# SEVEN-YEAR SSM/I-DERIVED GLOBAL OCEAN SURFACE TURBULENT FLUXES

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## 1. INTRODUCTION

Surface turbulent fluxes of momentum, latent and sensible heat over global oceans are very important to a wide variety of oceanic and atmospheric phenomena. Wind stress provides the most important forcing of the ocean circulation, while latent heat flux (LHF) is a key component of the surface heat budget and hydrological cycle. The LHF at the ocean surface can be estimated from the sea surface temperature (SST), surface wind speed, and surface specific humidity using an aerodynamic bulk method. Except for the surface humidity, these parameters can be directly retrieved from satellite radiance measurements. Thus the satellite retrieval of latent heat flux over oceans depends critically on the estimation of surface humidity. A number of techniques have been developed to retrieve surface humidity and LHF from satellite observations (e. g., Chou et al. 1995, 1997, 2000; Clayson and Curry 1996; Curry et al. 1999; Esbensen et al. 1993; Liu 1986, 1988; Schlussel et al. 1995; Schulz et al. 1993, 1997).

Chou et al. (1995) developed a method to retrieve instantaneous surface humidity from radiances measured by the Special Sensor Microwave/Imager (SSM/I). Using both SSM/I-retrieved surface wind and humidity and other data, they then computed daily air-sea turbulent fluxes of momentum, latent and sensible heat over global oceans with a stability-dependent bulk scheme. Chou et al. (1997) improved the methods for retrieving the surface humidity (thus the LHF) and sensible heat flux (SHF). To date, we have produced a low-resolution (2.0°x2.5° latitude-longitude) data set of daily surface turbulent fluxes over global oceans for the period July 1987-December 1994, from the SSM/I data and other data using the algorithm of Chou et al. (1997). In this paper, we discuss the flux retrieval accuracy and the global distributions of annual and seasonal climatologies (88-94) of SSM/I-derived turbulent fluxes.

## 2. DATA

The data sets used to derived turbulent fluxes are: 1) the SSM/I total precipitable water and 10-m wind speeds of Wentz (1994), 2) precipitable water in the lowest 500-m bottom-layer ($W_B$), 3) 0Z and 12Z analyses of SST–$T_{2m}$ (2-m temperatures) of the European Centre for Medium-Range Weather Forecasts (ECMWF), 4) weekly mean SST analyses of the National Centers for Environmental Prediction (NCEP), and 5) SSM/I 10-m wind directions of Atlas (1996). The $W_B$ is estimated from the SSM/I antenna temperatures of Wentz (1993) using the method of Schulz et al. (1993). Daily mean SSTs for computing LHF are interpolated from the weekly means of Reynolds and Smith (1994). Wind stress directions are taken from the SSM/I 10-m wind directions of Atlas et al. (1996), which used 10-m wind speeds of Wentz (1994) for analyses. The Defense Meteorological Satellite Program (DMSP) F8 and F11 SSM/I data are used to derive annual and seasonal flux climatologies, as they have better quality compared to F10 SSM/I data.

## 3. RESULTS

SSM/I-radiosonde comparisons show that the SSM/I-retrieved surface humidity is reasonably accurate over global oceans for February and August of 1988 and entire 1993. The accuracy of humidity retrieval for F8 and F11 SSM/Is is comparable and is slightly better than that of F10 SSM/I. The retrieved daily wind stress and LHF (over the western Pacific warm pool), compare reasonably well with that of IMET buoy and RV Moana Wave, measured during the intensive observing period (Nov92-Feb93) of the TOGA COARE (Fairall et al. 1996; Weller and Anderson 1996; Chou et al. 1997, 2000). The retrieved daily SHF does not agree well with that of IMET and Moana Wave. The poor retrieval accuracy of SHF is mainly due to small mean flux with large variability (general weak winds but with strong episodic events of westerly wind bursts).

da Silva et al. (1994) derived turbulent fluxes from the comprehensive ocean-atmosphere data set (COADS) of Woodruff et al. (1987) with corrections of wind speeds and produced global monthly fluxes for 1945-1993 with an objective analysis to fill missing data (referred to as UWM/COADS). Figures 1-4 compare annual mean turbulent fluxes and relevant parameters,

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derived from 7 years (1988-94) of F8 and F11 SSM/I data (Figs. 1 and 3), with those of 4 years (1990-93) of UWM/COADS (Figs. 2 and 4). The 1990-93 annual-mean SSM/I fluxes and relevant parameters (not shown) are essential the same as that of 1988-94 (Figs. 1 and 3), but are somewhat different from that of UWM/COADS (Figs. 2 and 4). The patterns are similar between SSM/I and UWM/COADS. However, the SSM/I (Figs. 1 and 3) shows more large-scale coherent patterns, while UWM/COADS (Figs. 2 and 4) shows more small-scale eddy structures. Wind stress patterns follow wind speeds, with the maxima located in the strong wind regions (trade winds and extratropical storm tracks). The minimum wind stress is located in the weak wind areas of intertropical convergence zones (ITCZ), Southern Pacific convergence zone (SPCZ), and subtropical highs. LHF patterns generally follow sea-air humidity difference, although they also depend on wind speeds. The maximum LHF is located in the trade wind regions, where sea-air humidity differences maximized. Large LHF is also found over the Gulf streams and Kuroshio areas, resulting from high winds and sea-air humidity differences as strong cold air blows over warm oceans during cold air outbreaks in the winters. The minimum LHF and sea-air humidity difference are located in high latitudes and decrease poleward, as SST decreases poleward. The SHF is generally very small due to the smallness of sea-air temperature difference, except for slightly larger fluxes in the NW Pacific and NW Atlantic caused by cold air outbreaks.

SSM/I-minus-UWM/COADS difference fields for the 1990-93 annual-mean fluxes and relevant parameters have been analyzed (not shown). The results show that, except large differences south of 50°S, the SSM/I wind stress is generally smaller (with negative difference reaching 0.1 N $m^{-2}$) in strong wind regions (trade winds and extra-tropical storm tracks), but is only slightly larger in some weak wind regions, as compared to UWM/COADS. The SSM/I LHF is generally larger, but is slightly smaller in weak wind areas (ITCZs, SPCZ, and subtropics). Over some data-missing areas (especially in the Southern Hemisphere), significant dipoles of LHF discrepancies (reaching -40 and +80 W $m^{-2}$) are found, which are likely due to the objective analysis of UWM/COADS to fill missing data. The difference in LHF is mainly due to discrepancies in surface humidity (reaching $\pm 3$ g $kg^{-1}$). The result is generally consistent with previous studies that ship measurements underestimate LHF (Bunker et al. 1982; Oberhuber 1988; da Silva et al. 1994; Chou et al. 1997). The small LHF of UWM/COADS may be due to overestimation of dew point of ship measurements (Isemer and Hasse 1987; da Silva et al. 1994; Chou et al. 1997). The SHF is generally within $\pm 10$ W $m^{-2}$ of UWM/COADS and is consistent with that of Chou et al. (1997).

Overall the results show that the global distributions of 7-year (1988-94) annual and seasonal mean turbulent fluxes and relevant parameters, derived from the F8 and F11 SSM/I data, are reasonably accurate. The results further suggest that the satellite technique of Chou et al. (1997) are promising for retrieving daily and monthly surface humidity and air-sea turbulent fluxes.

## 4. REFERENCES

Chou, S.-H., R. M. Atlas, C.-L. Shie and J. Ardizzone, 1995: Estimates of surface humidity and latent heat fluxes over oceans from SSM/I data. *Mon. Wea. Rev.* , 123, 2405-2425.

Chou, S.-H., C.-L. Shie, R. M. Atlas and J. Ardizzone, 1997: Air-sea fluxes retrieved from Special Sensor Microwave Imager data. *J. Geophys. Res.*, 102, 12705-12726.

Chou, S.-H., W. Zhao, and M.-D. Chou, 2000: Surface heat budgets and sea surface temperature in the Pacific warm pool during TOGA COARE. *J. Climate*, **13**, 634-649.

Curry, J. A., C. A. Clayson, W. B. Rossow, R. Reeder, Y.-C. Zhang, P. J. Webster, G. Liu, R.-S. Sheu, 1999: High-resolution satellite-derived dataset of the surface fluxes of heat, freshwater, and momentum for the TOGA COARE IOP. *Bull. Amer. Meteor. Soc.*, **80**, 2059-2080.

da Silva, A, C. C. Young and S. Levitus, 1994: Atlas of Surface Marine Data 1994 Vol. 1: Algorithms and Procedures. NOAA Atlas NESDIS 6, US Dept. of Commerce, NOAA, NESDIS, Washington, DC.

Fairall, C., E. F. Bradley, D. P. Rogers, J. B. Edson, and G. S. Young, 1996: Bulk parameterization of air-sea fluxes for Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment. *J. Geophys. Res.*, **101** (C2), 3747-3764.

Schulz, J., P. Schluessel and H. Grassl, 1993: Water vapor in the atmospheric boundary layer over oceans from SSM/I measurements. *Int. J. Rem. Sens.*, **14**, 2773-2789.

Weller R. A. and S. P. Anderson, 1996: Surface meteorology and air-sea fluxes in the western equatorial Pacific warm pool during the TOGA Coupled Ocean-Atmosphere Response Experiment. *J. Climate*, **9**, 1959-1990.

Wentz, F. J., 1993: *User's Manual SSM/I Antenna Temperature Tapes. Revision 2.* Tech. Rep. 060989, 16 pp, Remote Sensing Systems, Santa Rosa, California.

Wentz, F. J., 1994: *User's Manual SSM/I -2 Geophysical Tapes.* Tech. Rep. 070194, 20 pp, Remote Sensing Systems, Santa Rosa,California.

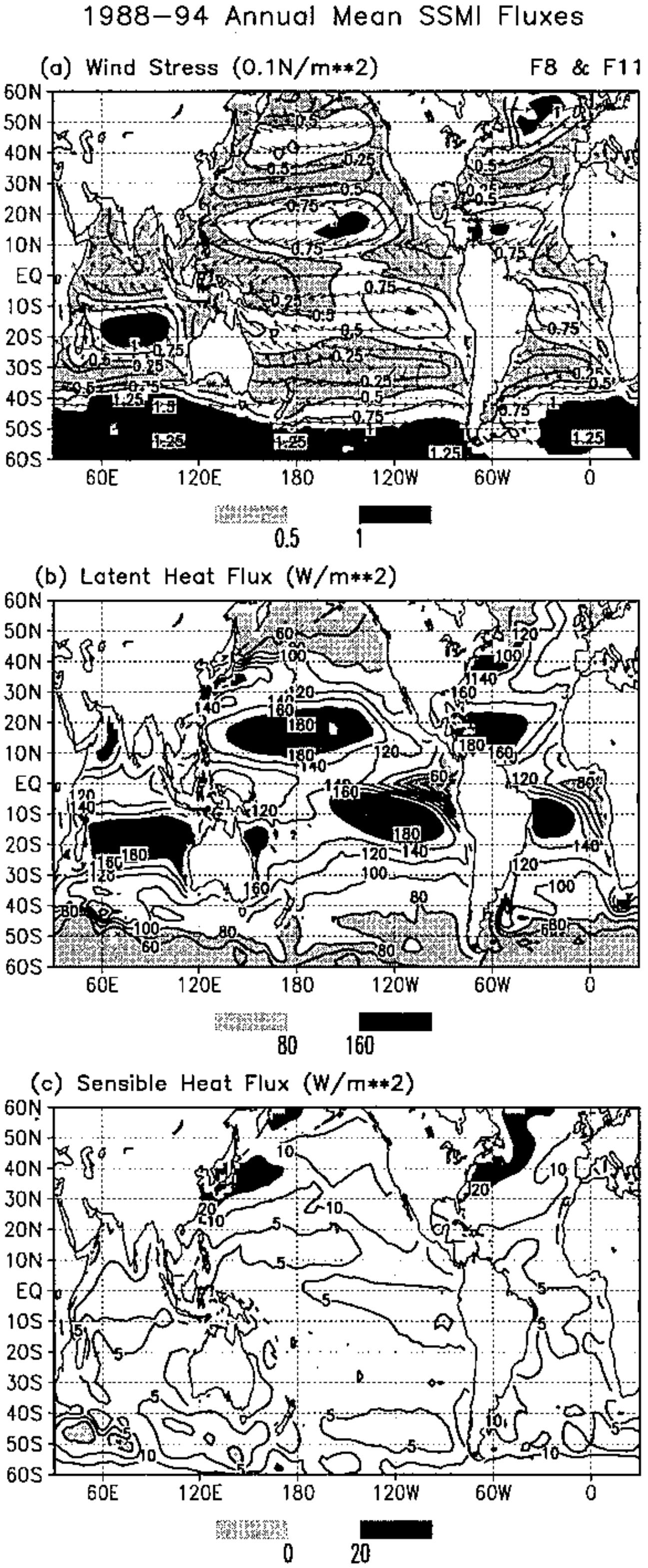


Fig. 1. Annual means (1988-94) of (a) wind stress, (b) latent heat flux, and (c) sensible heat flux, derived from F8 and F11 SSM/I data. Arrows indicate wind stress directions.

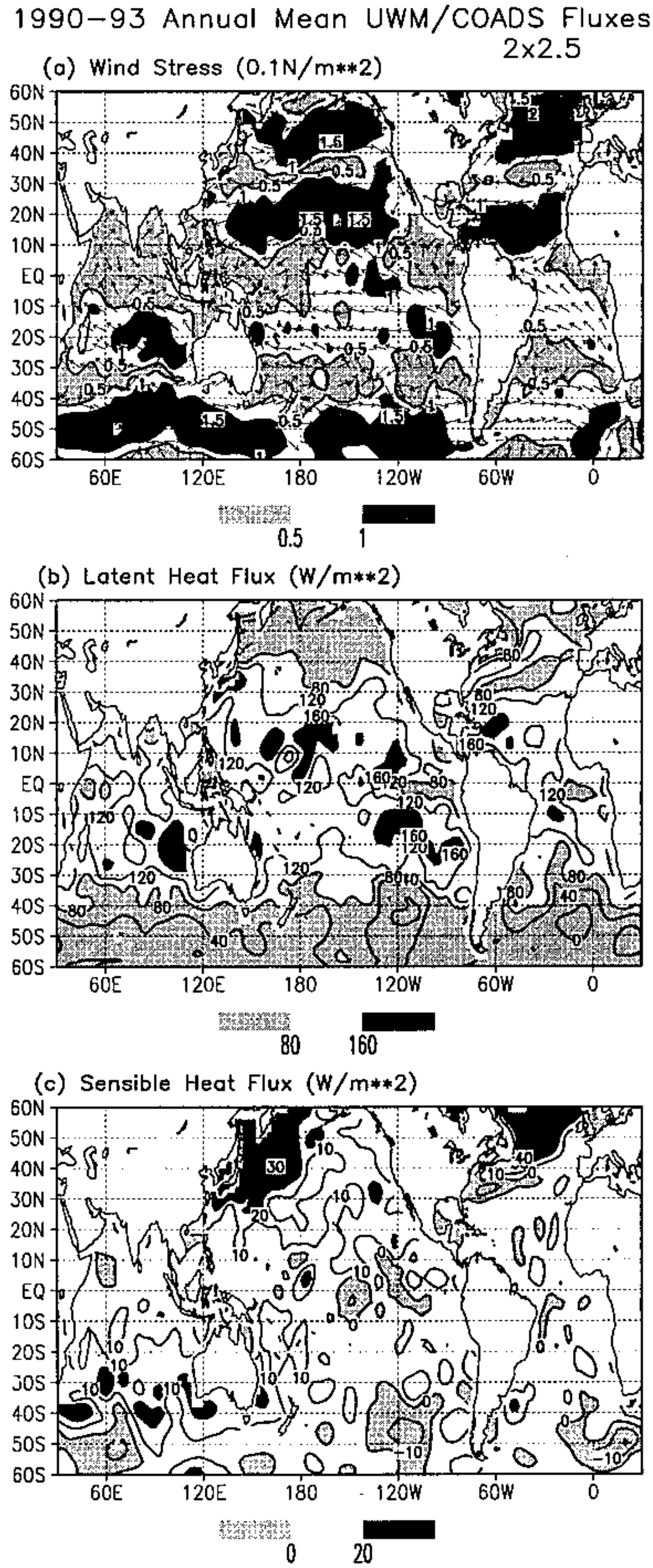


Fig. 2. Annual means (1990-93) of (a) wind stress, (b) latent heat flux, and (c) sensible heat flux, derived from UWM/COADS. Arrows indicate wind stress directions.

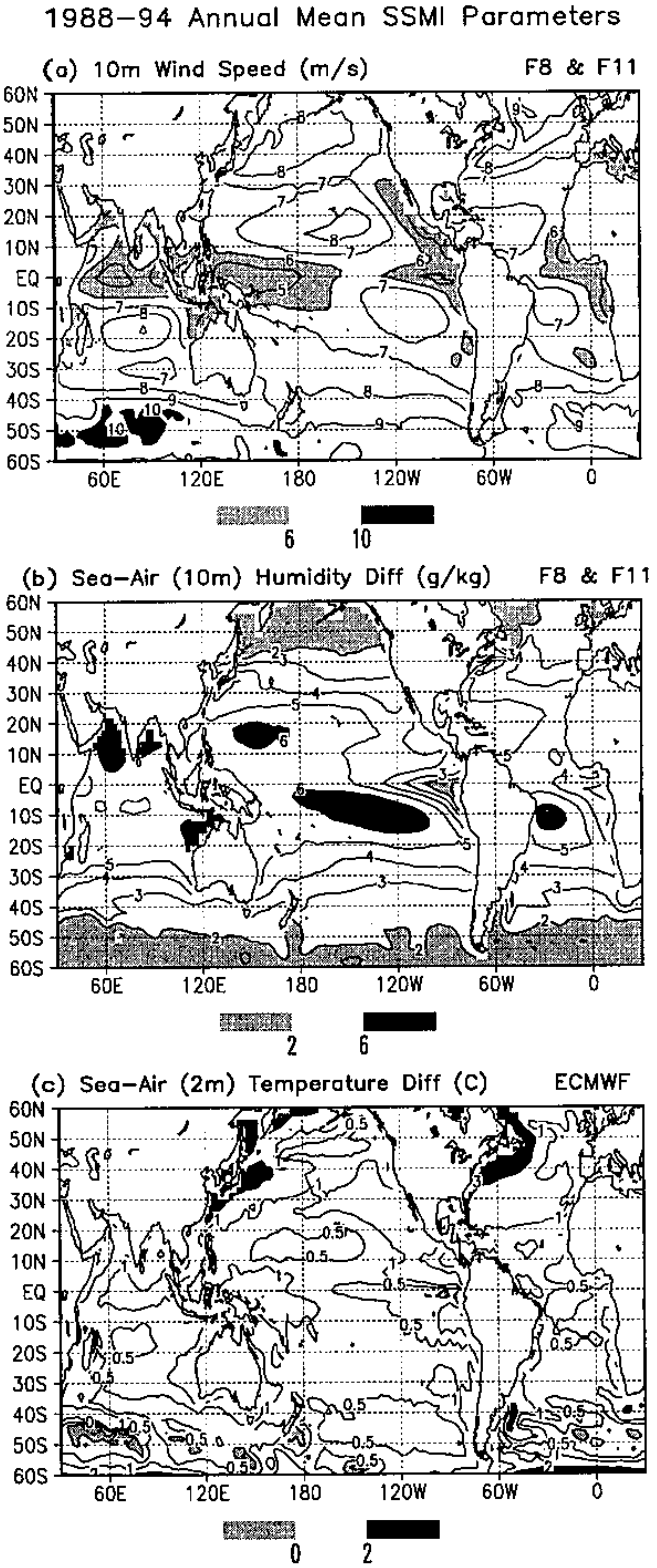


Fig. 3. Annual means (1988-94) of (a) 10-m wind speed, and (b) sea-air (10 m) humidity difference, derived from F8 and F11 SSM/I data, and (c) ECMWF sea-air (2 m) temperature difference.

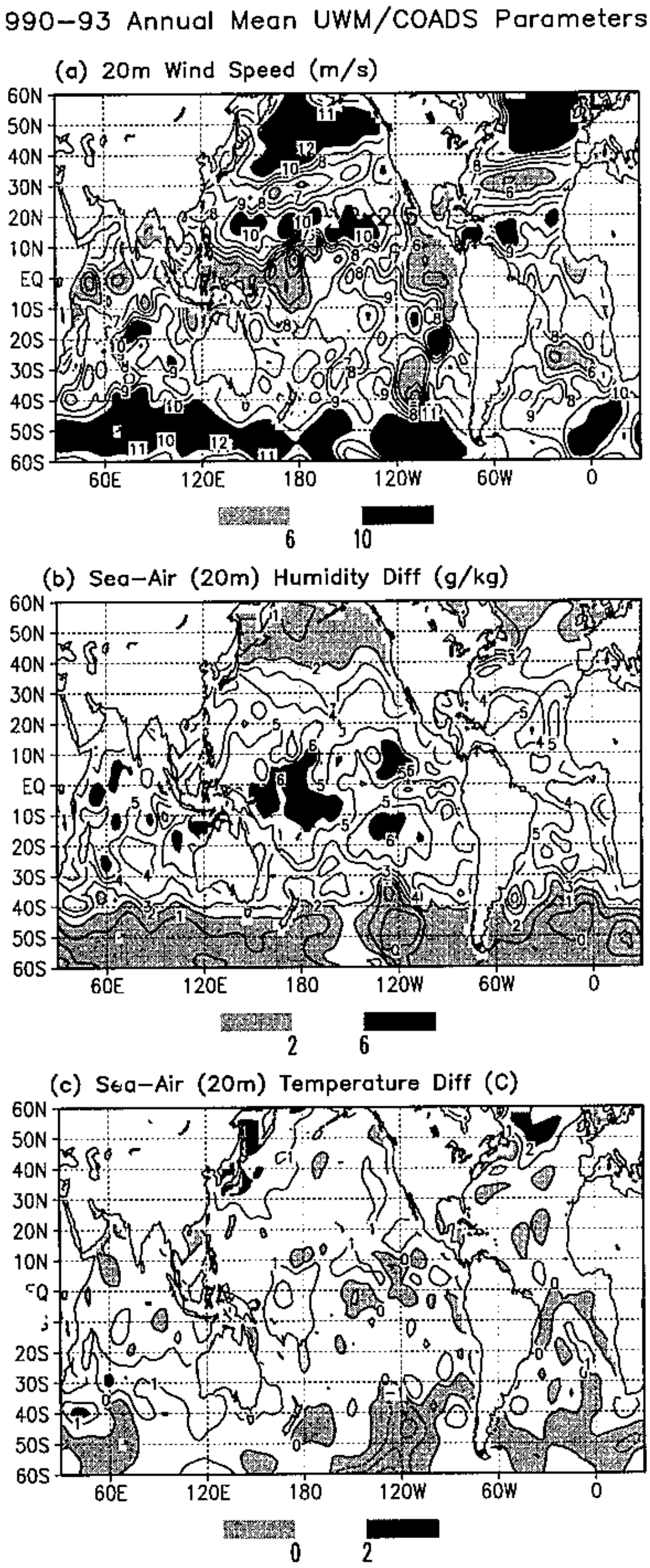


Fig. 4. Annual means (1990-93) of (a) 20-m wind speed, (b) sea-air (20 m) humidity difference, and (c) sea-air (20 m) temperature difference, derived from UWM/COADS.