6.4 An Examination of the Bias in the NCEP GFS, CFS Simulations Associated with the Marine Stratus Clouds

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1. INTRODUCTION

Despite their important roles in global climate, marine stratus clouds are not well represented in contemporary coupled general circulation models (GCMs). Improperly simulated stratus clouds, together with other factors, are linked to warm sea surface temperature (SST) biases over several key oceanic regions, adversely affecting the simulation and prediction of global climate by coupled models.

Recently, a new operational coupled climate forecast system (CFS) has been developed and implemented at the NOAA National Centers for Environmental Prediction (NCEP) for seasonal climate prediction (Wang et al. 2005). Diagnoses based on retrospective forecast indicate that the CFS performs significantly better than the previous NCEP coupled model in the forecast of ENSO-related variability. Systematic errors, however, exist in the CFS model climatology compared to the observations (Saha et al. 2005).

The objectives of this study are to examine the CFS model bias associated with the improperly simulated marine stratus clouds over the southeast Atlantic and southeast Pacific Oceans and to investigate the atmospheric circulation involved in the formation and variations of marine stratus clouds.

2. THE CFS MODEL SIMULATIONS

The NCEP climate forecast system (CFS) is an ocean-atmosphere coupled model. The atmospheric component of the system is the NCEP Global Forecast System (GFS) which uses a spectral truncation of 62 waves (T62) in the horizontal and a finite differencing in the vertical with 64 sigma layers. The oceanic component of the system is the Modular Ocean Model V.3 (MOM3) of Geophysical Fluid Dynamics Laboratory (GFDL).

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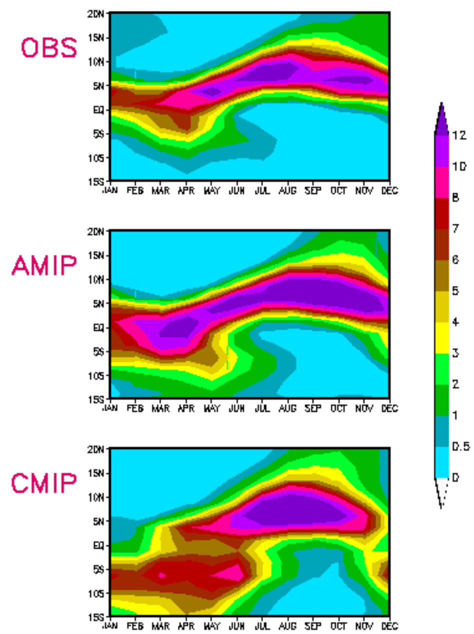

Fig.1: Mean annual cycle of precipitation (mm/day) averaged over the Atlantic [30°W-20°W] for the observations (top), CFS AMIP (middle) and CFS CMIP simulations (bottom). The observed climatology is based on the CMAP (Xie and Arkin 1997) for a 25-year period from 1979 – 2003.

While several other CFS-generated data sets are available, AMIP and CMIP simulations are utilized here in this study to examine the biases associated with the insufficiently simulated marine stratus clouds.

In the AMIP simulations, the atmospheric component of the coupled system is forced by observed SST of Reynolds et al. (2002) for a 25-year period from 1979 to 2003. In the CMIP simulations, the same atmospheric model is fully coupled with the oceanic model (MOM3). Four sets of CMIP simulations are generated for a 32-year period each with different initial times (Wang et al. 2005). Comparisons between the AMIP and

CMIP simulations will provide insights on the impact of the SST bias on the simulated climate.

3. THE CFS MODEL BIAS

As a first step to examine the model bias, the mean climatology of precipitation is defined for the CFS AMIP and CMIP simulations and compared with that based on observations. In general, the large-scale precipitation patterns are reproduced relatively well in both the AMIP and CMIP simulations over the globe, but differences exist in the magnitude of precipitation and in the latitudinal position of the ITCZ.

As shown in fig.1, the seasonal migration of the Atlantic ITCZ is well captured in the CFS AMIP simulations, though with excessive intensity. The Atlantic ITCZ in the CFS CMIP simulations, however, is displaced ~10^{o} latitude southward during boreal winter and spring. Similar differences between the AMIP and CMIP simulations are also observed over the SE Pacific (fig.2).

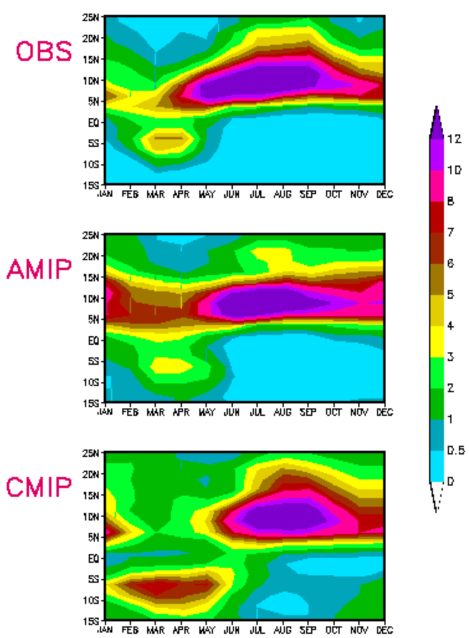

Fig.2 Same as in fig.1, except for eastern Pacific [120^{o}W-100^{o}W].

The differences in the simulated climatology between AMIP and CMIP runs are attributable to differences in the SSTs between the two runs. A comparison between the CFS simulations and the observations shows warm SST biases and associated systematic differences in surface winds over the SE Atlantic and SE Pacific Oceans (fig.3), indicating that the differences in the ITCZ position and precipitation fields shown in figs.1&2 are caused, at least in part, by the warm SST biases over the regions.

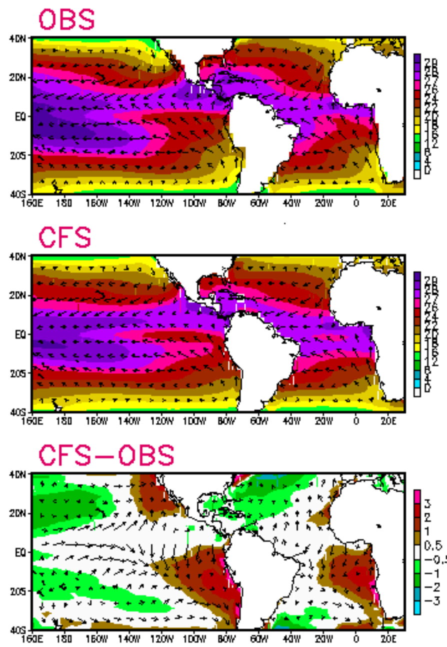

Fig.3: Annual mean climatology of SST (^{o}C, shaded) and surface wind (arrow) from observations (top) and CFS CMIP simulations (middle), as well as their differences (bottom). The OI SST analysis of Reynolds et al. (2002) and the QuikScatter surface wind are used as observations, respectively.

The warm SST biases over the regions may be caused by a) insufficient heat transport within the ocean, b) enhanced heat transport inside the atmosphere, c) reduced surface evaporation, or d) excessive incoming solar radiation. While some previous work with other coupled models has shown appreciable contributions from the oceanic heat transport, our work here focuses on the atmospheric issues.

A brief examination of the surface wind fields showed small differences in the surface wind between the CFS CMIP simulations and observations (not shown), suggesting only a limited role for the atmospheric heat transport and evaporation in forming the warm SST biases in the CFS. A comparison of the total cloud amount generated by the CFS model against that based on satellite observations (fig.4) revealed an overall tendency of the model to produce insufficient cloud amount over most of the domain. The under-estimates are particularly large over SE Atlantic and SE Pacific Oceans where warm SST biases are reported. The total cloudiness in the CFS CMIP simulations is only

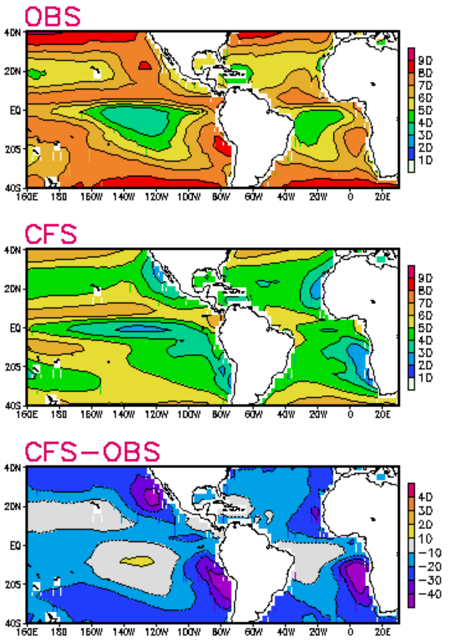

Fig.4: Annual mean climatology of total cloud amount (%) from the ISCCP satellite observations (Rossow and Schiffer, 1991, top), CFS CMIP simulations (middle), as well as their differences (bottom).

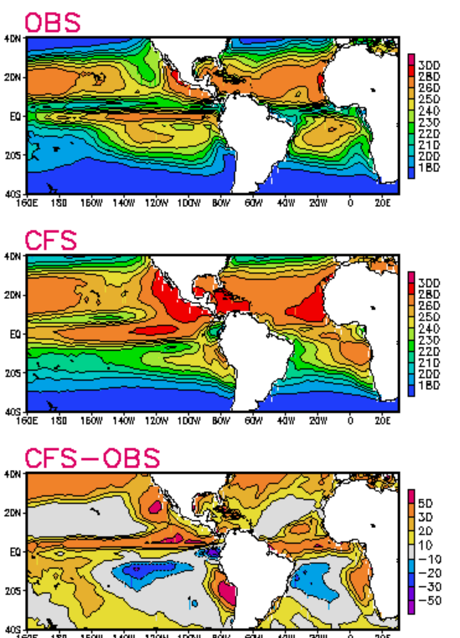

Fig.5: Annual mean climatology of downward surface radiation (W/m^2) from the SRB satellite observations (top, Pinker 1996), CFS CMIP simulations (middle), as well as their differences (bottom).

about half of that in the observations over the region. As a result, an excessive amount of incoming solar radiation is observed over the SE Atlantic and SE Pacific Oceans in the CFS CMIP simulations, generating warm SST biases over the regions (fig.5).

The above results based on comparisons with satellite observations are confirmed by comparisons with surface observations over the SE Pacific collected through the Eastern Pacific Investigation of Climate (EPIC) project (Cronin et al., 2002, Bretherton et al. 2004). As shown in fig.6, the satellite observations used in figures 3 and 5 agree quite well with those based on IMET buoy observations, while the CFS simulations exhibit a warm SST bias of ~3^{o}C and an excessive amount of incoming solar radiation of ~50W/m^2 over the IMET stratus buoy location at [85^{o}W,20^{o}S], compared to the satellite and buoy observations.

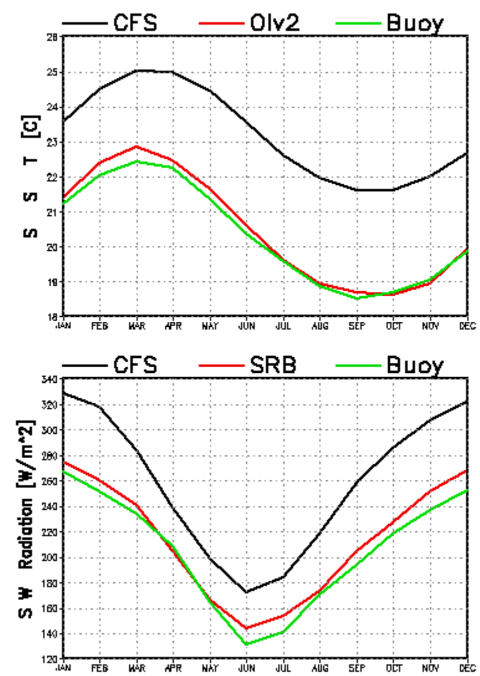

Fig.6: Mean annual cycle of SST (top) and downward shortwave (SW) radiation at (85^{o}W,20^{o}S) over SE Pacific as obtained from CFS (black), satellite (red) and buoy (green) observations. The buoy observations are based on IMET daily observations for a 5-year period from 2000-2004 (Colbo et al. 2005, Colbo and Weller 2005).

4. REGIONAL CIRCULATIONS

Further examination of several observation-based data sets revealed that most of the clouds over the SE Atlantic and SE Pacific are low-height stratus that have a strong diurnal cycle. As shown in fig.7, the spatial distribution of total cloud amount is characterized by a bi-polar structure with maxima observed over the SE Pacific and nearby South America, and a relative minimum along the coast. Distinct diurnal cycles with almost opposite phases are observed in the time-longitude section of the 3-hourly cloudiness across the west coast of South American continent (fig. 7, bottom), suggesting that the stratus clouds over the region are closely associated with the regional circulations caused by the land-sea contrasts.

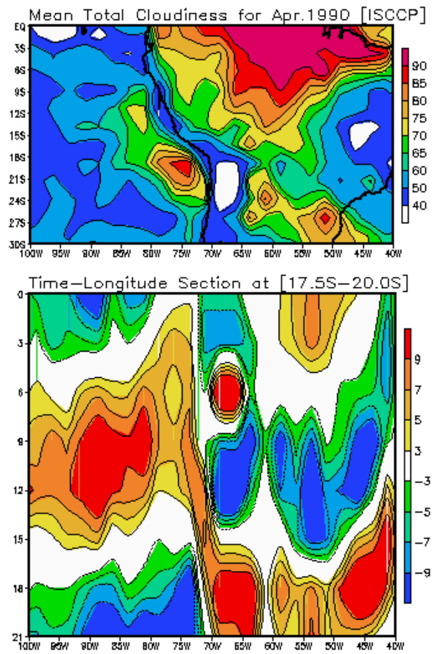

Fig.7: Spatial distribution of 24-hourly mean (top) and time-longitude section of 3-hourly total cloud amount over SE Pacific for April 1990 as obtained from the ISCCP product. The 24-hourly mean is subtracted from the 3-hourly values in plotting the time-longitude section.

An inspection of the 6-hourly circulation fields generated by the NCEP/NCAR Reanalysis (Kalnay et al. 1996) showed inter-connected cells of regional circulations over the region, with those over land penetrating deeply into the upper troposphere and those offshore limited below the 500-mb. Regional circulation patterns over the SE Atlantic are very similar to those over the SE Pacific (not shown).

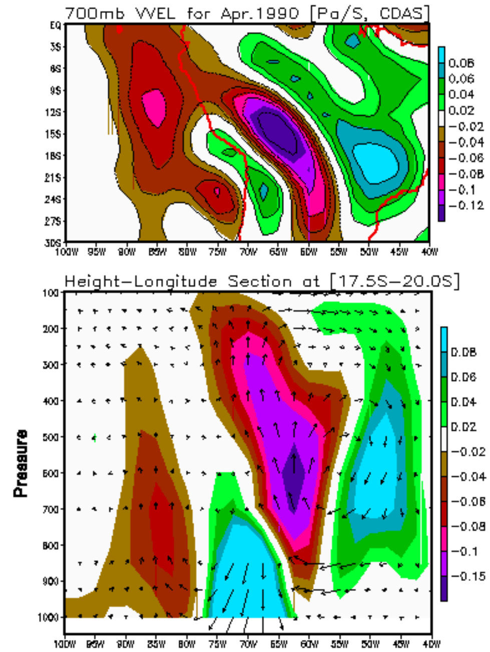

Fig.8: Spatial distribution of mean vertical velocity [Pa/S] at 700mb (top) and height-longitude section of the zonal/vertical winds (bottom) at 06Z over SE Pacific for April 1990 as obtained from NCEP/NCAR Reanalysis (Kalnay et al. 1996). Areas of uplift and subsidence are shaded in red and green, respectively.

5. SUMMARY

A preliminary investigation has been conducted to examine the bias associated with the insufficiently simulated stratus clouds over SE Atlantic and SE Pacific Oceans in the NCEP climate forecast system (CFS). Our initial results showed the following:

1) While large-scale precipitation patterns are reproduced reasonably well over the target regions in both the CFS AMIP and CMIP runs, differences exist in the magnitude of precipitation and in the latitudinal position of the ITCZ over both the Atlantic and the eastern Pacific sectors;

2) The latitudinal displacement of the ITCZ in the CFS CMIP run is closely related to the warm SST bias in the SE Atlantic and SE Pacific stratus deck regions;

3) The warm SST bias is largely attributable to the insufficient amount of

stratus clouds simulated by the CFS model; and

4) The stratus clouds over the regions have very low cloud top and present a strong diurnal cycle generated by regional circulation caused by land-sea contrasts between the oceanic regions and their adjacent continents.

Further work is underway to identify the impacts of the insufficient SE Pacific stratus clouds on the simulation of the mean state and interannual variability through numerical simulations and to investigate the physical and circulation processes involving the stratus clouds and their variations.

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