SYNOPTIC VALIDATION OF CLIMATE MODELS : ASPECTS OF VARIABILITY IN THE TROPICS OF THE UGAMP GENERAL CIRCULATION MODEL

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1. INTRODUCTION

Interesting exploratory studies and very long evolution studies of climate are often carried out with highly parametrized models, such as energy balance models. However, the detailed climate change predictions on the sub-century timescale are currently produced using primitive equation models that explicitly represent synoptic weather systems. These general circulation models (GCMs) are now being run with resolutions similar to the forecast models of a decade ago; their physical parametrizations are often developed from those used in forecast models.

The climate in a region can be considered to be the ensemble of the weather systems that affect that region. In the European sector, for example, the winter climate is determined by the relative dominance of blocking or mobile cyclonic sytems and the extremes in wind and temperature associated with them. If a GCM is unable to represent such behaviour, its prediction of climate change for the region cannot be used with confidence.

The physical parametrizations in a GCM are developed and modified so as to ensure that the errors in representing today's climatic means are minimized. Even if it is only such mean fields for which a predicted climatic change is required, confidence in this prediction must depend on knowing that the accuracy of the representation of the current state is due to the correct mixture of ingredients.

Finally, for those interested in understanding some of the vast range of interacting time and space scales that make up the climate of the Earth, the continual diagnosis and comparison of model and observational data on these various scales is of fundamental importance. This paper illustrates some examples of the diagnosis that can and should be performed on GCMs to assess their ability to represent the transient component of the present day climate, with particular reference to the tropics.

2. THE MODEL AND THE EXPERIMENTS

The UGAMP GCM, hereafter referred to as the UGCM, is derived from Cycle 27 of the ECMWF model.

Various changes have been made to the model, including the incorporation of the radiation parametrization developed by Morcrette (1990). Following the study of Miller et al. (1992), the surface fluxes have been enhanced in both the low wind speed limit and in the presence of deep convection. The vertical diffusion parametrization has been removed above the mid-troposphere; vertical advection is treated with a total variance diminishing (TVD) scheme (Thuburn 1993).

Two different convection schemes have been used in the model. The Kuo deep convection scheme, as included in the original Cycle 27 model (Tiedtke et al. 1988), relies on a moisture convergence criterion, with the converged moisture being partitioned between heating and moistening of the environment. This version of the convection also includes the diffusive shallow convection parametrization described by Tiedtke et al. (1988). The convective adjustment scheme, developed by Betts and Miller (1986, 1992) uses a relaxation towards observed thermodynamic structures for both deep and shallow convection; there is no dependence on moisture convergence.

All integrations described in this paper were run at T42 horizontal resolution (~ 2.8^o lat./long.) with 19 hybrid levels in the vertical. Two sets of experiments were performed with each convective parametrization, for seasonal northern summer and perpetual January conditions. The seasonal summer integrations used starting conditions for 1 May, based on data from a previous annual cycle integration, and were run out to 30 September with seasonally evolving sea surface temperatures. The perpetual January integrations were run for 360 days to allow a reasonable estimate of the variability associated with intraseasonal timescales. Subsequently, the integration with the convective adjustment scheme has been extended to 3600 days to allow a full study of the low frequency variability inherent in a GCM. However, the results shown in this paper will be primarily based on the first 360 days, unless otherwise stated.

The model results will be compared with estimates of the tropical transience from ECMWF daily analyses for the years 1986 to 1990, and with the Global Cloud Imagery (GCI) data from multiple satellites (Salby et al. 1990) for December 1983 to February 1984 (Hendon, personal communication).

3. RESULTS FROM SEASONAL NORTHERN SUMMER INTEGRATIONS

Figure 1 shows the square root of the total variance of the 850mb relative vorticity, as computed from daily ECMWF analyses at 12z, for June, July and August, averaged over the five years, 1986 to 1990. It shows the main areas of tropical transient activity, associated primarily with synoptic disturbances, but also with intraseasonal variation in the intensity and position of the summer monsoon trough (see later). The same diagnostic from the two versions of the UGCM (Figures 2 and 3) indicates that neither convection scheme has simulated the distribution of tropical transience correctly, although the adjustment scheme has produced more reasonable levels of transience than the Kuo scheme.

Both versions of the model developed a monsoon with a rapid acceleration of the monsoon flow during May. The mean 850 mb winds for July (Figure 4) show reasonable simulations with both convection

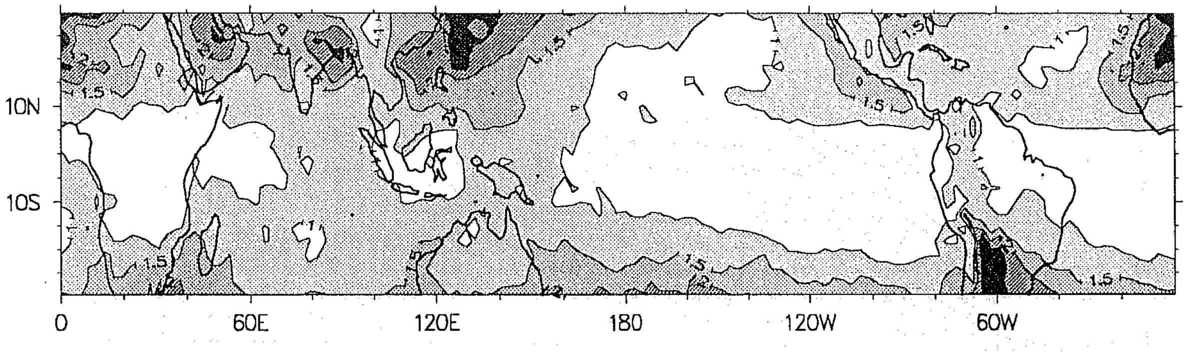


Figure 1 : Square root of the total variance of the 850mb relative vorticity ($10^{-5}s^{-1}$) computed from daily ECMWF analyses for June, July and August, 1986 - 1990.

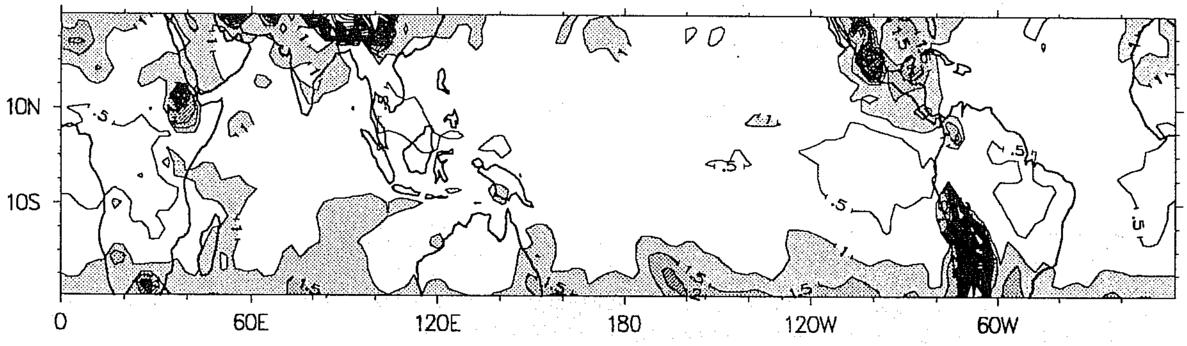


Figure 2 : Square root of the total variance of the 850mb relative vorticity ($10^{-5}s^{-1}$) for June, July and August from the UGCM integration with the Kuo scheme.

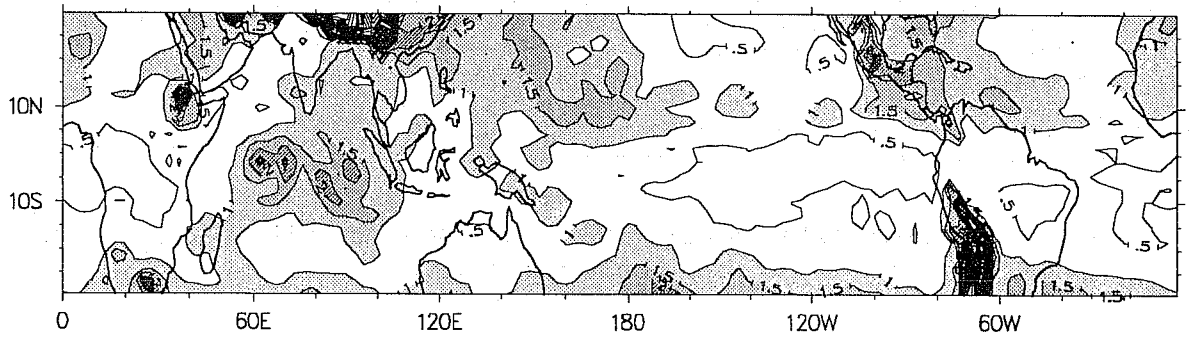
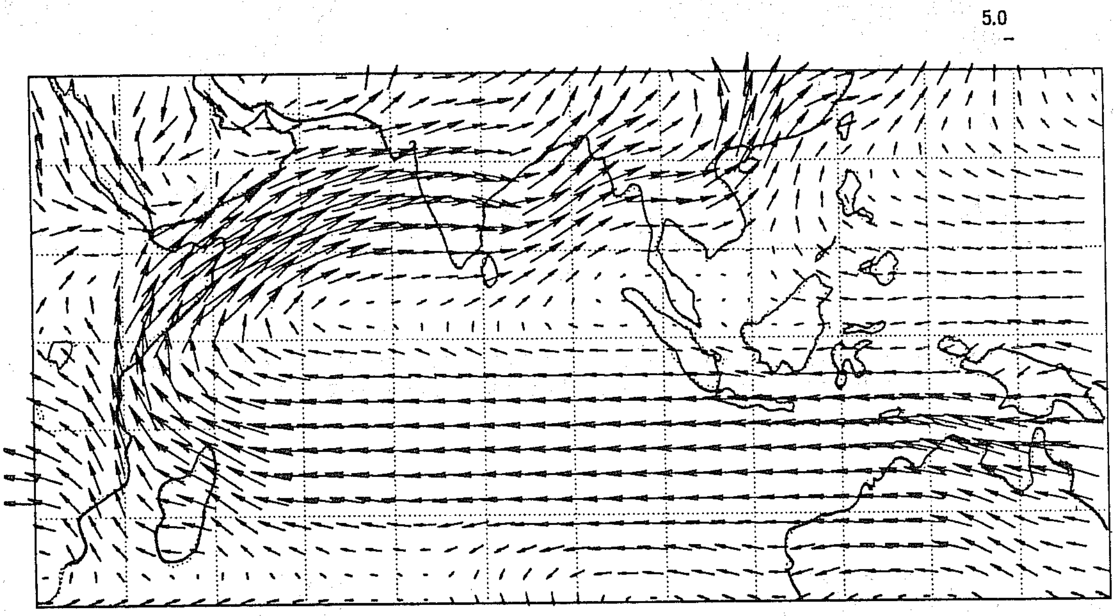


Figure 3 : As Figure 2, but for the UGCM integration with the convective adjustment scheme.

(a) Kuo scheme



(b) Convective adjustment scheme

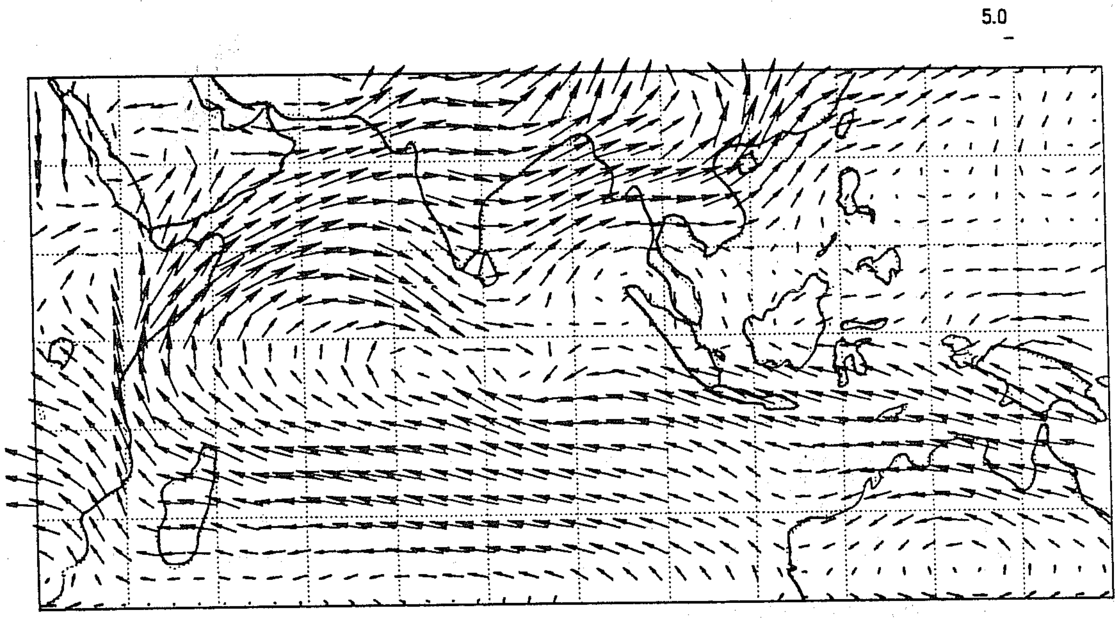


Figure 4 : Mean winds at 850mb for July from the UGCM integrations with (a) Kuo scheme and (b) convective adjustment scheme

schemes. However, whilst in a time mean sense both versions produced similar quality simulations of the monsoon, the evolution was markedly different. This is well demonstrated by the time series of precipitation over India (Figure 5). The adjustment scheme has produced a realistic, sudden onset to the rainfall in mid-June, followed by a break in early July. However, it does not re-establish the Indian rainfall as would be expected in reality, apart from a weak attempt at the beginning of August. Also shown in Figure 5 is the time series of the rainfall to the south, over the equatorial Indian Ocean, from the adjustment scheme. The onset of rain over India is preceded by rainfall further south and when the monsoon break occurs, the rainfall to the south rapidly redevelops. This bimodal behaviour of the ITCZ over Indian longitudes is quite realistic, although the observations show that it is the continental rather than the oceanic mode which should be dominant (Gadgil et al. 1992). The Kuo scheme, on the other hand, fails to produce the correct temporal characteristics of the monsoon, with no pronounced onsets or breaks. The rainfall is fairly continuous over India with a strong diurnal cycle which the adjustment scheme does not show.

The intraseasonal variation in the monsoon rains over India is generally associated with the northward propagation of the monsoon trough. This can be seen in Figure 6(a) which shows the latitudinal movement of the 850mb relative vorticity over the Bay of Bengal based on ECMWF analyses for the summer of 1990. Two well defined northward moving events can be seen during early June and early August. The rapid cessation of cyclonic activity to the north in late July is accompanied by intensification of the monsoon trough to the south over the ocean. A similar diagnostic from the two versions of the model (Figures 6(b) and (c)) shows that neither scheme has correctly produced the intraseasonal behaviour of the monsoon trough. The adjustment scheme has an onset with the correct northwards propagation of the trough at a realistic speed. The Kuo scheme shows no such northwards propagation, although the trough does show some intraseasonal variability in its intensity.

4. RESULTS FROM PERPETUAL JANUARY INTEGRATIONS

As with the seasonal northern summer integrations, the two versions of the model produced reasonable simulations of the time mean general circulation. However, they displayed markedly different transient behaviour. This is well demonstrated in Figures 7 and 8, which show the time mean and the total variance of the Outgoing Longwave Radiation (OLR) from each convection scheme. These can be compared with similar results from the GCI data (Figure 9), based on the window brightness temperature as observed by a number of satellites (Salby et al., 1991). It is evident from these results that the Kuo scheme has an unrealistically low level of transience, particularly in the warm pool region.

The temporal characteristics of the model's OLR has been studied by decomposing the variance into synoptic (2-6 days, 6-14 days) and intraseasonal (14-30 days, 30-70 days) timescales (Figures 10 and 11). These can be compared with a similar decomposition of the GCI data into the variance between 2 and 10 days and for greater than 10 days (Figure 12). With the Kuo scheme (Figure 10), most of the variance occurs at synoptic frequencies, associated with weak, lower tropospheric disturbances which propogate westwards around the equatorial belt. At intraseasonal timescales, the Kuo scheme produces virtually no

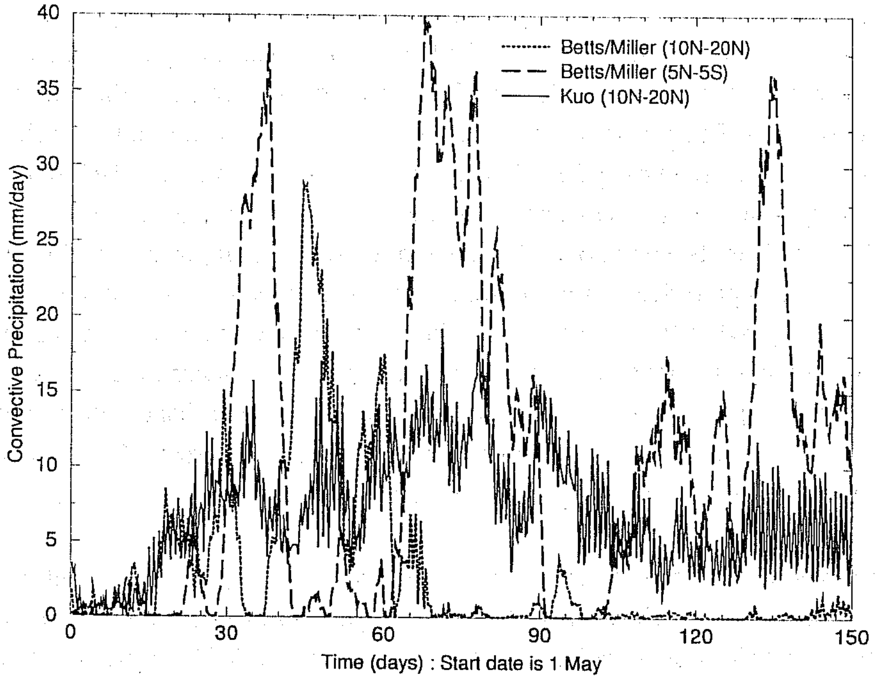


Figure 5 : Temporal evolution of the simulated rainfall (mm/day) over India (72°E - 82°E, 10°N - 20°N) from both convection schemes. Also shown is the evolution over the equatorial Indian Ocean (72°E - 82°E, 5°S - 5°N) from the convective adjustment scheme.

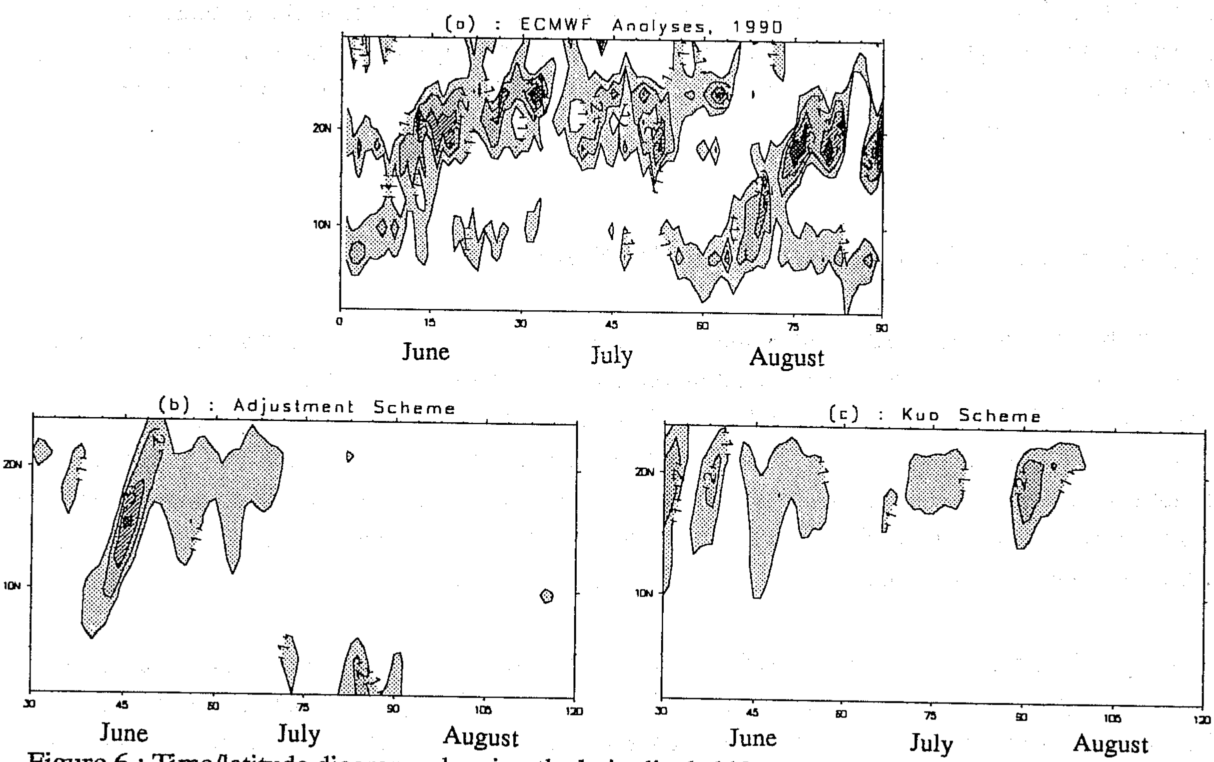


Figure 6 : Time/latitude diagrams showing the latitudinal shift of the monsoon trough over the Bay of Bengal (80°E - 90°E) using the 850mb relative vorticity from (a) ECMWF daily analyses for 1990, (b) integration with the convective adjustment scheme, and (c) integration with the Kuo scheme. Only positive (cyclonic) values are plotted. Contour interval is $1 \times 10^{-5} s^{-1}$.

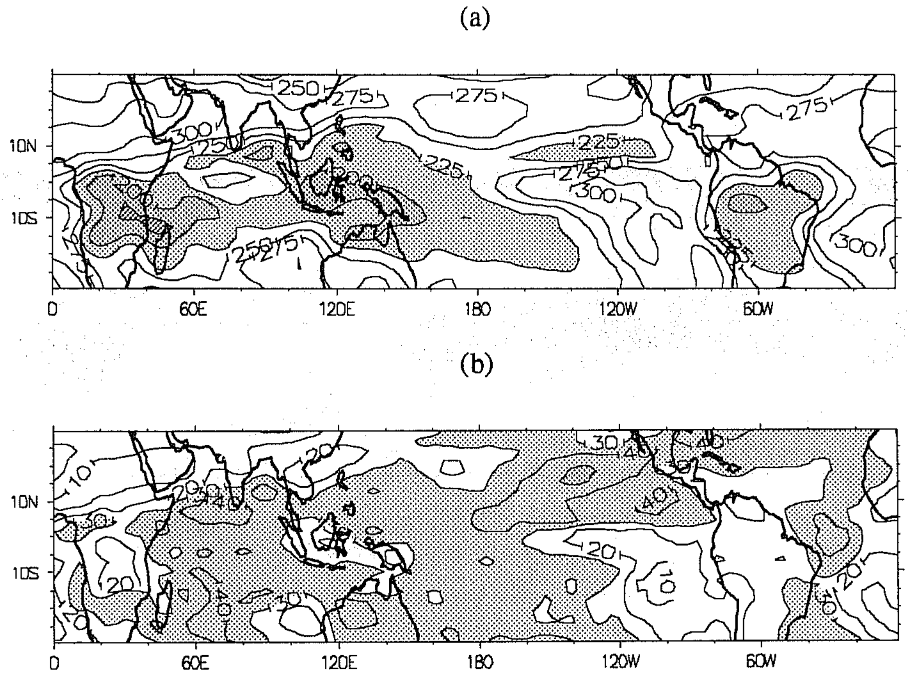


Figure 7 : (a) Time mean OLR (W/m^2) and (b) square root of the total variance of the OLR (W/m^2) for days 0 to 360 from the perpetual January integration with the Kuo scheme.

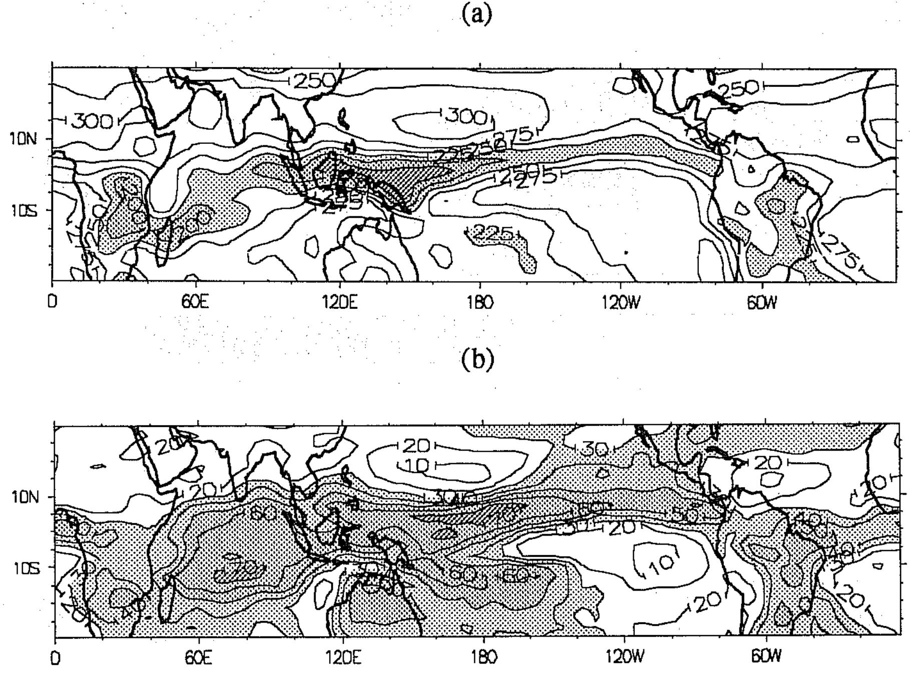


Figure 8 : As Figure 7, but from the perpetual January integration with the convective adjustment scheme.

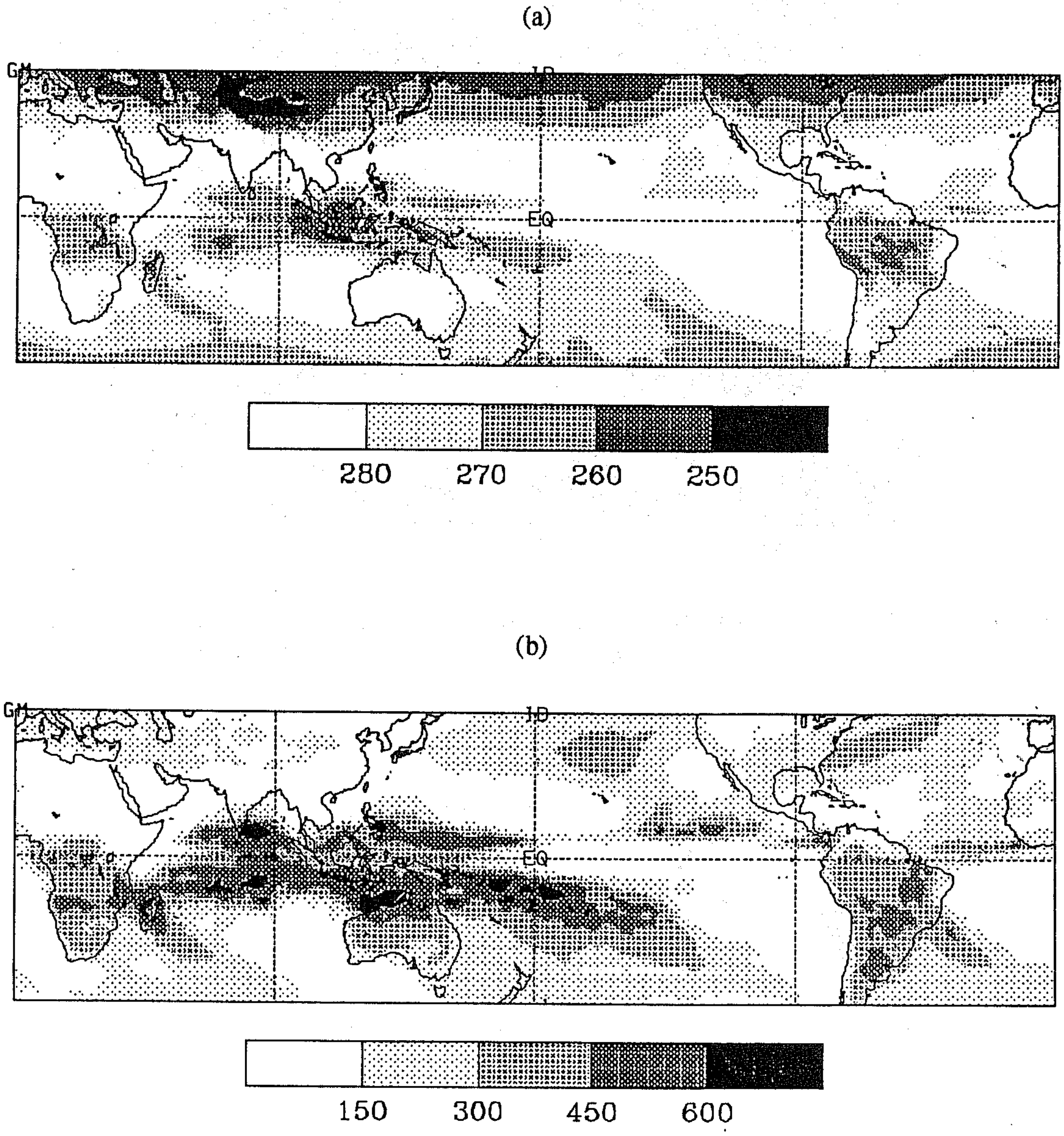


Figure 9 : (a) Mean (K) and (b) total variance (K^2) of the window brightness temperature from Global Cloud Imagery data for December, January and February, 1983/84.

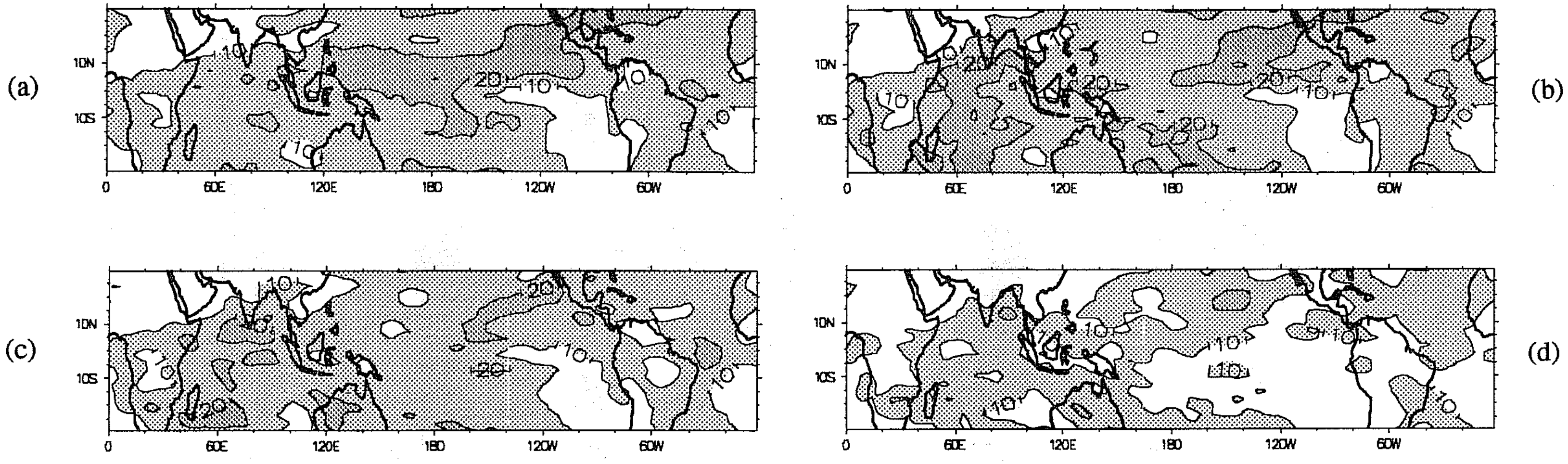


Figure 10 : Square root of the variance of the OLR (W/m^2) for days 0 to 360, simulated with the Kuo scheme, and explained by frequencies between (a) 2 and 6 days, (b) 6 and 14 days, (c) 14 and 30 days, and (d) 30 and 70 days.

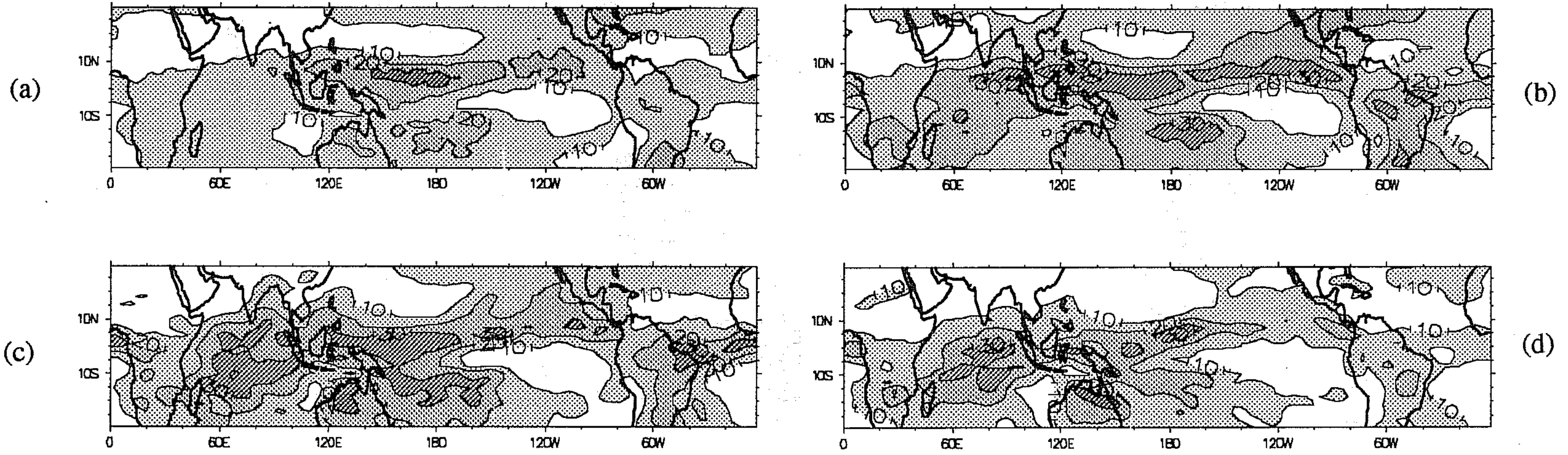


Figure 11 : As Figure 10, but from the integration with the convective adjustment scheme.

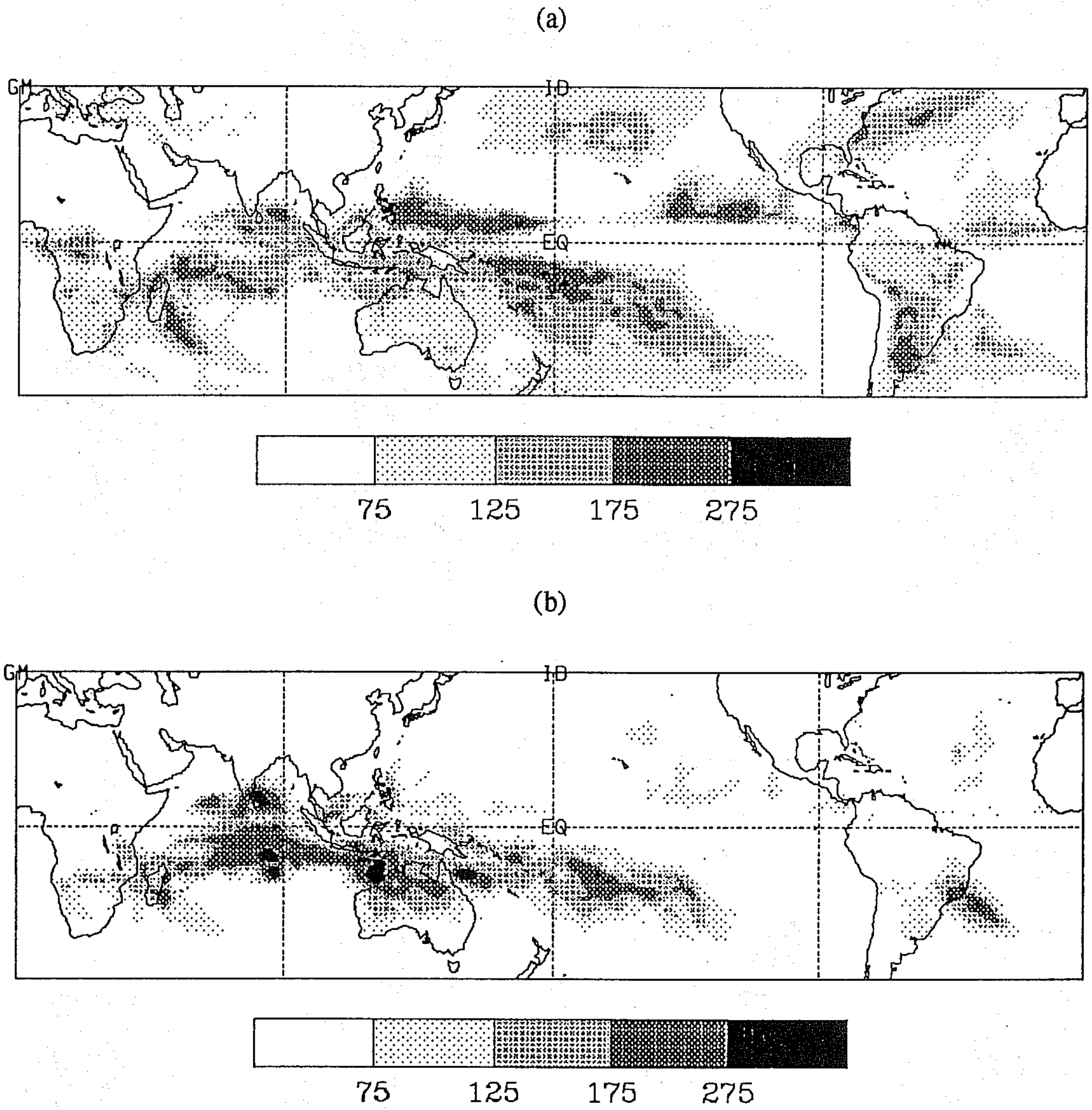


Figure 12 : Variance (K^2) of the window brightness temperature from Global Cloud Imagery data for December, January and February 1983/84, explained by frequencies (a) between 2 and 10 days, and (b) greater than 10 days.

variance, consistent with a poor simulation of the intraseasonal oscillation in this version of the model. In contrast, the adjustment scheme has considerably more variance at all timescales (Figure 11). At synoptic frequencies, the variance is associated with westward moving waves, as can be seen in Figure 13, which shows a Hovmöller (time evolution) diagram of the 850mb relative vorticity along 4°N for a typical 90-day period. These waves intensify over the warm pool, producing disturbances which occupy the depth of the troposphere and give substantial precipitation.

Both versions of the model produce a reasonable simulation of the upper tropospheric westerlies in the equatorial, central and east Pacific. The penetration of extra-tropical disturbances into this region (the Pacific wave guide) is considered to be an important trigger for convection (Kiladis and Weickmann 1992). With the adjustment scheme, there is an indication that synoptic waves are generated or intensify near the dateline (Figure 13), in association with the the Pacific wave guide. On the other hand, the Kuo scheme shows no such response.

Further west, over the warm pool, the adjustment scheme produces quite realistic cold surges over the South China Sea, associated with the winter monsoon. Figure 14 shows a time series of the 1000mb northerly wind component over the South China Sea for the same 90-day period used in Figure 13. Several strong bursts of northerly winds can be seen at intervals of between 10 and 20 days. These have a substantial influence on the variability in the West Pacific in this version of the model. For example, several of the strong cyclonic events seen in Figure 13 near 110°E, correlate well with the intense cold surges seen in Figure 14. Again, the Kuo scheme has failed to simulate these surges.

The convective adjustment scheme also produces a much more realistic distribution of transience at intraseasonal timescales, as was evident in Figure 11. Periodicities between 30 and 70 days are associated with eastward moving disturbances, characteristic of the intraseasonal oscillation (Figure 15). Over the Indian Ocean, the dominant period in the 200mb velocity potential is 50 days (Figure 16), with a similar periodicity in the area average OLR, indicating modulation of the large scale diabatic heating by the oscillation at these intraseasonal timescales.

5. DISCUSSION AND CONCLUSIONS

Despite showing similar quality simulations of the time mean climate for the two convection schemes, the model has demonstrated marked sensitivity to the convective parametrization in its representation of tropical transience. This is an important result for a number of reasons. In terms of local prediction, the ability of a model to simulate the correct spatial distribution of tropical synoptic disturbances is crucial both for short term forecasting and for longer term predictions of climate, in particular, the incidence of extreme events (e.g. destructive tropical cyclones). The interaction with the extratropics through either the direct migration of tropical systems or through the teleconnection patterns excited by tropical diabatic heating anomalies, depends critically on the ability of a model to reproduce the correct spatial and temporal characteristics of tropical convection. It is interesting to note that the version of the model with the Kuo

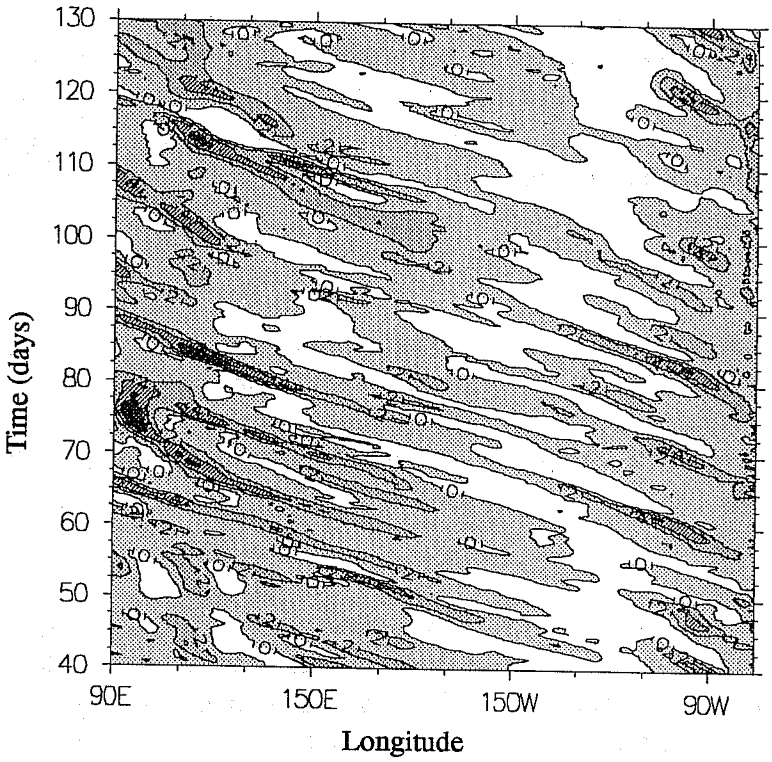


Figure 13 : Hovmöller diagram of the 850mb relative vorticity along 4°N for days 40 to 130 from the integration with the convective adjustment scheme. The contour interval is $2x10^{-5}$ s^{-1}; positive (cyclonic) values are shaded.

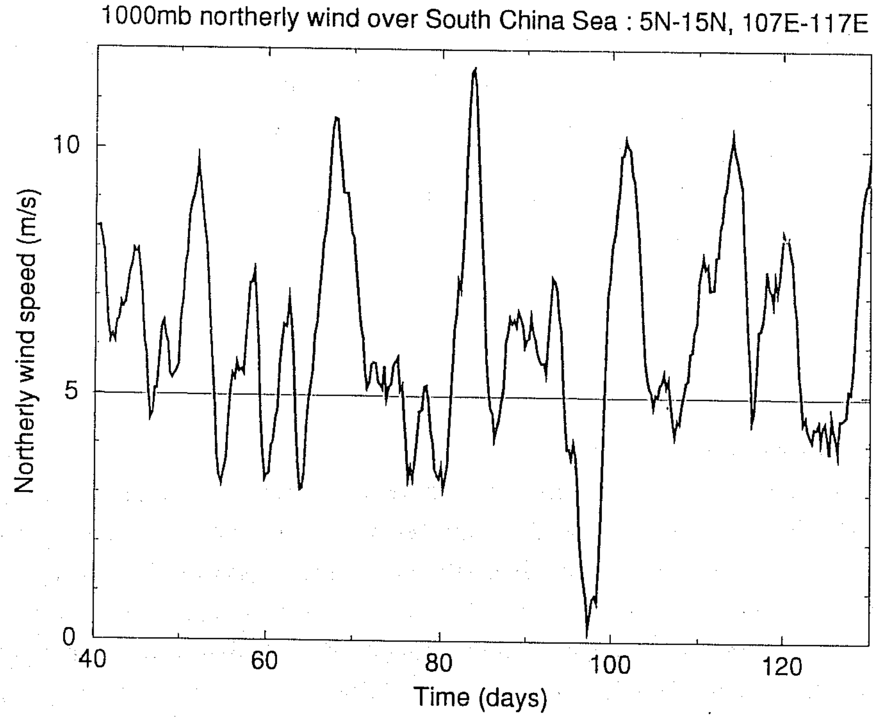


Figure 14 : Time series of the meridional wind (m/s) at 1000mb over the South China Sea for days 40 to 130 from the integration with the convective adjustment scheme.

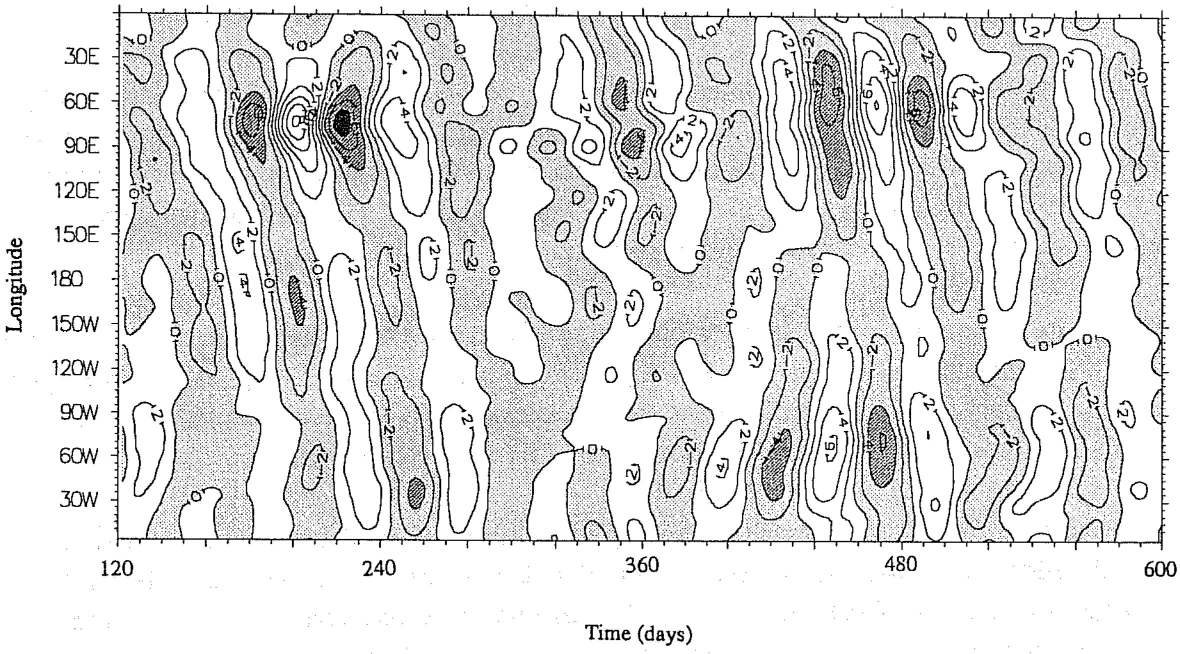


Figure 15 : Time/longitude diagram of the bandpass (30 to 70 day) filtered 200mb velocity potential anomaly, averaged between 10°N and 10°S, for days 120 to 600 from the integration with the convective adjustment scheme. The contour interval is $2\mathrm{x}10^6\ \mathrm{m}^2\mathrm{s}^{-1}$; negative values are shaded.

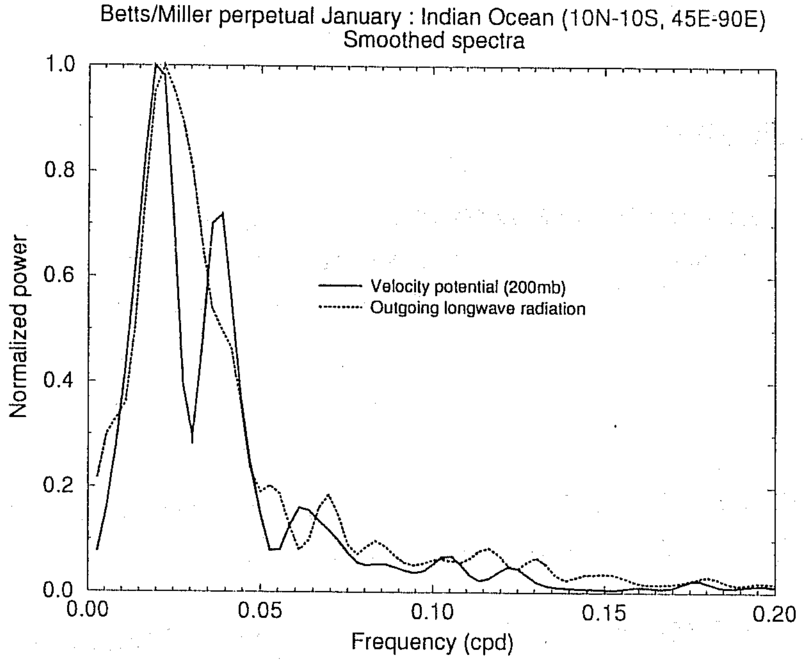


Figure 16 : Spectra of the 200mb velocity potential and OLR averaged over the Indian Ocean for days 0 to 360 from the integration with the convective adjustment scheme. The spectra have been normalized and smoothed with a Tukey window.

scheme, whilst lacking low frequency variability in the tropics, also underestimates the frequency of blocking events in the extratropics (Valdes, Haines and Hannachi; private communication).

Recent studies of satellite data (Lau et al. 1991) have suggested that tropical convection displays multiscale organization with a close link between the synoptic and low frequency transience. There is evidence from the results with the adjustment scheme that the synoptic disturbances are modulated on the intraseasonal timescale. It is possible that the inability of the Kuo scheme to produce an intraseasonal oscillation may be related to its lack of synoptic scale transience.

The ability of the adjustment scheme to simulate several features of the tropical transience, particularly in the northern winter and associated with interactions with the extratropics (e.g. Pacific wave guide, cold surges), is an encouraging result. However, neither scheme produced a good simulation of the evolution of the Indian Summer Monsoon and this remains one of the most crucial tests of a GCM.

This paper has clearly demonstrated that a study of the transient behaviour of a GCM is an essential part of model validation. In this context, more verification data is needed but could be made available by the appropriate diagnosis of satellite data and NWP analyses, as demonstrated here. The contrasting results produced by two convection schemes already point, perhaps, to the inappropriateness of the moisture convergence closure of the Kuo scheme when applied on the large spatial scales typical of climate models. In the future the results of a number of diverse GCMs, provided by the Atmospheric Intercomparison Project (AMIP), may provide clearer guidance on those aspects of convective parametrization which determine a model's transient characteristics.

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