References

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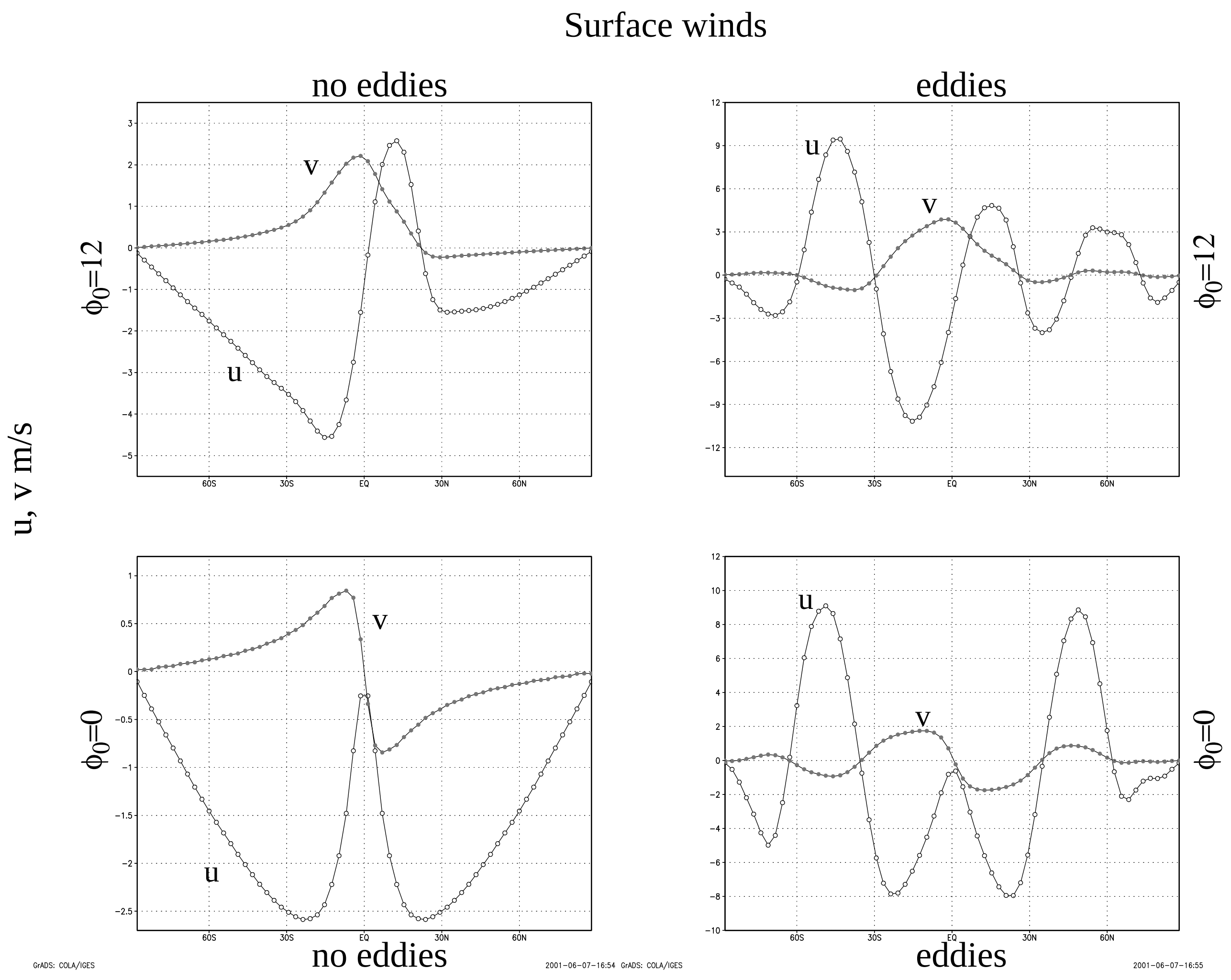

Figure 3. Simulated surface winds.

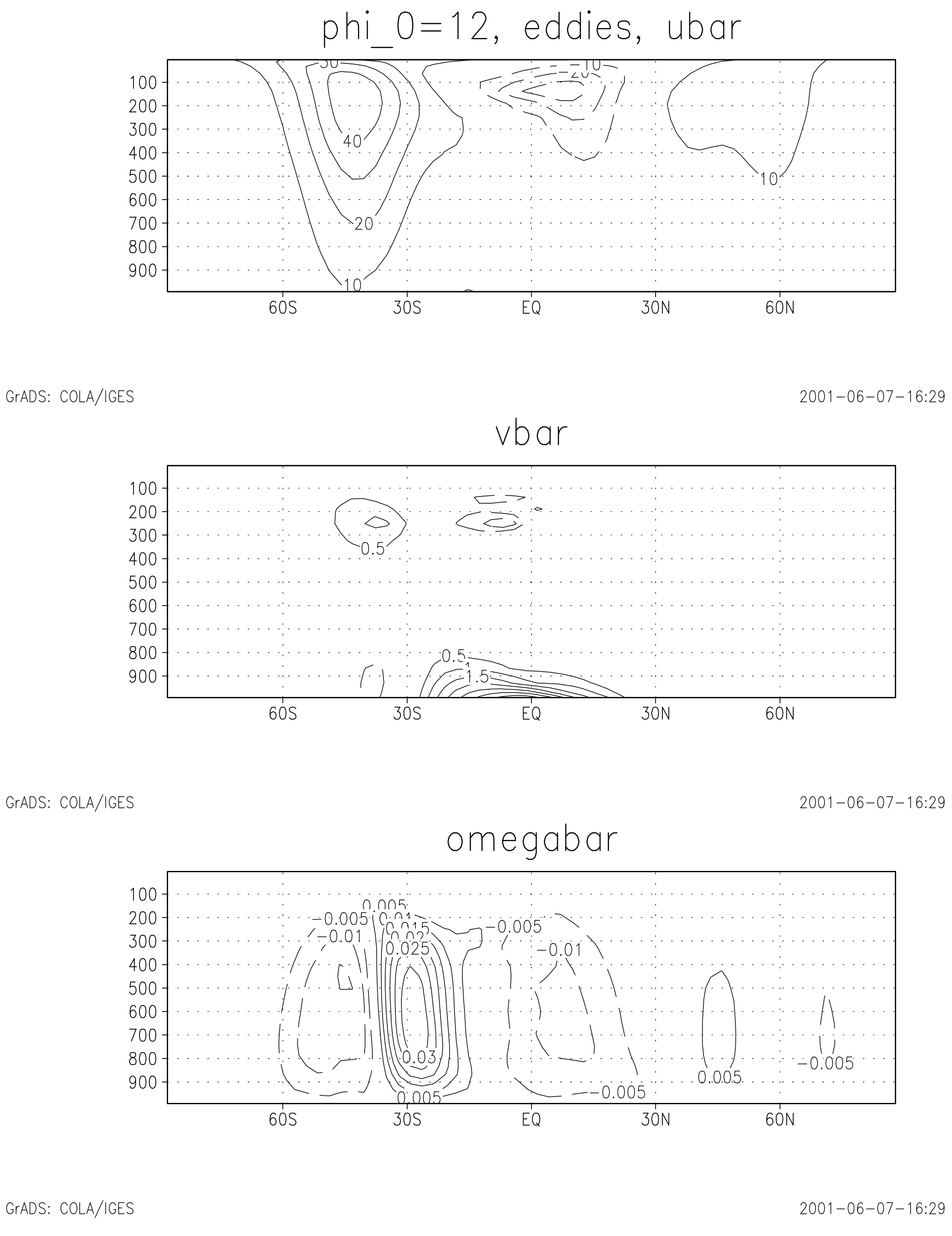

Figure 2d. Zonally averaged circulations for heating about 12N, with synoptic eddies.

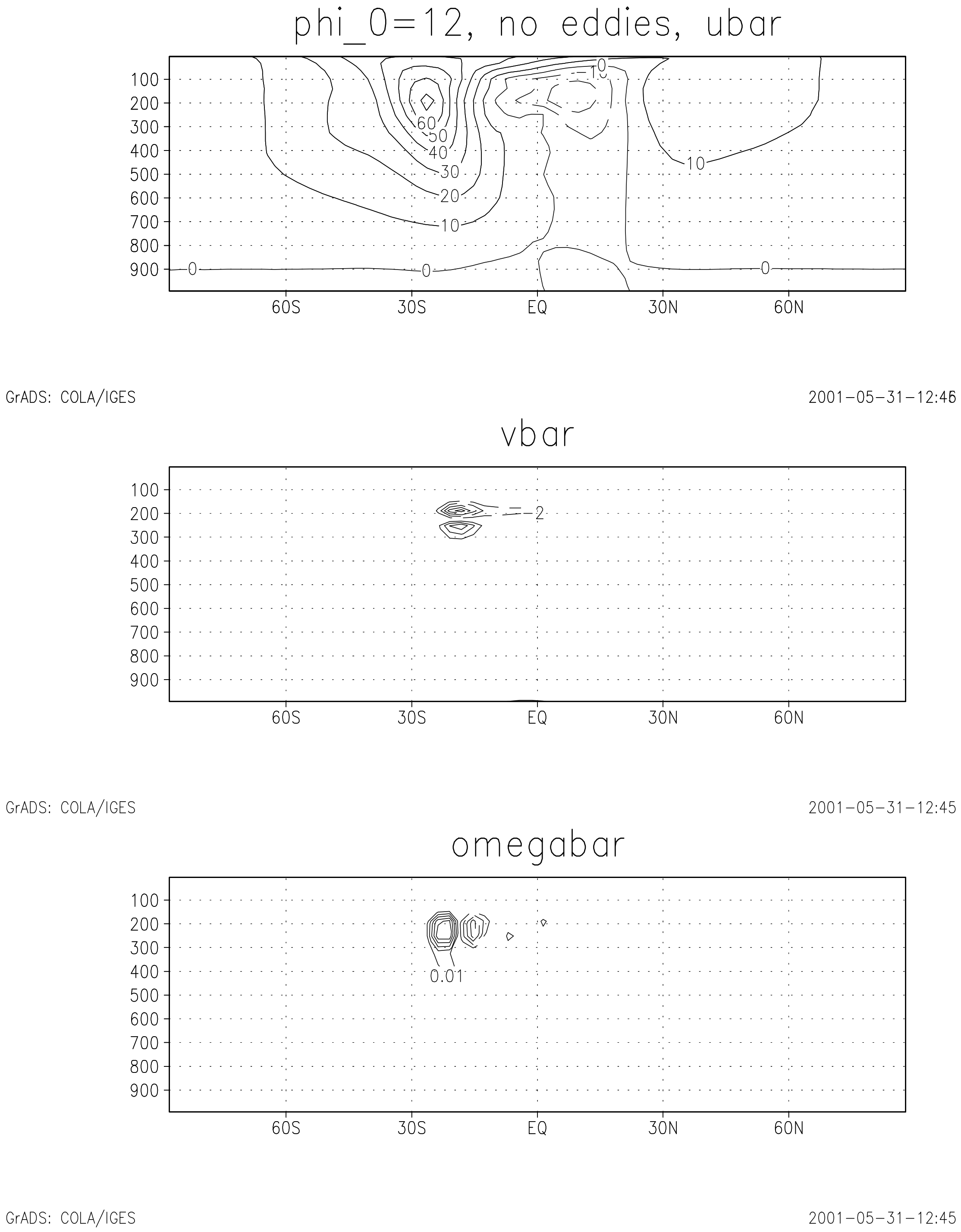

Figure 2c. Zonally averaged circulations for heating about 12N, without synoptic eddies.

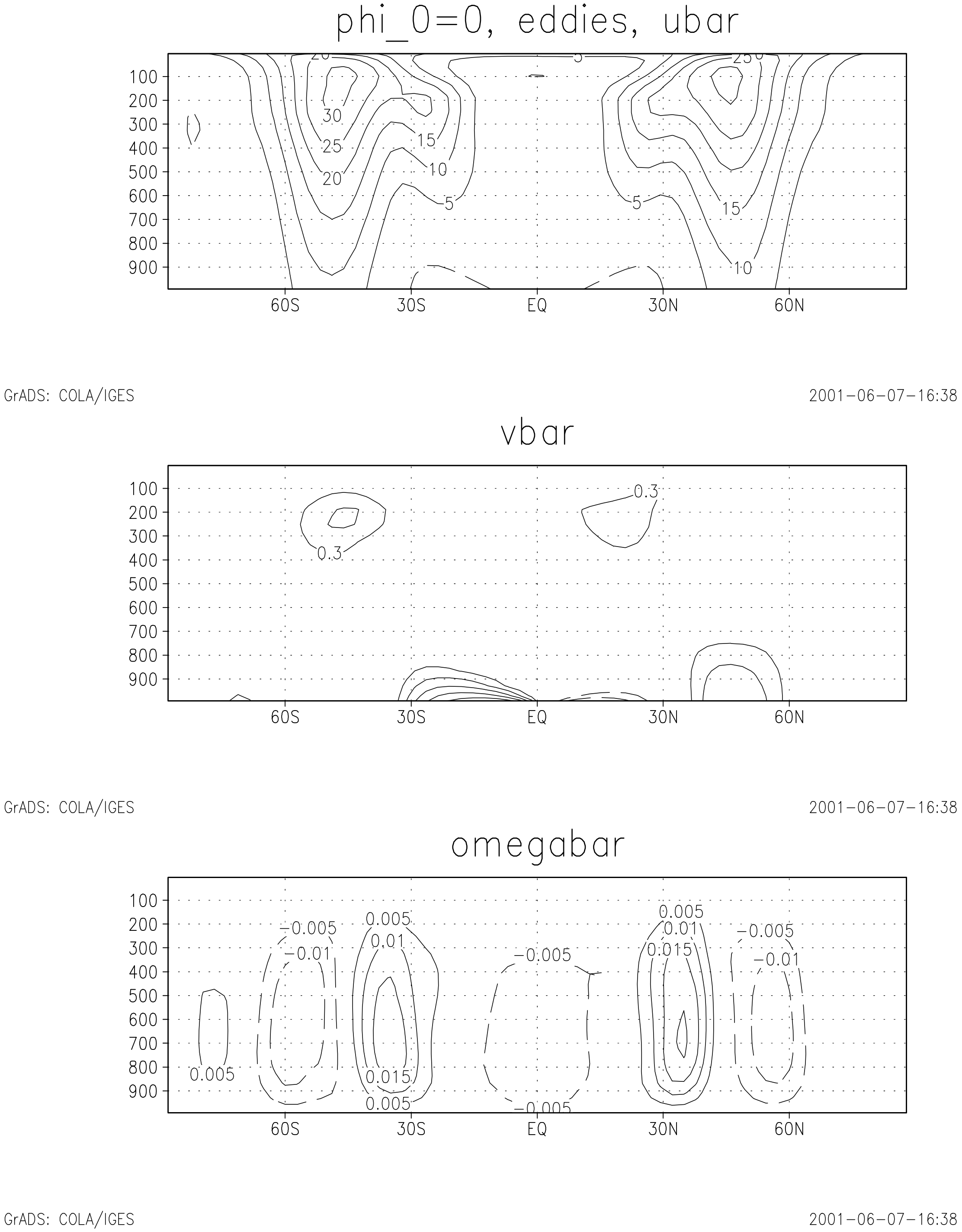

Figure 2b. Zonally averaged circulations for heating about the equator, with synoptic eddies.

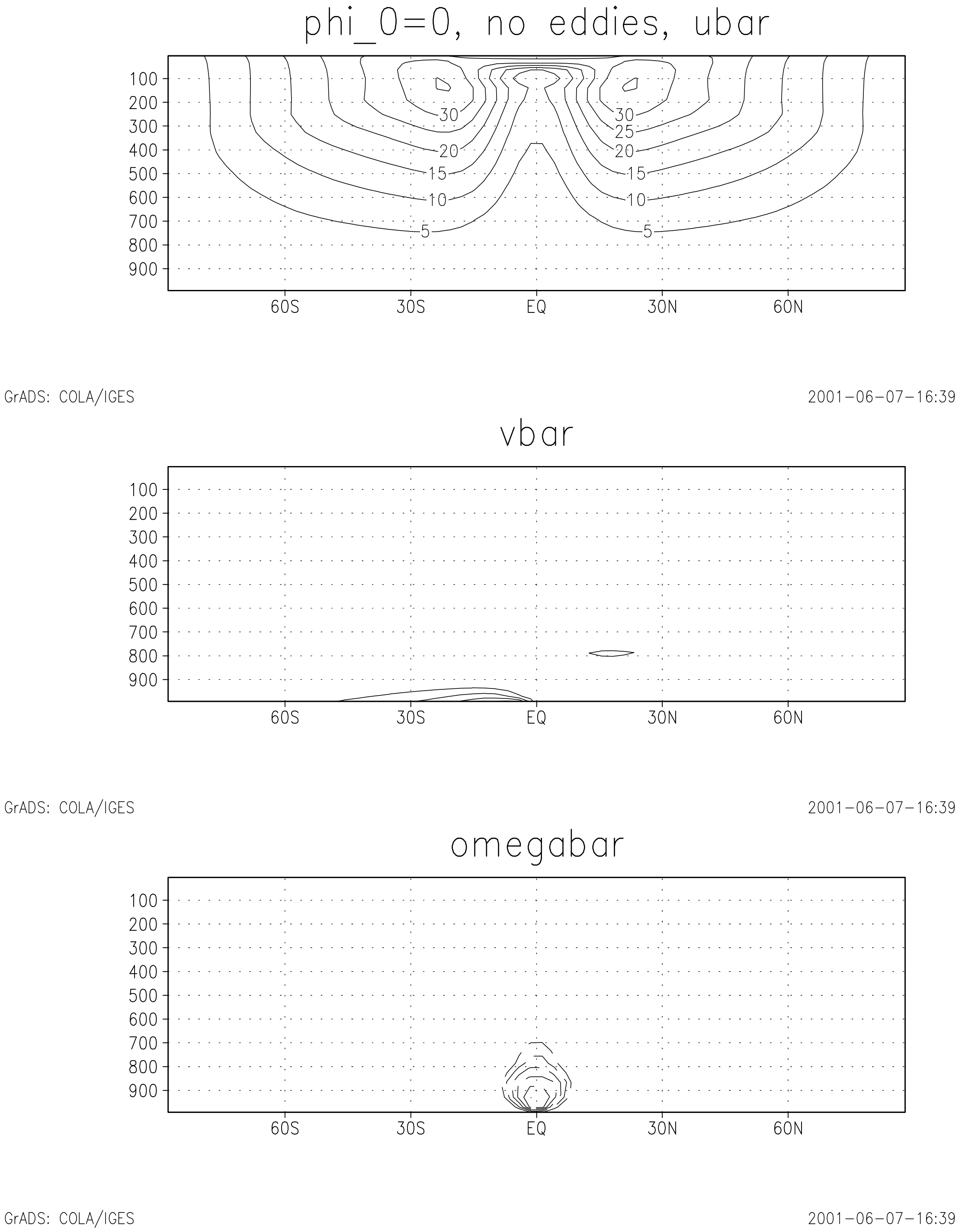

Figure 2a. Zonally averaged circulations for heating about the equator, without synoptic eddies.

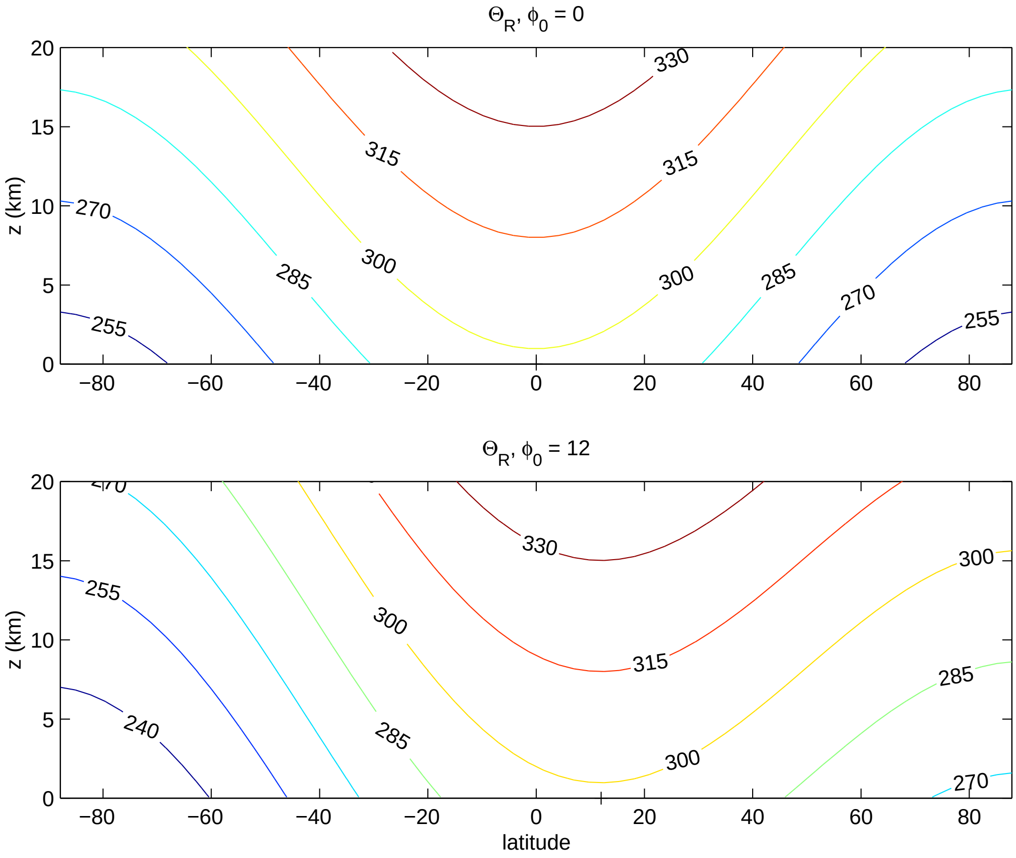

Figure 1. Reference heating distributions for heating centered at the equator and 12N.

For the heating centered at 12N, the winter hemisphere zonal jet is observed to be stronger than for the symmetric heating. Without eddies (figure 2c) the jet reaches 70 m/s in the winter hemisphere--so strong and narrow that some sort of instability develops. Large unrealistic meridional and vertical velocities are found around the zonal shear equatorward of the jet. In the absence of viscous effects, the circulation depends on eddies to be realistic. In the absence of both eddies and viscosity, no dissipative effects exist to balance the convergence of momentum. Eddies act to diffuse the tropical jet and transport momentum poleward (figure 2d). A strong 40 m/s zonal jet is in the winter hemisphere, while a weak 10 m/s midlatitude jet appears in the summer hemisphere. For heating centered off the equator, angular momentum can provide for easterly zonal jets about the equator, where the solid-body rotation of the earth has relatively more angular momentum than the air which has risen poleward of it. For the case with eddies, the westerlies reach the surface, and 5 m/s trade winds blow across the equator from winter to the summer hemisphere. The upper branch of the Hadley cell is not seen in these model runs, presumable because it is spread out vertically.

Figure 3 shows the zonal and meridional velocities for the four cases. While trade winds were not visible due to the contour interval in the meridional sections, easterly winds exist in all the simulations. Midlatitude surface westerlies only exist when eddies can mix angular momentum downward from the jets. Even though the top branches of the Hadley cells can’t be seen in the cross-sections, the surface winds indicate that the Hadley cells are present with a realistic magnitude.

Model

We use the dynamical core of the CCM3.6 configured as in Held's (1994) AGCM intercomparison study. Heating is specified indirectly by relaxation to the reference potential temperature given in Lindzen and Hou (1988), and shown in figure 1. The resulting heating is much more broadly distributed than the heating in the real atmosphere, where low level convergence causes a narrow band of convection at the ITCZ; nevertheless we used this reference potential temperature to have consistency with Lindzen and Hou.

The atmosphere is inviscid except for in the boundary layer where there is Rayleigh friction to simulate drag with the surface (Hyperdiffusion is included throughout the domain for numerical stability). Neither eddy viscosity nor cumulus friction are represented. Six cases were run in the GCM: heating centered at the equator, 6N, and 12N, each with synoptic eddies and without. Each case was spun up from rest and run for 400 days, the last 20 of which were averaged together to yield the "steady state" circulation. In this summary we will concentrate only on the cases with heating centered on the equator and at 12N.

Results

Figure 2(a-d) shows the zonally-averaged circulations for the four cases described above. The simulations are not very representative of the real atmosphere because the heating is so broad, and the atmosphere is inviscid. The results are quite untuned to match the other simulations or the atmosphere itself. Even so, some basic observations of the general circulation can be made.

In figure 2a, for equatorially centered heating and a zonally symmetric circulation, broad zonal jets of 35 m/s form at 25 latitude at upper levels. These are the result of angular momentum conservation as air rises from the surface and deposits its angular momentum poleward of its upward motion. Synoptic eddies act to weaken the tropical jet and feed a midlatitude jet at 45 latitude. Without vertical viscosity, the jets do not reach the ground without synoptic eddies without the eddies. Some meridional convergence at the surface is observed, but divergence at upper levels is broad and weak compared to observations.

The effect of meridional asymmetry and synoptic eddies on the Hadley circulation

Simon de Szoeke
Coupled Atmosphere-ocean Interaction

Introduction

The zonally-symmetric atmospheric circulation is the basic state from which synoptic eddies derive their energy. Much use has been made of zonally-symmetric models (Schneider 1977, Held 1980) to determine the basic state circulation on a sphere heated about the equator and cooled by radiation, in the absence of eddies. The synoptic eddies in turn redistribute heat and momentum in the atmosphere, modifying the zonally-averaged circulation. Thus the basic state is different with the action of eddies than it would have been in their absence.

The size and strength of the Hadley cell is determined by meridional angular momentum and heat advection in response to the tropical heating. Held (1980) investigated the zonally-symmetric circulation driven by heating centered on the equator. Lindzen and Hou (1988) discovered that heating centered off the equator causes profound asymmetry in the Hadley cells, in which the upward branch is centered poleward of the maximum heating, and the Hadley cell in the winter hemisphere is much stronger and larger than that in the summer hemisphere. Since zonally symmetric circulation sensitively depends on the asymmetric distribution of heating, shifts in the location of the ITCZ alter the general circulation. Also the annually averaged meridional overturning is greater than the meridional overturning predicted by the annually averaged heating.

Simple atmospheric general circulation models, which consider only the most basic dynamics of a dry atmosphere, have made possible this investigation of the role of heating centered off the equator, and the role of eddies in modifying the general circulation. The AGCM dynamical core runs in this study begin to address the combined effect of eddies and asymmetric heating.