1. Introduction

New estimates of time-dependent surface latent and sensible heat fluxes have been developed by the Objectively Analyzed air-sea heat fluxes (OAFlux) project (Yu et al., 2004a, b) and surface shortwave and longwave radiations by the International Satellite Cloud Climatology Project (ISCCP; Zhang et al., 2003). The two datasets combined provide the net surface heat flux that can be used to study the covariability between the atmosphere and the ocean, establish feedback mechanisms, verify coupled model simulations, and serve as forcing functions for ocean model analyses. This study provides an example of applying the combined OAFlux+ISCCP net surface heat flux to study the role of atmospheric thermal forcing in seasonal evolution of SST in the tropical Atlantic Ocean. Specifically, the objectives of the study include:

(a) Testing the response of SST changes to surface heat flux forcing by using the relation, \( dSST = \frac{dQ_{net}}{R_{ocean}} \),
(b) Determining to what extent the changes in SST are caused by changes in surface heat fluxes,
(c) Assessing the impact of flux data quality on the analysis.

2. Comparison of heat flux products

a. Brief description of OAFlux and ISCCP

The OAFlux dataset has daily latent and sensible heat fluxes for the Atlantic Ocean (64°S-65°N) for the period 1988-1999 (Yu et al., 2004a, b). The OAFlux was calculated from the COARE algorithm 2.6a (Fairall et al., 2003) with basic surface meteorological variables obtained from objectively blending satellite observations with numerical weather prediction model outputs.

The ISCCP-FD surface radiations are calculated from a complete radiative transfer model from the ISCCP observations (Zhang et al., 2004). The ISCCP and ECMWF reanalysis products are used to assess the impact of quality of data on the analysis.

b. Basic features of the four heat flux products

(1) OAFlux analysis: daily, 1° grid, blended product.
(2) ISCCP radiation: daily, 2.5° grid, based on satellite retrievals.
(3) SOC climatology analysis: monthly, 1° grid, based on COADS ship reports.
(4) NCEP reanalysis: daily, 2.5° grid, atmospheric model output.
(5) ECMWF reanalysis: 4-hourly, 1.125° grid, atmospheric model output.

3. Correlation between \( dSST \) and \( Q_{net} \)

Fig. 2. Correlation between \( dSST \) and \( Q_{net} \) on the four heat flux products. \( dSST \) is calculated as the difference between the averaged last five days and the averaged first five days of the month. The areas colored by red have a correlation greater than 0.8, significant at 99% confident level.

Interesting features in Fig. 2:

(1) OAFlux+ISCCP product indicates that the net surface heat flux is the dominant phase with the SST over most tropical Atlantic Ocean except two areas. One is the eastern and central equatorial Atlantic Ocean, and the other is the latitude band between the equator and 10°N coinciding with the mean position of the ITCZ. These two regions are known for the influence of oceanic processes on SST

(2) OAFlux+ISCCP produces a very similar correlation pattern to SOC everywhere except the ITCZ belt, while the pattern differs considerably from this based on NCEP and ERA40 in the equatorial latitude band 10°S-10°N.

4. How does the mixed layer vary with SST?

Fig. 3. Correlation between SST and the surface mixed layer depth (MLD) derived from the climatological temperature fields from World Ocean Atlas 94 (Levitus and Boyer, 1994). Negative correlation is shaded by blue colors.

Important features in Fig. 3:

(1) The negative correlation indicates that MLD and SST are out of phase, and suggests that \( Q_{net} \) is a dominant forcing in driving changes in MLD (Kouch and Turner, 1987; Yu et al., 2005).
(2) Fig. 3 provides an independent physical measure for assessing the accuracy of net surface heat flux product.

5. Predicting \( dSST \) using OAFlux+ISCCP heat flux product

Fig. 4 Model predicted (black) versus observed \( dSST \) (red) at selected locations.

Important features in Fig. 4:

(1) Much of SST variability in the tropical Atlantic can be modeled by simply storing the local net heat flux as a variable mixed layer depth in regions that \( dSST \) and \( Q_{net} \) are high correlation.
(2) Oceanic processes should be considered in regions that the correlation between \( dSST \) and \( Q_{net} \) is low.

6. Relation of \( Q_{net} \) to SST

Fig. 5. Correlation between \( Q_{net} \) and SST using heat fluxes from the four products. The areas colored by blue indicate negative correlations. Dark blue indicates the correlation is significant at 99% confidence level.

Interesting features in Fig. 5:

(1) Negative correlation indicates that the ocean receives less heat when SST goes up or vice versa, suggesting a feedback of the ocean to the atmosphere. NCEP and ERA40 heat fluxes show a larger SST dependence in the equatorial region.
(2) Compared to Fig. 2, whether \( Q_{net} \) is a forcing for SST variability depends on how much \( Q_{net} \) is influenced by SST.

7. Summary

The newly developed latent and sensible heat fluxes from OAFlux and surface radiation from ISCCP are combined to construct a net surface heat flux climatology for the base period 1988-1999. The combined dataset is used together with the SOC climatology, NCEP, and ERA40 reanalysis fluxes to study the role of surface heat fluxes in seasonal evolution of SST in the tropical Atlantic Ocean and the impact of flux data quality in the analysis. The major findings are as follows:

(1) OAFlux+ISCCP product shows that the net surface heat flux is the dominant forcing for the seasonal evolution of SST in the tropical Atlantic Ocean except the two regions: the central and eastern equatorial Atlantic and the ITCZ belt (Fig. 2).
(2) The OAFlux+ISCCP heat fluxes show a good consistency with the seasonal surface mixed layer dynamics then NCEP and ERA40 reanalysis heat fluxes (Fig. 3).
(3) Oceanic processes should be considered in the regions that the correlation between \( Q_{net} \) and SST is high.

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