1.3 Land surface-atmosphere feedbacks

Coordination: Jan Polcher and Nick Hall
Laboratories: IPSL, CESBIO, HSM, LTHE, CNRM

General Objectives

The interaction between the land surface and the atmosphere is a controlling factor for the development of the west African monsoon. The land surface and the atmosphere are two components of a coupled system, and each influences the other on a range of time and spatial scales. The coupled nature of the system is further complicated by the fact that the different scales are also coupled: small scales influence the larger scale and vice versa. This doubly coupled aspect, together with the wide range of processes implicated, makes the west African monsoon a particularly challenging system to describe and to simulate. The ultimate goal of a fully coupled modeling system with two way interactions between land and atmospheric components and between scales must necessarily be broken down into more manageable tasks that can provide insight into the processes at work. In this integrating work package we present a coherent strategy to draw on the individual modelling and observing efforts taking place elsewhere in the project to address the problems associated with land-atmosphere feedbacks. The problems we face can be posed in terms of the following questions:

- How does the land surface integrate the atmospheric input (fluxes and precipitation) at different scales ?
- What are the spatial characteristics of the resulting land surface state ?
- How does the spatial signature of the land-atmosphere exchanges agregate to influence the state of the atmosphere and the associated convection and rainfall ?
- What is the effect of heterogeneities in surface exchange on mesoscale convection ?
- How does temporal heterogeneity in the surface state affect the atmosphere above (the memory effect) ?
- How important are these effects relative to external influences such as the sea-surface temperatures ?
- How are the feedback processes simulate at the mesoscale by convection resolving models represented at the global scale ?

The order of these questions reflects to some extent the scientific strategy envisaged to answer them. We break into the coupled system by considering one-way influences, first from data-derived atmospheric states to the land surface, then from the land surface response back to the atmosphere. Integrating the work done in work packages 4.1, 2.3 and 2.1, the approach is first to force land surface models with atmospheric data – including data collected in the SOP/EOP, and then in turn to force atmospheric models with the surface states generated by these land surface modelling experiments. The approach is presented in illustration 1. The objective is to learn enough from this offline coupling approach to understand better the fully coupled system. The final outcome of this exercise is to compare the coupling simulated by mesoscale models with the one assumed in surface, planetary boundary and convection parameterizations of large scale models. This confrontation will provide the knowledge needed to understand the relative impact of surface processes in the evolution of the monsoon and the potential impact of surface perturbations.

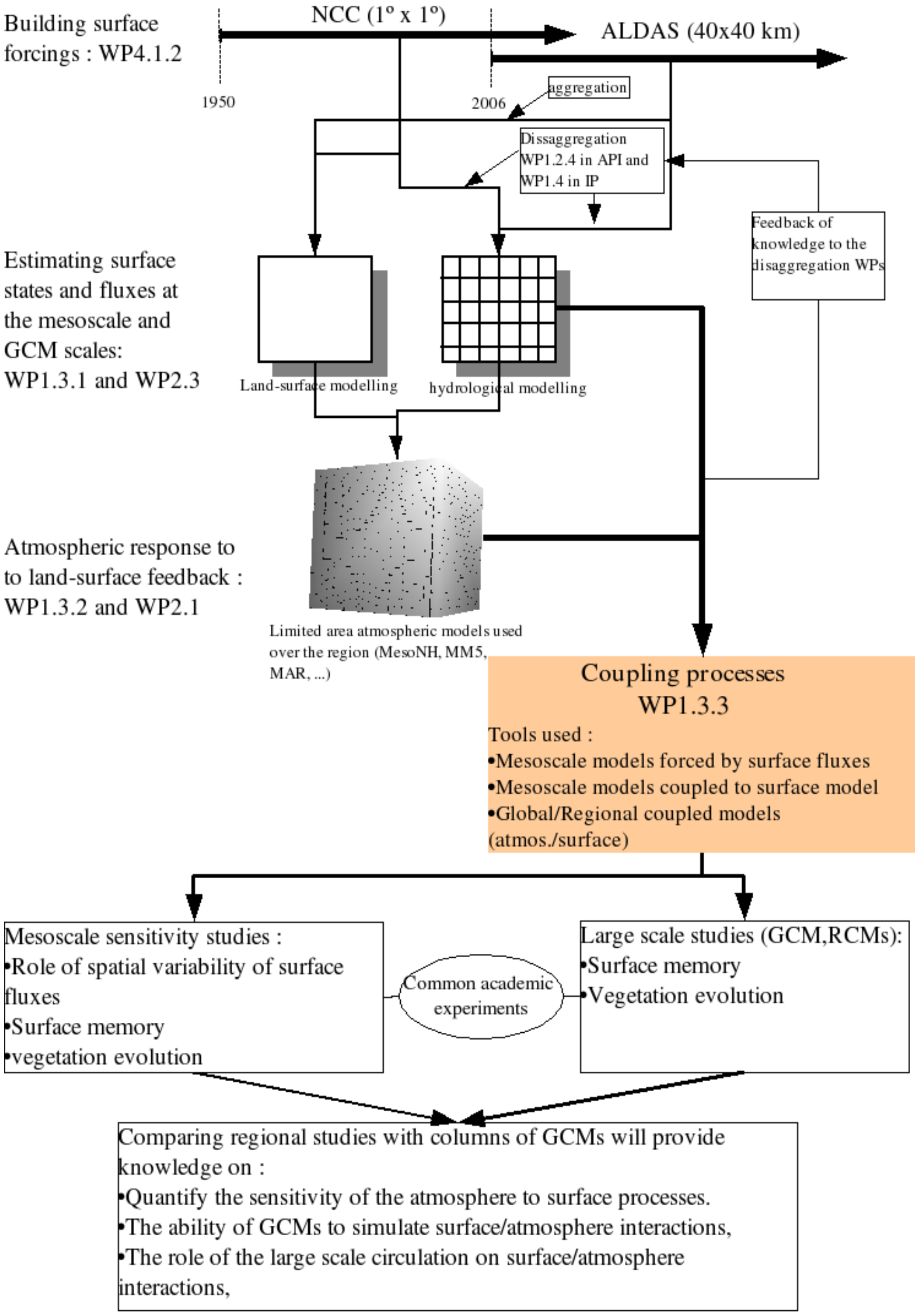

Figure 1 : Strategie proposed for WP 1.3

To help clarify the steps to be taken and the relation with other work packages involved, this work package split into three sub packages:

- 1.3.1: *Land surface processes and atmospheric forcing*, which details the plans for use of observations and experiments with land surface models.
- 1.3.2: *Atmospheric response to land surface processes,* which discusses the experiments to be performed with atmospheric models at the mesoscale.
- 1.3.3 *Coupling processes* confronts the mesoscale and the large scale view of the coupling processes in order to asses the role of surface processes in the West African Monsoon.

1.3.1 Land surface processes and atmospheric forcing

1.3.1.a 5 year Plan

Coordinator: To be determined
Laboratories: IPSL, CESBIO, HSM, LTHE, CNRM

Objectives

The objective of this sub work package is to use the land surface model experiments carried out in part in WP2.3.3 to assess the role of atmospheric conditions on land surface processes, to perform case study experiments based on forcing data from the EOP and SOP, and in turn to provide surface conditions for the atmospheric model experiments in 1.3.2. This subject has strong links with WP2.3.3, where land surface models are developed and tested with observed surface conditions. Here the emphasis is on the impact of the atmosphere on surface processes and in particular the role of spatial heterogeneities of the atmospheric forcing.

Before tackling a fully coupled problem at mesoscale it is important to understand the behaviour of the different components of the system. This necessitates an offline coupling approach for which the first step is to force land surface models with the best flux observations available. The land surface models described and developed in 2.3.3 will then be interrogated for their surface flux heterogeneity at the sub-mesoscale, a property thought to be partially forced by the atmosphere and of critical importance for the subsequent atmospheric response. The work to be done in this subsection can be broken down into three steps:

1) Initial experiments with land surface models using a range of idealised forcing heterogeneities to gauge sensitivity.
2) Preparation of input data emanating from SOP/EOP for case study experiments (link with WP4.1.2).
3) Analysis of the change in surface conditions owing to the land surface response to this forcing: in particular its heterogeneity.

Work content

- Initial land surface sensitivity experiments carried out in 2.3.3 analysed for their feedback potential.
- Land surface response to precipitation input typical to different regions (Sahelian, Sudanian) analysed for feedback – especially the “memory effect”. To be studies with land-surface models at different scales.

- LOP/SOP data from surface flux stations, precipitation estimates and airborne campaigns collated for input into ALDAS data assimilation program (cooperative work with European project).
- Adaptation ALDAS product for forcing land surface models at mesoscale and finer scales.
- Choice of appropriate land surface model product to provide forcing for atmospheric simulations at various resolutions to be carried out in 1.3.2 and 2.1.1.
- Preparation of all necessary land surface model output variables to provide boundary conditions for mesoscale atmospheric models.
- Upscaling of land surface model output to provide estimations of the role of heterogeneities forced by the atmosphere for large scale models (GCMs and RCMs).

Foreseen deliverables

- Report documenting time and space variability of surface properties over the course of the EOP, identifying dominant feedbacks in the system.
- Report documenting land surface response heterogeneity to observed (assimilated) EOP era atmospheric conditions.
- Assessment of land surface sensitivity to a range of idealised surface rainfall characteristics, with particular reference to feedback on the atmosphere.
- Provision of surface boundary conditions for a suite of mesoscale atmospheric model experiments based on idealised experiment and SOP/EOP case studies.
- Provision of upscaled surface flux and soil moisture data for GCM studies.

1.3.1b 2004 Activity report

Activity in 2004 has been limited to planing and discussion of scientific directions, resulting in a redefinition of the objectives and scope of this work package

1.3.1c 1-year Plan

Objectives

For 2005 the objectives of this work package will mostly be carried out under WP2.3.3 where initial experiments with land surface models will start to yield the necessary information on the nature of the land surface response in the different climate bands representative of West Africa. The ALDAS assimilated product will not be available until early 2007 so all that can be done is preliminary experiments with a atmospheric forcing variables at a coarser resolution. This data set will furthermore have the advantage of existing over 50 years and thus providing a historical context.

Work content

- An assessment of which properties are to be exchanged between initial data and surface models and in what format.
- Preparation of idealised forcing experiments representing differing precipitation regimes.
- Assessment of scaling properties of response and strategies for upscaling.
- Preparation of output protocols for the forcing of atmospheric models.

Deliverables

- Transfer of information and techniques from the general WP2.3.3 to the specific needs of WP1.3.

1.3.2 Atmospheric response to land surface processes

1.3.2a 5 year Plan

Coordinator: To be determined
Laboratories: IPSL, CESBIO, HSM, LTHE, CNRM

Objectives

This sub work package contains the second half of the experimental design for the investigation of land surface-atmosphere feedback, in which an atmospheric mesoscale model, which resolved explicitly the African convective systems, is forced by fluxes of heat and water vapor produced with the land surface model experiments to be defined under 1.3.1 and carried out in 2.3.3. While a comprehensive treatment of the full coupled problem at all scales is still judged to be beyond the scope of this investigation, much can be learned from an exercise where we simulate the atmospheric response to a land surface state which is itself a response to imposed atmospheric conditions. The degree of consistency between the atmospheric model and the original atmospheric input data will provide insight into a number of important phenomena, including:

- The role of small scale surface heterogeneity in modifying the mesoscale atmospheric response.
- Identify the large scale situation which allow the surface heterogeneities to express themselves in the local atmospheric processes.
- The importance of surface memory effects on the local level.

In parallel with the mesoscale modelling work, work with GCMs on the regional scale is ongoing, and some of the same questions will be addressed at these larger space and timescales. In particular the memory effect can also be investigated on a seasonal basis at large scale. The evolution of vegetation cover both on seasonal and interannual timescales is also of central importance to AMMA, both in terms of climate feedback and changes in land use.

The ultimate goal of this research is to gain insight into surface/atmosphere feedbacks at a scale at which they can be explicitly simulated to to a large extent. This will provide invaluable information to sensitivity of large scale models to surface processes.

Work content

This work is strongly linked to the work on mesoscale boundary layer simulations carried out in 2.1.1, where previous experience with the IHOP field campaign is brought to bear on the evaluation of the influence of surface heterogeneity. Initial sensitivity experiments at the mesoscale will be carried out under 2.1.1. There are many problems to be solved in terms of experimental design because a key difficulty in this work is the separation of the signal coming form the local surface from the larger scale environmental influence. The problem is interactive, and case dependent, so much care needs to be exercised if robust conclusions are to be drawn. The main thrust of the investigation must necessarily wait for SOP/EOP data, and the results from 1.3.1. At this point it will be possible to work with a range of case studies and use the results to inspire further sensitivity experiments with a view to achieving a statistically robust set of conclusions.

Specific actions will be:

- Mesoscale simulations under 2.1.1 with a range of surface flux scenarios designed to test the effect of surface heterogeneity at sub-mesoscale.
- Pre-ALDAS case studies based directly on historical boundary and surface conditions.
- Further mesoscale case studies based on output from land surface simulations carried out in WP1.3.1.
- A suite of experiments designed specifically to isolate the effects of the local surface from the influence and interaction with the larger scale environment.
- Further experiments focussing on the surface memory effect at the mesoscale.
- Quantitative and qualitative comparisons of model generated precipitation with the original precipitation used to force the land surface simulations. This has direct implications on the kind of conclusions which can be drawn from these experiments on the relative roles of local and remote influences .

Foreseen deliverables

- An assessment of the effect of sub-mesoscale heterogeneity in the land surface feedback on atmospheric convection and rainfall at the mesoscale.
- An assessment of the relative importance of local surface and remote influences on rainfall in different climatic regions based on case studies and carefully constructed sensitivity experiments.
- An improved understanding of the memory effect both at mesoscale over a few days and at regional scale over a seasonal to interannual timescales.
- Recommendations for new methods of parameterising surface flux heterogeneity in land surface/convection exchanges in GCMs.

1.3.2b 2004 Activity report

The studies were conducted in the framework of the IHOP_2002 (International H2O Project) experiment held in the southern great plains (SGP) of Oklahoma in May-June 2002. IHOP_2002 is a project that has several similarities with AMMA :

- the scientific objectives are similar (water vapor variability in the PBL and convection initiation),
- the SGP display a zonal gradient of land use and soil moisture whereas the AMMA target area display a meridian gradient,
- the instruments deployed during IHOP_2002 are those that will be deployed during AMMA (water vapour DIAL lidar LEANDRE-2, GPS, S-POL radar, energy budget measurements, radiosoundings,…).

The work consisted in mesoscale numerical simulations with the NCAR-University of Pennsylvania MM5 model initialized and forced by (i) ECMWF analyses for both the atmosphere and the surface; and (2) by ECMWF analyses for the atmosphere and by soil moisture and temperature from a high resolution land data assimilation system (HRLDAS, developed at NCAR) at the surface. This method was applied to a boundary layer heterogeneity (BLH) case (29 may 2002). This study showed that:

- the ECMWF/ECMWF simulation induces an inaccurate horizontal pattern for soil moisture and temperature, leading to large overestimation of atmospheric water vapor in some area within the domain (a comparison was made with the ground-based measurements, LEANDRE-2 and the radiosoundings). A good agreement is found with the observations with the wind and temperature fields.

- the ECMWF/HRLDAS simulation (i.e. forced at the surface with HRLDAS) is in better agreement with the observations in terms of water vapor concentration and PBL depth. The atmospheric wind and temperature fields are comparatively much less sensitive to the surface property change.

This work was conducted in cooperation with Cyrille Flamant and Philippe Drobinski at IPSL/SA and with Fei Chen and Kevin Manning at NCAR. The results were presented at the Ateliers de Modélisation et l'Atmosphère 2004 (Bastin et al. 2004).

1.3.2c 1-year Plan

Objectives

For the one year time frame it is obviously impossible to work with the output of land surface models that are still being developed. Mesoscale and GCM modelling will therefore continue in the vein of sensitivity studies and historical case studies under WP2.1.1 and 4.1.3.

Work content

Mesoscale experiments based on historical case studies (WP2.1.1)
Mesoscale sensitivity studies to look at the influence of surface heterogeneity (WP2.1.1)
GCM soil moisture sensitivity studies (WP4.1.3).

Deliverables

There are no specific deliverables for one year other than experience gained and planning of future experiments.

1.3.3 Coupling processes

1.3.3a 5 year Plan

Coordinator: *To be determined*
Laboratories: IPSL, CESBIO, HSM, LTHE, CNRM

Objectives

This sub work package integrates the accomplishments of the previous two sub-WPs and extends them to the global scale.
The experiments which can be done at the mesoscale are limited by the fundamental hypothesis that the local surface/atmosphere interactions do not affect the large scale forcing. This is inherent in the convection resolving models used as the large scale forcing is imposed.
On the other hand GCMs and RCMS represent the surface/atmosphere feedbacks under the premise that small scale heterogeneities do not impact these interactions. Even if the parameterizations of surfaces, boundary layers and clouds integrate some notion of heterogeneity their interactions assume

that spatially homogeneous fluxes are exchanged. In the case of RCMs the large scale forcing is imposed as in mesoscale models. Thus they offer an interesting intermediate tool in this integration of scales.

In order to make progress in the understanding of the land-surface atmosphere feedbacks it is essential to confront these contrasting views and produce a more fundamental understanding of these key processes of the West African Monsoon.

This will be achieved through the following steps :

1. Identify the rain producing systems which are explicitly represented in mesoscale models and the properties of which can be studied in GCMs and RCMs. This will set the metric used to compare the models results at the various scales.
2. Design model experiments based on the mesoscale studies which can be performed at all scales. It is likely that these experiments will be of a more academic nature but they need to be inspired by the results at the mesoscale.
3. Based on the results of the mesoscale models the results of the GCMs can be evaluate and their sensitivity to surface processes assesed.
4. Based on this knowledge and the enhanced confidence in the sensitivity of GCMs the relative role of surface processes and sea-surface temperatures can be evaluated.

Work content

- Based on results of subWP1.3.2 identify the rain producing systems with the strongest dependence on surface conditions. Describe their properties and sensitivities.
- Elaborate the diagnostic which identifies the corresponding systems in GCMs.
- Define the criteria on which the surface atmosphere feedbacks can be evaluated in both models.
- Identify from the work in subWP1.3.2 cases with the most pronounced feedbacks which affect the rainfall in the region.
- Design a numerical experiment for which the outcome in mesoscale and large scale models can be compared. This experiment will either deal with the impact of soil moisture or the rapid evolution of the vegetation at the start of the rainy season.
- Perform the experiments and compare the results based on the diagnostics defined above.
- Evaluate the outcome of the experiment and draw a conclusion on the usability of todays GCMs for sensitivity experiments.
- Evaluate the impact on the large scale circulation and the validity of the the mesoscale simulations.
- These two last result will guide us on the priorities of pursuing either of the following two paths :
    1. Improve the parameterization of the surface atmosphere feedbacks in GCMs and RCMs. This work would be done in collaboration with WP2.1 and WP4.1.
    2. Advance our understanding of the relative role of surface processes in the evolutions of the monsoon relative to the impact of sea-surface temperatures.

Foreseen deliverables

- An experiment to compare the surface atmosphere feedbacks over a range of scales
- A critical evaluation of the ability of regional and large scale models to simulate the surface atmosphere feedbacks which were revealed by mesoscale models.
- An evaluation of the impact of surface processes on the large scale circulation
- The relative role of land-surfaces and sea-surface temperature on the evolution of the West African monsoon.

1.3.3b 2004 Activity report

Activity in 2004 has been limited to planing and discussion of scientific directions, resulting in a redefinition of the objectives and scope of this work package

1.3.3c 1-year Plan

Activities of the this sub-WP will only start in 2007 when 1.3.1 and 1.3.2 will be well advanced.