Modelling of Atmospheric Angular Momentum in a simple AGCM

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Introduction

This work investigates the impacts of various large-scale thermal forcings on the global AAM. The investigation is based on numerical experiments with a simple GCM, PUMA (Portable University Model of the Atmosphere) [Fraedrich et al., 1998]. The non-linear hydrodynamics of the atmosphere are represented in PUMA in the same way as in a standard GCM, but the latitude-dependent radiative forcing is strongly simplified and expressed as a Newtonian cooling $F_R = \frac{T_R - T}{\tau_R}$, where F_R is the forcing, T_R is the restoration temperature and τ_R the e-folding time of the Newtonian cooling. By modifying the restoration temperature field, the large-scale thermal forcing of the atmosphere can be easily controlled.

A series of numerical experiments are carried out using different restoration temperature fields and orographies. The restoration temperature fields are zonally symmetric and have different meridional gradients. It is found that the global AAM increases with increasing meridional gradient in the thermal forcing. The increase in the AAM is characterized by a change in circulation regime in the mid- and high-latitudes: The structure of the transients changes from a zonal wavenumber six to three, and the number of cells in the meridional circulation reduces from three to two with a diminishing polar cell.

The ΔT-Experiment

An experiment is conducted to investigate the dependencies of AAM on the mean meridional temperature gradient. In this experiment the meridional gradient of the restoration temperature field is increased by steps of 10K from $\Delta T = T_R(EQ) - T_R(POLE) = 0$ to $\Delta T = 190K$. For each of these configurations the model is integrated over ten years. As it is to be expected, the AAM grows with increasing ΔT (Figure 1a). But unlike the total kinetic energy KE (Fig. 1b) the function of AAM is not "smooth". It shows three nearly linear regions which are divided by ranges of a remarkably smaller slope . This behavior arises from changes in the mid- and high-latitude circulation regimes.

The first region is a global Hadley-regime (not shown here). The second one is a Rossby-regime during which the mid-latitude eddies are growing in size and strength. For stronger meridional restoration temperature gradients ($\Delta T \geq 120K$) the eddies begin to extend pol-ward and a different Rossby-regime is formed with low pressure over the poles and huge anticyclones in the mid-latitudes. The change from regime 2 to regime 3 can be seen in the meridional mass-stream-function (Fig. 2) as well as in the shift of the predominant wave number of synoptic activity from six to three (Fig. 3).

So how do these transitions of circulation patterns affect the AAM? To answer this, one can look at the ratio of eddy kinetic energy to total kinetic energy EKE/KE (Fig. 1b). The EKE is, as well as the KE, a monotonicly growing function of ΔT. However the ratio of both is not. As long as the eddies are growing, the EKE's share of KE is growing too. So a smaller part of the growing KE is zonal mean kinetic energy KZ. After entering the third regime, KZ can hold its share of KE and the AAM grows faster again, though not as fast as in regime 2.

We continue our work with the investigation of transient and abrupt changes in the restoration temperature fields and experiments with real and idealized orographies.

References

Klaus Fraedrich, Edilbert Kirk, and Frank Lunkeit. Portable university model of the atmosphere. Technical Report 16, Deutsches Klimarechenzentrum, 1998.

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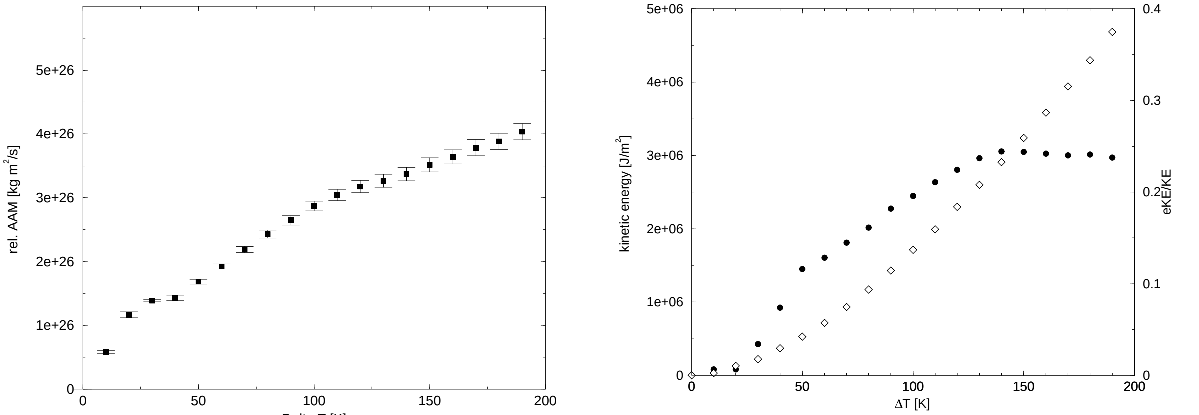
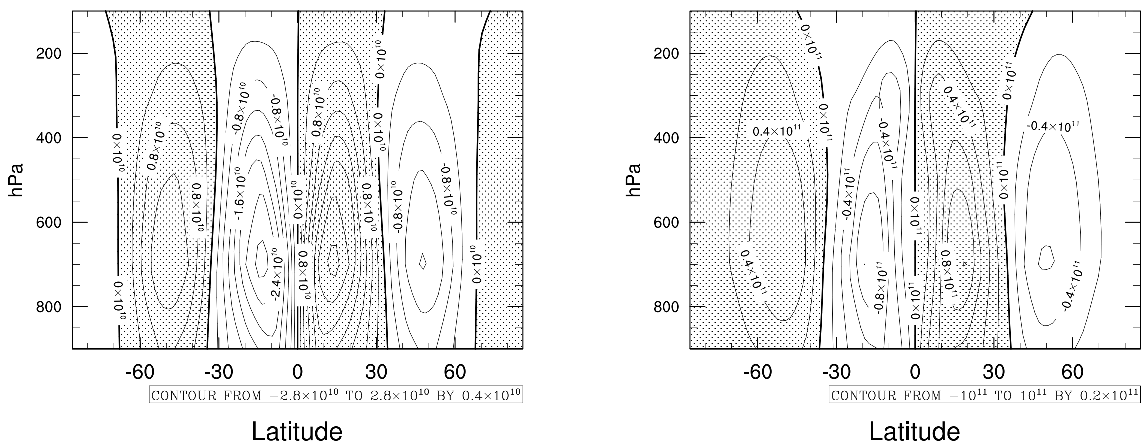


(a) Relative angular momentum.

(b) Total kinetic energy KE (open diamonds) and ratio EKE/KE (filled circles).

Figure 1: Relative angular momentum and kinetic energy



(a)

(b)

Figure 2: Meridional mass-stream-function for (a) $\Delta T = 60K$ and (b) $\Delta T = 180K$ given in kg/s.

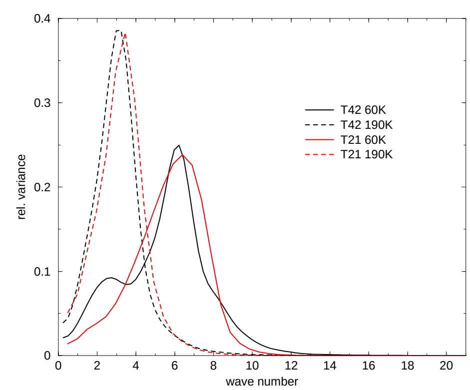


Figure 3: Wavenumber spectrum derived from the surface pressure along 45° N. The maximal variance is located at wavenumber 6-7 for $\Delta T = 60K$ but shifts to wavenumber 3 for $\Delta T = 190K$. The robustness of this result is checked by performing the same experiment with PUMA at T21 and T42 truncation.