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INTERCOMPARISON OF THE SOUTHERN ANNULAR MODE FOR THE MID HOLOCENE AND PRESENT BETWEEN TWO COUPLED GENERAL CIRCULATION MODELS

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1.INTRODUCTION

The dominant mode of atmospheric variability in sea level pressure (SLP) for the Southern Hemisphere is the Southern Annular Mode (SAM).
The SAM has been investigated by several authors, e.g. Thompson and Wallace (1998); Gong and Wang (1999); Thompson and Wallace (2000); Hall and Visbeck (2002). This mode is characterized by pressure anomalies of one sign centered over Antarctic and anomalies of the oposite sign centered about 40-50°S. Gong and Wang (1999) defined this mode as the Antarctic Oscilation (AO). They constructed an AO index which is the difference of the first mode of SLP-EOF, between 40°S and 65°S. According to the authors, the AO has low frequency in the Southern Hemisphere which persist throughout the year.
Hall and Visbeck (2002) show that the larger part of the ocean zonal variability south of 30°S is related the SAM. The positive phase of the SAM is associated with an intensification of the surface westerlies over the circumpolar ocean around 55°S, and a weakening of the surface westerlies further north. This pattern induces Ekman drift to the north at all longitudes of the circumpolar ocean, and Ekman drift to the south around 30°S. Through mass continuity, the Ekman drift generates anomalous upwelling along the margins of the Antartic continent, and downwelling around 45°S. The authors explain that this anomalous flow diverging from the Antartic continent, also increases the vertical tilt of the isopycnals in the Southern Ocean.In addition, the anomalous divergent flow advects sea ice further north. The meridional heat transport is afected too: the increase in poleward heat transport at about 30°S are approximately 15%, while 20% in the decreases occur in the circumpolar region. The heat transport anomalies result in a divergence of heat centered about 55°S and a convergence of heat centered about 40°S. This manifests itself in SST anomalies.
Thompsom and Solomon (2002) show that trends observed in the geopotencial height in the Southern Hemisphere polar cap are consistent with the trends in the high index polarity in the SAM. Months with high index polarity in the SAM index are characterized by cold anomalies, low geopotencial height and a strong circumpolar flow along 60°S. Months with low index polarity are marked by positive anomalies.
The Mid-Holocene (6000 years ago - 6K) is a period that the numerous well-dated proxy records indicating a climate that different from today's. Variations in the earth's orbital parameters, as determined Milankovich theory (Berger 1978), lead to changes in the seasonal and latitudinal distribution of incoming solar radiation at the top of earth's atmosphere, and the differences between the Mid-Holocene climate and the present climate are believed to be largely attributable to these changes (Hewitt and Mitchell (1996)).
The 6K is often used to evaluate how models respond to a changes in insolation (Hewitt and Mitchell (1996) and Joussaume et al. (1999)). During the mid-Holocene, the seasonal cycle of insolation forcing was larger in the Northern Hemisphere than today, with more solar radiation in summertime (~+5%), and less in wintertime (~-5%) than present (Bonfils et al. (2004)).
This study investigates the interannual variability of Southern high latitudes SLP (Sea Level Pressure) for the Mid-Holocene (6K) and the Present (0K) using two ocean-atmosphere coupled models. The models are from National Center of Atmospheric Research (NCAR CCSM3) and from the Institut Pierre Saint-Laplace (IPSL).*

2.MODEL DATA AND ANALYSIS

Coupled models used in paleoclimate studies have undergone a rapid development in recent years and have in several respects obtained a considerable degree of realism. In this study the SAM is investigated in the holocene using two different coupled models: The NCAR CCSM and the IPSL GCM.
The paleo version of the National Center for Atmospheric Research (NCAR)-Community Climate

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System Model (CCSM) consists of 4 components: atmosphere, ocean, land surface and sea-ice (the reader is referred to Boville and Gent (1998) for moredetails).
The atmospheric component is the Community Climate Model, version 3, with T42 resolution (approximately 2.8◦ in latitude and longitude) and 18 vertical layers (Kiehl et al., 1998; Hack et al., 1998). The ocean component of this model was developed
from the Geophysical Fluid Dynamics Laboratory z-coordinate primitive equation model (Gent et al., 1998). The spatial resolution is 2.4◦ in longitude, with
variable resolution in latitude ranging from 1.2◦ to 2.3◦, and 45 vertical levels. The meridional resolution is 2.2◦ at 20◦S and 1.8◦ at 40◦S. The sea-ice model dynamics is based on the cavitating fluid rheology by which the ice pack does not resist divergence or shear, but does resist convergence (Flato and Hibler, 1992;Weatherly et al., 1998). The land-surface model provides a comprehensive treatment of land surface processes allowing for different vegetation types (Bonan, 1998). Although the land-surface model computes river runoff, it is not transferred to the oceanmodel.
Simulations are run for the Mid-Holocene where orbital parameters and greenhous gas levels are adjusted to reflect conditions of 6000 years before present (hereafter referred to as 6K).
The IPSL GCM Coupled Model is described in detail in Marti et al., 2005. The atmosphere component is the LMDZ version 4 documented by Hourdin et al, 2005. The ocean component (Madec et al., 1998) is the OPA-ORCA model and the land surface model is ORCHIDEE (described in Krinner et al., 2005). Together with the ocean model there is a sea-ice component (LIM, Fichefet and Maqueda, 1997).
Paleo Model Intercomparison Project parameters are taken into account for the forcing (as with the NCAR-CCSM) for both present day and mid-holocene simulations.
In both models, the climatology of the last 100 years of a 400 year simulation is presented.

2.1 Methodology

The key region in this study is the South Atlantic. The variables of interest are sea level pressure (SLP) and zonal wind stress (τ_x). In Empirical Orthogonal Functions (EOF) are applied to the simulation results in order to identify the predominant modes of variability in the Soputhern Hemisphere for each climatic period.

3.RESULTS

EOF1 obtained from the CCSM SLP results for the present shows, as expected, a zonally simetric structure in SLP around the Antartic continent, which is the Annular Mode. This mode is responsible for more than half of the total variance in the CCSM simulation.. The time series associated with this mode is the SAM index (Hall and Visbeck, 2002) . Positive values in this index are associated with the negative anomalies in SLP over Antarctica and positive anomalies in mid latitudes.

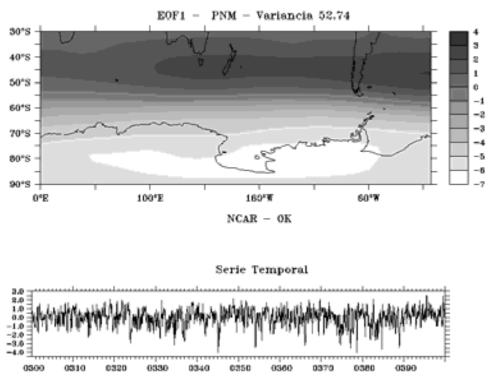

Figure 1: The first EOF mode for SLP and its associated time serie for the NCAR CCSM model for the Present day.

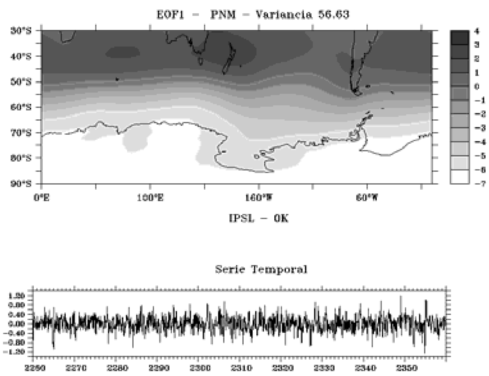

Figure 2: The first EOF mode for SLP and its associated time serie for the IPSL model for the Present Day.

Figure 2 presents the the SLP EOF1 for the IPSL simulation for the Present Day.. In this first mode the robust zonally symetric structure of the annular mode can be noted. This mode explais almost 50% of the total variance.

Figures 3 and 4 shows the SLP EOF1 at 6K for the simulations with the CCSM and IPSL, respectively. Similar with the Present Day results, the first mode shows a zonally symmetric structure over the Southern Ocean. These modes are very robust explaining in the mid Holocene 66.79% of the variance in the CCSM and 56.78% for the IPSL results. Considering how stable the annular mode is between climatic periods, one notices that the greater differences are relative to the simulations rather than for the climatic periods.

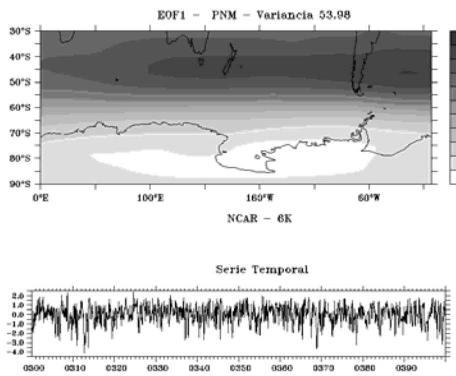

Figure 3: The first EOF mode for SLP and its associated time serie for the NCAR CCSM model for 6k (mid holocene).

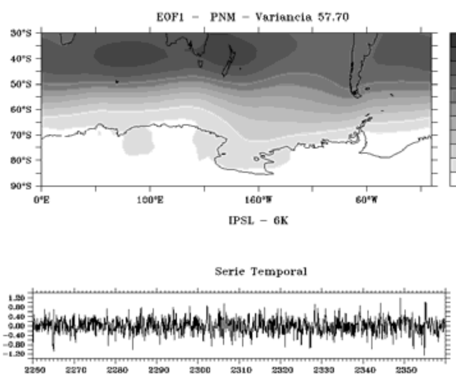

Figure 4: The first EOF mode for SLP and its associated time serie for the IPSL model for 6k (mid holocene).

Considering that the SAM in these simulations (for both models and for both climatic periods) present little changes correlation analyses with the respective SAM indices and the simulated wind field is used in order to verify if indeed there are changes in physical behaviour associated with the SAM.

Figure 5 shows the correlation between the SAM index and the zonal Wind stress for the CCSM in the Present Day Two belts with high correlation, one over the Southern Ocean and the other at the southern South Atlantic Ocean can be observed. Between 10°S-35°S and 45°S-65°S the correlation is greater than 60% and 40% respectively showing a significant change in the wind pattern associated with the SAM (as described in Thompson and Wallace, 2000; Hall and Visbeck, 2002).For the IPSL model results a similar pattern is also recovered which is shown in Figure 6. .

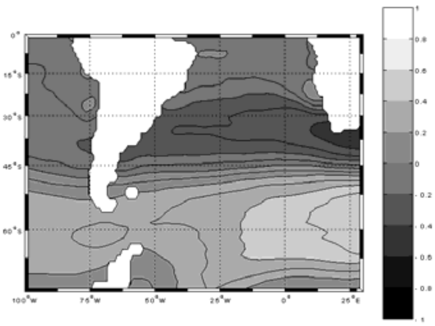

Figure 5: Spatial correlation between the SAM index and the zonal wind stress for the CCSM results for the Present Day.

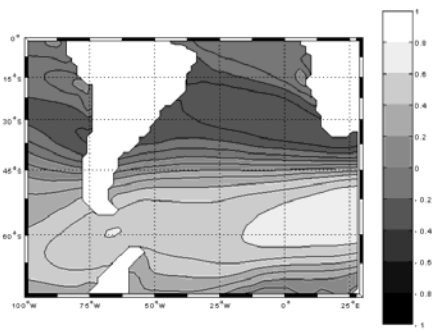

Figure 6: Same as Figure 5, but for the IPSL model results.

Figures 7 and 8 show the correlation between the SAM index and the zonal wind stress in the Mid-Holocene for the CCSM and IPSL simulations, respectively. The similar spatial structure obtained for the Present Day is however, with a much higher

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correlation coefficient, around 80%. The correlation results for the IPSL model, in contrast, shows lower correlation values with respect to Present Day. (fFgure 8).

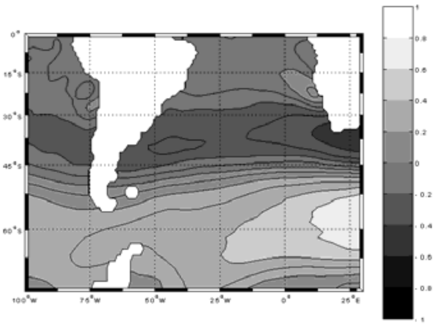

Figure 7: Spatial correlation between the SAM index and the zonal wind stress for the CCSM results for the Mid-Holocene.

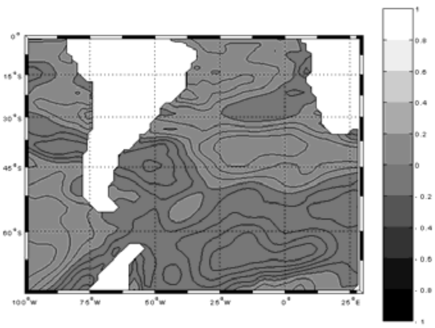

Figure 8: Same as Figure 7, but for the IPSL model results.

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4.SUMMARY AND CONCLUSION

In this study, an intercomparison of SLP EOF1 for the Mid-Holocene (6K) and the Present (0K) using two ocean-atmosphere coupled models is presented. The numerical integrations for both models and periods show that the zonally symmetric structure of the SLP EOF1 mode around Antarctica (SAM) is a very robust feature of the simulated climate system. For the two coupled models, the SAM accounts for approximately half of the total variance. There is very little variation between the SAM representation in the two simulations (NCAR CCSM and IPSL for the two periods). The results here indicate more differences between the models than between the two climatic periods.

In order to refine the differences between the climatic periods, correlation analyses of the SAM index with the zonal wind field was performed. Results confirm that the SAM modulate the subtropical westerlies but the only difference observed was in the magnitude of the correlation between the CCSM and IPSL.

It seems that the annular mode is too strongly represented in the numerical simulations in order that significant changes in physical mechanisms be identified. Nonetheless, difference associated with the time series are clear and periods.

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