PRELIMINARY RESULTS FROM THE ETL OPEN OCEAN AIR-SEA FLUX DATABASE

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1. INTRODUCTION

The COARE 2.5 algorithm (Fairall et al. 1996) was developed for the Coupled Ocean Atmosphere Response Experiment (COARE) program and has been evaluated against several sets of tropical data. It performs well, as do several other algorithms (Zeng et al. 1998). None of the new algorithms have been extensively tested against a large and latitudinally diverse data base. A joint CSIRO/ETL effort has been underway to use new data to evaluate the algorithm, continue improvements, and add better physics; this led to the recent issuance of a version 2.6 (Bradley et al. 2000). In this paper we evaluate the accuracy of version 2.6 against a database from 12 ETL flux cruises with about 5000 hr of usable direct flux measurements.

2. BACKGROUND

Bulk algorithms to estimate surface fluxes are widely used in numerical models and in applications (e.g., satellite retrievals) where highly detailed local information is not available. These are based upon Monin - Obukhov similarity (MOS) representations of the fluxes in terms of mean quantities (Smith et al. 1996)

$$\overline{w'x'} = c_x^{1/2} c_d^{1/2} S\Delta X = C_x S\Delta X \quad (1)$$

where x can be the u, v wind components, the potential temperature, θ, the water vapor mixing ratio, q, or some atmospheric trace species mixing ratio. Here c_x is the bulk transfer coefficient for the variable x (the d being used for wind speed) and C_x is the total transfer coefficient. ΔX is the sea-air difference in the mean value of x and S is the mean wind speed which is composed of a mean vector part (U and V components) and a gustiness part (U_g) toaccount for subgridscale variability

$$\Delta X = X_s - X(z) \; ; \; S = (U^2 + V^2 + U_g^2)^{1/2} \quad (2)$$

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The transfer coefficients have a dependence on surface stability prescribed by MOS

$$c_x^{1/2}(\xi) = c_{xn}^{1/2} / [1 - \frac{c_{xn}^{1/2}}{\kappa}\psi_x(\xi)] \; ; \; c_{xn}^{1/2} = \frac{\kappa}{\ln(z/z_{ox})} \quad (3)$$

where ξ is the MOS stability parameter, the subscript n refers to neutral ($\xi = 0$) stability, z is the height of measurement of the mean quantity [$X(z)$], ψ an empirical function describing the stability dependence of the mean profile, κ is von Karman's constant, and z_{ox} parameter called the roughness length that characterizes the neutral transfer properties of the surface for the quantity, x. For purposes of brevity we will restrict our comments in this paper to the TOGA COARE bulk algorithm (Fairall et al. 1996). The velocity roughness length is specified via a Charnock plus a smooth flow limit

$$z_o = \frac{\alpha u_*^2}{g} + \frac{0.11\nu}{u_*} \quad (5)$$

where u_* is the friction velocity. The scalar roughness lengths are parameterized in terms of the roughness Reynolds number, $R_r = z_o u_* / \nu$.

Table 1. Summary of ETL air-sea flux and bulk meteorological data cruises used in the analysis.

Cruise Name	Dates	Hours	Vessel	Latitude	Longitude
TIWE	11/21-12/13/91	460	Moana Wave	0	140 W
ASTEX	6/06-6/28/92	390	M. Baldrige	30 N	25 W
COARE-1	11/11/-12/03/92	589	Moana Wave	2S	156 E
COARE-2	12/17/-1/11/93	648	Moana Wave	2S	156 E
COARE-3	1/28/-2/16/93	385	Moana Wave	2S	156 E
SCOPE	9/17/-9/28/93	305	FLIP	33 N	118 W
FASTEX	12/23-1/24/97	730	Knorr	45 N	10-60 W
JASMINE	5/5-5/31/99	654	Ron Brown	8 N	89 E
Nauru99	6/15-7/18/99	794	Ron Brown	0.5 S	167 E
KWAJEX	7/28-9/12/99	875	Ron Brown	8 N	167.5 E
Moorings	9/14-10/21/99	746	Ron Brown	52 N	140 W

3. IMPROVEMENTS IN COARE ALGORITHM

The published version (2.5b) of the COARE algorithm is in widespread use but the Flux Working Group has continued to pursue improvements in the various components of the model. A new version of the model (2.6a) has been made public; the changes are summarized in Bradley et al. (2000). Aside from various structural improvements, the neutral transfer coefficients have been adjusted slightly. The Liu et al. (1979) scalar roughness relationship [$f_x(R_r)$] has been replaced with a much simpler one that fits both the COARE and HEXMAX data bases and the Charnock parameter has been given a slight wind speed dependence for winds between 10 and 18 ms^{-1}. These changes were intended to extend the algorithm's region of applicability from a maximum wind speed of 10 ms^{-1} to 20 ms^{-1}. Matlab and Fortran versions of both COARE 2.5b and 2.6a have been made publicly available at the ftp site at ETL: ftp://ftp.etl.noaa.gov/et7/users/cfairall/bulkalg/. Included is a description of the codes and a test data set file. The programs are set up to read the test file and output the results; output files and graphs of results are also provided.

4. ADDITIONS TO THE FLUX DATABASE

Version 2.6 was based on fits to ETL flux data from six cruises in the early 1990's plus published results on fluxes at high wind speeds (DeCosmo et al. 1998; Yelland and Taylor 1996). Six new cruises obtained with the ETL seagoing flux system (Fairall et al. 1997) recently became available and were combined with the original six cruises (see Table 1). This larger database has more high-latitude measurements and includes about 800 hrs of data at wind speed greater than 10 ms^{-1}. Because the initial ETL database of six cruises had only 67 hrs of data at wind speed greater than 10 ms^{-1}, this new data allows us to test the in the wind speed range of 10 - 20 ms^{-1}.

5. FLUX AND TRANSFER COEFFICIENT EVALUATION

The first step in evaluating the performance of the flux algorithm is to select a subset of the data that pass a set of criteria to reject invalid points. Such criteria include experimental aspects (such as the relative wind must fall within a certain range to eliminate obvious contamination by the ship's structure), instrument performance indicators, ship motion-correction errors associated with ship maneuvers, and requirements that certain variables (e.g., variances) fall within physically reasonable limits. The criteria are arbitrary but the results are only weakly affected by modest criteria changes. Both direct covariance and inertial-dissipation (ID) flux estimates are used in our analysis.

The next step is to compare the values of fluxes obtained from the bulk algorithm with the measurements in some rational fashion. Usually we are interested in the *average* performance of the bulk algorithm plus some information on its statistical scatter about the observations. One can compute mean and standard deviations of differences, linear regressions, etc. In this paper we will show mean comparisons averaged in bins of 10-m neutral wind speed. Fig.1 shows a comparison of the mean latent heat flux computed in wind speed bins from 0 to 22 ms^{-1}. The width of the bins is increased slightly at higher wind speeds where the density of data decreases. The turbulence values are the average of covariance and ID values; the bulk values (x's) are COARE 2.6. We have used both medians and means to indicate skewed distributions or effects of outliers. Fig. 2 shows these same values plotted on a linear scale as flux vs flux. A similar x - y plot for stress (not shown) indicates very close agreement except covariance values at high wind speds are about 10% higher than bulk and ID values.

These results suggest very close agreement between the model and the data, but a more critical test comes when we evaluate the transfer coefficients (Eq. 1). Because of the noisy nature of flux data and the difficulties of making very accurate bulk meteorological measurements, the experimental evaluation of transfer coefficients is problematical. Using (1) we can compute a transfer coefficient for each observation and average in wind speed bins (method 1). Or, we can average the fluxes and bulk variables in wind speed bins, compute 'effective' transfer coefficients that deliver the correct average flux (method 2). Another approach is to compute an average transfer coefficient that is the mean bulk coefficient times the ratio of the mean measured flux to the mean computed bulk flux (method 3). We have experimented with these (and other) approaches; at the moment we weakly favor method 3. Our results are shown for moisture flux (Fig. 3) and stress (Fig. 4). The data for both variables show a tendency for slightly lower transfer coefficients for wind speeds below 8 ms^{-1} and greater transfer coefficients for greater wind speeds. Surprisingly, the moisture roughness length parameterization is in good agreement with the data; the difference in transfer coefficient for moisture is caused by the velocity contribution (i.e., the $c_d^{1/2}$ part of Eq. 1).

ACKNOWLEDGMENTS

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REFERENCES

Bradley, E. F., C. W. Fairall, J. E. Hare, and A. A. Grachev, 2000: An old and improved bulk algorithm for air-sea fluxes: COARE 2.6A. *14th Symposium on Boundary Layer and Turbulence, AMS.* 7 - 11 August 2000, Aspen CO, 294-296.

DeCosmo, J., K. B. Katsaros, S. D. Smith, R. J. Anderson, W. A. Oost, K. Bumke, and H. Chadwick, 1996: Air-sea exchange of water vapor and sensible heat: The Humidity Exchange Over the Sea (HEXOS) results. *J. Geophys. Res.*, **101**, 12001-12016.

Fairall, C. W., E. F. Bradley, D.P. Rogers, J. B. Edson, and G. S Young, 1996: Bulk parameterization of air-sea fluxes in TOGA COARE. *J. Geophys. Res.*, **101**, 3747-3767.

Fairall, C.W., A.B. White, J.B. Edson, and J.E. Hare, 1997: Integrated shipboard measurements of the marine boundary layer. *J. Atmos. Oceanic Tech.,* **14**, 338-359.

Liu, W. T., K. B. Katsaros, and J. A. Businger, 1979: Bulk parameterization of the air-sea exchange of heat and water vapor including the molecular constraints at the interface. *J. Atmos. Sci*., **36**, 2052-2062.

Smith, S. D., C. W. Fairall, G. L. Geernaert, and L. Hasse, 1996: Air-sea fluxes: 25 years of progress. *Bound.-Layer Meteorol.*, **78**, 247-290.

Yelland, M. and P. K. Taylor, 1996: Wind stress measurements from the open ocean. *J. Phys. Oceanogr.*, **26**, 541-558.

Zeng, X., M. Zhao, and R. E. Dickinson, 1998: Comparison of bulk aerodynamic algorithms for the computation of sea surface fluxes using the TOGA COARE and TAO data. *J. Clim.*, **11**, 2628-2644.

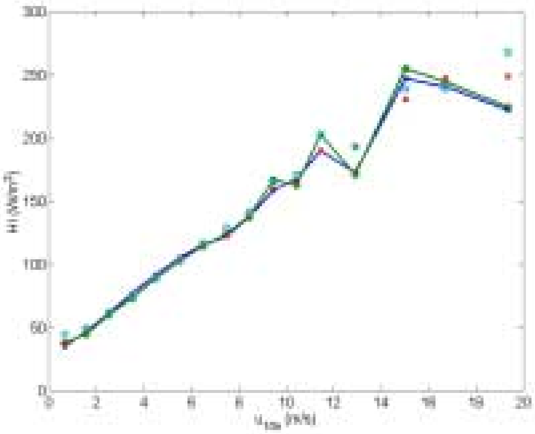

Figure-1 Mean (line) and median (no line) fluxes computed in wind speed bins for 4272 selected hours of latent heat flux data. The x's are COARE 2.6 values; the circles are the average of covariance and ID values.

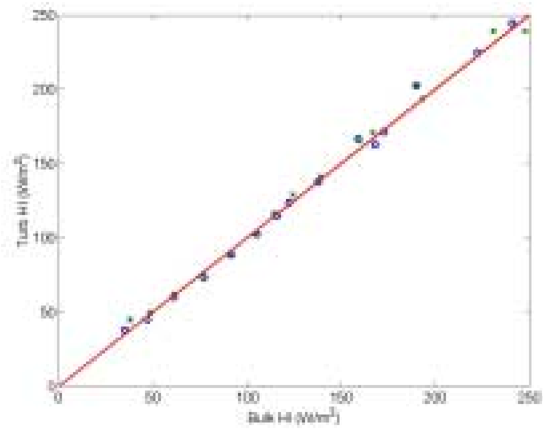

Figure-2. The same data points from Fig. 1 but plotted as bulk latent heat flux values versus turbulent values. The x's are the means; the circles are medians.

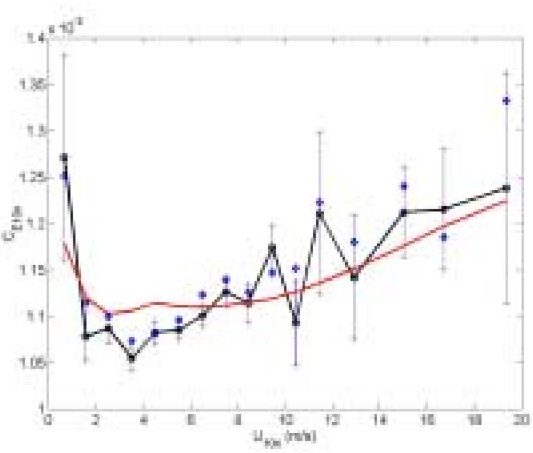

Figure- 4 Median moisture 10-m neutral transfer coefficient as a function of 10-m neutral wind. The diamonds are computed with method 1 (see text); the circles with method 3. Error bars indicate the statistical uncertainty (one sigma) of the *mean* estimate based on the distribution within the wind speed bin. The heavy solid line is COARE 2.6.

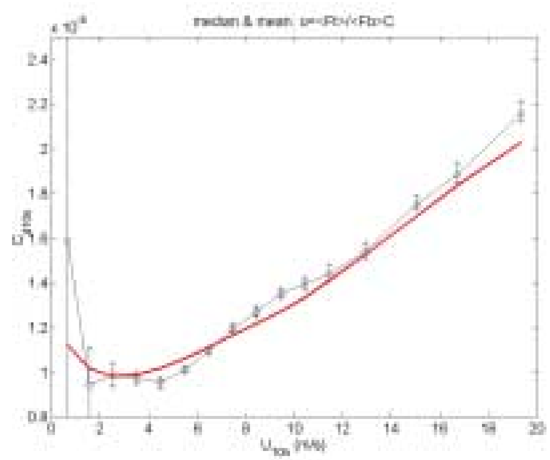

Figure-5 Median 10-m neutral velocity transfer coefficient as a function of 10-m neutral wind. The circles are computed with 3. Errors bars indicate the statistical uncertainty (one sigma) of the *mean* estimate based on the on the distribution within the wind speed bin. The heavy solid line is COARE 2.6