14C.4 INTERACTION BETWEEN SURFACE HEAT BUDGETS, SEA SURFACE TEMPERATURE AND DEEP CONVECTION IN THE TROPICAL WESTERN PACIFIC

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1. INTRODUCTION

The tropical western Pacific and eastern Indian Oceans are characterized by the highest sea surface temperature (SST), frequent heavy rainfall, strong atmospheric heating and weak mean winds with highly intermittent westerly wind bursts. The heating drives the global climate and plays the key role in the El Nino–Southern Oscillation (ENSO) and the Asian-Australian monsoon (Webster et al. 1998). In addition, small changes in the SST of the Pacific warm pool associated with the eastward shift of the warm pool during the ENSO events have been shown to affect the global climate (Palmer and Mansfield 1984). Thus, the Tropical Ocean Global Atmosphere (TOGA) Coupled Ocean-Atmosphere Response Experiment (COARE) was conducted with the aim to better understand various physical processes responsible for the SST variation in the Pacific warm pool (Webster and Lukas 1992; Godfrey et al. 1998). The 1997/98 is a strong El Nino warm event, while the 1998/99 is a strong La Nina cold event. In this study, we compare the SST, surface heat budgets, deep convection, and surface winds for these two events in the tropical western Pacific and eastern Indian Oceans using satellite-derived surface fluxes.

2. DATA

The data used are 1˚x1˚ lat.-long. monthly mean SST, surface radiative and turbulent fluxes, outgoing longwave radiation (OLR), and surface wind speed during the period November1997–October 2000 cover the domain 35˚S–35˚N and 90˚E–170˚W. The SST are taken from the NCEP/NCAR reanalysis (Kalney et al. 1996). The radiative fluxes are taken from the Goddard Satellite-retrieved Surface Radiation Budget (GSSRB), derived from Japanese Geostationary Meteorological Satellite radiance measurements (Chou et al. 2001). The GSSRB covers the domain 40˚S–40˚N and 90˚E–170˚W and a period from October 1997 to December 2000. The spatial resolution is 0.5˚x0.5˚ lat.-long. and the temporal resolution is 1 day. Daily downward solar radiative fluxes have a positive bias (larger retrieval) of 8 W m^{-2} and an rms difference of 30.2 W m^{-2}, as compared to the radiometric measurements at the Atmospheric Radiation Measurement (ARM) site on Manus Island (2.06^{0}S, 147.43^{0}E) from January 1998 to March 1999.

The turbulent fluxes are taken from Version 2 of the Goddard Satellite-based Surface Turbulent Fluxes (GSSTF-2). The GSSTF-2 contains daily, monthly, and climatological means of turbulent fluxes and the input parameters used in the derivation of fluxes over global oceans. The GSSTF-2 has a spatial resolution of 1^o x 1^o lat.-long. and cover the period July 1987–December 2000. Daily turbulent fluxes are derived from the Special Sensor Microwave/Imager (SSM/I)–inferred surface air humidity (Chou et al. 1997), SSM/I surface winds (Wentz 1997), SST and 2-m air temperature of NCEP/NCAR reanalysis, based on the method of Chou et al. (1997). The surface saturation specific humidity has been set to be 98% of the saturated value at the SST for pure water (the salinity effect). The in situ flux measurements of five field experiments conducted by research ships in the tropical and midlatitude oceans during 1992-99 have been used for the validation. Daily latent heat fluxes (LHF) have a positive bias of 0.1 W m^{-2}, and an rms difference of 30.1 W m^{-2}, as compared to those of in situ flux measurements. Daily sensible heat fluxes (SHF) have a positive bias of 6.4 W m^{-2} and an rms difference of 8.8 W m^{-2}, as compared to those of in situ flux measurements. Daily wind stresses have a positive bias of 0.004 N m^{-2} and an rms difference of 0.019 N m^{-2}, as compared to those of in situ flux measurements. Both the GSSRB and GSSTF-2 are archived at the NASA/GSFC DAAC (http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/hydrology/hd_main.html). Deep convection is inferred from the OLR of NOAA's polar-orbiting satellites.

3. RESULTS

The spatial distributions of seasonal correlation coefficients between net surface heating and time rate of change in SST (dSST/dt) over the domain 35˚S–35˚N and 90˚E–170˚W for the period November 1997–October 2000 are analyzed. The seasonal correlation is generally very high, with the coefficient of ~0.8-0.9 poleward of 15^o and ~0.4-0.6 within 10^o of the equator. On the other hand, the anomalous correlation between net surface heating and dSST/dt for the three–year period is generally very low, with the coefficient<0.4 over most of the domain. To understand the low anomalous correlation, we have compared the spatial distributions of SST, OLR, surface solar heating, evaporative cooling, net surface heating, dSST/dt, surface wind speed and zonal wind stress between the 1997/98 warm El Nino event and 1998/99 La Nino cold event for the winter (DJF) and spring (MAM) seasons.

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We use the seaonal difference plots (El Nino minus La Nina) for the analysis. Positive differences indicate higher values for the El Nino than for the La Nina and vise versa. The interactions between the surface heat budgets, SST and deep convection are quite different between the western tropical Pacific and eastern tropical Indian Oceans. Thus we will discuss the results for the former first then the latter. For the tropical western Pacific, the spatial distribution of SST difference is similar to that of the SST anomaly of an El Nino. The SST has a positive difference of ~1-3°C located around 155°E–170°W near the equator and a negative difference of ~0-1°C of large area with a horse–shoe shape surrounding the positive difference region. It is found that the spatial variability of the difference of SST is highly correlated to that of the OLR, surface solar heating, LHF and surface wind speed for the western tropical Pacific Ocean. The positive difference of SST is associated with the negative differences of solar heating (due to increased deep convection), and evaporative cooling (due to decreased wind speed), and vise versa. However, the change in evaporative cooling between El Nino and La Nina is larger than the change in solar heating. As a result, the change in the net surface heating is dominated by the change in the evaporative cooling. Over the western tropical Pacific Ocean, the spatial variability of the difference in dSST/dt between the El Nino and La Nina is found to be inconsistent with that of net surface heating. The total area with positive difference of dSST/dt is larger than that of net surface heating. The areas with positive difference of dSST/dt but negative difference of net surface heating are associated with positive difference of surface wind speed. It is generally recognized that the increased surface wind speed can increased the oceanic mixed-layer depth and reduced solar radiation penetration through the bottom of the mixed layer, which can then increase the net heating for the mixed layer. (Sui et al. 1997; Chou et al. 2000). It has been suggested by several studies (e.g., Sui et al. 1999; Chou et al. 2000; and others) that the penetration of solar radiation through the bottom of the mixed layer has a significant effect on the evolution of SST on the diurnal to intraseasonal timescales. Our study suggests that it is also important for the interannual variability of SST.

For the eastern tropical Indian Ocean, the SST difference is generally positive. During the El Nino, the solar heating is larger due to reduced deep convection, but the evaporative cooling is smaller due to reduced wind speed. Therefore, the net surface heating is larger during El Nino when compared to La Nina, especially over the southern part of the eastern tropical Indian Ocean. Over most of this region, the net surface heating is larger but dSST/dt is smaller for the El Nino as compared to the La Nina. This inconsistency between the change in net surface heating and the change in dSST/dt is most likely caused by the changes in the depth of the oceanic mixed layer and the northward transport of heat in the ocean – both are related to surface winds. The decreased wind speed in this area during El Nino reduces both the depth and, hence, the solar heating of the oceanic mixed layer. Furthermore, the difference in the zonal wind stress suggests a stronger northward transport of heat by the ocean current during El Nino than during La NIna. Thus, the ocean transport of heat is important in affecting the interannual variability of SST in the Indian Ocean, a conclusion which is consistent with that of Loschnigg and Webster (2000).

During the El Nino, the surface solar heating increases but the evaporative cooling decreases in the eastern tropical Indian Ocean, which reinforce the net surface heating. During the La Nina, the situations are reverse with an enhanced net surface cooling. On the other hand, changes in the solar heating and evaporative cooling offset each other in the western tropical Pacific, and the difference in net surface heating between El Nino and La Nina is much reduced. Therefore, the interannual variability of the net surface heating is larger for the former than the latter.

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