Preliminary Surface Energy Budget Measurements from Nauru99

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Introduction

The NOAA *R/V Ronald H. Brown* conducted a series of measurements in transit to and in the vicinity of the DOE CART site on Nauru in June-July 1999 as part of an joint NOAA-ARM intensive study of air-sea interaction and cloud/radiative processes in the tropical western Pacific. This cruise, which has been designated Nauru99, was a follow-up to an earlier study at Manus Island (Post et al. 1997). Also participating in this study were the Japanese *R/V Mirai*, the Flinders University research aircraft, and a host of investigators at the ARM Tropical Western Pacific (TWP) site on Nauru. See http://www.etl.noaa.gov/nauru99/ and associated links for more detail.

The ARM effort on *R/V Ronald H. Brown* for Nauru99 featured an ensemble of instruments to make measurements in the ocean and atmosphere with a combination of *in situ* and remote sensing methods. On the atmospheric and near-surface ocean side, measurements included gps rawinsondes, bulk near-surface meteorology, air-sea turbulent fluxes, radiative fluxes, numerous raingages, three profiling Doppler radars, microwave and IR radiometers, a cloud ceilometer, and a scanning C-band Doppler precipitation radar.

In this paper we will focus on one set of measurements made with the ETL air-sea flux system including preliminary calculations of various terms (sensible, latent, and cool-rain heat fluxes plus net solar and IR radiative fluxes) of the surface energy budget. Cruise averages will be compared with previous (and a few subsequent) ETL cruises in the tropics.

ETL Flux Measurement Systems

The ETL ship-based air-sea interaction system was used for bulk meteorology, radiative, and turbulent flux measurements with additional measurements provided by the ship's operational instruments. The majority of the sensors were mounted on a scaffold unit just aft of the bow; the turbulence sensors were mounted on a forward-facing boom on the ship's jackstaff at the most forward and best exposed location on the ship (Fig. 1). The ETL measurement system is described in detail by Fairall *et al.* (1997). A sonic anemometer/thermometer is used to make turbulent measurements of stress and buoyancy flux; a high-speed infrared hygrometer is used with the sonic velocity data to obtain latent heat flux. An inertial navigation system is used to correct for ship motions (Edson et al., 1997). Fluxes are computed using covariance, inertial-dissipation, and bulk techniques (Fairall et al., 1996). Sea-surface temperature is derived from bulk water measurements at a depth of 5 cm with a floating thermistor. Mean air temperature and humidity are derived from a conventional aspirated T/RH sensor; the infrared hygrometer provided redundant information. Cloud information is obtained from a commercial lidar ceilometer with a vertical resolution of 35 m and a maximum range of 7.8 km.

Air-Sea Flux Results

The ship departed Darwin, Australia on June 15, arriving at a TAO buoy at 2 S 165 W (Fig. 2) on June 23. After one week on station it departed, reaching Nauru Island the next day where it remained for another two weeks. Fig. 3 shows the daily averages of the main components of the net heat flux to the ocean

$$H_{net} = R_{ns} + R_{nl} + H_s + H_l + H_{rain} = R_{ns} + R_{nl} + H_T \tag{1}$$

where R_{ns} is the net solar radiative flux, R_{nl} the net longwave radiative flux, H_s the sensible heat flux, H_l the latent heat flux, and H_{rain} (not shown) the heat flux carried by precipitation. A positive value implies the flux warms the ocean. The solar flux is balanced primarily by evaporation and net IR cooling. Fig. 4 shows the time series of daily average of rain fall; disturbed (deep convection) periods are apparent as spikes in the rainfall. In undistrubed periods, the ocean warms by about 100 W/m^2 while in disturbed conditions it cools by about 100 W/m^2 . The cooling in disturbed conditions is a combination of cloud radiative forcing and stronger winds that increase evaporative cooling. The ship reached Nauru on day 182 but only experienced a few days of convective activity at that location.

A sample of flux component time series at higher time resolution is shown in Fig. 5. These data were taken while the ship was in the vicinity of the TAO buoy at 2 S 165 E. Winds were very light the first two days, then began to pick up in association with a mild disturbance that went through on day 178.

Table 1. Sea-air surface flux components in the tropics [W/m^2]; variables defined in text.

Experiment	R_{ns}	R_{nl}	H_s	H_l	H_{rain}	H_T	H_{net}
Earlier 6-Cruise Average	**204**	**-49**	**-8**	**-107**	**-2.0**	**-120**	**35**
JASMINE	205	-43	-9	-125	-1.9	-135	27
NAURU99	216	-54	-5	-123	-.5	-129	33
KWAJEX-1	220	-47	-7	-95	-2.5	-105	69
KWAJEX-2	214	-44	-8	-102	-2.9	-113	57
σ_X (10-cruise std)	18	5	2.5	11	1.1	12	26

Cruise averages and the 10-cruise standard deviation for surface flux components are given in Table 1 along with results from other tropical cruises made by ETL. The earlier 6-cruise average includes three cruise legs from TOGA COARE, the COARE Pilot, TIWE, and CSP cruises.

While precipitation was low for Nauru99 (about one-third average) presumably because of the strong La Nina, the mean low cloud fraction (0.27) was fairly typical and average flux components were similar to past cruises. However, surface cloud radiative forcing for solar flux was only 40W/m^2, significantly less than the 70 W/m^2 that is typical.

References

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Figure Captions

Figure 1. View of *R/V Ronald H. Brown* showing flux instruments on the bow tower and jackstaff. The large white sphere is the C-band Doppler radar.

Figure 2. Cruise track of *R/V Ronald H. Brown* during Nauru99. The diamonds are TAO buoy locations.

Figure 3. Time series of daily averaged flux components: sensible heat flux (green circles), latent heat flux (red line), net solar flux (blue line), and net IR flux (black dots).

Figure 4. Time series of daily averaged rainfall.

Figure 5. Time series of flux components while on station near the TAO buoy at 2 S and 165 W: sensible heat flux (green circles), latent heat flux (red line), net solar flux divided by 10 (blue line), and net IR flux (black dots).

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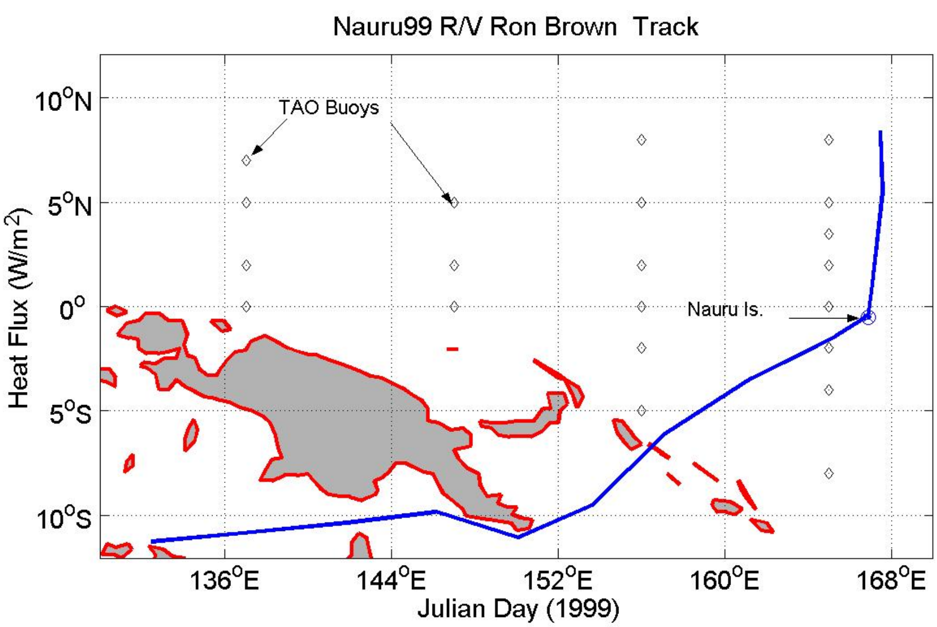

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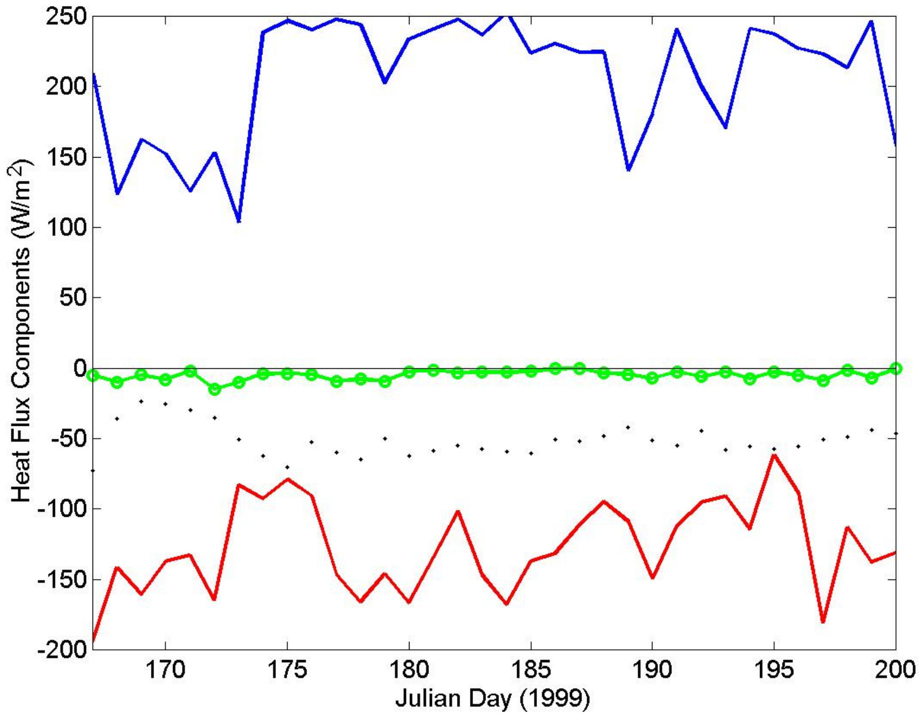

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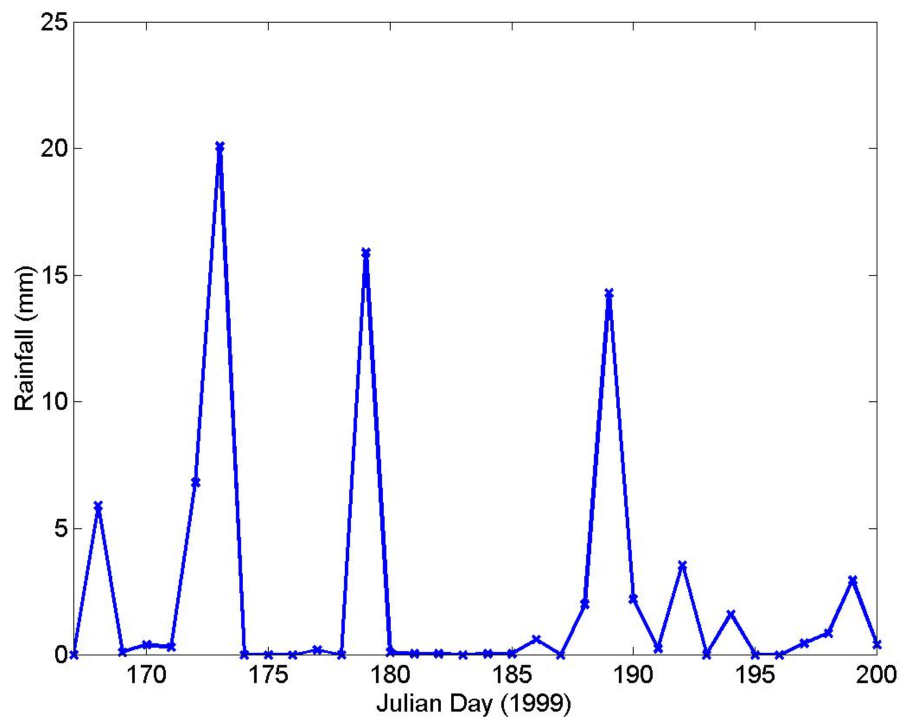

Figure 4. Time series of daily rainfall (mm).

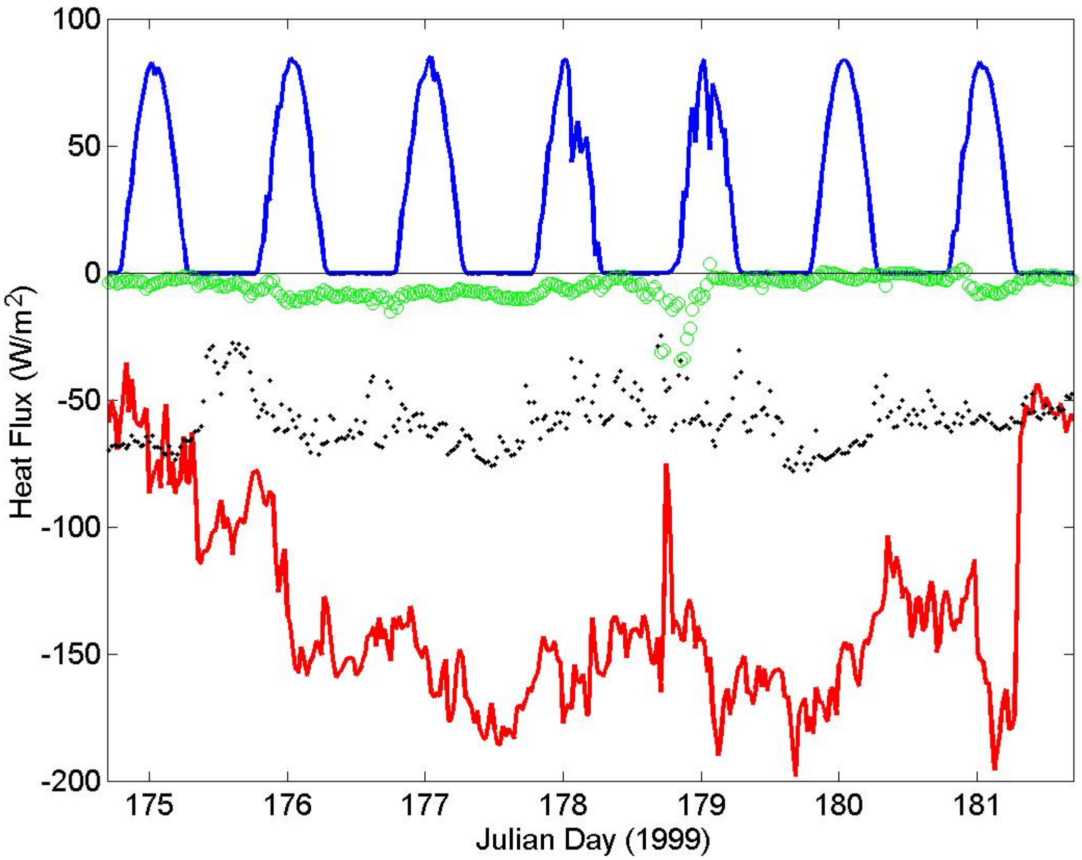

Figure 5 Time series of flux components while on station near the TAO buoy at 2 S and 165 W: sensible heat flux (green circles), latent heat flux (red line), net solar flux divided by 10 (blue line), and net IR flux (black dots).