Mesoscale climate analysis over West Africa

L. M. Druyan and M. Fulakeza
Center for Climate Systems Research, Earth Institute at Columbia University and the NASA/Goddard Institute for Space Studies, New York
Corresponding author: LDruyan@giss.nasa.gov

Introduction

The study focuses on the West African climate during August, the month marking the farthest northward advance of monsoonal rains. Characteristics of westward propagating precipitation maxima associated with African wave disturbances (AWD) are analyzed from two independent sources of data. In a recent CLIVAR Exchanges issue, Ward et al. (2004) stressed the importance of studying the interannual variability of such synoptic disturbances over West Africa in order to better understand the predictability of the summer monsoon climate. Detecting and monitoring AWD associated precipitation over this data-sparse region is paramount to these objectives.

TRMM

The Distributed Active Archive Center (DAAC) at the NASA/Goddard Space Flight Center provides the 3B42 on-line data set from the Tropical Rainfall Measuring Mission (TRMM) satellite. These TRMM data are estimates of daily precipitation rates (Huffman et al. 1997) for 1° by 1° squares between 40°N-40°S, beginning in 1998. The daily estimates are based on a modification of the Global Precipitation Index (GPI) from GOES geostationary satellite infrared (IR) measurements. To form the final data set, GPI values are calibrated by TRMM microwave, radar, visible and IR observations. Recent information from NASA indicates that the TRMM satellite could very well be retired toward the end of the summer of 2005 (Berger 2005). There is no comparable observing system scheduled until 2010.

No extensive validation of TRMM daily precipitation totals has apparently been made against rain gauge measurements. Lau et al. (2004) reported a favorable comparison between TRMM 3B42 data during July 2001 and daily rain gauge measurements at two stations in the Himalayas, including the detection of a heavy precipitation event on 19-20 July 2001, but this validation may not be relevant for West Africa.

RM3 Regional climate model

RM3 is a third generation regional atmospheric model run exclusively at Columbia University CCSR and NASA/GISS. It incorporates the GISS GCM land surface process model and the GISS GCM parameterizations of deep cumulus convection and cloud liquid water. For this study the model was integrated at 15 vertical levels on a horizontal grid with 0.5° spacing bounded by 35°N-20°S; 35°W-35°E.

RM3 simulations were made for each August, 1998-2003, the years for which TRMM estimates of daily August precipitation rates are available. The set of six simulations uses NCEP reanalysis data for the initial conditions and lateral boundary conditions. In order to improve the compatibility of moisture distributions with the RM3, preliminary simulations were begun on July 29 of each year. All fields, except the specific humidity, were then reinitialized at 00 UT on August 1.

Case study

We have been examining TRMM daily estimates over West Africa represented on time-longitude Hovmöller diagrams. Fig. 1a (page20) shows such a distribution for August 2003, for which the individual observations at each longitude between 20°W-25°E were averaged over 5-15°N. Fig. 1a clearly shows a number of diagonal bands of heavy precipitation that imply westward propagation of maxima, at speeds of about 6° day^{-1}, or about 7 ms^{-1}. Such precipitation trajectories have been called the "footprints" of AWD and have been simulated by GCMs (Xue and Shukla, 1993, Druyan and Hall, 1996).

As noted, the six RM3 simulations used NCEP reanalysis data as initial conditions and lateral boundary conditions. The simulation discussed here for August 2003 is representative of RM3 performance in that it was qualitatively similar to those for the other years that

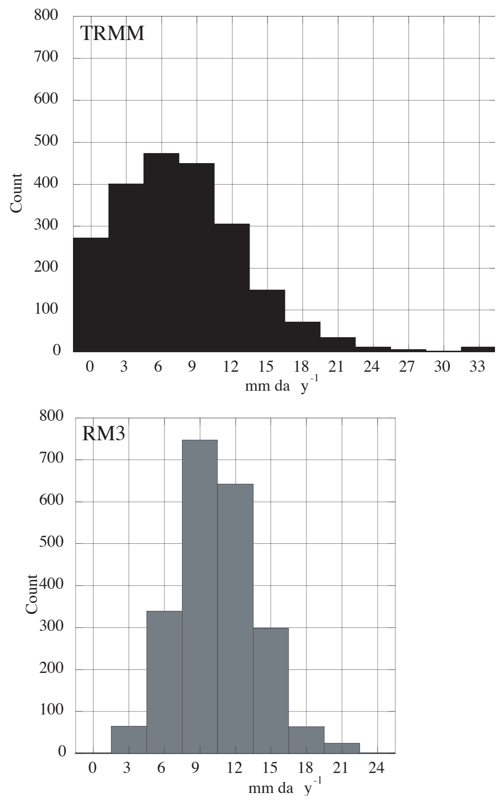

Fig. 2. Frequency distributions of the data plotted in Fig. 1a (top) and Fig. 1b (bottom), but only from August 8-31.

were analyzed. Fig. 1b shows that the RM3 did indeed simulate the AWD precipitation "footprints".

The location and timing of many of the precipitation bands in Fig. 1b follow the TRMM pattern shown in Fig. 1a, but less so during the first week. In all six simulations, RM3 precipitation was highly correlated to the corresponding TRMM pattern- but only after 5-8 days. The adjustment to NCEP reanalysis initial conditions was actually the most rapid in the example shown here for August 2003. Note, for example, the RM3 simulation of the TRMM-observed precipitation maximum that moves westward from 25°E on August 3. The following quantitative evaluation refers only to the data for August 8-31 in Fig. 1 so as not to consider the adjustment period. The correlation coefficient between TRMM and RM3 daily precipitation rates is 0.79, which is significant with >99% confidence. However, TRMM and RM3 do not agree on the absolute values of precipitation rates. The RM3 mean of the data shown in Fig. 1b (between August 8-31) is 2.7 mm day^{-1} greater than the corresponding TRMM value. Moreover, TRMM estimates reveal a much larger variability, as evidenced by their larger variance, 29.8 mm^2 day^{-2}, compared to only 11.5 mm^2 day^{-2} for the RM3. Fig. 2 shows the frequency distributions for the two data sets. The most glaring difference is that the RM3 has simulated very few rates between 0-4.5 mm day^{-1}. On the other hand, many more rates between 7.5-15 mm day-1 are modeled than are estimated by TRMM. We found that daily precipitation rates for NCEP reanalysis do not show well-correlated AWD footprints for any of the August periods considered.

Hovmöller time-longitude plots of additional RM3 simulated data averaged over 5-15°N were also examined for August 1-5 (but not shown here). In most cases, the patterns of the meridional component of the 12 UT 700 mb wind vector (v7) and the component of the 700 mb vorticity due to zonal gradients of the meridional wind (z=dv/dx), showed westward movement during the five days of a southerly wind maximum and z maximum parallel to a TRMM precipitation band. RM3 daily simulations during August 1-5 showed patterns of westward propagating sequential bands of northerlies and southerlies at 700 mb typical of AWD. The positive z associated with the wind shifts at the wave troughs ran mostly parallel and slightly east of TRMM observed precipitation maxima, which have the character of convective complexes. This suggests that RM3 circulation patterns are realistic even within the initial adjustment period.

Conclusion

The West African monsoon climate and its seasonal prediction cannot be studied without careful attention to African wave disturbances, whose characteristics are best monitored via daily precipitation distributions. We have found that TRMM estimates of daily precipitation rates are very helpful in this regard. While RM3 precipitation rates do not always match TRMM estimates, data from these two completely independent sources are well correlated in time and space. This correlation suggests that both the RM3 and the TRMM estimates describe the same reality.

TRMM may unfortunately be retired from service after this summer (2005) and a comparable replacement will not fly at least until 2010. Accordingly, the capability demonstrated here (and in additional results slated for future publication) to produce time-space distributions of precipitation using a mesoscale atmospheric model that are highly correlated with TRMM observations becomes very significant. Considerable experience has demonstrated that daily precipitation fields from NCEP reanalysis are not at all realistic over much of the tropics, and especially not over West Africa. Although this may relate to the performance of the moist convection parameterization in the NCEP model, it undoubtedly also reflects the coarse resolution of the global model, a resolution that is not optimum for capturing the interaction between terrain, circulation and temperature gradients leading to the formation and evolution of African wave disturbances. Our work suggests, however, that dynamic downscaling of global meteorological analyses by the RM3 or a comparable model can create realistic daily precipitation data sets. However, using the system for daily weather prediction will not be practical until the 5-8 day adjustment to observed initial conditions can be bypassed.

Results here also suggest that the RM3 could successfully provide regional detail to climate model seasonal predictions for West Africa. Testing has demonstrated that the positive aspects of RM3 simulations are not diminished in continuous four-month seasonal downscaling experiments. Still, the quality of RM3 seasonal climate predictions will also depend on the quality of the GCM predictions driving it. The RM3 shares the same ground hydrology and moist convection schemes with the GISS GCM. This may be an advantage for coupling the two models in order to explore the potential for seasonal climate model predictions for the summer monsoon season over West Africa.

This research was supported by NSF Grant ATM-0354589 and the NASA Climate Program.

References

Berger, B., 2005: Rainfall monitoring satellite's future to be set by summer. *Space News Intn'l*, **16**, 1, 4.

Druyan, L. and T. Hall, 1996: The sensitivity of African wave disturbances to remote forcing. *J. Appl. Met.*, **35**, 1100-1110.

Huffman, G., R. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A. McNab, B. Rudolf and U. Schneider, 1997: The Global Precipitation Climatology Project (GPCP) Combined Precipitation Dataset. *Bull. Amer. Meteor. Soc.*, **78**, 5-20.

Ward, M. N., K Cook, A Diedhiou, B Fontaine, A Giannini, A Kamga, P J. Lamb, A. Ben Mohamed, A Nassor and C Thorncroft, 2004: Seasonal-to-decadal predictability of West Africa climate. *CLIVAR Exchanges* **9**, 14, 19-20.

Xue, Y. and J. Shukla, 1993: The influence of land surface properties on Sahel climate. Part I: Desertification, *J. Climate*, **6**, 2232-2245.