# METEOROLOGICAL MEASUREMENTS MADE FROM THE *ORSTOM* SHIP "ALIS" AND THE *CSIRO* SHIP "FRANKLIN" DURING THE INTERNATIONAL *TOGA-COARE* EXPERIMENT

**Australia-France Collaboration - Preliminary Report April 1993**

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## Project Objectives

To make the best possible estimates of heat and moisture fluxes, and incoming radiation, in the western Pacific "warm pool" region, using the bulk meteorological method. To explore spatial variability of these fluxes from two identically instrumented ships operating simultaneously.

## Background

During November 1992 to February 1993 an international Coupled Ocean-Atmosphere Response Experiment (COARE) took place in the western Pacific ocean, centred on (2°S, 156°E) (WCRP, 1990). The principal objective was to obtain accurate meteorological and oceanographic physical data for studies of climate change, El Ninõ etc. The western Pacific has been identified as the most significant region for global climate, hence the international interest; however, for both France and Australia climatic impacts in the region are of particular importance.

From November-December 1992 the Australian ship R/V "Franklin" participated with Frank Bradley and colleagues aboard measuring sensible and latent heat fluxes directly using turbulence equipment. This equipment is complex and can only operate intermittently, so measurements were also made continuously of the routine meteorological quantities needed to estimate heat and evaporative fluxes using so-called "bulk" formulae. We have discovered that the normal ship's meteorological equipment, even on board a research vessel such as "Franklin", is not accurate enough to achieve the resolution required for COARE; so special sensors were installed for the purpose.

The French research ship "Alis", with physical oceanographer Marie-Hélène Radenac on board, also planned to be in the experimental area from 3 November to 12 December, several days coincident with "Franklin". We therefore installed identical meteorological equipment on "Alis" to conduct a joint sub-project with several objectives:

1. To obtain comparative measurements over the experimental domain to estimate spatial variability of the fluxes.
2. Because "Alis" and "Franklin" differ considerably in size, we hoped to obtain information on possible errors caused by ship distortion.
3. Since the two ships will operate for different periods overall, a longer continuous record of measurement will be obtained for COARE.

## Instruments

To overcome the inaccuracies inherent in ship's regular meteorological instruments, by virtue of their location and infrequent service, a special set of sensors was developed for use on "Franklin" during the TOGA-COARE expedition. These consisted of a sensitive anemometer/wind vane pair by McVan Instruments, chosen because of rugged brass construction and simple electrical systems. They were modified with the replacement of some stainless steel fittings and complete sealing of the cable connections - experience has shown corrosion of electrical contacts to be an insidious source of instrument failure at sea. Aspirated psychrometers developed at CEM were used for temperature and humidity measurement, rather than the Vaisala or Rotronics polymer absorption/capacitance sensors in common use for shipboard measurement. These have the advantage of unattended operation, but have poor resolution at the high humidities typical of the tropical Pacific. Provided accessibility to wash salt contamination from the wick, and power for the ventilating fan is available the wet/dry bulb principle can potentially achieve 0.01°C resolution.

These instruments were mounted on the well-exposed forward mast on "Franklin" rather than on the very cluttered main mast above the wheelhouse. A duplicate set was provided for "Alis"; in contrast, her main mast is well-exposed and has few other fixtures to interfere. Dr Bradley installed these instruments on "Alis" in Nouméa during September 1992 and provided instructions on their maintenance to the ORSTOM group. On "Franklin", the various components of radiation are measured independently using high-quality, and therefore very expensive, optical instruments. This was out of the question for "Alis", but since solar radiation is a dominant component of air-sea energy exchange, especially at low latitudes, she was equipped with a Licor pyranometer at the top of the mast. This is an inexpensive silicon cell detector developed for light studies in crops, and is often regarded as unsuitable for accurate solar radiation studies on account of a non-uniform spectral response. Nevertheless, the writer has compared these instruments with high-quality pyranometers in the past and found that, for most applications, this is not a serious limitation.

To ensure continuous time-series of fluxes into and out of the ocean, signals from all these essential sensors were recorded on each ship with a self-contained and powered data logger, so that if ship's power were lost or the central computer network crashed, a not infrequent occurrence, these signals would be secure. However, to more easily integrate the meteorological data with the ship's navigational data, recording was also made on each ship's data-logging system.

Prior to installation, all the instruments were calibrated against secondary standards in the CEM laboratory in Canberra; the anemometers in the large wind tunnel, and the psychrometer platinum resistance thermometers in a water bath. The Licor was compared with a Kipp pyranometer on the laboratory roof. Since returning from COARE, "Franklin's" instruments have been re-calibrated and show little change. "Alis'" instruments will be similarly re-calibrated when Dr Bradley brings them back to Canberra after a visit to Nouméa in April 1993 to discuss some results of the experiment with the ORSTOM group. Until after these events, the following "first-pass" presentation of selected results must be regarded as preliminary.

## Cruise details

From 12-22 November, "Alis" operated from a fixed station at 1°30S 156°15E, followed by a re-supply port call to Rabaul. From 27 November - 6 December she operated at 1°45S 156°10E, interrupted during 27-28 November by participation in an intercomparison exercise with "Franklin" and American and Japanese ships. From 23-27 November, "Franklin" worked around a drifting buoy near 2°30S 155°E making atmospheric and ocean measurements; she participated in the inter-ship comparisons before also leaving for Rabaul on 29 November. There were thus three periods during which "Franklin" and "Alis" overlapped in the COARE IFA (Intensive Flux Array), including the rather important ship intercomparison exercise which warrants a brief explanation.

Accurate air-sea momentum, sensible and latent heat flux measurement is the cornerstone of COARE objectives, but it is an extremely difficult measurement to make from shipboard. Only a small number of scientists believe that they have adequate technique to overcome the various problems of ship motion, air-flow distortion, instrumental accuracy etc. to measure fluxes directly, and nearly all (including the "Franklin" team) were involved in COARE. Intercomparison to test the various methods and instruments was therefore regarded as a vital component of the COARE program, such intercomparison to include "Alis" and the IMET buoy (at the centre of the IFA) both of which were equipped to measure bulk fluxes.

These intercomparisons were arranged by Gregg (U. of Washington), Takeuchi (Hokkaido U.) and Bradley in Tokyo during May 1992 and took place from 1000 UTC on Nov. 27 and 1000 UTC on Nov. 28. The procedure was basically as described in the COARE Operations Plan. " Franklin", "Alis", and "Hakuho-Maru" assembled in the operational area of "Moana Wave", near the IMET buoy. While H-M and M-W performed intercomparisons of their ocean microstructure instruments for the first three hours, F and A steamed into wind at three kts. to compare their identical meteorological packages.

During the rest of the period, five three-hour intercomparisons were made with all four ships steaming into wind separated cross-wind 1 mile apart. Some compromise on speed was necessary because M-W was hampered towing Gregg's profiler and H-M, a much larger vessel than the others, could not maintain a stable track below about 5 kts. "Alis" departed the area for her fixed station at about 0200/28 UTC. The operation proceeded smoothly and all ships were satisfied with the performance of their instruments during the period. From 0400 -0700 UTC the three turbo-prop aircraft based in Honiara also made several passes of the area on one of their boundary-layer missions. Weather conditions were ideal, with generally light winds, clear sky and smooth seas.

**Preliminary results**

We obtain sensible and latent heat fluxes from bulk formulae

$$H = \rho_a C_{pa} U C_H (\theta_s - \theta_a) \; ; \qquad E = \rho_a L U C_E (q_s - q_a) \qquad (1)$$

where $\rho_a$ and $C_{pa}$ are the density and isobaric specific heat of air, $L$ is latent heat of vaporisation, $U$ is mean wind speed, and $\theta$ and $q$ the potential temperature and specific humidity of the air at 10 metres height and at the sea surface, according to the subscripts $a$ and $s$ respectively. $C_H$ and $C_E$ are bulk transfer coefficients for which a number of empirical forms have been proposed [*Blanc*, 1985]. For the convectively-driven, low wind conditions of the tropical west Pacific, *Bradley et al.* [1991] found support for the model of *Liu et al.* [1979, hereafter LKB]. LKB solve the similarity relationships for momentum, heat and moisture fluxes for the atmospheric surface layer under conditions of aerodynamically smooth flow, taking account of molecular conductivity and viscosity either side of the interface. The model and the supporting measurements both exhibit a substantial increase in both $C_H$ and $C_E$ as mean wind speeds fall below about 3 $ms^{-1}$. Over the period of light (1-3 $ms^{-1}$) winds reported by *Bradley et al.*, [1991], this increased the estimate of turbulent fluxes by 28 $Wm^{-2}$ compared with constant $C_H = C_E = 0.0013$ [*Godfrey et al.*, 1991].

From Equation (1) it is seen that additional data is required for the calculation of the fluxes; notably ship speed to correct the apparent wind speed and direction as measured by the wind set to obtain the true wind $U$, and measurements of ocean surface temperature to construct the sea-air temperature and humidity differences. "Franklin" had an infrared radiometer to measure true SST, but for the comparisons with "Alis" we use data from both ship's thermosalinographs.

Figure 1 shows this comparison, while the ships were steaming together. Both air and sea temperature agree extremely well over the entire intercomparison period, excepting at the end when both ships were stationary. Atmospheric humidity measured by "Alis" is systematically higher, by 1-2 g/Kg, than that measured on "Franklin". The reason for this may become clear when the instruments are compared at CEM. Since temperature agrees so well, it is unlikely to be caused by ship effects. Humidity depends on the wet bulb depression and is sensitive to ventilation speed and the water feed. As will be seen, the overall effect of this discrepancy on net energy flux is not severe. Sea surface humidity is not shown in Figure 1; it is calculated directly as the saturated value above the salt water, and is therefore directly related to SST. Therefore that comparison will be as good as that of sea temperature.

More disturbing is the discrepancy between wind speeds measured by the two ships, shown in Figure 2a. The overall pattern of wind speed variability is similar, but "Alis'" values are generally 0.5 $ms^{-1}$ higher than "Franklin's. The reverse would have been expected as wind flow accelerates over the bulkier ship. However, it is quite feasible that the larger ship creates blockage; until we perform the intended wind tunnel tests we cannot be sure. Prior to this Franklin's anemometer had been giving trouble; and, as we shall see from other data, the one on "Alis'" may have been sticking (which would have decreased the measured wind speed). So the situation is complicated; data from the other ships will no doubt shed some light on the problem. Also in Figure 2a, we note that the Licor radiation measurements agree very well with those of the high-quality instrument aboard "Franklin".

Figure 2b shows a comparison between sensible and latent heat fluxes calculated from Equation (1) using the LKB model for $C_H$ and $C_E$. The difference is principally due to the discrepancy in wind speeds. The net heat flux, $Q$, into the ocean mixed layer through the surface is the resultant of radiative and turbulent components,

$$Q = (R_S\downarrow - R_S\uparrow) - (R_L\uparrow - R_L\downarrow) - H - E \tag{2}$$

The first bracketed term on the right is the net solar input [ = $(1 - \alpha)R_S\downarrow$ where $\alpha$ is the shortwave albedo], the second bracketed term is the net thermal radiation, $H$ and $E$ the sensible and latent heat fluxes respectively. Assuming an albedo of 6% and a net outward longwave radiative flux of 45 $Wm^{-2}$ (the average value measured by Franklin), we can construct the time series of air-sea energy flux using "Alis'" data. This is shown in Figure 3a in comparison with "Franklin's" measurements for the entire intercomparison day. The final step, integrated energy input to the ocean surface mixed layer is given for the two ships in Figure 3b. In each case, the mixed layer is taken to be 40 metres deep and the radiation transmitted through that depth 7% of $R_S\downarrow$ (Paulson and Simpson, 1981; Lewis et al, 1990). Over this period the two integrations have diverged by an amount equivelant to only 20 $Wm^{-2}$, a very satisfactory result but fortuitously due to the dominance of the radiation component.

For interest, we have also compared observations from the two ships in their overlapping periods before and after the intercomparison. Exact relative positions have not yet been worked out, but their separation probably varied from about 30 to 60 miles. Figure 4a shows that "Alis" was in slightly warmer water than "Franklin"; or perhaps the fact that she was stationary affected water at the thermosalinograph intake. However, "Franklin" experienced a storm in which air temperature fell by 5°C and the wind gusted to 10 $ms^{-1}$ (Figure 4b). This storm (or possibly another) was not felt at "Alis'" position until about an hour later, and then considerably attenuated; however, "Alis" received a second such storm some 4 hours later which completely bypassed "Franklin". The comparative radiation patterns are radically different; after a promising start to the day, the storm obviously brought considerable cloud cover over "Franklin", clearing somewhat later in the afternoon. "Alis'" radiation pattern is almost completely out of phase with this. Careful analysis of situations such as this will provide important information on the role of spatial variability in estimating air-sea fluxes on a variety of time scales.

The period immediately following "Franklin's" port call was marked by a series of fairly clear days. Despite being well separated, observations by the two ships of SST, air temperature and humidity, and radiation are very similar, particularly as regards the diurnal cycle (Figure 5a,b). The wind speed patterns, however, are quite different and rather puzzling. They seem to suggest that the anemometer on "Alis" was "sticking", requiring a significant gust to start the rotor turning, The fact that the bursts of wind are coincident with sudden drops in air temperature (i.e. storms) tends to support this theory. One important difference is that "Alis" was anchored, while "Franklin" cruised continuously at around 8 kts., so that her anemometer rotor was never becalmed. Again, resolution of this problem must await examination and recalibration of the instrument.

### Summary

Preliminary comparison of meteorological data from "Alis" and "Franklin" during TOGA-COARE indicates that air and sea surface temperature, and radiation measurements agree extremely well. There are differences in the measurement of atmospheric humidity and true wind speed which are as yet unexplained. "Alis'" psychrometer has yet to be recalibrated, and comparison with data from other sources will also be used when available to verify the performance of instruments on both ships. "Bulk" flux calculations of latent and sensible heat fluxes have been made, and combined with the radiation measurements to produce time series of air-sea energy exchange. These are very similar for the two ships, even at this early stage of data analysis. The small-scale variability of meteorological conditions, which is a significant feature of the western equatorial Pacific warm pool, is already evident in samples of data when the two ships were separated by a few tens of kilometres. It is clear that the observations made aboard "Alis" are an important contribution to the meteorology and air-sea flux data set for COARE.

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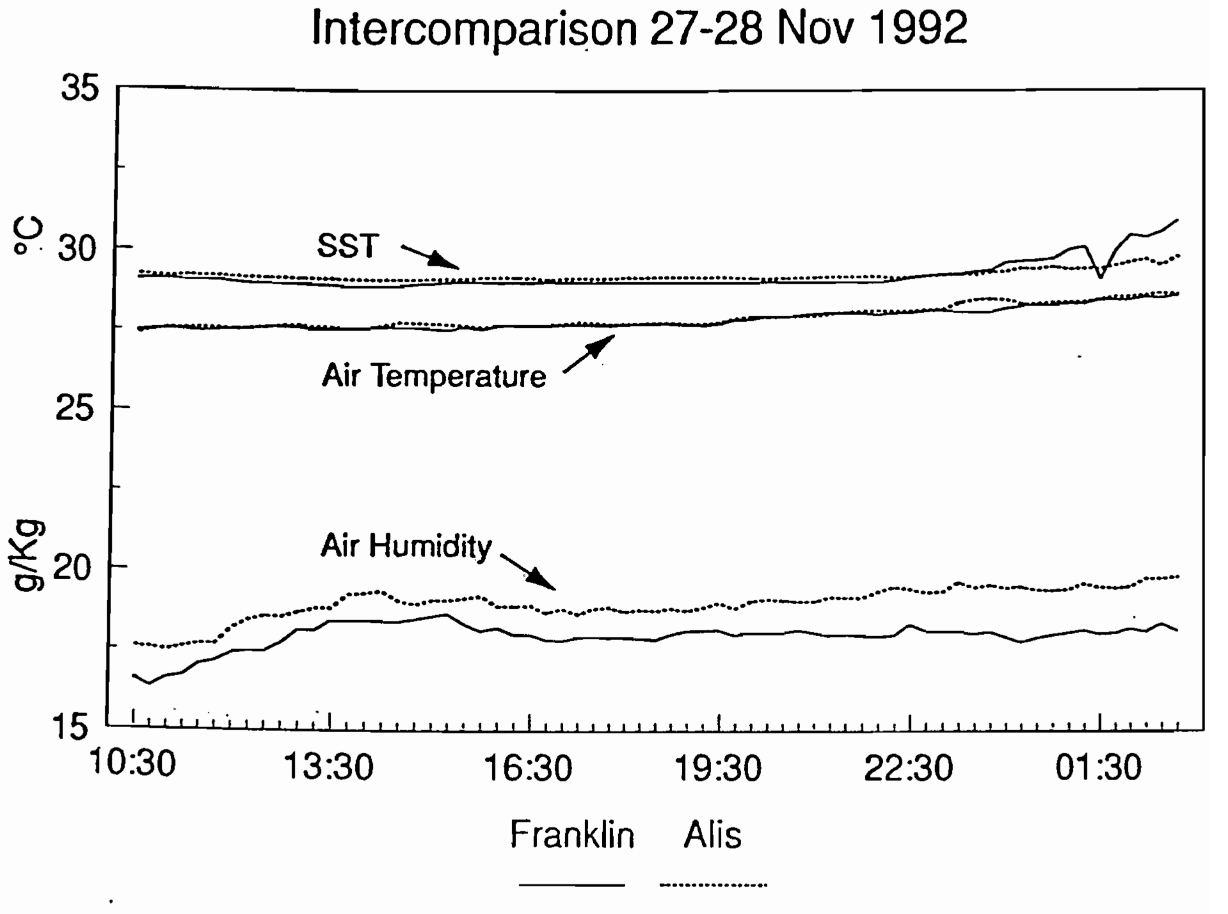
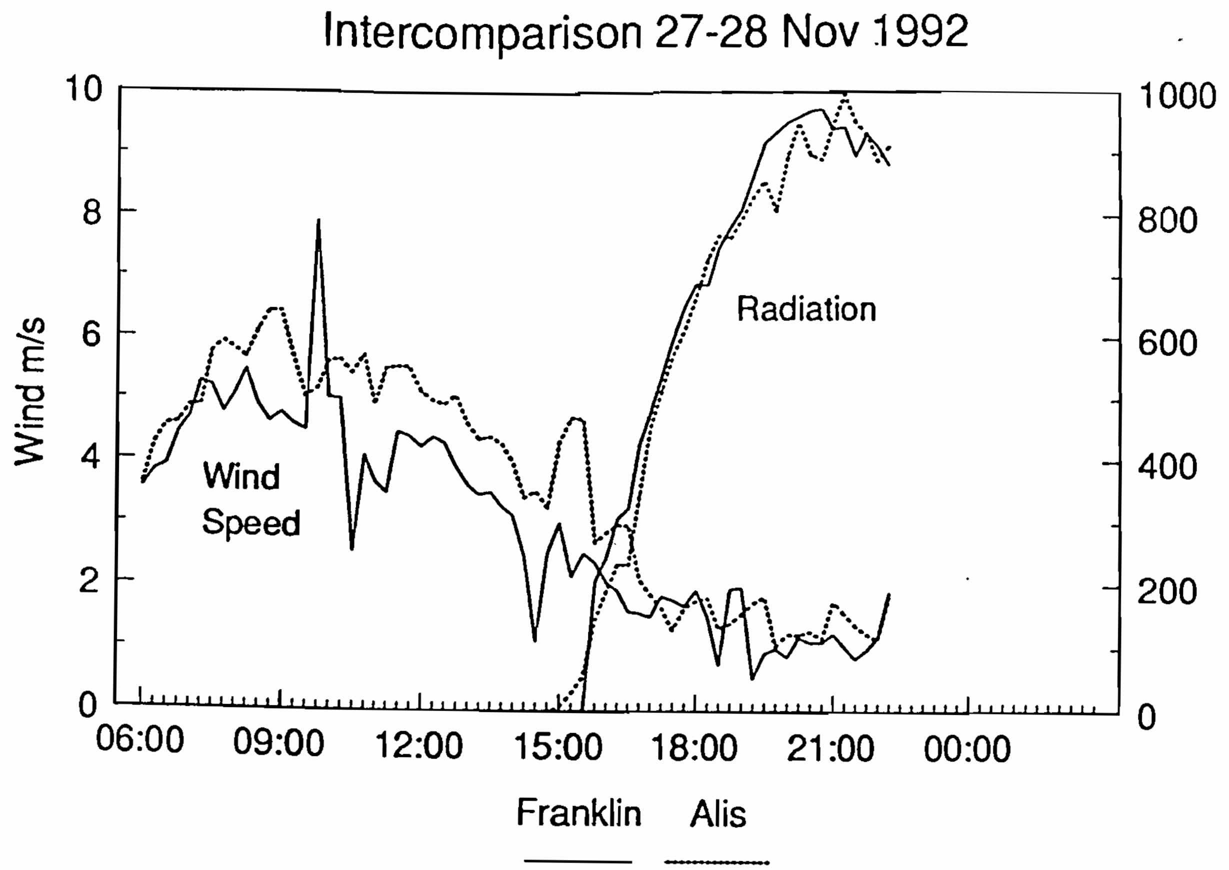



Figure 1. Comparison between air and sea temperatures measured by "Alis" and "Franklin" when the ships were steaming parallel tracks.



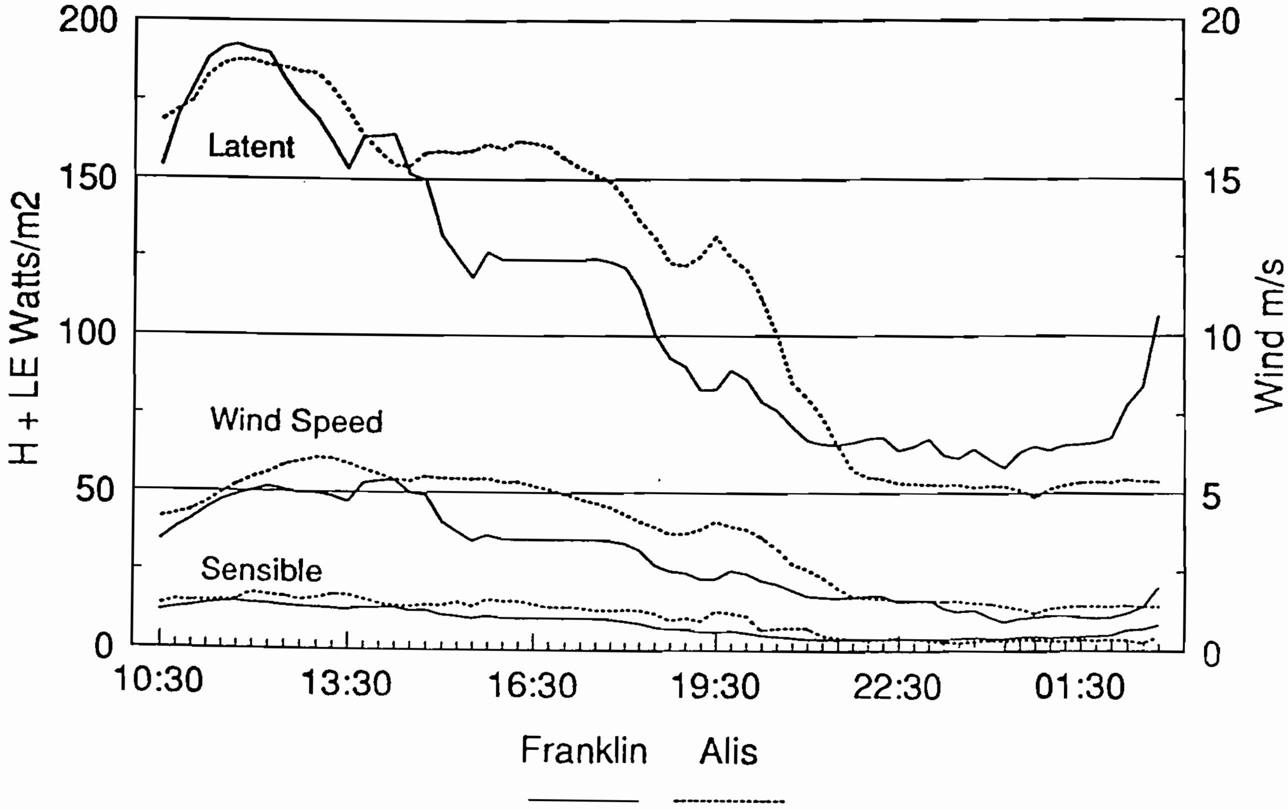




Figure 2. a) As Figure 1, for short-wave radiation and wind speed.
b) Bulk calculations of sensible and latent heat flux.

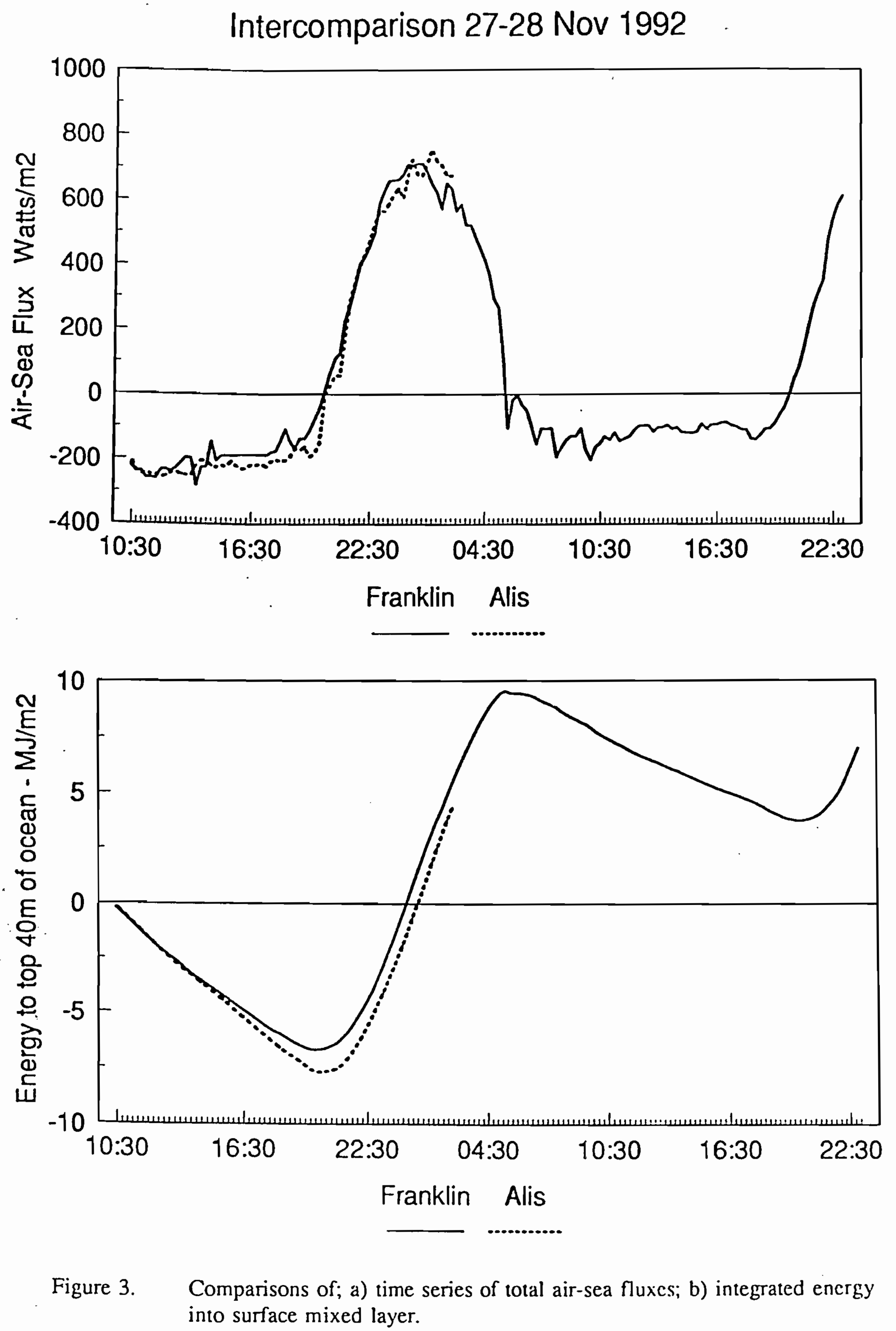
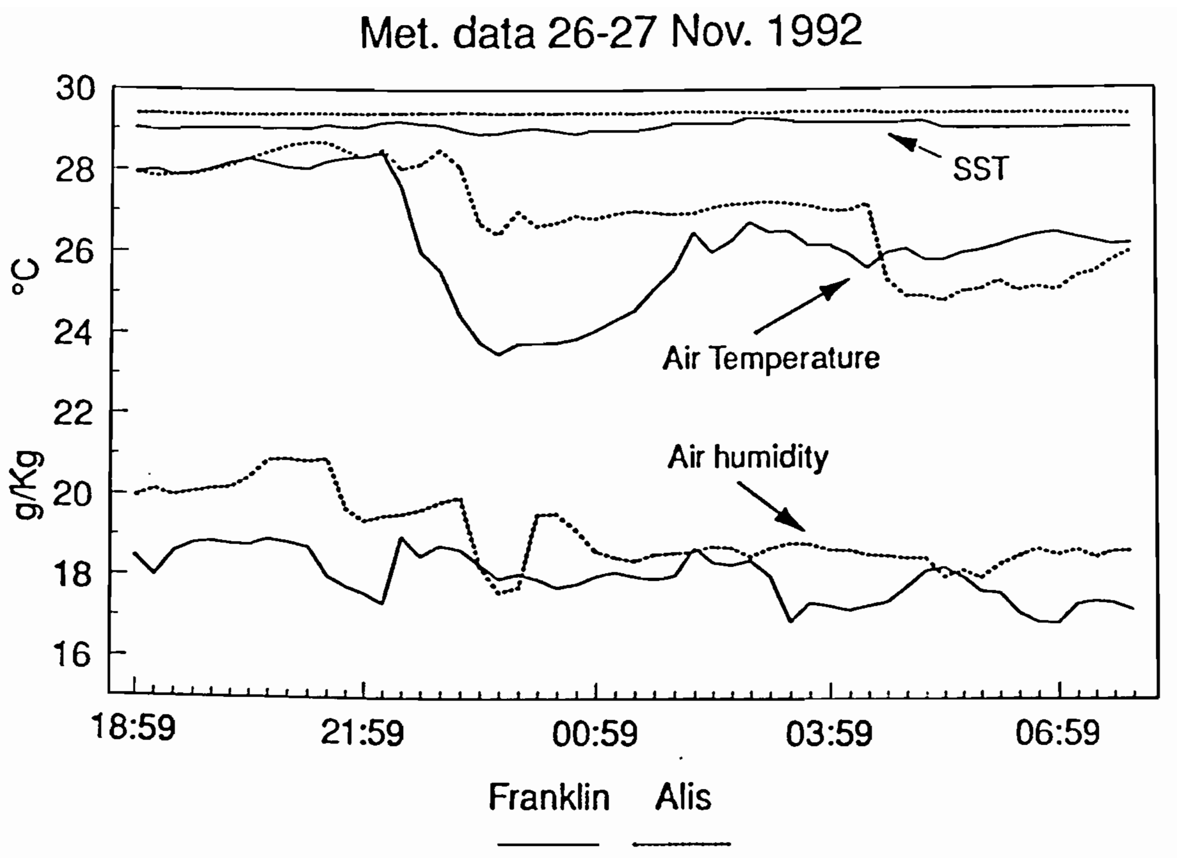



Figure 3. Comparisons of; a) time series of total air-sea fluxes; b) integrated energy into surface mixed layer.



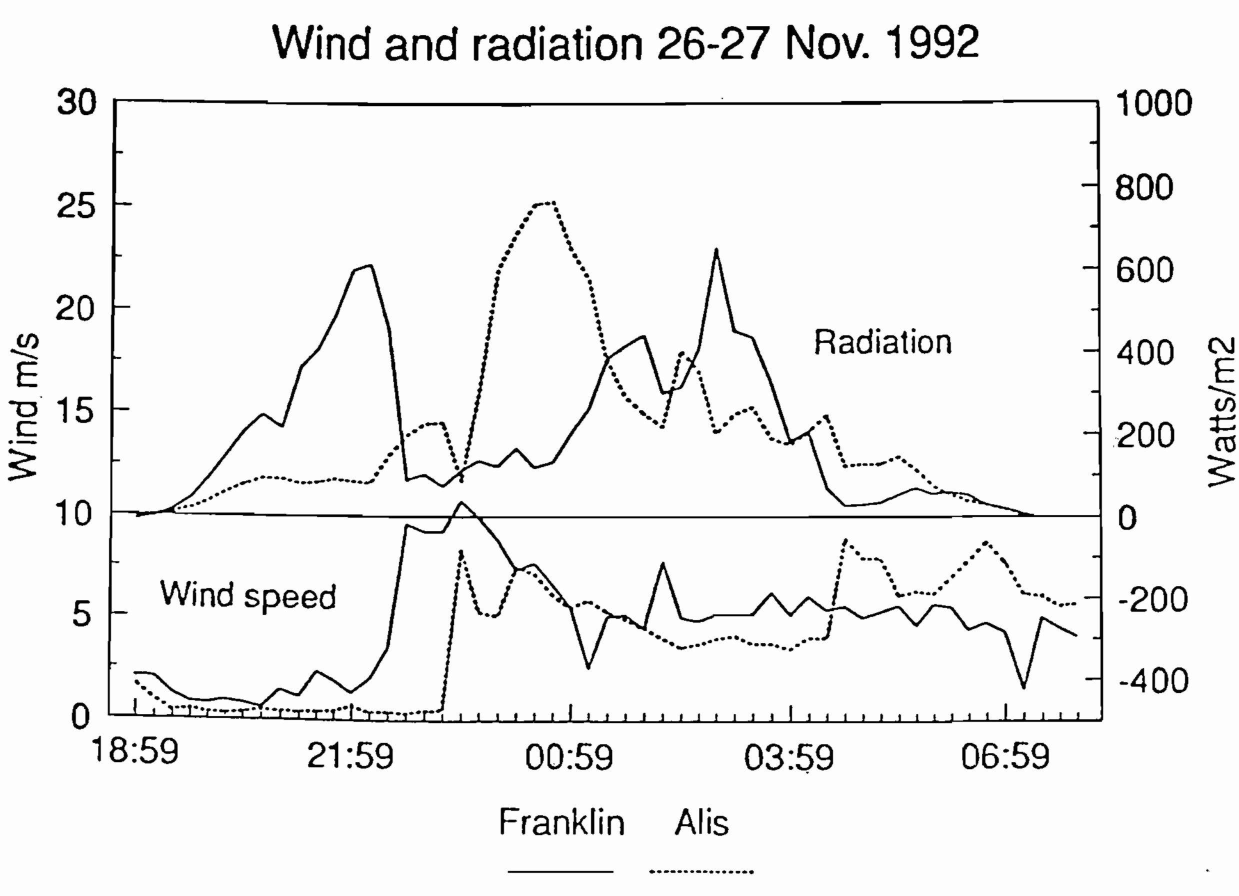




Figure 4. Comparison of meteorological measurements by the two ships at different locations in the IFA, 26-27 November 1992.

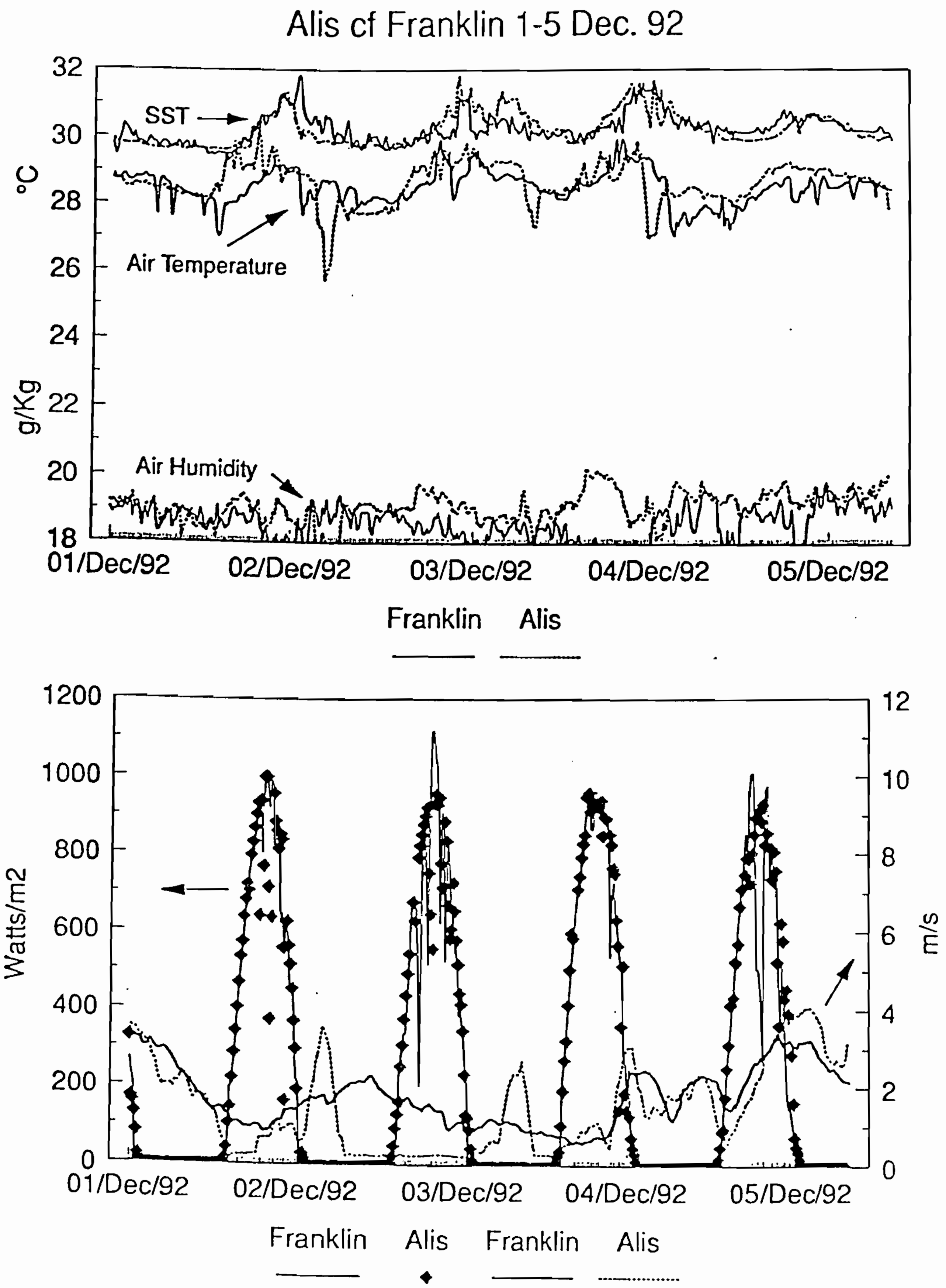



Figure 5. As Figure 4, 1-5 December 1992.

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