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The African Climate as Predicted by the IAP Grid–Point Nine–Layer Atmospheric General Circulation Model (IAP–9L–AGCM)

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ABSTRACT

A brief introduction is given of the Grid–point 9–layer Atmospheric General Circulation Model (AGCM) developed at the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences. The results of the 1980–1989 Atmospheric Model Inter–Comparison Program (AMIP) run were compared with observed European Centre for Medium–Range weather Forecasts (ECMWF) temperature data for the same period. The statistical analysis, and *Grids Analysis and Display System (GrADS) results have shown that the model holds a great promise in predicting* the African climate with considerable accuracy, within and across the seasons. This is a great hope for climate research in Africa which is data–sparse region.

Key words: Atmospheric General Circulation Model, Africa

I. INTRODUCTION

The coupled ocean–atmosphere–land climate system is characterized by substantial amounts of variability at a wide range of spatial and temporal scales (Delworth and Manabe, 1996). A key issue in climate research is obtaining a better description of this variability and the associated physical mechanisms. For example, there is growing evidence that interannual fluctuations in the African monsoon circulations and associated rainfall are predictable (WCRP, 1992). In particular, there is a coherent pattern of associations of regional rainfall with El Nino Southern Oscillation (ENSO).

The domain of boreal summer rainfall extending from the West African Sahel into Ethiopia and the western part of the East African highlands has a positive correlation with the Southern Oscillation index (SOI). Similarly, in the coastal regions of equatorial East Africa, the boreal spring and autumn rainy seasons are more abundant in the low SOI phase (WCRP, 1995). In the southern parts of Africa, the austral summer rains are negatively correlated with SOI. Hastenrath (1991) reported that boreal autumn rains in equatorial East Africa are influenced by Indian Ocean sea surface temperature (SST) anomalies. These anomalies are related to the strength of the preceding Asian summer monsoon.

Great contributions have been made to the development of General Circulation Models (GCM) at Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing (Zeng et al., 1995). The efforts are directed to the simulation of the climate system and its variability.

The GCM constructed by Zeng et al. (1987, 1989) was successful in modelling climate

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characteristics (Liang, 1986; Xue, 1992; Bi, 1993), in producing sensitivity experiments (Zhang and Liang, 1989), in coupling with other climate subsystems (Zhang et al., 1992) and in predicting short-term climate variability (Zeng, 1990). Wu et al. (1996) in their work used the observed SST and sea ice AMIP data from 1979–1988 to test the performance of a 9-layer spectral AGCM. Their model is capable of simulating the basic states of the atmosphere and its interannual variability.

The aim of this work is to present the results of comparing the observed ECMWF data and AMIP run using the IAP 9-layer grid point AGCM (IAP 9L AGCM) for the African environment.

II. BASIC INTRODUCTION OF IAP 9L AGCM

The IAP nine-level AGCM is the historical descendant of IAP two-level AGCM, but with most dynamical and physical parameterizations qualitatively changed. Its dynamical framework and finite-difference scheme keeps the physical coordination of overall property between difference equations and differential equations. The introduction of model standard atmosphere can effectively reduce the large truncational errors in the mountain regions. The model adopts detailed physical parameterization schemes, includes both diurnal and seasonal cycle NCAR CCM terrestrial and solar shortwave radiation scheme, fine-tuned Arakawa-Schubert deep convection cumulus parameterization and Albrecht shallow convection scheme, and comprehensive surface and atmosphere interaction module developed by Liang (1996).

A detailed description of the model is well documented in Zhang (1990), Liang (1996) and Bi (1993). They introduced the model dynamical framework and physics parameterization, respectively.

III. METHODOLOGY

The 10 year AMIP run by IAP 9L AGCM for 1980–1989 was compared with the ECMWF data for the same period in this paper. The only climatic variable available for Africa, a data sparse region, was temperature data for 850 hpa and 500 hPa levels.

The resolution of the AGCM is 40° latitude by 50° longitude, a total of 3170 grid points for the globe. The ECMWF data on the other hand, have a resolution of 2.5° × 2.5°. Africa lies in the window, 42°N to 42°S (latitude) and 30°W and 50°E (longitude). A computer routine was used to extract the data for the African continent. That gave 22 × 17 (374) grid points for the AMIP run and 33 × 37 (1221) for the ECMWF data set. The computing was done on the IAP Convex computer. The figures were analysed using the Grid Analysis and Display System (GrADS) of Doty (1992). The observed and simulated data were compared using the Student's t-test. Earlier authors (Chervin and Schneider, 1976; Manabe et al., 1981; and Ye et al., 1984) also used this method to compare their simulated and observed data.

The Student's t-test was used to compare the difference between the means of the AMIP run and ECMWF data, on the assumption that both samples were independent and normally distributed. The t-value was computed (Newmark, 1977; Dowdy and Wearden, 1983) as follows:

$$t = \frac{\Delta w}{\sigma \Delta} \tag{1}$$

and

$$\sigma\Delta = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}} \ . \tag{2}$$

In equations (1) and (2), Δw = difference between the monthly means of the observed (ECMWF) and simulated (AMIP) data, $\sigma\Delta$ = standard deviation of the difference Δw, N_1 = number of observed data for each year (899), N_2 = number of simulated data points (300), σ_1, σ_2 = standard deviations of the two samples, ECMWF and AMIP run in this case.

The differences between the monthly mean observed and AMIP run data were considered significant, 95 percent of the times if the computed value of t in Eq. (1) is $-1.96 \leqslant t \leqslant 1.96$.

This is a two-tailed test at degree of freedom, $N_1 + N_2 - 2 = 1199$ or ∞.

Table 1. Number of Months per Year for Which Differences between the Monthly Mean Observed and Simulated Temperature Data Were not Significant 95% of the Times

Year	Number of months					
	Northern Africa		Central Africa		Southern Africa	
	850 hPa	500 hPa	850 hPa	500 hPa	850 hPa	500 hPa
1980	12	0	9	0	0	0
1981	12	0	0	0	11	0
1982	12	10	11	0	5	0
1983	12	1	12	0	0	0
1984	12	12	4	12	12	12
1985	10	0	12	0	1	0
1986	12	0	10	0	10	0
1987	10	0	12	0	5	0
1988	12	0	12	0	1	0
1989	12	0	11	0	7	0
Total	116	23	93	12	52	12

IV. MODEL PERFORMANCE

Temperature at 850 hPa level

The IAP-9 layer Atmospheric General Circulation Model (AGCM) performed well within and across the seasons for the 1980-1988 AMIP period. The results in Table 1 show the number of months per year for which differences between the monthly mean temperature data (observed and simulated) were not significant. For most months of the year and for the period under consideration, the performance was okay. Out of the total period of 120 months or 10 years, only 16 months had significant differences from the simulated data in North Africa. Four months were not well simulated in Central Africa. However the model did not perform well in Southern Africa. 68 of the 120 months were badly predicted. The result should not be surprising since those regions are in the monsoon belt of Africa (Hastenrath, 1991; WCRP, 1995) that are teleconnected with Asian weather where the model was developed.

The January and July performance of the IAP-9L-AGCM for Northern, Central and Southern Africa are shown in Figs. 1-3. The simulated mean climate is in good agreement with the observations.

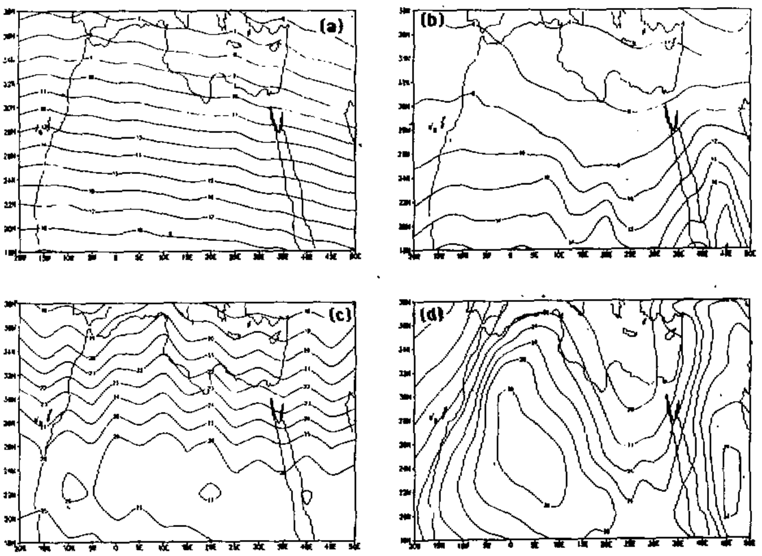

Fig. 1. Distribution of the monthly mean temperature (°C) at 850 hPa in Northern Africa for January and July in the IAP–AGCM simulation for the period 1980–1989 (a and c), and in ECMWF observation (b and d).

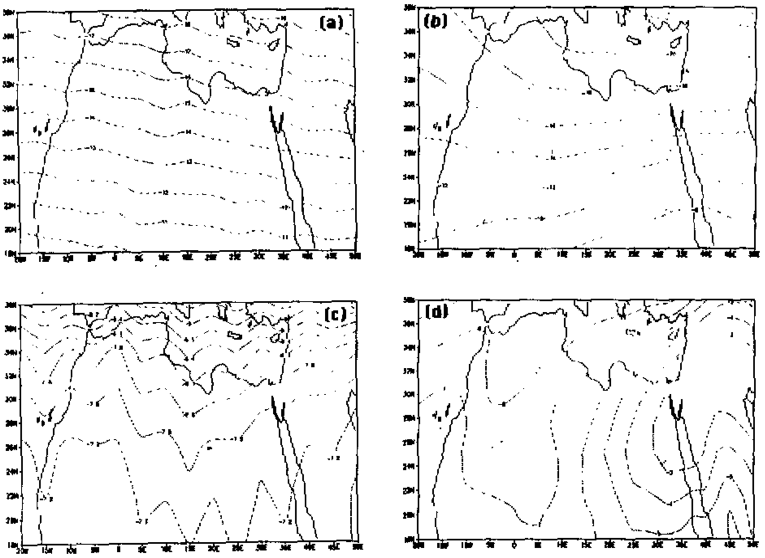

Fig. 2. Distribution of the monthly mean temperature (°C) at 850 hPa in Central Africa for January and July in the IAP–AGCM simulation for the period 1980–1989 (a and c), and in ECMWF observation (b and d).

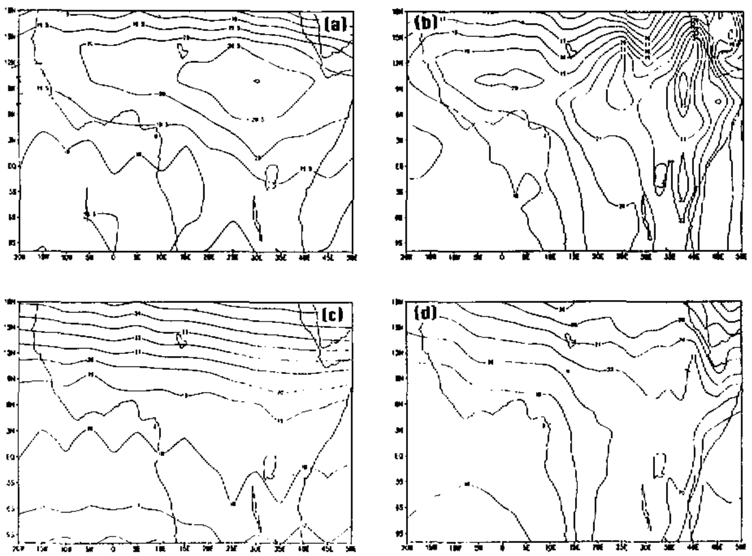

Fig. 3. Distribution of the monthly mean temperature (°C) at 850 hPa in southern Africa for January and July in the IAP-AGCM simulation for the period 1980-1989 (a and c), and in ECMWF observation (b and d).

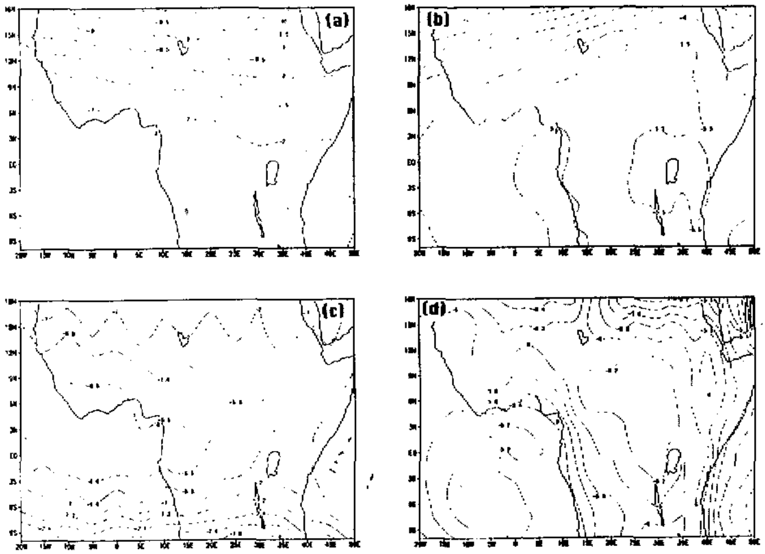

Fig. 4. Distribution of the monthly mean temperature (°C) at 500 hPa in Northern Africa for January and July in the IAP-AGCM simulation for the period 1980-1989 (a and c), and in ECMWF observation (b and d).

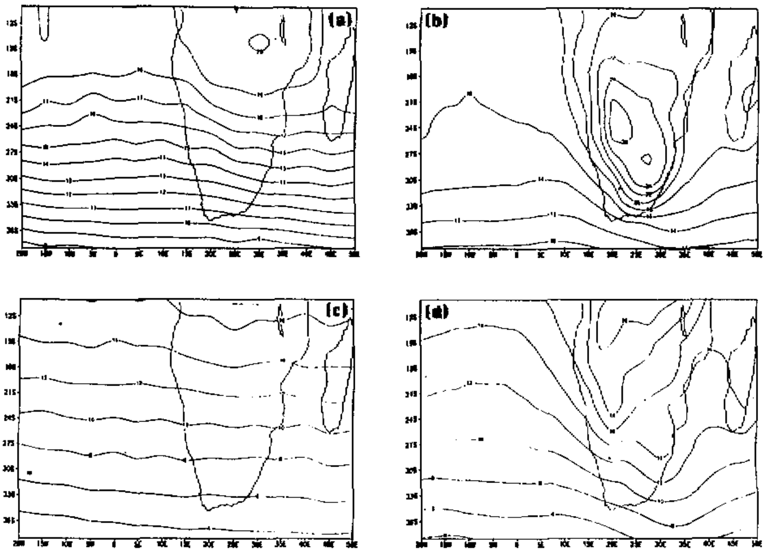

Fig. 5. Distribution of the monthly mean temperature (°C) at 500 hPa in Central Africa for January and July in the IAP–AGCM simulation for the period 1980–1989 (a and c), and in ECMWF observation (b and d).

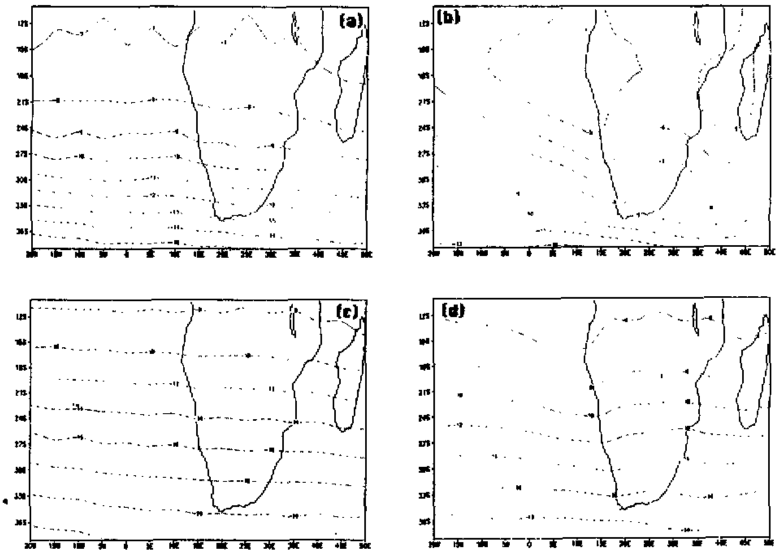

Fig. 6. Distribution of the monthly mean temperature (°C) at 500 hPa in Southern Africa for January and July in the IAP–AGCM simulation for the period 1980–1989 (a and c), and in ECMWF observation (b and d).

Temperature at 500 hPa level

The model performance for the monthly mean temperature at 500hPa level was not as good as that of the lower level. This is clearly seen from the results of the Student's t-test in Table 1. Only 23, 12 and 12 of the 120 months were okay for North, Central and Southern Africa, respectively.

A summary of the simulated and observed climatological January and July temperatures at the 500 hPa level is shown for the three regions of Africa in Figs. 4–6. The temperature distribution simulated by the IAP–9–level–AGCM is very similar to the observed. Schlesinger and Gates (1980) using their Oregon State University (OSU) two–level Atmospheric General Circulation model obtained similar results over Africa.

V. CONCLUSIONS

The results of the simulations of the African climate using the IAP grid point 9–level atmospheric general circulation model have revealed that the model is robust enough to simulate temperature data for Africa. For a continent where there is paucity of climatic data, especially upper air atmospheric meteorological variables, this holds a great promise in the years ahead. However, efforts should be devoted in data recovery activities in the region. To actually test the performance of any general circulation model, ground truth data are needed.

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REFERENCES

Bi, X. Q. (1993), *An improved nine–level atmospheric general circulation model and its application to climate simulation*, Ph.D thesis, Inst. Atmos. Phys., Chinese Academy of Sciences, 210 pp.

Chervin, R. and S. Schneider (1976), On determining the statistical significance of climate experiments with General Circulation Models, *J. Atmos. Sci.*, 33: 405–412.

Delworth, T. and S. Manabe (1996), Climate variability and land surface processes, *From Atmospheric Circulation to Global Change*, China Meteorological Press, Ed. by Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 477–502.

Doty, B. E. (1992), *Using the Grid Analysis and Display System (GrADS)*, Release Notes Version 1.3.1.

Dowdy, S. and S. Wearden (1983), *Statistics for research*, John Wiley and Sons, New York, 537 pp.

Hastenrath, S. (1991), *Climate dynamics of the tropics*, Kluwer Academic Publishers, Netherlands, 488 pp.

Liang, X. Z. (1986), *Design of the IAP AGCM and numerical climate simulation*, Ph. D thesis, Inst. Atmos. Physics, Chinese Academy of sciences, 250 pp.

Liang, X. Z. (1996), Description of a nine–level grid point Atmospheric General Circulation model, *Advances Atmos. Sci.* 13(3): 1–30.

Manabe, S., R. T Wetherald and R. J. Stouffer (1981), Summer dryness due to an increase of atmospheric CO_2 concentration, *Climate Change*, 3: 347–386.

Newmark, J. (1977), *Statistics and Probability in modern life, Holt*, Rinehart and Winston, New York, 516 pp.

Schlesinger, M. E. and W. L. Gates (1980), The January and July performance of the OSU two–level Atmospheric General Circulation model, *J. Atmos. Sci.*, 37: 1914–1943.

WCRP (1992), *Simulation of interannual and intraseasonal monsoon variability*, Report of workshop, Boulder, Colorado, USA, 21–24 October 1991, WCRP–68, WMO–TD–No. 470, World Meteo. Organiz. Geneva.

WCRP (1995), CLIVAR: *A study of climate variability and predictability, SCIENCE PLAN*, WCRP-89, WMO-TD-No. 690, World Meteo. Organiz. Geneva, 157 pp.

Wu, G., H. Liu, Y. Zhao and W. Li (1996), A nine layer atmospheric general circulation model and its performance, *Adv. Atmos. Sci.*, **13**(1): 1-18.

Xue, F. (1992), *Statistical analyses of the climate simulation of the IAP GCM and the model characteristics*, Ph.D thesis, Inst. Atmos. Phys., Chinese Academy of Sciences, 173 pp.

Ye, T.-C., R.T Wetherald and S. Manabe (1984), The effect of soil moisture on the short-term climate and hydrology change: a numerical experiment, *Mon. Wea. Rev.*, **112**: 474-490.

Zeng, Q. C. (1990), IAP GCM and its application to climate studies, *Climate change, Dynamics and modelling*, The 3rd International Summer Colloquim of LASG, Ed. by Zeng et al., 225-256.

Zeng Q.C., C.G. Yuan and X.H. Zhang (1995), IAP climate and their applications, *Progress in Natural Science*, **5**(3) 257-269.

Zhang, X.H. and X.Z. Liang (1989), Comparison and examination of the dynamical framework of IAP and OSU AGCM, *Adv. Atmos. Sci.*, **6**: 265-274.

Zhang, X.H. (1990), Dynamical framework of IAP nine-level atmospheric general circulation model, *Adv. Atmos. Sci.*, **7**(1): 67-77.

Zhang, X. H., N. Bao, R. Yu and W. Wang (1992), Coupling scheme experiments based on an atmospheric and oceanic GCM, *Chinese J. Atmos. Sci.* **16**: 129-144.