R.V. FRANKLIN

NATIONAL FACILITY
OCEANOGRAPHIC RESEARCH VESSEL

RESEARCH SUMMARY

CRUISE FR 7/90

Sailed	Cairns	0900	Thu 6 September 1990
Arrived	Lae	1500	Tue 24 September 1990
Sailed	Lae	1700	Wed 25 September 1990
Arrived	Lae	1100	Mon 1 October 1990

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Principal Investigators

Drs Eric Lindstrom & Stuart Godfrey
CSIRO Division of Oceanography, Hobart]

Drs Frank Bradley & Peter Coppin
CSIRO Division of Environmental Mechanics

Bismark Air-Sea Interaction And Circulation Study

--oOo--

Dr Eric Lindstrom
Dr Hideo Inaba
Tokai University, Japan

Australia - Japan Equatorial Moored Instrument Array

11 October 1990

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AUSTRALIA

R.V. FRANKLIN IS OWNED AND OPERATED BY CSIRO

RV FRANKLIN
National Facility
Oceanographic Research Vessel

Research Summary

Cruise FR07/90

Draft of 11 October 1990

Itinerary

Leg 1

Sailed	Cairns	0900	Thu 6 September 1990
Arrived	Lae, PNG	1500	Mon 24 September 1990

Leg 2

Sailed	Lae, PNG	1700	Tues 25 September 1990
Arrived	Lae, PNG	1100	Mon 1 October 1990

Principal Investigators

Bismarck Air-Sea Interaction and Circulation Study (BASICS)

Drs Eric J. Lindstrom and J. Stuart Godfrey
CSIRO Divsion of Oceanography, Hobart Tasmania

Drs E. Frank Bradley and Peter Coppin
CSIRO Centre for Environmental Mechanics, Canberra ACT

Australia-Japan Equatorial Moored Instrument Array

Dr Eric J. Lindstrom
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Professor Hideo Inaba
Tokai University, Japan

Cruise Objectives

1) To measure all components of the heat budget of one or more parcels of water in the Bismarck Sea over several days, so that the total budget is closed to an accuracy of 20 Wm^{-2}.

2) To measure the CO_2 flux over the ocean and relate its magnitude to the difference in CO_2 concentration between the water and the air.

3) To recover and redeploy a joint Australia/Japan current meter mooring on the equator at 147°E.

Personnel

Ship's Crew

Master	Neil Cheshire
Mate	Dick Dougal
2nd Mate	Mike McAuley
Chief Eng.	Peter Noble
2nd Eng.	Ron Parrott
Elec. Eng.	Jeff Cullen
Bosun	Jannick Hansen
AB	Bluey Hughes
AB	Kris Hallen
AB	Norm Marsh
Greaser	Paddy Mclure
Ch. Ste.	Ray Clarke
Ch. Cook	Gary Hall
2nd Cook	Bob Clayton

Scientific Party (entire cruise)

Eric Lindstrom, DO* (Chief Scientist)
Gary Critchley, ORV
Ian Helmond, DO
Jeff Butt, ORV
David Edwards, ORV
Frank Bradley, CEM
John Bryan, CEM
Ryo Kodama, TU

Leg 1 only

Stuart Godfrey, DO
Peter Coppin, CEM
Tom Denmead, CEM
Bob Cechet, DAR

Leg 2 only

Fred Boland, DO
Danny McLaughlan, DO
Kevin Miller, DO
Hideo Inaba, TU

*	DO	CSIRO Division of Oceanography
	CEM	CSIRO Centre for Environmental Mechanics
	DAR	CSIRO Divison of Atmospheric Research
	TU	Tokai University, Japan
	ORV	ORV Staff

Summary of work completed

Introduction

FR7/90 incorporated two projects. Each held centre stage during one leg of the expedition.

Leg 1

From Cairns, Franklin set out for the Bismarck Sea to particularly study air-sea interaction in the warmest tropical waters where low wind speeds might be expected. The experimental design was to follow a water parcel tagged with a drifter and to measure via a variety of means all components of the surface heat budget. The cruise track used at the site was a "butterfly" pattern of opposing equilateral triangles with sides of approximately 12 nm. The pattern was rotated based on the prevailing wind direction and centered on the location of the drifting buoy. Approximately four complete occupations of the butterfly were completed each day. The resulting cruise track resulting is shown in Fig. 1. Upper ocean measurements of temperature, salinity, and velocity obtained by the Franklin CTD, XBT, ADCP, and thermosalinograph systems and the project's "Flying Fish" and instrumented drifting buoy (see below) were the primary oceanographic tools. A time line of the CTD, XBT, and drifter deployments is shown in Fig. 2. Specialized micro-meteorological data, radiation data, and upper air soundings, along with the conventional Franklin meteorological observations were the central elements of the atmospheric measurements. The core of the experiment occured from the 12th to the 22nd of September. The first six days of the cruise (6-12 September) were required to set up all the specialized equipment for full scientific operations. Also during this time a CTD section was completed across Kimbe Bay, New Britain. A synopsis of the data obtained and preliminary results are detailed below.

Leg 2

From its intermediate port call in Lae, PNG, Franklin proceeded directly to the equator at 147°E to recover and redeploy a current meter mooring. The mooring, in 4575 m of water, was placed at the site in February 1990 by a CSIRO team aboard R/V Natsushima. The mooring was successfully recovered on 27 September. It had been vandalized, causing loss of the meteorological instrument tree and damage to the upper most current meter (10m). While servicing the current meters and other instruments for redeployment, a CTD section was completed between 1°S and 2°N along 147°E. Also, at the request of Dr. Stan Hayes of NOAA/PMEL in the USA, we inspected a meteorological/thermistor chain mooring at 2°N, 147°E. It had stopped transmitting data and we were prepared to attempt repairs. Unfortunately, we found that it too had been vandalized. This mooring had been completely stripped of instruments, including the data logger. We were unable to make any repairs. The mooring redeployment on the equator was successful. Final instrument depths included current meters at 10 m, 50 m, 100 m, 150 m, 200 m, 250 m, and 300 m. Seacats (measuring temperature and conductivity) were deployed at 3 m, 30 m, 75 m, and 100 m. Franklin returned to Lae to complete the cruise immediately following the mooring work and completion of the CTD section.

Data acquisition

CTD

Fifty seven CTD stations were completed during the cruise. The first was a test station in the Solomon Sea. Subsequently, two stations were completed in a preliminary survey of the air-sea interaction experimental site. Prior to beginning full heat flux studies near 4°S, 149°E in the Bismarck Sea, a hydrographic section was done across Kimbe Bay, New Britain (stations 4 to 11). These stations were to the bottom and included nutrient analyses.

During the 10 day air-sea interaction study CTD stations were done approximately every six hours, usually within one mile of the drifting buoy marking the centre of our study area. These stations, to 400 m, incorporated six salinity and oxygen samples for calibration purposes but no nutrient analyses (stations 12 to 47).

En route to the intermediate port call in Lae, three CTD stations were done in the lagoon at Garove Island. The third of these (station 50) included salinity, oxygen, and nutrient sampling on twelve bottle cast to the bottom (140 m).

During the second leg of the cruise stations along 147°E were all to 1000 m and included full sampling for salinity, oxygen and nutrients (stations 51 to 57).

XBT

An extraordinarily large number of XBT's (159) were utilized during the cruise. This was an essential element of the air-sea interaction study, where a time series of upper ocean heat content was required (see figure 3). Nominaly, XBT's were deployed every two hours during the experiment. Enhanced sampling (hourly XBT's) was undertaken during the first and last nights of the experiment. Many profiles were reported to the Bureau of Meteorology in real-time as bathy messages.

ADCP

The Acoustic Doppler Current Profiler worked extremely well during the cruise. Because of the large number of hours per day (perhaps 18) of GPS coverage and excellent sea conditions, a large amount of high quality velocity data was obtained. A transducer alignment exercise was completed in the Bismarck Sea at the end of the air - sea interaction experiment. The depth of penetration of the ADCP appeared to be limited to a maximum of 300 m while underway, but could extend beyond 400 m while on station. The reason for the limited penetration is not known. Depth of penetration was not particularly sensitive to reduced levels of data screening. Only the RDI signal-to-noise ration parameter appeared to reject any data. It was set at 20 during the cruise, but was set as low as 5 during some exercises to increase the depth of good data return. The main effect was to increase the noisiness of the profiles rather than increase depth penetration.

Boom and Foremast measurements

Micro-meteorology

With regard to the first cruise objective, the principal role of the micro-meteorological measurements is to determine the atmospheric components of the total heat budget of our parcel of water by direct means. That is, by eddy-correlation of the turbulent wind, temperature and moisture fluctuations to arrive at the ocean-air fluxes of sensible and latent heat. A more general purpose to this work is the continuation of study into the detailed mechanisms of air-sea energy exchange, within the context of TOGA and the validation of ocean-atmosphere coupled models, which was initiated with cruise FR4/88. Important results emerged from that cruise; they have generated considerable interest (and some controversy) in the international community. In BASICS we have modified our instrumentation and technique to widen the scope of the observations, to overcome problems which arose during the first cruise and to refine our methodology for anticipated participation in the international experiment TOGA-COARE scheduled for the western Pacific in November 1992.

Sensible and Latent Heat Fluxes

The 1988 measurements were made under conditions of very low wind speed. They are, in fact, the first determinations of fluxes and exchange coefficients in such a wind regime, which is the reason for their importance. However, to satisfy the requirements of BASICS, we needed to measure fluxes almost continuously throughout the cruise, and to accommodate whatever wind and sea conditions occurred The group of fast-response sensors used for this purpose are a sonic anemometer, fine-wire thermometer and a Lyman-alpha hygrometer. One set was installed at the end of the 10m boom, as before, and another set near the top of the foremast. When the boom set failed, generally due to rain, measurements could continue using the mast set while repairs were made. If rain was expected, the mast set was easily accessible to protect until the storm passed, whereas retracting the boom was a more cumbersome operation.

Using this strategy, and a day/night shift schedule, we have recorded about 170 hours of flux data during the period when running the "butterfly" pattern around the drifting buoy. This represents about 70% time coverage, randomly distributed. The lost time was due to the quite frequent rain storms and to the occasions on downwind legs when wind over the stern exceeded the ship's speed. Even when the inevitable "suspect" data is eliminated during detailed scrutiny, the final data set should provide very satisfactory spatial and temporal coverage of the volume of water being monitored.

The range of wind speed conditions (see (see figure 4) encountered (4-20 kts.) during this period was fortunate, since it will enable comparison of flux exchange coefficients with previous determinations by others. It will also provide additional information on the validity, or otherwise, of the "dissipation" method of estimating fluxes which is relied upon by most shipboard observers to avoid the problem of accounting for ship motion. Our previous work indicated that, for low wind speeds, this technique underestimated fluxes by about 20%; preliminary processing of a few runs during the present cruise suggests that at higher wind speeds agreement may be better.

It is a little unfortunate that the flat calm conditions of the previous cruise were not encountered for even a few hours during the period when we were following the drifting buoy, as a cross-check of our methodology. However, the full data recording was continued during the long track into Lae, which will provide further information on spatial variability, and also on the southerly run between 2°N and the equator. During several hours of the latter the sea was completely calm so that the cross-check will be possible.

Including these final runs, a total of about 240 hours of flux data has therefore been recorded. Even after elimination of bad data this should ensure statistically significant results for whatever form of analysis is attempted. For much of this time, both boom and mast instruments were operating simultaneously. This is quite important because comparison between them can provide information on the effects of flow distortion around the ship, and its effect on both eddy-correlation and dissipation measurements of the fluxes. It may also be possible to determine the height divergence of those terms in the turbulent budget equations for heat and moisture flux, which contribute to the transport of these fluxes under convective conditions.

A complete analysis of the turbulence data from this cruise will take a considerable amount of time, particularly since details of ship motion from the two systems aboard and from the ship's log must be incorporated. Signals from John Reid's inertial reference system were logged together with the turbulence data and it appears to have operated satisfactorily throughout the cruise. Similarly our own 6-accelerometer system gave no trouble. The challenge lies in the dynamic analysis needed to generate the orthogonal velocities and rotations to correct the wind signals.

However, our previous experience indicated that the scalar fluxes were relatively insensitive to motion contamination. We therefore tentatively offer a few hours of latent and sensible heat flux data, the first analysis with no correction and no screening for sensors which may have been faulty or switched off. The results are quite encouraging; the two sets of sensors agree well. The earlier sample with true wind speeds of around 6-8 m/s indicate consistently higher sensible and latent heat fluxes than on the 1988 cruise; in winds of around 1 m/s Runs 660-680 confirm our important observation of a "basic" evaporation rate between 25 and 40 watts/m2 (see figure 5).

Surface-layer Parameterization

We have tried to use the psychrometer data from the 1988 cruise to obtain flux-gradient relationships for the atmospheric surface layer over the ocean, and to determine the limits of Monin-Obukhov stability theory. This has not been done before. The problem is that the gradients over our height range 3-10 m were smaller than various errors of the psychrometers (0.1°C and 0.1mb vapour pressure). All the air-sea gradient of 1.5°C and 12mb must occur within the lowest 3m; i.e. Monin-Obukhov hardly applies at all. This was supported by our turbulence measurements which indicated that free-convection parameterization applied well below the level of the 6.5m sensors.

In an attempt to measure significant temperature and humidity gradients, we mounted sensors between 0.25m and 2m on the Flying Fish. Instability of the measuring system, described elsewhere, and a lack of completely flat calm water frustrated this strategy. However, Ian Helmond had also modified the vertical section of the boom so that the lowest psychrometer could be lowered to within 1m of the water. For much of the time seas were sufficiently light that it was set to 2m; only during the very calm period from 2°N to the equator was it safe to use the 1m position. There is the indication of a slight increase in the gradient between 1m and 10m, perhaps 0.5°C and 0.5mb; still a very small part of the total air-sea differences. None of the psychrometer data has been analysed in detail and the thermometers have yet to be recalibrated in the laboratory but the picture will not change greatly. The mechanisms of heat transfer close to the interface remain elusive, and the design of better temperature measurement for the Flying Fish is an important priority.

Radiation

A net radiometer was again installed at the end of the boom, a more accurate instrument which had been specially calibrated. Short and long-wave sensitivities were almost identical. The need to provide a flow of dry nitrogen to keep the domes inflated proved not to present any problem. The net outgoing longwave at night was about 40 watts/m2 as previously, and will provide a useful cross-check on the instrument mounted on the after A-frame. Comparison with a Kipp pyranometer mounted on the masthead indicates that net radiation during the day is often around 90% of incoming solar. Also, for the first time, we will have direct measurement of sea surface albedo, throughout several days, from a Lambda pyranometer mounted under the boom to measure outgoing shortwave. For comparison with the Kipp it was also mounted on top of the boom facing upward on several occasions.

Other Radiation Measurements

Two radiometers with filter functions in the 10-12 micron atmospheric window were located on the railing above the wheelhouse. They measured simultaneously the radiance of the "skin" of the sea surface and the sky radiance (weather permitting). This data which attempts to display the effect of the down-coming radiation on the sea-surface temperature (SST), indicated that in particular, differences in the water vapour content of the atmosphere and also reflection from clouds caused significant variations in the SST. Both radiometers gave trouble during the voyage, and thanks to the efforts of David Edwards only 24 hours of sea surface radiance data was lost.

Sea surface radiation data will also be correlated with current tropical SST algorithms derived from NOAA polar-orbiting satellite thermal infra-red data (so-called split-window algorithm). NOAA polar-orbiting satellite data and U.S. DMSP satellite data of the Bismarck Sea area were archived for the duration of the cruise. In addition, 55 radiosonde flights were completed during the cruise at the times of the satellite overpasses. DAR will use this data to determine:

(1) the atmospheric absorption of the satellite measured sea surface radiances

(2) the use of TOVS (TIROS-N Orbital Vertical Sounder data in statistical retrievals of temperature and humidity profiles for tropical SST algorithms (TOVS instrument is aboard the NOAA satellite).

Upper air observations

Radiosonde data was obtained under a variety of conditions ranging from a trade wind regime to local advection into developing distant cumulus clouds and severe thunderstorms in the local region. Real-time data was transmitted to the Bureau of Meteorology in Melbourne twice daily.

Flying Fish measurements

A new instrument which measures temperature structure in the first one metre of the ocean and the first two metres of the atmosphere was used during the first leg of the cruise. To measure while underway and in undisturbed water, a purpose built paravane device, the Flying Fish, was designed. This winged paravane was towed from the starboard hydrology wire approximately 25 m from the ship, clear of the wake. Platinum resistance thermometers were mounted at heights of 2 m, 1.5 m, 1.0 m, 0.5 m, and 0.25 m above the sea surface, and 0.0 m, 0.05 m, 0.1 m, 0.2 m, 0.4 m, 0.6 m, 0.8 m, and 1.0 m below the sea surface. These temperatures were recorded on two Datatakers 500 data loggers.

Initially the fish flew with a slight nose-up attitude and displayed some tendency to jump in wind waves. The geometry of the tow wire was changed on 16 September and the flight problems were thus resolved. The fish could be used in winds up to 10 knots at a tow speed of 6 knots. Some further mechanical modifications should improve stability in the future.The Flying Fish proved a stable platform and was masterfully launched and retrieved under the guidance of the designer, Ian Helmond. The instrument is still under development with further electronics requiring particular attention to increase precision of the temperature measurements.

Surface Drifter measurements

A drogued and instrumented buoy was used as a Lagrangian drifter during the heat flux studies. The buoy, a 1.4 m diameter toroid, was drogued at average depth of 24 m with a "holey sock" drogue of 1 m diameter and 15 m long. This drogue arrangement restrained the wind drift of the buoy to approximately 1% of the wind speed.

Platinum resistance thermometers were mounted at heights of 1.9 m and 0.65 m above the sea surface, 0.0 m, 0.05 m, 0.1 m, 0.2 m, 0.4 m, 0.8 m, and 1.5 m below the sea surface. The measuring system was identical to that used on the Flying Fish.

The buoy was deployed for four periods during the experiment.

Deployed	Recovered	Comments
1330 12/9/90	1530 15/9/90	SST Float failed 2000 13/9
1330 16/9/90	0700 19/9/90	55 hours of data
1700 19/9/90	1200 20/9/90	
1730 20/9/90	1400 22/9/90	

Carbon Dioxide measurements

1) The vertical flux of atmospheric CO_2

Two micro-meteorological approaches were used:

a) Eddy correlation method.

A sonic anemometer and an advanced Systems E009 open path, infrared gas analyser (IRGA) were mounted mounted near the top of the Franklin foremast. The E009 measures the instantaneous concentrations of water vapour and CO_2 which when correlated with the wind measured by the sonic anemometre, provided direct measurements of evaporation and the CO_2 flux.

b) Flux-gradient method

A transfer coefficient for mass transport across the air-layer between 2 m and 10 m above the sea surface was calculated from the ratio of the flux of water vapour to the gradient in water vapour density. The water vapour flux was measured by eddy-correlation. The transfer coefficient was then multiplied by the CO_2 concentration gradient, measured simultaneously over the same layer, to give the CO_2 flux.

The gradients of water vapour and CO_2 were measured with Analytical Development Company closed-path IGRA's, operated in differential mode. Air lines were mounted on a 10 m boom extending forward of the ship, and air from 2 m and 10 m was pumped to an IRGA on the foredeck. This measured the water vapour concentration gradient. Air was also pumped to a second IRGA in the General Purpose Laboratory for measurement of the CO_2 gradient. Before pumping air to the GP Lab, it was necessary to remove water from the air streams, which would otherwise condense in the air-conditioned interior of the ship. As well, water in the air stream interferes with the CO_2 measurement.

2) Difference in CO_2 concentration between water and air.

a) pCO_2 in seawater

Two systems were employed to measure the equilibrium partial pressure of CO_2 dissolved in the water, pCO_2. he first was the on-board continuous system based on the seawater chemistry, developed by Denis Mackey of the CSIRO Division of Oceanography.

The second system used an equilibration technique in which air and water were sealed in a flask and shaken vigorously. The air in the head-space was analysed continually for its CO_2 content with a third IRGA. Shaking continued until equilibrium was reached.

b) Atmospheric CO_2 concentrations.

This was measured continuously on a separate air stream pumped from the boom to the GP lab.

Selected Results

Heat fluxes and ocean heat storage

The cruise appears to have been basically successful in its aim of obtaining heat flux time series and near-surface heat content time series that can be compared with one another to an accuracy of order 10 watts/m^2; this has been largely due to our being able to follow a drifter for as long as 10 days. So far, the heat fluxes are obtained using the Franklin system wind, air temperature and humidity, with thermosalinograph SST, to get evaporation; longwave radiation has so far been taken as a constant at 50 watts/m^2, till the radiometers are calibrated. The ship's pyranometer has been used for shortwave radiation. A (very preliminary) comparison of the estimated heat added to the water column with observed ocean heat content in the top 40 m has been attempted. The two series drift apart at about 20 watts/m^2. This is almost certain to change once the instruments are checked, as discussed below; but the two time series correlate well enough to believe that a 10 w/m^2 accuracy may be possible.

Air-Sea interface

The Flying Fish enabled us to study the dynamics of the air-sea interface focusing on the structure which develops under light wind conditions. The instrument revealed detail associated with both day-time surface warming and nightly surface cooling effects. The slight cooling of the surface skin under well mixed sea conditions, which was noted on a previous cruise (FR4 /88) was confirmed.

Real-time modelling of the surface mixed layer

A one-dimensional mixed-layer model was adapted for use with "Franklin" data, on a real-time basis. The results show more sensitivity to wind mixing than expected. However, good first results have been obtained from comparisons of the model with the observed late afternoon warming of the top meter (Flyingfish data).

Carbon dioxide concentrations, fluxes, and gradients

i) Eddy correlation

The Advanced Systems fast-response IRGA performed very reliability despite salt spray, episodes of rain, and continuous ship motion. Some 200 hours of flux data have been obtained and await analysis.

The water vapour fluxes obtained with the instrument agree quite well with the more conventional Lyman-alpha humidiometer. The CO_2 measurements indicated apparent, small, downward CO_2 fluxes (air to water), but those have yet to be corrected for density fluctuations associated with heat and water vapour transfer (which will decrease the apparent downward CO_2 flux) and for interference water vapour absorption bands (which will increase it). In any event, the fluxes certainly appear to be orders of magnitude less than previously published measurements of the eddy-flux of CO_2 over the sea.

ii) Flux gradient measurements.

The IRGA's have performed well, without undue effects from the ships motion. The water vapour gradient measurements indicate typical difference of 0.2 to 0.3 mb between 2 m and 10 m.

Measurements of the CO_2 gradient, however have proved extremely difficult. On land, 0.02 ppm in CO_2 can be detected by the IRGA, but the gas handling problems on the Franklin have proved enormous. Although strenuous efforts have been made to dry the air streams (using an ice-bath and magnesium perchlorate dessicant), to remove pressure differences between them, and to bring them to the same temperature, these measures have not been enough to cope with the very difficult environmental factors of 30°C temperatures and a relative humidity of 80%. Given also the tortuous path of the air streams along some 130 m of tubing, and their passage from hot decks to ice bath, to air conditioned laboratory, it is not surprising that difficulties have been encountered. Future work will need to concentrate more on conditioning of the air streams if the same sensitivity as on land is to be achieved.

iii) Concentration differences.

The on-board Division of Oceanography results have yet to be analysed. The equilibration measurements suggest that the Bismarck Sea might be a weak sink for atmospheric CO_2. As on a previous cruise to this area in 1988 (FR4/88), the pCO_2 indicated by this technique appears to be 10 to 30 ppm less than in the ambient air, but further analysis has to be done to correct for temperature and pressure effects.

Problems experienced and suggestions

The balloon launching facilities, consisting of a railing-enclosed area on top of the ORV Biological Laboratory container, was usable but could be significantly improved. Firstly the container requires a step between it and the ship's deck, and secondly the container roof was very slippery when wet. Next, the antenna for the sonde receiver system required excessive manual intervention during flights. A proper antenna facility for the 400 Mhz band is required. It should be mounted above the bridge with an undisturbed 360 degree field of view.

The breakdown of the ship's ice-making machine created a large problem for the cooling of air streams used in the CO_2 measurement system. This forced use of the various freezers on board. Unfortunately, making ice in this way was time consuming and inefficient. Priority should be given to purchase of a new ice-maker.

The GP Lab is not the best place for gas analysis. There is a constant stream of people passing through enroute to the computer - all exhaling CO_2. The air conditioning is not very good and residual gases seem to drain to the Lab: tobacco smoke, paint vapours, and BBQ odours from the rear deck. A suggestion is to use a rear deck container for gas work, provided it is sufficiently air conditioned. This would not only be isolated, but it is probably a more straight forward route for cables, air lines, and investigators to the foredeck. However, despite the difficulties, the space provide was excellent by most standards.

Facilities to handle gas cylinders for both balloon and gas analysis experiments could be improved significantly.

The pyranometer on the topmast developed a fine dew on the inside. Dr. Bradley had a solarimeter with him, which was placed on the topmast, thereby solving the immediate problem; however, before the pyranometer can be accepted for routine Franklin work, it must be taken down, dried out, supplied with silica gel, sealed and replaced.

A further problem with the pyranometer is that it gives a reading of about -20 w/m2 at night. The electronics need to be checked. For this project we will intercalibrate the net radiometer at the bow, the pyranometer, the solarimeter and the upwards net radiometer on the A-frame, in order to get the best time series for the net radiation into the ocean. These results may be of use in further development of the Franklin system.

The net radiometer installed on the A-frame for this project appears to have been successful, thanks to the efforts of David Edwards. This instrument was a last-minute replacement for the pyrgeometer, which was found to be faulty shortly before the cruise. Due to the use of two silica gel tubes in series, the instrument appeared to remain dry on the inside at all times. High temperatures at the smokestack are a potential problem: however, a radiation thermometer found a spot at the funnel outlet with a temperature of 50°C, accounting for perhaps 0.1% of the solid angle at the instrument. Subject to confirmation, this is thought to be negligible, so that the A-frame is a good and accessible site for radiometers.

Occasional checks on the air temperature from the Franklin meteorological station thermistor revealed that it was consistently about 1.3°C too high; this is believed to be an electronic problem. The Humidicap has also not been checked. This project will need to intercalibrate both instruments with the values from the psychrometers on the boom — and with the ship's regular 6-hourly meteorological reports (that use separate instruments) in order to get the most accurate time series for the turbulent heat flux time series.

A major disappointment is with all the project's Datataker temperature bridge systems, on the buoy and the fish. These are detailed elsewhere. Useful results will still emerge, by thoughtful analysis of the time series. Ian Helmond will probably confirm my sentiment that we were measuring temperature reliably to 0.01°C about 20 years ago and seem to have regressed.

An intercomparison of all thermometers prior to mounting on the Flying Fish and drifter showed significant drifts from the laboratory comparison. The calibration measuring system was changed from a three wire bridge to a four terminal series system and recalibrated against a S.I.S. RTM-4002 digital reversing thermometer. This new calibration system was more stable but during the cruise it still showed significant drifts. This problem will need to be resolved during post-cruise analysis.

The modification to the boom to enable the bottom psychrometer to be positioned quickly at any level down to 1 m works well. The rolling in and out took more effort than last cruise; perhaps we are all becoming more feeble with age. Ian Helmond's suggestion of a simple boat winch would resolve the problem.

Additional visitor disc space on the VAX would enable near real-time turnaround of first-cut data analysis.

Unreliability of the sonic anemometers remains a problem as during the previous cruise. Our prototype units are reliable as regards the electronics, and we understand and can repair them; but the transducers are ruined by rain. The commercialised version has rain-resistant transducers and is conveniently packaged; but the electronic layout is awkward and not totally reliable. The rock and the hard place.

I wish that there were an easier cable route from the foredeck to the ops. room. Installing and removing cables is a tiring, labour-intensive and time-consuming task. The effort would be better expended on more creative aspects of an experiment.

Acknowledgements

Thanks are due to the entire Franklin crew for excellent support and cooperation throughout the voyage. Special thanks to Bluey Hughes who built a sun cover for the radiometers above the wheelhouse. Gary Hall and Bob Clayton were very helpful in the ice-making emergency. That effort and their terrific cooking were greatly appreciated. We are also grateful to Ron Parrot for many hours spent welding the drifter drogue.

Among the scientific staff, Gary Critchley of the ORV support group was most helpful and supportive, Ian Helmond deserves praise for ingenuity, coupled with sound engineering and hydrodynamic design. Accolades to Dave Edwards who can fix anything electronic or mechanical. Special thanks to Jeff Butt for all his help with computing and data analysis, including reducing the micro-meteorology data to bite size.

Appendix 1

Electronics Report - David Edwards

Meteorological Station

Prior to the commencement of the cruise, the refurbished wind speed sensor, the solar radiation sensor assembly and the new rain gauge sensors were installed on the mast. The air temperature and humidity sensor was installed on the monkey island. The following sensors were logged for the duration of the cruise:

wind speed
wind direction
air temperature
relative humidity
Licor solar radiation
Eppley solar radiation
air pressure
rainfall

In the first week of the cruise, it was noted that the indicated air temperature was in error when compared to a mercury in glass thermometer. The calibration offset coefficient was adjusted to correct the temperature. The existence of an error was surprising since the temperature sensor and associated electronics had been calibrated in Hobart prior to the cruise.

It was also noted that the air pressure reading was sometimes extremely large, and that there was an offset of approx 7 HPa compared with the ship's digital barometer. It was found that the large readings were occuring when the scanner pressure interface card was dropping out of lock and returning a count of 0000 hex. This seemed to occur at random. No faults could be detected in the interface card. The large readings occur because the MET software does not ignore the out of lock readings.

XBT System

The 110V power on light of the deck unit has failed. This caused minor problems at the first XBT dropped. No other problems were experienced.

CTD System

CTD #1 Underwater unit was used for the entire cruise. No problems were experienced. On 23/9/90, the drive cord on the salinity channel of the YEW chart recorder failed. As a spare cord was not available, the remaining cord was removed and the recorder used in single trace mode only for the remainder of the cruise.

GPS System

The GPS receiver performed flawlessly throughout the cruise. GPS coverage in the cruise area, as detailed in the printed schedule, appears to be in excess of 20 hours per day with only two periods without coverage. Actual coverage is somewhat less, due to many periods of high PDOP. These periods can be established by printing out PDOP charts for selected satellite constellations. This is a time consuming process.

Intech Satellite Navigator

The TV monitor in this unit is now over 10 years old, and is proving difficult to keep operational. This instrument should be replaced as soon as possible.

In the short term, the navigation software should be changed so that the ship's compass heading and speedlog data is obtained directly from the existing interfaces on Micro 7, and not from the Intech. The DELP program should be modified so that keyboard input can be accepted from the bridge monitor. This would allow the navigating officer to enter waypoints, and reduce his reliance on the Intech.

Inertial Reference System (provided by John Reid)

This was installed on the bench above the Scintillation Counter in the Drawing Office. An RS 232 interface was provided to the Environmental Mechanics data logging system, and to Micro 7. Data from this system was logged throughout the cruise. No problems were experienced.

Personal Computers

The MAC SE/30 and NEC APC-IV computers were moved from the Library and installed on the port side bench in the Drawing Office. Sufficient space was available, so the NEC LC890 printer was also installed on this bench. Serial lines from the two computers were run to the VAX.

New instructions for operating the NEC LC890 were written. A hardware printer buffer could be used to allow both the MAC and the NEC to communicate directly with the printer. This would also allow the VAX to be interfaced to the printer.

The 40 Mbyte hard disk in the NEC APC-IV computer mounted in the Chemistry Laboratory was swapped with the 20 Mbyte unit in the NEC APC-IV in the Drawing Office. Both disks were reformatted. All the data from the Chemistry Laboratory unit was transferred to the 20 Mbyte disk. The 40 Mbyte disk in the Drawing Office was re-partitioned as two 20 Mbyte logical disks, C: and D:. All the programs on this unit were installed in the D: drive. This leaves the C: drive for user data and programs.

A READ.ME file was written detailing the preferred way in which files and programs should be placed on this computer. This file is printed out each time the computer is turned on or re-booted.

The 4 Mbyte RAM card was installed in the Drawing Office APC-IV as expanded memory.

In order to reduce operator discomfort, the height of the bench should be lowered. This can be done fairly easily by reducing the length of the legs. Bookshelves should be provided for the bulkheads above this bench to enable storage of the software and hardware manuals.

The P6 printer was installed in the Chemistry Laboratory adjacent to the NEC APC-IV.

VAX Over-temperature Alarm

The alarm sounded once during the cruise. The VAX air-conditioner was unable to keep the temperature below the 27°C setpoint in conditions of high sea surface temperature. The alarm set-point was increased to 28°C, and the trip margin reduced from 5 to 4°C to allow a little more leeway.

Fluke 23 digital voltmeter

This was accidently soaked in sea-water. Damage was confined to the area around the battery terminals. The unit was dismantled, washed in fresh water and then cleaned with ultra-clean. On re-assembly, it did not operate correctly. Later tests after the unit had dried out showed that the unit was operating correctly. However, it will need to be cleaned again, the PCB re-lacquered, and a full calibration performed.

Swissteco Net Radiometer

This was installed on the port side of the rear A-frame using the prefabricated mast brought from Hobart. The Campbell data logger provided with the radiometer was mounted on the A-frame adjacent to the radiometer. The supply air hose and RS232 cable were run into the Chemistry Laboratory via the existing cable tubes, with the RS232 cable being extended to Micro 7 in the Operations Room. The return air hose from the radiometer was terminated at the foot of the A-Frame. After initial teething problems, data was logged for most of the cruise. The Campbell batteries went flat just prior to the end of the first leg, so the system was dismantled at this point.

VHF Radio

This failed to operate when required on the first port call to Lae. No reason for this could be ascertained. The fault seems to be intermittent. This unit should be serviced as soon as possible.

ADCP

The transducer was not lowered in the well until just before Jomard Entrance was reached, as the chain block could not be found. It was eventually located (as expected!) in the bosun's store. No other problems were experienced with the ADCP.

Radiometers (Atmospheric Research)

Assistance was provided to Bob Cechet in keeping the two radiometers operational. A major fault in the SCATIR unit was located and rectified. A blown fuse and damaged track in the Datataker 500 used to log the SCATIR data in the last week of the cruise was located and rectified.

INMARSAT System

Midway through the cruise, it was found impossible to make outgoing voice connections (to send faxes). No problems were experienced with the telex facility. The problem disappeared when the power supply was cycled.

Drifting Buoy

Assistance was provided to Ian Helmond in repairing the printed circuit board of the rain gauge mounted on the buoy. Unfortunately, the water damage caused the high impedance sensor circuitry to drift, and the unit was not used as it could not be made to operate reliably.

EK400 Sounder

No problems were experienced with this unit. Trace noise was minimal on most of the cruise, probably due to the low ship's speeds (less than 6 knots), with good bottom detection.

Computing Report - Jeff Butt

Prior to cruise

The VAX USERDISK (DUA1) was backed up onto Exabyte. Software upgrades for HYDRO, DELP, MET and FRNMON were installed on the appropriate computer. A general RS232 logging package was installed on Micro 7 for purposes of collecting Ship Attitude Monitor (SAM) data for John Reid and radiometer data for Stuart Godfrey. All PDP-11's were backed up onto tape after the installations.

The VAX

When attempting to remove obsolete (FR6/90) users files from the VAX problems occurred with DUA1. Not all files in account [BURRAGE] could be removed due to disk read errors. After copying my own software to the VAX I found that there were directories I couldn't access as whenever attempts were made Fatal Drive Errors occurred. These problems didn't cause too much concern, in all other respects DUA1 worked faultlessly.

During the cruise there was a critical shortage of space on DUA1. Several times (early in the cruise) backups to Exabyte caused DUA1 to fill up. In order to remove this annoying problem about 200000 blocks of ADCP data from previous cruises was removed from account [ADCP]. Even with this things were tight for the entire cruise. The Environmental Mechanics people were limited to processing one data tape at a time (about 60000 blocks). There is clearly a need for a thorough clean up of the userdisk and/or another disk. (See the section entitled 'Other" at the very end of this report). For information, during the latter part of the cruise a rough bit of disk space accounting showed the following:

• Cruise data in [CROOKS.CRUDAT]	140000
Environmental Mechanics use	35000
(no data being processed either, when this happens need another 60000 Blocks for just one data tape. They produced 50 on the cruise)	
• ADCP data in [ADCP.DATA]	80000
• software/data in [BUTT]	30000
SUB TOTAL =	285000
FREE SPACE ON DUA1	119000
TOTAL	404000

The VAX system disk DUA0 failed without reason on 9/9. Several spin-up/spin-down cycles did not clear the problem. After two power off/on cycles of the RA80 drive the fault cleared (power switch left on local). DUA0 behaved for the remainder of the cruise.

During weekly backups of DUA1 Fatal Drive Errors were encountered, at one time these caused the Backup to fall in a heap. On a subsequent attempt Backup exited successfully. Evidently there is a bad patch on the DUA1. (Is there some way the VAX can be told about these sectors so as to avoid these problems?)

Micro 1

On 9/9 the power supply to the hard disk DU1 failed. The offending resistors (open circuit) had obviously been replaced in the past. On 11/9 DU1 failed (drive light stayed on). Multiple attempts at rebooting yielded no joy. DEC PDP-11 diagnostic disks confirmed that the hard-disk unit had indeed failed. The unit was disconnected and was destined for being swapped. On a whim I decided to re-connect it for one last try.

Amazingly it worked. As a precaution I manually copied all FR7/90 files remaining on it to tape, just in case it failed prior to MTSPOL doing its end of cruise cleanup (details below). DU1 did not cause any trouble for the rest of the cruise.

Micros 2, 3, 6 and 7

All performed without giving any problems. Micro 2 was frequently rebooted in order to get DELP 'unhung'.

Micro 7 was used to log John Reid's Ship Attitude Monitor and also Stuart Godfrey's Radiometer. One comment I could make is that there doesn't seem to be any logical numbering of the ports on the rear of the Micros. Additionally there are a stack of other numbers written all around the ports which basically confuse the situation, for example on Micro 7 the Port labelled C1 is actually Port 4. Trial and error worked successfully.

Exabyte Unit

The unit hung several times during intra-cruise backups of DUA1, I assume this was consequential to the DUA1 faults referred to above. Powering the Exabyte unit off and on did not always unstick the unit, however rebooting the VAX solved the problem.

On two occasions whilst backing up cruise data to Exabyte there were problems, ie. The error message 'BACKUP-I-READYWRITE' would appear as would a request to type YES after the correct volume was mounted. Control-Y was the only way out of this no-win situation. One time simply logging out and a repeated attempt worked. On the other occasion this did not work on the first attempt, in that case the files were copied across manually. After a second log out/in cycle everything was back to normal. These perturbations resulted in gaps in the numbering of savesets on the Exabytes.

The Environmental Mechanics people were introduced to the unit and quickly saw the advantages of it. Their 50 tapes were put onto Exabyte Cartridge for the convenience of a lightweight trip home.

Magnetic Tapes

With the new Exabyte system (which is an exceedingly convenient way of carting data around the country) there is an accumulating number of tapes on the Franklin. I realise that these are destined for reuse (just like CTD audio tapes) but there are now about 80 used and 20 new tapes floating around the GP Lab/VAX room and I wondered how many constituted a valid 'working set'?

For interest we found that one General tape was created each day, the manual suggests one each 3 days. I suppose this is primarily due to the greater up time of GPS and the fact that we logged the GYRO.

Terminals

TXA7 (the VT240 terminal normally used for Exabyte and tape operations) suffers an intermittent hang up (which on several occasions caused lots of bother). The terminal Box appears to get rather warm-this could be related to the problem. As of 28/9 TXA7 refused to work at all.

The Macintosh (from the Library) and a NEC APC IV next to TXA7 are both connected to the VAX and it is suggested that these be used rather than TXA7 when operations involving backup to Exabytes are being performed.

Air Conditioning

The VAX room air conditioner just handled conditions, the room temperature was generally in the 27-29C temperature range. The alarm tripped only once.

The OPS room air conditioner also had problems, as did some of the ops room staff. If the thermostat tripped the unit OFF then it failed to successfully restart. As a result the thermostat was set at 12C to ensure the unit never went OFF. During the middle of the night the temperature would reach a chilly 15C, or less in the region of the outlets. This might be great for the computers, but not so for the Operators.

Meteorology Data Logging

MET caused a considerable amount of bother during the first few days. The new software did not function as intended, nothing would appear on the DELP screen (except for occasionally all zeros), and only files full of zeros were written onto tape and the VAX. Numerous reboots and fixits were tried, all to no avail. Sometimes the menu for the MET Mark 1 logging package appeared, sometimes MET Mark 2. It all became terribly confusing, given that the operator was also trying to come to grips with RSX and the motion of the ship (a particularly wicked and synergistic pair!). A telex of helpful hints from Bob Beattie helped considerably.

The new version of the logging package could not be made to work. After reverting to the previous version (as used on FR6/90) and after resetting the baudrate of terminal TT14 to 9600 things looked better, at least real numbers were appearing on the screen. Note that if the console indicates 'Bad Data' things are working and good data will appear on the next cycle. For some reason data was not being written to the VAX. (in the early stages files full of zeros were written to the VAX), it was found that renaming the existing version of F.MET (to OLDF.MET) allowed a new F.MET to be created and then data started appearing on the VAX.

Once realistic data was obtained a few further problems became obvious:

-atmospheric pressure was way out, generally low by about 9 HPa, but it would often be jumping erratically anywhere in the range 900 to 1100 HPa

-air temperature was always high, by as much as 3C

-the rain-gauge data was subject to large amounts of noise, (one possible cause being the Radphone)

-the wind would stop being corrected for no apparent reason, ie even when the Navigation was constantly available.

The problem with the atmospheric pressure was never resolved, however it was noted that whenever the pressure was behaving erratically so did values from some of the other instruments. Noise from the radphone, etc. may be involved?? After removing the noisy data it may be possible to use the Bridge records taken from the digital aneroid barometer to derive a correction factor for the transducer and its instruments.

It was realised that perhaps the incorrect options file (METLOG.OPT) was being used- there were differences in the temperature calibration constants between the latest versions. We reverted to a former version, which reduced the temperature measured by 2.4C. On 9/9 the options file was altered to reduce the temperature by an additional 1.4C (As determined by comparing values from an Assman psychrometer on the Monkey Island). On the 13/9 it was apparent that the temperature was again high by about 1.3C, but further fine tuning was decided against. The general feeling is that from that time onwards the air temperature was about 1.3C too high. During the first leg of the cruise radiosonde observations were made each 6 hours. As a part of the sonde calibration the Assman psychrometer was used to measure atmospheric conditions atop the launching container. This data should allow correction factors to be derived for both the logged temperature and humidity data.

The numbers logged for rainfall are actually tenths of a mm, not mm. The rainfall record contains two 'types' of noise, one is a fairly regular low amplitude (corresponding to about 0.5 mm) spike downwards, the other is an irregular large amplitude (corresponding to in excess of 5.0 mm) spike upwards (related to the radphone?). If these are removed the data obtained is reliable. The self siphoning of the gauge performs well.

For some reason in the archived files (F.MET) the corrected wind speed has periods where it is stuck on a constant value, presumably this is related to MET dropping the wind speed correction?

The Eppley radiometer appears to have an offset of the order 20W/m2 (ie it reads negative values at night and all daytime values are lower than from the Licor radiometer). After adding the offset the values agreed very well with data from the Licor instrument.

Display and Event Logging Program (DELP)

Extra decimal places were added to waypoint distances and heading, this was at the request of the Bridge (the Intech Satellite Navigator was playing up very frequently).

DELP was a fairly constant thorn in our sides. During this cruise no manual event log was kept, all the events were to be logged via DELP. Some of the annoying features are:

-it crashes (with screen disappearing) for no apparent reason

-painfully slow screen response

-whenever an event is initiated another screen of data is created before the event is registered

-comments 14 lines long (there is provision for 14 lines) don't get printed, they disappear, as does the rest of the event.

-gaps of several hours appear in the event log printer due to the select button being off (due to people looking at the printed event log), can the software or hardware be made to overide this?

-CTD and XBT events seem to register much later than they should (eg. say start of XBT event when the XBT is nearly completed)

-DELP crashes when different combinations of keys are used (I succeeded in causing it to crash when trying to alter a waypoint using the 'arrow' and delete keys. The space bar and tab key are the correct ones to use).

General Data Logging (MTSPOL)

On 9/9 it was noted that MTSPOL hadn't written anything to the VAX since about 0600-7/9. After aborting and restarting MTSPOL records started being copied (except for MET records, see MET section above). As a result of this hiccup there were about 150 files that hadn't been transferred to the VAX, they remained on the PDP-11 hard-disks. As I wasn't sure if these files would be captured in the end of cruise cleanup (the MTSPOL manual suggested they wouldn't), and given the dodgy nature of DU1 on Micro 1 (where a large proportion of these files were located) I manually coped these files to a separate tape. It was noted that the DU1 drives also contained a number of files from earlier cruises. Do these just accumulate? Perhaps it would be a good ideal to periodically delete these to avoid cluttering the disks with obsolete data.

Ship Attitude Monitor (SAM)

This was continuously logged by the Environmental Mechanics people and occasionally (along with the Gyro) on Micro 7 for John Reid. The acquisition of data was carried out by a general purpose RS-232 logging package. This system worked faultlessly and was extremely simple to operate. Data for four runs were collected for John, each containing course changes and the roughest weather available. Unfortunately(?) there was not much in the way of rough weather, (20 kts of wind and 1-1.5 m seas being the worst) after getting north of the Louisade Archipelago. We did have much rougher conditions whilst crossing the Coral Sea, but there were many other problems to contend with at that stage of the cruise. Perhaps FR8/90 people can log some rough weather data on the return leg across the Coral Sea?

Acoustic Doppler Current Profiler (ADCP)

The ADCP has at last become extremely reliable and easy to operate. It (and the CTD logging package) are now two of the friendliest pieces of software on the ship. The ADCP log is a good idea, as without it one would not tend to observe the data as frequently as one should.

CTD

At the very first station the CTD program was hung up. This problem was rectified by deleting the Master File and restarting. The dodgy Master File was most probably created by myself when I control-C'd out of the interrogations of Micro 6 during the installation of software prior to the cruise. From then on all worked fine. (Setting up the CTD deck unit is always a real joy, learning the difference between display number, channel number and parameter always takes a while. It's true that it's all in the manual, but how about a single page summary from and expert to make life a lot easier for the not so expert?).

Gyrocompass

From the Manuals it is not obvious if the Gyro should be logged routinely. The Gyro files (F.CPG)on the VAX take up about the same amount of room as the GPS files (of order 50000 Blocks) so it would be useful to have it spelled out just when this instrument should be routinely logged. During this cruise it was logged at an interval of 5.0 seconds, except when SAM was being logged on Micro 7. When this situation arose the logging interval was changed to 0.5 seconds.

Hydrology data processing

The new version of HYDRO installed prior to departing did not work. In the first instance it could not locate the file HYD.OLB in [HYDRO.NEWHYD.LIB]. Upon looking this subdirectory didn't exist. I created it and copied the file across. The program build worked (if I remember correctly, though I have some vague memories of warnings about referrals to DISK$FRANK; which is not a Franklin VAX disk!). Upon the subsequent test running of HYDRO an almost blank screen appeared (no menu), at the lower left the message "Please enter a choice" flashed repeatedly (in differing amounts of red and green). The terminal did not respond to any input. As a result all the new software was deleted and we ran with the old. This software performed well, but during the cruise the automatic entering of nutrient tube numbers ceased to occur and could not be reinstated. There was insufficient time at the end of the cruise to try the new software out a second time.

Franklin Cruise Utilities

From reading the manuals these sounded perfect, just what one wants on the Franklin. However the instructions in the manuals did not work. [CRUISUTIL] contained nothing, (apart from empty directories), not even a LOGIN.COM. As a result it was not surprising that the suggested commands NAVUPD etc. did not produce anything other than error messages.

After a bit of hunting around the software was found in [CRUISPROGS] and was copied across to [CRUISUTIL]. In order to make the programs work all the .FOR files had to be recompiled and the LOGIN.COM created to include suitable linking for DPGSHR etc. Once all this was done the utilities worked well. I assume that having to do all this investigative and programming work is not the way it is meant to be?!

Miscellaneous

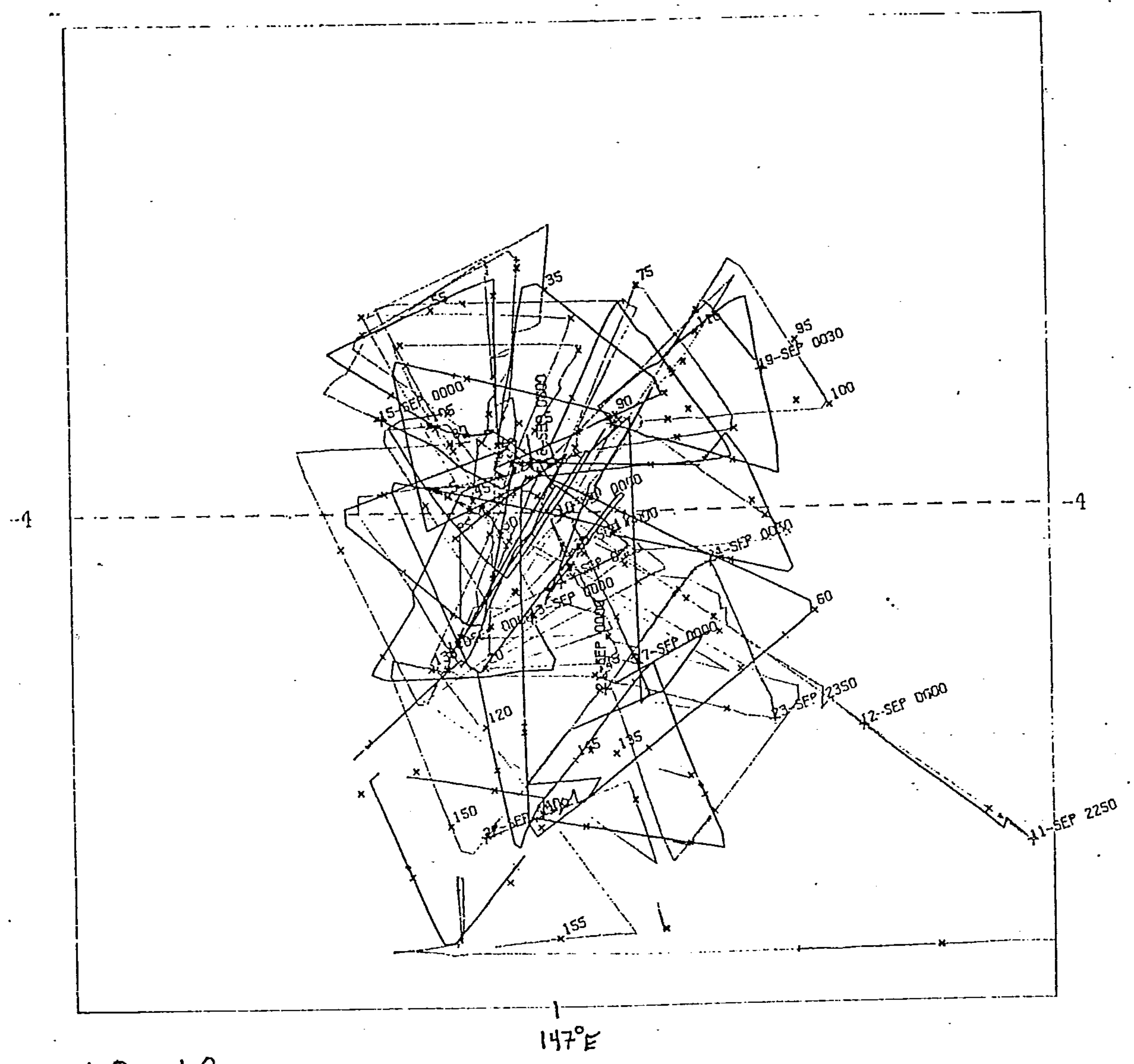
Is it easy/possible to connect the Laser Printer up to the VAX so that plots and test can be queued directly to it (cf TXB4:, TXE2 in Hobart)?

Is there anyway (such as a pull down menu) to simplify the 12 step process for setting up the Laser printer for the Mac and Nec?

Environmental Mechanics has donated a large amount (about four or five boxes) of Zeta plotter consumables to the Franklin (their Zeta bit the dust and was not worth repairing). So there is no need to purchase any Zeta Paper for a while.

Environmental Mechanics also is likely to be getting rid of their VAX (11/750) in the near future. Peter Coppin suggested that we may like one of the disc units (ie. to alleviate space problems here?) I suspect that we can get it for a very reasonable price (their entire VAX SYSTEM (second hand) cost something like $10,000.)

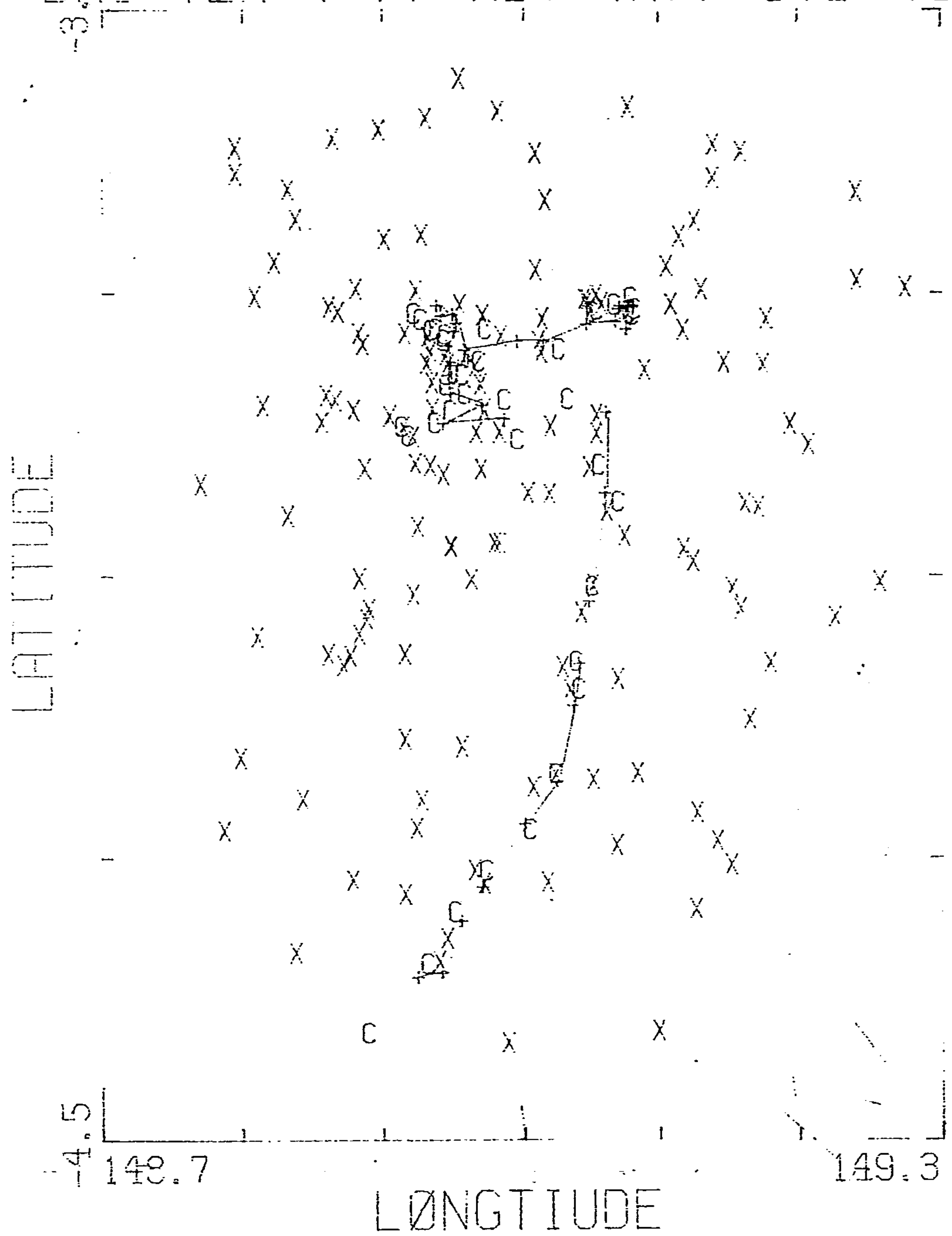
AIR-SEA INTERACTION EXPERIMENT



1/2° x 1/2° SQ

FIGURE 1

BASICS STUDY AREA-DATA LØCATIØNS
DRIFTER (+), XBT (X), CTD (C)



FR7/90 TIMELINE SHØWING DATA
CØLLECTED IN THE STUDY AREA

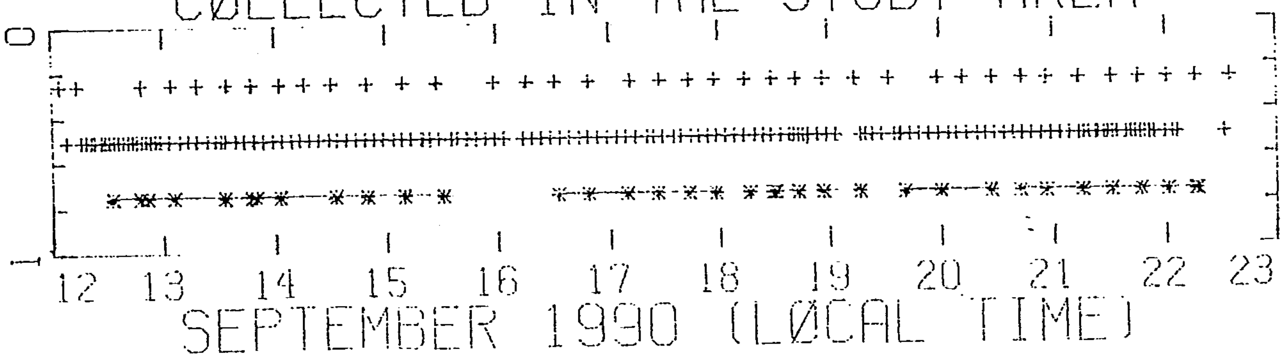


FIGURE 2.

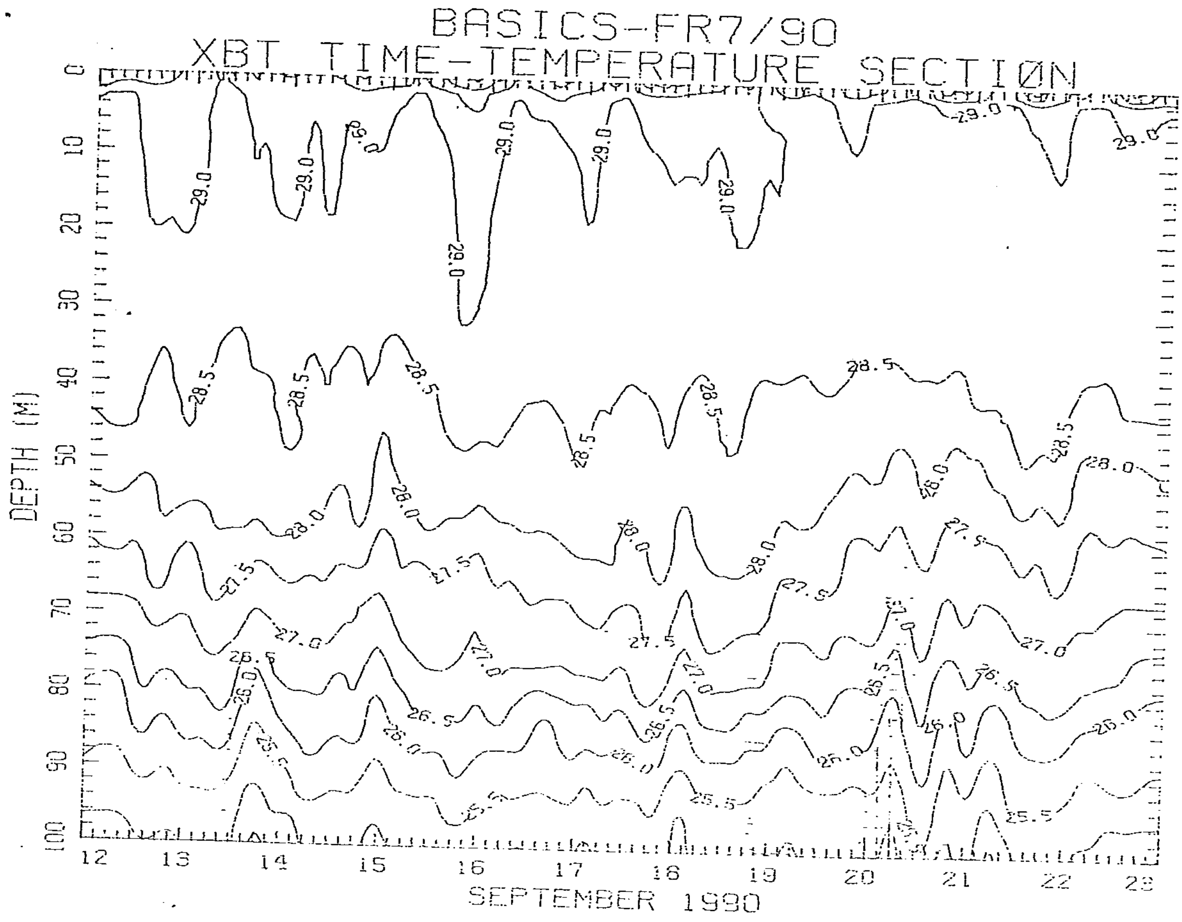


FIGURE 3

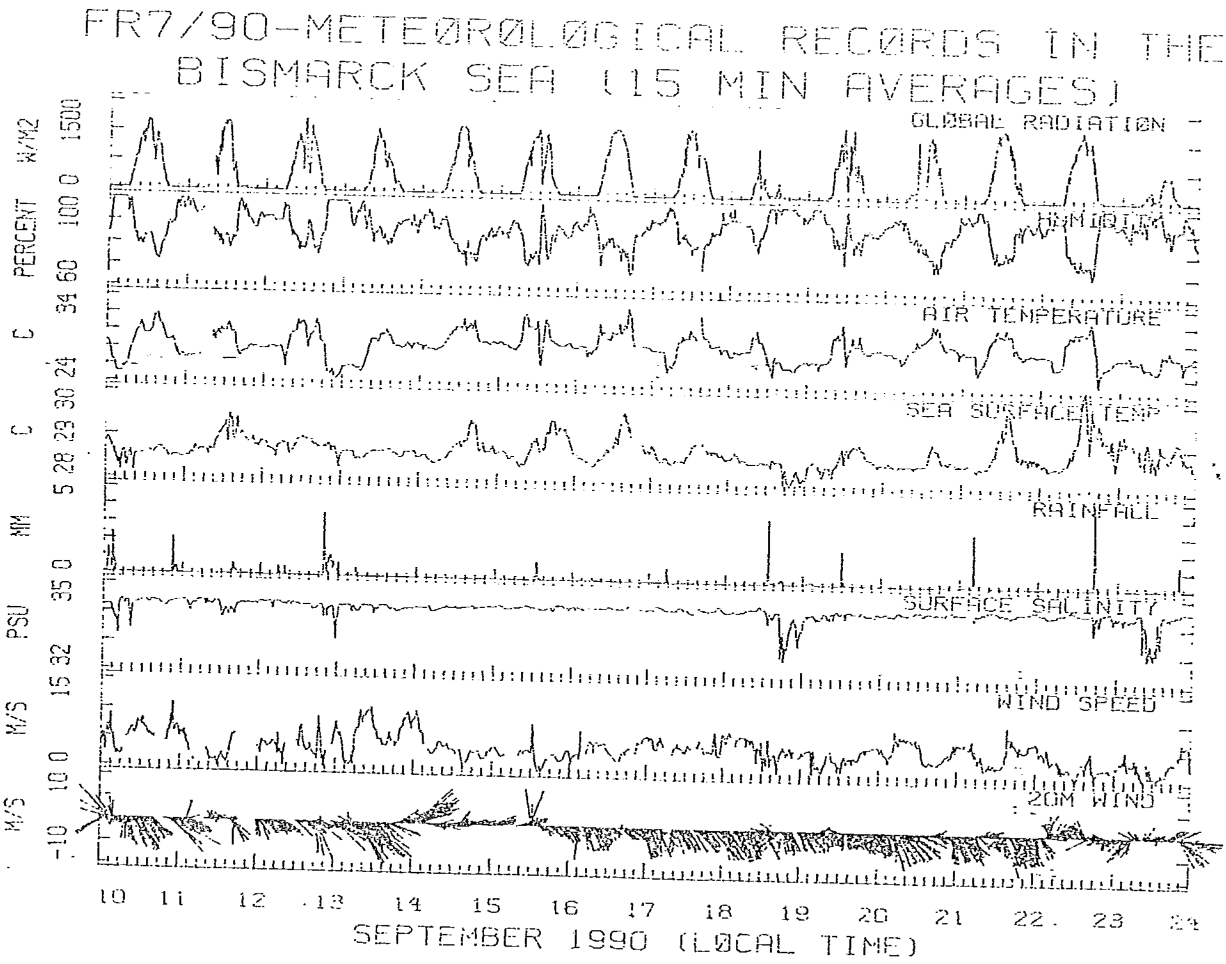
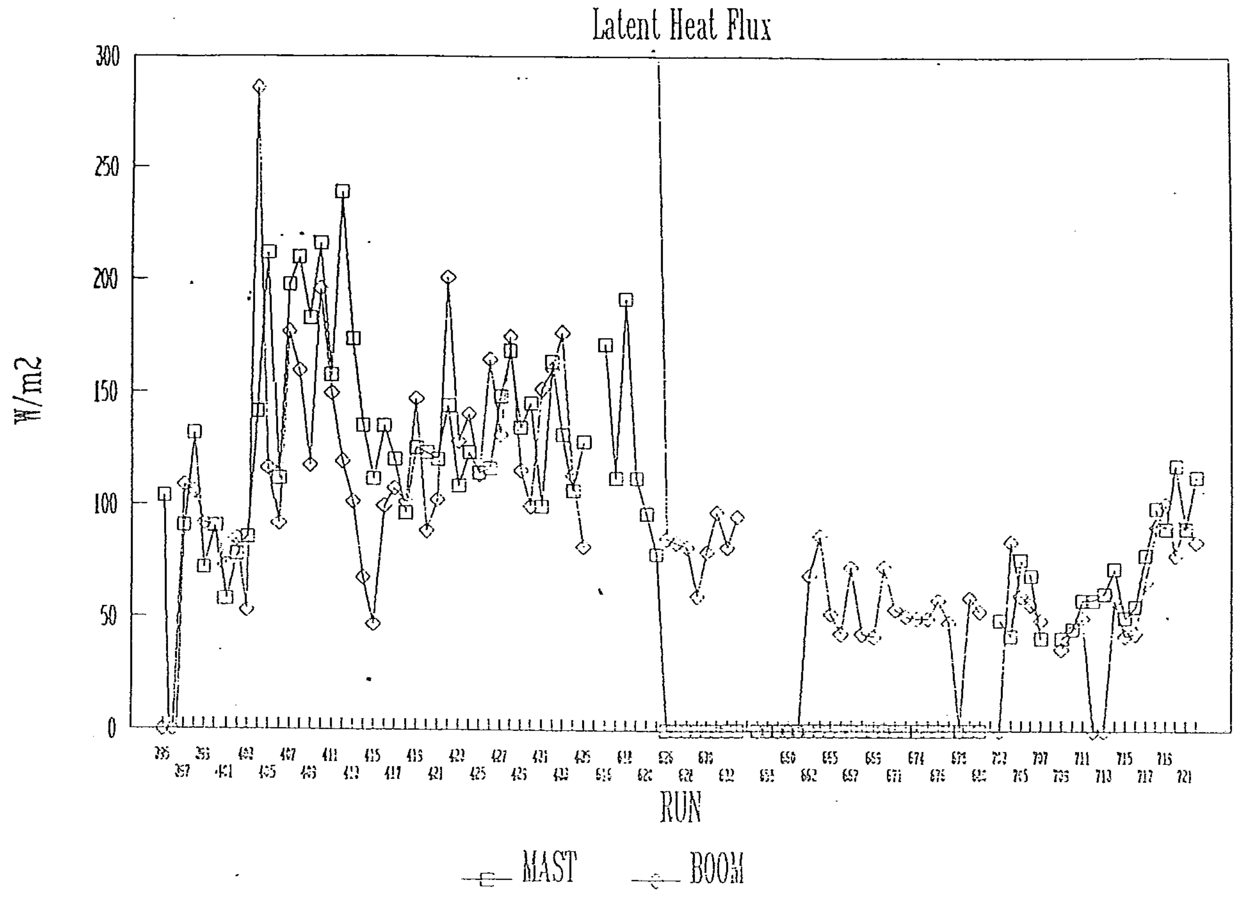


FIGURE 4


Latent Heat Flux
300
250
200
150
100
50
0
W/m2
RUN
MAST
BOOM

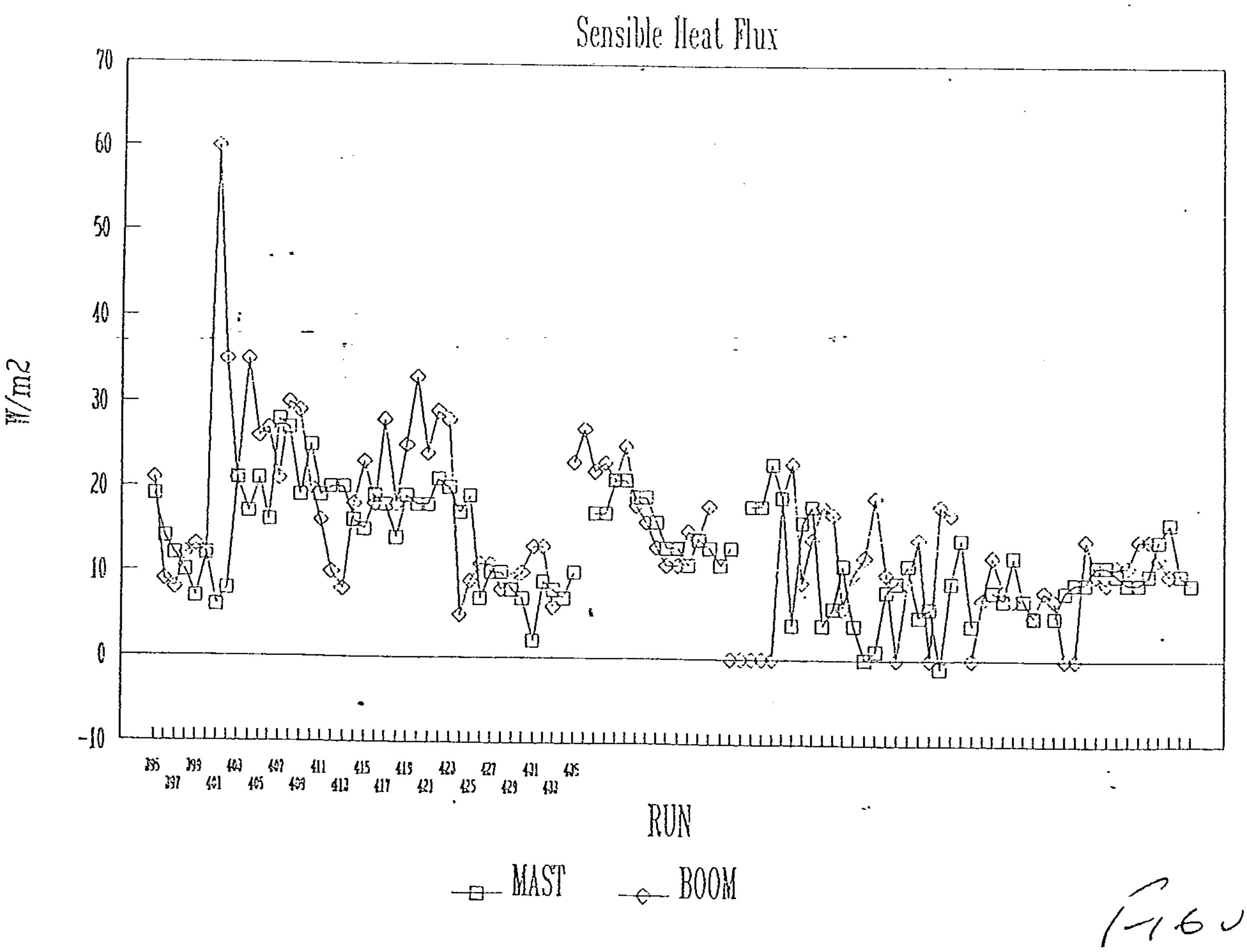

Sensible Heat Flux
70
60
50
40
30
20
10
0
-10
W/m2
RUN
MAST
BOOM

FIGURE 5

4