4.1.3 Representation of the WAM and atmospheric composition in regional and global models

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Objectives

This work package concerns assessment of the model capabilities that are used in the AMMA integrative science studies (WP1) and impact studies (WP3). Assessment will concern **(A)** the simulation of the WAM and its variability (from intra-seasonal to interannual), **(B)** the representation of the distribution of trace species (O3, OH, NOx, hydrocarbons, …) and aerosols (dust, carbonaceous aerosols, ..) over west Africa, both during summer and winter.
The models include forced and coupled global climate models, regional models nudged by analysis as well as off-line chemistry/transport models. This range of models will enable an estimation of uncertainties in our current predictive capability. A major point of WP4.1.3 will be **(C)** the improvement and evaluation of parametrizations of large-scale models using the results of meso-scale simulations of particular situations documented during the SOPs. This approach, originally developed to evaluate and improve parametrizations of climate models, will be extended here to the coupling with surface schemes and aerosols microphysics and chemistry. The proper representation of atmospheric transport and WAM will be a key issue for the performance of the chemistry-transport models in AMMA.
WP2.x delivers the (improved) descriptions of the key processes concerning convection and atmospheric transport, surface processes, coupling with ocean, chemistry and aerosols (in particular atmospheric sources and surface emissions) and coupling mechanisms (through radiation and/or cloud schemes). This work package will objectively assess the improvements gained by the AMMA observations and process studies by targeted model inter-comparisons and by comparison with satellite observations, and independent observations made during LOP, EOP & SOP of AMMA.

Link with other packages

This work package establishes a link between all "integrative sciences" (WP1x) or "impact studies" (WP3) and "process studies" (WP2x). It will provide better numerical tools suitable to study the WAM system in other WPs and provide improved forecasting system during the campaign.

4.1.3.a 5-year plan

Work content

A) Evaluation of global and regional models capability to simulate the WAM

- **Review previous work** that tried to assess the skill of global and regional models to represent the WAM variability, in particular WAMP European project, IMPETUS and AMIP project.
- **Define relevant diagnostics to characterize the WAM** (cloud and precipitation distribution, jet structure, position of the ITCZ, soil variability, teleconnections with other regions, etc.), from its intraseasonal to interannual variability (together with WP1.1). Specific attention will be paid to diagnostics that characterize the whole WAM system such as water and energy budgets. Diagnostics will also be designed in terms of a mean meridional vertical slab in the WAM region, following the approach proposed by Siebesma et al. (2004) for the Tropical Pacific area.

- **Evaluate the global** (ARPEGE/ISBA/ORCA, LMDZ/ORCHIDEE/ORCA in coupled and forced models) **and regional** (zoomed versions of the same models, MAR, MM5, RegCM) **climate models as well as meteorological predictions of chemistry transport models** (RAMS, MOZART, Meso-NH, TM4) based on the above diagnostics. This part concerns models involved in AMMA but also results from other models made available through international programs such as AMIP, ENSEMBLES, MERESEA, ... A particular attention will be paid to the evaluation of the coupling with continental surface processes and subgrid-scale hydrology (LMDZ/ORCHIDEE, ARPEGE/ISBA, MAR/abc).
- **Evaluate the skill of the various coupled models** (in particular those used in the ENSEMBLE project) to simulate the WAM. Evaluate the interanual variability predicted by coupled models including decadal and climatic scales (paleo-climates).
- **Design of ad hoc sensitivity experiments** to complete the intercomparison exercise in order to identify the weakest element of the system. This will concern in particular the sensitivity to key processes such as convection parametrizations and coupling with surface schemes as well as scavenging associated with entrainment and detrainment linked to condensation and evaporation processes.
- **Evaluate seasonal forecasting.** Realisation and evaluation of ensemble runs starting at the beginning of each month during the campaign. Simulations are done with ARPEGE-Climat T63 forced by SSTs predicted by a statistical model or coupled to ORCA2. Evaluate the DEMETER seasonal forecasts over West Africa and rerun a subset of the DEMETER forecasts with an improved atmospheric physics and/or an improved land surface initialization.

B) Evaluation in terms of the simulation of the distribution of aerosols & trace gas.

- **Selecting existing observational data** on atmospheric composition to evaluate regional and global (chemistry-transport and chemistry-climate) models used in AMMA
- **Defining numerical experiments** to generate model output for comparison with existing observations, and existing chemical analyses such as from ASSET FM5 and from the GEMS proposal, in order to test different (1) mineral and biogenic aerosol distributions, (2) atmospheric transport and chemistry distributions, (3) descriptions of sources / sinks of aerosols and trace gases, and (4) coupling schemes of atmospheric composition with dynamics.
- **Evaluate model performances of several global chemistry transport or chemistry-climate models** (LMDz, MOCAGE, MOZART) and **regional chemistry models** (Meso-NH, RAMS, CHIMERE) using existing data to identify deficiencies in model parametrization schemes (e.g. convection). Assess the ability of models to capture particular events (e.g. long-range transport out of West Africa seen in MOPITT CO data, GOME NOx data, for dust : SeaWifs, POLDER and MSG data for high resolution simulations and Meteosat and TOMS for long term simulations). Assess of the long-term variability of the mineral dust cycle (CHIMERE)
- **Assess the sensitivity of the aerosol and trace gas distributions to different representations of key processes** (dust mobilisation, lightning NOx emissions, biomass-burning and biogenic emissions, mixing between fires plumes and dust, inter-action between African dust and European emissions, convective transport) related to the WAM (input from WP2). In particular, this point will require implementation of improved lightning NOx production (MesoNH, RAMS, LMDz), implementation of new emission of biogenic NOx, VOC, biomass burning and fossil fuel aerosols (TM4, RegCM3, MOZART) as provided from WP2.4. A particular attention will be given to the representation of the dust emissions, vertical transport and dry/wet deposition during squall lines

events in order to estimate the budget of the dust emissions at the regional scale (RAMS, CHIMERE).

- **Evaluate radiative feedbacks on the WAM**. Evaluation of the sensitivity of WAM simulations (i.e. dynamics and chemical composition) to different ways of coupling the aerosol/trace gas distributions and the model physics/dynamics (direct radiative impact of aerosols; effect of CCN on cloud processes). Coupling of aerosols with clouds microphysics and radiation (LMDz, RAMS, MesoNH). Evaluation of radiative effect of dust on the moving of WAM. Assess the effects of two-way coupling the atmospheric composition, in particular aerosols, with the model dynamics (LMDz, RAMS, MesoNH). Assess the effect on atmospheric composition as well as on e.g. cloud formation and precipitation.

C)Improvement of atmospheric parametrizations.

The improvement of atmospheric parametrizations is based on a hierarchy of models, including non-hydrostatic CRMs to provide a link with in-situ observations during the SOPs.

- **The simulations performed with Cloud Resolving Models (CRMs) of typical convective events over West Africa (performed within WP2.1) will be used to force Single Column Models (SCM) in order to test and improve available parametrizations** of dry and moist convection. This methodology has already been applied successfully for the EUROCS project. ARPEGE-SCM will be used to implement the various cases. The physical package of LMDZ will be interfaced within ARPEGE-SCM to provide a common tool for intercomparison and validation of the parametrizations of ARPEGE and LMDZ (already started in the frame of the "physique commune" project).
- **Extension of the above methodology to the parametrization of the transport of trace species, chemical compounds and aerosols** by boundary layer turbulence and convective systems.
- **Extension of the above methodology to the coupling with surface processes.**
- **Extension of the above methodology to a 2D framework.** Development of a novel 2D approach, intermediate between the 1D framework (which prevents retro-actions from the large-scale circulations) and fully coupled complex 3D large-scale models. The idea is to analyse the coupling between parametrizations and the larger-scale within a 2D latitude-altitude model of the WAM adapted from Meso-NH, and if is affected or not by changes in parametrizations, and how.
- **Extension of the above methodology to a simplified aqua-terra GCM**. This approach will allow to get further insight into the retro-actions between the parameterisations and the large-scale circulations, in particular through the explicit treatment of easterly waves.

The improvements will concern the following points.

- **Improvement of planetary boundary layer schemes** (Mellor and Yamada, TKE prognostic scheme, mass flux thermal plume model) with a particular focus on the Saharian PBL, heat low, transport of aerosols and gases, as well as coupling with clouds and convection (ARPEGE and LMDZ).
- **Imrpovement of the parametrization of moist convection** with emphasis on the representation of triggering, propagation and interaction with dry mid level layers (according to WP2) as well as representation of the diurnal cycle of convection and convective downdraughts with Bougeault, Tiedtke, Emanuel and new Arpege schemes. Inclusion of tracer transport in the above parametrizations. Parametrization of in-cloud microphysics and scavenging.

- **Introduction and test of a parametrization of density currents or WAKE** generated by the downdraughts of the moist convection. This parametrization may be used also to predict dust mobilization.
- **Improvement of the interplay between parametrizations**, including surface, planetary boundary layer, moist convection and cloud schemes.

The improvements will be assessed the climate and chemistry transport model.

<u>Strategies for the use of AMMA observations</u>

The strategy of use of observations for validation of atmospheric-transport models depends on the particular models and type of observations, notably as a function of their respective scales.

Satellite data (in particular those available on the AMMASAT database) are the most adapted for validation of global or regional models. This is true both for climate and chemistry. The satellite observations are however indirect and not always easy to relate to model variables. One possible approach, which is still under discussion in the frame of AMMA, is the development and use of a model-to-satellite approach. This helps for some points but do not solve all the problems by far.

The use of in-situ observations (including active and passive remote sensing from the surface or aircrafts) is most generally subject to a problem of representativeness.

- Results from chemistry-transport will be compared directly to in-situ observations. For off-line models or nudged on-line models, the comparison can be done day after day. Far enough from local sources, concentrations of aerosols and chemical compounds are in some cases smooth enough so that direct comparison with observations is meaningful. This is true in particular for near surface concentrations. Representativity is more an issue for the free troposphere where layering, not captured by large-scale models, is often observed.

- For regional models, budgets for various species (inert like CO, primary species like NOx or secondary species like ozone) will be analyzed inside domains containing convective cell or ITCZ region to evaluate the detrainment and entrainment processes.

- For climate models, the problem of representativity of in-situ measurements is generally more serious. A very important link with AMMA observations will be through meso-scale modelling of SOP observations performed in the frame of WP2.4 and used as a reference for the validation of atmospheric parametrizations (as explained above).

- Nudged versions of general circulation models may be used for direct comparison with in-situ observations. This strategy, tested with some success in the mid-latitudes, may be less efficient in the frame of AMMA, for which analysis may be much less reliable and the local meteorology less constrained by the synoptic situation. The method could be significantly improved by introducing information on the location of convective systems based on satellite images. Such a strategy is developed for operational analysis in the framework of AMMA. A similar strategy will be envisaged for the LMDZ climate model.

- A particular set of data which may be particularly useful for climate models is the documentation of the meridional dependence of turbulent fluxes in the boundary layer both by flux stations and aircrafts during SOP1. The problem of representativity could be partly overcome for the flux stations by the fact that different types of vegetal covers will be continuously sampled at each of the 3 main sites along the main transect and for the aircraft measurements by the length of the flights. Those measurements will be anyway very useful in view of the importance of this near surface fluxes for the AMMA perspective and of the lack of other relevant data.

Foreseen deliverables

- Evaluation of the global and regional model of climate and chemistry available at the beginning of the study.
- Improved global and regional climate models and chemistry transport models for integrative science (WP1) and impact studies (WP3).
- Assessment of the improved models.
- Assessment of the effect on the model skill of the two-way coupling of aerosol distribution and dynamics.
- A parameterisation of the emission and deposition of mineral dust by the squall lines.
- A regional budget of the dust emissions and deposition in the Sahel.
- Climatology of the regional cycle of mineral dust over western Africa and assessment of the radiative effect on the moving of WAM.
- The identification of the respective influence of the meteorological variability and land use change in the long-term variation of the atmospheric dust content.
- Modelling systems that combine explicit large scale dynamics with statistically driven proxy precipitation outputs
- A computationally light approach to dynamically driven climate variations in a realistic framework.

Model configurations to be assessed for AMMA

A description of the various model has been made available on http://www.lmd.jussieu.fr/~hourdin/AMMA/MODELS or on file "Fiches modèles"

Models	Domain	Horizontal resolution	Typical length	Offline/Online/ Meteo nudging	Chemistry /aerosols	Real time during SOPs
ARPEGE	Global	T63	Pluri-annual	climate simulations	No	Seasonal ensemble forecasts
ARPEGE/OPA coupled model	Global	T63	Pluri-decenal	climate	No	Seasonal ensemble forecasts
ARPEGE/ mediterranée	Global +zoom over WA	80 km over WAM		climate	No	
LMDZ/ORCHIDEE	Global	400 km and 200 km	Pluri-annual	climate	No	
LMDZ/ORCHIDEE /ORCALIM coupled model	Global	400 km	Pluri-decenal	climate	No	
LMDZ/ORCHIDEE	Global +zoom		Pluri-annual	nudging	No	X
LMDZ-INCA (LSCE-SA-LMD)	Global +zoom	Version zoomée pour AMMA (50km)		Online Nudging ECMWF	Yes	
MAR/abc	Regional WA	40 km	Season to pluri-annual	Forcing at the boundaries	No	
MOCAGE (CNRM)	Global +zoom over WA	2° (globe) ; 0.4° (continental zoom)		Off-line (ARPEGE, ECMWF)	Yes	
CHIMERE (IPSL/LISA)	regional to north Atlantic	2 to 50 km	A few dys (CTM) to pluri-an. (dust)	offline (ECMWF/MM5)	Yes	Yes
MOZART (SA)	Global	T63	Pluri-annual	Offline (ECMWF; ECHAM-5)	Yes	
TM4 (LA)	Global	3°x2°		Offline ECMWF	Yes	
Meso_NH (CNRM-LA)	Regional WA +nested grids	Nesting grids 40km to 1km	A few days	Online ECMWF MOCAGE ALADIN/ARPEGE	Yes	X
RAMS (LaMP + LPCE)	Regional WA +nested grids	Nesting grids 100km- 1km	A few days to 1 season	Online nudging ECMWF	Yes	

Specificity of chemistry/aerosols models

Models	Transport schema	gaseous chemistry	Aqueous chemistry	Aerosols chemistry	NOx from lightnings
MOCAGE (CNRM)	Semi-lagrangian advection, mass-flux convection (Bechtold or Tiedtke)	RACM + REPROBUS (118 species, strat. + trop. chemistry, including heterogeneous chemistry on PSC)	Wet scavenging of gases and aerosols (Mari, Giorgi-Chameides	in progress : dust emissions (LISA), sulfur cycle (LGGE-LOA),ORISAM (LA).	in progress
LMDz-INCA (LSCE)	Van Leer, Mass flux convection (Emanuel, thermal plume model)	NMHC (88 species)	Formation sulfates	SO4, BC, POM Dust, seasalt	Price+Rind Pickering
CHIMERE (LISA)	Mass flux, PPM and others	Melchior or Moca	yes	yes (+mineral dust)	no
MOZART (SA)					
TM4 (LA)	Slopes and Prather advection methods	CBM4	Wet deposition	In progress	Van Velthoven et al.
Meso_NH (CNRM-LA)	MPDATA Eulerian scheme	ReLACS (38 gaseous species) or RACM	Wet deposition coupled with mass flux in parametrized convection + wet deposition in explicit warm clouds	Organics Minerals BlackCarbon 20 aerosol species in two modes or 4-7 spectral bins	Implicit convection based on mass fluxes + lightning scheme coupled to cloud microphys.
RAMS (LaMP + LPCE)	Mass Flux	MOCA (29 species) or RACM (77)	Up to C2	Dust (spectral-20 bins), BC, SO4, Organics in progress	**Pickering**

4.1.3.b Progress report (expected to be done by the end of 2004)

A) Evaluation of WAM simulations.

- The strategy of model evaluation and inter-comparison has been defined further. From discussions during the Dijon meeting, it appears that the first expected output from climate models concerns the water budget, the seasonal cycle of rainfall (onset, break, jump, precipitation over Sahel) and impact on the surface. It has been decided that the validation will concern not only the global and regional climate models but also the `climate' of the chemistry-transport models.
- A climatology will also be designed as a mean meridional transect 10W-10E.
- The strategy of the use of climate models in AMMA has been defined further. On one hand, results of multi-annual simulations with forced SSTs will be made available on a database. Longest simulations with climate model will consist of ensemble simulations of the AMIP period (1979-2002) and C20C simulations forced by HadISST from 1860 to 2000. The shortest simulations will focus on 2000-2001 (also chosen as a test period for chemistry-transport models). The data will consist in a set of 2D variables (rainfall, winds, temperature and humidity at three pressure levels, ...) at a diurnal frequency on a domain 45W-120E, 45S-45N including part of the Atlantic ocean, Guinean gulf and tropical Indian ocean (the definition will be finalized at the beginning of 2005). On the other hand, studies requiring coding in the models or specific diagnostics will be done in coordination with the modelling teams.
- A preliminary inter-comparison using simple diagnostics will be done by the end of 2004 and presented at a meeting of the modelling part of AMMA-API, planned in early 2005.
- Realization of an ensemble simulation over the AMIP period with the IPSL climate model and a C20C simulation with ARPEGE-climat.
- IPCC simulations of the period 1860-2000 have also been performed with the same model versions.

B) Evaluation in terms of atmospheric composition

The strategy for the evaluation and intercomparison has been defined further. A first set of experiments will be performed with available surface inventory (as from GEIA) for the 2000/2001 period.

C) Improvement of atmospheric parametrizations.

- Development of the ARPEGE/LMDZ single column model. The implementation of the LMDZ physical package into ARPEGE single column model, started with old versions of both models, has been extended to the most recent versions: LMDZ4 and ARPEGE-cycle25. The new version has been tested on the TOGA-COARE squall line (Redelsperger et al., 2000) and Bomex test cases.
- The strategy of evaluation of atmospheric parametrizations of convection and boundary layer turbulence for chemistry-transport models has been defined further. Existing convective cases such as the HAPEX-Sahel case will be re-simulated with non-hydrostatic meso-scale models including tracer transport to serve as a basis for validation of parametrizations of tracer transport in a single column configuration. Other cases will be identified from regional simulations with chemistry transport models and non-hydrostatic simulations will be ran with simplified chemistry in addition to idealized tracers. The same approach will be applied after the campaign using the numerical experiments ran for SOP observations (WP2.4).

- A 2D latitude-altitude version of meso-NH has been developed in order to study the interaction between convection and the large-scale organisation of the WAM.
- Tracer transport has been included in the Emanuel convection scheme (LMDZ). The chemical composition obtained with this new version has been compared with that obtained with the standard version (LMDZ-INCA with Tiedtke convection scheme).
- The new ARPEGE physical package, calibrated in the frame of EUROCS and with the use of the SCM version, is already implemented in the GCM version since the mid-2004. A pronostic scheme is used for the CBR/TKE and for the Lopez/microphysics, in association with Gueremy/convection (Shallow and Deep). A tuning of the autoconversion for the transformation of ice into snow makes the present simulations realistic and it offer the possibility to test indirect effects of Tegen/aerosols.

4.1.3.b 1-year plan

Main objectives for 2005:

Meeting in early 2005 concerning integrative modelling.
Produce a report on model capability and intercomparison before the SOPs.

Description of work

A) Evaluation of WAM simulations.

- Define and implement in models or as a post-treatment a series of diagnostics for model evaluation and intercomparison.
- Model evaluation and intercomparison. Make available a set of simulations (ensemble simulations of the AMIP period for climate models and focus on 2000/2001 for regional and chemistry transport models.
- Report on sensitivity experiments to the convection and surface schemes (LMDZ).
- Definition and evaluation of a zoomed configuration over West Africa with or without nudging.

B) Evaluation in terms of atmospheric composition

- Global chemistry models (LMDZ-INCA, MOCAGE) will be compared to available data (e.g. MOZAIC, IDAF).
- Sensitivity of results to convective parameterisations will be assessed with LMDZ-INCA using the Tiedtke and Emanuel convection schemes. Results will be compared to available MOZAIC O3 and CO data. Interesting cases will be identified where regional scale models will also be run and evaluated.
- Results from recent global scale evaluations of aerosol models will also be assessed over West Africa and used to define further comparisons/evaluations.

C) Improvement of physical parametrizations.

- Definition of a series of test cases for the ARPEGE/LMDZ single column model including diurnal cycle of convection, boundary layer and organized convection schemes. In particular, the following cases will be implemented and tested: 1) the EUROCS/Cumulus ARM case (diurnal evolution of shallow convection, Brown et al. 2002) and 2) the EUROCS ARM case developed by Guichard et al. (2004) for the transition from shallow to deep convection and 3) the Hapex-Sahel case.

- The HAPEX-Sahel and EUROCS-ARM cases will be rerun with non-hydrostatic meso-scale models including tracer transport to serve as a basis for validation of parametrizations of tracer transport in a single column configuration. Other cases (relevant in terms of ozone signature for instance) will be identified in regional simulations (50 km resolution covering west Africa) and rerun with a non-hydrostatic high-resolution (1 km or less) version of the same models. If possible, cases will be identified for which measurements concerning CO, a good transport tracer, or loss of HNO3 (IDAF) will be identified and run with simplified chemistry. The same approach will be applied after the campaign using the numerical experiments ran for SOP observations (WP2.4).
- Building of test cases with tracers (Meso-NH) and inclusion of tracers in the ARPEGE/LMDZ framework.
- Extension to the LMDZ climate model of the 2D approach originally developed with meso-NH at CNRM.
- Realization of nested simulations with the 2D latitude-altitude version of meso-NH allowing an explicit representation of moist convection, and analysis of the differences with previous coarser resolution simulations using a convection scheme.
- Realization and preliminary analysis of idealized aqua-terra planet simulations with ARPEGE, which allows to get further insight into the retro-actions between the parameterisations and the large-scale circulations, in particular through the explicit treatment of easterly waves.

Deliverables

- Reference simulations on the AMIP period for the climate models and 2000/2001 simulations for the regional and chemistry transport models.
- Report on evaluation and intercomparison of WAM simulations in the climate and chemistry-transport models.
- Report on evaluation and intercomparison of simulation of aerosols and chemistry over west Africa.