19.11 CLIMATE CHANGE SIMULATIONS AROUND THE ANTARCTIC PENINSULA

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1. Introduction

Recent studies of Antarctic surface temperatures have documented differences in trends among several stations around the continent. Over the second half of the 20th century, Antarctic Peninsula stations show a strong warming trend, while stations in other areas show no significant trend or slight cooling (Comiso, 2000). This recent observed warming on the Antarctic Peninsula region has been a critical climatic change, the fastest regional warming in the Southern Hemisphere (SH), with an order of magnitude greater than global mean warming (Vaughan et al. 2001). The Antarctic Peninsula record may reflect the influence of both remote forcing due to ENSO or Southern Annular Mode (SAM) (Thompson and Wallace 2000) and local air-sea-ice interaction (Marshall and King 1998).

Global coupled circulation models are currently used in order to study the mechanisms that control climate mean state and variability, and how these mechanisms are affected in a global change scenario (Houghton et al, 2001). Unfortunately, many coupled models present large systematic errors at high southern latitudes especially in non-flux-corrected versions. Moreover, they tend to underestimate the interannual variability over Southern oceans near Antarctica. Even those models that reproduce the observed large-scale changes in surface temperature over the 20th century do not reproduce regional changes around Antarctica (Vaughan et al. 2001).

The mechanisms that caused the rapid regional warming over the Antarctic Peninsula are still unknown and in consequence it is difficult to anticipate whether this trend will remain in the next century. Changes in the large-scale atmospheric circulation over the Southern Ocean and particularly over the eastern South Pacific may exert strong controls on Antarctic Peninsula temperature variability. But the modification of the sea-ice characteristics and the change of the oceanic circulation and their interaction with the atmosphere are other feasible major contributors to the observed trends.

The main issue of this study is to examine the ability of a realistic global climate model to reproduce this observed regional change. We also try to assess different atmospheric processes in order to explain these changes. We use a state-of-the-art low resolution ocean-atmosphere general circulation model (IPSL/CM2) which includes coupled-to-land and -ocean carbon models to simulate the evolution of climate from 1860 to 2100 with no flux corrections (http://www.lmd.jussieu.fr/Climat/couplage/ipsl_ccm2). Two 241-years simulations were carried out: a control simulation in which no anthropogenic CO2 sources are considered and a climate-change scenario simulation in which CO2 emissions are prescribed following the IPCC SRES98 A2 scenario.

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2. Model Evaluation and temperature response

Vera et al. (2001) show that the most important features of the SH climate are well reproduced by this low resolution global coupled model. Both the control and the scenario simulation present close realistic representations of the leading patterns of SH atmospheric low-frequency variability. Three leading modes of low-frequency variability were found. The first is the southern annular mode (SAM) while the next two have a dominant tropical Pacific signal with teleconnections to extratropical latitudes known as Pacific-South America patterns. As the IPSL/CM2 coupled model reproduces well the main characteristics of the SH climate we assume that the global-scale response of the climate system to anthropogenic greenhouse gases might be plausible and the mechanisms of global change over the Antarctic can be studied using this model.

The control run displays no significant drift of the global mean surface temperature while the scenario run presents an increase of the global temperature consistent with the observations (Dufresne et al. 2002). Besides the large-scale climatology that is well captured by the model, the geographical distribution of the changes in the mean annual near-surface temperature for 1950-2000 (figure 1) suggests that the model is able to capture the main regional changes around Antarctica like the warming in the vicinity of the Antarctic Peninsula and a weaker and not uniform change along the coasts of Eastern Antarctica(see e.g. Vaughan et al. 2001 for a review of observed temperature trends over the region). A cooling in the Eastern Weddell Sea is also evident and consistent with the trend observed at Halley station.

Figure 2 represents the annual mean near-surface temperature anomaly of the scenario run at 70°S for the period 1900-2100 respect to the 1860/1899 climatology (annual means are computed first and a 10-yr running mean is then applied). This figure provides further evidence about the model ability for capturing this rapid regional warming in the Antarctic

Peninsula region. After around 1950, the region around 50°W gets warm suddenly in the scenario simulation. As well as exhibiting a significant positive long-term trend, Antarctic Peninsula temperatures show large interannual variability, especially during winter (King 1994). The geographical distribution of interannual variability of surface temperature (not shown here) indicates that the model is reasonably close to the observations, including over the high latitudes near the Antarctic coasts.

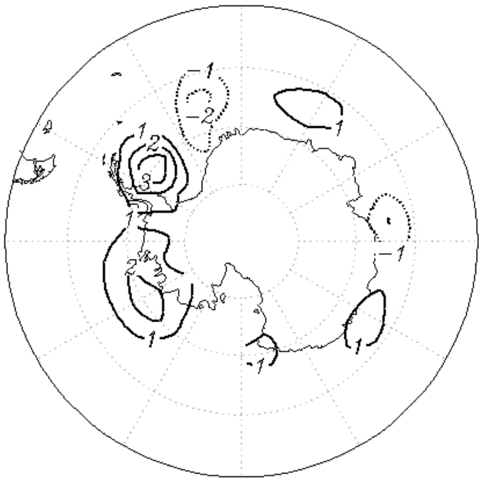

Figure 1 Annual mean near surface temperature change during 1950-2000 (units: °C/100yrs)

3. Sea-ice changes and annular mode response

The simulated interannual variability of sea-ice concentration also reflects strong regional scale climatic influences. The response (defined as the 2050-2100 time mean of the scenario simulation minus the 241-yr time mean of the control simulation) of the interannual standard deviation of sea-ice concentration is particularly significant over the Weddell Sea (positive anomalies near the Antarctic Peninsula and negative anomalies over the eastern Weddell Sea, not shown). As observed (at least during the satellite era) the simulated warming trend around the Antarctic Peninsula correlates with the major reduction in sea-ice extension in the region, especially evident over the Weddell Sea (figure 3). It is worth noting that this is the region of Antarctica with more significant annual and long-term correlations between the anomalies of sea-ice concentration and surface air temperature, both in the simulation and observations (Weatherly et al. 1991, Vaughan et al. 2001).

The response of the SH circulation to transient anthropogenic greenhouse warming mainly consists in an increase of the meridional pressure gradient between the high and mid latitudes modulated by a wave-3 like pattern (not shown). The structure that characterizes the linear trend of the SH circulation, resembles the leading mode of interannual variability, SAM (Thompson and Wallace 2000). The SAM involves an oscillation of atmospheric mass between the middle and high southern latitudes. It explains 30 % of the observed extratropical SH surface pressure variability and 50% of zonal mean geopotential heights variability (Thompson and Wallace, 2000). Kwok and Comiso (2002) suggest that the SAM accounts for nearly 35% of the recent Antarctic temperature changes. The impact of the SAM on the surface temperature anomalies in the Antarctic Peninsula region is out of phase with the rest of the continent (Kwok and Comiso, 2002).

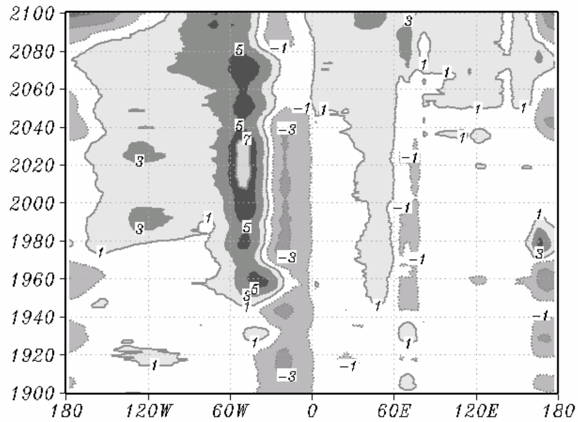

Figure 2 Evolution of the temperature anomalies along 70°S in the scenario run for the period 1900-2100 with respect to the 1860-1899 mean.

In that sense, we defined a SAM index as the difference between the zonal mean geopotential-height at middle latitudes (40°S-50°S) and that at subpolar (60S-70S) regions. The index exhibits positive trend in the climate-change simulation (fig.4a) which is consistent with the above mentioned

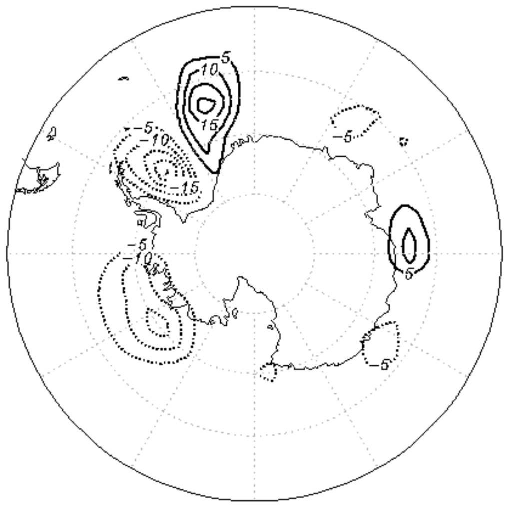

Figure 3 Annual mean sea ice extent change during 1950-2000 (units: %/100yrs)

amplification of the mean meridional pressure gradient in the simulation and with the observed trend of the SAM over the last three decades (Thompson and Solomon 2002). Other climate change scenario simulations have also captured this trend in the SAM (e.g. Kushner et al. 2001). This marked trend in the tropospheric circulation is also consistent with a tendency towards stronger circumpolar flow in the scenario simulation (fig. 4b). The frequency and characteristics of blocking and high frequency eddies in the Amundsen - Bellingshausen Seas and South Pacific are related to the strength of the polar jet. So, changes in the SAM would probably affect the climatology of synoptic systems in the region of the Antarctic Peninsula.

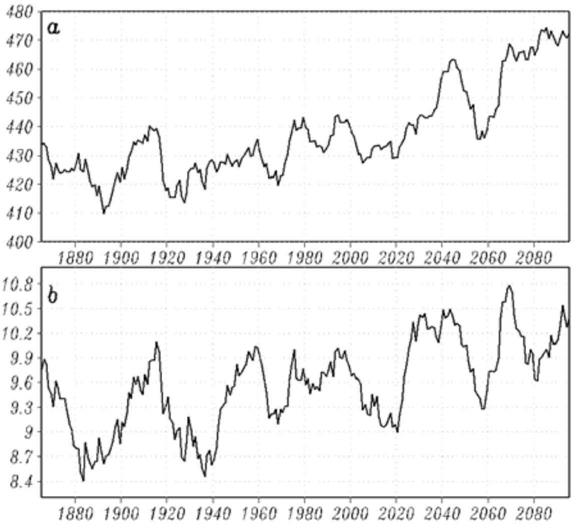

Figure 4 Temporal evolution (a) SAM index and (b) 850 hPa zonal wind regional mean over 135E/90W-70S/55S in the scenario run (a 10-year running-mean was applied)

4. Discussion

The model, though coarse grid, has shown a surprising ability to reproduce many aspects of variability in the coupled climate system over the Bellingshausen Sea-Antarctic Peninsula-Weddell Sea region. The simulated changes in the near surface air-temperature and sea-ice distribution are qualitatively coherent with recent observed changes in this region. The model also captures some aspects of ENSO and the associated teleconnections to the southern mid- and high latitudes (Vera et al. 2001).

Yet the mechanisms that caused the recent warming on the Antarctic Peninsula are not fully understood (Vaughan et al. 2001). Clearly, further studies are necessary to determine the role of air-sea-ice interactions and others various feedbacks that control the evolution and response of surface temperature and sea-ice distribution in the region. This study suggests that global circulation models indeed can help in determining these mechanisms.

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