3.4 THE IMPACT OF CONVECTIVE PARAMETERIZATION SCHEMES ON CLIMATE SENSITIVITY

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1. INTRODUCTION

The range of equilibrium temperature responses to a doubling of CO_2, as estimated from climate models, has remained in the range 1.5°C to 4.5°C over the past thirty years. This is despite substantial progress in the parameterization of climate processes in the models. A key factor in the different model estimates of climate sensitivity to the doubling of CO_2 is the parameterization of clouds and convection. A difficulty in estimating the role of convective parameterization in climate sensitivity has been that most climate models differ not only in their convection schemes, but also differ in many other aspects of their physical parameterizations.

We have investigated the role of moist convective parameterization scheme in determining a model's climate sensitivity. A new global coupled atmosphere-ocean climate model has been developed at the University of Oklahoma. It has a range of cumulus parameterizations available. A series of 110-year simulations (1990-2100) has been carried out with increasing CO_2 concentrations based on the IS92a scenario, as well as a parallel control series with fixed CO_2. Each series is comprised of an ensemble with three different moist convection parameterization schemes. All the control climate runs give reasonable simulations of the mean climate and its interannual variability.

In the next section, the climate model is described briefly and then results from the control simulations with fixed concentrations of greenhouse gases are discussed. The results from the simulations with increasing greenhouse gases are described in Section 4, including the impact of the different convective parameterizations schemes on the climate sensitivity. We concentrate on the Transient Climate Response (TCR), and not the equilibrium climate sensitivity, as the model simulations have not been run to equilibrium. The global mean temperature change at the time of CO_2 doubling (around 2070) is the key measure of the magnitude of the TCR. As expected, the global mean precipitation change is also dependent on the parameterization scheme.

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The continental scale pattern of temperature change is not sensitive to the convective parameterization scheme, but the magnitude of the temperature change is. The patterns of precipitation change are more sensitive to the choice of convection scheme, particularly in the tropics.

2. DESCRIPTION OF THE CLIMATE MODEL

The OU-HIRES coupled atmosphere-ocean GCM (OU-CGCM) was initially developed as an AGCM at the University of New South Wales, Sydney by Leslie and Fraedrich (1997). Since then it has been developed further, first as an AGCM, then as a coupled atmosphere-ocean GCM (CGCM). Over the past 3 years it has been run over many 50 -100 year periods as a CGCM, mainly for applications related to detecting any trends in tropical cyclone frequency, intensity, duration and geographical shift. The OU-CGCM model is described in more detail in an accepted journal article by Leslie et al. (2004). In its current standard configuration, the atmospheric model has 21 levels in the vertical and a horizontal resolution of 1.8 degrees of latitude by 1.8 degrees of longitude. It has an option for concentrating grid points over an arbitrary region of the earth, using a graded mesh approach. In this way, we effectively have a two-way nesting without the need for internal boundaries. The oceanic component of the model has 20 levels with a standard horizontal resolution of 1 degree of latitude and 1 degree of longitude. The longitude resolution increases to 0.5 degrees at the equator, starting at 15 degrees N and 15 degrees S.

The model does not use a flux adjustment as the climate drift has been found to be very small over the typical 100 to 150 years of model runs that have been completed to this stage. Currently, several 500 year runs have been made but have not yet been fully assessed.

There are two numerics kernels in the OU-CGCM. Both are energy and mass conserving. The model numerics of the most recent version of OU-CGCM are similar to those of one version of the WRF model, except that they are cast in conserving, positive-definite form for both the AGCM and the climate model runs. In this version, the time differencing is third-order Runge-Kutta and the advective terms are 5^{th}-order.

The physical parameterizations are not described in detail here as the focus is on the impact of moist convective schemes. There is a large number (9) of moist convection schemes on option for the OU-CGCM including: moist convective adjustment (hard and soft); a modified Kuo scheme with downdrafts; two versions of the Arakawa-Schubert scheme; the Kain-Fritsch scheme; the Betts-Miller scheme; and for very high resolution runs, a six water phase “explicit” cloud microphysics scheme.

The model is initialized in a manner similar to the HadCM3 model. The spin-up period for the coupled model is 25 years, starting in 1950. The atmospheric model is spun up in the usual manner from an arbitrary January 1 initial state, derived from the OU-CGCM, run as an AGCM for one year, using specified SSTs for that period. The ocean model is spun up from a static state, with annual mean temperatures and salinity derived from Levitus (1994).

The model currently is run on a Linux workstation cluster housed at the School of Meteorology at OU. The sustained speed of the cluster is approximately 200 Gflops and will soon be upgraded to a cluster of dual processor machines that will achieve a sustained performance of over 500 Gflops. A 10 year model run currently takes approximately 100 hours on the current Linux cluster, when the cluster is dedicated solely to the OU-CGCM.

The control and increasing greenhouse gas concentration runs begin on Jan 1, 1975 and end on Dec 31, 2099. In the increasing greenhouse gas model runs, the IS92a version of increasing CO2 was used. For the model runs presented here, an ensemble of 6 versions of the model was run, with two versions of the numerics and 3 parameterizations of moist convection. The moist convection schemes selected were modified versions of moist convective adjustment (MCA), Kain-Fritsch (KFC) and the reduced Arakawa-Schubert (RAS) schemes.

2. RESULTS FROM THE CONTROL SIMULATIONS

The control simulations with the model have fixed concentrations of greenhouse gases and have been run from 1975 to 2100. The spatial patterns of annual

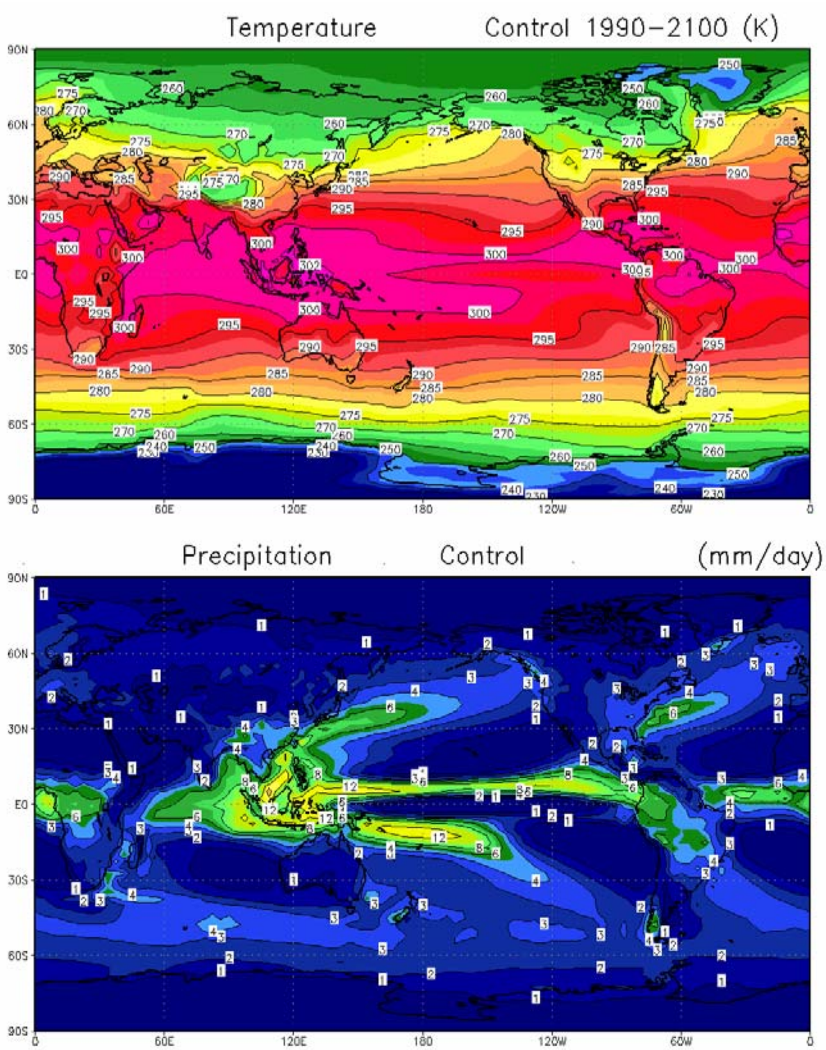

FIGURE 1. *Annual mean long-term mean (110 year average) surface air temperature (top) and precipitation (bottom) from a control run with the OU-CGCM climate model. The patterns agree well with observations.*

mean surface air temperature and precipitation are shown in Figure 1 and they agree reasonably well with observations. They show some problems common to other coupled models, including a too weak equatorial cold tongue in the eastern Pacific Ocean, too strong precipitation in the ITCZ in the north equatorial Pacific and an eastward extension of the SPCZ in the tropical south Pacific. There is negligible trend over the century duration of the control runs in both global mean temperature and precipitation, as shown in Figure 2 below. However, the simulations with moist convective adjustment show reduced interannual variability of global mean temperature compared with observations and simulations with the other two convection schemes.

3. RESULTS FROM THE GREENHOUSE SIMULATIONS

The simulated response to increasing greenhouse gases for the three different convective schemes is shown in Figure 2 also. The Transient Climate Response (TCR) is estimated from the 20 year average global mean temperature increase over the control run at the time of CO_2 doubling. For the MCA scheme, it is about 2.4K while for the KFC and RAS schemes it is somewhat smaller at 2.0K. These TCR values for KFC and MCA convection are in the middle of the range of TCRs for the nineteen CMIP2 models (1.1K to 3.1K) considered in the IPCC Third Assessment (Cubasch et al., 2001), while the TCR for the MCA convection is larger than the average.

The simulated global mean precipitation response to increasing greenhouse gases shows an increase that appears to follow the global warming in the model simulations. At the time of CO_2 doubling, there had been an increase in global mean precipitation of about 2.7% in the MCA run and about 2% in the KFC and RAS runs, close to the average increase of 2.5% for the nineteen CMIP2 models (Cubasch et al., 2001).

The spatial patterns of the temperature response at the time of CO_2 doubling are very similar for the three convection schemes, as shown in Figure 3. They show the typical pattern of increased warming at high latitudes and over land, and least warming in the North Atlantic. The pattern of precipitation change is more variable, as shown in Figure 4, with general increases of precipitation in the tropics and decreases in the subtropics, independent of the convection scheme. Most of the increases in tropical precipitation are over the ocean. The details of these precipitation patterns are likely to be affected by the natural variability of 20-year average precipitation, which is much larger than for temperature.

Analysis of the impact of the different convective parameterization schemes on the cloud and water vapour distributions and on the precipitation intensity in both the control and greenhouse simulations is continuing.

ACKNOWLEDGEMENTS

This development of the OU-CGCM has been supported in part by funding from the Office of Naval Research and the Insurance Australia Group. DR is supported by funding from the Gary Comer Science and Education Foundation.

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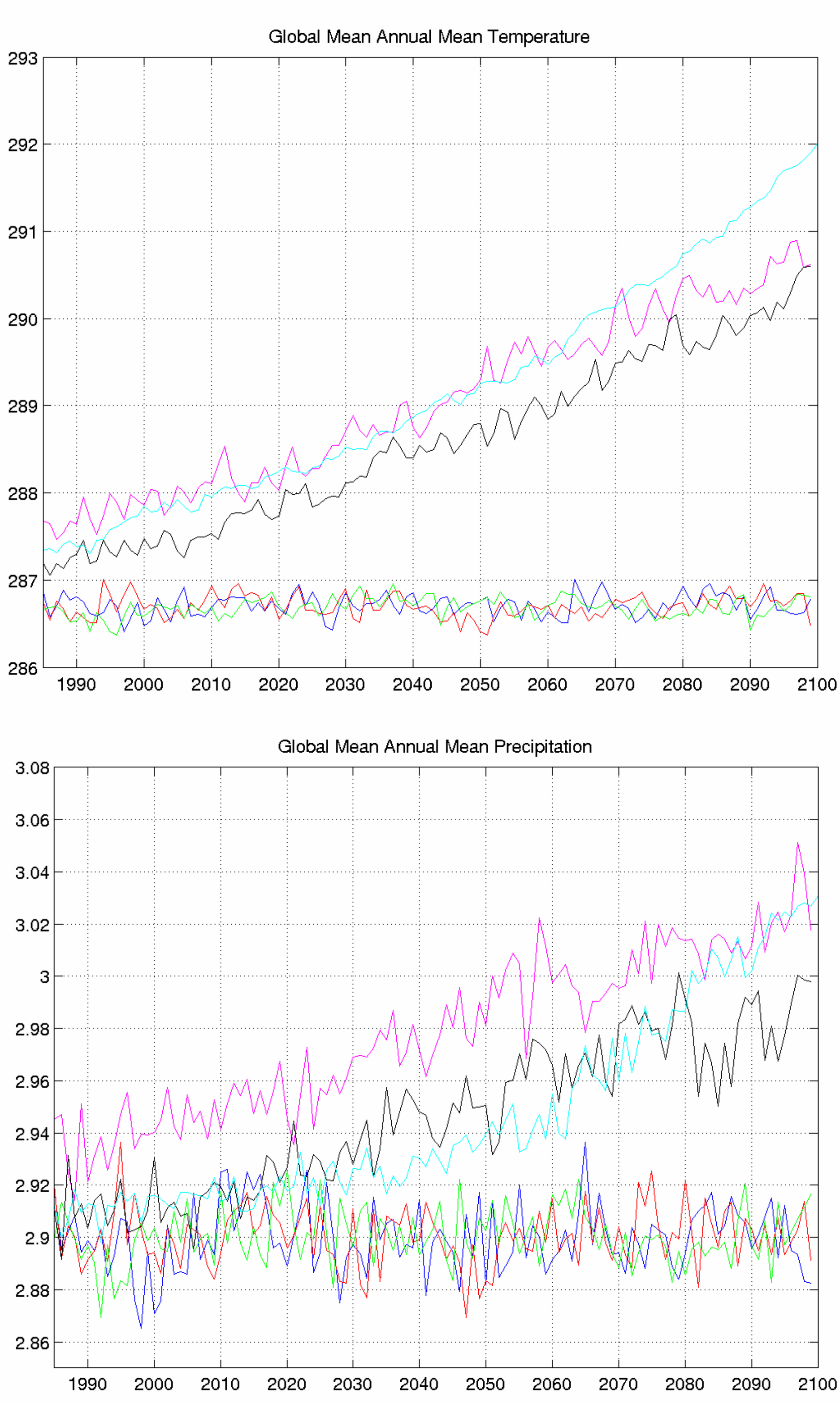

FIGURE 2. *Time series of global mean annual mean temperature (top) and precipitation (bottom) from the control and increasing greenhouse gas simulations. Note that the greenhouse gas increases started in 1975, while the time series graphs shown here start in 1985. The simulations with the moist convective adjustment parameterization show a greater warming and increase in precipitation than the other two schemes.*

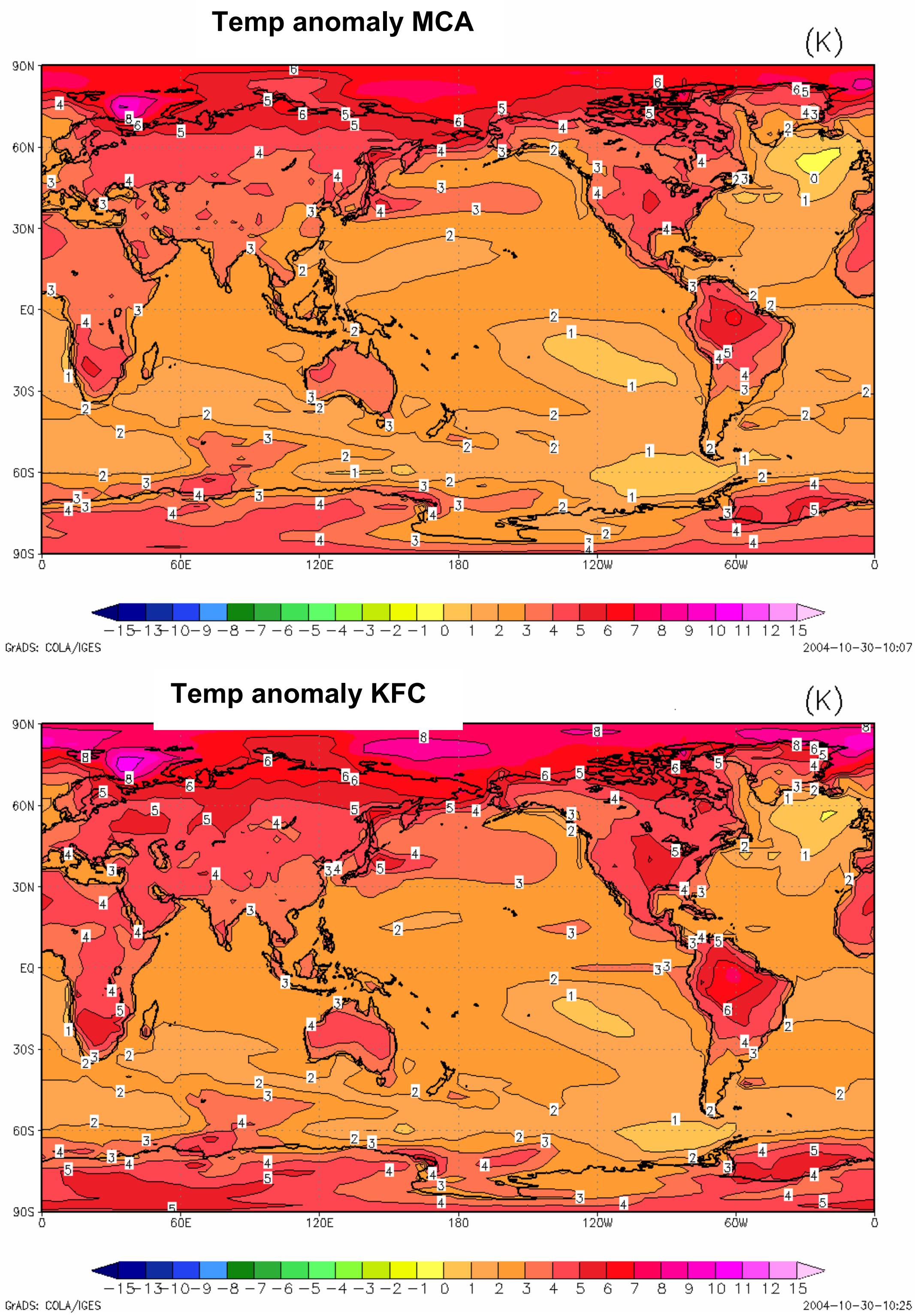

FIGURE 3. *Twenty-year average temperature anomaly at the time of CO_2 doubling for the simulations with the MCA scheme (top) and the KFC scheme (bottom). The anomaly is calculated from the long-term mean of the respective model control simulation.*

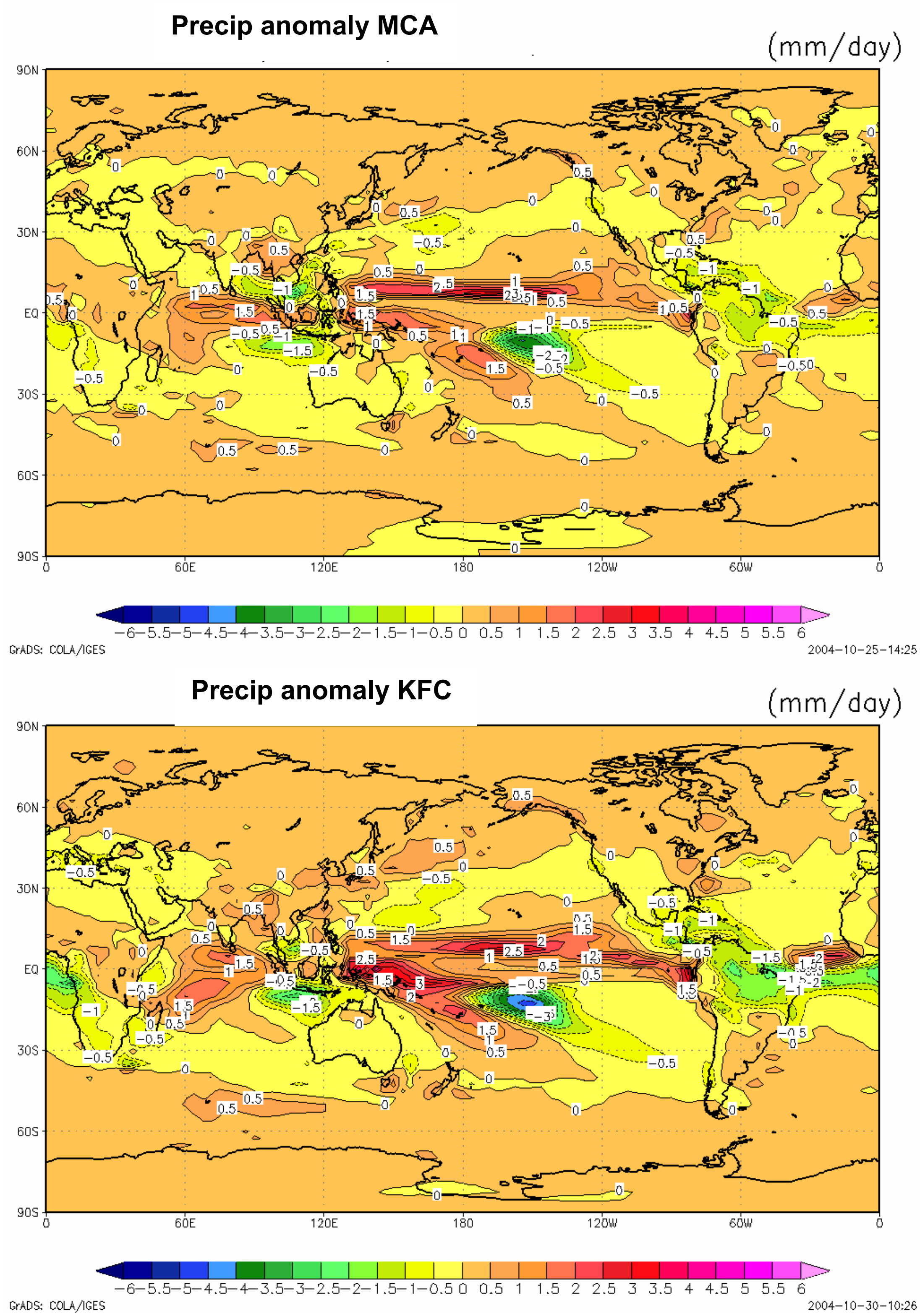

FIGURE 4. *Twenty-year average precipitation anomaly at the time of CO_2 doubling for the simulations with the MCA scheme (top) and the KFC scheme (bottom). The anomaly is calculated from the long-term mean of the respective model control simulation.*