Connection between the South Pacific anti-cyclone, Peruvian stratocumulus, and the South American Monsoon System

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Abstract

We examine the connection between the strength of the subtropical anti-cyclone in the South Pacific, Peruvian stratocumulus and the South American Monsoon System. The approach is based on experiments with a coupled atmosphere-ocean general circulation model (GCM) in which different treatment of land surface processes in the atmospheric model provide different representations of convection over the continents. Specifically the atmospheric model is the University of California Los Angeles Atmospheric GCM (UCLA AGCM) in versions with simple land scheme (SLS) or the Simplified Simple Biosphere Model (SSiB) that allows for consideration of soil and vegetation biophysical processes. The oceanic GCM is the Massachusetts Institute of Technology Oceanic GCM (MIT OGCM). The impact of these land surface processes on the monsoon climatology shows improved convection in central Amazonia in the SSiB version, which is too strong in the version with SLS. The subtropical anticyclone in the South Pacific weakens, in a way consistent with the Rodwell-Hoskins mechanism, i.e., through the Rossby wave response to the west of the SAMS convection. The Peruvian stratocumulus is improvement due to both weaker subsidence and warmer underlying sea surface temperature.

Key word: GCM, land surface processes, South Pacific anti-cyclone, stratocumulus

1. Introduction

The South American Monsoon System (SAMS) affects and is affected by several other climate features, such as the Intertropical Convergence Zone (ITCZ) and sea surface temperature (SST) distributions over both the Pacific and Atlantic Oceans, and the stratocumulus clouds decks in the southeastern tropical Pacific (Nogués-Paegle et al. 2003; Vera et al. 2006). Monsoon convection associated with SAMS originates both Kelvin waves that propagate eastward and Rossby waves that propagate westward and poleward with associated subsidence that can be enhanced by diabatic and other effects (Rodwell and Hoskins 2001; Miyasaka and Nakamura, personal communication).

The existence of these interactions suggests that simulation of the oceanic features by a coupled ocean-atmosphere general circulation model (CGCM) would be sensitive to the representation of convection over the continents in the atmospheric component (AGCM). In this case, different treatments of land surface processes (LSPs) would impact the results over both continents and oceans. An intriguing possibility, therefore, is that upgrading the LSP parameterization might help reduce the systematic errors in the tropics that plague CGCMs (e.g., Mechoso et al. 1995).

The present paper explores such possibility of error reduction. The topic is well aligned with one of the main goals of VOCALS, which is the elimination of tropical errors of CGCMs. Our approach is based on comparing northern winter simulations by a CGCM with different land surface schemes. We have already determined in an AGCM study (Ma et al. 2010) that the simulation of diabatic heating over the South American continent is sensitive to the representation of LSPs. For example, upgrading the LSP parameterization as described later in Section 2 improved the simulation of precipitation over the tropical region - including Amazonia - and provided a stronger and more realistic surface heat flux in the Chaco Low over the central region. Differences in the simulations over the tropical oceans are not affected by oceanic feedbacks, however, as the same SST distribution is prescribed in the AGCM runs with the different LSP parameterizations. In the present paper we examine whether the results in Ma et al. (2010) are affected by allowing for atmosphere-ocean interactions, i.e. by using a CGCM.

The remainder of the text is organized into four sections. Section 2 provides a brief reference of models and experiments. Section 3 examines the response of the south Pacific anti-cyclone and Peruvian stratocumulus to different convection intensity and distribution from two

LSP schemes. Section 4 presents a summary of the results.

2. Models and experiments

We examine two century-long simulations with the University of California Los Angeles (UCLA) AGCM version 7.1 (Mechoso et al. 2000) coupled to the global Massachusetts Institute of Technology oceanic GCM (MIT OGCM, http://www.mitgcm.org). The horizontal resolution of the AGCM is 2.5° longitude and 2° latitude; there are 29 layers in the vertical. The horizontal resolution of the OGCM is 1° longitude and 0.3° latitude within 10° of the Equator increasing to 1° latitude poleward of 22°N and of 22°S; there are 46 levels in the vertical.

One CGCM experiment is control, and is performed with a simple LSP scheme that specifies soil moisture availability (Ma et al. 2010). The other experiment is with the same model, except for use in the AGCM component of the first generation of Simplified Simple Biosphere Model (SSiB; Xue et al. 1991). Both simulations produce reasonable amounts of annual mean precipitation and SST distributions, and a good seasonal cycle of equatorial Pacific SST. In general, the simulation is more successful when SSiB is used. The experiments with the simple land scheme and with SSiB will be referred to as CGCM/SLS and CGCM/SSiB, respectively. In the following we concentrate on South America and the southeastern Pacific (SEP) during the December - February (DJF) period

3. Response of South Pacific anticyclone and Peruvian stratocumulus

According to Ma et al. (2010), incorporation of SSiB in the UCLA AGCM has a significant impact on the intensity and vertical profile of diabatic heating over the continents. In particular for South America, the comparison between CGCM/SLS and CGCM/SSiB reveals that the latter simulation produces significant less precipitation in the core region of SAMS, and higher sensible heat flux at the surface over central sector with a strengthened Chaco low. Furthermore, the simulation with the more detailed LSP scheme is closer to the observation.

Figures 1a and 1b present the DJF mean velocity potential and divergent wind fields at 200 hPa from CGCM/SLS and CGCM/SSiB, respectively. At that level there are strong divergent outflows from the core region of SAMS in CGCM/SLS. These outflows are weaker in CGCM/SSiB, as expected from the weaker (and more realistic) convection obtained with this model configuration. Figures 1c and 1d present the differences between the DJF mean vertical velocity (subsidence) and sea level pressure from CGCM/SLS and CGCM/SSiB, respectively. The values of these two fields in the SEP are weaker in CGCM/SSiB. This simulation, therefore, produces a weaker South Pacific high in the SEP.

We next focus on the total cloud cover along the Peruvian coast where the contribution from the stratocumulus is dominant. According to Fig. 2 for DJF, both model versions produce too high and extensive cloud cover compared to observational estimates by the International Satellite Cloud Climatology Project (ISCCP). Nevertheless, CGCM/SSiB shows decreased and better total cloud cover and closer agreement with the observation.

Let us attempt an interpretation of these results in the light of connections among monsoon, anticyclone, and stratocumulus found in previous specialized studies with GCMs in both idealized and realistic scenarios. From Rodwell-Hoskins we expect a weaker South Pacific anticyclone in CGCM/SSiB, in which SAMS is weaker. The impact expected from Miyasaka-Nakamura is in the opposite direction: We expect a stronger South Pacific anticyclone in CGCM/SSiB, in which low-level diabatic heating over the Chaco Low is stronger. (The longwave cooling over the less extensive stratocumulus decks is weaker, however.) In principle, therefore, the two mechanisms mentioned would compensate each other, at least partially. Our results indicate that the Rodwell-Hoskins dominates farther away from the South America coast, where sea level pressure decreases in CGCM/SSiB; while Miyasaka-Nakamura prevails near the coast, along which low-level southerlies strengthen.

Additional effects arise in the coupled system since SST changes can also impact stratocumulus coverage. We indicated earlier in this section that stratocumulus incidence and extent is better captured in CGCM/SSiB. The stratocumulus amount in the observation is positively correlated with the inversion strength or static stability of the lower troposphere (Klein and Hartmann 1993), which is defined as the potential temperature difference between 700 hPa and the surface. The change of cloud incidence between the two simulations we are analyzing is consistent with the change in static stability of the lower troposphere. A close look at the reasons for changes in this parameter reveals that they are both due to weaker subsidence and warmer SSTs along the Peruvian coast. With less stratocumulus and more solar radiation incident at the ocean surface, the SST becomes warmer, which leads to lesser clouds and even warmer SST in a positive feedback. In contrast, in the uncoupled AGCM experiments (not show) cloudiness over the SEP is hardly affected since the same SST distribution is prescribed.

4. Summary

We examined the connection between the strength of the South Pacific anti-cyclone, Peruvian stratocumulus, and the South American Monsoon System (SAMS). The approach is based on experiments with a coupled ocean-atmosphere GCM in which different parameterizations of land surface processes (LSPs) in the atmospheric model provide different representations of convection over the continents in general and South America in particular. Using the more detailed parameterization (SSiB, an advanced land surface model that allows for consideration of soil and vegetation biophysical processes) the simulation of the coupled atmosphere-ocean system is more successful than with the simpler scheme.

The CGCM/SSiB simulation shows weaker convection over tropical South America, and an enhanced Chaco Low. The impact on the southeastern Pacific involves subsidence weakening and SST increasing, both of which contribute to the lower but more realistic Peruvian stratocumulus amount. The lower sea level pressures away from the South American coast are consistent with decreased convection over Amazonia (Rodwell-Hoskins mechanism). However, this outcome was not evident *a priori* since erroneous convection decrease over central South America is replaced by stronger low level heating over the Chaco Low, which would enhance the sea level pressures to the west (Miyasaka and Nakamura mechanism). In addition, the enhanced low-level heating is partially compensated by reduced stratocumulus incidence in the SEP. The results suggest that the stronger Chaco Low results in stronger low-level southerlies along the coast.

An important result is that including atmosphere-ocean interactions strongly influences the simulations by allowing for establishment of positive feedbacks between stratocumulus and underlying SST. Stratocumulus incidence decreases in the SEP despite weaker subsidence in the region as static stability of the lower atmosphere weakens primarily due to SST increase.

Our current research aims to clarify further the connections between other monsoons and contemporary oceanic features. We have not shown here, for example, that the other systematic errors of the CGCM in the tropics also appear to decrease with a better simulation of the monsoons. A confirmation of this result would help achieve one of the primary goals of VOCALS.

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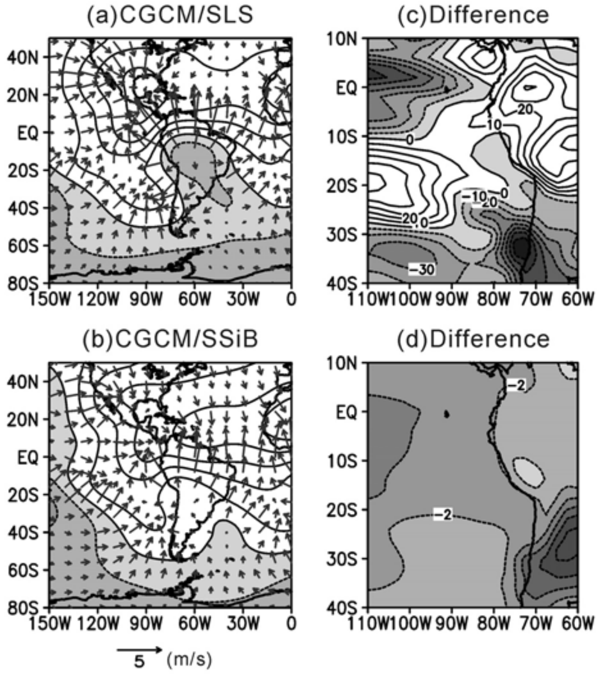

Fig.1 Dec-Feb mean velocity potential ($m^2 \cdot s^{-1}$, shaded) and divergent winds ($m \cdot s^{-1}$) at 200 hPa from the CGCM with (a) the simple land scheme and (b) SSiB. Also plotted is the difference between the CGCM with SSiB and with the simple land scheme of (c) vertical velocity ($mb \cdot day^{-1}$), at 700 hPa and (d) sea level pressure (hPa).

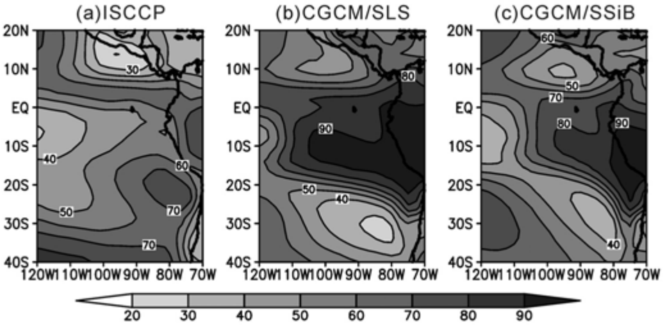

Fig.2 Dec-Feb mean total cloud cover (%) from (a) ISCCP, (b) CGCM with the simple land scheme, and (c) CGCM with SSiB.