 for details).

A micrometeorological & flux station, operated and funded by the Laboratoire d'Aerologie, has been installed near the village of Nangantchori, 10km ESE of Djougou (9° 38.820' N, 1° 44.460' E). It consists of the instrumentation shown in Table 2b and ANNEX.1.

A long path large aperture scintillometer system has been installed between the villages of Nalohou I and Nalohou II over the Ara water basin in the Djougou region by LTHE, Grenoble. This instrument will provide long-path averaging of sensible heat flux, (and evapotranspiration from energy budget considerations) over a distance of 2.4 km (Table 2c and ANNEX.1).

Another flux station is operational at 9° 06'160" N, 1° 56'37.6" E in the HVO catchment near Parakou in the east of Benin. This is a modified Bowen Ratio machine operated within the IMPETUS project and run by the University of Cologne. The instrumentation is summarised in Table 2d and more fully detailed in ANNEX.1

2.3.4 Southern Benin

A more southern site at Ejura in Ghana was to have been established alongside the on-going GLOWA project. This is a site of 1300mm annual precipitation but with markedly different seasonality compared to the Ouémé sites. However, the logistical difficulties of operating multiple flux stations across west Africa that became apparent during the Mali installation, and budgetry considerations, demanded a re-appraisal of the location of the allocated Mk4 system. In consequence, a MK4 system will be installed in a similar climatic zone to the previously proposed site at Ejura. Ideally, this would be over tropical forest in an area close to Cotonou. However, the cost of providing a tower for supporting the flux system above the tall forest is prohibitively expensive. It is expected that a MK4 flux system will be installed over a Palm plantation near Cotonou. The instrumentation will be the same as shown in Table 2a and ANNEX.1.

The flux systems to be installed at the above locations consist of the following instruments and measurement parameters shown in the following tables. (See Table 3 for symbol explanation).

Table 2a. Systems composing the main network of 12 flux stations funded by AMMA-UK, AMMA-EU, AMMA-API, and CLASSIC.

Table 2a Flux stations

System	Sensor	Measurements										
API Flux system	Campbell CSAT3 Sonic Anemometer	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+Variances
	Licor 7500 IRGA	CO2c	H2Oc	Fc	LE							
	Kipp & Zonen CNR1 Radiation	Sin	Sout	Lin	Lout	al	Rn					
	Vaisala HMP45	Ta	RH									
	Young Propeller Anemometers	Ws	Wd		At 2.5m and 8m heights							
	Rimco 0.5mm Raingauge	Pg	Pd	Pi								
	TDR Soil Moisture Profile	VWC		Profile of 6 sensors								
	Soil Temperature Profile	Tsoil		Profile of 6 sensors								
HFS	Solent R3-50 Sonic Anemometer	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+Variances
	Vaisala WTX510 Weather Station	Ta	RH	Pr	Ws	Wd	Pg	Pd	Pi			
	Kipp & Zonen CNR1 Radiation	Sin	Sout	Lin	Lout	al	Rn					
	Campbell CS616 Soil moisture	VWC		at 10 and 50 cm depths								
	Campbell T107 Soil thermistors	Tsoil		at 10 and 50 cm depths								
	Rimco 0.5mm raingauge						Pg	Pd	Pi			
MK4	=HFS system above + following											
	(Embedded IRGA)	CO2c	H2Oc	Fc	LE							

Table 2b Micrometeorological and flux station operated by the Labo. d'Aérologie in the region of Djougou (Ouémé)

Operator	Sensor	Measurements										
L d'A	Solent R1 Sonic Anemometer	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+Variances
	Licor 7500 IRGA	CO2c	H2Oc	Fc	LE							
	Kipp & Zonen CNR1 Radiation	Sin	Sout	Lin	Lout	al	Rn					
	Micromet Station	u	RH		Wd	Ta	Pg	Pd	Pi			
	Soil Temperatures	Tsoil										
	Campbell CS616 soil moisture	VWC										

Table 2c Scintillometers operated by LTHE on the Djougou and Wankama mesosites

Operator	Sensor	Measurements										
LTHE		u	v				H	M	u*	z0	z/L	+Variances

Table 2d The modified Bowen Ratio flux system operated by the Univ. of Cologne within the IMPETUS project

IMPETUS	METEK USA-1 Sonic Anemometer	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+Variances
	2 Frankerberger psychrometers	Ta	Twb									
	Kipp & Zonen NR-LITE	Rn										
	2 HFP01 Soil Heat flux plates	G										
	Equitensiometer	SWP										
	Raingauge						Pg	Pd	Pi			

2.3.5 Other Instrumentation

Other flux Instrumentation

During the Special Observation Periods (SOP), various sites will be operating flux systems for short periods in combination with other SOP activities.

ALGERIA

A flux site at Tamanrasset (22° 47’ N, 5° 31' E) is being set up for the SOP period associated with the TRESS system operated by IPSL/SA. During this period, a Campbell Scientific CSAT3 sonic anemometer, together with an IPSL-developed Optical Depth Sensor (ODS) and a CIMEL CE 312 CLIMAT radiometer will be operational. These instruments will augment the TReSS system at the same site observing the radiative and structural properties of clouds and aerosol layers, and ABL dynamics. This instrument package includes CIMEL sun photometers, Nephelometers, and an Heitronics IR radiometer. This SOP instrument primarily associated with TT7 and TT8, has measurements of interest to TT2a which are shown in Table 2e.

Table 2e Flux measurements associated with the TRESS system operated by IPSL/SA in Tamanrasset

Operator	Sensor	Measurements										
IPSL/SA	Campbell CSAT3 Sonic Anemometer	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+Variances
	CLIMAT radiometer	Lin										
	Heitronics IR Radiometer	Lin										

BURKINA FASO

In Burkina Faso, Forschungszentrum Karlsruhe (FZK) will be operating two flux systems at sites in Bontioli Park near Dano. One will be a Gill Solent/Lyman-α/Licor-7500 flux system with associated energy balance measurements (PI is Norbert Katthoff), and the other a Campbell CSAT3/Licor-7500 flux system, again with associated energy balance measurements (PI is Harald Kunstmann). These SOP systems and their measurements are more fully detailed in TT8 but measurements of interest to TT2a are shown in Table 2f

Table 2f FZK Flux system measurements at Dano and Bontioli Park sites in Burkina Faso

Operator	Sensor	Measurements										
FZK/Dano_1	Gill Solent R3-50	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+variances
	Lyman-α humidity sensor		H2Oc		LE							+variances
	Kipp & Zonen CM14 radiometer	Sin	Sout									
	Vaisala HMP34 humidity sensor	Ta	RH									
	Licor 7500	CO2c	H2Oc	Fc	LE							+variances
	Schulze net radiometer	Rn										
	3 Heat flux plates	G										
	Meteolabor Dew-Point sensor	Td										
FZK/Dano_2	Campbell CSAT3 Sonic Anemometer	u	v	w	Wd	Ts	H	M	u*	z0	z/L	+variances
	Licor 7500	CO2c	H2Oc	Fc	LE							+variances

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The list of instruments as defined in the introduction of the implementation plan is given in the tables of section 3.

Other Instrumentation

Depending on users needs, it may be necessary and useful to increase the measurements by the addition of PAR (Photosynthetically Active Radiation) sensors, NDVI sensors and Diffuse radiation at some of the locations. InfraRed Thermometers to record surface “skin” temperature may also be useful. The current budget does not include the provision of any of these instruments. However, provision of a limited number of these sensors has been built in to the design, construction and operating software of the HFS and Mk4 systems. The UK CLASSIC programme has funded the provision of four NDVI sensors (SKR1800, Skye Instruments, UK) and two Total/Diffuse solar radiation sensors (BF3, Delta-T Devices, UK). The NDVI sensors will be attached to all the Mali flux stations, while the BF3 sensors will be attached to the Grassland Mk4 system and the Bamba HFS system. The Institute of Geography, University of Copenhagen have supplied five SKR1800 dual channel radiometers which correspond to Meteosat Second Generation (MSG) SEVIRI channels and AVHRR channels. These will be installed at the Bira fallow bush site in Benin (AVHRR configuration) and at the Wankama degraded fallow bush site in Niger (SEVIRI configuration).

Table 3 Nomenclature used in Tables 2a-2e.

Legend	Description
u, Ws,	Horizontal wind velocity in the direction of the mean wind
v	Crosswind velocity
w	Vertical velocity
Wd	Wind direction
Ta, Ts, Td	Air temperature (air, speed of sound derived), Dew-point temperature of the air
H	Sensible heat flux
M	Momentum flux
u*	Friction velocity
z0	Roughness length
z/L	Atmospheric Stability parameter
RH	Relative Humudity
Pr	Atmospheric Pressure
Pg, Pd, Pi	Rainfall amount, duration, intensity
Sin, Sout	Shortwave radiation; incoming, reflected
Lin, Lout	Longwave radiation; incoming, outgoing
al	Albedo – derived quantity
Rn	Net radiation from sensor components
VWC	Volumetric Water Content
SWP	Soil Water Potential
Tsoil	Soil temperatures
CO2c, H2Oc	Surface level CO2 and H2O concentrations
Fc, LE	Fluxes of CO2 and Evaporation
G	Soil Heat Flux

2.4 Priorities

The HFS, Mk4 and API flux systems cited in this document have secured funding from NERC, the EU or French API. Priorities with regard to production of such systems is therefore not necessary.

The additional instrumentation that can be attached to the HFS and Mk4 systems, i.e. Diffuse radiation, PAR, NDVI and IRT do not currently have funding within the EU or NERC funding of AMMA. The CLASSIC programme is providing funding for the inclusion of some of these measurements at one or more of the Mali supersite locations.

In the case of extra but limited funding being found, priorities will need to be decided for the above instrumentation.

With regard to risk, the following areas of concern may apply during the operation of the instrumentation in the EOP. Most of this information is particular to the AMMA-EU and AMMA-NERC equipment but many of the risks are pertinent to the operation of sophisticated instruments in west Africa.

Delay in manufacture of HFS and Mk4 systems will ultimately impinge on the deployment date for the systems.

All equipment has allocated funds for airfreight and experience shows that this is the best option for the shipping of delicate items with low risk of damage and/or non-arrival. Equipment will be shipped allowing sufficient time for airfreight and customs release.

The deployment of the systems has taken note of the current political and social stability of the countries within west Africa. Mali, Benin, Niger and Ghana have all been stable for several years and local knowledge has been sought at every opportunity to minimise this risk.

The production of the HFS and Mk4 systems has taken note of the valuable nature of items in the systems, e.g. batteries, solar panels etc to the local economy and has taken precautions to prevent opportunist loss of these items. The deployment has tried to avoid the placement of systems in remote areas so that adequate local guarding of the valuable equipment can be organised. However, the requirements of the AMMA programme with regard to the latitudinal rainfall gradient has inevitably meant that some stations have been located in the north of Mali and southern Algeria. The use of solar powered battery systems for data measurement and collection has avoided some of the problems associated with reliance on mains-power.

The risk of loss of data during the EOP has been addressed through a thorough design process of the instrumentation and logging equipment with regard to the climate, robustness of the sensors, the current general inexperience of the proposed operators and the length of the EOP. Thorough training of operators, provision of a complete spare HFS system and regular maintenance field visits by flux system experts during the EOP will help this situation but this risk cannot be eradicated and some loss of data should be expected from one or more of these continuously running systems during the EOP. The long-term unattended running of multiple eddy correlation flux systems in remote and harsh conditions has not been attempted before anywhere. With visits to field sites often being of the order of every 6 weeks, there is the very real possibility of up to 6 week gaps in the flux data. More frequent field visits will be effected during the periods around each SOP.

In the Djougou area, there are frequent power cuts which will affect all systems running on mains power. The system at Nangantchori is running on mains power with backup APS on line. To further minimise data loss during long power cuts or through thunderstorm damage, a technician will drive from Djougou to site to assess the situation and restart the system. It is expected that data loss will be of the order of a few minutes/hours per day during these events.

3 Deployment

3.1 Instruments and related detailed observation program

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3.1.2 Deployment

Planning

Lead times for manufacture and supply of sensors, together with the necessary time to construct and test the equipment, has meant that hardware for 3 Mk4 systems and 2 HFS systems have already been ordered and delivered (1 Feb 2005) from within the AMMA-NERC budget which came on-stream at the beginning of October 2004. This allowed some systems to be installed in Mali in April. OSIL received their funds from AMMA-EU on the 1st June 2005. Construction of the four HFS systems by OSIL commenced at that time. To maintain compatibility within the training, data collection and subsequent analysis, CEH have liased directly with OSIL in the design and production of the AMMA-EU funded flux systems being produced by OSIL. The four systems were completed at the beginning of October 2005.

3.2 Logistical considerations

Installation and maintenance field visits to the flux station locations has to correspond with the presence of local field staff who can organise the transport and accomodation arrangements. It is imperative that the local knowledge of staff is used at all times with regard to local political activity and changing governmental bureauacracy and political situation. West African states have different policies with regard to visas, airfreight and customs control. Sufficient time needs to be allocated for the release of airfreighted equipment from customs control at the airport. The remote site at Bamba, Mali can only be serviced at 6 week periods in contrast to the remaining sites which will be serviced at 3 weekly periods - although operational considerations with regard to the Hombori site may require 6-week visits as well. This has necessitated some change to the data collection hardware and the controlling software. The longer time between servicing has attendant risks for the vulnerability of the equipment and loss of data, but modelled gap filling of lost data is easier at this site than more vegetated sites.

Three of the AMMA-NERC flux systems and the CLASSIC-funded flux system were installed during 9-25 April. Two HFS systems were installed at the Bamba desert site and at a laterite site. The CLASSIC funded Mk4 system was installed at the grassland site and the AMMA-NERC Mk4 over a sparse forest site. The install period also included time for training of local IRD personnel and for field testing of the systems. No local African researcher has yet been found to service the Hombori sites - efforts are continuing. In the meantime, IRD staff and occasionally visiting CEH staff are servicing the systems.

Locations for flux systems at the Wankama, Niger and Djougou, Benin supersites were identified in early May 2005. Subsequently, the two API funded flux systems were installed at the Wankama, Niger field site in June 2005.

The IMPETUS flux system has been operational for some time.

The next install was dependent upon the timing of the completion of manufacture and testing of the systems currently on order. The install timing was also dependent upon the availability of both CEH and OSIL staff to install the systems and local staff to provide both logistical support and to be available for system training. For the HFS systems being constructed under the EU funding programme, 20-24 weeks were required for construction and testing. OSIL did not receive funds from AMMA until the 1st June 2005 This set a likely date for delivery of the HFS systems for field testing as the beginning of October 2005 at the earliest. The systems were delivered on time. As the systems, both in design and structure, are completely new, it would have been beneficial if a period of field testing prior to shipment to their final locations had been done. However, the time required to clear customs in Niger and Benin (3 weeks) and the planned installation in early November 2005, precluded this action and the flux systems were airfreighted to Benin in the second week of October with the other flux systems airfreighted to Niger during the 3rd week of October. The remaining two Mk4 systems constructed under NERC funding were available for installation in June 2005. But other fieldwork operations by CEH staff and budgetry constraints precluded these installations before the major Benin installation in November 2005. It was also decided at the Biarritz meeting in September 2005 that the planned Mk4 installation at Ejura in Ghana would now be redeployed over a suitable site in southern Benin.

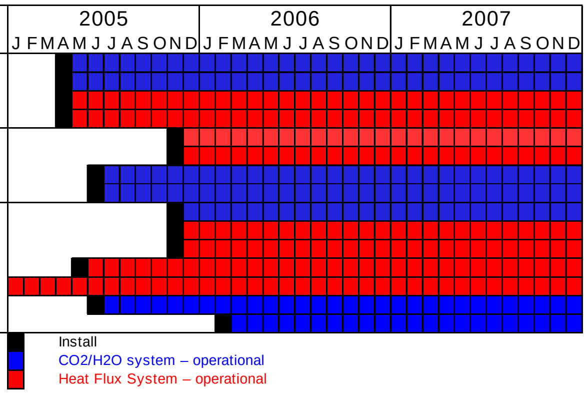
The two AMMA-EU HFS systems and one AMMA-UK Mk4 Hydra system were installed in the Djougou area of Benin between 7-12 November. The remaining two AMMA-EU HFS systems were installed at the Wankama/Banizoumbou sites during 14-17 November. It is currently planned that the last AMMA-UK Mk4 Hydra system will be installed at the southern Benin site in February 2006.

The installation timing and operational periods for the flux systems are shown in table 4 below.

Table 4 The installation timings and operational period for the flux systems.

Location	Location Site	Operator	System	Surface
Mali	AE.H2OFlux_G	CEH/CESBIO	Mk4(C)	Grassland
	AE.H2OFlux_G	CEH/CESBIO	Mk4(N1)	Forest
	AE.SHFlux_G	CEH/CESBIO	HFS(N1)	Laterite
	AE.SHFlux_G	CEH/CESBIO	HFS(N2)	Desert
Niger	AE.SHFlux_Nc	CEH/IRD	HFS(E1)	Degraded Fallow Bush
	AE.SHFlux_Nc	CEH/IRD	HFS(E2)	Millet/Aerosol
	AE.H2OFlux_Ncw	IRD	CSAT3/7500 (API-1)	Fallow Bush
	AE.H2OFlux_Ncw	IRD	CSAT3/7500 (API-2)	Millet
Benin	AE.H2OFlux_Odc	CEH/IRD	Mk4(N2)	Forest
	AE.SHFlux_Odc	CEH/IRD	HFS(E3)	Cropland
	AE.SHFlux_Odc	CEH/IRD	HFS(E4)+7500	Fallow Bush
	AE.Scintil_Od	LTHE	Scintillometer	Mixed Surface
	AE.SHFlux_Od	U.Cologne	Bowen Ratio	Scrub Forest
	AE.H2OFlux_Od	Lab.d'Aerologie	Solent/7500	Composite scrub forest
	AE.H2OFlux_Ve	CEH/IRD	Mk4(N3)	Palm Plantation

N – AMMA-UK
E – AMMA-EU
C- CLASSIC
API – French Funds



The general operation and maintenance of the flux systems and the collection of data will be the responsibility of the locally trained operators under the supervision of the supersite captains or designated AMMA personnel. Regular inspection and maintenance field visits will be conducted by CEH and OSIL staff. The timing of these trips must be flexible in order to respond to instrumental non-operation and the technical capability and knowledge of the local operating staff in dealing with the problem, and with the priority placed upon that system at any particular time of year. A general series of field visits by OSIL and CEH staff prior to the SOPs will help to ensure correct operation during these important periods.

Vehicles

The staff of CEH and OSIL are entirely dependent upon the provision of vehicles by AMMA organisations resident in Mali, Niger, Benin and Ghana. It is necessary therefore to organise installation and maintenance visits to coincide with the field operations of the local staff wherever possible. Installation at each supersite will require carriage of approximately 2000 kg of equipment from the airfreight airport to the general area of deployment. This can generally be done before the installation staff arrive. Subsequent deployment of each system will require use of one 4 x 4 vehicle of LandCruiser size. Each installation trip will therefore need the use of one 4 x 4 vehicle and driver for the duration of the installation trip i.e. of the order of 2 weeks. Subsequent maintenance visits (requiring one 4 x 4 vehicle + driver) will generally be of the order of 1 week.

After installation, the regular 3 week (6 week at Bamba) visit to each flux station to inspect and download the data will require transportation to be arranged locally. The close proximity of the flux stations at each supersite means that all flux stations could be visited in a single day.

Human Resources

The installation of the flux stations will require a minimum of 2 people (for safety reasons) to build each station. Each station will be built consecutively. It would be more efficient if 3 people were involved in the assembly of each flux station.

Regular inspection and downloading of the data from each station can be undertaken by 1 person. That same person will be responsible for the upload of data to supplied computer and subsequent copying of data to CD-ROM for posting to designated people within the AMMA community for quality control and databasing.

Infrastructure

The flux station installation and maintenance personnel will have to liase with and rely upon local staff for provision of invitation documents for visas, collection of airfreight from airport customs authorities, provision of vehicles and accomodation. The flux systems are solar panel battery powered and therefore mains power is not essential. Installation can be done without any specific office facilities but occasional use of a bench or part of an office for the use of laptops and inspection of sensors may be necessary.

Four mains-powered Dell PC's have been purchased for the downloading of data and transfer to CD-ROM. These four PC's will require permanent bench space in an office at each of the supersites in Mali, Niger, Benin and Ghana for the whole of the EOP. There is no operational reason for these PC's to be linked into the local computer network

3.3 List of instruments

Table 5 TT2a List of Instruments

#	Code	PI Names	E-Mail Address	Instrument	Platform
EB1/EF7	AE.H2OFlux_G	F.Timouk C.Lloyd	franck.timouk@ird.fr crl@ceh.ac.uk	2 MK4 systems in Hombori (grassland and open forest sites)	Hombori Super Site
EB2	AE.SHFlux_G	F. Timouk, C.Lloyd	franck.timouk@ird.fr crl@ceh.ac.uk	2 HFS systems in Bamba (very dry) and Hombori (extensive laterite pan)	Gourma Meso Site
EB3/EF9	AE.H2OFlux_Odc	S.Galle C.Lloyd	galle@ird.fr crl@ceh.ac.uk	1 Mk4 system over forest at Belefoungou	Ouémé - Donga Super Site
EB4	AE.H2OFlux_BS	S.Galle C.Lloyd	galle@ird.fr crl@ceh.ac.uk	1 Mk4 system over Palm plantation in southern Benin	Benin
LE2/LF9	AL.SHFlux_Odc	S.Galle S.Holland	galle@ird.fr Stuart.Holland@osil.co.uk	2 HFS (OSIL) systems at Bari (Fallow bush) and Nalohou (Crop)	Ouémé - Donga Super Site
LE1/LF8	AE.SHFlux_Nc	B.Cappelaere S.Holland	Bernard.cappelaere @msem.univ-montp2.fr Stuart.Holland@osil.co.uk	2 HFS (OSIL) systems at Wankama (Degraded fallow) and Banizoumbou (Millet)	Niamey Central super site
EF8	AE.H2OFlux_Ncw	N.Boulain B.Cappelaere	Bernard.cappelaere @msem.univ-montp2.fr	2 CSAT3/Li7500 H2O/CO2 flux systems over Fallow bush and Millet at Wankama	Niamey Central super site
		Andreas Fink	af@meteo.uni-koeln.de	METEK USA1 Heat flux system	Parakou
EF10	AE.Scintil_Od	Jean-Martial Cohard	Jean-Martial.Cohard@ hmg.inpg.fr	Sensible Heat Flux Scintillometer	Donga Super Site
SF14	AS.TRESS_Tam (TRESS)	C.Flamant	cyfl@aero.jussieu.fr	TReSS multi-sensor active/passive remote sensing of radiative and aerosol layers	Tamanrasset, Algeria
EF33	AE_VAN_Od	D.Serça	Serd@aero.obs-mip.fr	Gas/combustion particle analysers+energy flux+NO2 profile	Ouémé - Donga Super Site
EF34	AE_Nox_G	D.Serça	Serd@aero.obs-mip.fr	Chamber measurements of soil NO and CO2	Gourma Meso Site

Table 6 List of instruments related to TT2a

#	Code	PI Name	E-Mail Address	Instrument	Platform	TT
SE04	AS.H2OFlux_D	Norbert	Norbert.kalthoff@imk.fzk.de	Solent/Lyman-α/Licor7500	Bontioli Park	TT8

		Kalthoff		system*		
SU1	AS.smet_S	Anthony Slingo	as@mail.nerc-essc.ac.uk	ARM Mobile Facility	Banizoumbou	ARM

* A CSAT3/Licor7500 system was reported to be run by Harald Kunstmann on the same site; no further info.

Table 7. Location, system designation and surface type for the TT2a flux systems

Country	Site Name	Latitude	Longitude	System	Vegetation
Mali	Bamba	17°05.907' N	1°24.073' W	HFS (NERC)	Desert
	Hedgerit	15°30.171' N	1°23.460' W	HFS (NERC)	None – Gravelly Red Soil
	Agoufou	15°20.595' N	1°28.841' W	Mk4 (CLASSIC)	Grassland
	Kelema	15°13.422' N	1°33.972' W	Mk4 (NERC)	Open Forest
Niger	Wankama	13°38.853' N	2°38.022' E	CSAT3 / Li7500	Fallow Bush
	"	13°38.628' N	2°37.805' E	CSAT3 / Li7500	Millet
	"	13°38.779' N	2°38.581' E	HFS(EU)	Degraded Fallow Bush
	Banizoumbou - Koma Koukou	13°31.294' N	2°37.737' E	HFS (EU)	Spare/ Aerosol/dust Campaign fluxes Millet
Benin	Bari, Djougou	9°49.397' N	1°43.067' N	HFS (EU)	Fallow Bush
	Nalohou, Djougou	9°44.456' N	1°36.335' E	HFS (EU)	Mixed Crops
	Belifoungou,	9°47.279' N	1°43.158' E	Mk4 (NERC)	Forest
	Nangantchori	9°38.820' N	1°44.460' E	Solent/Li7500	Secondary forest/woody Savanna
	Djougou Area			Wide Aperture Scintillometer	Composite
	Parakou	9°06'160" N	1°56'37.6" E	Modified Bowen	Open Forest
s. Benin	??	?° ??'N	?° ??'E	Mk4 (NERC)	Plantation

4 Partnership

4.1 Field observations

It is imperative, in any long-term measurement programme, to have dedicated staff to service the equipment and to collect the data. Each of the Super sites have very experienced staff who have worked in the region for many years. They have built up good relationships with the local people and have experience of the sophisticated equipment comprising the flux systems.

WP 4.2.3 indicated that the "training of African scientists and technicians is a very important component of the activity of European teams involved in LOP-EOP" This is still the required aim; to employ and train local African researchers to operate and maintain the equipment, download and analyse the data and either write scientific papers or contribute to the writing of those papers. However, it has proved difficult to identify suitable local staff to maintain the novel and instrumentally sophisticated HFS, Mk4 and similar flux systems and currently there is no general solution within budget. The priority for CEH and Ocean Scientific International Ltd (OSIL) has been to build and deploy these systems before the first SOP which has left little time to organise structured and comprehensive training before the systems were installed. More effort needs to be applied to find suitable African technicians and to train them sufficiently to be able to routinely run the flux systems

A local technician employed by the Institut d'Economie Rurale (IER) at the Bamba (Mali) site has been recruited. The remoteness of this site and the unavoidable short training programme given to him during the installation of the flux system has meant that currently data is sporadic from this site. The other sites in Mali are being operated by staff of IRD from Bamako (16 hours travel from Hombori) which is expensive and deflects IRD staff from their normal duties.

The situation in Niger and Benin, where field sites are no more than 1 hour from the main supersite centre, will be easier to organise and maintain. The Site Captains at Niamey and Djougou have identified competent researchers to undertake the maintenance and data collection from the flux systems. In Niamey, this is Manon Rabanit (IRD) and at Djougou Simon Alloganvinon (University of Cotonou).

At the Mali Supersite around Hombori, Dr Eric Mougin (Supersite Captain) and the staff of CESBIO will be conducting intensive vegetation surveys throughout the EOP and will provide the staff to service the flux systems at Hombori on a 3 week cycle. Currently, this is being performed by Ing. Franck Timouk (CESBIO, IRD) but it is highly desirable to find an African researcher to take on this responsibility. The northern site at Bamba is being serviced by M. Lamine Touré, chef d'antenne de conservation de la nature de Bamba. This site, due to its remote location, will only be serviced every 6 weeks. A strong linkage to IRD is important for transport and other logistics.

At the Banizoumbou, Niger supersite, Dr Luc Descroix (supersite Captain), Dr Bernard Cappalaere, Dr Jean-Louis Rijot have project interest in the flux data. Mme Manon Rabanit and will be involved with the collection and use of the flux field data.

At the Djougou, Benin supersite, Drs Sylvie Galle and Christophe Peugeot (supersite Captains) will be requested to assume overall responsibility for the supervision of the maintenance of the flux systems and the collection of the data.

4.2 Training programme

Training is an important component of the AMMA programme and OSIL UK and CEH Wallingford will provide suitable training in understanding the design, technical specification and field operation of the flux systems. Of equal importance when operating flux systems is an appreciation of the micrometeorology of the local region around the flux system. A short and concise training package will be created that provides field operatives with the background knowledge to appreciate the operation of the flux systems and the micrometeorology of the flux station site. Training will be given locally on the operation of the measurement systems but funding is being sought to allow a Workshop to be convened in west Africa that will provide a much wider appreciation of the measurement techniques, operation and use of the resultant data. Close collaboration with ST4 on this latter topic will help in identifying suitable candidates, training locations, possible funding and the workshop organisational aspects.

A workshop is being planned for the spring of 2006 in Cotonou, Benin to acquaint AMMA field scientists involved in the collection and analysis of flux data with pertinent aspects of micrometeorological theory and practice that will provide them with further information for the correct appreciation of the strengths and weaknesses of the eddy correlation method in the interpretation of the flux data.

5 Organisation of the TT.

5.1 Leaders, core group, membership

Drs Colin Lloyd and Chris Taylor will jointly lead the TT to provide an amalgam of observation and modelling (Colin Lloyd will spend some length of time in the field).

Surname	First name	email address	Function
TT Leaders			
Lloyd	Colin	crl@ceh.ac.uk	Surface Fluxes
Taylor	Chris	cmt@ceh.ac.uk	Land-Atmosphere Interactions
Core Group Members			
Boone	Aaron	aaron.boone@cnrm.meteo.fr	ALMIP modelling intercomparison
Cappelaere	Bernard	Bernard.Cappelaere@msem.univ-montp2.fr	TT4 Niger & surface interactions
Diedhiou	Arona	diedhiou@ird.ne	AMMA-AFRICA: Meteo-France
Ottlé	Catherine	catherine.ottle@cetp.ipsl.fr	Land surface modelling; Satellite
Serça	Dominique	serd@aero.obs-mip.fr	Benin Flux and Chemistry measurements
Timouk	Franck	Franck.timouk@cesbio.cnes.fr	TT3 Mali Flux measurements & Satel.
Other members			
Beljaars	Anton	Anton.beljaars@ecmwf.int	Numerical Weather Prediction
Boulain	Nicolas	Nicolas.Boulain@msem.univ-montp2.fr	TT4 Niger: API flux measurements
Cohard	Jean-Martial	jean-martial.cohard@hmg.inpg.fr	TT5 Benin Scintillometry
Descroix	Luc	descroix@ird.ne	TT4 Supersite Captain
Fink	Andreas	af@meteo.uni-koeln.de	Benin (Parakou) Flux measurements
Galle	Sylvie	galle@ird.fr	TT5 Benin Supersite Captain
Hanan	Niall	niall@nrel.colostate.edu	Afriflux
Laurent	Jean-Paul	jean-paul.laurent@hmg.inpg.fr	
Marticorena	Béatrice	marticorena@lisa.univ-paris12.fr	TT2b EOP/LOP Aerosols
Morse	Andy	A.P.Morse@liverpool.ac.uk	Disease Vector Modelling
Mougin	Eric	eric.mougin@cesbio.cnes.fr	TT3 Mali Supersite Captain
Norgaard	Anette	an@geogr.ku.dk	Senegal: remote sensing
Parker	Doug	doug@env.leeds.ac.uk	AMMA-UK Leader
Peugeot	Christophe	cpeugeot@ird.fr	TT5 Benin Supersite Captain
Rabanit	Manon	rabanit@ird.ne	Niger Flux measurements
Rajot	Jean-Louis	rajot@ird.ne	Niger: Dust deposition, Aerosols
Sandholt	Inge	is@geogr.ku.dk	Senegal: remote sensing
Slingo	Tony	as@mail.nerc-essc.ac.uk	ARM Facility, Niger
Kounouhéwa	Basile		African Representative, Benin

5.2 Internal coordination

Diffusion of information will be made by email using the member list above. A web-based mailing list has been set up using the UK academic ISP Jiscmail. This mailing list and its archives is visible to the whole AMMA community and items can be posted to the list by registered members. The mailing list can be found at: http://www.jiscmail.ac.uk/lists/AMMA-SURFACE-FLUXES.html

This mailing list has, as one of its functions, to provide for the rest of the AMMA community, up to date information on such items as instrumental deployment, travel plans, site visit reports, data reports, data availability and problems.

5.3 Request handling for new instruments

There is no money in either the AMMA-EU or AMMA-UK budgets to purchase new instruments. Instruments that will be of use at some sites include a PAR (Photosynthetically Active Radiation) sensor, an NDVI (Vegetation Index) sensor, a soil heat flux plate and an Infrared thermometer to measure soil surface "skin" temperature. The ability to plug these instruments in to the Flux Systems is provided. Funds will then need to be sought to purchase these sensors. Any other requested instruments to run concurrently with the Flux Systems will need separate power, logging and data collection facilities which would require negotiation with Site Captains with regard to the training and extra workload placed on researchers currently engaged in servicing the Flux systems.

5.4 External diffusion of the information and reporting

External diffusion of information will be subject to the dissemination rules decided within AMMA. News items and contact information in the first instance will be provided via the AMMA International Implementation Web Page. The TT will report to the appropriate organisational and funding bodies, i.e. ICIG, AMMA-EU and the relevant national programmes.

6 Coordination with other TTs.

Coordination with the other task teams will initially be through diffusion of information via email and the mailing list site described above. In particular, the following strong linkages will be maintained.

TT2b	Coordination with boundary layer radiation measurements
TT3	Coordination with the intensive vegetation, soil moisture and soil respiration studies. Coordinate to provide efficient and cost-effective logistical arrangements
TT4	Coordination with the catchment and sub-catchment hydrological studies. Coordinate to provide efficient and cost-effective logistical arrangements
TT5	Coordination with the ongoing hydrological and vegetation studies. Coordinate to provide efficient and cost-effective logistical arrangements
TT7	Coordination and comparison with the larger scale radiation, sensible and latent heat fluxes.
TT8	Coordination and comparison with the mesoscale modelling aspects of the surface flux regime. Coordination with the experimental aspects of this TT.