Naval Postgraduate School FLUX Buoy

Data Report

for the

MUSE Deployment

August - September 2000

Monterey Bay, California

Paul A. Frederickson, Kenneth L. Davidson, F. Keith Jones and Tamar Neta

Boundary Layer Studies Group
Department of Meteorology
Naval Postgraduate School
Monterey, CA

5 April 2001

NPS Flux Buoy Data Report

MUSE Deployment, Aug – Sep 2000 Deployment

Monterey Bay, California

Table of Contents

1. Introduction 3
2. Buoy Deployment Information 4
   - 2.1 Buoy Deployment and Data Availability Times 4
   - 2.2 Buoy Location Information 4
3. Buoy Measurements 5
   - 3.1 Mean Measurements 5
   - 3.2 Turbulence Measurements 6
4. Data Processing and Analysis Procedures 7
   - 4.1 Bulk Surface Layer Parameters 7
   - 4.2 Direct Covariance Flux Parameters 9
   - 4.3 Wave Spectra and Wave Parameters 12
5. Data File Descriptions 14
   - 5.1 One-Minute Averaged Meteorology Data File: ‘fb_mean_1min.dat’ 14
   - 5.2 Fifteen-Minute Averaged Bulk Data File: ‘fb_bulk_15min.dat’ 15
   - 5.3 One-Hour Averaged Flux Data File: ‘fb_flux_1hr.dat’ 16
   - 5.4 Nine-Minute Spectral Wave Energy Density Data File: ‘fb_wspectra_9min.dat’ 17
   - 5.5 One-Hour Spectral Wave Energy Density Data File: ‘fb_wspectra_1hr.dat’ 17
   - 5.6 One-Hour Directional Wave Energy Density Spectra Data Files: ‘dws_*ddd_hh*.dat’ 18
6. References 19

1. Introduction

The Boundary Layer Studies Group (BLSG) of the Department of Meteorology, Naval Postgraduate School (NPS), deployed its 'Flux' buoy in Monterey Bay in July-November 2000 as part of the MUSE collaborative research project. The Flux buoy (FB) is a 2 m diameter disk buoy instrumented with sensors to measure mean environmental parameters, atmospheric turbulence quantities and spectral wave data. This data report provides details of the flux buoy and specific information on the MUSE deployment. The details of the flux buoy MUSE deployment are presented in section 2. The buoy measurements are described in section 3 and the data processing and analysis methods are described in section 4. Finally, the format of the data files is presented in section 5.

Any questions regarding this report or the Flux buoy data files should be addressed to:

Paul Frederickson
Department of Meteorology
Naval Postgraduate School
589 Dyer Rd., Room 254
Monterey, CA 93943-5114
Phone: (831) 656-2407
FAX: (831) 656-3061
E-mail: pafreder@nps.navy.mil

2. Buoy Deployment Information

2.1 Buoy Deployment and Data Availability Times

The FB was deployed in Monterey Bay on 30 July 2000 and was recovered on 2 November 2000. Mean meteorological data is available for this entire period. Atmospheric turbulence and wave data are available continuously from 0206 UTC, 1 August 2000 to 1833 UTC, 9 September 2000, and then intermittently to 0928 UTC, 23 October, when the on-board data storage disk became full.

In order to reduce the amount of data to be stored, only data for the period of the actual MUSE experiment, 1 August through 5 September 2000, are included in the data files described in this report. To obtain data not contained within these data files, please contact the Naval Postgraduate School, as described in section 1 above.

2.2 Buoy Location Information

The FB mooring location in Monterey Bay was about 8.47 km (4.57 nautical miles) off Moss Landing, California, on a bearing of 262°. The nominal buoy location was:

Latitude: 36° 48.6′ North
Longitude: 121° 53′ West

The actual buoy location at a given time will vary slightly from the above location depending upon the wind and surface current, since the buoy is anchored with a scope of chain. The mean water depth at the FB location was approximately 83 m (42 fathoms). The magnetic deviation from true north for this location on 1 September 2000 (as computed by the GEOMAGIX software program available on the web) was 14.96°.

3. Buoy Measurements

The FB contains two separate data acquisition systems, one for obtaining mean environmental data, and one for obtaining high frequency atmospheric turbulence and platform motion data, from which turbulent fluxes and wave spectra are computed. These separate data acquisition systems are described in the next two subsections.

3.1 Mean Measurements

The mean data acquisition system samples environmental data from a suite of instruments at a 1 Hz sampling rate. These 1 Hz values were averaged into one minute blocks which were then stored in the onboard Onset computer disk. The FB mean sensors are described in Table 1. During post-processing the mean data were averaged into 15 minute and 1-hour blocks and bulk surface layer parameters were computed, as described in section 4.1 below.

Due to power constraints, the air temperature and relative humidity sensor (Rotronic MP101A) was mounted within a passively aspirated radiation shield, rather than a forced aspiration shield. For this reason when wind speeds are low the air temperature may have a slight positive bias and the relative humidity may have a slight negative bias during the day, and especially just after sunrise and just before sunset when the sun angle permits the most reflected radiation from reaching the sensors.

All mean data sensors and computers functioned normally during the entire deployment, with the exception of the float thermistor for measuring the sea surface temperature, which was destroyed by sea lions and stopped functioning at 1813 UTC, 8 September 2000. This sensor damage represents only a minor loss of data, since the sea temperature was also measured by an IR temperature transducer and a hull-mounted thermistor.

Table 1. Flux Buoy Mean Data Measurements

Measured Parameters	Sensor Type	Manufacturer And Model	Height Above Surface
Wind Speed/Direction	Propeller-vane anemometer	R. M. Young Wind Monitor Model 05106	3.90 meters
Air Temperature	Pt 100 RTD	Rotronic MP101A	3.94 meters
Relative Humidity	Rotronic Hygromer	Rotronic MP101A	3.94 meters
Atmospheric Pressure	Barometer	A.I.R.	2.1 meters
Sea Surface IR Temperature	IR Temperature Transducer	Everest Model 4000	2.40 meters
Bulk Skin Sea Temp	Floating thermistor	NPS custom design	0 to –5 cm
Bulk Sea Temperature	Hull thermistor	NPS custom design	–1.17 meters
Buoy Heading relative to Magnetic North	Magneto-Inductive Compass	Precision Navigation TCM-2	0.41 m

3.2 Turbulence Measurements

The FB turbulence data system measures atmospheric wind and temperature turbulence and buoy motion properties at a sampling rate of 10 Hz. These data are stored in the onboard computer in files of 992 Kbyte size. Each file contains a 38.7 minute time series record. The turbulence sensors are described in Table 2. These sensors have the capability to measure high frequency three-dimensional wind speed and sonic temperature and the buoy's three-dimensional linear accelerations, angular rotation rates and heading. All turbulence data sensors and computers functioned normally during the entire deployment. Direct covariance momentum and sonic buoyancy fluxes and wave spectra were derived from these high frequency measurements, as described in sections 4.2 and 4.3, respectively.

Table 2. Flux Buoy Turbulence Data Measurements

Measured Parameters	**Sensor Type**	**Manufacturer and Model**	**Height above Surface**
3-D Wind Speed & Sonic Temperature	3-D Ultrasonic Anemometer	Gill Instruments Model 1012/R3A	5.16 meters
3-D Buoy Linear & Angular Motion	Accelerometers & Rate Gyros	Crossbow Technology DMU-VGX	0.41 meters
Buoy Heading relative to Magnetic North	Magneto-Inductive Compass	Precision Navigation TCM-2	0.41 meters

4. Data Processing and Analysis Procedures

The methods used to compute bulk surface layer scaling parameters, direct covariance fluxes and surface wave parameters during post-processing are described in the next three subsections.

4.1 Bulk Surface Layer Scaling Parameters

Bulk surface layer scaling parameters (u_*, T_*, q_* and L) were computed from 1 hour averaged meteorology data using an NPS-modified version of the TOGA-COARE model described by Fairall et al. (1996). A brief description of the bulk model is presented here.

The bulk surface layer model is based upon Monin-Obukhov similarity (MOS) theory. According to MOS theory, conditions are assumed to be horizontally homogeneous and stationary, and the turbulent fluxes of momentum, sensible heat and latent heat are assumed to be constant with height in the surface layer. Scaling parameters for wind speed (u_*), temperature (T_*) and specific humidity (q_*) are defined in terms of the assumed-constant kinematic fluxes, as follows:

$$u_* \equiv \left[\langle -w'u' \rangle^2 + \langle -w'v' \rangle^2 \right]^{1/4}, \tag{1a}$$

$$T_* \equiv -\frac{\langle w'T' \rangle}{u_*}, \tag{1b}$$

$$q_* \equiv -\frac{\langle w'q' \rangle}{u_*}, \tag{1c}$$

where u is the along-stream wind component, v is the cross-stream wind component, w is the vertical wind component, T is the air temperature, q is the specific humidity and a prime denotes the instantaneous turbulent fluctuation of a quantity from its mean value.

According to MOS theory, any dynamic surface-layer property made dimensionless by the proper scaling parameters can be expressed as a universal function of ξ, defined as:

$$\xi = \frac{z}{L} = \frac{zkg(T_* + 0.61Tq_*)}{\theta_v u_*^2}, \tag{2}$$

where z is the height above the surface, L is the Obukhov length scale, k is the von Karman constant (≈ 0.4), g is the gravitational acceleration and θ_v is the virtual potential temperature. The mean vertical profiles of wind speed (U), temperature (T), and specific humidity (q) within the surface layer are defined according to MOS theory as follows:

$$U(z) = U_o + \frac{u_*}{k}\left[\ln\left(\frac{z}{z_{oU}}\right) - \Psi_U(\xi)\right], \quad (3a)$$

$$T(z) = T_o + \frac{T_*}{k}\left[\ln\left(\frac{z}{z_{oT}}\right) - \Psi_T(\xi)\right], \quad (3b)$$

$$q(z) = q_o + \frac{q_*}{k}\left[\ln\left(\frac{z}{z_{oq}}\right) - \Psi_q(\xi)\right], \quad (3c)$$

where the Ψ functions are the integrated forms of the respective dimensionless profile functions. We have used the dimensionless profile Ψ functions given by Grachev et al. (2000) for unstable cases (ξ =< 0), and the functions given by Beljaars and Holtslag (1991) for stable conditions ($\xi > 0$). We hereafter make the assumption that $\Psi_T = \Psi_q$. The 'roughness lengths' z_{oU}, z_{oT} and z_{oq} are the heights where the log-z profiles of U, T and q, respectively, reach their surface values (denoted by the subscript 'o').

The momentum roughness length, z_{oU}, is parameterized as (Fairall et al. 1996):

$$z_{oU} = \frac{\alpha u_*^2}{g} + \frac{0.11\nu}{u_*} \quad (4)$$

where ν is the kinematic viscosity of air and α is Charnock's parameter, which is thought to depend upon such factors as wave age, fetch, water depth, etc., although the exact relationships are not clear. We have used a value of 0.014 for α, which is thought to be generally representative of coastal ocean regions. Use of a constant value for α implicitly assumes that the wave field is fully developed (i.e. in equilibrium with the wind and hydrographic conditions).

Observations have indicated that the scalar roughness lengths behave quite similarly, therefore we assume $z_{oT} = z_{oq}$. The thermal roughness length z_{oT} is parameterized as follows in the TOGA-COARE model version 2.5:

$$z_{oT} = 5.5 \times 10^{-5} R_R^{-0.63} \quad (5)$$

where R_R is the roughness Reynolds number, defined as $R_R = z_{oU}u_*/\nu$.

The specific humidity at the surface, q_o, is determined by assuming the sea surface is saturated, therefore, $q_o = 0.98q_{sat}(T_o)$, where $q_{sat}(T_o)$ is the saturation specific humidity at the sea surface temperature T_o, and the factor 0.98 accounts for salinity effects.

The wind speed at the ocean surface is assumed to be zero (U_o = 0). We have adopted the 'free-convective' parameterization described by Fairall et al. (1996), in which U includes a 'gustiness' component when $\xi < 0$, as follows:

$$U = \left(u_{avg}^2 + w_g^2\right)^{1/2}, \tag{6}$$

where u_{avg} is the scalar averaged wind speed and w_g is the 'convective gustiness velocity' given by:

$$w_g = \beta\left[-\frac{g z_i u_*}{\theta_v}\left(T_* + 0.61 T q_*\right)\right]^{1/3}. \tag{7}$$

β is an empirical constant with a value of about 1.25, and z_i is the convective boundary layer height, which we assume to be 600 m, as recommended by Fairall et al. (1996).

Solving Eq. (3) for the scaling parameters results in:

$$u_* = Uk\left[\ln\left(\frac{z}{z_{oU}}\right) - \Psi_U\left(\frac{z}{L}\right)\right]^{-1}, \tag{8a}$$

$$T_* = \Delta T k\left[\ln\left(\frac{z}{z_{oT}}\right) - \Psi_T\left(\frac{z}{L}\right)\right]^{-1}, \tag{8b}$$

$$q_* = \Delta q k\left[\ln\left(\frac{z}{z_{oq}}\right) - \Psi_q\left(\frac{z}{L}\right)\right]^{-1}, \tag{8c}$$

where the Δ operator denotes a mean air-sea difference. Inserting Eq. (8) into (2) results in:

$$L = \frac{\theta_v U^2\left[\ln\left(z / z_{oT}\right) - \Psi_T(\xi)\right]}{g(\Delta T + 0.61 T \Delta q)\left[\ln\left(z / z_{oU}\right) - \Psi_U(\xi)\right]^2} \tag{9}$$

The bulk surface layer scaling parameters u_*, T_* and q_* are computed by an iterative process from Eqs. (4) to (9) using the averaged measurements of wind speed, air temperature, sea temperature and relative humidity.

4.2 Direct Covariance Parameters

Direct covariance flux values were computed from the high frequency sonic anemometer and motion sensor data over 9.25 minute block averages using the following procedure:

1) The platform motion is subtracted from the observed buoy-referenced wind data using the methods outlined in Edson et al. (1998). This procedure not only removes the platform motion contamination from the observed wind data, but also converts the observed wind data into an earth-based reference frame with east-west, north-south and vertical wind components.

2) The motion-corrected horizontal wind components are rotated into the mean wind direction giving along-stream (u), across-stream (v) and vertical (w) wind components such that $\overline{v} = 0$, using the following equations:

$$u_{rot} = -u_{obs}\cos(\phi) + v_{obs}\sin(\phi) \tag{12a}$$

$$v_{rot} = -u_{obs}\sin(\phi) - v_{obs}\cos(\phi) \tag{12b}$$

where ϕ is the vector averaged wind direction.

3) The 'tilt' correction is applied by rotating the u and w wind components such that $\overline{w} = 0$, using the following equations:

$$u_{cor} = u_{rot}\cos(\theta) + w_{obs}\sin(\theta) \tag{13a}$$

$$w_{cor} = -u_{rot}\sin(\theta) + w_{obs}\cos(\theta) \tag{13b}$$

where $\theta = \arctan\left(\overline{w}/\overline{u}\right)$.

4) Co-spectra were computed from consecutive 9.25 minute time series records of the motion-corrected wind components and sonic temperature using an FFT routine. The co-spectra computed were for a) the vertical wind fluctuations (w') and the along-stream wind fluctuations (u'), b) the vertical wind fluctuations and the across-stream wind fluctuations (v') and c) the vertical wind fluctuations and the sonic temperature fluctuations (T_s'), where a prime denotes the instantaneous turbulent fluctuation of a quantity from its mean value.

5) Direct covariance kinematic fluxes were computed by summing the co-spectra over all frequencies. The **kinematic along-wind momentum flux** is computed as follows:

$$-<u'w'> = -\sum_f Co_{u'w'}(f) \tag{14a}$$

The **kinematic across-wind momentum flux** is computed as follows:

$$-<v'w'> = -\sum_f Co_{v'w'}(f) \tag{14b}$$

The **kinematic sonic buoyancy flux** is computed as follows:

$$-<T_s'w'> = -\sum_f Co_{T_s w'}(f). \qquad (14c)$$

6) Six consecutive 9.25 minute-averaged kinematic flux values were then averaged into a nominal 1 hour block (actually 55.5 minutes).

7) The 1 hour flux values were then merged with the 1 hour-averaged meteorology data and bulk parameters, computed as described in section 4.1.

At this point it is important to illustrate the difference between the sonic temperature, the air temperature and the virtual temperature and how these differences relate to the different buoyancy fluxes. The virtual temperature T_v is given by:

$$T_v = T(1 + 0.61q) \qquad (15)$$

where T is the air temperature and q is the specific humidity. The sonic temperature T_s is given by:

$$T_s = T(1 + 0.51q) \qquad (16)$$

The kinematic buoyancy flux is defined as:

$$b = \langle w'T_v' \rangle = \langle w'T' \rangle (1 + 0.61\bar{q}) + 0.61\bar{T} \langle w'q' \rangle \qquad (17)$$

The kinematic sonic buoyancy flux is defined as:

$$b_s = \langle w'T_s' \rangle = \langle w'T' \rangle (1 + 0.51\bar{q}) + 0.51\bar{T} \langle w'q' \rangle \qquad (18)$$

These two buoyancy flux quantities are usually very close to each other, within 5% for absolute Bowen ratio values less than ~0.3. When the air-sea temperature difference is large and humidity is high, the sonic buoyancy flux will be an excellent approximation of the true buoyancy flux. When the air-sea temperature difference is small and the humidity is low, the sonic buoyancy flux becomes a poorer approximation of the true buoyancy flux. Since direct measurements of virtual temperature fluctuations (T_v') are extremely difficult to make over the ocean from an unattended buoy, it is common to use the sonic temperature fluctuations instead to estimate the buoyancy flux, as we have done here.

Once 1 hour averaged values of the along wind ($-<u'w'>$) and across-wind ($-<v'w'>$) kinematic momentum fluxes and the kinematic sonic buoyancy flux ($-<T_s'w'>$) have been determined, the following parameters are computed:

The **friction velocity (u_*)** is computed as follows:

$$u_* \equiv \sqrt{\frac{\tau}{\rho}} = \left[\langle -u'w' \rangle^2 + \langle -v'w' \rangle^2\right]^{1/4} \tag{19}$$

where τ is the momentum flux and ρ is the air density.

The **momentum flux direction relative to the mean wind (τ_{ang})** is given by:

$$\tau_{ang} = \arctan\left(\frac{< -v'w' >}{< -u'w' >}\right) \tag{20}$$

τ_{ang} is defined as an angle rotated clockwise from the mean wind direction. Positive values of τ_{ang} indicate the momentum flux vector points to the right of the wind vector, ang negative values of τ_{ang} indicate the momentum flux vector points to the left of the wind vector.

The **Obukhov length (L)** is computed as follows:

$$L = -\frac{\theta_v u_*^3}{kg < w'T_s' >} \tag{21}$$

where θ_v is the virtual potential temperature.

4.3 Surface Wave Spectra and Wave Parameters

In order to compute wave spectra, the north-south, east-west and vertical buoy displacement time series were computed by rotating the observed buoy linear accelerations obtained from the three-dimensional motion sensor into the earth reference frame and then double integrating. Every eighth available data point was used in the wave spectra computation, resulting in a 2 Hz sampling rate.

One-dimensional wave height spectra were obtained by computing FFTs from consecutive 256 point blocks of the vertical displacement time series. These 256-point wave height spectra were then averaged by frequency bins into 9.25 minute spectra and wave parameters were determined from these averaged wave spectra, as described below.

The averaged wave height spectra were summed over all frequencies to obtain the variance of the wave height, σ^2_{wave}. The **significant wave height** (H_s) was then estimated from σ^2_{wave} as follows:

$$H_s = 4\sqrt{\sigma^2_{wave}}\,. \tag{22}$$

The significant wave height defined by this equation is approximately equal to the crest-to-trough height exceeded by one-third of the waves.

The **peak spectral frequency** (f_p) was determined by finding the wave height spectral frequency containing the maximum energy. The **peak spectral period** (P_p) is simply the inverse of the peak spectral frequency ($1/f_p$). The wave number (k_p) corresponding to the peak spectral frequency (f_p) was determined from the surface dispersion relationship for finite water depth and neglecting surface tension, as follows:

$$\omega_p^2 = g k_p \tanh(k_p D) \tag{23}$$

where ω_p is the peak radian frequency ($= 2\pi f_p$), g is the gravitational acceleration, k_p is the peak wave number, and D is the water depth (83 m). The surface dispersion relationship was solved iteratively for k_p using Newton's method and the **peak phase speed** (c_p) was then computed from the relation

$$c_p = \frac{\omega_p}{k_p} = \frac{2\pi f_p}{k_p}. \tag{24}$$

The wave spectra were cumulatively summed from low to high frequencies to find the frequencies corresponding to where 25%, 50% and 75% (denoted as f_{25}, f_{50} and f_{75}, respectively) of the total wave height variance (σ_{wave}^2) is obtained. The frequency corresponding to 50% of the total variance, f_{50}, is also known as the 'characteristic' frequency of the wave spectra. A useful parameter for describing the width of frequencies containing energy in the wave spectra can be given by calculating the bandwidth that includes 25% to 75% of the accumulated variance (i.e. $f_{75} - f_{25}$).

Directional wave spectra were computed from the earth-referenced north-south, east-west and vertical displacement time series using the Maximum Entropy Method (MEM) described by Lygre and Krogstad (1986). The directional wave spectra were computed with a directional resolution of 1°. The **peak wave direction** was determined from the directional wave spectra by finding the direction that contained the peak spectral energy.

5. Data File Descriptions

The FB data collected during the MUSE experiment deployment of August-September 2000 are contained in separate data files: one containing raw 1 minute averaged mean meteorological data; one containing 1 hour averaged mean meteorology data, air-sea fluxes and wave statistics; one containing one-dimensional wave spectral density data; and 862 files containing directional wave spectral density data. These files are described in the following sections.

5.1 One-minute averaged meteorology data file: 'fb_mean_1min.dat'

One-minute averaged 'raw' meteorology data are contained in the file named 'fb_mean_1min.dat'. The file contains data from 0000 UTC, 1 August 2000 to 0000 UTC, 6 September 2000. Each data record of this file contains 14 parameters in separate columns, as described in Table 3. Values of –99 indicate missing data or bad data identified in post-processing.

Table 3. Format for 'fb_mean_1min.dat' Data File

Column	Parameter	Units
1	Year Day (UTC) at end of 1 min averaging interval	Decimal day
2	Date (UTC) at end of 1 min averaging interval	MMDD
3	Time (UTC) at end of 1 min averaging interval	HHMM
4	Wind speed at 3.90 m above surface	m/s
5	Wind direction at 3.90 m above surface relative to True North	Deg cw from True North
6	Wind direction at 3.90 m above surface relative to buoy bow	Deg cw from buoy bow
7	Magnetic Compass heading	Deg cw from Mag. North
8	Air temperature at 3.94 m above surface	°C
9	Relative humidity at 3.94 m above surface	%
10	Atmospheric pressure at 2.10 m above surface	Mb
11	IR sea surface temperature	°C
12	Hull sea temperature at 1.17 m below surface	°C
13	Float sea temperature within 2 cm of surface	°C
14	Battery Voltage	Volts

5.2 Fifteen minute averaged bulk data file: fb_bulk_15min.dat

Fifteen-minute averaged meteorology data and bulk surface layer scaling parameter estimates are contained in the file named 'fb_bulk_15min.dat'. The file contains data from 1 August 2000 through 5 September 2000. The format of this data file is described in Table 5. Values of –99 indicate missing data or bad data identified in post-processing. In some low-wind speed cases the bulk model will not converge to a solution and the bulk parameters are set to –99.

Table 5. Format for 'fb_bulk_15min.dat' Data Files

Column	Parameter	Units
1	Year Day (UTC) at beginning of averaging interval	Decimal day
2	Year Day (UTC) at end of averaging interval	Decimal day
3	Date (UTC) at end of averaging interval	MMDD
4	Time (UTC) at end of averaging interval	HHMM
5	Wind speed at 3.90 m above surface	m/s
6	Wind direction at 3.90 m above surface	Deg. cw from True North
7	Air temperature at 3.94 m above surface	°C
8	Relative humidity at 3.94 m above surface	%
9	Atmospheric pressure at 2.1 m above surface	mb
10	IR sea surface temperature	°C
11	Hull sea temperature at 1.17 m below surface	°C
12	Float sea temperature within 5 cm of surface	°C
13	Bulk friction velocity (u_*)	m/s
14	Bulk temperature scaling parameter (T_*)	°C
15	Bulk specific humidity scaling parameter (q_*)	g/g
16	Bulk Obukhov length (L)	m

Note: Values of –99 indicate missing data or bad data.

5.3 One-Hour Averaged Flux Data File: fb_flux_1hr.dat

One-hour averaged mean meteorology data, bulk scaling parameters, turbulent fluxes and wave parameters are contained in the file named 'fb_flux_1hr.dat'. The file contains data from 1 August through 5 September 2000. The format of this data file is described in Table 6. Values of –99 indicate missing data or bad data identified in post-processing. Note that in the following table DC = direct covariance.

Table 6. Format for 'fb_flux_1hr.dat' Data File

Column	Parameter	Units
1	Year Day (UTC) at beginning of averaging interval	Decimal day
2	Year Day (UTC) at end of averaging interval	Decimal day
3	Date (UTC) at end of averaging interval	MMDD
4	Hour (UTC) at end of averaging interval	Hour
5	Wind speed at 5.23 m above surface	m/s
6	Wind direction at 5.23 m above surface	Deg. cw from True North
7	Air temperature at 3.94 m above surface	°C
8	Relative humidity at 3.94 m above surface	%
9	Atmospheric pressure at 2.1 m above surface	mb
10	IR sea surface temperature	°C
11	Hull sea temperature at 1.17 m below surface	°C
12	Float sea temperature within 5 cm of surface	°C
13	Bulk friction velocity (u_*)	m/s
14	Bulk temperature scaling parameter (T_*)	°C
15	Bulk specific humidity scaling parameter (q_*)	g/g
16	Bulk Obukhov length (L)	m
17	DC friction velocity (u_*)	m/s
18	DC along-wind kinematic momentum flux ($-\langle u'w' \rangle$)	m^2/s^2
19	DC across-wind kinematic momentum flux ($-\langle v'w' \rangle$)	m^2/s^2
20	DC momentum flux direction (τ_{ang})	Deg. cw from mean wind
21	DC sonic temperature scaling parameter (T_{s*})	°C
22	DC kinematic sonic buoyancy flux ($-\langle w'T_s' \rangle$)	m/s × °C
23	DC Obukhov length (L)	m
24	Significant wave height (H_s)	m
25	Wave period of peak energy (P_p)	seconds
26	Phase speed at peak frequency (c_p)	m/s
27	Wave spectra frequency at 25% accumulated variance (f_{25})	Hz
28	Wave spectra frequency at 50% accumulated variance (f_{50})	Hz
29	Wave spectra frequency at 75% accumulated variance (f_{75})	Hz
30	Direction containing maximum wave energy	Deg. cw from True North

5.4 Nine-Minute Spectral Wave Energy Density Data File: 'fb_wspectra_9min.dat'

The one-dimensional spectral wave energy density data computed from 9.25 minute time series records are contained in the file named 'fb_wspectra_9min.dat'. Each data record in this file contains 78 separate columns, as described in table 7.

Table 7. Format for 'fb_wspectra_9min.dat' Data File

Column	Parameter	Units
1	Year Day (UTC) at beginning of averaging interval	Decimal Day
2	Year Day (UTC) at end of averaging interval	Decimal Day
3-78	Spectral Wave Energy Density (76 point array) for frequencies $f = i \times \Delta f$ where i = 1,2,3,…,76 and Δf = 2/256 = 0.0078125.	cm^2/Hz

5.5 One-Hour Spectral Wave Energy Density Data File: 'fb_wspectra_1hr.dat'

The one-dimensional spectral wave energy density data averaged over 1 hour intervals are contained in the file named 'fb_wspectra_1hr.dat'. These averaged spectra were averaged in frequency bins from the 9.25 minute spectra described above. Each data record in this file contains 78 separate columns, as described in table 8. These data files can be read and wave energy density spectra plotted using the accompanying MATLAB program named "plot_wave_spectra.m".

Table 8. Format for 'fb_wspectra_1hr.dat' Data File

Column	Parameter	Units
1	Year Day (UTC) at end of 1 hour averaging interval	Year Day
2	Hour of day (UTC) at end of 1 hour averaging interval	Hour
3-78	Spectral Wave Energy Density (76 point array) for frequencies $f = i \times \Delta f$, where i = 1,2,3,…,76 and Δf = 2/256 = 0.0078125.	cm^2/Hz

5.6 One-Hour Directional Wave Energy Density Spectra Data Files: 'dws_*ddd_hh.mat'*

The one-hour averaged directional wave energy density spectra are contained in separate files for each spectrum. The file name convention is 'dws_*ddd_hh*.mat,' where *ddd* is the Year Day 2000 and *hh* is the hour of day (UTC). The files start at year day 214, hour 03 and run continuously through to year day 250, hour 00, for a total of 862 files. The files are in MATLAB .mat binary format and can be read into MATLAB programs using the 'load' command. The data in each file consist of a 76 (frequency) × 360 (direction) matrix named 'dwspec.' The 'dwspec' matrix contains directional wave energy density spectral data points in cm^2/Hz, corresponding to frequencies $f = i \times \Delta f$ where i = 1,2,3,…,76 and $\Delta f = 2/256 = 0.0078125$ and directions from 0 to 359 degrees in 1 degree intervals. These data files can be read and directional wave spectra plotted using the accompanying MATLAB program named "plot_dir_wave_spectra.m".

6. References

Beljaars, A. C. M., and A. A. M. Holtslag, 1991: Flux parameterization over land surfaces for atmospheric models. *J. Appl. Meteor.*, **30**, 327-341.

Edson, J. B., A. A. Hinton, K. E. Prada, J. E. Hare, and C. W. Fairall, 1998: Direct covariance flux estimates from mobile platforms at sea. *J. Atmos. Oceanic Technol.*, **15**, 547-562.

Fairall, C. W., 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**, 3747-3764.

Grachev, A. A., C. W. Fairall, and E. F. Bradley, 2000: Convective profile constants revisited. *Bound.-Layer Meteorol.*, **94**, 495-515.

Lygre, A., and H. E. Krogstad, 1986: Maximum entropy estimation of the directional distribution in ocean wave spectra. *J. Phys. Oceanogr.*, **16**, 2052-2060.