GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L18709, doi:10.1029/2007GL031270, 2007

Spatial variability of regional model simulated June–September mean precipitation over West Africa

Leonard M. Druyan,[1,2] Matthew Fulakeza,[1,2] and Patrick Lonergan[1,2]

Received 16 July 2007; revised 28 August 2007; accepted 30 August 2007; published 29 September 2007.

[1] The study examines the spatial variability of June–September 2003 mean precipitation rates (Pr03) simulated by a regional climate model on a horizontal grid with 0.5° spacing. In particular, it evaluates the relative impact of different initial conditions versus the influence of the lateral boundary conditions (LBC), and it compares small spatial scale distributions of modeled Pr03 to data from the Tropical Rainfall Measuring Mission (TRMM) and the NOAA Climate Prediction Center data for the African Famine Early Warning System (FEWS). Simulations over West Africa were made with the CCSR/GISS RM3, driven by synchronous data from NCEP reanalysis. A five-member ensemble for a single season was generated by staggering the initial conditions of each member by 36 hr within the period May 9–15, 2003. Results showed that the LBC influence dominated over that of differing initial conditions, implying that the precipitation simulations suffered little contamination of random noise. In a second evaluation, small spatial scale distributions of Pr03 were computed as the difference between Pr03 and spatially smoothed fields. Spatial correlations between the RM3 product versus the TRMM and FEWS small-scale components of Pr03 were highest using TRMM data provided at 1° elements. Results suggest that the model may be challenged to simulate realistic small-scale features of the seasonal mean precipitation field, and/or that observational data sets do not adequately capture these fine spatial features. **Citation:** Druyan, L. M., M. Fulakeza, and P. Lonergan (2007), Spatial variability of regional model simulated June–September mean precipitation over West Africa, *Geophys. Res. Lett.*, *34*, L18709, doi:10.1029/2007GL031270.

1. Introduction

[2] Regional climate model (RCM) simulations are driven by synchronous lateral boundary conditions (LBC) that represent either observational analyses or model forecasts within a larger domain. In the usual configuration of nested RCM simulations, the RCM effectively downscales meteorological fields to a higher spatial resolution than the resolution of the forcing data. The goal is for the downscaling to add useful information about the spatial variability of climatological fields, based on the integration of the governing equations at the higher resolution and accounting for a higher resolution specification of lower surface characteristics, such as topography and vegetation. The null hypothesis is that the RCM produces noisier meteorological fields that are no more realistic than the driving data.

[3] Information about the evolving climate is conveyed to the RCM via the LBC. Random noise, on the other hand, can be added during each time step, beginning with the initial conditions. Simulations driven by the same LBC, but from different initial conditions, should diverge from one another if random noise dominates, and they should converge to a single solution if the LBC dominate. Convergence of such simulations to a single solution determined by the LBC indicates that the RCM produces a high-resolution representation of the atmospheric evolution defined by the driving analysis or prediction.

[4] This paper presents results of five parallel RCM simulation experiments over West Africa on a 0.5° grid, driven by NCEP reanalysis (NCPR) data gridded at 2.5° during June–September (JJAS) 2003, that were begun from different initial conditions (see below). In addition, in order to demonstrate the value of spatial details in one simulation field, the study compares small-scale RCM precipitation patterns with validation data from the Tropical Rainfall Measuring Mission (TRMM) gridded at 1° and 0.5°. TRMM data are based on a modification of the Global Precipitation Index (GPI) from geostationary satellite infrared measurements. TRMM microwave, radar, visible and IR observations are observed at best only once per day, so to form the final data set they are used in statistical relationships to calibrate the GPI. They are not merged with any rain gauge data. A second data set for precipitation validation is available from NOAA/CPC for the Famine Early Warning System (FEWS). We use FEWS, version 2, gridded estimates of precipitation rates for June–September 2003, which are based on a combination of rain gauge and METEOSAT remote radiometric measurements, which they have in common with TRMM. *Herman et al.* [1997] explained the methodology, although version 2 was only implemented in 2000.

2. Description of the RCM

[5] *Druyan et al.* [2006] described the important components of the third-generation RCM at the Goddard Institute for Space Studies (GISS), the RM3, so only a brief description is given here. The latest version of the RM3 is integrated at 28 vertical levels and the domain for the simulations described here is bounded by 35°N–20°S, 35°W–35°E. The RM3, driven by NCPR, has been shown to faithfully simulate time-space patterns of westward-propagating precipitation swaths that compare quite favorably with daily estimates from TRMM satellite data, after an initial spin-up of about six days [*Druyan and Fulakeza*, 2005].

[1]Center for Climate Systems Research, Columbia University, New York, New York, USA.
[2]NASA Goddard Institute for Space Studies, New York, New York, USA.

0094-8276/07/2007GL031270$05.00

Model precipitation, even during four- month simulations, has been shown to remain well correlated with TRMM and rain gauge observations of daily accumulations.

[6] The RM3 uses the same land surface (LS) process model used in the GISS GCM [*Rosenzweig and Abramopoulos*, 1997; *Hansen et al.*, 2002]. The LS model consists of two integrated parts, the soil and the canopy, and it conserves water and heat while simulating their vertical fluxes. The RM3 modeled soil is divided into six layers to a depth of 3.5 m, and the model distinguishes between five textures of soil. The canopy, modeled as a separate layer located above the soil, is responsible for the interception of precipitation, evaporation of accumulated water and removal of soil water through transpiration.

[7] The *Del Genio and Yao* [1993] moist convection parameterization and the *Del Genio et al.* [1996] scheme for the effects of cloud liquid water and cloud ice have also been incorporated into the RM3. These are components originally developed for the GISS GCM, which itself has been extensively applied to climate sensitivity studies [e.g., *Hansen et al.*, 2002]. The cloud liquid water scheme allows for life cycle effects in stratiform clouds and permits cloud optical properties to be determined interactively. The applicability of these schemes at RM3 horizontal resolutions finer than 0.5° grid spacing has not yet been tested.

3. Ensemble Simulations for June–September 2003

3.1. Sensitivity to Initial Conditions

[8] The impact of differences in initial conditions on the simulated seasonal rainfall was investigated by comparing RM3 JJAS 2003 mean precipitation rates (Pr03) over the part of the domain bounded by 5°S–20°N, 20°W–30°E (hereafter Area A) from each member of a five-member ensemble to each other, to the ensemble mean and to TRMM data. This area encompasses the principal rain band of the summer monsoon over West Africa. Ensemble members were begun from NCPR initial conditions (including soil moisture) spaced 36 h apart, beginning with 00 UT on 9 May and until 00 UT on 15 May. NCPR LBC were identical for each simulation, supplied four times per day. Correlation coefficients between Pr03 of ensemble members over Area A were greater than 0.97, demonstrating that LBC influences dominated while the different initial conditions had almost no impact on the seasonal precipitation. The correlation between the RM3 ensemble Pr03 (not shown) versus TRMM estimates available on a 0.5° grid (not shown) was 0.87 and against FEWS, 0.86. TRMM Pr03 at 0.5° resolution exhibits a higher spatial variability than the modeled Pr03 distribution, while the TRMM Pr03 field at 1° resolution (not shown) exhibits a spatial smoothness comparable to model results. The correlation between the RM3 ensemble Pr03 versus the corresponding TRMM Pr03 for 1° elements was 0.92. The correlation between TRMM (0.5°) and FEWS (0.5°) Pr03 was 0.93.

3.2. Small-Scale Precipitation

[9] There have been efforts to evaluate how well mesoscale regional model weather and climate simulations succeed in producing small spatial scale weather or climate information. *Denis et al.* [2002] concluded that their regional model weather simulations at 45 km grid spacing recovered spatial details of weather systems that were not resolved by the coarse-gridded driving analysis for which all disturbances having wavelengths smaller than 500 km were filtered. *Herceg et al.* [2006] reported mixed results regarding the regional model simulated small-scale features of seasonal mean precipitation rates. The relative success of the RM3 in producing small-scale precipitation features that stand out above the model's random variability was also evaluated for the RM3 Pr03 ensemble and compared to TRMM and FEWS.

[10] *Giorgi et al.* [1994] separated MM4 precipitation fields into large-scale (LgSc) and small-scale (SmSc) components in order to examine mesoscale results of regional model simulations. A similar approach was used here to compute the SmSc signal of RM3 simulated precipitation rates over Area A. For each ensemble member, the distribution of Pr03 was first interpolated to a 2.5° grid, the resolution of NCPR. Each coarse-grid distribution was then interpolated back to the original 0.5° grid to form the LgSc distribution, which filtered out small-scale features, reflecting the smoothness of the NCPR gridded at 2.5°. To make the SmSc distributions, residual values were computed at each i-th grid element:

$$\mathrm{SmSc_i} = \mathrm{Pr03_i} - \mathrm{LgSc_i} \qquad (1)$$

where $\mathrm{Pr03_i}$ represents the JJAS 2003 mean precipitation rate at each i-th grid element.

[11] The SmSc therefore shows the spatial variability of results on the 0.5° grid that is not captured by the NCPR gridded at 2.5°.

[12] Figure 1a shows the SmSc distribution for the ensemble mean Pr03 over the rain belt of West Africa. To what extent is it a measure of the effects of the small-scale forcing represented on the 0.5° grid, such as topography and land surface characteristics, and to what extent is it contaminated by noise of the model system? Correlation coefficients between the SmSc distributions of the ensemble members all exceeded 0.90 (significant at the 99% confidence interval). This demonstrates that RM3 simulations of seasonal mean small-scale precipitation features are mostly determined by the LBC and the topography (which were common to all ensemble members), and that the small-scale component of the simulated precipitation is also not sensitive to differences between initial conditions; nor is it contaminated by random model noise.

[13] The SmSc signal present in TRMM observations was also computed according to equation (1), where $\mathrm{Pr03_i}$ represents the TRMM JJAS 2003 mean precipitation rates for each 0.5° spatial element. The distribution of SmSc for TRMM Pr03 (not shown) exhibited a higher spatial variability than the corresponding model distribution, consistent with the high degree of spatial variability of the TRMM 0.5° data. The correlation between the SmSc of the RM3 ensemble mean Pr03 versus the SmSc distribution based on TRMM 0.5° gridded observations (over Area A) was 0.20, and similar between TRMM and each individual run. While this is statistically significant, it means that the model fields do not explain very much of the spatial variance of SmSc estimated by TRMM data provided on the 0.5° grid. Given the high spatial variability of the TRMM 0.5° data set

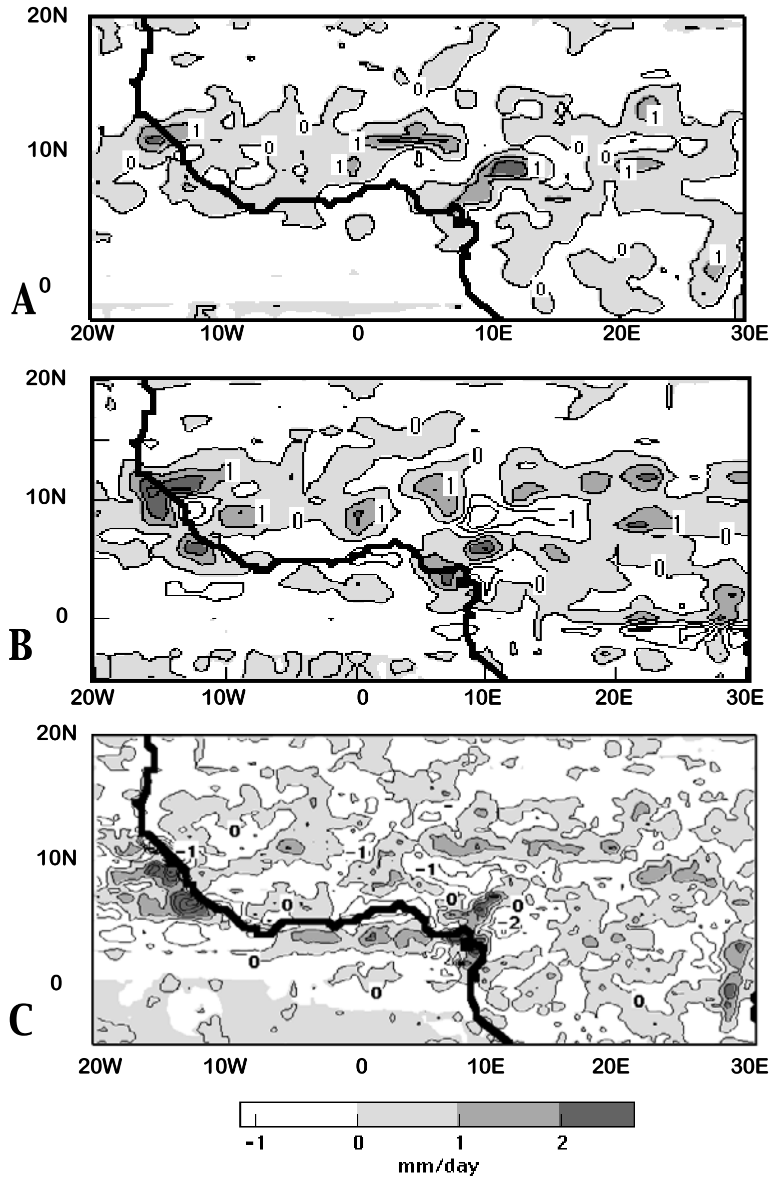

Figure 1. Distributions of the small-scale component (see text) of June–September 2003 mean precipitation rates (mm/day): (a) RM3, (b) TRMM (based on 1° grid), (c) NOAA/CPC FEWS (based on 0.5° grid).

and its SmSc component (not shown), an alternative TRMM SmSc was constructed from the archived TRMM 1° Pr03 (Figure 1b). Its LgSc was made by interpolating to a 3° grid, then interpolating back to the 1° grid. Equation (1) was applied on the 1° grid to compute the SmSc distribution. This SmSc was next interpolated to the 0.5° grid for the comparison to model results. Figure 1b shows that this version of the TRMM SmSc pattern has a spatial variability comparable to that of Figure 1a. Indeed, correlations between the RM3 SmSc distributions of Pr03 versus the TRMM SmSc based on 1° TRMM data are 0.54, meaning that model results explain 29% of the spatial variance of the TRMM SmSc. The SmSc fields in Figures 1a and 1b have matching positive swaths at 10°N along the ITCZ over West Africa and positive centers over several orographic maxima: 5°N and 10°N at the coast, at 8°E, and over the Cameroon Highlands. Several negative areas in Figure 1b are not featured in the model results. Figure 1c shows the SmSc distribution based on FEWS precipitation data for JJAS 2003, interpolated to the model's 0.5° grid. The spatial correlation between this FEWS SmSc versus the RM3 ensemble SmSc (Figure 1a), both for JJAS 2003, was 0.22, which is comparable to the correlation between RM3 versus TRMM SmSc distributions. Note that the FEWS SmSc pattern shows strong maxima similar to those featured in Figures 1a and 1b.

[14] *Druyan et al.* [2007] showed that the RM3 computes too few extreme precipitation rates- too few dry events and too few heavy rain events. These discrepancies undoubtedly lower the correlation between all of the components of model versus TRMM seasonal mean rainfall rates. There is, however, a rather wide gap in model versus TRMM correlations between validations of the total Pr03 as compared with the validations of the SmSc fields (0.87

compared to 0.20). This gap implies that the RM3 is challenged to reproduce very fine spatial features of the seasonal precipitation field that are depicted by TRMM 0.5° data. The possibility of noise contamination in the TRMM and/or FEWS analyses (at 0.5°) is suggested by the finding that the spatial correlation between the TRMM SmSc distribution based on 1° data (Figure 1b) versus the SmSc TRMM based on 0.5° data was only 0.19, and between TRMM (0.5°) versus FEWS (0.5°) SmSc fields, only 0.36.

4. Conclusions

[15] Based on an ensemble of five simulations for one season, the study found that RM3 spatial patterns of precipitation within the main monsoon rain band over West Africa are entirely determined by the lateral boundary forcing and the fixed topography and other land surface characteristics, so that different initial conditions do not introduce noise into either the total fields or the smaller spatial scales. Unrealistic features in lateral boundary data can be expected to adversely affect regional model simulations. The analysis suggests that even though the RM3 is integrated on a 0.5° grid, its current configuration provides meaningful spatial variability of simulated precipitation more comparable to the TRMM 1° mapping, against which the small-scale spatial correlations were about 0.54. The small-scale precipitation patterns of the two observational data sets considered here were only weakly correlated with each other. Consequently, it is not yet clear how much of the lack of correlation between the modeled versus "observed" small-scale patterns is due to RM3 deficiencies and how much is due to the inability of TRMM and FEWS to map the actual small-scale patterns. Increasing topographical relief or decreasing internal smoothing could perhaps improve RM3 generation of the SmSc signal, but the destabilizing effect on simulations will have to be overcome.

[16] **Acknowledgments.** Research was supported by NSF grant ATM 0652518, NASA grant NNX07A193G and the NASA Climate and Earth Observing System Programs. TRMM data used in this study were acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC). FEWS data sets were created at the NOAA Climate Prediction Center and made available on-line by the International Research Institute for Climate Prediction of Columbia University. We acknowledge the helpful suggestions of two anonymous reviewers.

References

Del Genio, A., and M.-S. Yao (1993), Efficient cumulus parameterization for long-term climate studies: The GISS scheme, in *Cumulus Parameterization*, *Am. Meteorol. Soc. Monogr. Ser.*, vol. 24, edited by K. Emanuel and D. Raymond, pp. 181–184, Am. Meteorol. Soc., Boston.

Del Genio, A., M.-S. Yao, W. Kovari, and K.-W. Lo (1996), A prognostic cloud water parameterization for global climate models, *J. Clim.*, *9*, 270–304.

Denis, B., R. Laprise, D. Caya, and J. Coté (2002), Downscaling ability of one-way nested regional climate models: The Big-Brother experiment, *Clim. Dyn.*, *18*, 627–646.

Druyan, L., and M. Fulakeza (2005), Mesoscale climate analysis over West Africa, *CLIVAR Exch.*, *10*, 34–35.

Druyan, L., M. Fulakeza, and P. Lonergan (2006), Mesoscale analyses of West African summer climate: Focus on wave disturbances, *Clim. Dyn.*, *27*, 459–481.

Druyan, L., M. Fulakeza, and P. Lonergan (2007), The impact of vertical resolution on regional model simulation of the West African summer monsoon, *Int. J. Climatol.*, in press.

Giorgi, F., S. Hostetler, and C. Brodeur (1994), Analysis of the hydrology in a regional climate model, *Q. J. R. Meteorol. Soc.*, *20*, 161–183.

Hansen, J., et al. (2002), Climate forcings in Goddard Institute for Space Studies SI2000 simulations, *J. Geophys. Res.*, *107*(D18), 4347, doi:10.1029/2001JD001143.

Herceg, D., A. Sobel, L. Sun, and S. Zebiak (2006), The Big Brother Experiment and seasonal predictability in the NCEP regional spectral model, *Clim. Dyn.*, *27*, 69–82, doi:10.1007/s00382-006-0130-z.

Herman, A., V. Kumar, P. Arkin, and J. Kousky (1997), Objectively determined 10-day African rainfall estimates created for famine early warning systems, *Int. J. Remote Sens.*, *18*, 2147–2159.

Rosenzweig, C., and F. Abramopoulos (1997), Land-surface model development for the GISS GCM, *J. Clim.*, *10*, 2040–2054.

L. M. Druyan, M. Fulakeza, and P. Lonergan, Center for Climate Systems Research, Columbia University, 2880 Broadway, New York, NY 10025, USA. (ld12@columbia.edu)