6A.8 LONG TERM MEASUREMENT OF TURBULENT FLUXES AT SEA

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1. INTRODUCTION

From May through December of 1999, scientists from the Air-Sea Interaction Group within the NOAA Environmental Technology Laboratory deployed a semi-unattended turbulent flux measurement system on board the *NOAA Ship Ronald H. Brown*. Motion-corrected direct covariance measurements of the turbulent fluxes of sensible heat, latent heat, and momentum were made continuously over the 7-month expedition, in which the *Brown* traveled in various regions of the world's oceans (see Figure 1), including in the Bay of Bengal (the JASMINE experiment), in the vicinity of the Pacific islands of Nauru (NAURU99 experiment) and Kwajalein (KWAJEX), the Gulf of Alaska, the U.S. West Coast, and the Equatorial Eastern Pacific (PACS/EPIC experiment). These areas represent widely disparate meteorological regimes, and therefore represent a unique opportunity to test and improve the bulk parameterizations which are routinely used in numerical models over a variety of conditions. Therefore, these flux measurements serve not only as meteorological support for the several science missions on the *Brown*, but they also provide developmental benefits. The long deployment enables us to develop indirect flux measurement methods (inertial-dissipation), to improve the method for making direct covariance flux measurements (Edson et al., 1997), and to improve the automated systems for use on ships of opportunity.

Over the course of the long deployment, wind speeds ranged from 0-18 m/s, sea-air temperature differences ranged between -1.6 and 4.9 degrees, sea-air specific humidity differences between 0 and 12 g/kg (see Figure 2). In addition, remote-sensing systems such as a ceilometer, a high-resolution Doppler lidar, C-band, S-band, and Ka-band radars, a wind profiler, a microwave scatterometer, a variety of radiometers, and regular rawindsonde flights were deployed during individual legs of the excursion, and these data sets provide detailed descriptions of the structure of the atmospheric boundary layer.

2. THE ETL TURBULENT FLUX SYSTEM

The Air-Sea Interaction Group at ETL has been conducting marine atmospheric research cruises since 1989. The ship-based system results in a combination of very accurate bulk meteorological measurements with both direct covariance (ship motion corrected) and inertial-dissipation turbulent fluxes. We are currently working on the creation of a single data base, which will include the flux measurements from all of the past cruises (approximately 20) undertaken by the Group. Details of the system can be found in Fairall et al. (1997). The cornerstones of the system are the fast-response Gill Solent sonic anemometer/thermometer and a Hewlett-Packard UNIX-based data acquisition computer. Additional components include an Ophir infrared hygrometer, a 3-axis accelerometer/ rotation rate sensor package, a GPS receiver and gyrocompass, plus sensors for the measurement of mean air temperature, humidity, sea surface temperature, rain rate, and downwelling solar and infrared irradiance. Figure 3 shows the *Brown* in the port of Singapore prior to the start of the 7-month deployment with the ETL flux package mounted on the *Brown* jackstaff, 18 meters above the mean sea surface.

Although the flux system is not fully automated at this time, only a modest degree of attention is required to maintain its operation. Besides the obvious issues of monitoring the data stream and possible replacement of faulty instrumentation, the operator tasks include daily and weekly data backups, cleaning of optics on some of the instruments, running the preliminary processing routines and e-mailing a data summary

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file back to scientists at ETL. This information makes it possible for us to remotely assess the operation and performance of individual instruments on a daily basis and to quickly communicate instructions to the operator.

3. COARE 2.6a PARAMETERIZATION

The COARE Bulk Flux Algorithm (Fairall et al., 1996) was developed for the COARE program, and as a result, has been demonstrated to perform well in tropical regimes (Zeng et al., 1998). However, the algorithm has not been extensively tested against a large and latitudinally diverse data base. In some cases, there is a clear physical basis for questioning the global generality: the Coriolis effect on the warm layer, the balance of sensible and latent heat fluxes (Bowen ratio), the climatology of swell versus wind seas, the distribution of mean winds and sea-air temperature difference all change with latitude.

As detailed in Bradley et al. (this volume), we continue to make improvements to the COARE Bulk Flux Algorithm. The latest version, Coare 2.6a, includes an improvement with an empirical wind-speed dependent Charnock formula based on the work of Yelland and Taylor (1996) and Hare et al. (1999), a simplified scalar roughness parameterization, as well as improvements to the profile functions. The COARE 2.6a algorithm is publically available in both Matlab and Fortran formats at the ETL ftp site: ftp://ftp.etl.noaa.gov/pub/et7/users/cwf/bulkalg/

4. RESULTS AND CONCLUSION

A total of 180 days of turbulent flux data were acquired during the long deployment, and the system and instruments performed well despite the harsh environment. However, a number of factors reduce the total volume of quality data, including flow distortion, relative wind direction, multiple course and/or ship speed changes, strong rain, etc. After filtering out these effects, more than 2000 hours of useful data were processed. The processed fluxes and mean meteorological variables (Figure 2) were averaged into one-hour segments, and these data were then bin-averaged with respect to mean wind speed and are presented in Figure 4.

Although these data are preliminary, the figures demonstrate our capacity to produce measurements over long-period deployments. The data sets described here will be incorporated into the global data base. Because the accurate estimation of the turbulent fluxes of heat and momentum is an integral element to numerical weather and climate models, direct observation of the turbulence is an essential strategy for the improvement of the bulk parameterizations. Furthermore, there is a current need to extend the bulk algorithms for global coverage. This, combined with the need for the development of satellite retrieval algorithms, points to the requirement for accurate *in situ* turbulent data sets over the global ocean. Although fully-automated covariance measurements are still somewhat logistically cumbersome, we have overcome many of the technical difficulties of making continuous measurements of turbulence over the open ocean.

5. ACKNOWLEDGEMENTS

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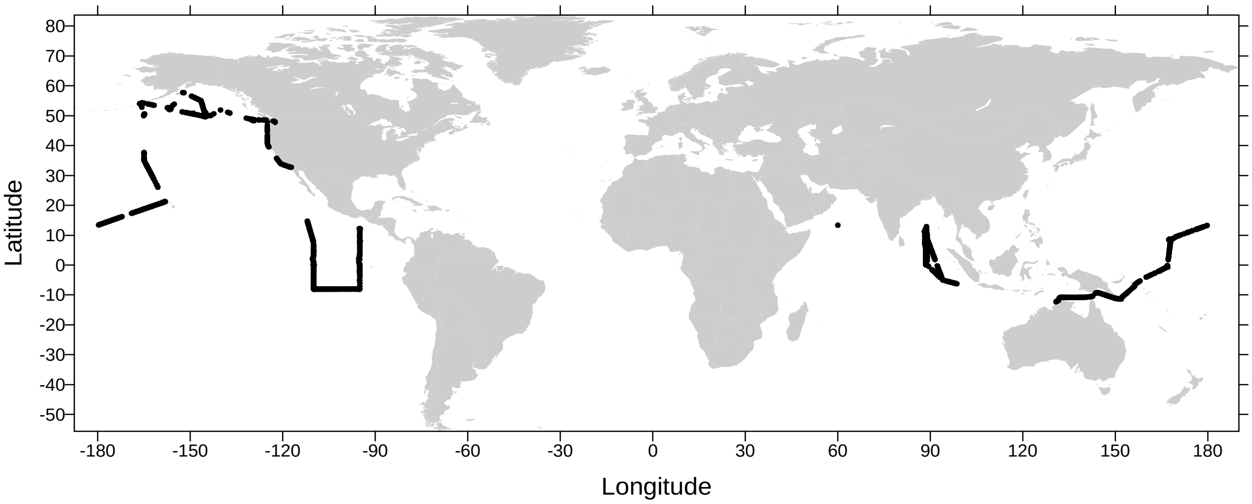

Figure 1 Map showing the track of the NOAA Ship *Ronald H. Brown*. Plotted points denote locations where quality hourly turbulent flux data were acquired.

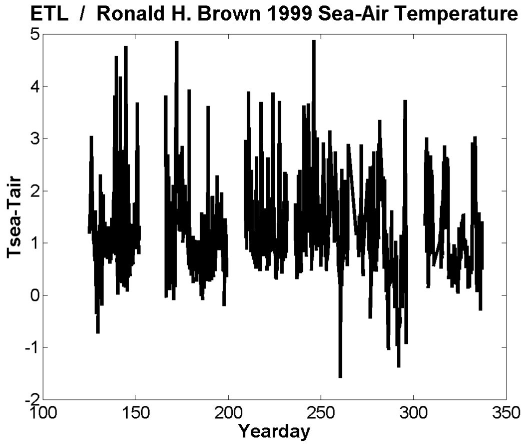

Figure 2a Sea-air temperature difference over the 7-month deployment.

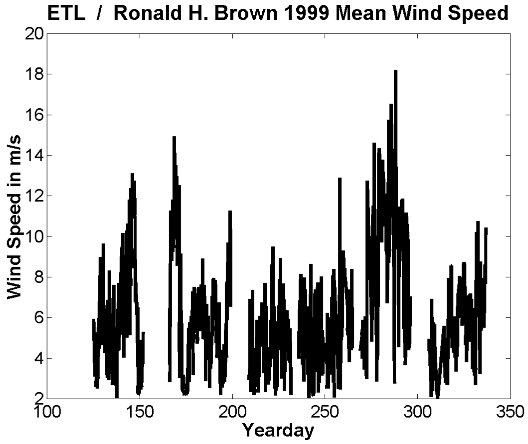

Figure 2c Hourly wind speed.

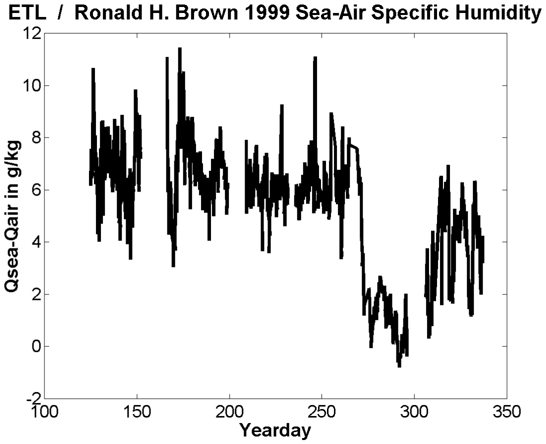

Figure 2b Sea-air specific humidity difference for the entire period.

Figure 3 Photo of the *Ronald H. Brown*, showing the ETL Turbulent Flux System mounted on the jackstaff.

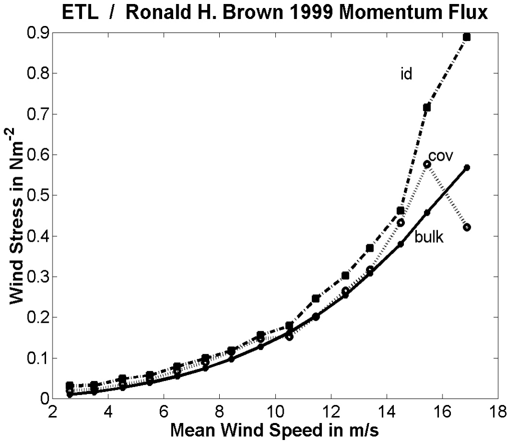

Figure 4a Wind-speed bin-averaged momentum flux

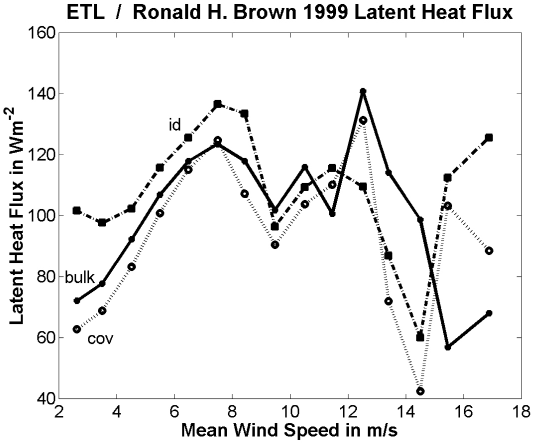

Figure 4b Latent heat flux

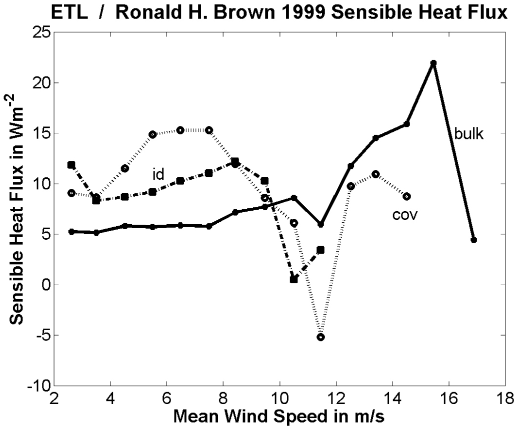

Figure 4c Sensible heat flux