Second WAMME Experiment
WAMME Working Group

1. Introduction

In the first WAMME experiment, we have evaluated WAMME GCMs' and RCMs' performances in simulating the variability of West African monsoon (WAM) precipitation, surface temperature, and major circulation features at seasonal and intraseasonal scales (Xue et al., 2009; Druyan et al., 2009; Boone et al., 2009). The analyses indicate that despite deficiencies in many aspects, models generally have reasonable simulations of the spatial distribution of WAM seasonal mean precipitation and surface temperature as well as the average zonal wind in latitude-height cross-section and low-level circulation. Common deficiencies in model simulation were identified. Analyses based on preliminary results have also revealed that model simulated WAMs are highly sensitive to SST, land surface, and aerosol forcing and parameterisations.

Recent observational evidence has supported the notion that there are strong decadal climate variabilities in the Sahel and surrounding areas from the 1950s to the 2000s, not only in precipitation, but also in SST, vegetation cover, land use and land cover (LULC) change, and aerosol types and spatial distributions. While the 1st WAMME experiments have provided a rudimental understanding of the seasonal variations of the WAM, understanding of the complex interactions of the WAM/Sahel precipitation variability associated with SST and land surface and aerosol forcings are still lacking. Further multi-model intercomparison experiments have to be carried out to improve understanding of the possible feedback to SST, land use change, vegetation, and aerosol forcings at seasonal to decadal scales. Given the complexity of the WAM/Sahel precipitation variability associated with these forcings, the WAMME-2 objectives are established as: (a) to provide basic understanding of impacts of these forcings on the regional water cycle of the WAM/Sahel, (b) to evaluate the sensitivity of the seasonal and decadal variability of the West African climate to those external forcings, and (c) to assess their relative contributions in producing/amplifying the Sahelian seasonal and decadal climate variability. Our strategy is to apply observational data-based anomaly forcing, i.e., "idealized but realistic" forcing, in general circulation model (GCM) and regional climate model (RCM) simulations to test the relative impacts of such forcings. We believe that our efforts would complement, not duplicate, a number of national or international efforts such as IPCC AR5, CORDEX (Coordinated Regional Downscaling Experiments), CLIVAR-Climate of the 20th Century Project (C20C), and the African Monsoon Multidisciplinary Analysis (AMMA) Project. WAMME will continue collaborating with AMMA and C20C for the WAMME-2 experiment.

2. SST effects

There are a number of recent papers discussing the SST variability in the last century and its link to Sahelian precipitation variability. Relationships between Sahel precipitation and Atlantic, Pacific, Indian, and Mediterranean Oceans SST have been studied. However, there remain some important unanswered questions:

• Why do models vary in their ability to reproduce the observed relationship between the forcing of any given ocean basin and Sahel rainfall (noting also that the level of skill of individual models is not generally consistent across these different SST-rainfall teleconnections). For example, observed Mediterranean SST data show a significant relationship with the Sahel, which

some modeling studies have been able to reproduce (e.g., Rowell, 2003; Jung et al 2006), whereas it has not been confirmed by multi-model studies (e.g., Fountain et al., 2010).
• Which ocean basins are the most important drivers of Sahelian precipitation variability? And has the relative role of the different oceans varied significantly over the last 50-100 years? For instance, Hastenrath and Polzin (2010) show that during the 1950s to 1980s transition to Sahel drought, the tropical North Atlantic became cooler and the tropical South Atlantic became warmer (Slide 1, from Figures 5 and 6 in their paper). However, during the 1980s to 2000s recovery period, the tropical North Atlantic became warmer but the tropical South Atlantic had no significant changes (Slide 1). For the Indian Ocean SST, the statistical correlation with the Sahel was very high before the 1980s but became smaller in more recent decades. A number of modeling studies have shown difficulty in producing its impact on Sahel rainfall recovery after the late 1980s. One study indicated that the Indian Ocean's effect on the Sahel rainfall recovery may be via its effect on the Atlantic circulation (Hagos and Cook, 2008). However, a key issue to address first is whether apparent changes in the influence of the Atlantic and Indian Oceans on the Sahel are simply due to sampling variability or whether they reflect genuine and interesting long-term changes in the climate system.

• What causes seasonal/decadal variability in the strength of SST-Sahel relationships when it is more pronounced than expected from sampling variability? For example, is it due to natural multi-decadal modes of variability in the SST patterns, or natural multi-decadal variability in the atmospheric response to these SSTs? Alternatively, is it due to changes in the basic state, which then impacts the SST variability and teleconnections, and if so, are these changes in basic state natural or anthropogenically forced?

In WAMME-2, we plan to impose composite SST anomalies in the Atlantic, Indian, Mediterranean and Pacific oceans, and compare these with a run using climatological SSTs (with 5 ensemble members). These SST forcing patterns will be based primarily on an SVD (singular value decomposition) analysis of SST and Sahel precipitation variability. SVD allows focus on the common patterns between two variables (Wallace et al., 1992). The amplitude of the forcing patterns will be determined such that it is strong enough to achieve a good response, it is realistic (including an annual cycle in amplitude), and is also consistent with the forcing amplitude used in other (land and aerosol) experiments. These anomalies will be added to climatological SST (with also 5 ensemble members). This analysis will include tests against the null hypothesis that the multi-decadal variations in SST-rainfall correlations shown in SVD analysis might arise simply from random sampling. The seasonal WAM features at different decades will be evaluated. By using the equilibrium type test, models should have less internal variability and produce clearer signals. This run will also be compared with the land and aerosol experiment runs discussed below.

To test each ocean's effect, we will remove anomalies of SST forcing in each ocean sequentially (Atlantic, Gulf of Guinea, Indian Ocean, Mediterranean Ocean, and Pacific Ocean). When the forcing of a particular ocean SST forcing is removed, the direct effect from that ocean's mode and the effect due to its interactions with other oceans' SSTs are eliminated. In this way, we will also test weather that ocean's statistical relationship with the Sahel rainfall is a true indication of that ocean SST's effect or just a coincidence due to its close correlation with other oceans. The SVD PCs will represent the interannual and interdecadal variability. We will test three periods:

50s, late 70s and early 80s, and late 90s and early 2000 based on SVD PC modes. We expect some oceans change the phases of their modes after the 1980s while others do not. So ocean influences may combine synergistically to favor drought but not to fully influence rainfall recovery.

3. Land Effects

Land effects will also be tested, mainly through land use land cover (LULC) change. In the Climate of the 20th Century international project (C20C), 14 state-of-the-art GCMs were forced by observed SSTs and other observed data in order to study climate variations and changes over the last 130 years. Among these models, only two models simulated half the magnitude of the Sahel rainfall changes between the 1950s and the 1980s. Scaife et al. (2008) conclude that the Sahel drought is only partly forced by SSTs in their experiment, which did not reproduce the magnitude of the Sahel drought. They also note that the two models that reproduce the largest change in Sahel rainfall include land surface changes via parameterized vegetation-climate interaction or specified land cover changes, respectively. In the 2nd WAMME Experiment, the effect of LCLU change and natural vegetation change will be tested.

Despite the fact that, the impact of LULC change in the Sahel was the first focus in land/atmosphere interaction studies, its role in West African climate is still controversial. The key is how to specify the LULC change in the model. In a recent LULC change study with multi-models (Pitman et al., 2009), the land use map used indicated that there was no substantial land use change in West Africa since 1875 to now. Therefore, it is not surprising to see that this study fails to show land use impact on West African climate. However, in Hurtt's land use map (2006), which has been adapted for the IPPC AR5 experiment, there is a clear pattern of substantial land use change in past century (Slide 2), which is consistent with the significant population increase there. We will impose the land use change pattern from Hurtt's data for our 2nd WAMME Experiment. We will test whether decadal variability in the strength of LULC change-Sahel relationships can be shown to be beyond that expected from sampling variability, and investigate what causes the variability in LULC change-Sahel relationship.

Since each model may use a different vegetation map, we will ask each group to submit their vegetation maps and parameter sets to the Working Group. Yongkang and Aaron will suggest how to introduce Hurtt's LULC change to their maps, to promote some consistency between different groups in this experiment. We will only test the 50s and the 80s land use map in the first stage of the experiment. We will postpone testing the 2000s map to when the satellite based high resolution LULV change maps become available, as they are currently under construction.

In addition to land use change, the natural vegetation evidences a response to the Sahel decadal rainfall variability. It has been shown that an increase in rainfall and Normalized Difference Vegetation Index (NDVI) over the northern edge of the WAM rain belt (southern edge of the Sahel), is associated with the recovery of the Sahel drought since the 1980s. NDVI-derived leaf area index (LAI) also shows similar trends. Slide 3 displays two satellite products (FASIR LAI and GIMMS LAI). Both show similar trends but with quite large discrepancies. This trend has also been confirmed by a product based on a biophysical/dynamic vegetation model (SSiB4/TRIFFID). We will consider testing this natural vegetation effect during the second phase of the 2nd WAMME Experiment, after the first phase experiment is completed.

4. Aerosol Effects

Aerosols may have contributed to late 20th century drought in the Sahel via 2 mechanisms. First, studies have suggested a direct impact of aerosols (both natural and anthropogenic) on the radiation budget over North Africa, which in turn can influence Sahel rainfall. Second, a number of studies based on the coupled models have suggested that differing anthropogenic emissions of aerosols in the northern and southern hemispheres may have impacted SST gradients in the tropical Atlantic, thereby influencing Sahel rainfall by a different mechanism. We will test the first effect first, while the second effect may be tested during the second phase of the WAMME-2 Experiments when more consensuses can be reached on this issue.

(a) Local Aerosol Effects

Slide 4 based on the MATCH data and Slide 5 based on GOCART data clearly indicate that the aerosol optical thickness/depth in the Sahel region has a trend since the 1980s. The MATCH in slide 4 is an aerosol model product, but is consistent with satellite products over the ocean. The GOCART products include the Sahel. The decadal aerosol trend in Slides 4 and 5 indicate that the recent decade (1998-2007) shows an increasing trend of Saharan dust loading over the North and West Africa land, but a decreasing trend over the North Atlantic Ocean, which seems to support Lau et al.'s argument that the dust effect contributes to the Sahel rainfall recovery.

However, there is a complexity regarding the aerosol effect. Some argue that aerosol feedbacks may act to amplify the ocean-forced component of monsoon circulation, i.e., effects of aerosols affect the SST gradients, which favor drying at the northern edge of the ITCZ (Biasutti and Giannini, 2006). For this experiment, we expect most modeling groups to use Atmospheric General Circulation Models (AGCMs) to test the aerosol effect using the GOCART data. Some groups may use both AGCM and coupled atmosphere/ocean GCM (AOGCM), which will assess the uncertainty due to missing the ocean feedback as indicated in Biasutti and Giannini (2006).

(b) Anthropogenic Aerosol Effects via SSTs (test in the second phase of 2nd WAMME Experiment)

Williams et al. (2001) and Rotstayn et al. (2002) both showed that historical aerosols trends may be related to Atlantic SST changes. Held et al. (2005), Biasutti and Giannini (2006), and Ackerley et al. (2011) are amongst those who have suggested that observed Sahel precipitation changes were partly due to this external anthropogenic forcing acting via the Atlantic. Held et al. (2005) analyzed ensembles of two versions of a coupled model, and concluded that the drying trend over the Sahel is partly anthropogenically forced (aerosol loadings and greenhouse gas emissions) and partly due to internal variability of the ocean-atmosphere climate system. Ackerley et al. (2011) used a perturbed physics ensemble to examine the impact of anthropogenic aerosol emissions on tropical Atlantic SST gradients, and concluded that historic aerosol changes likely explain a notable proportion of the 1950-1980 drying trend.

We plan to test these ideas in a multi-model environment by forcing each model with the component of global SST anomalies that can be attributed to anthropogenic aerosol forcing. These SST patterns, provided by the Met Office Hadley Centre, will derive from CMIP3 models using the difference between runs with all anthropogenic emissions and runs with GHG only emissions, and using a formal attribution methodology. Between 2 and 4 patterns will likely be provided to sample the uncertainty in this model-based attribution approach, with the amplitude of each pattern consistent with the period when Sahel drought was most severe.   This effect is to be test in the second phase of WAMME-2.

5. Regional model experiments

Regional models will downscale the results of the planned global model simulations that test various SST anomaly patterns. (This means using GCM output for lateral boundary conditions, LBC). The strategy for these RCM runs would exactly parallel the strategy decided for the global models in terms of SST and time periods. All regional models will include some ocean areas within the domain, and SST forcing should be consistent with the data used by the global models. However, only the global models can include the full SST forcing from more distant oceans, such as the Pacific and Indian Oceans. The influence of the remote SST on the circulation will be communicated to the RCMs via the LBC. If the RCMs do improve the spatial distributions of simulated variables, then they will add new valuable information to the GCM results. We will examine whether the RCM can provide additional information regarding SST impacts.

The RCMs are particularly well suited for testing sensitivity to land surface because the higher resolution allows more detail in the land forcing. Prescribed LULC change experiments, as in the GCM experiments, should establish the models' sensitivity to gross changes. These experiments could parallel the GCM tests, but in this case, the RCMs will be forced with reanalysis for historical periods. Similarly, their high horizontal resolution make RCMs appropriate for studying the role of African easterly waves in climate change scenarios.

6. Summary of the experiments

Control Run: Climatological SST. All experiments are integrated over five annual cycles.

Anomaly pattern	**1950s**	**1970s-1980s**	**1990s-2000s**
First Phase			
SST (Global anomaly)	X	X	X
SST (Individual Ocean, total 5)	X	X	X
Land Cover Change	X	X	
Aerosol		X	X
Second Phase			
Land Cover Change			X
Natural vegetation	X	X	X
Aerosol effect through Atlantic Ocean	X	X	

7. Funding

We plan to seek funding support for the data analyses and workshops for this experiment.

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