

# Australian involvement in TOGA-COARE: a journalistic view\*

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**TOGA-COARE was a major international field experiment in the western equatorial Pacific Ocean in 1992-93, aimed at providing data for understanding some presently obscure aspects of the ENSO phenomenon. Twenty nations were involved in COARE. Australian scientists from the Bureau of Meteorology, three Divisions of CSIRO, and from Monash, Flinders and Tasmania Universities participated. This article provides a brief 'science journalist's' view of their results and experiences.**

## Introduction

From November 1992 through February 1993, one of the most intensive oceanographic and meteorological experiments ever undertaken — the TOGA Coupled Ocean-Atmosphere Response Experiment (COARE) — was conducted just to the east of Papua New Guinea. This region has the highest mean sea-surface temperature in the world, and also has close to the highest mean rainfall of any part of the ocean. However, the location of this rain often oscillates several thousand kilometres east and west along the equator, with typical time-scales of thirty to sixty days (the Madden-Julian Oscillation, MJO). The associated winds along the equator — westerly wind bursts — vary substantially in total duration and strength from year to year. Years when there are frequent bursts are also El Niño — Southern Oscillation (ENSO) warm events, and if anything can be identified as the 'cause' of an ENSO event in the tightly coupled ocean-atmosphere system, it is the westerly wind bursts. Some skill in predicting ENSO is found in coupled ocean-atmosphere models which average out the winds associated with MJO (e.g. Cane et al. 1986). However, the TOGA (Tropical Ocean Global Atmosphere) program of 1985 to 1994 was designed primarily to increase our ability to predict ENSO events, and the Scien-

tific Steering Group of TOGA came to the conclusion that further increases in predictive skills were limited by our lack of understanding of the very complex phenomena that occur in the ocean and atmosphere, associated with the Madden-Julian Oscillation.

TOGA-COARE was designed to provide a detailed, quantitative picture of coupled ocean-atmosphere processes, including one or two MJO events, from the top of the troposphere through the ocean thermocline. The observational strategy consisted of an enhancement of the array of regular meteorological soundings in the region where MJO activity is most marked (Fig. 1(a)); an Outer Sounding Array of five rawinsondes and an Integrated Sounding System (ISS) on Nauru, with four ship-based and two land-based ISSs within it (Fig. 1(b)); long-range weather radars on three ships within the Intensive Flux Array (IFA — Fig. 1(c)); an enhanced Tropical Atmosphere Ocean (TAO) array, Proteus and Acoustic Doppler Current Profiler (ADCP) moorings, providing surface meteorology and subsurface temperature, salinity and currents (Fig. 1(d)); and several dedicated research vessels (Fig. 1(e)). In addition to the ships shown in Fig. 1(e), *Le Noroit* from Noumea traversed back and forth along 156°E between 4°N and 4°S regularly throughout the four-month Intensive Observation Period (IOP). On most days, up to seven research aircraft flew missions in or near the IFA, from bases in Townsville, Honiara and (in the case of the Flinders University Cessna) from Rabaul. They obtained data on radiation, turbulent fluxes, rain droplet sizes and

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Fig. 1(a) The enhanced upper air sounding network for TOGA-COARE. From the TOGA-COARE IOP Operations Summary (1993).

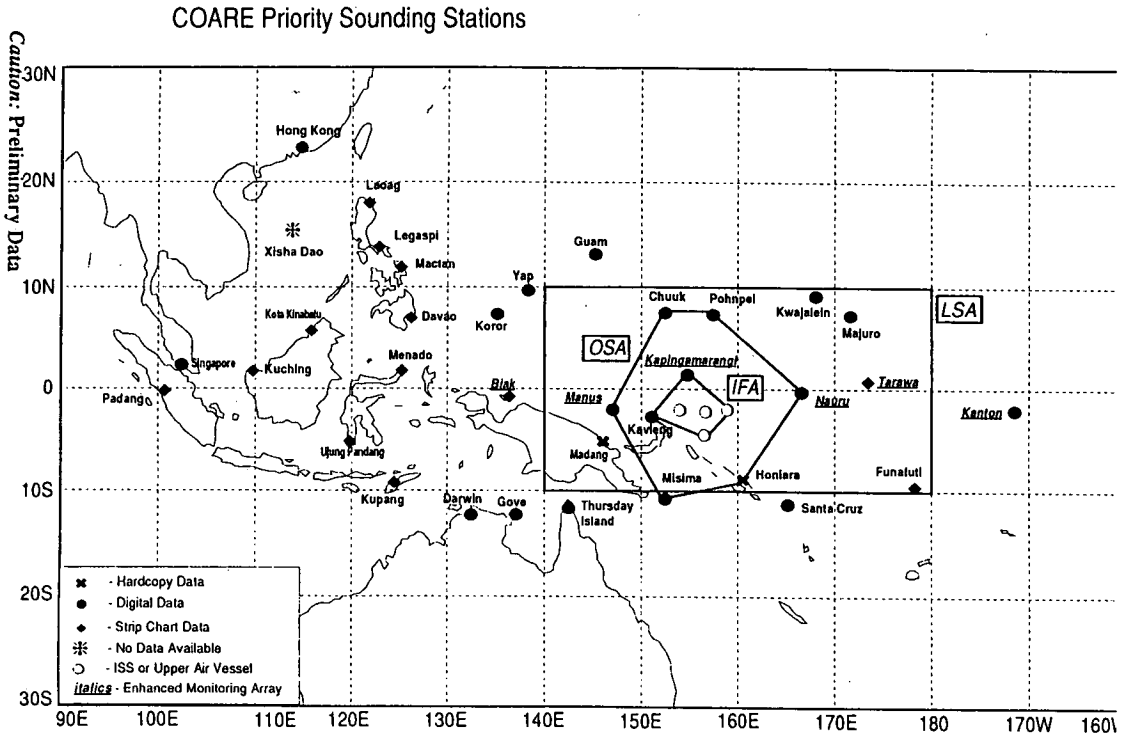


Fig. 1(b) The Outer Sounding Array (OSA) is a hexagon consisting of five rawinsondes and an Integrated Sounding System at Nauru. Within the OSA are three ship-borne ISS sites (*Moana Wave*, *Kexue 1*, *Shiyan 3*), and three land-based ISSs at Manus, Kavieng and Kapingamarangi. From Webster and Lukas (1992).

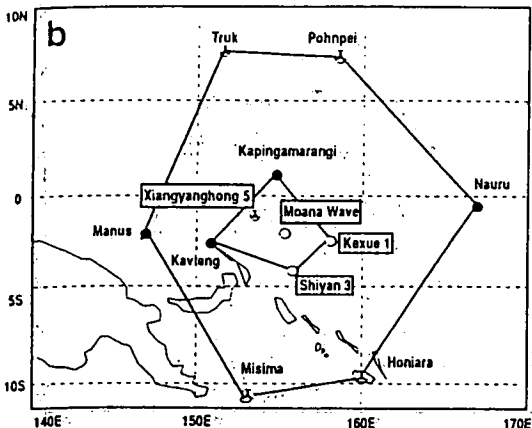


Fig. 1(c) The location of ship-borne radars on *Vickers*, *Xiangyanghong 5* and *Keifu-Maru*, and COARE mooring locations. From Webster and Lukas (1992).

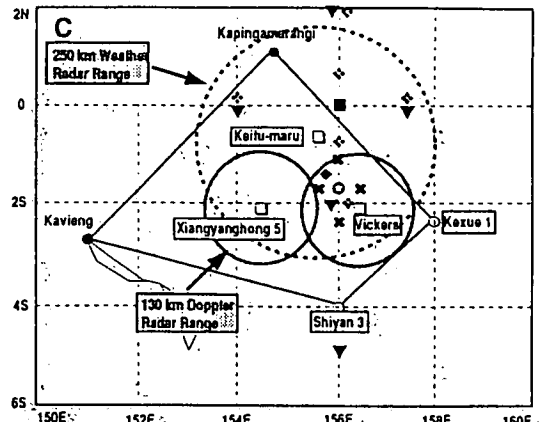
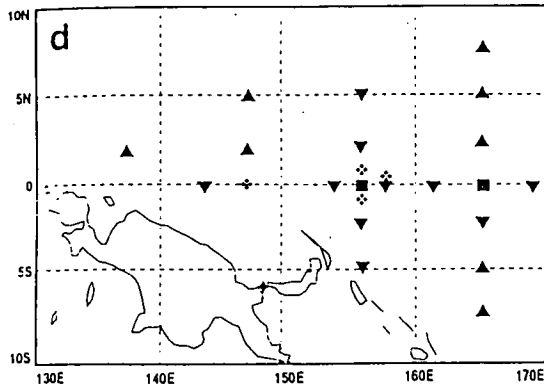


Fig. 1(d) The large-scale oceanographic mooring array (TAO and COARE moorings). From Webster and Lukas (1992).

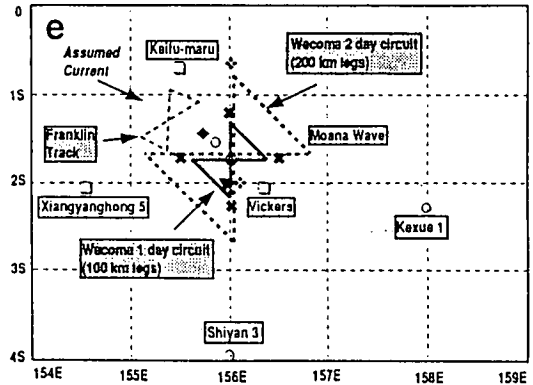


Legend: □ - Radar Vessel ○ - ISS Vessel ● - ISS Land Site ⊕ - Rawinsonde Site ⊙ - IMET Mooring ▲ - Atlas Mooring (Temperature only) ▼ - Atlas Mooring (Temperature and Conductivity) ⊛ - ADCP Mooring \* - Proteus Mooring ■ - Acoustic Mooring ◆ - PCM Mooring + - Villaz Strait Mooring

other phenomena, according to predetermined strategies based on the type of convective activity found in the region. The whole operation was controlled from the COARE Operations Centre at the RAAF base in Townsville; this was jointly managed by the International TOGA COARE Project Office and the Bureau of Meteorology (BOM). Some 1200 people from 20 countries participated in the field work of TOGA-COARE. Interested readers will find more details about COARE in Webster and Lukas (1992), the TOGA COARE Operations Plan (1992), and the TOGA COARE IOP Operations Summary (1993). An International Data Workshop was held recently in Toulouse; its report will shortly be available, and will provide a guide to the massive and diverse dataset that was collected during COARE. If previous large experiments are any guide, the 'payload' from the COARE dataset will take several more years yet to appear.

It would be quite impossible to attempt any comprehensive review of COARE results; the aim of this article is to highlight some Australian contributions to COARE. However, to set the scene it is worth noting that two vigorous MJO episodes occurred during the IOP, so the dataset should contain plenty of information to meet the main objectives of COARE. Figure 2 shows the record of net heat flux into the ocean, rainfall, wind-stress magnitude and sea-surface temperature from a mooring at the centre of the IFA (1°45'S, 156°E); the westerly bursts occurred in late December-early January, and in late January. They were marked by intermittent rainfall, and a rapid reduction in SST.

Fig. 1(e) The oceanographic cruises within the IFA. R/V *Le Noroit* repeated track between 4°N and 4°S along 156°E not shown. From Webster and Lukas (1992).



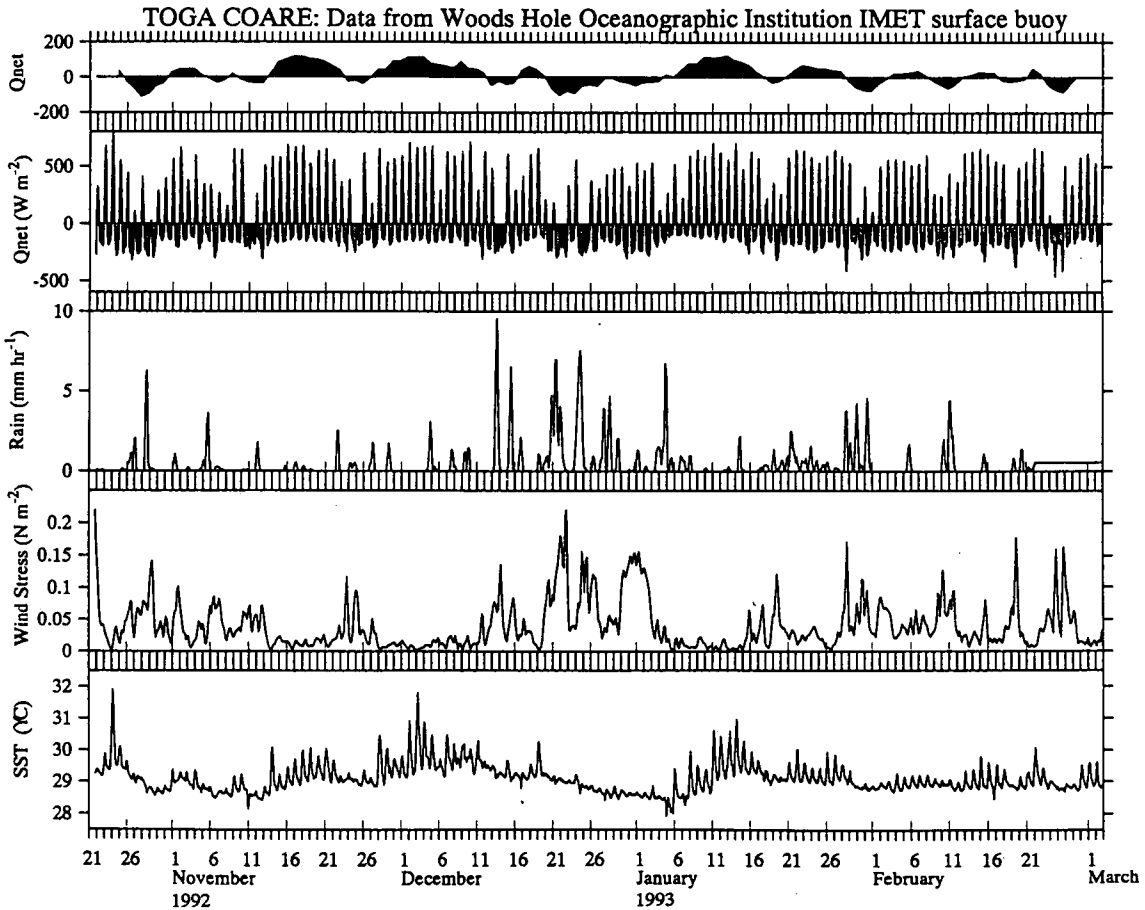
## The Operations Centre

COARE was controlled from a few offices next to a hangar on the RAAF base. The Director of the TCIPPO, David Carlson, established a fixed daily routine for the Operations Centre. At 1400 hours local time a briefing session would be held, including reports of the previous day's operations and a weather forecast by the two BOM forecasters, Greg Bond and David Alexander. These would be based on their interpretations of the available reports, and of forecasts from the ECMWF, NMC and BOM models. The forecast would be faxed to the main aircraft group in Honiara. The major business of the day occurred in general around 1800, when telephone discussions were made with Honiara to decide the flight plan for the next day. (In general, to reach target areas at the peak of convection, aircraft needed to take off in the early hours of the morning.) These discussions could be very vigorous affairs, since the aims of NASA participants differed somewhat from the main aims of COARE: it says much for the diplomacy of Dave Carlson that by the end of the IOP, all parties declared themselves happy with the dataset collected. David Jasper of BOM looked after the interests of Australian researchers at the Project Office.

## The sounding array

Throughout the region of Fig. 1(a), efforts were made to enhance the usual soundings to reduce the data dropouts that frequently occur at several stations in this region. Jeff Stickland of the BOM

Fig. 2 Meteorological observations from the Wood's Hole Oceanographic Institute (WHOI) mooring at 1°45'S, 156°E. By courtesy of R. Weller and S. Anderson. Second panel: net heat flux into the water, estimated from radiometers for the net short wave and long wave radiation and from bulk algorithms for the other three components. Top panel: 24-hour running mean of the data from the second panel. Third panel: measured rainfall rate. Fourth panel: magnitude of wind stress. Fifth panel: sea-surface temperature, measured 45 cm below the surface.



undertook this work for Papua New Guinea. This involved training and motivating local observers, and installing a new station at Misima. This work resulted in a considerable improvement in the number of reports received from these stations, compared to the period preceding COARE.

Further east, four staff and four graduate students from the Centre for Dynamical Meteorology at Monash University maintained a Marwin upper-air sounding station during the COARE IOP, on Santa Cruz Island (Károly et al. 1994a); they reported that 'after initial problems, this system was working well and the major difficulty was encouraging the graduate students to return to Monash from their idyllic tropical island location'. However, the island suffered its first tropical cyclone in more than 20 years; while there

were no deaths or serious injuries, about half the buildings were destroyed or severely damaged, including the building housing the Marwinsonde equipment.

### The *Franklin* cruises

Scientists from three divisions of CSIRO, and from Flinders University, participated in two cruises of R/V *Franklin* into the COARE IFA, between 18 November and 17 December 1992, and between 7 January and 9 February 1993. Logistic considerations only permitted *Franklin* to be in the region for these short periods, so it was decided to adopt a strategy that made best use of experience in the region on earlier cruises (Godfrey et al. 1991; Bradley et al. 1991; Coppin

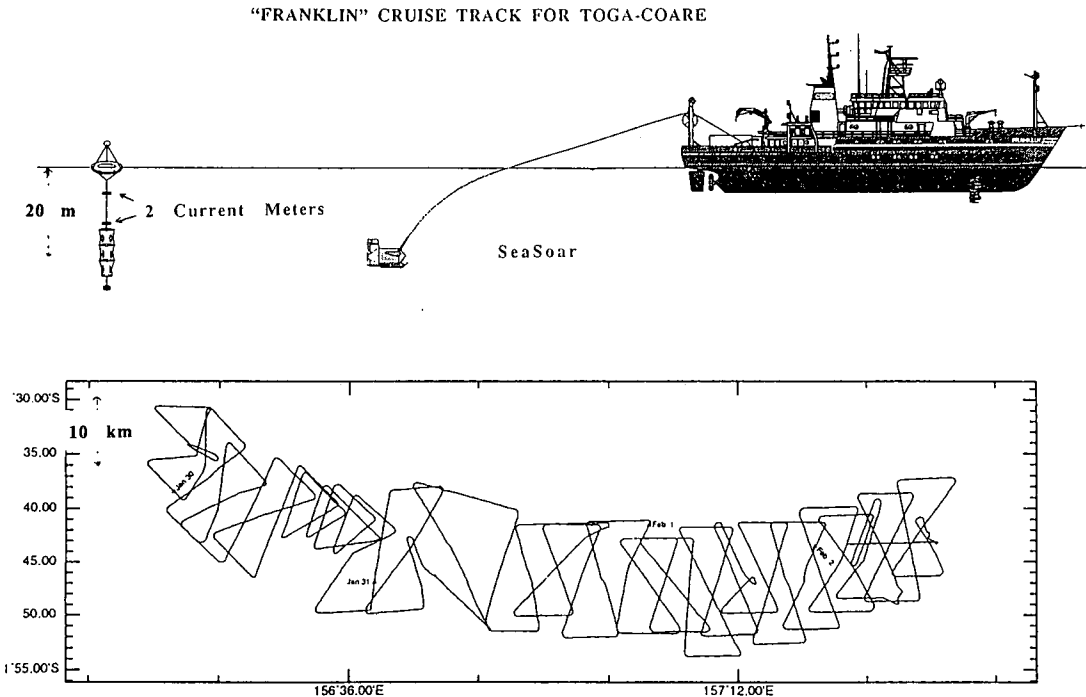
et al. 1991; Bradley et al. 1993). These cruises had concentrated on trying to close the heat budget of the ocean mixed layer. Accurate and redundant observations of the radiative and turbulent components of the surface heat flux were made from the bow, and (in the 1993 paper) these were compared to changes in the ocean heat content near a drifting buoy. While the approach was not fully rigorous, the heat budget appeared to close to about 10 watts/m<sup>2</sup>. Consequently it was felt that *Franklin* could act as a 'floating reference standard' for the numerous other observation platforms in the region.

In COARE, the earlier strategy was enhanced by using SeaSoar observations (Fig. 3). Temperature and salinity were measured from the SeaSoar towed body, which oscillated between the surface and 200 m every two kilometres. By following triangular paths around a drifting buoy with SeaSoar, and using current meter data from the buoy, horizontal advection could be estimated, and also vertical advection beneath the mixed layer, on the assumption that mixing was weak there. Results are still preliminary, but Fig. 4 suggests that, after

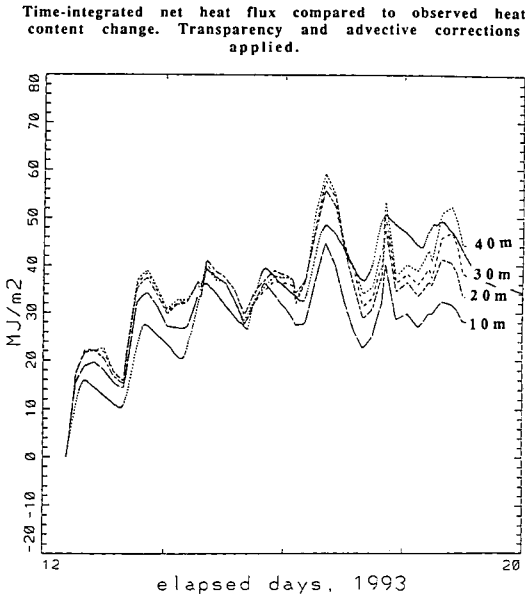
allowance for advection, the observed changes in heat content of water above the 21.6 isopycnal (roughly the top 40 m) are being accounted for well by the measured heat input. In addition, two intercalibration days were arranged, on which several ships came together to make measures of all meteorological variables in close proximity. Planes also participated in these intercalibrations, and overflew the *Franklin* whenever possible. Rainfall measurements were also made, and used to test the closure of the freshwater budget. However, this has so far proved problematical because of the very patchy nature of the rain input and uncertainty in rainfall measuring techniques.

Our strategy was not without its problems. In following a complicated track such as shown in Fig. 3, following a drifting buoy, we (or rather, the ship's officers) had to be very careful not to approach any of the numerous moorings in the region. The SeaSoar is towed on a faired cable to reduce friction and permit deeper towing. On one occasion the weld holding the winch drum to the axle failed and several hundred thousand dollars worth of equipment spooled freely out. When the

**Fig. 3** Upper panel: R/V *Franklin* instrumentation for TOGA-COARE. The SeaSoar towed from the stern provided temperature/salinity data in the top 200 m, while meteorological data were obtained from the 10 m boom mounted on the bow and from masthead instruments. The drifting buoy carried two current meters and a meteorological station. Lower panel: a typical cruise track for R/V *Franklin* during COARE, consisting of triangles following the drifting buoy.



**Fig. 4** The heavy line shows the time integral of the net heat flux into the water, from *Franklin* meteorological instruments. The four light lines show the net heat content of the top 10 m, 20 m, 30 m and 40 m of water, after correction for light penetration through the base of each layer and after correction for advective effects.



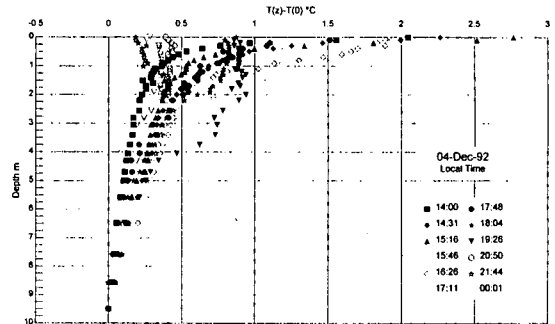
end of the faired cable was reached, a kink developed which caught in the block and held! Some hours of hard work on the winch ensued, with 400 m of Sea Soar out — alarmingly close to one of the COARE moorings. However, a temporary repair was made and the SeaSoar was successfully recovered.

Under the very light winds encountered in this region, sea-surface temperature (SST) can rise by two or more degrees through the morning in the top few meters; this can have quite strong effects on the evaporation. A specially designed instrument was towed from the boom, allowing it to sample the top few metres forward of the ship's bow; Fig. 5 shows a sample of the temperature profiles obtained. SeaSoar obtained closely similar profiles when it surfaced outside the ship's wake.

## The Cessna flights

The South Australian twin-engine Cessna aircraft owned by Flinders Institute for Atmospheric and Marine Sciences (FIAMS) flew 18 missions within the warm pool area during January and February 1993 (Williams and Hacker 1993).

**Fig. 5** Near-surface profiles of temperature in undisturbed water in early afternoon of a light-wind day in the COARE region.



In addition to a number of grid and stack patterns in the atmospheric boundary layer above the Intensive Flux Array, two radiation missions were flown near the Integrated Sounding System (ISS) at Kavieng (New Ireland), and a number of inter-comparisons were conducted with other platforms (aircraft, ship and buoys).

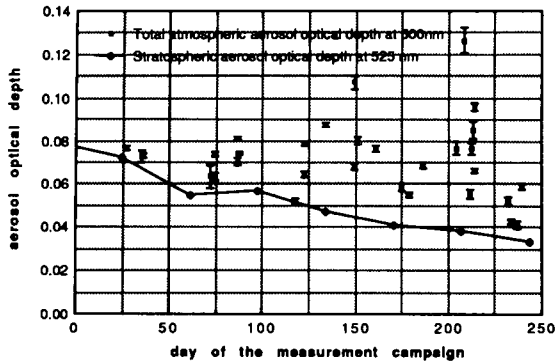
Based in the Papua New Guinean port of Rabaul (now buried in ash from recent volcanic eruptions), the Cessna ferried to and from the IFA every day. The many long (up to 430 km) and low-level (20–70 m) ferry runs were logged at full resolution, producing an overall dataset unique for the large range of horizontal scales covered, and ideal for investigations of the multiscale nature of near-surface processes.

## Radiation measurements, Nauru Island

Nunez and Valiente at the University of Tasmania have been concerned with developing algorithms to model solar radiation. Previous algorithms using measurements or satellite data were based on measurements which were largely not taken in the western tropical Pacific, or relied on a fairly short pyranometer time series for validation. It was therefore decided to concentrate on detailed continuous radiation measurements at a station within the COARE area during the IOP. The study also focused on the aerosol depletion term which is presently most difficult to parameterise and shows high variability in time and space (Nunez 1993).

The measurements of spectral and broadband radiation taken on Nauru Island have enabled aerosol depths to be calculated for the cloudless

Fig. 6 The points with error bars indicate measurements of the total aerosol optical depth at 500 nm, at Nauru. The full line gives the stratospheric aerosol depth at 525 nm.



days during COARE. The time series of aerosol optical depths (Fig. 6) show substantial daily variability around a mean of about 0.08 for 500 nm wavelengths. However, there is an obvious decrease towards the end of the campaign, which is even more evident at longer wavelengths. This decrease can be clearly correlated with the decrease in Pinatubo stratospheric optical depth as seen in Fig. 6. The difference between these two optical depths represents the tropospheric optical depth associated with the marine boundary layer. Further analysis is proceeding to obtain both aerosol complex index of refraction and aerosol size distribution; these two parameters are the most important controlling radiation absorption by aerosols.

## Some analyses

Work on the COARE dataset is only beginning. So far, only a few papers (or meeting abstracts) analysing the data have appeared. McBride et al. (1995) report an analysis of the flow during COARE, as diagnosed by the BMRC Tropical Analysis and Prediction System, while Karoly et al. (1994b) consider the links between tropical convection and variations of the mid-latitude circulation during COARE and Karoly et al. (1994c) examine gravity wave activity associated with COARE tropical convection. Godfrey et al. (1994) provide a preliminary analysis of the heat budget results from the *Franklin* observations, while Tomczak (1995) considers the salinity variability of the surface layer from the same source. Fairall et al. (personal communication)

describe a simple parametrisation of near-surface temperature effects which successfully reproduces COARE observations, such as Fig. 5; this parametrisation is now incorporated in the 'COARE Mark 2 algorithm' for estimating latent and sensible heat fluxes (Fairall, personal communication). Williams and Hacker (1993) describe their flight details. The flow of results will get stronger in the coming years.

## References

- Bradley, E.F., Godfrey, J.S., Coppin, P.A. and Butt, J.A. 1993. Observations of net heat flux into the surface mixed layer of the western equatorial Pacific Ocean. *J. geophys. Res.*, *98*, 22,521–32.
- Bradley, E.F., Coppin, P.A. and Godfrey, J.S. 1991. Measurements of sensible and latent heat fluxes in the western equatorial Pacific Ocean. *J. geophys. Res.*, *96*, (Suppl), 3375–89.
- Cane, M.A., Dolan, S.C. and Zebiak, S.E. 1986. Experimental forecast of the 1982–83 El Niño. *Nature* *321*, 827–32.
- Coppin, P.A., Bradley, E.F., Barton, I.J. and Godfrey, J.S. 1991. Simultaneous observations of SST in the western equatorial Pacific Ocean by bulk, radiative and satellite methods. *J. geophys. Res.*, *96*, 3401–9.
- Godfrey, J.S., Butt, J.A., Helmond, I., McDougall, T., Pender, L. and Ravier-Hay, P. 1994. *A report on "Franklin" oceanographic results from the TOGA-COARE cruises*. Abstract, TOGA-COARE International Data Workshop, Toulouse, August 2–11, 1994.
- Godfrey, J.S., Nunez, M., Bradley, E.F., Coppin, P.A. and Lindstrom, E.J. 1991. On the net surface heat flux into the western equatorial Pacific. *J. geophys. Res.*, *96*, 3391–400.
- Karoly, D., Cresswell, R., Griffiths, M. and Roff, G. 1994a. *Encounters with Nina on Santa Cruz* (or "How to survive a cyclone that wasn't supposed to be there"! ). Abstract, TOGA-COARE International Data Workshop, Toulouse, August 2–11, 1994.
- Karoly, D., Tyrrell, G. and McBride, J.L. 1994b. *Link between tropical convection and variations of mid-latitude circulation during COARE*. Abstract, TOGA-COARE International Data Workshop, Toulouse, August 2–11, 1994.
- Karoly, D., Reeder, M. and Roff, G. 1994c. *Gravity wave activity associated with tropical convection identified from COARE sounding data*. Abstract, TOGA-COARE International Data Workshop, Toulouse, August 2–11, 1994.
- McBride, J.L., Davidson, N.E., Puri, K. and Tyrrell, G.C. 1995. The flow during TOGA-COARE as diagnosed by the BMRC Tropical Analysis and Prediction Scheme. *Mon. Weath. Rev.*, *123*, 717–36.
- Nunez, M. 1993. The development of a satellite-based insolation model for the tropical western Pacific Ocean. *Int. J. Climatol.*, *13*, 607–27.
- TOGA-COARE 1992. *TOGA-COARE Operations Plan: Working Version*. TOGA COARE International Project Office, UCAR, PO Box 3000, Boulder, CO 80307, USA.
- TOGA-COARE 1993. *TOGA-COARE Intensive Observing period Operations Summary*. TOGA-COARE International Project Office, UCAR, PO Box 3000, Boulder, CO 80307, USA.
- Tomczak, M. 1995. Salinity variability in the surface layer of the tropical western Pacific Ocean. *J. geophys. Res.* (in press).
- Williams, A.G. and Hacker, J.M. 1993. Description of instrumentation and flights conducted with FIAMS Cessna 340A Aircraft EOS During the International Experiment TOGA-COARE, *FIAMS Technical Report No. 10*, FIAMS/School of Earth Sciences, Flinders University, Adelaide, Australia.
- Webster, P.J. and Lukas, R. 1992. TOGA-COARE: The Coupled Ocean-Atmosphere Response Experiment. *Bull. Am. met. Soc.*, *79*, 1377–416.