Satellite Observation of Surface Forcing over the Warm Pool

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ABSTRACT

Daily variations of wind and solar forcing derived from satellite data were compared with sea surface temperature and temperature tendency during the Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE). The correlation between solar flux and temperature tendency is positive indicating that the solar forcing is a significant factor in daily sea surface temperature change. Daily change in sea surface temperature does not have a significant effect on incoming solar flux. Wind speed is negatively correlated with sea surface temperature and temperature tendency, underscoring the need to understand the feedback mechanism between wind forcing and thermal response.

INTRODUCTION

There has long been strong interest in relating sea surface temperature (SST) to surface wind and thermal forcings in the tropical oceans. Over these warm waters, numerical experiments have demonstrated that small changes to SST would significantly affect the climate. The Warm Pool is located in the tropical western Pacific and eastern Indian oceans, called the warm pool. Over this area, SST is relatively uniform between 28°C and 30°C. The factors which maintain this high temperatures are controversial. It has been postulated that cirrus cloud is the dominant natural thermostat which keeps the temperature in the warm pool at an equilibrium temperature. The inference is that any increase in sea surface temperature produces a greatly increased cloud cover and subsequent cooling. However, the SST changes are typically small so that the impact of the atmosphere may be substantial. In 1991, Liu and Gautier (1990) found no significant correlation between the seasonal change of SST and sea flux implying the seasonal change of solar heating is not controlled by sea surface temperature but by the solar incident angle. Significant positive correlation are found between solar flux and temperature tendency (temporal derivative of SST) over most of the global ocean, implying that seasonal change in upper ocean heat balance is strongly affected by solar heating. This result is in agreement with the equatorial wave guide where ocean dynamics may play a more important role. They also found significant negative correlations between daily SST and wind speed, which correlates positively with evaporation this is known as the bulk aerodynamic formula but it is found to be negatively correlated with SST and temperature tendency.

The recent debate on natural thermostat is based on analysis of low frequency variations, from seasonal to decadal. However, large high-frequency fluctuations caused by intermittent and organized convection have been observed in the warm pool. Using monthly-mean parameters in estimating correlation neglect the high-frequency variance. One of the objectives of the Coupled Ocean Atmosphere Response Experiment (COARE) of the Tropical Ocean and Global Atmosphere (TOGA) program is to examine the effect of this fluctuation affects large-scale and long term averages (TOGA-COARE SWG, 1989). In study, daily surface solar flux and wind vectors were derived from spaceborne sensors and their temporal variability is compared with those of SST and its derivatives during the TOGA-COARE.

WIND AND SEA SURFACE TEMPERATURE

The daily SST were provided by the TOGA COARE International Office (D. Carlson, personal communication, 1993); they were computed by averaging measurements from a network of eight ships in the Intensive Flux Array (IFA) during the experiment. The temperature tendency is approximated by the gradient of the linear regression through three day of SST data. Ocean surface wind vectors were derived from observations of the microwave scatterometer on ERS-1 using the good physical model of Freilich and Dunbar (1993). Daily fields of the wind vectors over global oceans were computed from these scatterometer wind, using a successional correction method (Gardin, 1963). They arc averaged over an area 5°S-5°N, 150°E-158°E, covering the IFA.

SURFACE SOLAR FLUX

The method used to compute the surface solar radiation flux, originally developed by Gautier et al. (1980), is based on simple, physical model of the most important radiative processes occurring within the atmosphere, namely scattering and absorption of molecular and aerosol clouds. The cloudiness in the tropical atmosphere is a large high-frequency fluctuations caused by intermittent and short-lived events. The cloudiness in the tropical atmosphere is a significant factor in determining the effect of clouds on the surface temperature. The effect of clouds can be computed accurately from simple formulas. The method is based on the cloud history and the surface temperature tendency during a period of cloud-free days. The method is applicable to the computation of the GMS VISSR data (one observation every 30 minutes) allows a sufficient sampling of the diurnal cloud variability.

Images composed of 888 x 444 pixels centered on the equator and 155°E and covering a region of approximately 400,000 km² have been acquired every 30 minutes from GMS-6 over the TOGA-COARE area from the University of Hawaii (courtesy of P. Flamant and R. Freilich). The daily clear sky albedo has been averaged over 5 x 5 km². The first step in the computation procedure is to calibrate the data. We have used the preflight calibration coefficients (gain and offset) and adjusted the gain for a drift in time. This gain adjustment has been obtained by comparing results from our computations with the surface solar flux measurements at a number of islands. The gain has been computed so that it minimizes the bias between the satellite estimations and the surface measurements. The next step is to estimate the minimum brightness of the surface in clear conditions in order to determine a threshold for cloud fractions. This minimum value defines a threshold that is used to classify each GMS VISSR (Visible Infrared Scan Radiometer) pixel as clear or cloudy. By comparison with a procedure based on a fixed surface albedo, this procedure allows us to detect clouds in regions of sunglint. Once the pixel's nature (clear or cloudy) has been determined, it is possible to apply clear and cloudy sky radiative transfer models accordingly. In clear sky conditions, the surface insolation is expressed as:

$$I_0 = S_0 (\tau/\rho) \times \exp \left(-C_1 (\cos \theta)/C_2 \right) \times \exp \left(-a_0 (u\cos \theta) + a_1 \right) \times \exp \left(-a_2 (u\cos \theta) \right)$$

where So is the solar constant, \(\rho\) is the ratio of actual to mean earth-sun distance, \(\theta\) is solar zenith angle, \(u\) and \(v\) are ozone and water vapor transmittances, \(C_1\) and \(C_2\) are coefficients of aerosols. The term \(C_2 (a_0, a_1, a_2, b_0, b_1, b_2, C_1, C_2)\) accounts for photons that have sustained multiple surface reflections. Ozone...
and water vapor amounts are specified from climatology and $A_b$ is obtained by solving the following equation:

$$A_{sat}(B_{min}) = a + (1 - a)(1 - a)(1 - a'o)A_b$$  \hspace{1cm} (2)

where $A_{sat}$ is the albedo measured at the satellite (the surface is assumed to reflect solar radiation isotropically), $B_{min}$ is the minimum brightness, $a$ and $a'$ are direct and diffuse reflection coefficients, respectively, and $a'o$ characterizes ozone absorption. Eq. (2) simply states that $A_{sat}$ is the sum of an atmospheric component (photons reflected back to space without surface reflection), and the signal reflected by the surface and diffusely transmitted to space.

In cloudy sky conditions, the clear sky formulation is modified to account for reflection and absorption by clouds which are assumed to occur in one layer. Cloudy sky insolation is therefore given by:

$$I_c = I_0(1 - A_c - a_c)/(1 - A_c A_b)$$  \hspace{1cm} (3)

where $A_c$ is cloud albedo and $a_c$ is cloud absorption. The denominator represents the effect of multiple reflections between the cloud and the surface. This effect is small over the ocean. Cloud albedo is obtained by solving the following quadratic equation:

$$A_{sat} = a + (1 - a)(1 - a')(1 - a'o)A_c + (1 - A_c - a_c)2(1 - a')(1 - a'o)A_b$$ \hspace{1cm} (4)

where $A_{sat}$ is the top-of-atmosphere albedo, assuming that clouds reflect solar radiation isotropically. This equation, in fact, gives $A_c$ in the GMS VISSR solar channel (mostly wavelengths in the visible). We assume that $A_c$ takes the same value in the spectral interval of total insolation.

Preliminary comparisons with surface solar flux data at Kapingamarangi show that the clear conditions are extremely well reproduced by our method (within a 2-3 %) and that in all conditions, our computations have an uncertainty of about 10% of the surface measurements. The biases have been minimized through the calibration procedure. The surface solar flux is then averaged over the same area as the surface wind speed.

**RESULTS**

The time series of daily SST, temperature tendency, surface solar flux, and surface wind speed are compared in Fig. 1. The best contemporary correlation is between the temperature tendency and the solar flux. For the 55 pairs of data, the correlation coefficient is 0.51, which is significant at 99% level if the data pairs are independent from each other. The positive correlation infers that the change of upper ocean heat balance in the daily time scales is significantly influenced by solar forcing at the surface. This is different from the month mean data examined by Liu et al. (1994) who found low correlation in the equatorial ocean. The correlation between 60 pairs of SST and solar flux is -0.28. The negative correlation may imply that increase in sea surface may

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Fig. 1 Comparison of the temporal variations of (from top to bottom) sea surface temperature, temperature tendency, surface solar flux, and surface level wind speed. The data are daily averages over the TOGA COARE Intensive Flux Array.
decrease solar heating through cloud cover, but the coefficients is too low to be significant at 99%, Liu et al. (1994) also found low correlation in the seasonal variation. The wind speed is negatively correlated with SST and temperature tendency. The correlation coefficients are -0.43 between wind speed and temperature tendency and -0.32 for 99 pairs of wind speed and SST. In both cases, the correlations coefficients are significant at 99% level, assuming independent data. The negative correlations are similar to those for monthly means examined by Liu et al. (1994) and similar reasoning may apply. Increase in wind, therefore, the available kinetic energy may change thermocline depth and entrainment intensity. Increase in wind may also increase evaporative cooling. Convective activities may also increase with SST and cause surface wind convergence and low wind speed.

CONCLUSION

The solar flux shows stronger influence on SST over the warm pool at the daily time scale than at the monthly time scale. SST has little influence on solar flux at daily time scales, in agreement with previous results for monthly data. Wind speed is found negative correlated with both SST and temperature tendency in agreement with monthly data. Only very preliminary results are presented in this study. Further analysis with more supporting data from TOGA COARE is anticipated.

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References


