MAUSAM, 50, 4 (October 1999), 391-400

551.589.1 : 551.513

Simulation of winter and summer climates with PRL Atmospheric General Circulation Model

BIJU THOMAS, S.V. KASTURE

Physical Research Laboratory, Ahmedabad - 380009, India

and

S.V. SATYAN

Indian Institute of Tropical Meteorology, Pune - 411008, India

(Received 17 April 1997, Modified 17 September 1999)

सार — जलवायु के अध्ययनों के लिए अपने ही देश में भौतिक अनुसंधान प्रयोगशाला (पी आर एल) में एक विश्व स्तरीय स्पेक्ट्रमी वायुमंडलीय सामान्य परिचालन निदर्श विकसित किया गया है । यह निदर्श में छः उर्ध्वाधर (σ)ओ सतहें और चतुष्कोणी तिर्यकों सहित 21 तरंगों के क्षैतिजीय विभेदन हैं । इस निदर्श में सम स्थलाकृति, भूमंडलीय परिसीमा स्तर, गहन संवहन, बृहत मान संघनन, अन्योन्यक्रिया जल विज्ञान, अन्योन्यक्रिया मेघ विकिरण और दैनिक आवृति का प्रावधान है । वर्ष के विभिन्न महीनों के जलवायु विज्ञान के आँकड़ों पर आधारित समुद्र सतह तापमान और समुद्र बर्फ मानों को नियत किया गया है ।

इस निदर्श को छः वर्षों के लिए समाकलित किया गया जिसका प्रारम्भ समतापी वायुमंडल (240° K) शून्य पवनों की आरम्भिक अवस्थां से और संवर्धन आगत सौर विकिरण से होता है । एक वर्ष के पश्चात् यह निदर्श स्थिर हो जाता है । इस शोध पत्र में विभिन्न क्षेत्रों के गत पाँच वर्षों के मौसम औसतों पर विचार किया गया है । यह देखा गया है कि यह निदर्श वायुमंडलीय परिचालन, ऋतुनिष्ठ परिवर्तिता और गोलार्धक भिन्नताओं के मौसमी लक्षणों को ठीक से प्रस्तुत करता है ।

ABSTRACT. A global, spectral Atmospheric General Circulation Model (AGCM) has been developed indigenously at Physical Research Laboratory (PRL) for climate studies. The model has six σ levels in the vertical and has horizontal resolution of 21 waves with rhomboidal truncation. The model includes smooth topography, planetary boundary layer, deep convection, large scale condensation, interactive hydrology, radiation with interactive clouds and diurnal cycle. Sea surface temperature and sea ice values were fixed based on climatological data for different calender months.

The model was integrated for six years starting with an isothermal atmosphere (240°K), zero winds initial conditions and forcing from incoming solar radiation. After one year the model stabilizes. The seasonal average of various fields of the last five years are discussed in this paper. It is found that the model reproduces reasonably well the seasonal features of atmospheric circulation, seasonal variability and hemispheric differences.

Key words — Climate, Convection,Condensation, General Circulation Model, Hydrology, Radiation, Season, Spectral.

1. Introduction

The General Circulation Models (GCMs) are used for climate studies. They are based on primitive equations, include all essential physical processes and require enormous computer resources for climate time scale integrations. it is an extremely difficult task to run complex GCMs with limited computer resources for longer time scales. Some computationally efficient low resolution models have been developed with simplified physical parametrization (Otto-Bliesner *et al.*, 1982, Gallimore *et al.*, 1986). But these models do not take into account of many feedback processes like cloud radiative interaction. Further more, the radiative schemes used in these models are unsuitable for assessing the effects of environmental changes. This paper reports the summer and winter climate simulated by an indigenously developed GCM by us over years which is an extension of our earlier adiabatic model (Keshavamurty *et al.*, 1986, Krishnakumar *et al.*, 1993).

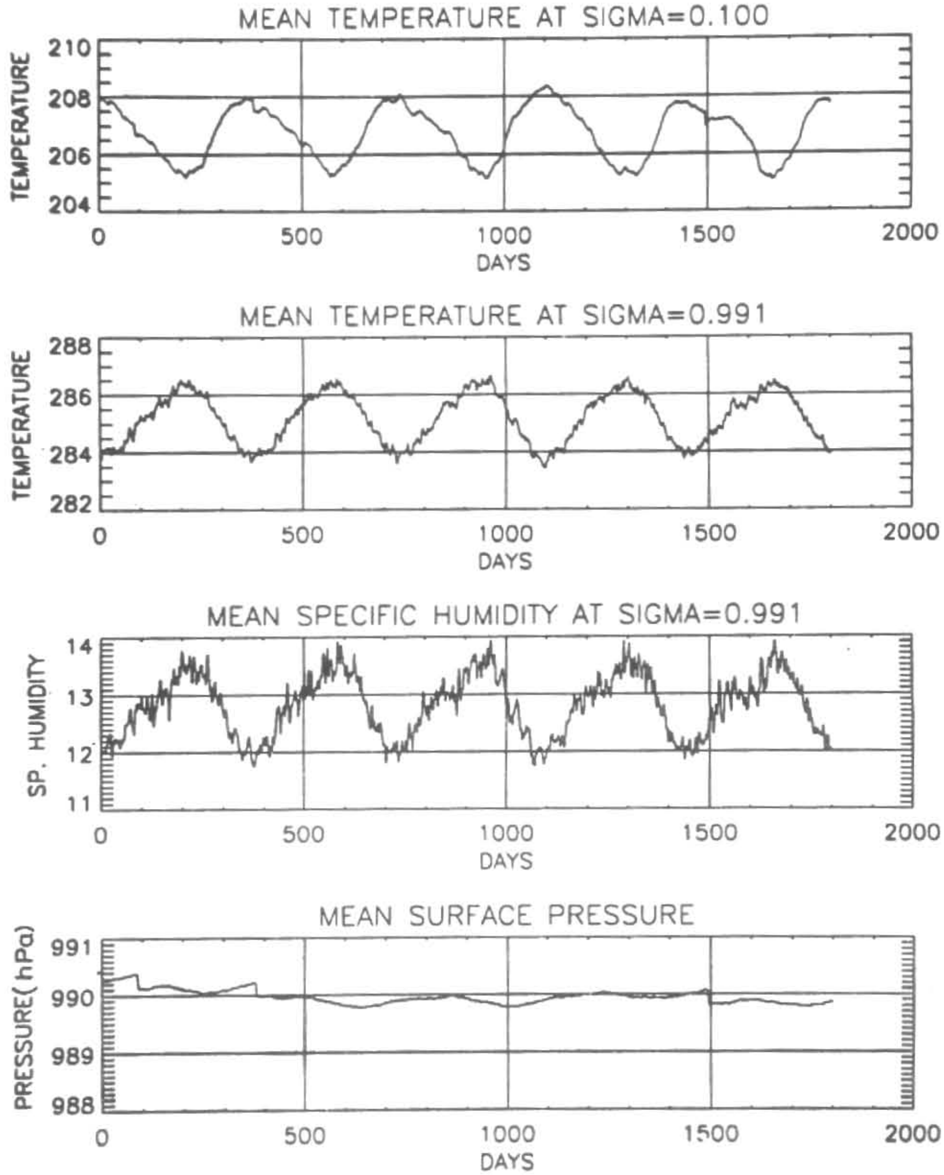
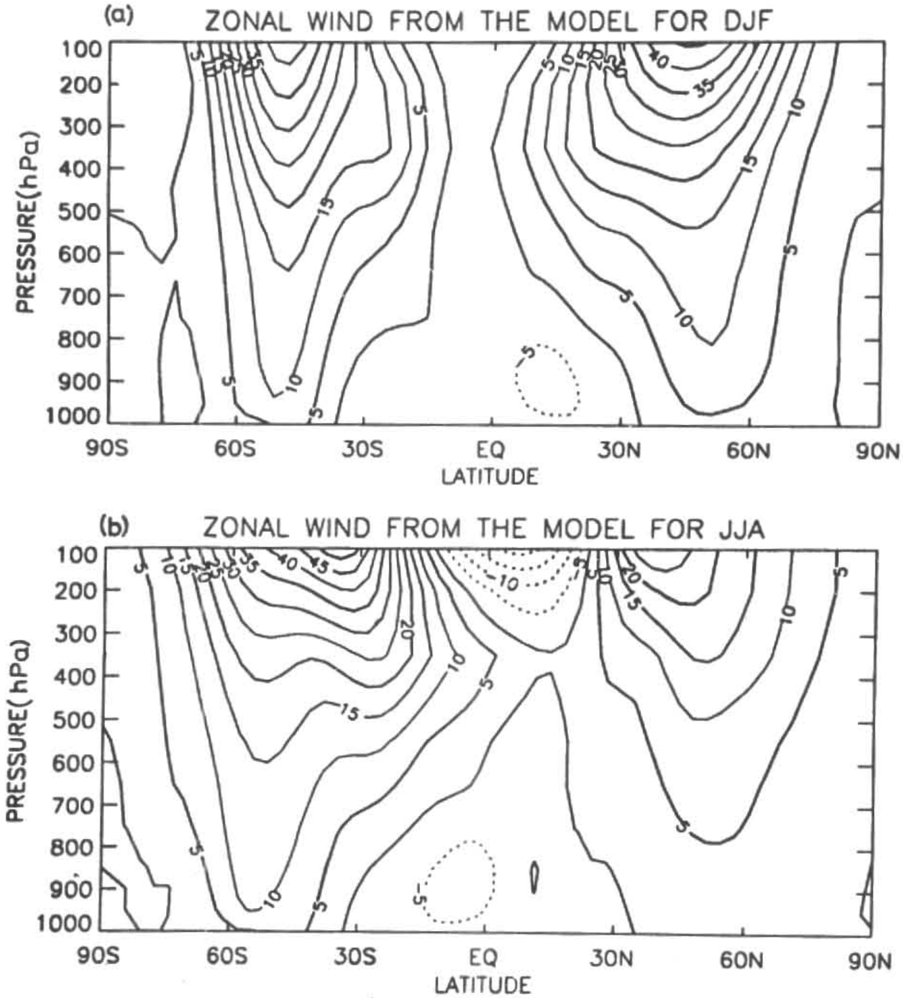


Fig. 1. Time variance of global mean of pressure (hPa) temperature (°C) at level 6, at level 1, and specific humidity(g kg $^{-1}$) at level 1

We have seen that even with a GCM of intermediate complexity and from a very idealized initial condition, we can simulate the seasonal climatology of the atmospheric circulation reasonably well. A number of GCMs are available with different groups today which simulate the general circulation pattern fairly well. But most of these models are not completely free from biases and errors as documented by Boer *et al.*, 1991. In this paper we do not claim any particular improvement in simulation of seasonal climatology. Our longterm objective is to develop a climate model which can simulate monsoon and tropical climate (seasonal mean circulation, precipitation pattern and their variability) reasonably well and use it for studies of monsoon climate change. The present paper marks the beginning in this direction. The details of the model and the model run are given in section 2, the results are discussed in section 3 and the conclusions are discussed in section 4.

2. Description of the model

A primitive equation global spectral model with 21 waves in horizontal with rhomboidal truncation and six σ levels in the vertical placed at σ = 0.991, 0.9,0.7, 0.5, 0.3, 0.1 is developed indigenously. The vertical velocities and



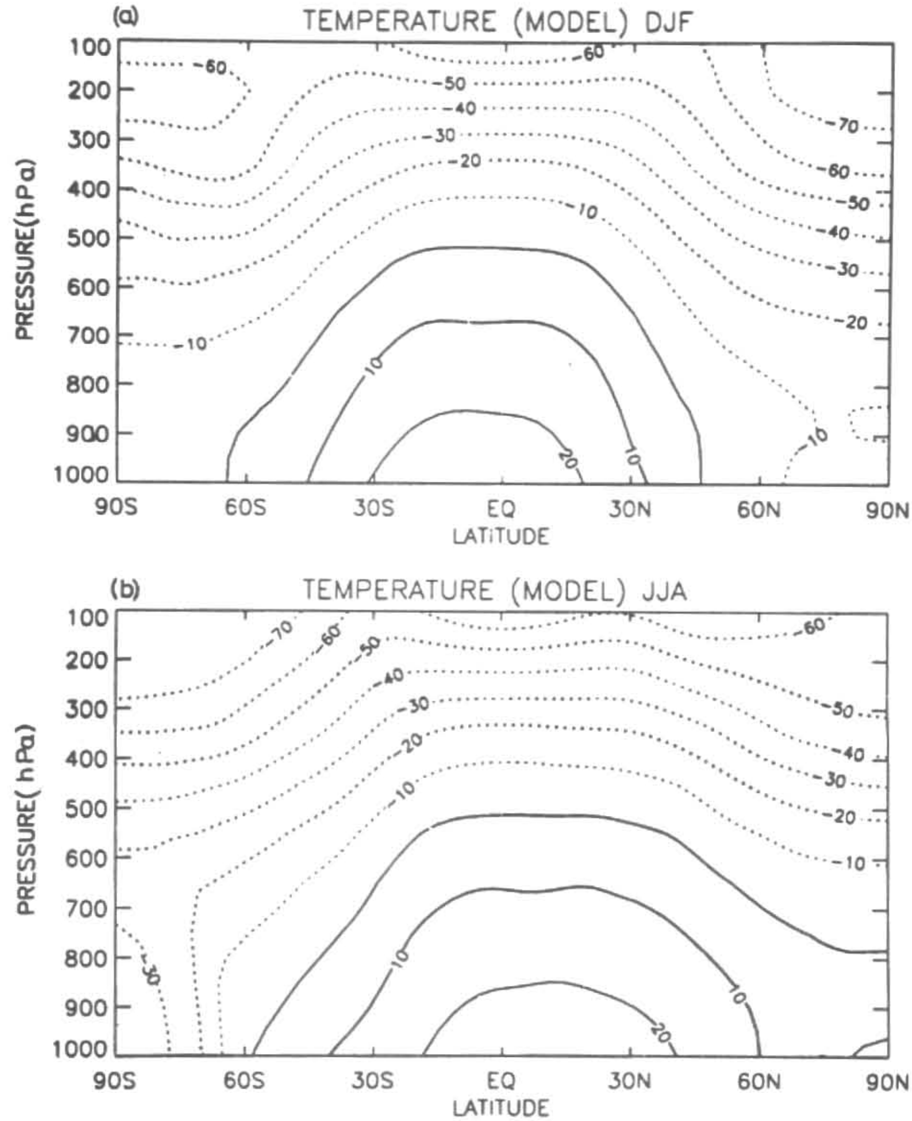
Figs. 2(a &b). Zonal mean field for zonal component of wind (m s^{-1}) for DJF and JJA respectively

vertical derivatives are calculated at intermediate levels at first and then weighted average with respect to σ of adjacent half level values are taken for full level values. The physical processes like radiation and convection are calculated at 10 pressure levels and interpolated back to six model σ levels. For time integration the model uses a leapfrog semi-implicit time differencing scheme (Bourke, 1974) and the high frequency computational modes are controlled by Asselin filter (Asselin, 1972). The physical processes included in the model are vertical and horizontal diffusion (Bourke *et al.*, 1977), surface fluxes with varying drag coefficient (Williamson *et al.*, 1987), dry adjustment scheme, deep convection (Krishnamurti *et al.*, 1983), large scale condensation and radiation (Chang, 1979) with interactive clouds (Senior and Mitchell, 1993).

Surface temperature is calculated by solving surface energy balance condition over land grid points (Bourke *et al.*, 1977). Climatological monthly mean surface temperature data (Shea *et al.*, 1992) is used over oceanic grid points. Surface albedo over land is taken from seasonally varying albedo data sets of Mathews (1983) and over oceanic grid points it is fixed as 0.06. Over sea ice and permanent snow covered land points albedo is fixed at 0.7 and 0.8 respectively. For topography 1 × 1 degree latitude/longitude tabulated surface elevation data is interpolated for 21 waves resolution and is used in the model.

2.1. *Integration of the model*

The model was started with zero wind conditions and an isothermal atmosphere with 240 °K temperature with forcing from incoming solar radiation. The bottom boundary values of SST and albedo were fixed from monthly mean climatological data. The model was integrated for six years. After one year the model stabilizes and seasonal averages of



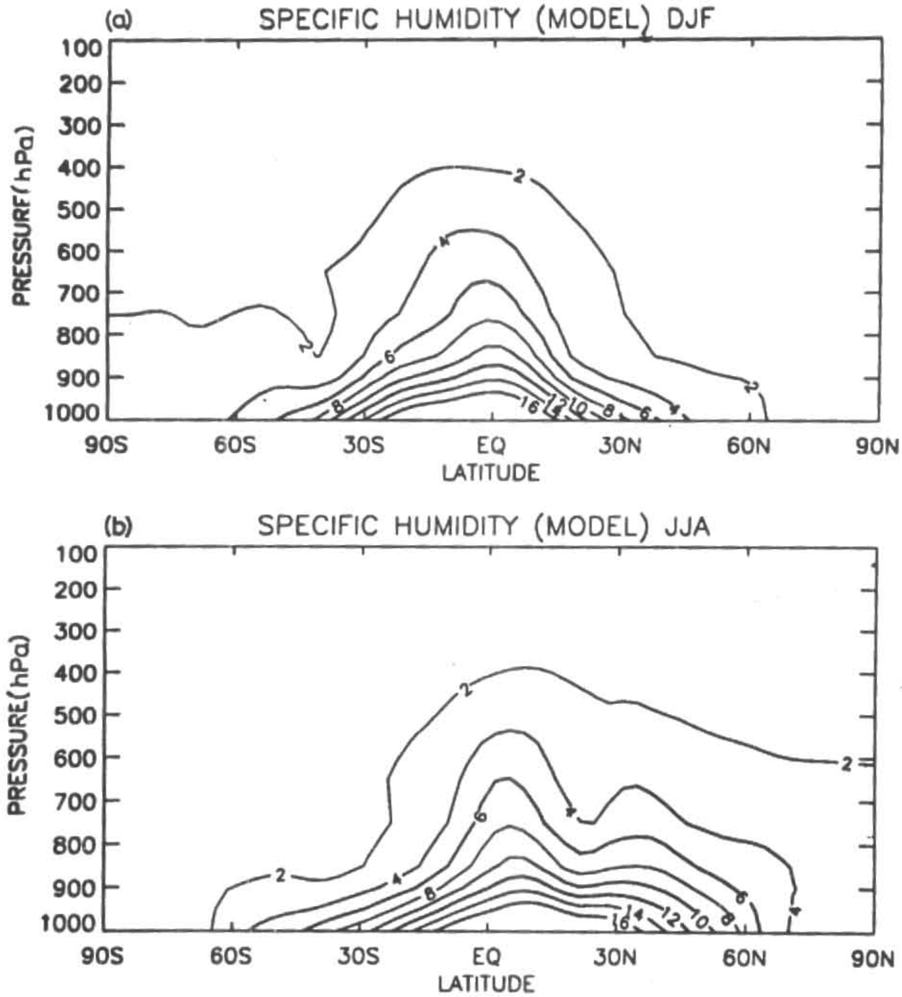
Figs. 3 (a & b). Zonal mean field for temperature (°C) for DJF and JJA respectively

various fields of the last five years were taken as mean climatology for winter/summer season. The results are presented in the next section.

3. Results and discussion

3.1. *Time variation of global means*

Time variation of global means for temperature at level 6($\sigma = 0.1$) and level 1 ($\sigma = 0.991$), specific humidity at level 1 and surface pressure and shown in Fig. 1. In the figure the zero on the x-axis refers to January 1st. The time evolution of the model global mean values give indication of the stability and conservation properties of the model. The global mean temperature at level 1 has no trend over four year simulation as it is driven by prescribed climatological monthly mean SST. Its seasonal cycle has 3 K range with minimum in January and maximum in August. The global mean temperature at top model level is out of phase with level 1. It has same temperature variation (3 K) like the lower level. The global mean specific humidity at the lowest level has cycle similar to temperature at that level. It has variation of 2 g/kg and is small. The global mean surface pressure has a decreasing trend at a rate of 0.1 hPa per year. The time variations of temperature and mixing ratio are similar to the results of Otto-Bliesner *et al.* (1982). But, in our simulation surface pressure has negligible variation and



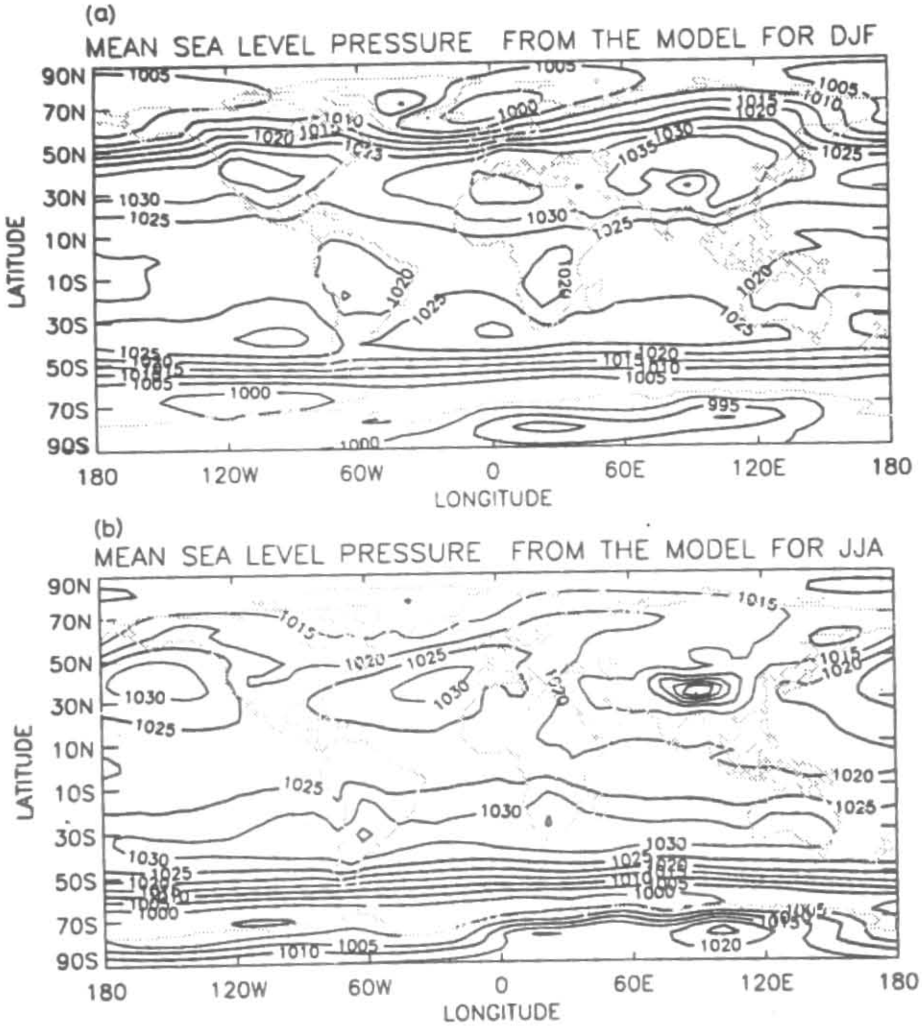
Figs. 4 (a & b). Zonal mean field for specific humidity (g kg^{-1}) for DJF and JJA respectively

has very small decreasing trend while Otto-Bliesner *et al.* (1982) reported an increasing trend of 1 hPa per year in their simulation.

3.2. *Zonal mean fields*

(*i*) *Zonal winds*

The zonal mean fields of the model simulation for December- February(DJF) season is shown in Fig. 2a and for June-August (JJA) season in Fig. 2b. For observations refer Oort (1983). The main features of the zonal wind distribution of the model simulation which nearly agree with climatological features (Oort, 1983) are, "mid-latitude westerlies and low latitude easterlies during both the seasons, slightly poleward movement and weakening of northern hemispheric jet in JJA and the less pronounced seasonal variability of the amplitude of the southern hemispheric jet". One discrepancy is that the subtropical jets are not closed in the simulation. A similar discrepancy is seen in other GCMs like MRI, OSU *etc.* which have poor vertical resolution (see Boer *et al.*, 1991). The winter hemispheric jet is not well simulated in most of the currently using GCMs. During DJF the subtropical westerly jets in Southern Hemisphere (S.H.), low level wind distribution and the position of zero-wind line are nearly reproduced by the model. However, maximum wind in the Northern Hemisphere (N.H.) during DJF is simulated around 10° poleward than is observed. The easterlies in the tropical region are seen in the simulation in both the seasons. During JJA model simulated maximum westerly winds are latitudinally well positioned in the both hemispheres. Like observation, seasonal variations in intensity are largest in N.H. and the intensity is nearly half in N.H. summer than N.H. winter. Like the observations, model simulated subtropical westerly jets are stronger in winter hemisphere than summer hemisphere.



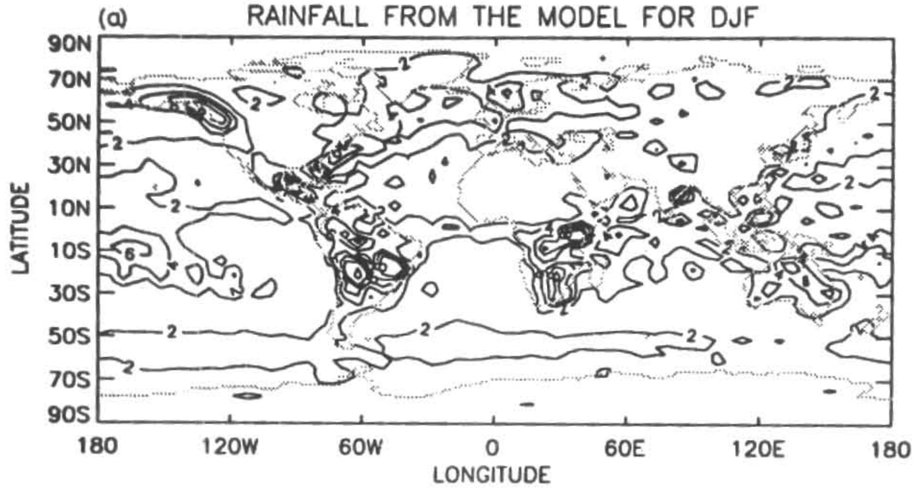
Figs. 5 (a & b). Mean sea level pressure (hPa) for DJF and JJA respectivly

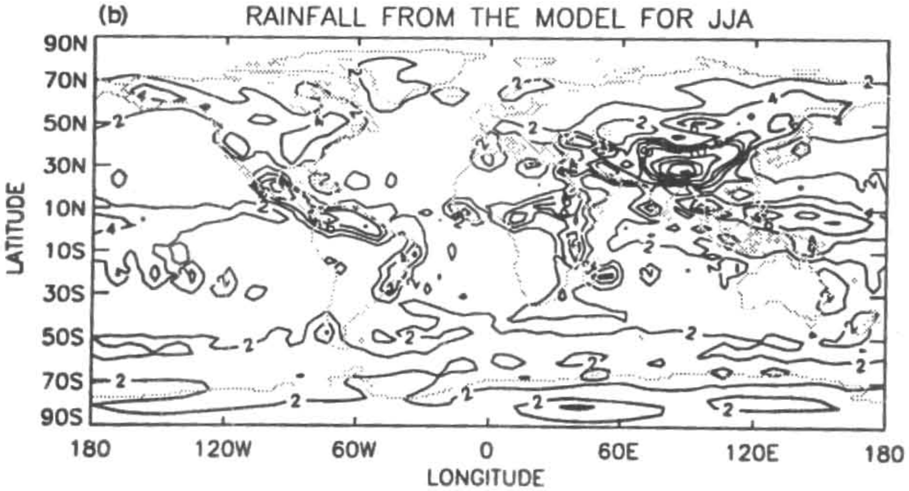
(ii) Vertical wind

The upward and downward motions related to the Hadley cell in the both seasons are simulated by the model. (figures are not reproduced for reasons of space). The upward motion during N.H. summer extends to higher northern latitudes and downward motion to lower southern latitude like observations. The strength of the Hadley cell in both the DJF and JJA simulation is less than observations. Also a weak upward motion is seen around 25°-40° N during JJA. This may be due to the spurious vertical motion associated with the model topography of Himalayan region. Rainfall field (Fig. 6b) also shows this effect. Model also captures the observed Ferrel and Polar cells in both hemispheres and both seasons. For observations refer Oort (1983).

(iii) Temperature

The zonal mean temperature for DJF and JJA are shown in Figs. 3(a&b) respectively. For observations refer Newell *et al.* (1972). The broad structure of the model simulated zonally averaged temperature field nearly agrees with observations. The model captures the temperature inversion at high northern latitude (65°) during DJF but is warmer by 10°. Like in observations, model field also shows more seasonal variability in N.H. than S.H. and at higher northern latitudes. The temperature at low latitudes of the middle and lower troposphere matches nearly well with observations. However, during both seasons, middle latitude and low latitude of the upper troposphere is warmer than it is observed. Also during DJF north pole has a cold bias at upper troposphere. The model simulated stronger N.H. mid-lati-





Figs. 6 (a & b). Rainfall rate(mm day^{-1}) for DJF and JJA respectively

tude westerly jet during DJF is consistent with the warm bias at low latitude and cold bias at North pole. A warm bias at low latitude and cold bias at North pole is commonly seen in other simulations with GCMs like GFDL, MRI and CCC (Boer *et al.*, 1991).

(*iv*) *Specific humidity*

The specific humidity values for DJF and JJA are shown in Figs. 4(a&b) respectively. For observations refer Oort (1983). The model distribution of specific humidity exhibits maximum moisture near the surface in the tropics and decreases with altitude and poleward like observations. Also model simulates the seasonal migration of contours to northern hemisphere from DJF to JJA. During DJF, like observations maximum specific humidity values are located near equator region while during JJA, more moisture is at northern latitudes. Although the pattern in general agrees with observations, the details differ. The simulated distribution is not as smooth as observed one. This is clear during N.H. summer around 35°N. This may be due to the excessive convective activity over Tibetan plateau in the model atmosphere and the associated upward motion. Also model atmosphere is slightly more moist at tropical region near the surface than observations.

3.3. *Geographical distribution*

(*i*) *Mean sea level pressure*

The mean sea level pressure during DJF and JJA are presented in Figs. 5(a &b) respectively. For observations refer Schutz and Gates (1971,1972b). The model simulated features include the familiar picture of equatorial low, subtropical high during both the seasons, and the low pressure area over north Indian region during JJA. During N.H.

winter, model reproduced Icelandic low is well positioned and is slightly broad but Aleutian low is broader and is shifted northward than observation. During DJF, the model has captured S.H. subtropical high, equatorial low pressure zone with a low over south America, south Africa and Asiatic high. But the Asiatic high is broader and extends further over western Africa than observations. The other climatological features like Antarctic low pressure band and Siberian high are well reproduced by the model. During N.H. summer, like observations, high pressure zones are appearing over oceanic region and lows are appearing over relatively warm land mass in N.H. Also model has captured other climatological features like subtropical high pressure near 30°S, N.H. subtropical high, and low pressure over south Asia. Model simulated closed high over northern Pacific is well positioned but it is slightly stronger than observation. In general, eventhough model simulated sea-level pressures are sometimes 5-10 hPa higher than observed, pressure gradients match well with observations. Other models like GFDL (Boer *et al.,* 1991) also produce higher sea level pressures than observations. One discrepancy is that model simulates an intense high during N.H. summer over Antarctic region. This discrepancy is seen in other models like, GFDL, NCAR and MGO (Boer *et al.,* 1991).

(*ii*) *Surface air temperature*

The global distribution of the temperature at the lowest model level ($\sigma = 0.991$) is compared with observed surface temperatures of Schutz and Gates (1971, 1972b). During N.H. winter over south Asia, Africa, Australia, south America and southern part of north America model field nearly agrees with observations. Eventhough the temperature minimum in Siberia and north Canada are reproduced by the model, it underestimates the cold pools over these regions by 15-20°. Model reproduces the seasonal migration of surface temperature well. During N.H. summer, except in Antarctic and Greenlands model field nearly matches with observations. Over Antarctic and Greenlands model has a strong warm bias. However it should be noted that the observational data is uncertain in these regions and the effects of mountain are also important. (Fig. are not reproduced).

(*iii*) *Precipitation rate*

The rainfall rate for DJF and JJA are shown in Figs. 6(a&b) respectively. For observed rainfall rate refer Schutz and Gates (1972a). The model reproduces reasonably well the tropical rain belt, subtropical dry region, seasonal differences like the rainfall maximum over south America and south Africa, shift by 15-20°N from DJF to JJA and development of the south Asian monsoon in northern summer. In DJF simulation rainfall maximum east of north America is slightly stronger and rainfall maximum east of Asia is of the same strength as observed. During DJF the rainfall over western Pacific and north Atlantic is less than observed. The dry zone over central north America and north Africa are reproduced like observations. But model simulates more rainfall over Brazil and equatorial Africa than observations. The model simulated rainfall nearly matches in the north-west region of north America and central and eastern Pacific ocean. The model produces more rainfall over southern part of south Africa, Australia, north-west Arabian sea and north Bay of Bengal.

During JJA the model simulation of rainfall over western Pacific ocean nearly agrees with observations. Like observations, the model reproduces less rainfall activity over Australia, south-east Pacific ocean and central south America. Also model captures the small pockets of rainfall maximum over northern part of south America and Malagasy. During JJA the model simulation of rainfall over south-east pacific ocean, Indonesian region, south America and equatorial Africa nearly agrees with observations. But model produces less rainfall over southern part of Chile. During both seasons model rainfall activity over central north America agrees reasonably well with observations but the model reproduced rainfall over central pacific ocean during JJA, is less than observed. But model overestimates the rainfall over north Asia. We feel that a more smoothened model topography over Himalayan region and a realistic representation of snow cover over Eurasia during previous winter will prevent the unrealistic splitting of rainfall maxima from Pacific to north Asia during JJA.

4. Conclusions

We have developed indigenously a relatively simple spectral GCM with 21 waves in horizontal and six levels in the vertical. It includes all important physical processes like horizontal and vertical diffusion, planetary boundary layer, dry adjustment scheme, cumulus convection, large scale condensation, radiation with interactive clouds and hydrology. The GCM was integrated for a reasonably longtime (six years) with our limited computer resources, from a very idealised initial condition *i.e.* an isothermal atmosphere, zero winds initial conditions and forcing from incoming solar radiation. The time series of global average temperature, moisture and surface pressure for the last five years show good stability and conservative properties of the model. The structure, magnitude and seasonal variability of zonally averaged zonal and meridional components of winds reasonably agree with observations. One discrepancy is the large magnitude of westerly maximum in the upper troposphere in both hemispheres and in both seasons. These errors could be due to the result of errors in the simulation of the temperature at upper troposphere and we feel that these errors could be minimized by improving the vertical resolution of the model especially in the stratosphere. The zonal mean vertical component of wind shows the three cell structure of the atmosphere during both the seasons and both the hemispheres and they agree fairly well with observations. The zonally averaged distribution of temperature and humidity, in general agrees with observations.

Model simulated sea-level pressure include Icelandic low and Asiatic high during N.H. winter and monsoon low and oceanic subtropical highs during N.H. summer. The model captures well the observed gradient of pressure and land-ocean contrast. The temperature field at the lowest model level shows seasonal variability and land-ocean difference and resembles well with surface temperature with the exception of a warm bias at south polar region during N.H. winter and warm bias at north polar region during N.H. summer. The overall main features of the precipitation field agree with observations. However, model overestimates the rainfall activity over central Asia and Central north America during N.H. summer. The model reproduces well the mid-latitude westerly winds at 850 and 200 hPa during both the seasons and both hemispheres. The model also reproduces well the reversal of winds at 850 hPa in NW Arabian Sea from N.H. winter to N.H. summer. The model captures the structure of the observed temporal variability of zonal and meridional components of winds and temperature in both the seasons and both hemispheres with slightly lesser magnitude. Thus the large scale general features of the atmospheric circulations are reasonably well reproduced by the model with seasonal and hemispheric differences. The discrepancies of GCMs to the state of art of simulating present day climate are discussed in Boer *et al.*, 1991. Eventhough basic numerical techniques are standard, the physical parameterizations are different in different models, and the evolution of climate in a climate model mainly depends on physical parameterizations used in it and model resolutions. So simulation of climate with different models will give more insight to the nature of certain discrepancies of currently used GCMs and it will help to improve the model numeric, resolution and physics. The time taken by this model for one day integration on HP-9000/735 workstation is 6 minutes. We feel that with limited computer resources, this kind of GCM is still a useful tool to understand the various physical and dynamical processes occurring in the earth-atmosphere system.

Acknowledgement

This work was supported by the Indian Space Research Organization (ISRO)-GBP project. We thank to Scientific Computing Division of NCAR for providing us the climatological data for our model run.

References

Asselin, R., 1972,"Frequency filter for time integrations", *Mon.Wea.Rev.*, **92**, 91-104.

Boer, G.J., Apre, K., Blackburn, M., Deque, M., Gates, W.L., Hart, T.L., Treut, H.L., Roeckner, E., Sheinin, D.A., Simmonds, I., Smith, R.N.B., Tokioka, T., Wetherald, R.T. and Williamson, D.,1991,"An intercomparison of the climates simulated by 14 Atmospheric General Circulation Models". Report No.15, WMO/TD-No.425.

Bourke, W., 1974, "A multi-level spectral model I. Formulation and hemispheric integrations", *Mon.Wea.Rev.*, **102**, 687-701

Bourke, W., McAvaney, B., Puri, K. and Thurling, R., 1977, "Global modelling of atmospheric flow by spectral methods", *Methods in Comput. Phy.*, **17**, 267-324.

Budyko, M.I.,1969, "The effects of solar radiation variations on the climate of the Earth", *Tellus*, **21**, 611-619

Chang, C.B., 1979, "On the influence of solar radiation and diurnal variation of surface temperature on African disturbances". Rep. No. 79-3, Department of Metereology, Florida State University, Tallahassee, FL 32306.

Gallimore, R.G., Otto-Bliesner, B.L. and Kutzbach, J.E., 1986, "The effects of improved parametrizations for orography, snowcover, surface fluxes and condensational processes on the climate of a low resolution GCM", *J.Atmos. Sci.*, **43**, 1961-1983.

Hoskins, B.J., Hsu, H.H., James, I.N., Masutani, M.,Sardeshmukh, P.D. and White, G.H., 1989, "Diagnostics of the global atmospheric circulation based on ECMWF Analysis 1979-89". WMO/TD- No. 326, 300p.

Keshavamurty, R.N., Kasture, S.V. and Krishnakumar, V., 1986,"30-50 day oscillation of monsoon: A new theory", *Beitr.Phys. Atmos.*, **59** 443-454.

Krishnakumar, V., Kasture, S.V. and Keshavamurty, R.N., 1993, "Linear and nonlinear studies of the summer monsoon onset vortex", *J. Meteor. Soc.*, Japan, **71**, 1-20.

Krishnamurti, T.N., Low-Nam, S. and Pasch, R., 1983, "Cumulus parameterization and rainfall rates II", *Mon. Wea. Rev.*, **111**, 815-828.

Manabe, S.and Strickler, R.F., 1964, "Thermal equilibrium of the atmosphere with a convective adjustment", *J. Atmos. Sci.*, **21**, 361-385.

Mathews, E., 1983,"Global vegetation and land use: new high resolution data bases for climate studies", *J.Clim. Appl. Meteo.*, **22**, 474-487.

Newell, R.E., Kindson, J.W., Vincent, D.G. and Boer, G.J., 1972, "The General Circulation of the Tropical Atmosphere and interactions with extratropical Latitudes", Vol. 1. The MIT Press. 258p.

Oort, A.H., 1983, "Global Atmospheric Circulation Statistics 1958-1973". NOAA Prof. paper 14, 180p. [U.S. Govt. printing press]

Otto-Bliesner, B.L., Branstator, G.W. and Houghton, D.D., 1982, "A global low-order spectral General Circulation Model part I: Formulation and seasonal climatology", *J. Atmos. Sci.*, **39**, 929-948.

Schutz, C. and Gates, W.L., 1971, "Global climatic data for surface, 800 hPa, 400 hPa January". R-915-ARPA, The Rand Corporation, Santa Monica, CA, 173p.

Schutz, C. and Gates, W.L., 1972a, "Supplemental Global climatic data, January". R-915/1-ARPA, The Rand Corporation, Santa Monica, CA, 41p.

Schutz, C. and Gates, W.L., 1972b, "Global climatic data for surface 800 hPa, 400 hPa July". R-1029-ARPA, The Rand Corporation, Santa Monica, CA 180p.

Senior, C.A. and Mitchell, J.F.B., 1993, "Carbon dioxide and climate: The impact of cloud parametrization", *J. climate*, 6, 393- 418.

Shea, D.J., Trenberth, K.E. and Reynolds, R.W., 1992, "A Global monthly sea surface temperature climatology", *J. Climate*, **5**, 987- 1001.

Williamson, D.L., Kiehl, J.T., Ramanathan, V., Dickinson, R.E. and Hack, J.J., 1987, "Description of NCAR Community Climate Model (CCM1)'. NCAR Technical note NCAR/TN-285+STR National Centre for Atmospheric Research, Boulder, Colorado.