On the Regulation of the Pacific Warm Pool Temperature

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Abstract

Analyses of data on clouds, winds, and surface heat fluxes show that the transient behavior of basin-wide large-scale circulation has a significant influence on the warm pool sea surface temperature (SST). Trade winds converge to regions of the highest SST in the equatorial western Pacific. The reduced evaporative cooling due to weakened winds exceeds the reduced solar heating due to enhanced cloudiness. The result is a maximum surface heating in the strong convective and high SST regions. The maximum surface heating in strong convective regions is interrupted by transient atmospheric and oceanic circulation. Regions of high SST and low-level convergence follow the Sun. As the Sun moves away from a convective region, the strong trade winds set in, and the evaporative cooling enhances, resulting in a net cooling of the surface. We conclude that the evaporative cooling associated with the seasonal and interannual variations of trade winds is one of the major factors that modulate the SST distribution of the Pacific warm pool.

Keywords: Surface heat budgets, Sea surface temperature, SST regulation

1. Introduction

The tropical western Pacific is warm and cloudy. The sea surface temperature between 20訕 and 20祇 is nearly homogeneous with a magnitude between 28蚓 and 30蚓. Regions with SST>30蚓 are rare and associated with a stable and clear atmosphere with descending air (Waliser and Graham, 1993). Ramanathan and Collins (1991) hypothesized that the increase in thick cirrus clouds in response to an increase in SST had an effect of reducing the solar heating of the ocean and limited the SST to the observed high values. Subsequently, various mechanisms were proposed by a number of investigators that regulate the SST in the Pacific warm pool (e.g. Fu et al., 1992; Hartmann and Michelsen, 1993; Lau et al., 1994; Sud et al., 1999; Wallace, 1992). Most of the studies stressed the importance of large-scale circulation in distributing heat. Some also stressed the importance of the high sensitivity of evaporation to temperature in regulating the SST. In this study, we use the surface heat fluxes derived from satellite radiance measurements to investigate the transient nature of the atmospheric circulation in limiting the increase of SST and reduce the SST gradient of the Pacific warm pool.

2. Data source

The data used in this study include the SST, surface wind, high-level clouds, and the surface radiative and turbulent heat fluxes. All the data have a spatial resolution of 1°x1° latitude-longitude and temporal resolution of 1 day except for the SST, which has a temporal resolution of 1 week. The SST is taken from the National Centers for Environmental Prediction (NCEP) archive (Reynolds and Smith, 1994), and the surface wind is taken from the Special Sensor Microwave Imager (SSM/I) wind retrieval (Wentz, 1997). The high-level cloud cover is inferred from the brightness temperature measured in the 11-μm channel of Japan's GMS-5 (Chou et al., 2001).

The surface latent and sensible heat fluxes are derived from the improved algorithms of Chou et al. (1997), which use the NCEP SST analysis and the SSM/I precipitable water and wind retrievals (Wentz, 1997). The surface solar and IR radiative fluxes are derived from the GMS-5 0.6-μm albedo and 11-μm brightness temperature (Chou et al., 2001).

3. Seasonal variations

In the tropical western Pacific, the sea surface temperature is high. It is in the ascending branch of both the Hadley and Walker circulations. Trade winds converge in this region that induce strong deep convection and produce large amount of clouds. Figure 1 shows the SST, high-level cloud cover, and wind speed averaged over a three-year period January 1998–December 2000. Regions of high SST cover most of the western Pacific and eastern Indian Oceans in the tropics (20訕-20衹). These high SST regions have a high cloud cover (middle panel) and small wind speed (lower panel). Clouds reflect the incoming solar radiation and reduce the solar heating of the ocean. On the other hand, weak winds cause a weak evaporative cooling. Figure 2 shows the net downward solar flux, latent heat flux, and the total heat (solar, infrared, latent heat and sensible heat) flux at the sea surface averaged over the same three-year period. As can be seen from Figures 1 and 2, the distribution of the surface solar heating follows that of clouds, and the distribution of evaporative cooling follows that of surface winds. The magnitude of the solar heating is significantly larger than that of the evaporative cooling, but the spatial variation is larger for the latter (~90 Wm^{-2}) than the former (~50 Wm^{-2}).

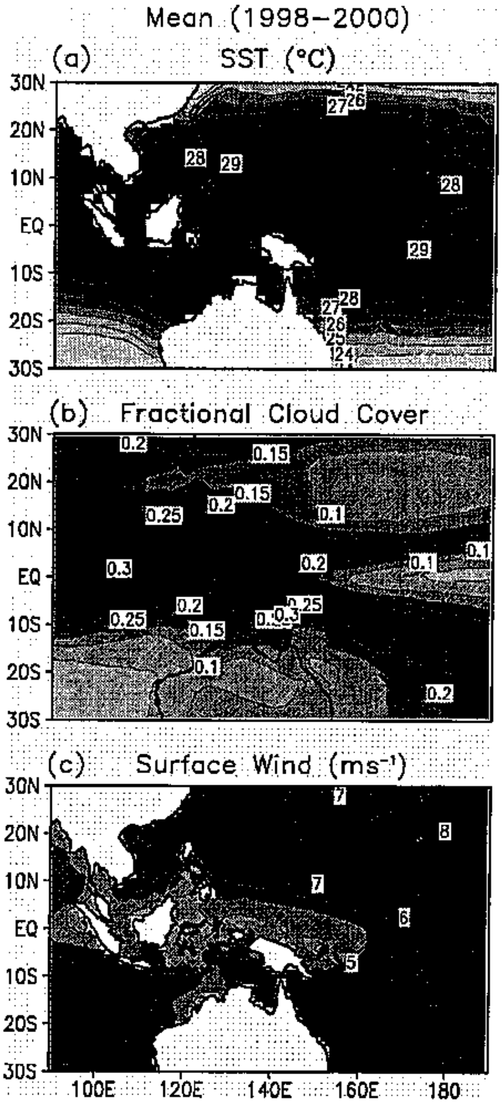

Figure 1. The SST, high-level cloud cover, and wind speed averaged over a three-year period (1998-2000).

As a result, the spatial distribution of the total surface heating follows that of the evaporative cooling (middle and lower panels of Figure 2). Because the spatial variation of evaporative cooling is larger than that of solar heating, regions of the maximum total surface heating correspond to regions of minimum evaporative cooling, where wind speed is a minimum and cloud cover is a maximum.

The maximum surface heating in the high SST and strong convective regions is in variance with the cirrus-cloud thermostat hypothesis of Ramanathan and Collins (1991) that the reduced solar radiation at the surface due to an increase in the cloud cover leads to a reduction of SST. It is also in variance with the suggestion by Wallace (1992) that the evaporative cooling would increase with increasing SST and, together with large-scale circulation, imposed an upper limit to the SST. With the maximum heating occurring at high SST regions, the large-scale ocean-atmosphere interaction must be a dominant factor that prevents the SST from increasing further. The large-scale ocean-atmosphere interaction is influenced by the transient nature of the solar radiation.

The surface heating and cooling shown in Figure 2 are for an annual mean over three years (1998-2000). Due to the seasonal variations of the insolation at the top of the atmosphere and the corresponding shifts in the intertropical convergence zone (ITCZ) and trade winds, the maximum heating as shown in the lower panel of Figure 2 does not occur in all seasons. For a given season, generally the regions of maximum cloudiness, i.e. ITCZ, coincide with the maximum SST, minimum winds, and maximum insolation at the top of the atmosphere. As the season advances, the Sun moves away from this maximum SST region to the neighboring regions where are less cloudy. The neighboring regions then receive much solar heating, the SST increases, the convergence zone follows, and the wind speed decreases. The decrease in wind speed further enhances SST and convection in the neighboring regions. Simultaneously, the region of maximum surface heating in the previous season experiences a decrease in clouds and an increase in winds, which enhances the evaporative cooling. The high SST region in the previous season is then cools down as the Sun moves away and the strong trade wind sets in.

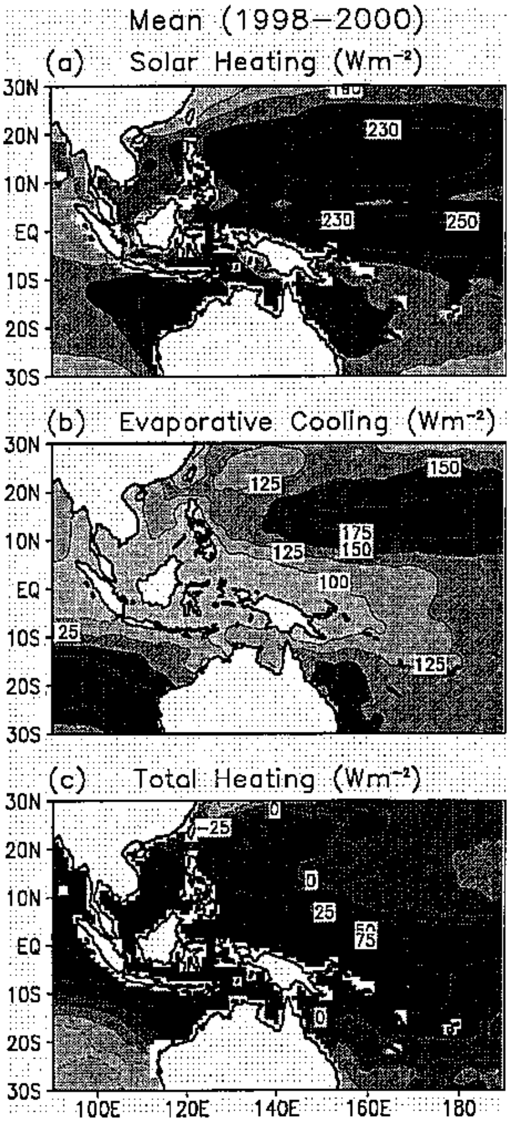

Figure 2. The surface solar heating, evaporative cooling, and the total surface heating averaged over a three-year period (1998-2000).

The processes outlined above can be demonstrated in Figure 3, which shows the time series of the SST, the insolation at the top of the atmosphere (S_o), the surface solar heating (SW), and the evaporative cooling (LH) averaged over the warm region 5祇-15祇 and 130蚩-160蚩. The insolation reaches a minimum in December and increases till April. It remains nearly constant from April through September and decreases afterward as the Sun moves southward. From April to September, the S_o remains nearly constant, but SW decreases, indicating an increase in cloudiness. Simultaneously, LH also decreases but with a much larger rate than SW, indicating a much reduced wind speed in the convective and cloudy region. After August-September, the Sun moves southward, the SW keeps decreasing but the evaporative cooling enhances when the strong northeast trade wind sets into this region. The SST follows S_o with a lag of ~2 months.

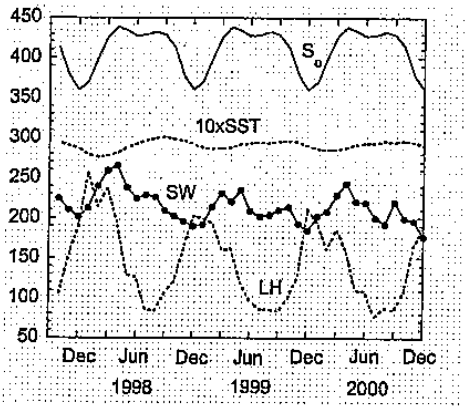

Fig. 3. Monthly-mean SST, the incident at solar radiation, S_o, the surface solar heating, SW, and the evaporative cooling, LH, of the region 5祇-15祇 and 130蚩-160蚩. Units: C for SST and W m^{-2} for heat fluxes

4. Concluding remarks

Analyses of data on clouds, winds, and surface heat fluxes show that the transient behavior of basin-wide large-scale circulation has a significant influence on the warm pool SST. Trade winds converge to regions of the highest SST in the equatorial western Pacific. These regions have the largest cloud cover and smallest wind speed. Both surface solar heating and evaporative cooling are weak. The spatial variation of evaporative cooling is significantly larger than that of solar heating, and the distribution of the total surface heating is found to follow the distribution of the evaporative cooling, which has a minimum in the strong convective and high SST regions. In these strong convective and high SST regions, the reduced evaporative cooling due to weakened winds exceeds the reduced solar heating due to enhanced cloudiness.

Data also show that the maximum surface heating in strong convective regions is interrupted by transient atmospheric and oceanic circulation. Due to the seasonal variation of the insolation at the top of the atmosphere, trade winds and clouds also experience seasonal variations. Regions of high SST and low-level convergence follow the Sun, where the surface heating is a maximum. As the Sun moves away from a convective region, strong trade winds set in, and the evaporative cooling enhances, resulting in a net cooling of the surface. Therefore, the SST is modulated by evaporative cooling associated with strong trade winds.

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