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The onset of the West African monsoon: A numerical study

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1. Introduction

The West African monsoon system is a climatological feature of major economic and social importance to the population of the region whose economy heavily relies on agriculture. Understanding its dynamics and variability at various timescales, and ultimately improving our skill in predicting its onset and evolution, would contribute toward food security and the stability of the region.

The monsoon season begins with intense rainfall along the Guinean coast in April. The precipitation maximum remains there till the end of June, while a weaker, secondary precipitation maximum develops at 10^0N in late May. During the last week of June, the precipitation maximum moves from the Guinean coast to about 10^0N over a few days, and follows the approximate seasonal cycle afterwards. This 'jump' in the major rainfall system is in sharp contrast with the fact that the ultimate cause of the seasonal migration of the ITCZ, the northward march of the sun, follows a smooth and continuous cycle.

The purpose of this study is to address the following questions

- What are the moist, wind and thermodynamic processes involved in the monsoon onset?
- What is the nature of the interactions among different vertical layers of the atmosphere and the surface during the onset?

Model description and simulation design

The regional climate model (RCM) used in this study is an adaptation of the PSU/NCAR MM5-V3 modified as in Vizy and Cook (2002). The model simulation is run over a rectangular domain enclosed by 50^0E to 50^0W and 30^0S to 45^0N. The grid spacing is 90 km. There are 23 vertical levels and the model time step is 90 seconds. The top of the atmosphere is fixed to be at 50 hPa for this tropical application. An upper radiative boundary condition is used.

The model is initialized with climatological conditions from the NCEP/NCAR reanalysis and integrated from the 15th of March to the 15th of August, with the first 15 days of output discarded as the spin-up period. The NCEP/NCAR reanalysis is also used for lateral boundary conditions and SSTs.

Comparison of the model precipitation time-series with TRMM-3B42 data set (Fig. 1) shows that the model simulates the abrupt jump at the end of June with reasonable accuracy.

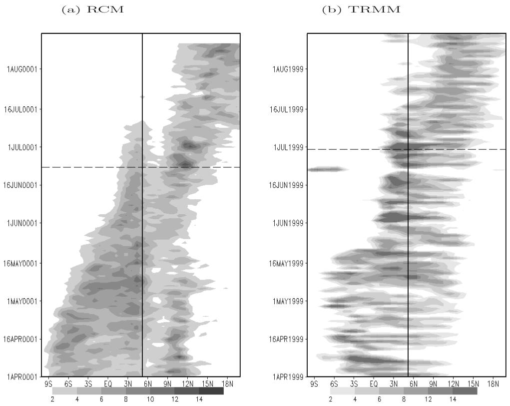

FIG. 1. Daily mean precipitation from the (a) RCM simulation and (b) TRMM (1999). Both fields are averaged between 10^0E and 10^0W and are in mm/day. Dashed lines indicate approximate date of the monsoon onset and the bold lines represent the approximate latitude of the coastline.

2. Analysis

The free troposphere in the model can be classified into two layers in which the condensation field evolves in a distinct manner. Figs 2a and 2b show the development of the condensation field in the upper layer (above 525hPa) and the lower layer (825-525hPa), respectively.

In the upper layer, there is a discontinuity in the evolution of the condensation field around the 21st of June (Fig. 2a). In the middle-layer, a discontinuity occurs about on around the 16th of May (Fig. 2b). The jump in precipitation (Fig. 1a) coincides with the jump

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in the upper layer condensation and intensification of the middle layer condensation near the 21st of June.

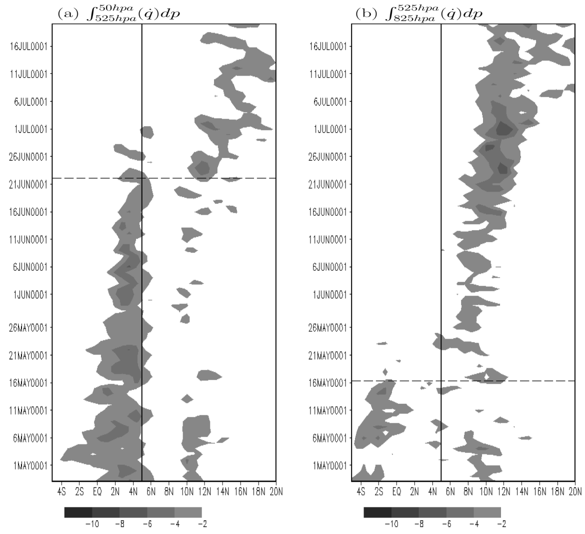

FIG. 2. Mass-weighted vertical integral of moisture condensation between (a) between 525 hPa and 50 hPa and (b) between 825 hPa and 525 hPa in the model in mm/day, Both are averaged between 10^0E and 10^0W. The bold line represents the approximate latitude of the coastline and the dashed lines in (a) and (b) represent the approximate dates of onset and the start of pre-onset precipitation respectively.

Moisture budget analysis shows that the main source of moisture for condensation in the upper layer is vertical flux from the lower layer which displays a jump three weeks before the monsoon jump (not shown). The vertical flux of moisture is related to meridional wind convergence $(-\frac{\partial}{\partial y}\overline{v})$ in the lower layer. In the model, the African easterly jet and associated fluctuations in the zonal wind drive moisture away from the continental region.

Analysis of the divergence equation shows that the abrupt shift in $(-\frac{\partial}{\partial y}\overline{v})$ in Fig. 3a is due to heating in the lower troposphere overcoming the inertia posed by the Coriolis force gradient $(-\frac{\partial}{\partial y}f\overline{u} - \frac{\partial^2}{\partial y^2}\overline{\phi} < 0)$ at the continental region (Fig. 3b). The heating is supplied by the pre-onset condensation. The condensation in this layer gradually increases during the second half of May when potentially unstable air capped by dry air advected from the Sahara is released.

Primarily, meridional moisture convergence within the boundary layer, which is forced by sensible heating, supplies moisture for the pre-onset condensation at the continental lower troposphere.

3. Summary

The model results suggest that the onset of the West African monsoon involves three stages; (i) sensible heating driven boundary layer circulation supplies moisture for the continental boundary layer and maintains potential instability (PI). (ii) The PI is gradually released during the second half of May and (iii) the associated condensational heating then forces inertial instability and the shift of the ITCZ from the Coast of Guinea to the continent. A more detailed discussion of the monsoon onset process is provided in Hagos and Cook (2006).

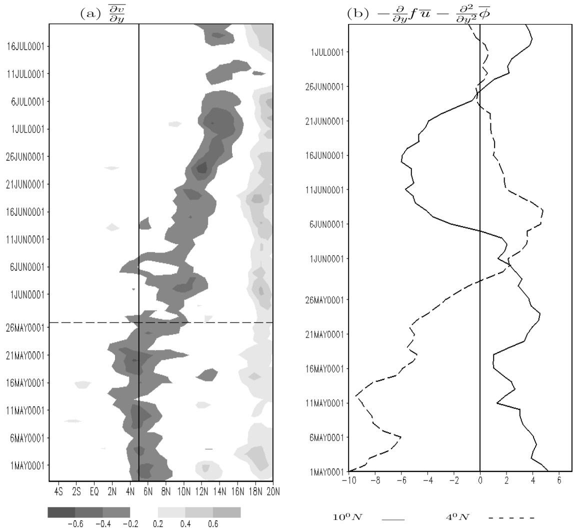

FIG. 3. (a) $\frac{\partial \overline{v}}{\partial y}$ in $10^{-6}/s$ (the bold line represents the approximate latitude of the coastline) and (b) $-\frac{\partial}{\partial y}f\overline{u}-\frac{\partial^2}{\partial y^2}\overline{\phi}$ in $10^{-6}/kms^2$ at 10^0N (solid line) and at 4^0N (dashed line) . Both are averaged between 10^0E and 10^0W as well as 825 hPa and 525 hPa.

References

Hagos, S. M. and K. H. Cook, 2006: The onset of the West African monsoon: A numerical study, submitted to *J. Clim*

Vizy, E. K., and K. H. Cook, 2002: Development and application of a mesoscale climate model for the tropics: Influence of sea surface temperature anomalies on the West African monsoon, *J. Geophys. Res.- Atmos.*, **107** (D3).