Interaction of the West African Monsoon Circulation and Eastern Tropical Atlantic SSTs

Samson M. Hagos and Kerry H. Cook

Department of Earth and Atmospheric Sciences, Cornell University, Ithaca NY14853

1) Introduction

SST variability over the eastern tropical Atlantic is marked by a strong annual cycle. During boreal spring, temperatures in the Gulf of Guinea are at their maximum, the sun is directly overhead and the equatorial trade winds are weak. The band of high SST occupies the equatorial region extending from 10^0S to 5^0N. As the year progresses, the trade winds along the equator intensify and a rapid decline of SST over eastern equatorial Atlantic is observed. For example at 10^0W, equatorial SSTs reach 28^0C in April and drop below 23^0C in July and August. This seasonal warming and cooling is highly asymmetric, with the cooling taking only three months to develop while the warming takes seven months (Xie and Carton 2004). Over the northeastern tropical Atlantic, on the other hand, April to August is a period of rapid warming. The purpose of this study is to investigate the mechanisms through which the West African monsoon dynamics interact with these seasonal SST changes. A coupled regional climate model (CRCM) is developed and applied to the problem.

The atmospheric component of the CRCM is an adaptation of the PSU/NCAR MM5-V3 (Grell et al. 1994). It is also described in some detail in Hagos and Cook (2007a). In the ocean component, the evolution of mean temperature of the mixed layer is governed by ocean-atmosphere heat transfer as well as advection and upwelling associated with wind driven currents (see Navarra 1999 pp 27, Sterl and Hazeleger 2003, Hagos and Cook 2007b). The prescribed observed mixed layer depth varies spatially and in time. The model simulations are run over a rectangular domain that includes the tropical Atlantic Ocean and West Africa (30^0 E to 60^0 W and 30^0 S to 30^0 N) for one year. The 90km grid spacing used in these simulations allows for resolution of the important SST features.

2) Analysis

Figs. 1a and 1b show the difference between July and April SSTs from the NCEP/NCAR reanalysis project (NNRP; Reynolds and Smith 1995) and CRCM simulations, respectively. As the cold tongue develops over the Gulf of Guinea (5^0S – 5^0N and 10^0E -10^0W, GOG hereafter) there is a rapid cooling in both the reanalysis and the CRCM SSTs. Over the northeastern Atlantic, on the other hand, (the region surrounded by the box 10^0N - 23^0N and 18^0W -38^0W, NETA hereafter), there is a rapid warming of up to 3K in both the reanalysis and the model. The model also captures the cooling and warming over the southern and northern subtropics, respectively.

Figs. 1c and d show the evolution of the simulated and NNRP SSTs averaged over the GOG and NETA regions. The rapid cooling between April and August is captured in the model, but with a delay of about two weeks. In both the simulation and the NNRP, the mean SST over the GOG is reduced by about 4K. Over the NETA, on the other hand, April to August is a period of rapid warming and the mean temperature increases by about 3K. This warming is captured by the model, but with a warm bias which makes the modeled SSTs lead the observations by 2-4 weeks.

To identify the roles of various heat transfer processes in these SST changes, the seasonal cycle of surface heat budget is analyzed. Over the GOG, the primary balance is between radiative heating and evaporation cooling. All the heat is supplied by radiation is used up in evaporation and modulating the heat content of the mixed layer. The contribution to the mixed layer heat content from other terms is much smaller.

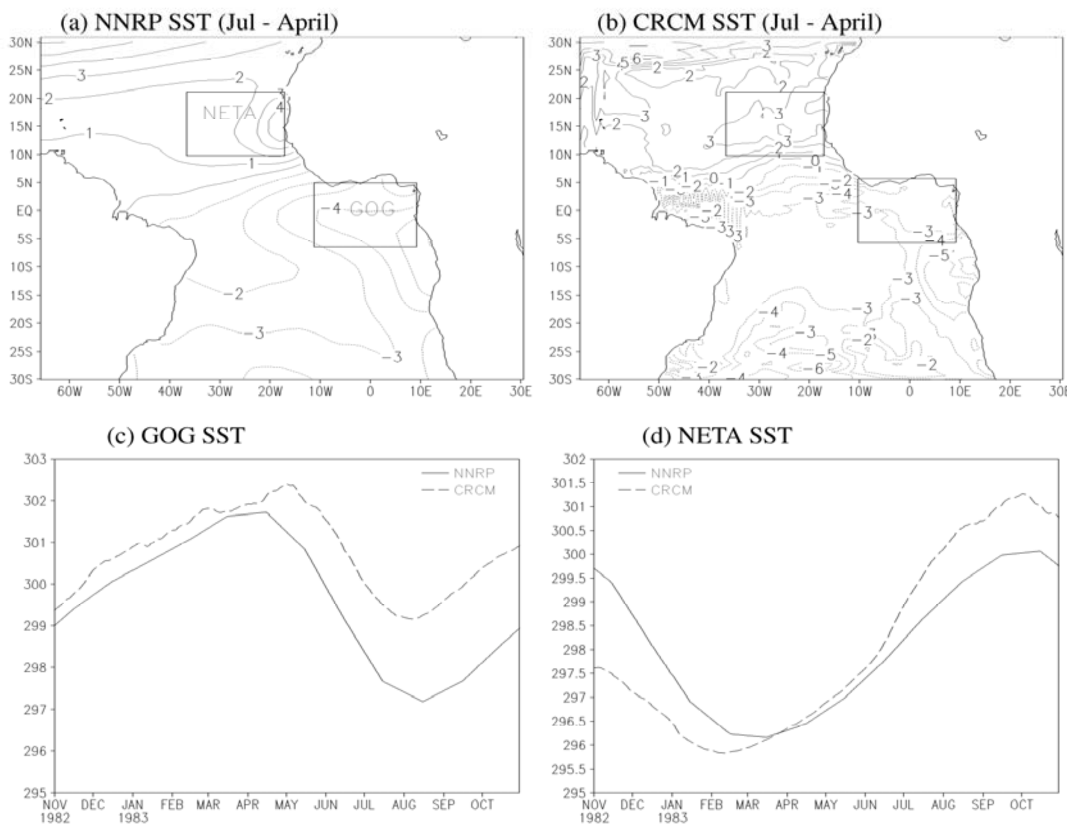

Fig. 1. SST (K) difference between July and April from (a) NNRP and (b) the CRCM, and the area averaged SST cycle over (c) GOG and (d) NETA in the model and reanalysis.

Fig. 2a shows the terms in the energy budget averaged over the GOG minus their respective annual means. Over the GOG, the main causes of the rapid cooling is evaporation, which is at its maximum in June, and a reduction in net radiative heating, which reaches a minimum in July. The contribution of entrainment to the cooling is about half of that of evaporation. The roles of the other processes are less significant.

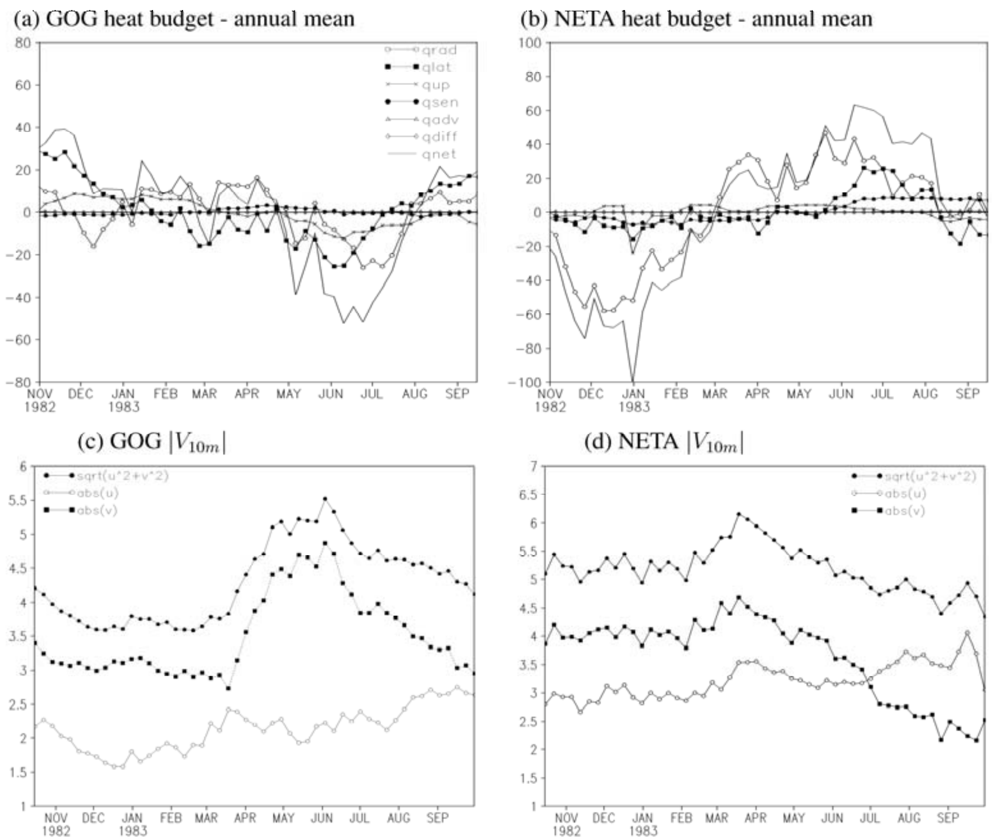

Fig. 2. The energy budget terms minus their annual mean over (a) GOG and (b) NETA (Wm^{-2}).

Over the NETA (Fig. 2b) the annual SST cycle is primarily determined by radiative heating. However, the warming during summer is significantly augmented by reductions in evaporation and sensible cooling. During July and August, the sum of the reduction in evaporation and sensible heat loss is comparable to the radiative heating.

Over both regions, surface winds play an important role in the SST cycle by enhancing evaporation and entrainment (over the GOG) and by reducing evaporation and sensible cooling (over the NETA). In order to identify the nature of the wind variations that influence SSTs, the seasonal cycles of wind speed over the two regions are considered. Figs. 2c and 2d display the evolution of the area average horizontal wind speed and the magnitudes of its components over the GOG and NETA, respectively. Over both regions, rapid changes in wind speed between April and July are apparent, and these predominantly reflect change in the meridional component. Over GOG the mean meridional speed is almost doubled, and over the NETA it is reduced by about half. Over both regions the changes in the zonal wind speed are gradual.

The rapid increase in the meridional surface wind over the GOG is related to the intensification of the heat low over western Africa. The decline in the meridional wind over NETA is related to the northward migration of the ITCZ and the associated northward movement of the line of confluence of the southeasterly and northeasterly winds.

3) Discussion

In this study, the atmosphere-ocean interactions responsible for observed accelerated SST changes over the eastern Atlantic during the onset of the West African monsoon are investigated using a coupled regional climate model. Over the Gulf of Guinea the intensification of the heat low over western Africa and the associated cross equatorial southerly flow enhances evaporation. Additionally, the atmospheric stress associated with this meridional flow introduces a significant amount of cooling due to entrainment. Both processes contribute to the accelerated cooling.

The rapid warming of the northeastern tropical Atlantic, off the west coast of Africa, is found to be primarily due to declining southeasterly flow reducing evaporation and, to some extent, sensible heat transfer. Especially in July, variability associated with this change in evaporation is comparable to that due to the seasonal variation in radiative heating.

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