Profiler, Radiometer, SST, and Meteorological Observations from the R/V Mirai During Nauru99

W. O. J. Brown, D. B. Parsons, E. R. Miller, and S. A. Cohn
National Center for Atmospheric Research
Atmospheric Technology Division
Boulder, Colorado

K. Yoneyama
Japan Marine Science and Technology Center
Yokohama, Japan

Introduction

The National Center for Atmospheric Research (NCAR) participated in the Nauru99 campaign, a large multi-agency international campaign, which intensively observed the atmosphere and ocean around the small tropical western Pacific island of Nauru (167°E, 0°S). The campaign ran from mid-June to early July 1999 and was sponsored by the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program. Nauru is the site of an ARM climate monitoring station or Atmospheric Radiation and Cloud Station (ARCS). One of the aims of the campaign was to gauge how representative measurements made at this site are of the surrounding ocean. One of the two highly instrumented research ships used for the campaign was the research vessel (R/V) Mirai, an 8700-ton vessel operated by the Japan Marine Science and Technology Center (JAMSTEC) (see Figure 1). NCAR operated a range of equipment on the Mirai including the following:

- Multiple Antenna Profiler Radar (MAPR) an advanced ultra-high frequency (UHF) wind profiler radar
- Doppler Beam Swinging (DBS) UHF wind profiler
- Radio Acoustic Sounding System (RASS), which uses profiler radar to track sound waves in order to measure air temperature
- Microwave radiometer to measure integrated liquid water vapor
- "Sea Snake" sea surface temperature sensor
- Surface meteorology sensors to monitor wind, temperature, humidity, and long and short wave solar radiation
- Navigation (Global Positioning System [GPS] and flux-gate magnetometer) and tilt/roll sensors to correct wind measurements for ship motion

NCAR also operated an S-Band vertically pointing radar on behalf of National Oceanic and Atmospheric Administration/Environmental Technology Laboratory (NOAA/ETL). More information on NCAR's activities for Nauru99 as well as daily summary plots from the various instruments and assorted other plots is available on the web at: http://www.atd.ucar.edu/sssf/projects/Nauru99/

A large number of other instruments were also operated on the Mirai by various other organizations. More information on the Mirai operations for Nauru99 is available on the Web at: http://w3.jamstec.go.jp:8339/

The Mirai was in the Nauru99 operations area from June 17 to July 5. The Mirai was stationed just off the coast of Nauru on June 17-19 for intercomparisons with the ARCS site on Nauru, then 200 km west of Nauru for the so-called “large triangle” phase of the campaign on June 20-30, then 20 km northwest of Nauru for the “small triangle” phase on July 1-4. NOAA’s R/V Ron Brown steamed to the Mirai for 4 hr of intercomparison experiments on July 3.

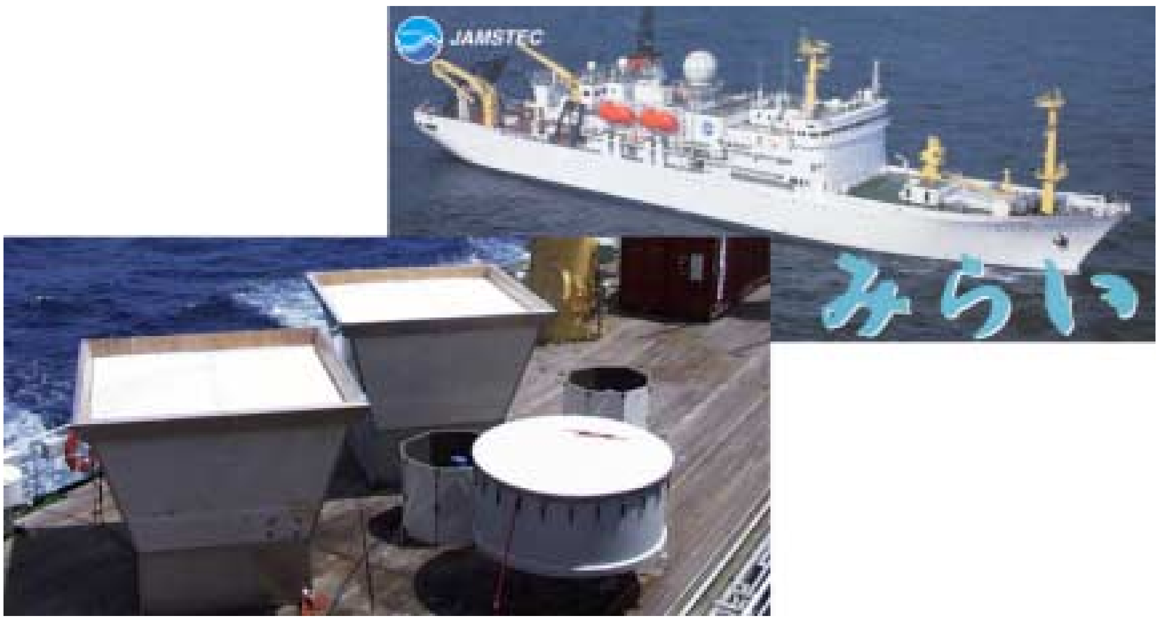

Figure 1. The R/V Mirai and radars on the aft deck. The two UHF profilers are in the large white boxes, which make up the clutter screens and stabilization platforms; MAPR is the profiler in the foreground; the DBS profiler is behind MAPR and is surrounded by four RASS speakers. The drum antenna is the NOAA/ETL S-band radar.

RASS Observations of Island Heating

RASS measurements made from the Mirai showed evidence of heating of the boundary layer by the island of Nauru. Continuous RASS observations were made for 3 hr while the Mirai cruised downwind and just off the coast of the island on June 19. Figure 2 has schematic maps showing the approximate course of the Mirai with respect to the island at various times during the observations and the contour plot below shows the corresponding virtual temperature as observed by RASS.

There was a steady easterly breeze blowing across the island for the whole experiment. While the Mirai was directly downwind (i.e., west) of the island, the average temperature through the boundary layer was about 0.8 K warmer than while the Mirai was north of the island (from about 3:00 Universal Time [UT] to about 4:30 UT). A sounding made at 5:30 UT indicates the mixed layer was about 650 meters deep, and average speed of the easterly wind was 3.5 $m.s^{-1}$.

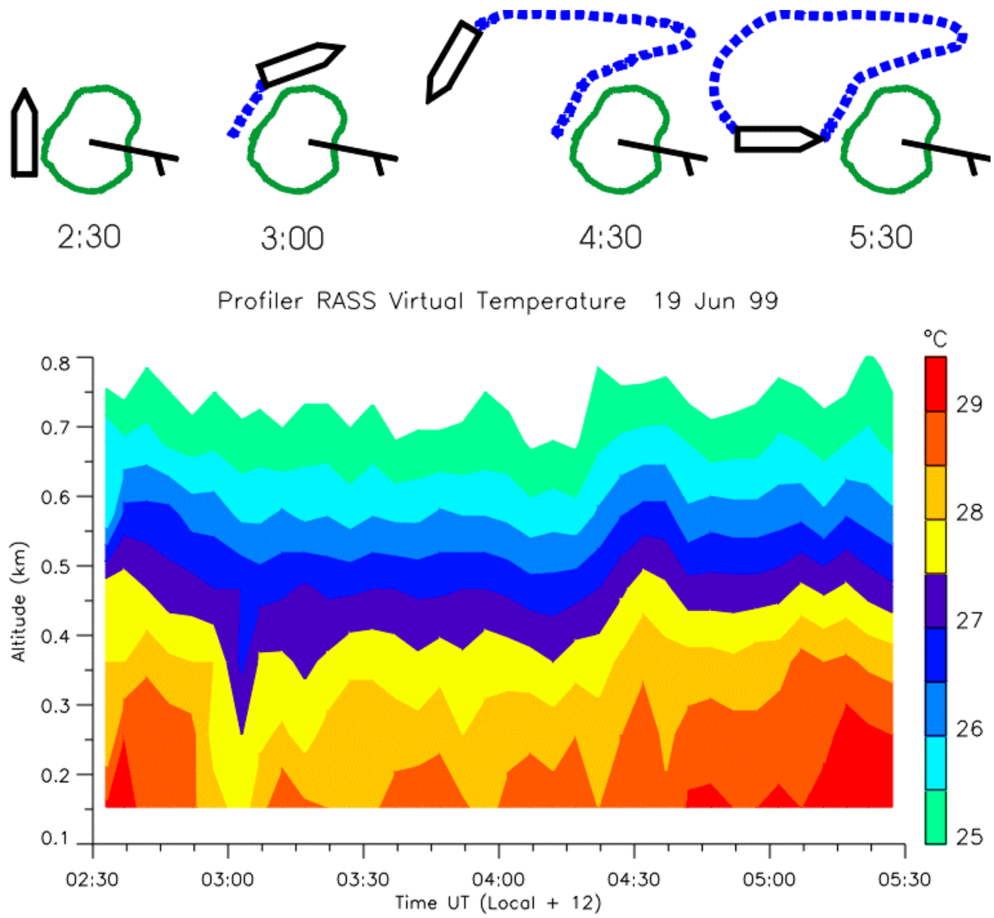

Figure 2. Island heating observations with RASS. The schematic maps indicate the course of the R/V Mirai with respect to Nauru island (green) at the indicated times, the wind barbs indicate the average wind. The contour plot shows the RASS virtual temperature from the deck of the Mirai.

Given these observations, it is possible to make a rough estimate of the heat flux from the island. The island is about 5 km across in the east-west direction; therefore, with a wind speed of 3.5 $m.s^{-1}$, the heat was imparted over about 1500 seconds. The rate of heating was $H_s \approx 0.8K \times 650m / 1500s = 0.35K.m.s^{-1}$. The heat flux therefore can then be approximated as $Q_h = H_s \rho C_p \approx 400\ Wm^{-2}$, where ρ is the density of humid air (≈ 1.15 kg m^{-3} at 30 C) and C_p is the specific heat of air (≈ 1004 $m^2 s^{-2} K^{-1}$). This heat flux is around two orders of magnitude greater than the sensible heat flux from the open sea.

MAPR Observations of Squalls

MAPR is a spaced antenna UHF wind profiler developed at NCAR (Cohn et al. 1997; Brown et al. 1999). It is capable of making wind measurements on time scales of a minute or less, which is considerably faster than conventional DBS profilers. This campaign was the first time a spaced antenna profiler has been operated at sea. The same procedures used with DBS profilers at sea (e.g., Fairall et al. 1997) were followed for MAPR. For example, the antenna was mounted on a platform stabilized with gyroscopes to keep it pointing vertically and additional clutter screening was installed to minimize the effects of sea clutter. Navigational information from a GPS receiver and a compass was fed in to the winds analysis procedure (here based on full correlation analysis; Briggs 1984) to continuously correct for the ships course and heading.

Figure 3 shows an example of the high time resolution measurements possible with MAPR. The figure shows two squalls passing over the Mirai while at its station 200 km west of Nauru for the “large triangle” phase of Nauru99. The falling rain can be clearly seen as the dark regions in the upper panel (signal to noise ratio) and in the middle panel (vertical velocity). In between the two squalls there appears to be oscillating upward and downward motion with a period of about 5 min. The updraft phase of this oscillation strengthens as the second squall approaches. Strong updrafts can also be seen following the squalls, particularly above about 4 km. The lower panel shows spaced antenna wind measurements at 5-min consensus averaged steps (unaveraged wind measurements were made at 1-min intervals). The darkest wind barbs indicate there were wind gusts of up to 50 knots around both squalls, particularly above about 3 km. A sounding taken at 9:00 UT also observed wide variability in wind speed with altitude, and sharp gradients in relative humidity, which may correspond to the layered structures seen in the signal to noise ratio observations. Note that observations in the lowest 500 meters or so appear to be strongly affected by sea clutter.

Figure 4 shows the daily median winds above the Mirai for the period it was in the Nauru99 campaign area. The winds were predominantly easterly and gradually strengthened during the campaign. Little convective activity was observed during the campaign.

Composite Day

The Mirai was stationed at a Tropical Atmospheric Ocean (TAO) buoy (165°E, 0°S) for 10 days during the “large triangle” phase of Nauru99. To find the characteristics of a typical day, observations from the various NCAR instruments were collected to give a composite day for each, and these can be seen in Figures 5 to 8.

Figure 5 shows the composite echo strength and winds from the wind profiler. There was little variability in the average echo strength or altitude, indicating little variation in the boundary layer height during the day. The winds were predominantly easterly and at upper levels tended to be stronger during the day than at night. A slight semidiurnal variability can be discerned in the eastward wind. A light southerly component to the winds in the 1 km to 2 km altitude range can also be seen.

RASS virtual temperatures through the boundary layer were about half a degree warmer during the afternoon and early evening than during the rest of the day (Figure 6).

Microwave radiometer integrated water vapor was lower in the morning than during the afternoon and evening (Figure 7). Integrated liquid water showed greatest variability in the evening, and also showed some variability late morning. The radiometer was supplied by Radiometrics Corporation and used software supplied by Jim Liljegren of Argonne National Laboratory.

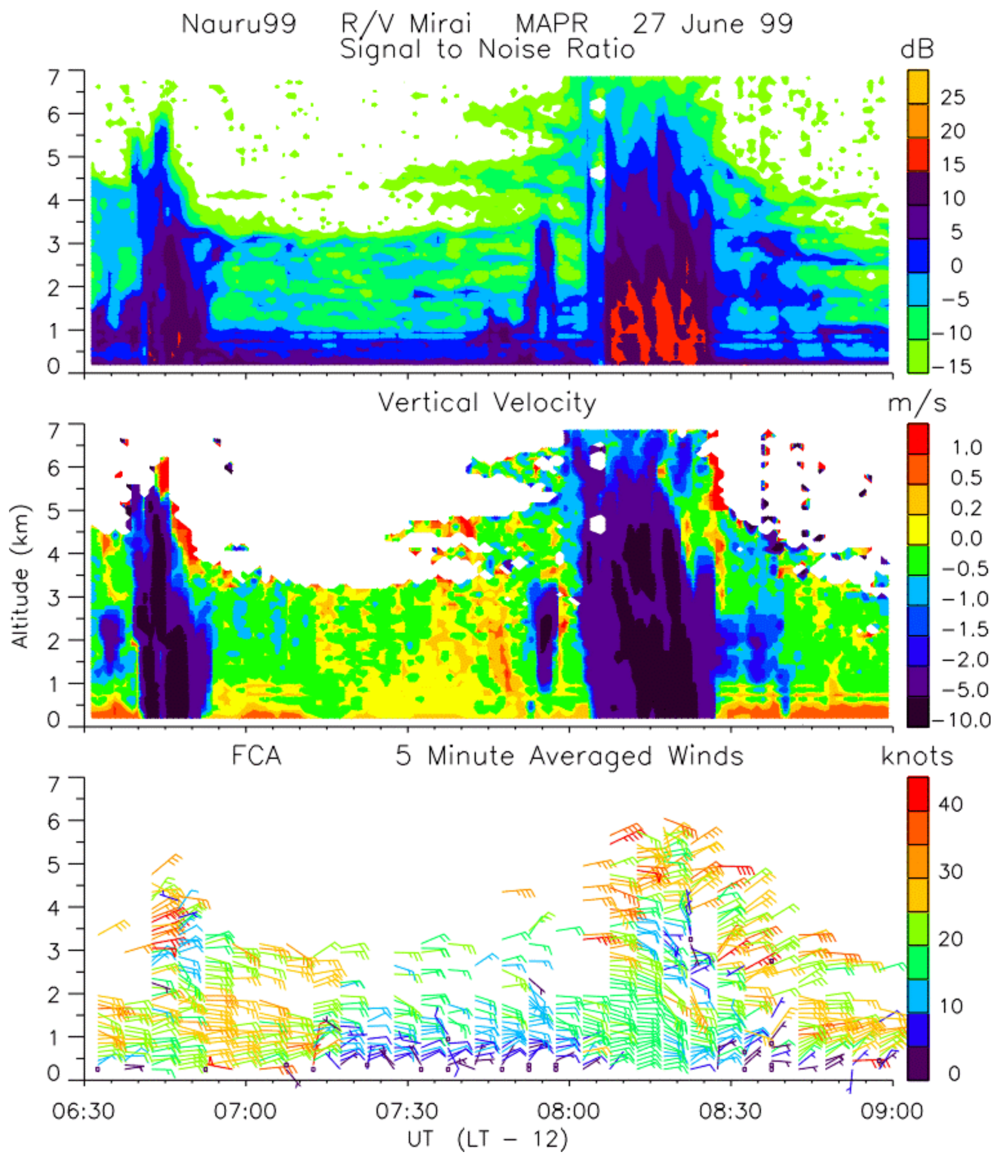

Figure 3. MAPR observations of two squalls from the deck of the R/V Mirai at 165°E, 0°S.

Figure 8 shows composite surface observations made using NCAR instruments. Warming of the air and sea surface can be seen during the day, as can a drop in relative humidity in the afternoon. Note the semi-diurnal tide in surface pressure. Bulk flux was calculated using Chris Fairall's Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) algorithm (Fairall et al. 1996). There seems to be little systematic variation in the latent heat flux, however the sensible heat flux seems to be reduced during the day.

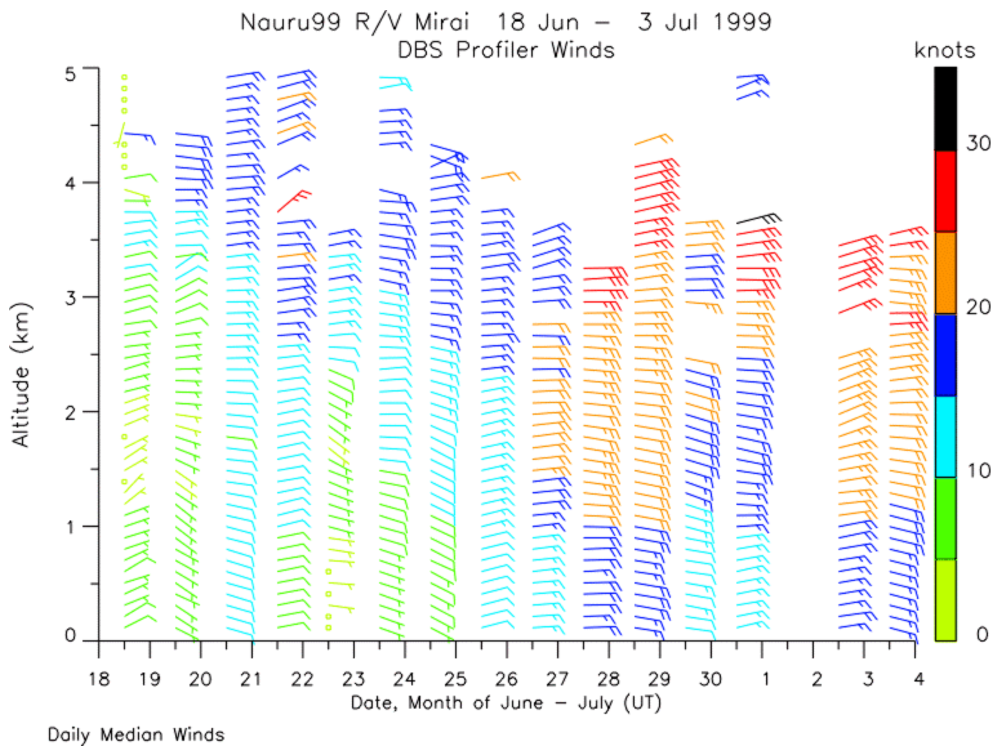

Figure 4. Daily median winds as observed by the DBS wind profiler on board the Mirai.

Profiler verses Soundings

Profiler observations were compared with radiosonde soundings. Figure 9a shows examples of virtual temperatures as measured by RASS and the soundings. The sondes were launched 15 min after the 5-min RASS observations. Figure 9b shows an example of DBS profiler winds compared with sounding winds. The sonde was launched halfway through the 30-min consensus-averaging period of the profiler. Given the difference in sampling volumes as well as the displacement of the sondes and the Mirai, the profiler and sondes generally agreed well.

Conclusions

Two UHF wind profilers were operated on board the R/V Mirai for the Nauru99 field campaign. RASS observations revealed that the boundary layer is significantly heated immediately downwind of the island of Nauru. It was estimated that the heat flux from the island was around two orders of magnitude greater than the heat flux from the surrounding ocean. The recently developed spaced antenna profiler, MAPR, operated successfully at sea, and made unique high time resolution observations of convection around tropical squalls. The profilers and surface instruments were also used to build up a brief climatology over the open ocean west of Nauru.

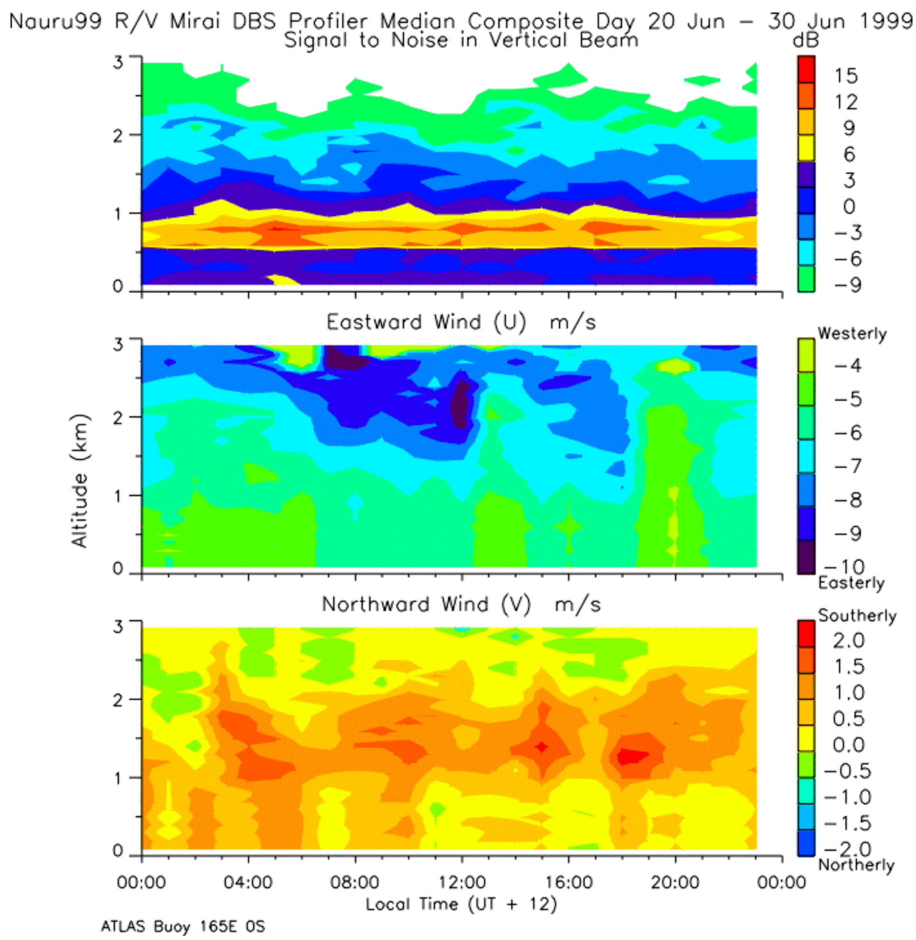

Figure 5. Wind profiler composite day, signal to noise, and eastward and northward wind components.

Acknowledgements

This work was supported by the U.S. Department of Energy's ARM Program. The R/V Mirai is operated by the Japan Marine Science and Technology Center (JAMSTEC). NCAR is operated by the University Corporation for Atmospheric Research under the sponsorship of the National Science Foundation.

Corresponding Author

W. O. J. Brown, wbrown@ucar.edu, (303) 487-8774.

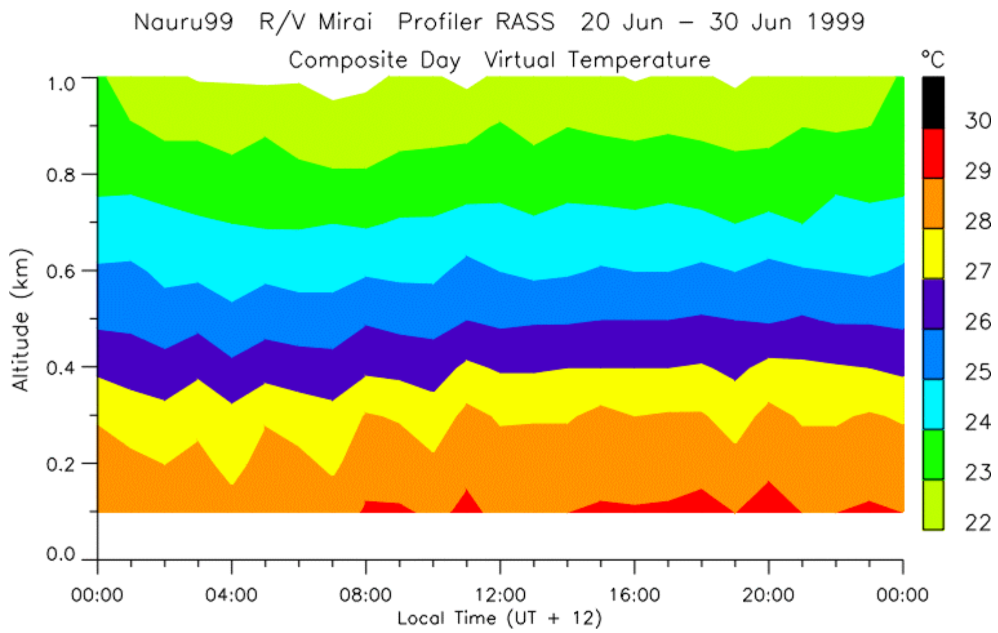

Figure 6. RASS virtual temperature composite day.

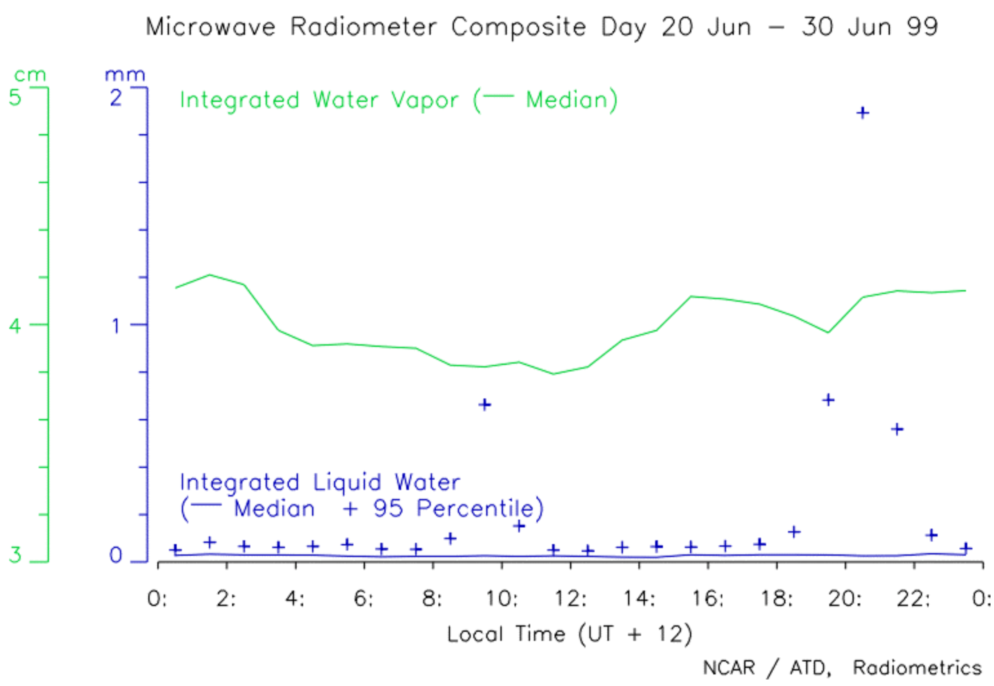

Figure 7. Microwave radiometer composite day.

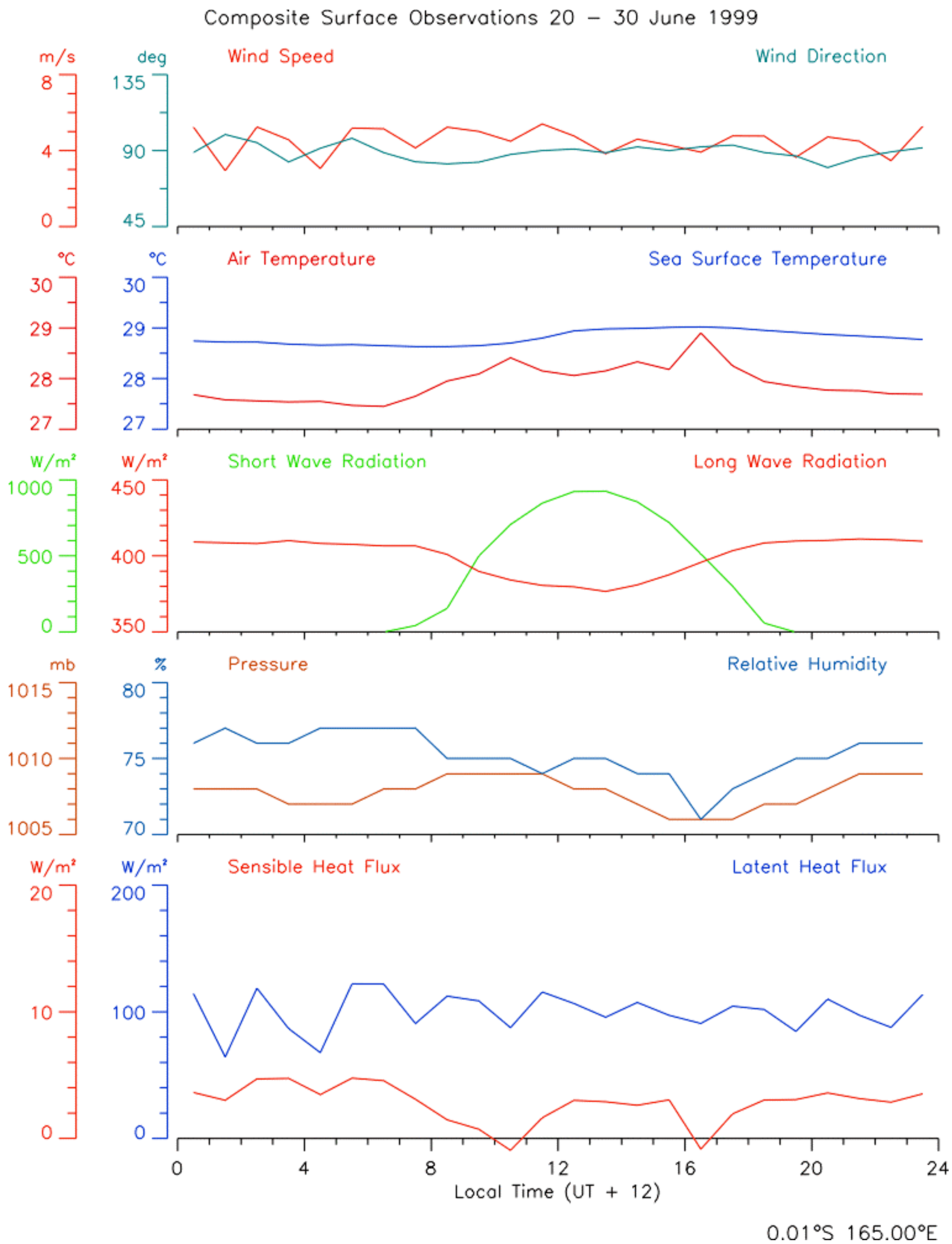

Figure 8. Surface observations composite day.

References

Briggs, B. H., 1984: The analysis of spaced sensor records by correlation techniques. *Handbook for MAP*, **13**, 166-186, SCOSTEP Secrt., Uni Illinois, Urbana, Illinois.

Brown, W. O. J., S. A. Cohn, M. E. Susedik, C. L. Martin, G. Maclean, and D. B. Parsons, 1999: The NCAR/ARM Multiple Antenna Profiler. In *Proceedings of the Ninth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9903/brown-99.pdf

Cohn, S. A., C. L. Holloway, S. P. Oncley, R. J. Doviak, and R. J. Lataitis, 1997: Validation of a UHF spaced antenna wind profiler for high resolution boundary layer observations. *Radio Sci.*, **32,** 1279-1296.

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.