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A standard test for AGCMs including their physical parametrizations: I: The proposal

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Abstract: To assist model intercomparison and development of a set of eight numerical experiments is proposed as a test-bed for the interaction of dynamics and physical parameterizations in atmospheric GCMs. The framework for the experiments is that of an aqua-planet and the prescribed sea-surface temperatures (SSTs) are highly idealized.

Keywords: AGCM, sea-surface temperature, aqua-planet.

1.INTRODUCTION

In recent years the comparison of the output from different atmospheric GCMs run under controlled conditions has been identified as vital in order to probe the reasons for differences in the systematic errors of each of the models. This has culminated in the ongoing Atmospheric Model Intercomparison Project (AMIP) (Gates, 1992) which aims to compare the behaviour of AGCMs with prescribed sea-surface temperatures (SSTs). The project has identified systematic errors which are common to many of the models, in addition to errors which are similar across models which parametrize a particular physical process in a certain way e.g. convection. Subsequent AMIP sub-projects have tried to identify the reasons for such errors. This is difficult due to the complex nature of the many interactions that exist in present day AGCMs. Understanding these interactions is further complicated by the complexity in the spatial and temporal variability of the boundary conditions such as the land/sea distribution, orography and SST forcing. A simplified approach is taken in the study of Held and Suarez (1994) who proposed an intercomparison project comparing the dynamical cores of AGCMs. The AGCM physical parametrizations are replaced with relaxation towards a prescribed temperature distribution and dissipation terms. In this way differences between the models due purely to differences in the formulation of the dynamical core can be isolated.

However for any physical parametrization there is currently no test between its performance in a single column experiment and the performance of the whole model including it in an AMIP-style integration. What is required are tests of the interaction of the physical parametrizations in an AGCM with each other and with the dynamics. The context of these tests should be simple enough that classes of behaviour and obvious problems become apparent. The proposal here is for a standard set of experiments in which the full AGCM is

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retained but the surface boundary is drastically simplified. In particular we propose a set of aqua-planet test experiments with prescribed, very idealized SST distributions. The 'correct'' solution is not known for these tests. However, there is theoretical guidance to aid in the analysis of, for example, the zonal mean circulation (e.g. Held and Hou, 1980) and the model's transient tropical wave response (e.g. Wheeler and Kiladis, 1999). Indeed, one may hope that the experimentation will itself extend our understanding of atmospheric behaviour.

Aqua-planet experiments with AGCMs are not new and have been used to investigate a wide range of atmospheric phenomena including the Madden Julian Oscillation (MJO) (Hayashi and Sumi, 1986; Swinbank *et al.*, 1988) and the Inter-Tropical Convergence Zone (ITCZ)/ Hadley Circulation system (Gotswami *et al.*, 1984; Numaguti, 1995). Hess *et al.*, (1993) examined the response of an aqua-planet with simplified SST forcings when two different convective parametrizations were used. The results showed that two distinctly different tropical ITCZ regimes occurred purely in response to using the two different schemes. Such obvious differences in the response demonstrate the usefulness of aqua-planet experiments in emphasizing model differences which may be less easily identifiable when subject to complex observed boundary forcing.

2. EXPERIMENTS AND MODEL SET-UP

The proposed suite of experiments has been designed to test how AGCMs respond to different characteristics of SST forcing. The nature of the zonal mean circulation of the model is addressed with a set of five zonally symmetric SST distributions varying in latitude only. The form of the SST distributions are specified by simple smooth geometric functions defined in the Appendix and shown graphically in Figure 1(a). Maximum SST is 27 °C at the equator in all cases apart from the Control 5N experiment where the 27 °C peak is at 5 °N. Poleward of both 60 °N and S the SST remains constant at 0 °C with sea-ice switched off. The SST distributions differ crucially in the tropics and range from the Peaked experiment where a strong SST gradient is retained in both hemispheres right up to the equator, to the Flat experiment with, according to Held and Hou (1980), a latitudinal curvature in SST which would no longer force a mean meridional circulation. The Control experiment is taken as the standard experiment as it leads to a definite, but not unrealistic, single ITCZ regime and also forms the basic SST distribution for use in the SST anomaly experiments. The Qobs SST distribution is a simple geometric function closest to the observed zonal mean SST distributions. These four experiments are intended to probe the tendency of the AGCM to produce convection on the equator, in twin ITCZs and at a lower intensity in the whole tropical region. In the real atmosphere both single and twin ITCZs are found over the oceans. The Control 5N experiment is intended to examine the asymmetry in the response when the SST maximum is moved off the equator. In particular the asymmetry in the convection and in the Hadley cells is of interest.

Three further experiments are proposed to examine the effect of a longitudinally varying SST anomaly imposed on the Control zonal profile. The distribution of the total SST and the anomaly from the Control for each of these experiments is shown in Figure 1(b)–(g). The experiments are summarized in Table 1 and the analytic forms are given in the Appendix. The 1KEQ and 3KEQ experiments, with maximum SST anomaly magnitudes of 1 K and 3 K respectively, test the response to a local warm pool at the equator. Some aspects of the response that are of interest are where the maximum convection is situated with respect to the peak SSTs, what remote suppression of precipitation occurs and how linear is the response. Experiment 3KW1 with a wavenumber one SST variation along the equator of amplitude 3 K may be thought of as mimicking the observed warmer SSTs through the Indian Ocean and West Pacific regions which contrast with cooler SSTs in the East Pacific and Atlantic Ocean regions, or perhaps a single enlarged Pacific ocean. As well as the enhancement and suppression of tropical convection the overall response to this tropic-wide forcing is of interest.

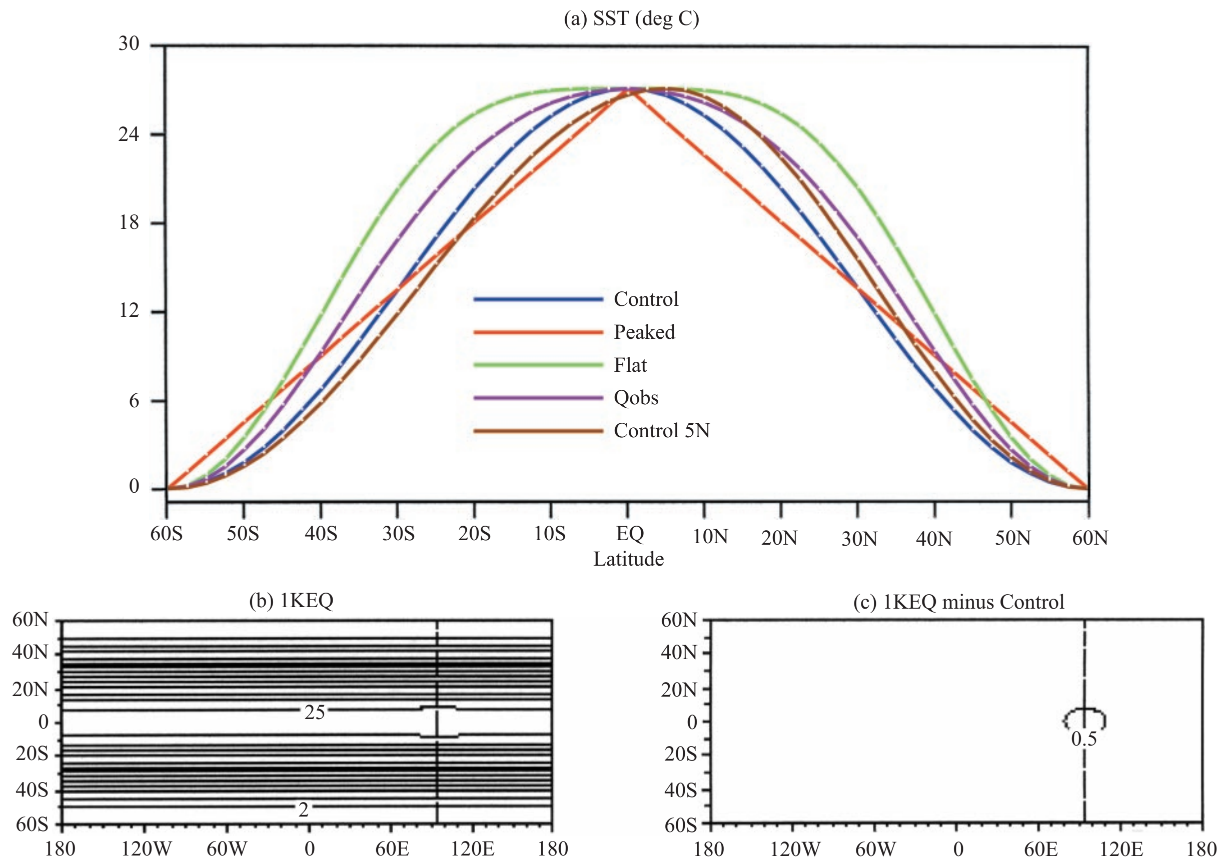

Figure 1. SST distributions used in the suite of aqua-planet experiments (in °C); (a) axisymmetric experiments; (b) experiment 1KEQ; (c) experiment 1KEQ with the Control profile removed; (d) and (e) as (b) and (c) but for experiment 3KEQ; (f) and (g) as (b) and (c) but for experiment 3KW1. The analytic forms for the distributions are given in the Appendix. The vertical dashed line in each figure indicates the longitude of the SST anomaly maximum.

Table 1. Summary of the magnitude of spatial distribution of the SST anomaly in each of the three zonally asymmetric experiments

Experiment Name	Peak Anomaly Magnitude	Region Occupied
1KEQ	1 K	15°N to 15°S, 60° longitude
3KEQ	3 K	15°N to 15°S, 60° longitude
3KW1	± 3 K	30°N to 30°S, 360° longitude

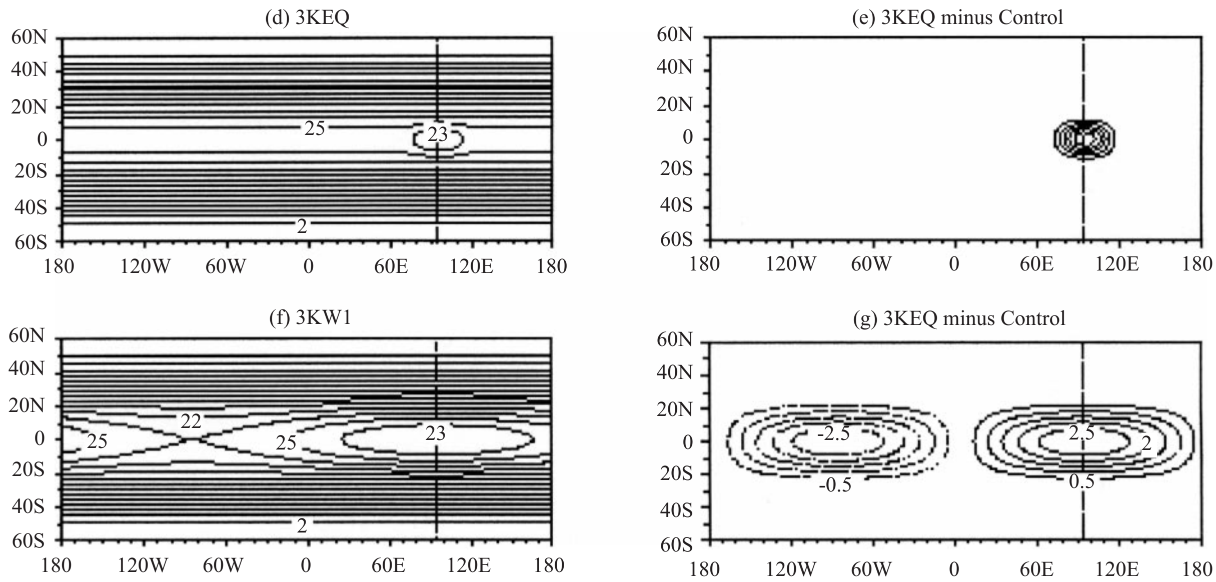

Figure 1(d–g). Caption on previous page.

In order to illustrate their usefulness a selection of results for the proposed experiments performed with a version of The Met Office Unified Model (UM) are summarized in Part II of this paper (Neale and Hoskins, 2001). The results outline the mean climate response for the set of experiments in addition to the transient activity.

3. THE PROPOSAL

It is proposed that this set of experiments should form a test-bed for different AGCMs and for examining the impact of different physical parametrizations—complementing the traditional AMIP type model intercomparison. Ideally these experiments should be performed using as wide a range of AGCMs as possible in order to identify common model behaviour as well as to understand model differences. This is particularly important since numerical and physical parametrization schemes can vary extensively between models. In this way the results are useful both for intercomparison and individual model development purposes. In order to further simplify the external forcing the insolation is fixed at March equinoctial conditions remaining effectively symmetric about the equator such that any response not symmetric about the equator must arise due to internal model variability. Since seasonal variability is effectively removed, due to the fixed nature of the insolation forcing, a much shorter integration than in the AMIP experiments is required to diagnose the mean climate.

In each experiment an 18-month integration is performed, initialized using a model dump from the full AGCM and interpolating to zero orography. The final 12-month period of each experiment is used for analysis. Adjustment to a change in the underlying SST occurs within the first 30–60 days of the integration and although there may be variability beyond the 12-month analysis period it is felt that this is

Table 2. List of diagnostics for the 12-month diagnostic period of each experiment required for a basic model intercomparison

Diagnostic	Units	Name	Domain	Experiments	Time Frequency
Convective Precipitation	mm/day	ppnc	Global	All	Time Average
Convective Precipitation	mm/day	ppnc_t6	30°N-30°S	Control	6 Hourly Average
Outgoing Long-Wave Radiation	W/m^2	olr	Global	All	Time Average
Outgoing Long-Wave Radiation	W/m^2	olr_t6	30°N-30°S	Control	6 Hourly Average
Dynamic/Large-Scale Precipitation	mm/day	ppnd	Global	All	Time Average
Surface Evaporation	W/m^2	evap	Global	All	Time Average
Surface Pressure	Pa	psurf	Global	All	Time Average
Zonal Wind		up	Global	All	Time Average
Meridional Wind		vp	Global	All	Time Average
Omega (dp/dt)	Pa/s	omegap	Global	All	Time Average
Temperature	K	tp	Global	All	Time Average
Specific Humidity	kg kg	qp	Global	All	Time Average
Geopotential Height	m	zp	Global	All	Time Average
Diabatic Heating	K/s	diah	Global	All	Time Average

small compared to differences between individual experiments and model differences for the same experiment. This makes aqua-planet experimentation an attractive model development tool. Model output should conform to the data format conventions outlined by the Program for Climate Model Diagnostics and Intercomparison (PCMDI) to facilitate ease of comparison. In particular the netCDF data format is preferred. A list of diagnostics required for a basic model assessment and intercomparison is given in Table 2. Multi-level fields should be interpolated to the AMIP II (http://www-pcmdi.llnl.gov/) standard pressure levels up to 50 mb. It is hoped that the AGCMs used in the intercomparison would be identical or similar to the versions submitted to the AMIP II project and so would have a horizontal resolution of T42 or greater.

4. CONCLUSIONS

The set of aqua-planet experiments described here is designed to probe aspects of the interaction between the dynamics and physical parametrizations of a full AGCM. It can be envisaged that a further set of experiments including the interaction of land surface processes could later be established by the use of simple continents in the Control experiment. However, such experiments may require longer integrations in order to reach equilibrium.

APPENDIX

The equations below describe the functional form of the variation of SST in the aqua-planet experiments. (1) Control experiment; (2) Peaked experiment; (3) Flat experiment; (4) Control-5N experiment; (5) 1KEQ and 3KEQ experiments; (6) 3KW1 experiment. The Qobs SST distribution is an average of the Flat and Control distributions.

$$T_s(\lambda, \phi) = \begin{cases} 27\left(1 - \sin^2\left(\frac{3\phi}{2}\right)\right)^\circ C & : \quad -\frac{\pi}{3} < \phi < \frac{\pi}{3} \\ 0^\circ C & : \quad \text{otherwise} \end{cases} \tag{1}$$

$$T_s(\lambda, \phi) = \begin{cases} 27\left(1 - \frac{3|\phi|}{\pi}\right)^\circ C & : \quad -\frac{\pi}{3} < \phi < \frac{\pi}{3} \\ 0^\circ C & : \quad \text{otherwise} \end{cases} \tag{2}$$

$$T_s(\lambda, \phi) = \begin{cases} 27\left(1 - \sin^4\left(\frac{3\phi}{2}\right)\right)^\circ C & : \quad -\frac{\pi}{3} < \phi < \frac{\pi}{3} \\ 0^\circ C & : \quad \text{otherwise} \end{cases} \tag{3}$$

$$T_s(\lambda, \phi) = \begin{cases} 27\left(1 - \sin^2\left(\frac{90}{55}\left[\phi - \frac{\pi}{36}\right]\right)\right)^\circ C & : \quad \frac{\pi}{36} < \phi < \frac{\pi}{3} \\ 27\left(1 - \sin^2\left(\frac{90}{65}\left[\phi - \frac{\pi}{36}\right]\right)\right)^\circ C & : \quad -\frac{\pi}{3} < \phi < \frac{\pi}{36} \\ 0^\circ C & : \quad \text{otherwise} \end{cases} \tag{4}$$

$$T_s'(\lambda, \phi) = \begin{cases} \chi \cos^2\left(\frac{\pi}{2}\left[\frac{\lambda - \lambda_0}{\lambda_d}\right]\right) \cos^2\left(\frac{\pi}{2}\left[\frac{\phi}{\phi_d}\right]\right)^\circ C & : \quad \lambda_0 - \lambda_d < \lambda < \lambda_0 + \lambda_d \\ & : \quad -\phi_d < \phi < \phi_d \\ 0^\circ C & : \quad \text{otherwise} \end{cases} \tag{5}$$

$$T_s'(\lambda, \phi) = \begin{cases} \chi \cos(\lambda - \lambda_0) \cos^2\left(\frac{\pi}{2}\left[\frac{\phi}{\phi_d}\right]\right)^\circ C & : \quad -\phi_d < \phi < \phi_d \\ 0^\circ C & : \quad \text{otherwise} \end{cases} \tag{6}$$

χ—Maximum magnitude of SST anomaly.
λ_0—Longitude of maximum SST anomaly.
λ_d/ϕ_d—Decay, in longitude/latitude, of SST anomaly from its maximum.

REFERENCES

Gates, W. L., 1992. AMIP: The atmospheric intercomparison project. *Bull. Am. Met. Soc.*, **73**, 1962–1970.

Goswami, B. M., Shukla, J., Schneider, E. K. and Sud, Y. C., 1984. Study of the dynamics of the intertropical convergence zone with a symmetric version of the GLAS climate model. *J. Atmos. Sci.*, **41**, 5–19.

Hayashi, Y.-Y. and Sumi, A., 1986. The 30–40 day oscillations simulated in an aqua-planet model. *J. Meteorol. Soc. Japan*, **64**, 451–467.

Held, I. M. and Hou, A. Y., 1980. Nonlinear axially symmetric circulations in a nearly inviscid atmosphere. *J. Atmos. Sci.*, **37**, 515–533.

Held, I. M. and Suarez, M. J., 1994. A proposal for the intercomparison of the dynamical cores of atmospheric general circulation models. *Bull. Am. Met. Soc.*, **75**, 1825–1830.

Hess, P. G., Battisti, D. S. and Rasch, J. R., 1993. Maintenance of the intertropical convergence zones and the large-scale tropical circulation on a water-covered earth. *J. Atmos. Sci.*, **50**, 691–713.

Neale, R. B. and Hoskins, B. J., 2000. A standard test for AGCMs including their physical parametrizations. II: Results for the Met. Office Model. *Atmos. Sci. Lett.*, doi:10.1006/asle.2000.0020.

Numaguti, A., 1995. Dynamics and energy balance of the Hadley circulation and the tropical precipitation zones. Part II: Sensitivity to meridional SST distribution. *J. Atmos. Sci.*, **52**, 1128–1141.

Swinbank, R., Palmer, T. N. and Davey, M. K., 1988. Numerical simulations of the Madden and Julian oscillation. *J. Atmos. Sci.*, **45**, 774–788.

Wheeler, M. and Kiladis, G. N., 1999. Convectively-coupled equatorial waves: Analysis of clouds and temperature in the wavenumber-frequency domain. *J. Atmos. Sci.*, **56**, 374–399.