Role of Surface Heat Fluxes in Seasonal Variations of SST in the Tropical Atlantic Ocean

Lisan Yu, Robert A. Weller, Xiangze Jin

Department of Physical Oceanography, Woods Hole Oceanographic Institution

Woods Hole, MA 02543 Email: lyu@whoi.edu

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 2004*). 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 excersice. 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:

(1) testing the response of SST changes to surface heat flux forcing by using the relation, dSST = dt Qnet/ρcph.

(2) determining to what extent the changes in SST are caused by changes in surface heat fluxes.

(3) 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 predication model outputs.

The ISCCP-FD surface radiations are calculated from a complete radiative transfer model from the GISS GCM using ISCCP observations (*Zhang et al. 2004*). The data are available for the whole globe with 2.5°×2.5° grid resolution and for the time period July 1983 through June 2001.

The OAFlux and ISCCP products are combined to construct a monthly climatology of net surface heat flux for the based period 1988-1999. This dataset is used together with the SOC climatology (*Josey et al. 1999*) and the NCEP and ECMWF reanalysis flux products to assess the impact of the quality of data on the analysis.

b. Basic features of the four heat flux products

(1) **OAFlux analysis:** daily, 1°-grid, blended product.
ISCCP radiation: 8× daily, 2.5°-grid, based on satellite retrievals.

(2) **SOC climatology analysis:** monthly, 1°-grid, based on COADS ship reports.

(3) **NCEP reanalysis:** 4× daily, 1.875°-grid, atmospheric model output.

(4) **ECMWF ReAnalysis-40 (ERA40):** 4× daily, 1.125°-grid, atmospheric model output.

c. Mean pattern comparison

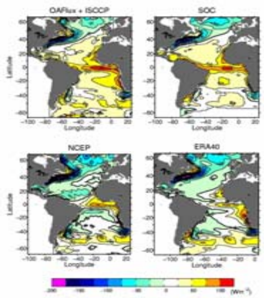

Fig.1 Comparison of the mean net surface heat fluxes from OAFlux+ ISCCP analysis, SOC climatology, NCEP reanalysis, and ERA40. The values are the average over the 1988-1999 period.

3. Correlation between dSST and Q_{net}

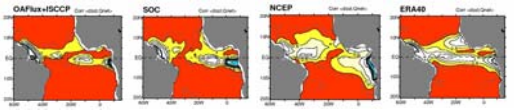

Fig.2 Correlation between dSSTand Q_{net} based on the four heat flux products. dSST is calculated as the difference between the averaged last five days and the averaged first five days of the month. The areas colored by red have a correlation greater than 0.8, significant at 99% confident level.

Interesting features in Fig.2:

(1) OAFlux+ISCCP product indicates that the net surface heat flux has the same phase with dSST over most tropical Atlantic Ocean except two belts. One is the eastern and central equatorial Atlantic Ocean, and the other is the lantitude band between the equator and 10°N collocating with the mean position of the ITCZ. These two regions are known for the influence of oceanic processes on SST (*Merle et al 1979; Molinari et al 1985; Houghton 1991; Weingartner and Weisberg 1991: Mitchell and Wallace 1994; Foltz et al 2004*).

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

4. How does the mixed layer vary with SST?

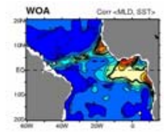

Fig.3 Correlation between SST and the surface mixed layer depth (MLD) derived from the climatological temperature fields from World Ocean Atlas 94 (*Levitus and Boyer 1994*). Negative correlation is shaded by blue colors.

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 the changes in MLD (*Kraus and Turner 1967; Yu et al. 2005*).

(2) Fig.3 provides an independent physical measure for assessing the accuracy of net surface heat flux product.

Low or positive correlations indicate that Q_{net} is not a primary driving forcing for changes in MLD. These regions are well produced only by the combined OAFlux+ISCCP flux product.

5. Predicting dSST using OAFlux+ISCCP flux product

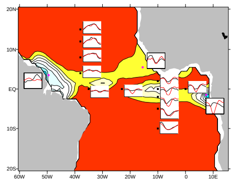

Fig.4 Model predicted (black) versus observed dSST (red) at chosen locations.

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 into a variable mixed layer depth in regions that dSST and Q_{net} have 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

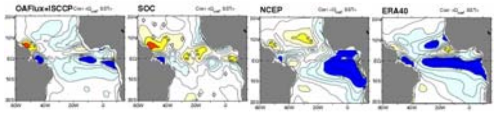

Fig.5 Correlation between Q_{ne} and SST using heat fluxes from the four products. The areas colored by blue indicate negative correlations. Dark blue indicates the correlation is significant at 99% confidence level.

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). The OAFlux+ISCCP heat fluxes show a good consistency with the seasonal surface mixed layer dynamics than NCEP and ERA40 reanalysis heat fluxes (Fig.3).

(2) Aside from the two belt regions, much of SST variability in the tropical Atlantic can be modeled by simply storing the local net heat flux into a variable mixed layer depth (Fig.4).

(3) How much Q_{net} serves as forcing for SST variability is closely related to how much Q_{net} is influenced by SST. NCEP and ERA40 heat fluxes show a strong SST dependence in the equatorial region (Fig.5).

Ongoing work:

Work is underway to construct the heat flux (turbulent + radiation) analysis for the global oceans for the past 50 years.

Acknowledgement

Bill Rossow is acknowledged for providing ISCCP-FD dataset and Simon Josey for the SOC climatology. ERA40 is obtained from the Data Support Section at NCAR, and WOA94 and NCEP reanalysis from the NCEP Climate Diagnostics Center.

References

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson, 2003: Bilk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm. J. Clim., 16(4), 571-591.

Foltz, G. R., S. A. Grodsky, J. A. Carton, and M. J. McPhaden, 2003: Seasonal mixed layer heat budget of the tropical Atlantic Ocean. J. Geophys. Res., 108(C5), 3146, doi:10.1029/2002JC001584.

Houghton, R. W., 1991: The relationship of sea surface temperature to thermocline depth at annual and interannual time series in the tropical Atlantic Ocean. J. Geophys. Res., 96, 15173-15185

.Josey, S.A., E.C. Kent and P.K. Taylor, 1999: New insights into the ocean heat budget closure problem from analysis of the SOC air-sea flux climatology. J. Clim., 12, 2685-2718.

Kraus, E. B., and J. S. Turner, 1967: A one-dimensional model of the seasonal thermocline: II The general theory and its consequences. Tellus, v19, 98-106.

Levitus, S., and T. P. Boyer, 1994: World Ocean Atlas 1994, vol. 4, Temperature, NOAA Atlas NESDIS 4, 117 pp., Natl. Oceanic and Atmos. Admin., Silver Spring, Md.

Merle, J., M. Fieux, and P. Hisard, 1979: Annual signal and interannual anomalies of sea surface temperature in the eastern equatorial Atlantic Ocean. Deep Sea Res., GATE Suppl. II to V, 26, 77-101.

Mitchell, T. P., and J. M. Wallace, 1992: On the annual cycle in equatorial convection and sea surface temperature. J. Clim., 5, 1140-1156.

Molinari, R. L., J. F. Festa, and E. Marmolejo, 1985: Evolution of sea surface temperature in the tropical Atlantic Ocean during FGGE, 1979: II. Oceanoggraphic fields and heat balance of the mixed layer. J. Mar. Res., 43, 67-81.

Weingartner, T. J. and R. H. Weisberg, 1991: On the annual cycle of equatorial upwelling in the central Atlantic Ocean, J. Phys. Oceanogr., 21, 68-82.

Yu, L., R. A. Weller, and B. Sun, 2004a: Improving latent and sensible heat flux estimates for the Atlantic Ocean (1988-1999) by a synthesis approach. J. Clim., 17, 373-393.

Yu, L., R. A. Weller, and B. Sun, 2004b: Mean and variability of the WHOI daily latent and sensible heat fluxes at in situ flux measurement sites in the Atlantic Ocean. J. Clim., 17, 2096-2118.

Yu, L., R. A. Weller, and X. Jin, 2005: Role of surface heat fluxes in seasonal variations of SST in the tropical Atlantic Ocean. To be submitted.

Zhang, Y-C., W.B. Rossow, A.A. Lacis, V. Oinas, and M.I. Mishchenko, 2004. Calculation of radiative fluxes from the surface to top of atmosphere based on ISCCP and other global data sets: Refinements of the radiative transfer model and the input data. J. Geophys. Res., 109, D19105, doi:10.1029/2003JD004457.

The project is supported by NOAA CLIVAR Atlantic, Climate Observation, Climate Change and Data Detection.

Daily latent and sensible heat fluxes from OAFlux, short and longwave radiations from ISCCP for the Atlantic Ocean (1988-1999) can be obtained from the WHOI ftp site: ftp://ftp.whoi.edu/pub/users/lyu/flux

For more information about the project, please visit the project website: http://www.whoi.edu/science/PO/people/lyu/ or contact Lisan Yu (Email: lyu@whoi.edu)