Climate coupling

Dr Yongkang Xue discusses his project which applies climate models for the meteorologically unstable region of the African Sahel to better project anthropologically-induced climate change

Why is the African Sahel such a significant region to examine in terms of its climate?

The Sahel is a tropical semi-arid region in Africa along the southern margin of the Sahara desert. There has been rapid population growth in the region over the past half century. Dramatic change over the Sahel from wet conditions in the 1950s to much drier conditions in the 1970s and the 1980s, and then to partial recovery since the 1990s, represents one of the strongest inter-decadal signals on Earth in the 20th Century. The Sahel drought starting from the late 1960s was the longest and most severe drought worldwide on human record last century. The devastating environmental and socioeconomic consequences resulting from the drought-induced famines in the Sahel have presented a strong motivation for the scientific community and society to understand the causes of the drought and its impact.

Why is it that a new approach is required in order to study the climate of this area?

Studies suggest that Sahel climate anomalies, especially the drought, and variability are strongly influenced by external surface forcings: sea surface temperature (SST), land surface processes, especially land use, land cover change, and aerosols. However, general circulation model (GCM) studies with a single external surface forcing (for example, SST) have not been able to reproduce full magnitude of the Sahel droughts and full seasonal, inter-annual, and decadal variability and anomalies of Sahel climate. The distinct climate features, the strong coupling between Sahel climate and surface forcings, the controversy on the causes of the Sahel climate anomalies, especially the drought, and significant social and economic implications of Sahel climate, make this region extremely important for the scientific community.

What are the major benefits of the integrated modelling systems which you are utilising within the project?

In this project we apply a recently-developed fully coupled Atmospheric-Ocean general circulation model (A-O GCM), a biophysical model and a dynamic vegetation model, which fully incorporates two-way feedback processes between vegetation and atmosphere and between ocean and atmosphere, to explore the causes of Sahel climate anomalies. This will focus on the drought variability and assess the relative contribution of ocean and land, including human-induced land use and land cover change, through a set of experiments. In the A-O GCM, ocean SST is predicted not specified and in the dynamic vegetation model, ecosystem condition is also predicted not specified. The coupled GCM/biophysical model/dynamic vegetation model was developed under previous NSF grant support and provides a crucial foundation for this project.

Could you detail the main aims and objectives of your project on climate variability in the African Sahel?

The main objectives of this project include the analysis of the effect of these surface forcings, especially the full feedback processes, on the West African monsoon evolution, its onset and demise, precipitation intensity and frequency, the long-term Sahel drought and its partial recovery, as well as on the terrestrial carbon emission and ecosystem variability and anomalies. In addition, a regional climate model (RCM) using atmospheric GCM simulations from selected years as lateral boundary conditions will be applied to preliminarily assess the regional details of surface-atmosphere interactions in the Sahel climate variability. We will test whether the RCM is able to provide supplementary skilful fine-resolution regional information not available in coarse scale GCM predictions.

What types of numerical climate modelling simulation experiments were carried out as part of the research?

A series of multi-decadal integrations will be conducted with different sea/land processes in the Atmospheric-Ocean GCM. In the control experiment, SST and vegetation conditions are specified, so both SST and vegetation will not respond to the climate forcing, which is standard practice in most current models. To test how ecosystems will change under different scenarios and its feedback to climate and water resources, in the first sensitivity experiment the surface vegetation condition in the GCM will be simulated by the dynamic vegetation model. A number of other variations will also be tested, including testing two-way coupling of ocean and atmosphere. The comparisons between these sets of experiments will be used to achieve our research objectives, and will also provide useful ground work for further investigations. Furthermore, GCM results will be downscaled using the RCM model. The regional model will be run only for selected years, which include wet, dry, and normal years from the GCM experiments discussed above.

Three score years in the Sahel

The **University of California**'s project on Sahelian climate anomalies is seeking to pinpoint the causative factors in the six decades of swift change the region has experienced, and the role anthropogenic elements have within this

IN THE COMPLEX INTERACTIONS which make up climate variability and changes, highlighting the causative factors can be incredibly difficult. The power of computer modelling in such investigations is undeniable, and the University of California has been using models in order to try to understand the issues which have been experienced in the African Sahel over the last 60 years. These changes include a shift from wet conditions to drought, and then a partial recovery. Previous understanding maintains that anthropologically-induced changes in factors such as sea surface temperature warming and land use are 'forcings' which have a significant effect on climate variability. However, recent studies have highlighted that anthropologically-induced warming is not closely related to the Sahel droughts. In fact, most sea surface temperature studies have viewed this change as a natural one. Similarly, the land cover changes, frequently viewed as a human effect, are also natural. A team led by Dr Yongkang Xue of the University of California has been able to address the misconceptions of previous studies by introducing historical land use data in order to quantify its importance to the Sahel climate. This has been coupled with detailed climate simulations in the hope of providing a quantitative evaluation of anthropogenic versus natural climate change.

If the project is successful, it will be in a position to predict the outcome of changing human activity within the African Sahel, allowing action to be taken to improve the situation. While the study is not directly related to policy-making in the region, the results from the team's research could have a significant impact on the way in which climate legislation is implemented within the area.

A MODEL APPROACH

Xue and his team have developed an Earth System Model to aid the project, which is capable of assessing the implications of future planning and policies related to the ecosystem or water resource management in the Sahel region, with the view to improving climate stability. Their comprehensive model includes physical, biological and human processes, all of which drive the climate system, and by taking into account the impacts of climate variability on Sahel ecological systems, terrestrial carbon emissions and water resources, the holistic approach is able to provide wide-ranging predictions about the impact of alterations in practice.

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The strength of the approach lies in its breadth. By coupling a number of different models into one wide-ranging simulation, and then comparing this with observational data, a convincing and comprehensive approach is created. The method has already proved to be a success, with a previous study in West Africa identifying the region as having the strongest land and atmosphere interaction in the world and that land surface heating contributes to the large scale atmospheric circulation across a number of continents during the early monsoon season.

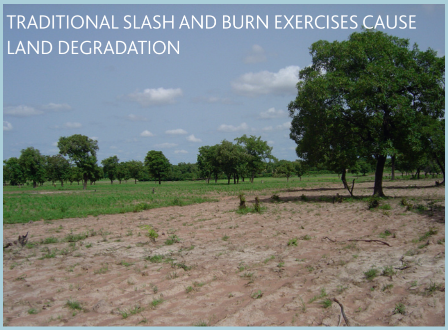
INTERCONTINENTAL INTERACTION

The compound approach adopted is matched by the collaboration across a number of teams within the project. These include Dr Aaron Bonne of the Centre National de Recherches Météorologiques in France, one of the leaders of the African Monsoon Multi-disciplinary Analysis (AMMA) project, and the leader of the African land surface model inter-comparison project (ALIMP). Through ALIMP, products which will be used to evaluate the simulated surface components from the project can be gained. These include their offline tests using multi-land surface models, which address the limitations of land surface models to simulate the processes over West Africa. Consequently, they produce a model climatology of high resolution soil

moisture, soil fluxes, and water and energy budget derived from a combination of numerical model output, observation and satellite based data. The other major figure is Dr Ibrah Seidou Sanda of the Universite Abodou Moumouni, Niger, who is directly participating in some experiments. He also liaises with the African Centre of Meteorological Applications for Development in Niger, examining the potential social applications of the results which the project produces. Both of these co-investigators visit the University of California at least once a year to participate in information sharing and project management.

MODELLING THE MONSOON

These significant breakthroughs are matched by the desire to continue working towards new discoveries. The West African Monsoon Modelling and Evaluation (WAMME) project examines the use of general and regional circulation models to evaluate the ability of the models to accurately simulate the West African Monsoon. Beyond this, it also aims to increase the understanding of associated processes and their interactions for monsoon predictions. Finally, the project addresses issues regarding the role of land, ocean, atmosphere and aerosol interaction, land and water use change, and vegetation dynamics, in the development of the monsoons. The grass roots investigation collaborates with the AMMA project and the Climate of the 20th Century (C20C) international project. Having openly published available results in 2010, the project continues to move forwards with the WAMME-2 strategy. Following the success of the Sahelian methodology, WAMME-2 seeks to apply observational data-based anomaly forcing, idealised but still realistic, into its general and regional circulation models to better understand the processes that affect the African Monsoon. With a total of 17 models being utilised in the experiment, it is expected that it will produce robust results which will increase knowledge about this phenomenon.


TRADITIONAL SLASH AND BURN EXERCISES CAUSE LAND DEGRADATION

DISSEMINATION AND APPLICATION

As with all the investigations into African climate issues, WAMME gains a great deal of its strength from its collaborative approach. Working closely with AMMA, data from that organisation has been applied in order to produce evaluations of general and regional climate models, a major contributing factor for the initial production of those results. WAMME also publishes numerous articles in the AMMA newsletter in order to disseminate its results. Further to this, AMMA conferences have provided a platform for the communication of progress and achievements. This mutual relationship has also led to reports of AMMA modelling activity in WAMME workshops, and the joint organisation of a special issue of Climate Dynamics in 2010, entitled 'West African Monsoon and its Modelling'. This allowed the presentation of the latest developments in monsoon modelling studies, and was an achievement for both parties. With WAMME providing one avenue for the Sahelian work to go down, there are other ways in which the investigation may continue to exert influence. The fully coupled Earth System Model developed through the project could be applied to global and other regional climate variability and change studies. As such, the methodology has developed a pattern from which future prediction and attribution investigations will be able to draw, providing a powerful tool to discover the causative factors in regional shifts in climate.

INTELLIGENCE

SURFACE BOUNDARY FORCING AND SAHELIAN CLIMATE VARIABILITY AND ANOMALIES

OBJECTIVES

To better evaluate the relative roles of SST, land surface forcings and land-atmosphere coupling strength over different (diurnal, seasonal, interannual and longer) time scales in order to better project potential human-induced climate change in this significant region.

KEY COLLABORATORS

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