Sensitivity of the general circulation and extratropical cyclone characteristics to tropical and polar heating

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In a warmer globe caused by increasing CO_2 greater warming is expected over the polar region in the lower troposphere and over the tropics in the upper troposphere (Figure 1) (IPCC 2001), and Southern Hemisphere winter extratropical cyclones in the CSIRO Mark2 atmosphere-ocean coupled model are seen to reduce in their number with doubled CO_2 (Figure 2) (Sinclair and Watterson 1999, Lim 2005). In this study we examine the influence of each of the tropical and the polar warming on the general circulation and the characteristics of Southern Hemisphere (SH) extratropical low pressure systems by conducting idealised temperature 'nudging' experiments.

Using Melbourne University atmospheric general circulation model (MUGCM, R21/L9), warm temperature anomaly, 0.04ºC hr^{-1} was nudged over (a) the tropics between 21.5ºS and 21.5ºN at sigma level = 0.336 - TU (Tropics/Upper level); (b) the high latitudes between 65ºand 90º latitudes in both hemispheres at sigma = 0.991 and 0.926 - HL (High latitude/Lower level); and (c) the tropics at sigma = 0.336 and the high latitudes at sigma = 0.991 and 0.926 - TU+HL. These warm anomalies were forced at all points on the relevant latitude circles. The resultant vertical temperature profile is shown in Figure 3.

Our three sets of 8 year MUGCM simulations demonstrate that warming over the tropics in the upper troposphere results in stronger Ferrel circulation and westerlies between 40ºS and 60ºS in winter. Whereas, warming over the high latitudes in the lower troposphere causes the meridional and vertical circulations to be slightly weaker over most of the SH extratropics and the upper level zonal winds to be less strong over the 60ºS latitude band. When the equal amount of positive temperature anomaly was nudged over the high latitudes in the lower troposphere and over the tropics in the upper troposphere, the weakening of the meridional-vertical circulation is more obvious than that in the HL experiment. The axis of westerly jet tends to move equatorward.

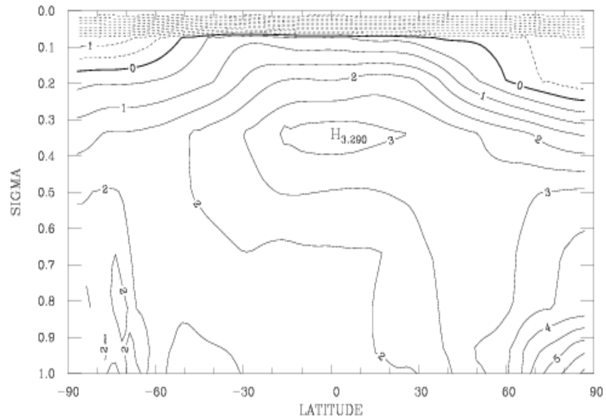
Figure 4 shows zonal means of winter MSLP cyclone system density and depth which were simulated in three different nudging experiments. Warming in the TU experiment tends to cause the frequency and depth of extratropical cyclones to increase in the high latitudes at the surface. By contrast, warming over the high latitudes in the lower troposphere (HL and TU+HL), the frequency and depth of MSLP cyclones tend to decrease in the higher latitudes. In the midlatitudes between 30º-50ºS fewer surface cyclones are found with the TU warming, but slightly more systems are found with the HL and TU+HL warming. However, the cyclone property changes with the HL and TU+HL warmings are very subtle in the midlatitudes, and it needs further investigation whether this less sensitivity to the polar warming is model dependent or not.

Consequently, the TU warming seems an important contributor to the decrease in cyclone system density over most of the SH extratropics in a doubled CO_2 atmosphere shown in Figure 2.

IPCC (2001). Climate Change 2001, The scientific basis, edited by Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X.Dai, K. Maskell and C. A. Johnson. Cambridge, U.K.: New York, USA: Cambridge University Press.

Lim, E.-P. (2005). Global changes in synoptic activity with increasing atmospheric CO_2, Ph. D. thesis, University of Melbourne, Victoria, Australia

Sinclair, M. R. and I. G. Watterson (1999). Objective assessment of extratropical weather systems in simulated climates, *Journal of Climate*, **12**, 3467-3485.



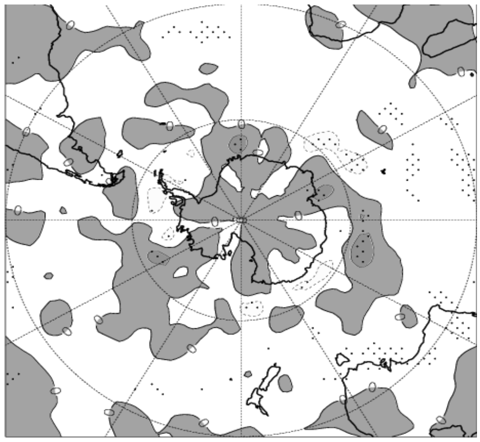
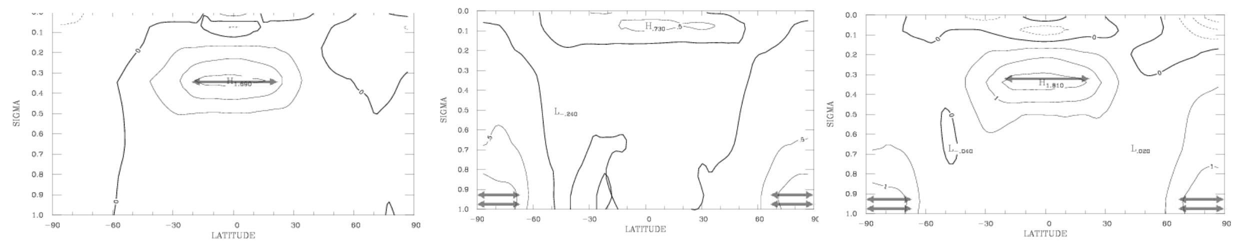


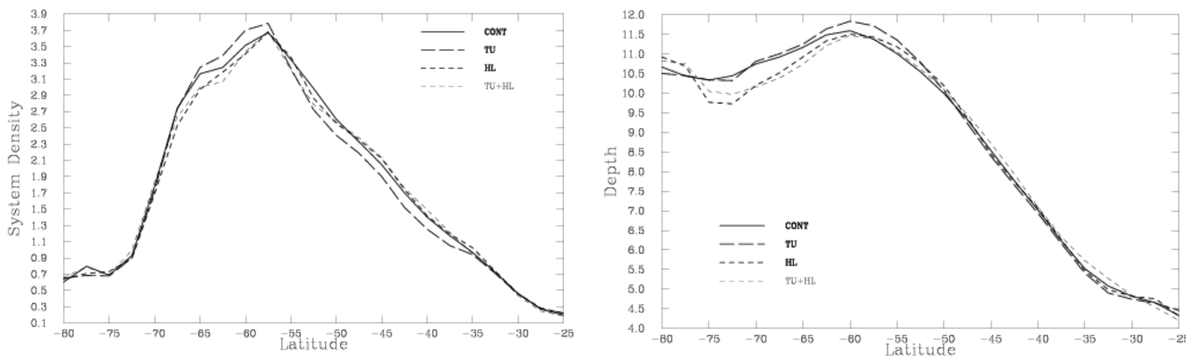
Figure 1 Vertical profile of annual mean temperature change of 2xCO2-1xCO2 simulated in the CSIRO Mk2 AOGCM. The contour interval is 0.5 K.

Figure 2 Changes in MSLP cyclone system density from 1xCO2 to 2xCO2 simulated in the CSIRO Mk2 AOGCM. Shaded areas show positive changes, and stiples show statistically significant changes at the 95% confidence level



(a) (b) (c)

Figure 3 Vertical profile of annually averaged temperature difference between the control experiment and (a) the tropical/upper troposphere (TU) warming, (b) the high latitudes/lower troposphere (HL) warming, and (c) the TU+HL warming experiments. The arrows indicate the locations where the temperature forcing is placed. The contour interval is 0.5 K.



(a) (b)

Figure 4 Zonal means of MSLP cyclone (a) system density and (b) depth simulated in the control run (solid line) and the transient runs with the TU warming (solid long dash line), the HL warming (solid short dash line), and the TU+HL warming (short dash line)