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VARIABILITY OF AIR-SEA HEAT FLUXES IN THE ATLANTIC OCEAN INDICATED FROM THE WHOI ANALYSIS, SOC ANALYSIS, AND NWP REANALYSIS

Lisan Yu†, Xiangze Jin, and Robert A. Weller
Department of Physical Oceanography, Woods Hole Oceanographic Institution
Woods Hole, MA 02543

1. INTRODUCTION

Gridded air-sea heat flux fields for the Atlantic Ocean (65°S – 65°N) that covers the period from 1988 to 1999 with daily and 1°×1° resolution have been recently developed at WHOI (Yu et al, 2004a,b). The latent and sensible heat fluxes were created from a synthesis of satellite data and numerical weather prediction model data from ECMWF operational analysis and NCEP/DOE reanalysis 2 (hereafter NCEP2) by a weighted objective method and the use of the COARE bulk flux algorithm 2.6a (Bradley et al. 2000). The flow chart showing the development procedure is given in Fig.1.

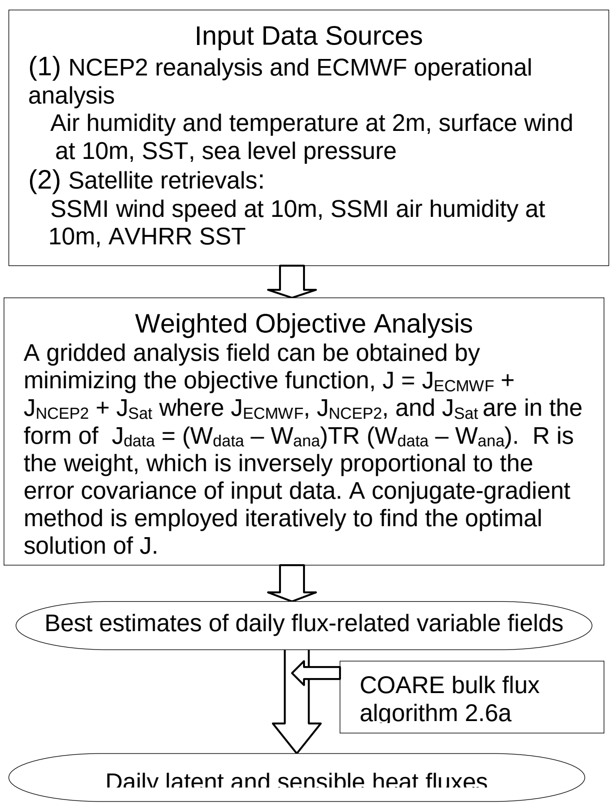


Fig.1 The procedure used in developing the WHOI latent and sensible heat fluxes

† *Corresponding author address*: Dr. Lisan Yu, Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA, 02543. Email: lyu@whoi.edu

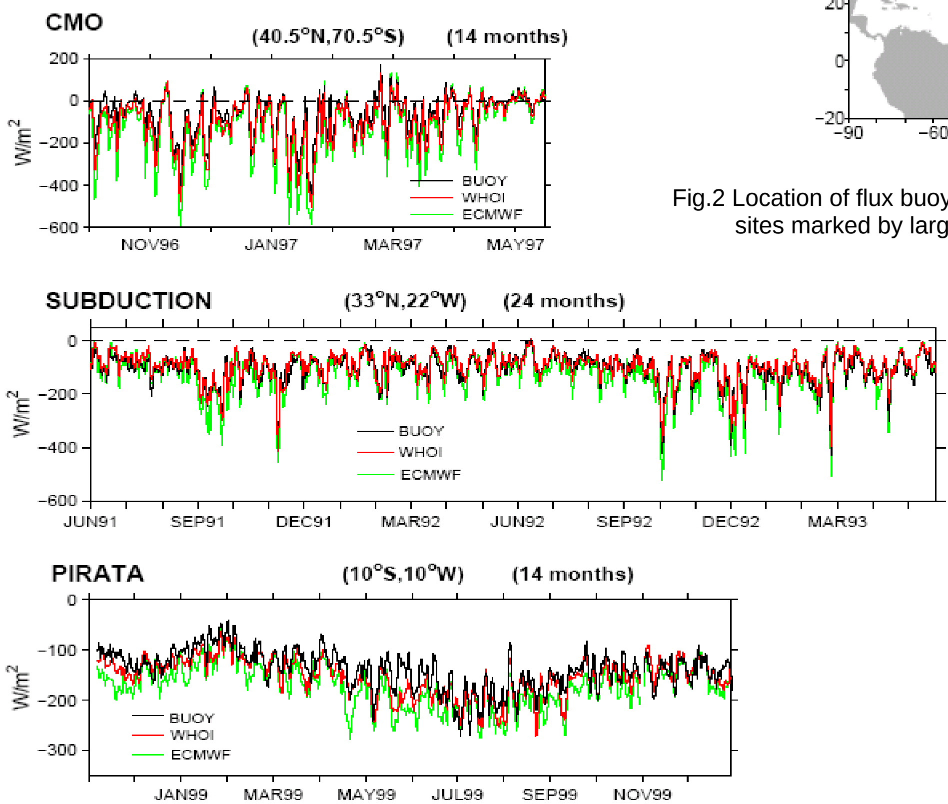
The net surface shortwave and longwave radiations of the WHOI analysis are derived from the International Satellite Cloud Climatology Project (ISCCP) FD dataset, kindly provided by Dr. William B. Rorrow. The ISCCP-FD data are available every three hours over the whole globe on 2.5°×2.5° grid for the period from July 1983 to June 2001. To derive a radiation dataset for the Atlantic Ocean that has the same spatial and temporal resolution as the latent and sensible heat fluxes, daily average and linear interpolation in space were applied to the ISCCP-FD data.

In this study we show daily variability of the WHOI heat flux analysis at selected in situ flux buoy sites, and analyze the basin-scale mean and variability of the net heat fluxes. We compare the results with the ECMWF operational analysis, NCEP1&2 reanalyses and discuss the differences of these products in depicting air-sea interaction patterns over the basin scale. In the following discussion, positive (negative) flux represents the oceanic heat gain from (loss to) the atmosphere.

2. VARIABILITY OF DAILY HEAT FLUXES AT IN SITU FLUX BUOY SITES

In situ flux buoy/ship measurements provide valuable benchmark time series for quantifying the accuracy of flux products. Over the 12-year synthesis period (1988-1999), there exist only a dozen flux buoy deployments plus the Pilot Research Moored Array in the Tropical Atlantic (PIRATA) (Fig.2) and a few cruises in the Atlantic basin. The comparisons between observed and the WHOI analyzed daily turbulent latent plus sensible heat fluxes at three buoy sites are shown in Fig.3. ECMWF turbulent fluxes are also included in Fig.3 to indicate the improvement of the WHOI analysis. They are not an independent data source because surface meteorological variables from ECMWF were used in the synthesis when producing the WHOI heat flux analysis.

WHOI analysis produces well daily fluctuations of turbulent air-sea flux exchange at the buoy sites. Both the phase and amplitude are compatible with the CMO and SUBDUCTION observed values, but the amplitude is stronger than the PIRATA measurements at the southern Atlantic location. Yu et al. (2004b) found that the overestimation is due to a dry bias in near-surface air humidity. All NWP models are biased dry in the tropical Atlantic (Sun et al. 2003). The lack of direct observations of air humidity makes the WHOI synthesis unable to correct the input data biases.



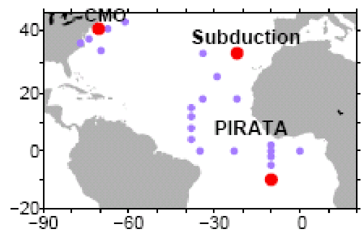


Fig.2 Location of flux buoy measurements. The three sites marked by large red dot are used in Fig.3.

Fig.3 Time series plots of measured (black), WHOI analyzed (red), and ECMWF produced (green) turbulent heat fluxes at three buoy locations.

Fig.3 also shows that ECMWF produces strong turbulent heat flux loss from the ocean at all sites. In fact, NWP models, including ECMWF and NCEP1&2, all overestimate the latent and sensible heat losses over the Atlantic basin by about 10–35% (Smith et al. 2001; Sun et al. 2003; Yu et al. 2004b).

3. MEAN NET SURFACE HEAT FLUX PATTERN

The mean net heat flux (sum of latent, sensible, net shortwave and longwave radiation heat fluxes) over the period from 1988 to 1997 constructed by WHOI analysis plus ISCCP radiations is shown in Fig.4. The patterns produced for the same period by the Southampton Oceanographic Centre (SOC) analysis and NCEP1 and NCEP2 reanalysis are also included for comparison. SOC fluxes were composed from marine surface weather reports from Voluntary Observing Ships (VOS). Clearly, despite that the WHOI-ISCCP and SOC analysis used differences data sources, different approaches, and different resolutions, the two produced a very similar mean pattern. They show that over the 10-year period the tropical and subtropical oceans gain heat from the atmosphere while the Gulf Stream region and the area north of 40°N loss heat to the atmosphere. By contrast, NCEP1&2 reanalyses show that, except the narrow equatorial band and high southern latitudes, the Atlantic basin loses heat to the atmosphere.

Zonal averages of the mean net heat fluxes from the four sources are shown in Fig.5. The WHOI-ISCCP analysis has a heat surplus up to the latitude at 35°N, and the estimate is very close to the SOC analysis for the latitudes between 15°S and 45°N, which is the region best sampled by VOS. On the other hand, the net heat gain in the ocean produced by NCEP1&2 is much smaller. NCEP1 obtains an oceanic heat loss for the northern Atlantic Ocean from 10°N northward. NCEP2 gives the weakest heat gain in the equatorial Atlantic Ocean, which differs from the WHOI-ISCCP by about 50 Wm^{-2}. The difference is even larger than the NCEP2 flux estimate (~30Wm^{-2}) at the location. The agreement between the SOC and WHOI-ISCCP analyses justifies the climatological mean aspect of the two products.

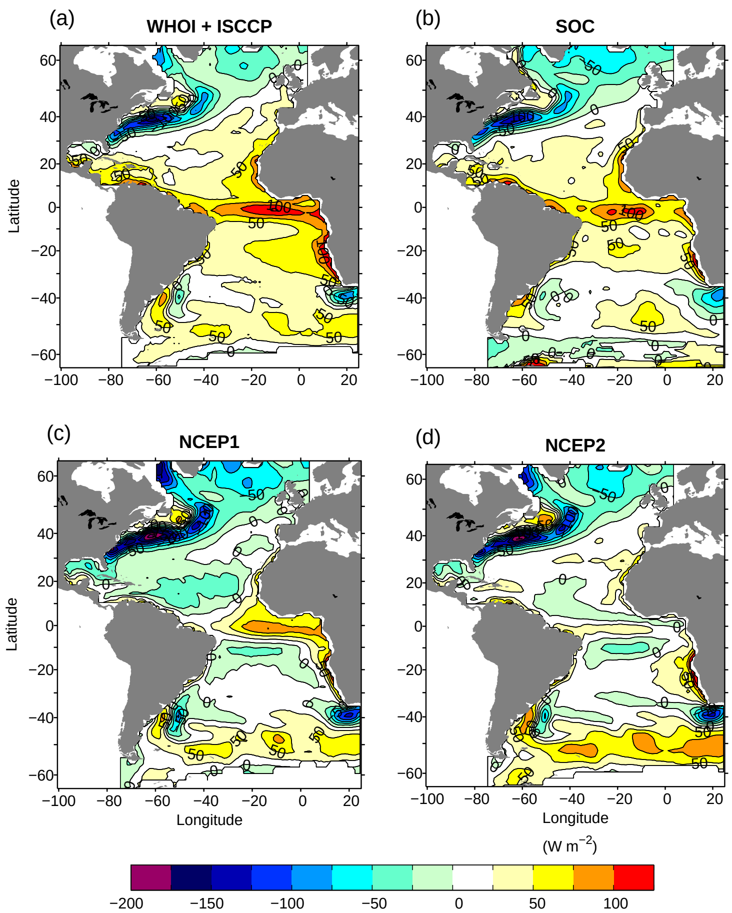


Fig.4 Mean net heat flux averaged over the period of 1988-1997 from (a) WHOI turbulent heat fluxes plus ISCCP net radiation fluxes, (b) SOC analysis, (c) NCEP1 reanalysis, (d) NCEP2 reanalysis.

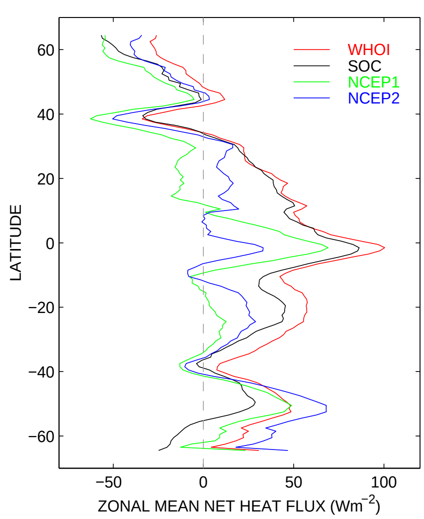


Fig.5 Zonal mean net heat flux averaged over 1988-1997 from (a) WHOI-ISCCP, (b) SOC, (c) NCEP1, and (d) NCEP2.

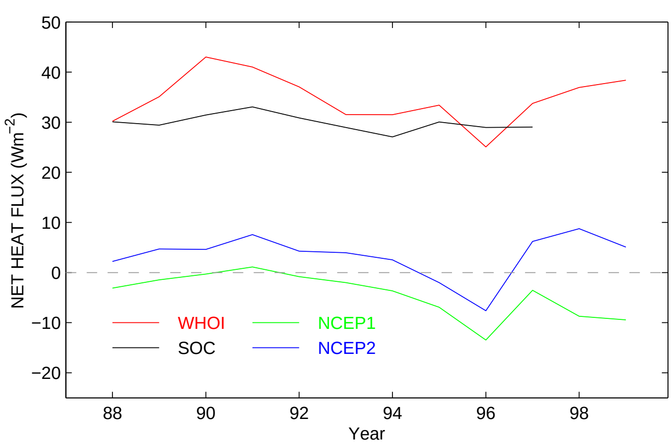


Fig.6 Year-to-year variations of the yearly mean net heat flux averaged over the basin [15°S, 45°N] from (a) WHOI-ISCCP, (b) SOC, (c) NCEP1, and (d) NCEP2.

4. YEAR-TO-YEAR VARIATIONS OF NET HEAT FLUX

Year-to-year variations of yearly mean net heat flux averaged over the basin from 15°S to 45°N are plotted in Fig.6 using the four heat flux products. The region of interest is best sampled by VOS and shows the best agreement between SOC and WHOI-ISCCP flux analyses. Clearly, the yearly fluctuation of the two flux products shows the similar tendency that the ocean in this region gains heat by around 35 Wm^{-2} on the annual basis, albeit the amplitude of the SOC net heat flux is about 5 Wm^{-2} weaker on average. NCEP1 suggests that the net heat flux in this region is near zero before 1992 and the ocean releases heat thereafter. NCEP2, however, has the oceanic heat gain about 5Wm^{-2} except a slight loss in 1996. The net heat flux from the WHOI-ISCCP analysis consistently differs from NCEP1 (NCEP2) by about 30 (35) Wm^{-2}.

5. SUMMARY

The study presents the analysis of the daily gridded surface latent and sensible heat fluxes newly developed at WHOI and ISCCP net surface radiation fluxes. The study shows that the WHOI analysis produces well the daily flux fluctuation compared with daily values from flux buoy measurements. The net heat flux from the combined WHOI and ISCCP datasets has a good agreement with the SOC analysis that is based on ship meteorological reports, but differs considerably from NCEP1&2 reanalyses in both pattern and amplitude. The largest difference is found in the tropical and subtropical regions, where WHOI-ISCCP and SCO analyses both show an oceanic heat gain contrast to the oceanic heat loss suggested by NCEP1&2 reanalyses. Year-to-year variations of the neat heat flux averaged in the north Atlantic region also show that the WHOI-ISCCP and SOC analyses are consistent and that on average the NCEP1&2 reanalyses are consistently weaker than the WHOI-ISCCP and SOC analyses by about 30-35Wm^{-2}.

6. FURTHER INFORMATION ON THE WHOI HEAT FLUX ANALYSIS AND DATA

The WHOI surface latent heat, sensible heat, net shortwave and longwave radiative fluxes and related meteorological variables for the Atlantic Ocean (65°S - 65°N) with daily and 1°×1° resolution for the period from 1988 to 1999 can be downloaded from the WHOI ftp site:
ftp://ftp.whoi.edu/pub/users/lyu/flux.
The flux project website
http://www.whoi.edu/science/PO/people/lyu/res-flux.html

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