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Sea temperature variability off Western Australia 1990 to 1994

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Contents

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Abstract

Analysis of temperature data from coastal waters between Shark Bay and Cape Mentelle has shown the main features of temporal and spatial variability in temperature along the Western Australian coastline. Three distinct periods of variability emerge: the annual cycle (peak temperatures generally in January-February and troughs in July-August), a few-day (weather-related) cycle, and the diurnal pattern.

Summer temperatures range from 24° C (South Passage) to 19° C (Cape Mentelle), and winter temperatures from 21° C (South Passage) to 16° C (Marmion). Mean annual temperature ranges (winter minimum to summer maximum) are between 3° C (South Passage) and 7° C (Alkimos), these differences being interpreted in terms of varying cross-shelf water exchange with the Leeuwin Current. The overall along-shore temperature gradient is about 0.4° C per degree latitude. The few-day cycle has a typical range of 1° to 2° C. The mean diurnal temperature range varies from about 0.2° C (deep offshore site) to as much as 1.7° C (some inshore sites during mid-summer).

Some applications of these data to the western rock lobster industry, marine aquaculture and satellite remote sensing are briefly explored. Short-term temperature changes are generally less than about 0.2° C/hour, but at some sites the daily variation can be as much as 3° C over a 12-hour period.

1.0 Introduction

In 1986, the Western Australian Marine Research Laboratories (WAMRL) commenced a program recording sea temperatures at a number of locations along the West Australian coast, to examine the effect of temperature variability on catches of the western rock lobster (Brown and Rossbach 1990). Temperature loggers were located at rock lobster puerulus collector sites between Shark Bay (26° S) and Cape Mentelle (34° S) (Figure 1, Table 1) (Caputi *et al*.1993).

The study has been the most comprehensive survey of coastal ocean temperatures so far undertaken off Western Australia. Apart from a brief review of sea temperatures by Pearce (1986) showing the main characteristics of the monthly temperature variability at coastal and open-shelf sites between King Sound (16°44´ S, 123°18´ E) and Albany (35°00´ S, 117°52´ E), all other studies have been regional in extent. In an early paper, Hodgkin and Phillips (1969) compared inshore and offshore seasonal temperature cycles off Fremantle, while more recently Pearce *et al*. (1985) analysed monthly temperature averages off Marmion derived from a series of coastal surveys between 1979 and 1982. As part of a study of coral ecology and spawning, sea temperatures were measured off Dampier (20°39´ S, 116°43´ E) between 1981 and 1983, and within the Ningaloo Reef system in 1985 by Simpson (1988) and Simpson and Masini (1986) respectively. Monthly changes in temperature off Augusta on the south coast of Western Australia were studied by Pearce (1992), while Lenanton *et al*. (1996) described cross-shelf temperature changes off Fremantle and used spot monthly temperatures from the puerulus collector sites to assess the "preferred temperature environment" for tailor along the coast. Vertical temperature and salinity sections sampled during the Southern Metropolitan Coastal Waters Study off Fremantle between 1991 and 1994 showed the interaction between coastal and offshore waters in response to wind and Leeuwin Current forcing (Department of Environmental Protection 1996). Pearce (1997) analysed temperature and salinity data at Seven Mile Beach (Dongara) and Rat Island to show the influence of the Leeuwin Current on offshore temperatures at the Houtman Abrolhos Islands. The effect of the newly-described Capes Current on coastal water temperatures in the Cape Naturaliste/Cape Leeuwin area has been assessed by Pearce and Pattiaratchi (1999).

This report documents the processing and analysis of hourly temperature data recovered from the loggers to describe the temperature variability in the State's coastal waters, as a prelude to more sophisticated analysis and correlation with lobster catches. Some overall statistics are derived and the oceanographic significance is briefly discussed. As the early loggers proved somewhat unreliable, much of the temperature data prior to 1990 have proved difficult to process and of uncertain accuracy. As a result, this report only deals with data over the five-year period 1990 to 1994 when improved loggers were used. The temperature logging project is continuing at most sites as part of the long-term puerulus collector program (Caputi *et al*.1993).

2.0 Description of sites

Temperature loggers were deployed at seven coastal sites between Shark Bay and Cape Mentelle, these were South Passage (Shark Bay), Seven Mile Beach, Jurien, Alkimos, Marmion, Warnbro Sound and Cape Mentelle; as well as an offshore sites at Rat Island and another out from Green Head (Figure 1, Table 1). Six of the inshore sites were at the positions of puerulus collectors; the logger site in Marmion Lagoon was established near the inlet to the WAMRL aquarium. Offshore loggers were also originally installed off Shark Bay, Rat Island and Rottnest Island (Brown and Rossbach 1990) however, these were discontinued due to mooring problems and equipment losses.

The inshore loggers were mounted in concrete cradles on the seabed in about 5 m water depth at the puerulus collector sites (Brown and Rossbach 1990). The loggers off Green Head were installed on a mooring mid-shelf in about 60 m of water, with the "near-surface" logger at about 4 m depth and the "near-bottom" instrument some 45 m below the surface. Figure 2 illustrates the periods for which data are available at each site; the gaps are due either to deployment problems or instrument malfunctions.

At all the coastal sites except Marmion, the loggers were deployed in the lee of coastal reefs for protection from waves and swell. The site in South Passage is on the northern bank of the 2 km wide inlet; although not directly in the main force of the inflow and outflow, the site experiences daily flushing as tidal currents sweep strongly through the channel into and out of Shark Bay. The Rat Island logger lies amongst broken reefs in a well-flushed position some 2 km northeast of the island, and the logger at Seven Mile Beach is in the reef system very close inshore. At Jurien, the logger is positioned on the coastal side of Tern Island (near Boullanger Island) about 2 km off the coast, while the Alkimos deployment is just inside a reef amongst the Eglinton Rocks less than 500 m offshore. The Marmion logger is situated at the WAMRL aquarium inlets about 150 m offshore in Marmion Lagoon, which is bounded by a reef system about 4 km from the coast but the exchange of water with the open ocean is reasonably good. The recorder in Warnbro Sound is some 4 km offshore in depths of 5-10 m near a reef chain called "The Sisters" with good water movement.The logger at Cape Mentelle nestles behind a reef very close inshore in the small bay of Kilcarnup.

3.0 Methods

3.1 Temperature loggers

Three types of WESDATA temperature loggers have been used in the project (Brown and Rossbach 1990):

a) model 886 - the original 8-channel logger with 64K memory;
b) model 187 - an inexpensive single-channel logger with 32K memory;
c) model 389 - the most consistent and versatile intrument.All the data analysed in this report have been collected using model 389.

The rated accuracy of the loggers is 0.1° C. Model 389 can store sufficient samples to record for almost six months at a 15-minute sampling interval. The sampling interval for the inshore loggers was 15 minutes, and 30 minutes for the offshore loggers off Green Head.

3.2 Data analysis

Because the procedures involved in downloading, calibrating and validating the temperature data are relatively complex, they are documented here in detail (following Tait 1994). Early attempts were made to write a sophisticated computer program to completely automate most aspects of the processing, but it soon became apparent (particularly with the earlier loggers) that manual intervention was required to detect and correct timing or temperature problems. As a result, a more time-consuming manual method was adopted which has considerably improved the reliability of the final datasets.

3.2.1 Calibration

Initially, the loggers were calibrated only when they were new or when changes had been made (such as the installation of new batteries). After about 1993, however, each logger was calibrated both before deployment and on recovery.

Calibration consisted of immersing the temperature probe of the logger in a beaker of crushed ice with an average temperature of 1° C for approximately half an hour so that it could equilibrate. The WESDATA software package for the temperature loggers was then run: from the menu "PROBE TEST CALIBRATION", the logger serial number and the frequency of recording were entered into the fields *SERIAL No.* and *FREQUENCY* respectively. The screen displayed the temperatures currently being recorded by the temperature logger and after three consecutive similar results, this temperature was noted.

The procedure was repeated with a beaker of hot water at approximately 40° C, again following the program, and a maximum point selected. The program computed the slope and offset of the calibration line using these two points.

3.2.2 Deployment

When a logger was deployed, the water temperature at the site was measured with a mercury thermometer as a validation check and the deployment time noted. The existing logger was recovered and returned to the laboratory for extraction of the data. At the deep-water site off Green Head, a reversing thermometer was sometimes used to validate the temperature at the near-bottom logger. On occasion these check-temperatures were not taken (especially for the offshore site), and it also appears that incorrect temperatures were occasionally written down on the logsheets; as a result, there is doubt about the absolute accuracy of some of the data (discussed below).

3.2.3 Downloading and preliminary processing

The field temperature data were downloaded from the logger in binary format as "dat" files, which were converted to calibrated temperatures by the WESDATA program as ASCII (text) files with file names SSSyyddd.txt, where SSS = site and yyddd = year and day of downloading.

The "txt" files were examined in a text editor, and all pre- and post-deployment data (air temperatures) removed from the ends of the in-water record. Because of the smoothing/averaging mentioned below, the 15-minute files were manually edited to ensure that the first valid record was at a time of quarter to the hour (e.g. 11:45) and the last at quarter past the hour (e.g. 15:15). For 30-minute sampling intervals, the corresponding times were both half past the hour (e.g. 14:30). The files were then renamed so that yyddd represented the year-day number of the first valid record.

Program TLUNPACK.bas processed the edited file and created an hourly time-series. For 15-minute samples, the "xx:45", "xx:00" and "xx:15" times were averaged to yield hourly means, while for 30-minute samples, the hourly means were computed from the "xx.30", "xx.00" and "xx.30" samples, overlapping on the half-hours. The hourly data were saved with the file extension "hd0".

3.2.4 Data validation and correction

The tables in Appendix 1 summarise the logger deployments and temperatures measured at each site. As can be seen, there were occasionally differences of more than a degree between the two loggers (one being recovered and the other installed) and/or between either logger and the mercury temperature. Where these large discrepancies in temperature occurred, we cannot be sure of the "true" water temperature at the time of deployment/recovery, so have adopted the (somewhat subjective) procedure of estimating it as follows:

a) If there is no mercury temperature, we have averaged the two logger temperatures;
b) If there is a mercury temperature, we have generally taken that to be accurate, and therefore adjusted the two loggers to match it; or
c) If the two loggers agreed closely but differed appreciably from the mercury temperature, we have again averaged the two logger values (effectively ignoring the thermometer value).

The logged temperatures were then adjusted linearly throughout the datafile to match the temperatures at each end. Many of the loggers have been repaired over the years and had new sensors fitted, so we have not been able to assess possible logger drifts with time in any consistent way. As a quality control estimate, we have attempted to assign a "reliability code" by flagging as "A" those occasions when the logger and mercury temperatures agreed within 0.5° C, "B" when they were within 1.0° C and "C" when the differences were larger than 1° C or there were no matching measurements. These codes are listed for each individual logger datafile in Appendix 1, so that (for example) "AA" represents first quality data (good at both ends), "AB" good at one end and poorer at the other, and "CC" must be considered of questionable reliability.

3.2.5 Working files

After the temperatures were adjusted in the individual logger datafiles, the files were merged into annual datasets containing hourly temperatures at each site, with filenames SSSyyyy.hd0. Gaps in the dataset (due to deployment problems or instrument malfunction) were left blank. As a further check on the data, time-series charts for each site were plotted for two-monthly periods over the year and examined for consistency, especially at the change-over times. By scrutinising both the absolute temperatures and the diurnal and few-day variability, a number of uncertainties were resolved.

3.2.6 Preliminary data analysis

Program TLOGSTAT.bas was run for each site, calculating over the 5-year period:

a) daily mean temperature, standard deviation, minimum and maximum (as long as there were at least 20 of the 24 hours data for the day); the output filename was SSS.dd0.
b) monthly mean diurnal temperature cycle, *i.e.* the average temperature pattern over 24 hours (if there were at least 20 of the 30 or 31 days with full hourly temperatures in that month); saved as SSS.diu.
c) monthly mean temperature, standard deviation, minimum and maximum values (if there were at least 500 hours of data in the month); saved as files SSS.md0.
d) histograms of the absolute hourly temperatures, daily temperature ranges (maximum-minimum) and hourly changes; files SSS.hst.
e) listings of all times and temperatures when the hourly temperature change exceeded 1° C; files SSS.dif.

Spreadsheets were constructed for each of the final datafiles (a) to (d), and relevant time-series and histogram charts plotted. The difference listings (e) were used as another check for irregularities in the data; manual editing was carried out on the few remaining "spikes" and small data gaps were interpolated.

4.0 Results

The annual histograms of the temperature differences at deployment/recovery effectively illustrate the improvement in the calibration and validation techniques over the five-year period (Figure 3). As the need for reliable check-temperatures became apparent and quality control was tightened, the discrepancies between the mercury thermometer and logger measurements decreased. In 1990 these differences exceeded 1° C on 25% of occasions and less than 50% were within 0.5° C; by 1994 only 3% exceeded 0.5° C.

Although there are different periods of data at each site and many data gaps (some substantial), a good indication of overall thermal conditions off Western Australia can be obtained by averaging over the five years of available data (Table 2; Figures 4 and 5). The main features of the temperature variability at each site are illustrated in Figures 6 to 15; in which the top panel shows the daily mean temperatures by year, the centre panel shows the diurnal patterns and the monthly mean temperatures are shown in the bottom panel of each figure. To illustrate the shorter-term variability, daily mean sea temperatures in 1994 have been plotted in Figure 16; daily mean air temperatures for Perth have also been included to assess the effect of air-sea heat fluxes on coastal water temperatures.

For applications such as marine aquaculture which require information on the rate of change of temperature as well as absolute temperatures, histograms of the temperatures and temperature variations at the shallow-water sites are plotted in Figures 17 to 24.

5.0 Discussion

5.1 Overall statistics and the seasonal cycle

The annual mean temperature at the coastal sites (Figure 4a) falls from 22.3° C at South Passage (Shark Bay) to 18.8° C at Cape Mentelle. This equates to an along-shore temperature trend of 0.004° C/km, identical with the gradient derived from surface temperatures in 1 degree latitude/longitude squares representing open continental shelf conditions (United States Navy 1992). These temperatures off Western Australia are much higher than those at corresponding latitudes in the Benguela Current (southwestern Africa) and the Humboldt Current (Chile/Peru), where there are cool northwards currents and wind-driven upwelling of colder, nutrient-rich waters onto the continental shelf (Pearce 1991).

The annual temperature range has been calculated from the monthly mean summer maximum and the mean winter minimum at each site (Table 2, Figure 4b) and represents the amplitude of the seasonal pattern. The sites may be grouped into large-range (annual range about 7° C at Seven Mile Beach, Alkimos, Marmion and Warnbro Sound) and small-range (< 4° C at South Passage, Rat Island, Green Head, Jurien and Cape Mentelle). The former appear to experience particularly cool conditions in winter resulting from heat loss to the atmosphere and relatively poor flushing/exchange with warmer offshore waters, while the small-range sites presumably have greater exposure to offshore waters and the Leeuwin Current, maintaining higher winter temperatures and therefore smaller seasonal ranges.

The Leeuwin Current obviously has a greater influence on water temperatures at the Rat Island and Green Head sites than along the coast, but it appears that South Passage, Jurien and Cape Mentelle also experience a greater effect of the Leeuwin Current during the winter months. The tidal influx of water through South Passage into Shark Bay would explain the warmer conditions at that site in winter. Pearce and Pattiaratchi (1999) have shown that the relatively small seasonal range at Cape Mentelle is due to the Leeuwin Current being close inshore in that area between April and September, keeping winter temperatures up, and the cool Capes Current lowering the coastal temperatures during the summer months. The warmer winter temperatures at Jurien may be because the logger there is further offshore than the recorders at the other coastal sites as well as a possible Leeuwin Current effect.

This interpretation is also partially supported by the timing of the seasonal cycle. At most of the coastal sites the water is warmest in January/February and coolest in August (in phase with air temperature); however, the warmest months at South Passage are March-April-May, while at Cape Mentelle these months are December, April and May. At both these sites the coolest month is October (Table 2). Jurien also has a small seasonal range (although not as small as South Passage and Cape Mentelle) and peak/trough temperatures in March and September respectively. Air-sea heat budgets indicate that the total heat flux into the water is greatest in December and January, while the water loses heat to the atmosphere between April and September with the maximum heat loss in June/July (Hastenrath and Greischar 1989).

Cross-shelf temperature gradients are most clearly illustrated by comparing the seasonal cycles at Rat Island (representing offshore/Leeuwin Current) and Seven Mile Beach at Dongara (indicative of coastal waters). As seen in Table 2, Seven Mile Beach is warmest in January (24.1° C) while Rat Island experiences highest temperatures averaging 23.3° C in March. The winter temperature troughs are 17.5° C in July/August at Seven Mile Beach and 19.5° C at Rat Island in August. There is clearly a seasonally-reversing cross-shelf temperature gradient, with the coastal water being almost a degree warmer than that at the Abrolhos Islands in summer as a result of coastal heating processes and 2° C cooler during the winter months when the shallow waters are losing heat to the atmosphere (Pearce 1997). It should be mentioned that these figures are slightly different from (and an improvement on) those in Pearce (1997) who used spot monthly temperature samples at Seven Mile Beach and Rat Island rather than continuously logged data.

The cycles of diurnal temperature changes at the sites (Figure 5) illustrate differences in the shorter-term variability along the coast. As anticipated, the day-night temperature ranges at most of the coastal sites are appreciably higher in summer than in winter, averaging 1.0-1.5° C during the summer months of October to March and only 0.1-0.4° C in mid-winter. It is not clear why Marmion has such a small diurnal range in summer, but it is noteworthy that the neighbouring sites of Alkimos and Warnbro also have smaller diurnal ranges than the other coastal sites.

The offshore site at Green Head has very small diurnal ranges (Figure 5) because of the greater depth of water for mixing there. The surface waters off Green Head appear to be 1-2° C warmer than the near-bottom waters throughout the year (Table 2), but these figures should be viewed with caution because of problems with data calibration at this site: at the CSIRO coastal monitoring station off Rottnest Island (in a similar water depth to the Green Head site) the surface-bottom temperature differential rarely exceeds 1° C (CSIRO unpublished data) except during the mid-summer months. Nevertheless, the Green Head data also indicate that there is little thermal stratification off Western Australia compared with the classic upwelling regions: Pearce (1991) has shown that in the Benguela region, for example, temperature differentials of as much as 4° C can occur between the water surface and a depth of 20 m during the upwelling season.

While the data are probably too patchy to reveal true interannual variability, some reasonably consistent trends are evident in the diurnal patterns (centre panels) and monthly mean temperatures (bottom panels) in Figures 6 to 15. In 1994 it was warm along the whole coast, although this tendency was less pronounced at Cape Mentelle. Winter 1990 was cooler than average (again with the exception of Cape Mentelle) and 1993 was also a cool year at most coastal sites where sufficient data are available. Although the data offshore from Green Head do not seem to follow these interannual changes at the coast (and Rat Island has only two years of data), the warm and cool years along the coast match unpublished surface temperature data from the CSIRO monitoring station off Rottnest Island near Perth, and may be due to variations in the strength/transport of the Leeuwin Current.

5.2 Few-day variability

Superimposed on the annual cycle is a temperature fluctuation of a few days (top panels Figures 6 to 15), probably related largely to weather events as well as to cross-shelf mixing of offshore waters. The range of this irregular pattern is between 1° and 4° C. By superimposing the plots of the daily temperature anomalies for 1994 (Figure 16), together with a plot of the air temperature (partially-smoothed) from Perth for the same time period, it is clear that there is an along-shore coherence between the various sites and a clear relationship with major weather events as characterised by changes in air temperature. The correlation coefficients indicate that most of the correlations are significant at the 99% level (Table 3). It appears that, on occasion, the water temperatures lag the air temperature by a day or two but at other times are in phase. There are also lags in the water temperature from north to south, but these cannot be quantified without a detailed analysis.

It would appear, therefore, that water temperature variability near the coast is largely a result of air-sea heat exchange rather than advective/mixing processes (Pattiaratchi *et al.* 1995). Accepting the along-shore temperature trend of 0.004° C/km described above, along-shore advection at mean current speeds of about 10 cm/s (Cresswell *et al.* 1989) over five days, will result in water movements of about 50 km and corresponding temperature fluctuations of only 0.2° C. Winter cross-shelf gradients are approximately 2° C in 50 km, or 0.04° C/km (an order-of-magnitude greater than the along-shelf gradient), such that cross-shelf current pulses of about 5 cm/s over three days (Pearce and Phillips 1994) can result in near-coastal temperature fluctuations of up to 0.6° C.

Heat budget calculations off Perth indicate that net heat input to the ocean can be 300 W/m^2 on a summer day compared with less than 100 W/m^2 on a winter day (Pattiaratchi *et al.*1995). In the absence of advection and horizontal mixing processes, and assuming vertical mixing down to the bottom in 5 m water, these heat inputs can raise the temperature of the water column over a day by up to 2° C in summer and about 0.4° C in winter, which are in the order of the observed diurnal ranges in Figure 5.

5.3 Diurnal cycles

The shortest period of variability is the 24-hour pattern, with the temperature being lowest between 0600 and 0800 hours and highest in the early afternoon (centre panels in Figures 6-15). The diurnal range varies seasonally and with site (Figure 5), but the pattern is remarkably consistent at all the sites, except South Passage during the winter months of May to August (centre panel Figure 6) when the ebbing tide is transporting cool water out through South Passage during daylight hours, out of phase with the diurnal heating/cooling cycle.

The diurnal range is appreciably higher inshore than at the deep-water site off Green Head (centre panels of Figures 5, 9 and 10), where the greater water depth (60 m) allows deeper mixing of any heat entering or leaving the water. The mean daily temperature variation near the surface is between 0.3° C and 0.4° C in summer, falling to about 0.1° C during the winter months. At the near-bottom logger, there is no distinct diurnal pattern. At Rat Island, the other offshore (but shallow) site, the diurnal pattern is similar to that at the coast.

5.4 Applications

Apart from the oceanographic significance of the temperature data discussed above, there are a number of other useful applications to fisheries, marine aquaculture and remote sensing.

5.4.1 Western rock lobster *(Panulirus cygnus)*

Temperature is one of the most important environmental factors affecting western rock lobster growth and behaviour. In early studies of the ecology of the western rock lobster, Morgan (1974) and Chittleborough (1975) showed that the growth rate of juvenile lobsters increases with water temperature to a maximum at about 26° C (beyond which both growth rate and survival decline). There is also evidence that the incubation time of eggs decreases with temperature (Chittleborough 1976). Larval survival and juvenile growth are therefore dependent on local water temperatures (Evans 1991), so monitoring of coastal temperature is important for understanding and managing fluctuations in the rock lobster fishery.

The histograms of hourly temperatures in Figures 17-24 show that the water temperature rarely reaches Chittleborough's (1975) threshold of 26° C, even in the northern-most site of South Passage. Conversely, the bulk of the temperatures at the more southern sites are below 20° C, distinctly towards the cool end of the desirable range for optimal growth (Chittleborough 1976). Monthly and/or seasonal temperature variations in coastal waters bathing the nursery reefs may, therefore, influence growth of the juvenile lobsters. On the other hand, fluctuations in water temperature of 2-3° C over a few days (Figure 16) are more likely to affect the behaviour of juveniles and adults and hence their catchability.

5.4.2 Aquaculture

With the growing interest in marine aquaculture and the likelihood of 'fish farms' being established along the Western Australian coast, information on the local temperature regime and its variability will be a crucial element in the planning for industrial development. While the ocean temperature data analysed in this report do not extend north of Shark Bay or east of Cape Leeuwin, nor into the semi-enclosed waters of Shark Bay, they comprise by far the most comprehensive measurements to date of the coastal area between Shark Bay and Cape Leeuwin.

The histograms in Figures 17-24 provide the basic information for assessing the overall temperature characteristics along the coast. The temperature distributions are uni-modal at half the sites (South Passage, Rat Island, Jurien, and Cape Mentelle, identified earlier as areas where the Leeuwin Current seems to have a relatively greater influence), but distinctly bi-modal at Seven Mile Beach, Alkimos, Marmion and Warnbro Sound. The reason for this is that the temperature change between summer and winter is comparatively rapid at the latter sites and the annual range is also larger, whereas at the 'small-range' sites the summer and winter peaks overlap to form the uni-modal distribution. The summer mode at Seven Mile Beach is a little higher than the winter mode, while further south the winter peak is larger.

Apart from critical limits of absolute temperatures for the various species, the rate of temperature change is also likely to be very important for growth and stock management. Both hourly and daily changes may be important: although the hourly *rates* of change may be larger than the daily rate, the *net* temperature change over a day is obviously much higher. Figures 17-24 show that at all sites, hourly changes are almost universally less than 0.5° C, indeed most are less than 0.2° C. However, daily ranges are large at some sites, such as South Passage and Seven Mile Beach, with the water temperature occasionally rising (or falling) by more than 3° C over approximately a 12-hour period. It is noteworthy that the larger daily ranges tend to be at the northern sites and then in the far south at Cape Mentelle (Table 4).

5.4.3 Satellite validation

There is the potential of using well-calibrated near-surface temperature data from the offshore sites (Rat Island and Green Head) and those coastal sites more than a couple of kilometres from land (Jurien and Warnbro Sound) for validation of satellite-derived temperatures, such as from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA satellites. The upper logger at Green Head was within 5 m of the sea surface and the shallow-water loggers were in water depths of only 5 m, so under the windy conditions normally occurring off the Western Australian coast the water should be reasonably well-mixed to at least this depth. Due to the lack of other ongoing temperature recording off Western Australia, the offshore data could provide a valuable check on temperatures derived from satellite data.

6.0 Conclusions and recommendations

The dataset presented in this report is an invaluable time-series revealing temperature variability in the coastal waters of Western Australia. Despite some lengthy gaps in the data at some sites, three dominant periods of variability are evident: seasonal, few-day and diurnal. These temperature variations may play an important role in the life-histories and catches of many commercial species, as well as in the prospects for aquaculture enterprises along the coast. It must be borne in mind that the data cover only part of the west coast (Shark Bay to Cape Mentelle), so there are still large areas of the State's coastal waters that are not being monitored on a regular basis.

Bearing in mind the cost of the temperature logger program (in equipment, manpower to deploy and recover the loggers, and effort expended in data processing and analysis), it is useful to examine whether any sites could be discontinued. It is evident from Figures 4 and 16 that Alkimos, Marmion and Warnbro Sound have very similar characteristics, probably because they are relatively close together. We recommend that Marmion be retained as (1) it lies between the other two sites, (2) it is readily accessible from the Marine Laboratories, (3) it monitors the coastal waters being drawn into the aquarium system, and (4) it is complemented by other measurements in this area by CSIRO. If funding becomes a consideration in the future, the other two sites could perhaps be dropped. It is debatable whether a more appropriate site for the Shark Bay logger could perhaps be found: the present site (albeit conveniently near the puerulus collectors) is dominated by the flow of water into and out of Shark Bay and does not really represent either the coastal waters in this area nor the waters of the bay itself. The Green Head site should be maintained because it is the only deep-water site being regularly sampled in Western Australia.

7.0 Acknowledgements

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9.0 Tables

Table 1 Nominal positions of the temperature loggers

Site	Latitude °S	Longitude °E
South Passage (SP)	26°08'	113°12'
Rat Island (RAT)	28°42'	113°46'
Seven Mile Beach (SMB)	29°10'	114°54'
Green Head (GH)*	30°00'	114°45'
Jurien Bay (JUR)	30°19'	115°00'
Alkimos (ALK)	31°38'	115°39'
Marmion (MAR)	31°51'	115°45'
Warnbro Sound (WAR)	32°21'	115°41'
Cape Mentelle (MEN)	33°57'	114°59'

* The Green Head (offshore) mooring had near-surface and near-bottom loggers.

Table 2 Monthly mean temperatures at each of the temperature logger sites, averaged over the period 1990 to 1994. The overall means and annual temperature ranges (monthly maximum to minimum) are at the bottom of the table. The coastal sites are grouped separately from the offshore sites of Rat Island and Green Head.

	SP	SMB	JUR	ALK	MAR	WAR	MEN	*	RAT I.	GHT	GHB
Latitude °S	26.13	29.17	30.32	31.62	31.80	32.32	33.96	*	28.69	30.00	30.00
January	22.11	24.09	21.76	22.91	22.44	22.62	19.42	*	22.50	22.40	20.57
February	23.30	23.94	21.60	23.08	22.61	22.23	19.53	*	23.20	22.99	20.98
March	23.78	23.68	22.18	23.45	22.24	21.66	19.28	*	23.30	23.69	21.91
April	23.84	21.97	21.44	21.05	20.62	19.67	19.92	*	23.14	23.92	22.22
May	23.59	20.64	21.07	19.39	19.26	18.57	19.95	*	22.63	23.77	21.93
June	22.70	18.41	20.32	17.11	16.88	17.19	19.00	*	21.43	22.93	20.45
July	21.87	17.51	19.26	16.64	16.55	16.56	18.10	*	20.12	20.66	19.65
August	21.36	17.56	18.56	16.37	15.91	16.17	17.43	*	19.52	19.73	19.24
September	21.26	18.27	18.32	16.93	16.80	16.93	17.49	*	19.71	19.77	18.79
October	20.89	19.85	18.72	18.10	18.08	17.93	17.13	*	19.98	19.93	18.81
November	21.38	21.68	20.31	20.05	19.69	19.96	18.49	*	21.04	20.75	19.63
December	22.01	23.27	21.53	21.55	21.27	21.66	20.15	*	21.97	21.53	20.26
Mean	22.34	20.90	20.42	19.72	19.36	19.26	18.82	*	21.54	21.84	20.37
Min	20.89	17.51	18.32	16.37	15.91	16.17	17.13	*	19.52	19.73	18.79
Max	23.84	24.09	22.18	23.45	22.61	22.62	20.15	*	23.30	23.92	22.22
Max-Min	2.95	6.57	3.87	7.08	6.70	6.45	3.02	*	3.78	4.19	3.43

Table 3 Correlation coefficients of daily mean temperatures at the various coastal sites (except Alkimos) and daily mean air temperatures at Perth for 1994. Coefficients in italics are significant at the 99% level.

Site	SP	RAT	SMB	JUR	MAR	WAR	MEN
RAT	*0.59*						
SMB	*0.68*	*0.72*					
JUR	*0.56*	*0.63*	*0.74*				
MAR	*0.43*	*0.51*	*0.65*	*0.66*			
WAR	*0.63*	*0.61*	*0.72*	*0.75*	*0.77*		
MEN	*0.52*	*0.58*	*0.53*	*0.46*	*0.32*	*0.67*	
AIR	*0.53*	*0.28*	*0.36*	*0.24*	0.14	*0.35*	*0.44*

Table 4 Frequency of daily temperature ranges greater than 2° C and 3° C at each of the shallow-water sites.

Site	Frequency > 2° C	Frequency > 3° C
SP	32.7%	2.7%
RAT	3.8%	——
SMB	10.2%	——
JUR	6.5%	——
ALK	——	——
MAR	0.2%	——
WAR	0.7%	0.2%
MEN	5.4%	——

10.0 Figures

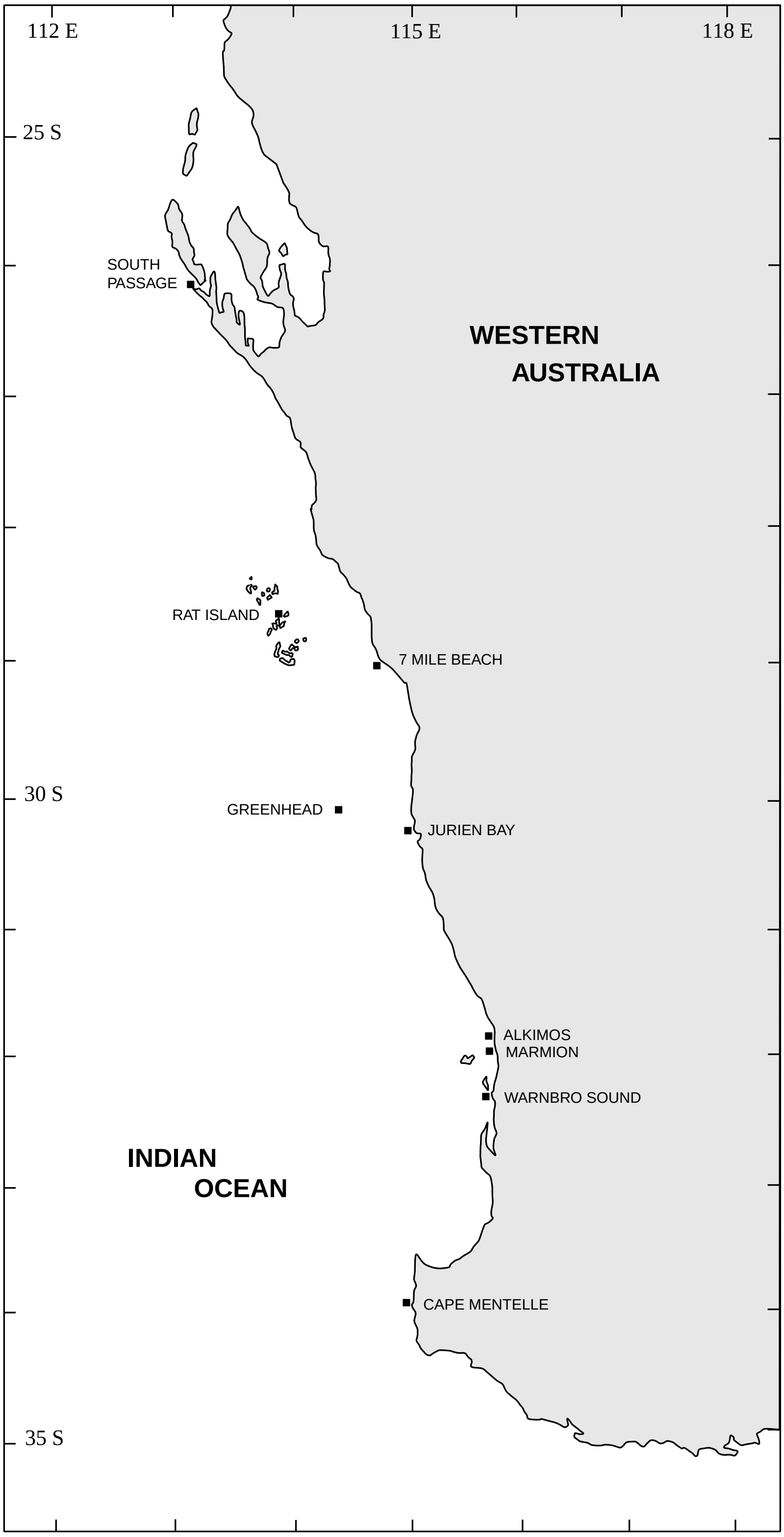


Figure 1 Location map of the temperature logger sites. The inshore loggers are in about 5 m water depth near the puerulus collector frames, as is the logger near Rat Island at the Houtman Abrolhos Islands. The deep-water loggers are moored in 60 m water some 25 km off Green Head.

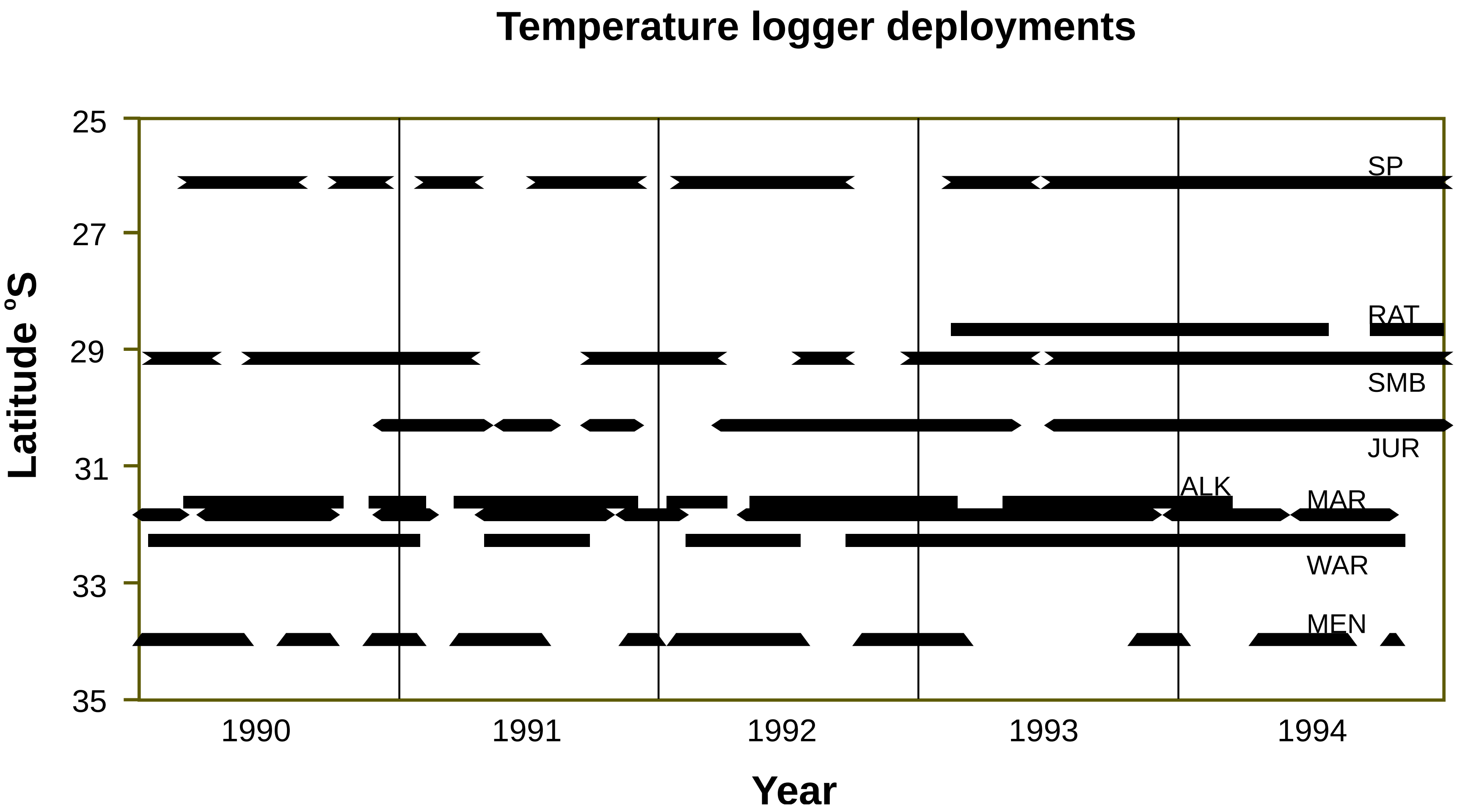


Figure 2 Time-chart of deployment of the temperature loggers at the shallow-water sites.

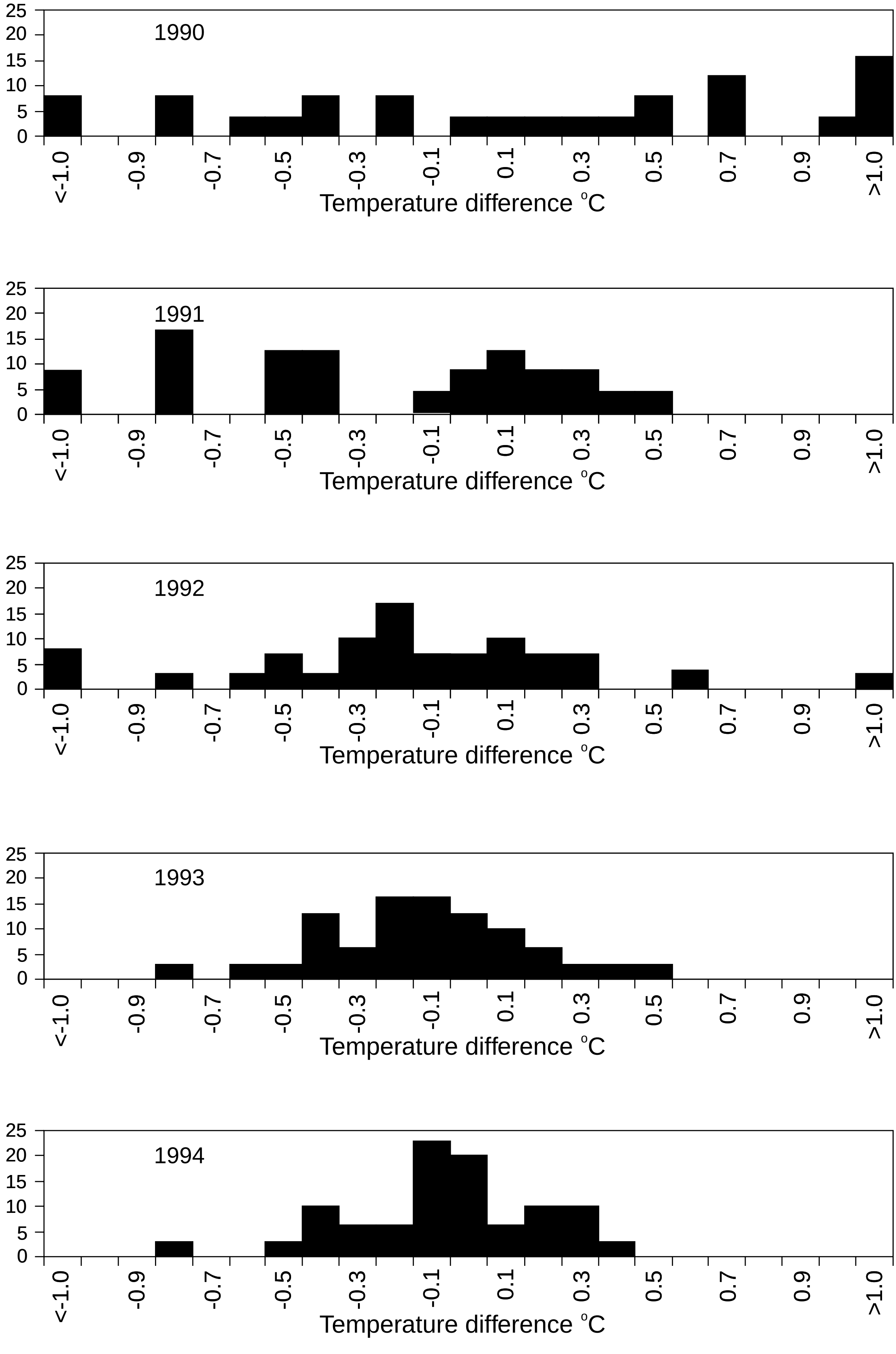


Figure 3 Histograms of the temperature differences between the mercury thermometer readings and the logged temperatures at each deployment and recovery between 1990 and 1994.

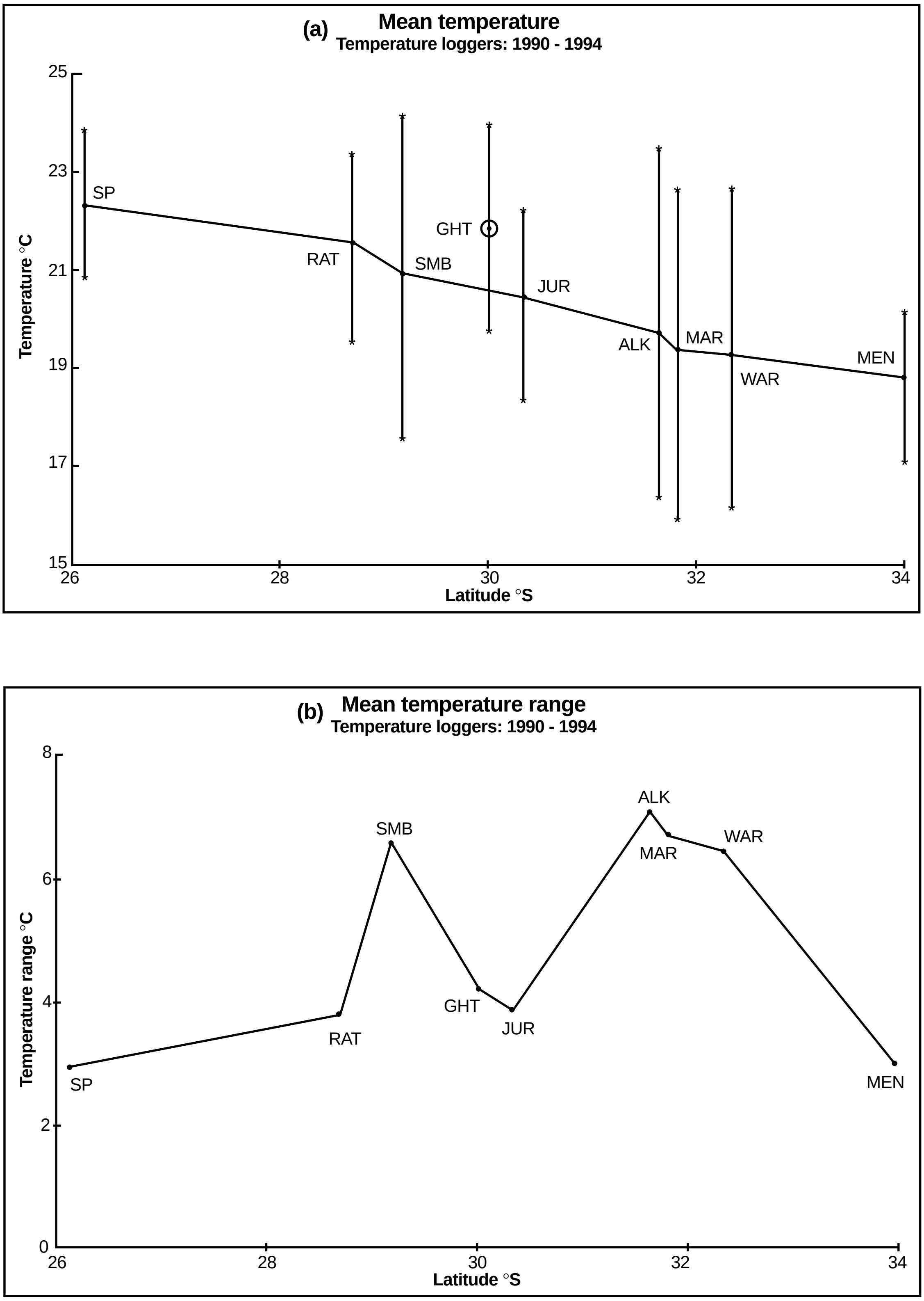


Figure 4 (a) Overall mean temperature with monthly minimum and maximum values (asterisks joined by vertical bars) at the shallow sites and the Green Head surface logger (circled) as a function of latitude (data from Table 2). The solid line represents the alongshore gradient of coastal temperature. (b) Annual mean temperature range (summer monthly maximum to winter monthly minimum) at each site.

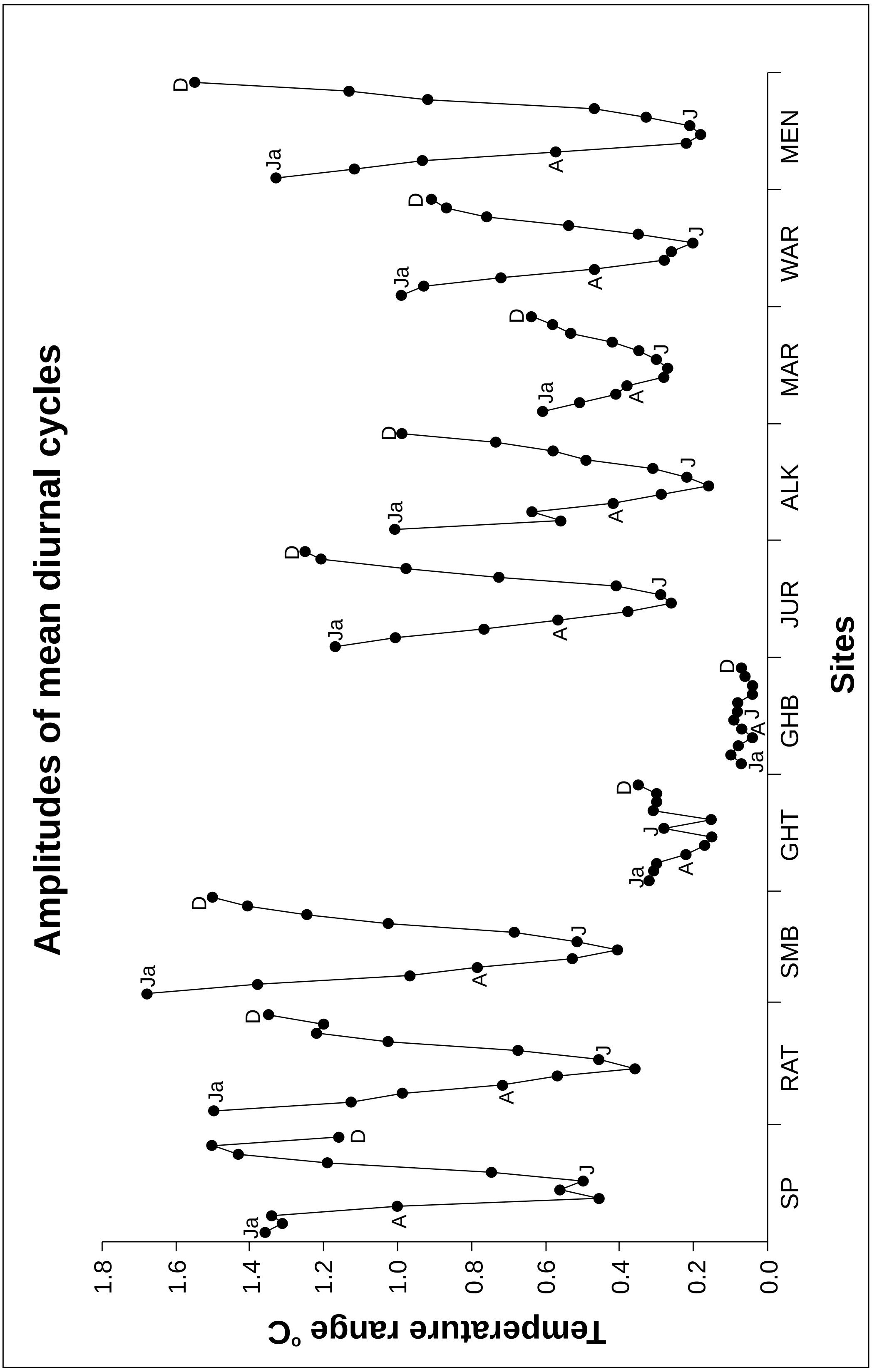


Figure 5 Monthly mean diurnal temperature ranges at the nine logger sites. Each curve represents the mean daily temperature range by month (January to December), illustrating the greater diurnal variations during the summer months. For example, the second curve shows that the day-night temperature range at Rat Island averages 1.5° C in January and falls to 0.35° C in June. Where: Ja = January, A = April, J = July and D = December.

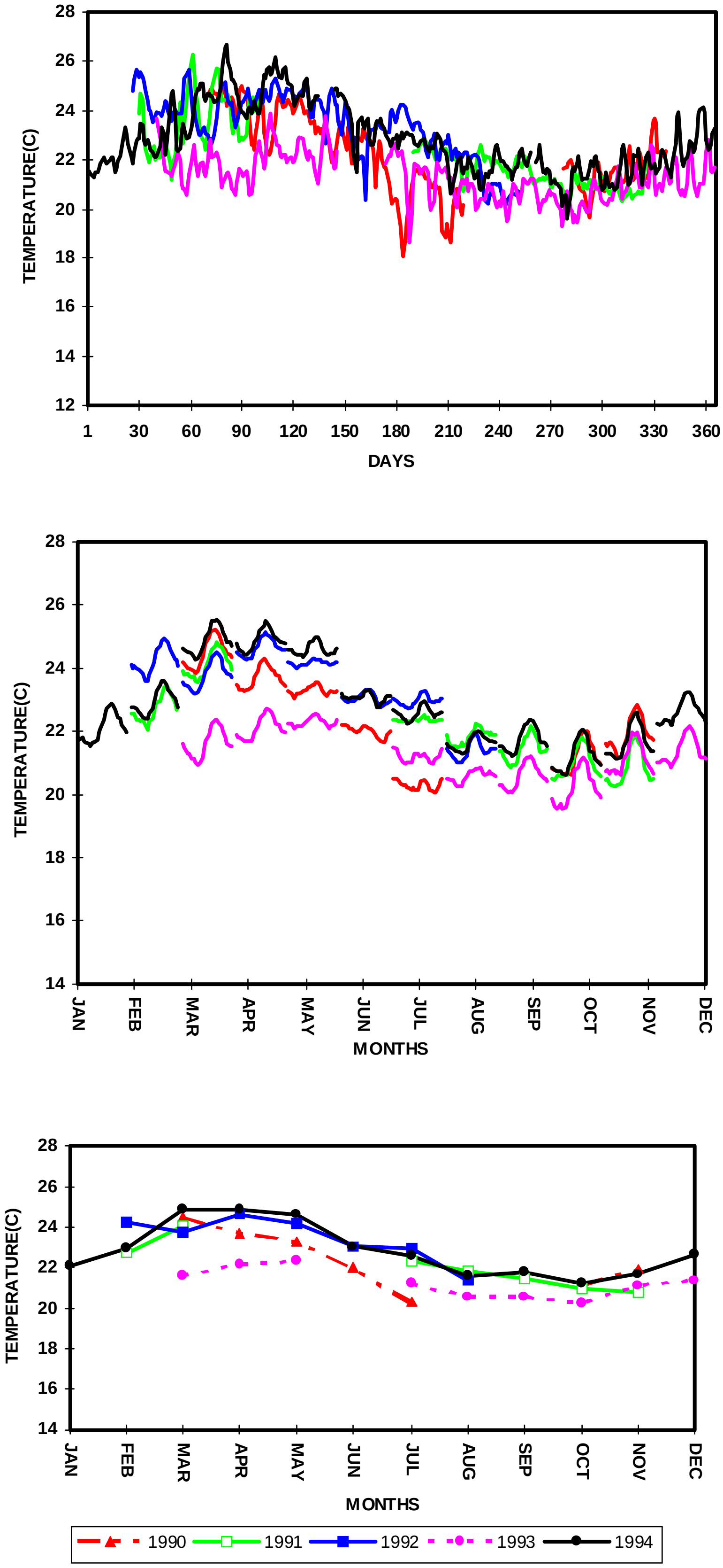


Figure 6 Daily mean temperatures at South Passage (Shark Bay) for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

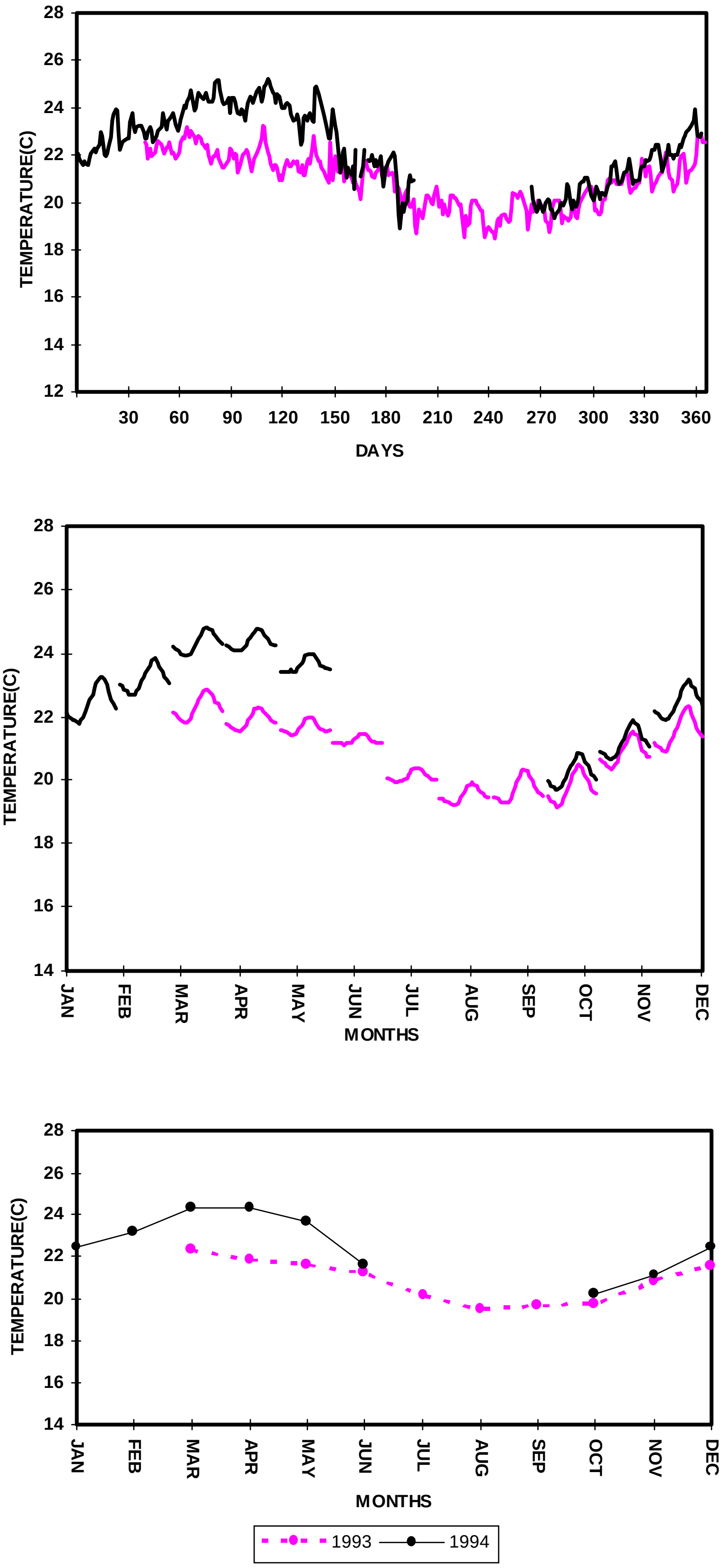


Figure 7 Daily mean temperatures at Rat Island for the years 1993 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

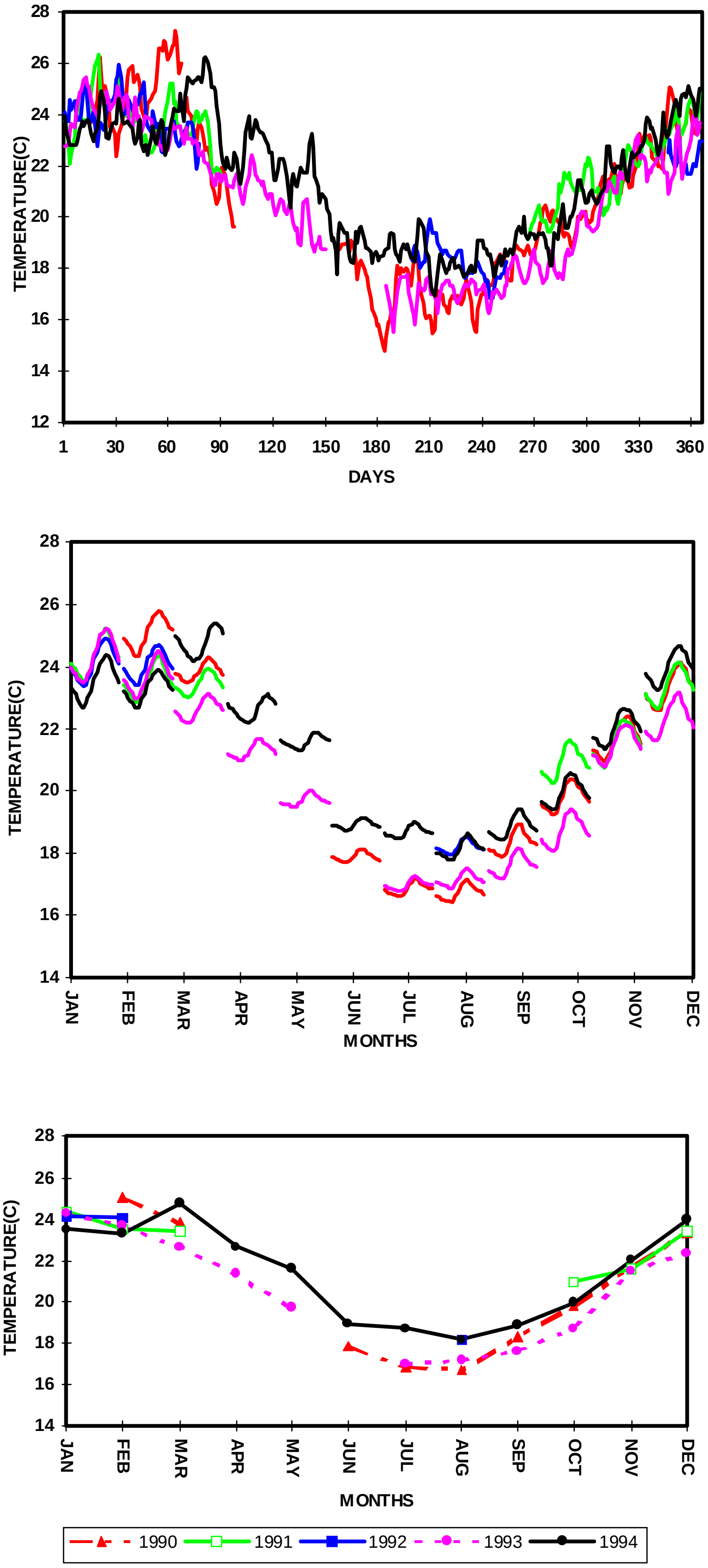


Figure 8 Daily mean temperatures at Seven Mile Beach (Dongara) for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

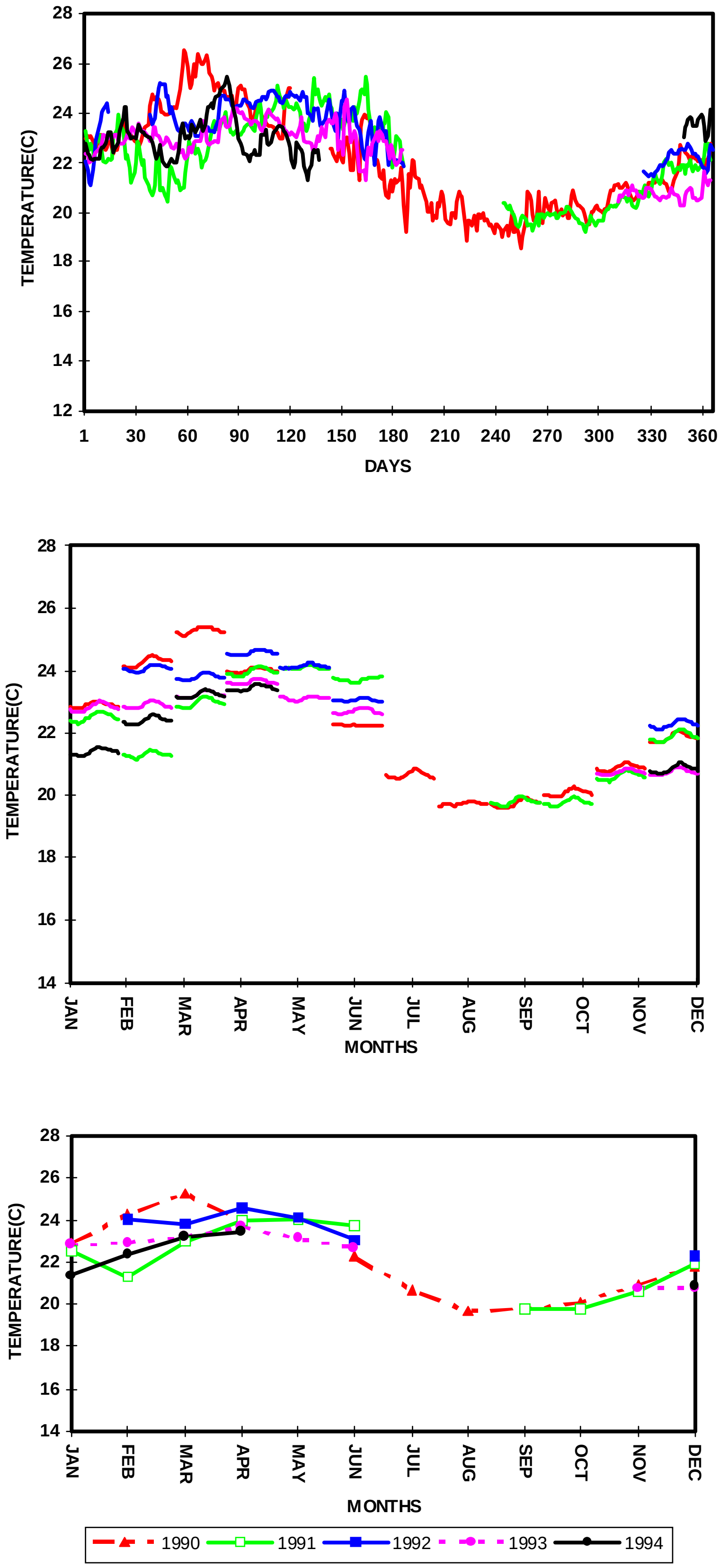


Figure 9 Daily mean temperatures at Green Head (near-surface logger) for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

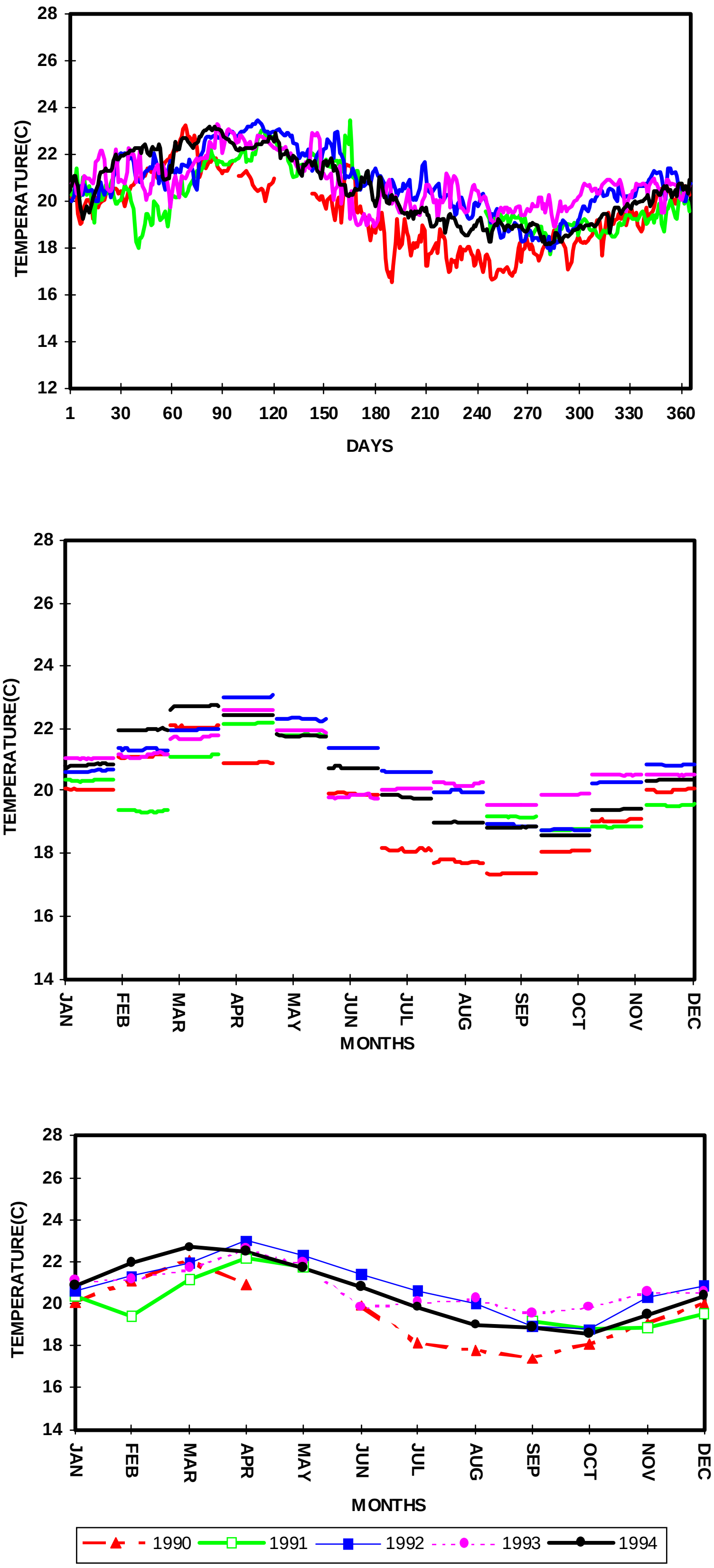


Figure 10 Daily mean temperatures at Green Head (near-bottom logger) for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

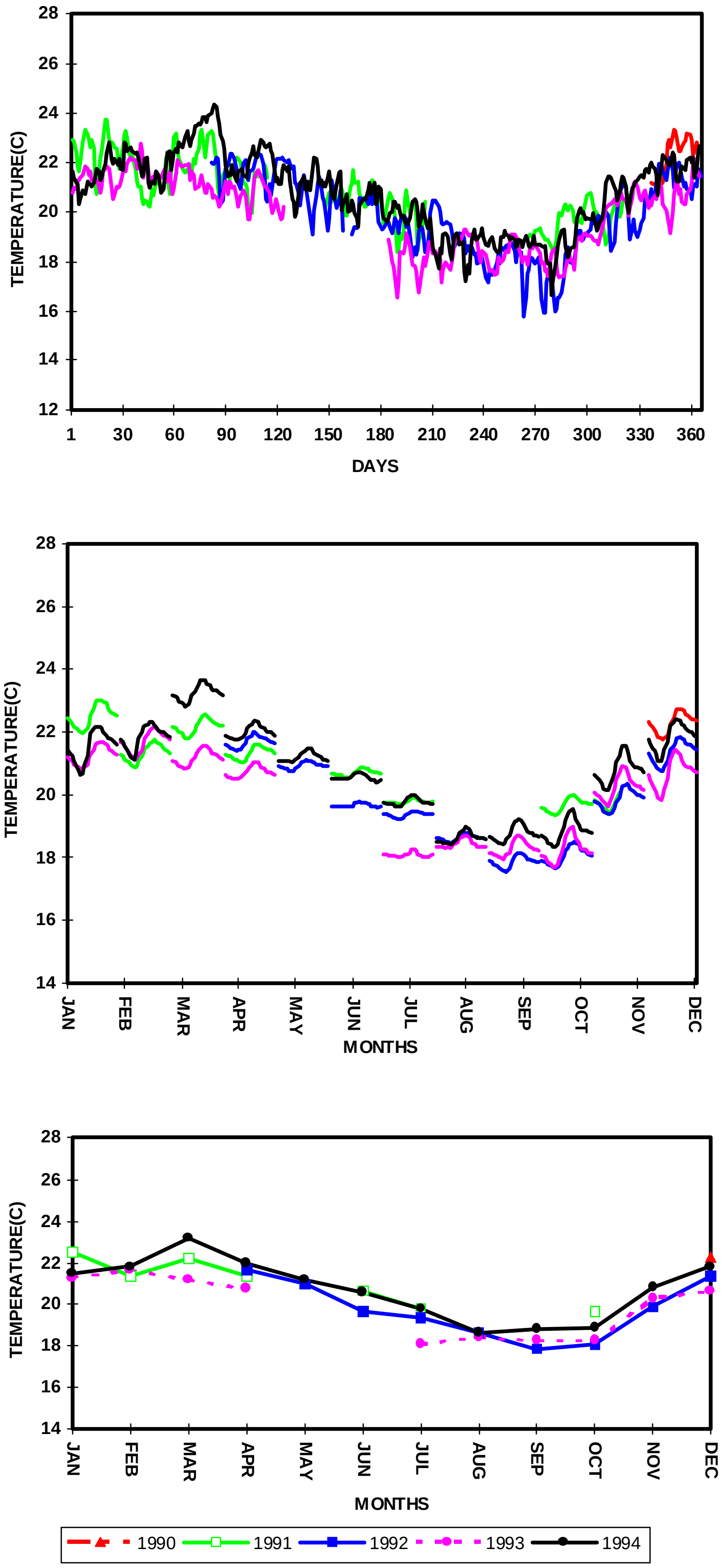


Figure 11 Daily mean temperatures at Jurien for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

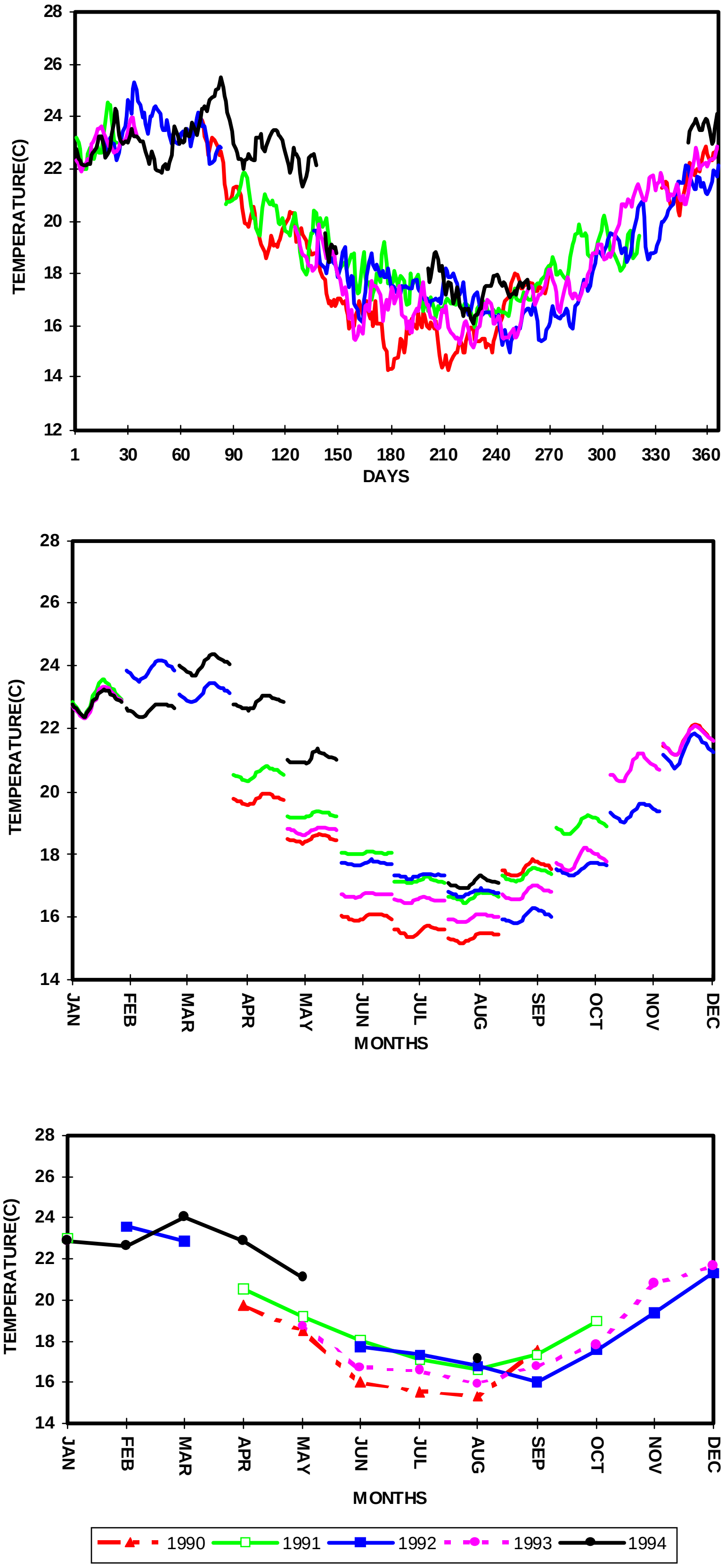


Figure 12 Daily mean temperatures at Alkimos for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

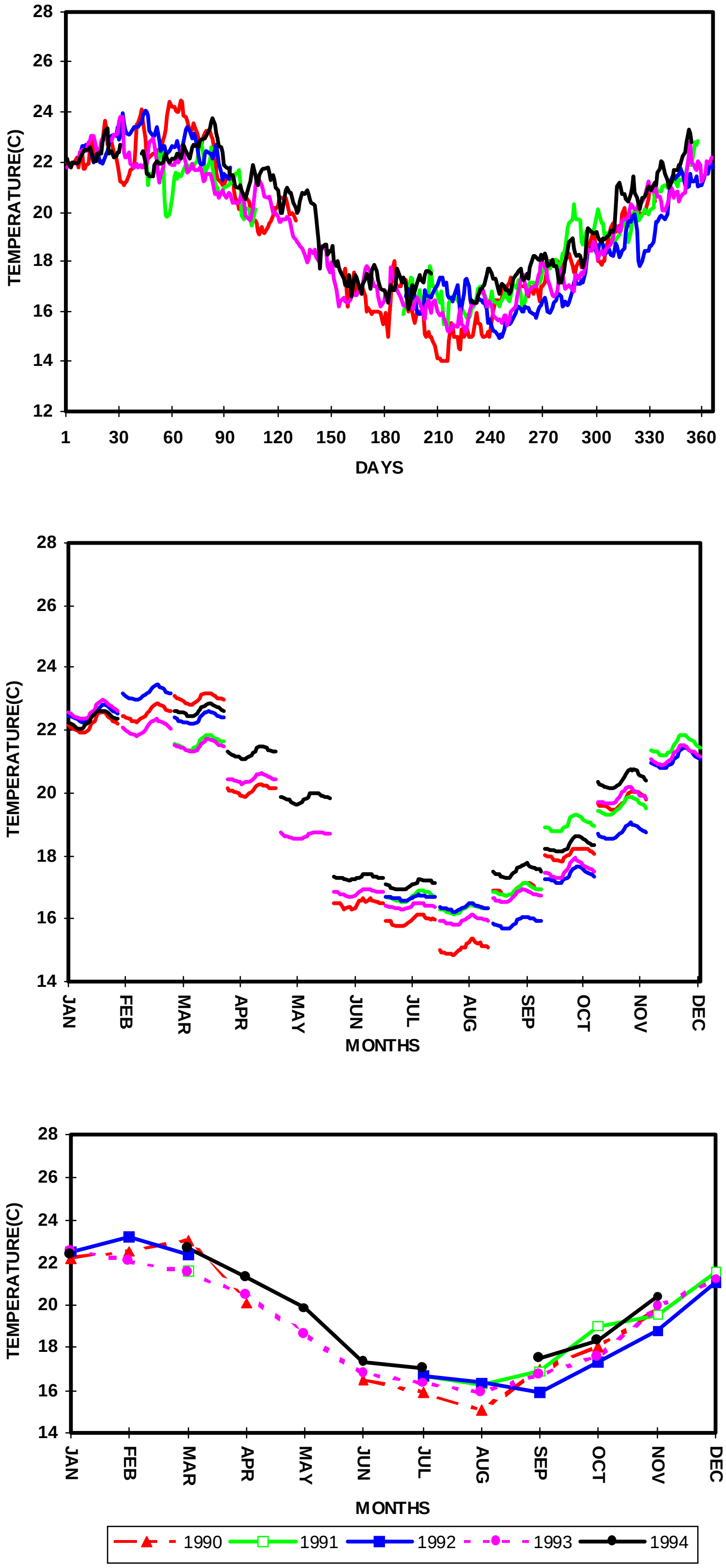


Figure 13 Daily mean temperatures at Marmion for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

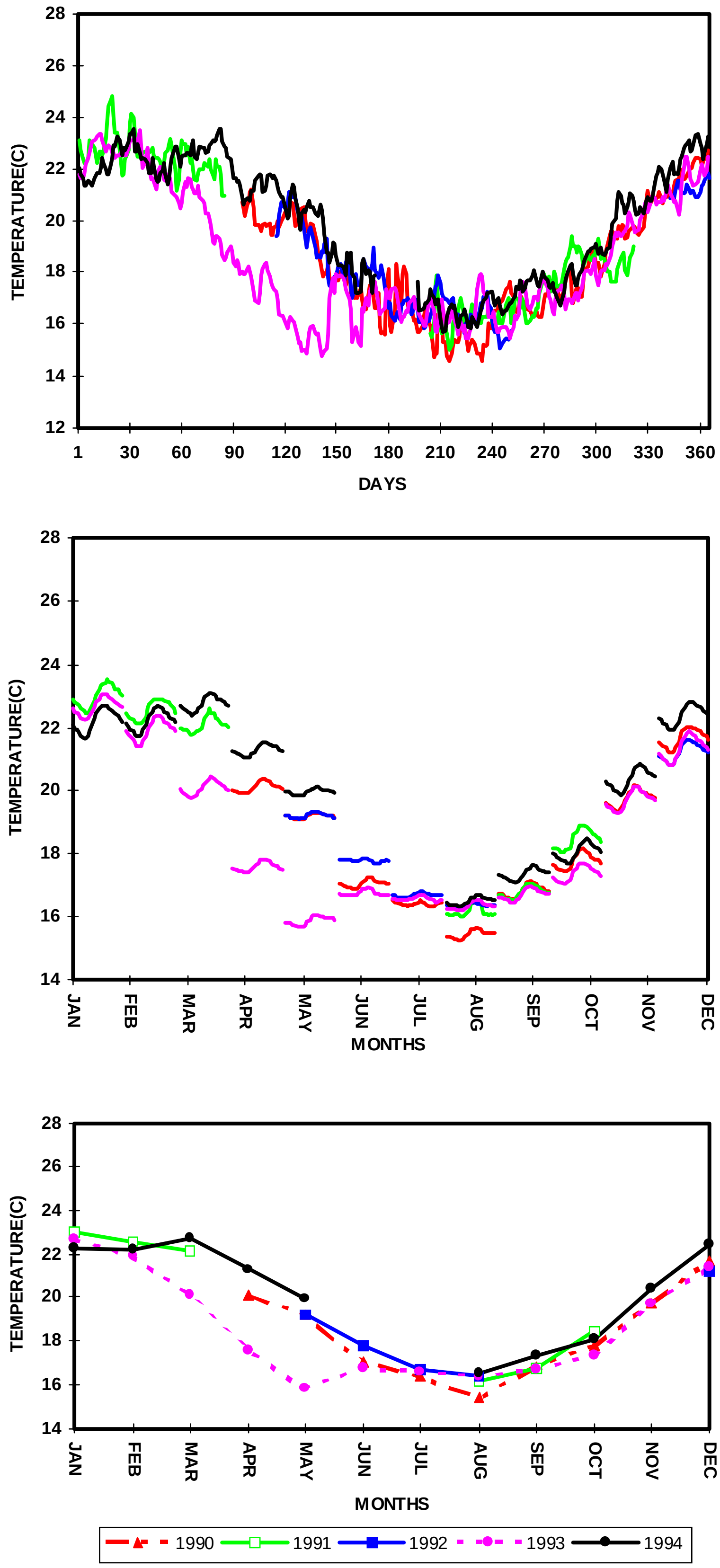


Figure 14 Daily mean temperatures at Warnbro Sound for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

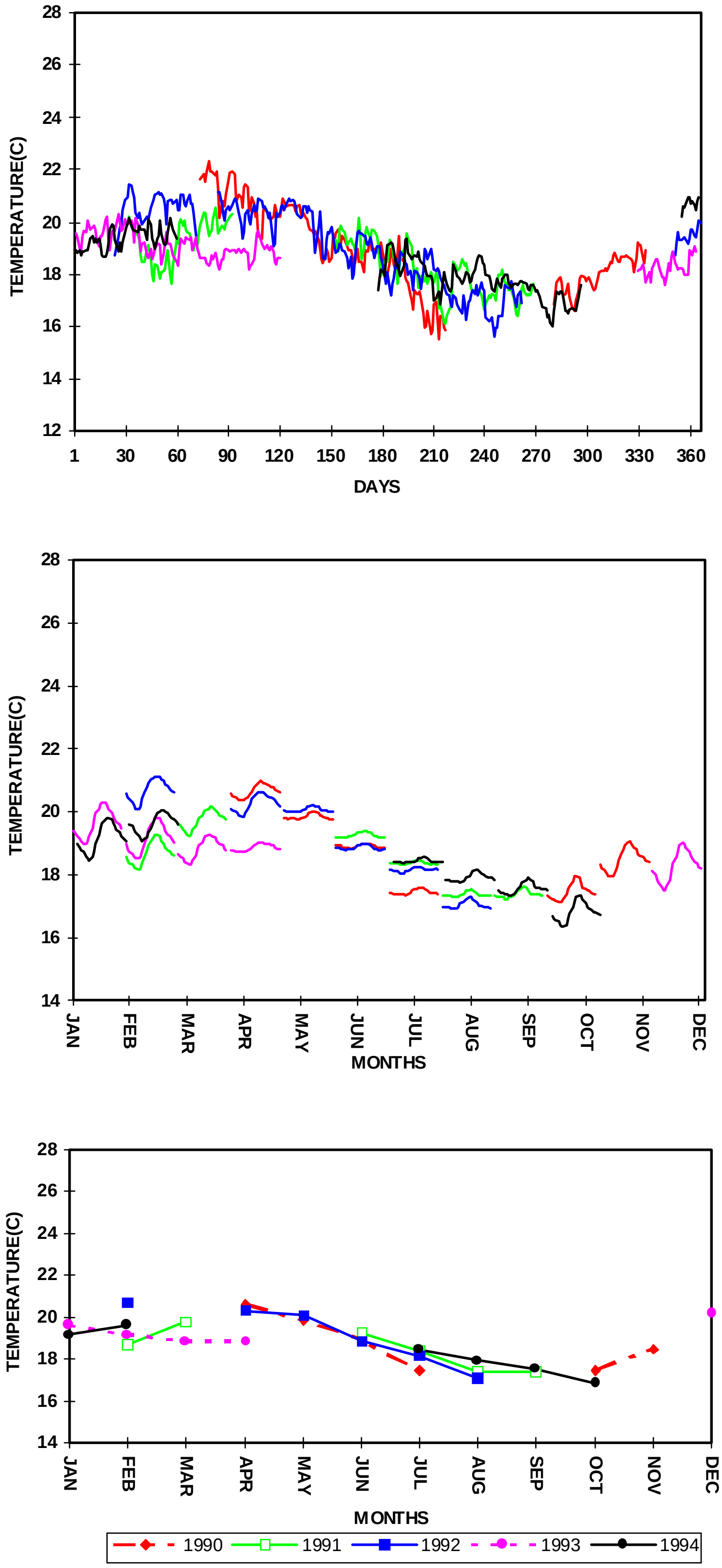
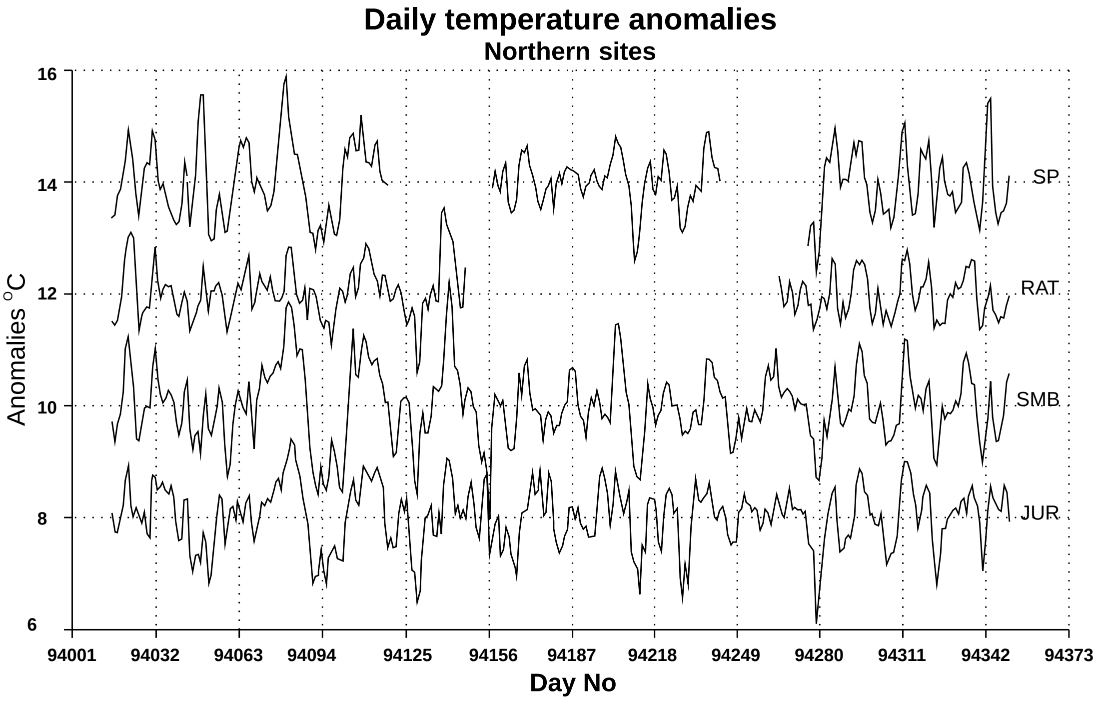


Figure 15 Daily mean temperatures at Cape Mentelle for the years 1990 to 1994 (top panel), diurnal patterns (centre panel) and monthly mean temperatures (bottom panel). The diurnal patterns represent the temperature variation over 24 hours for each month between January (left) and December (right).

(a)



(b)

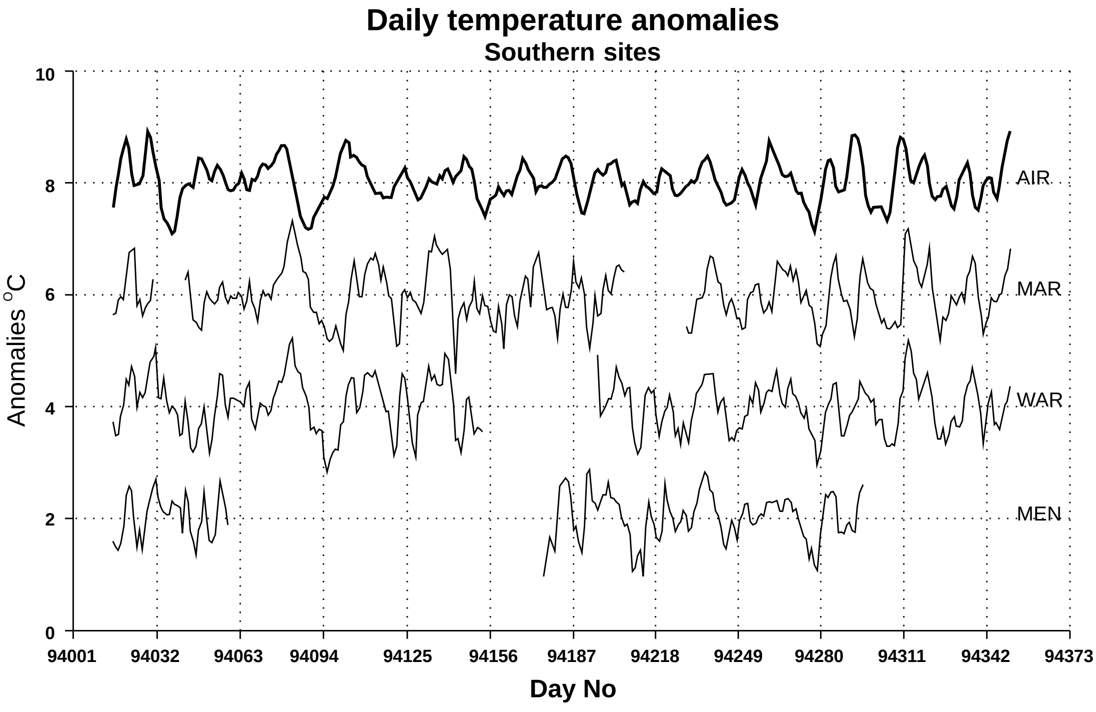


Figure 16 Daily mean temperature anomalies for 1994 at (a) the northern sites and (b) the southern sites (except Alkimos where there are many gaps in the data); progressively off-set by 2° C to avoid clutter. The top line in (b) is the air temperature for Perth during 1994, partially smoothed by a five-day running mean and plotted to a different scale to match the variability of the water temperatures. The anomalies have been derived by high-pass filtering the daily temperatures with a 31-day running mean and subtracting this from the individual daily values. Air temperature data are from a site in Duncraig, Perth.

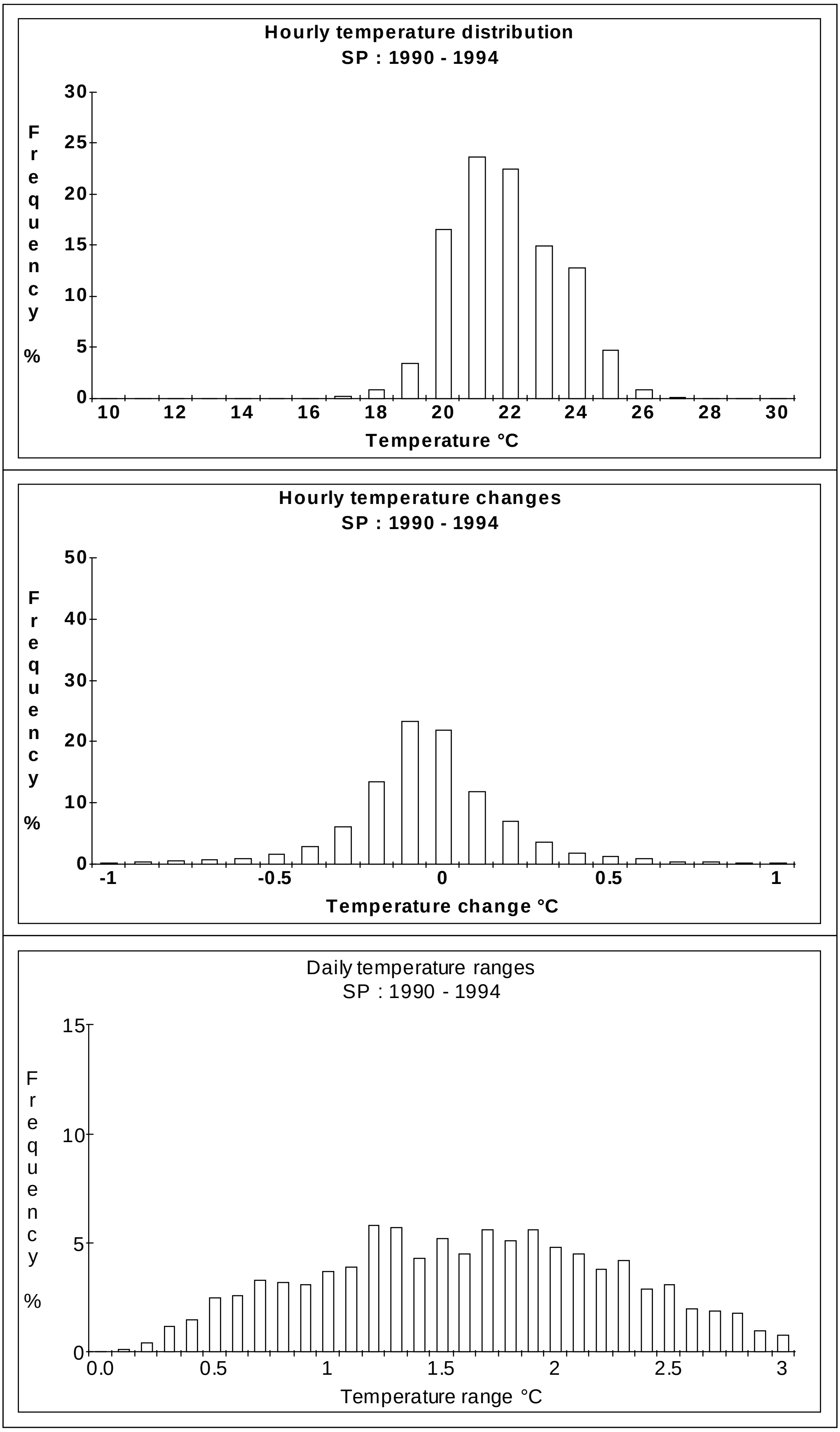


Figure 17 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) at South Passage (Shark Bay).

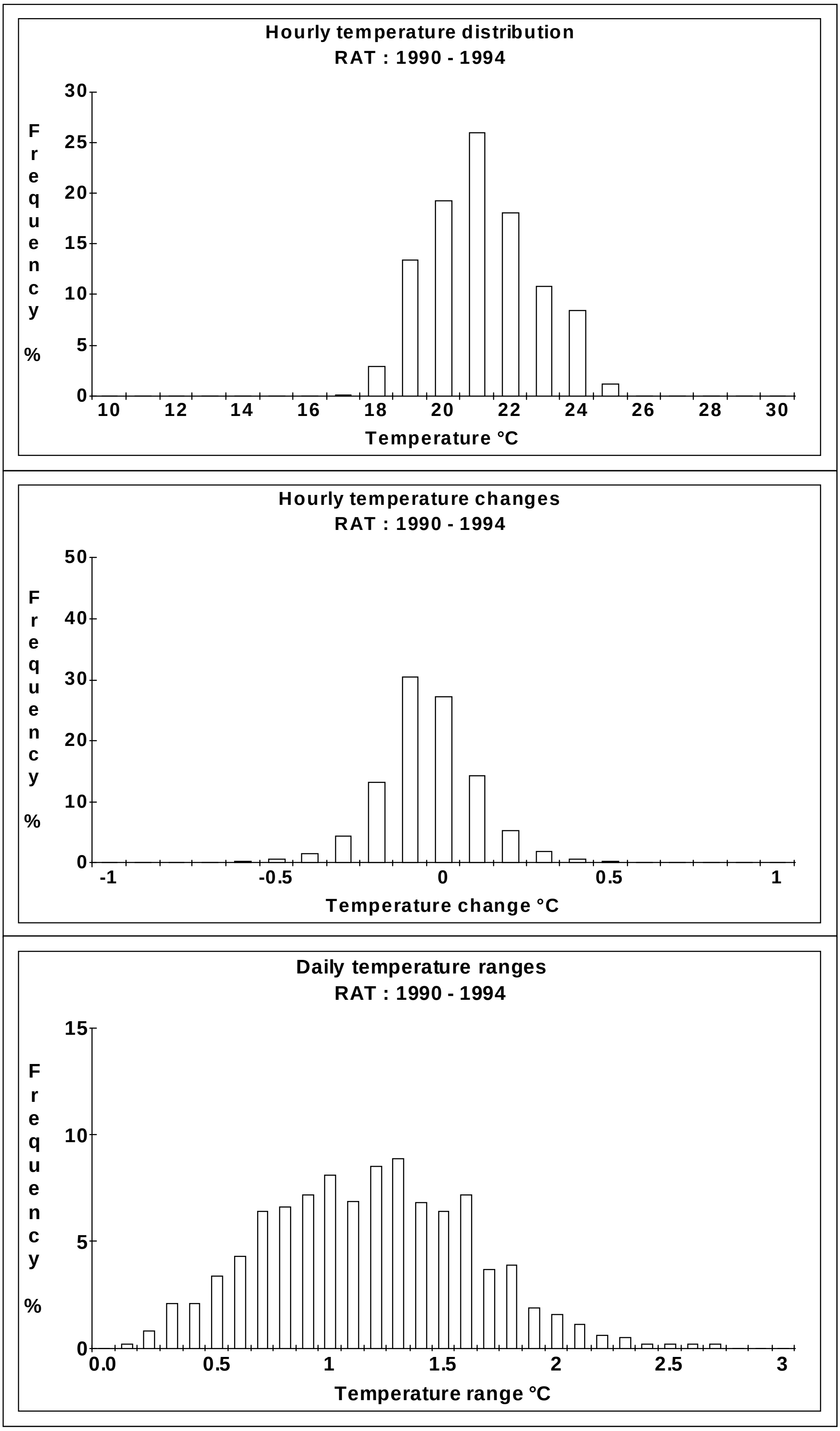


Figure 18 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) at Rat Island.

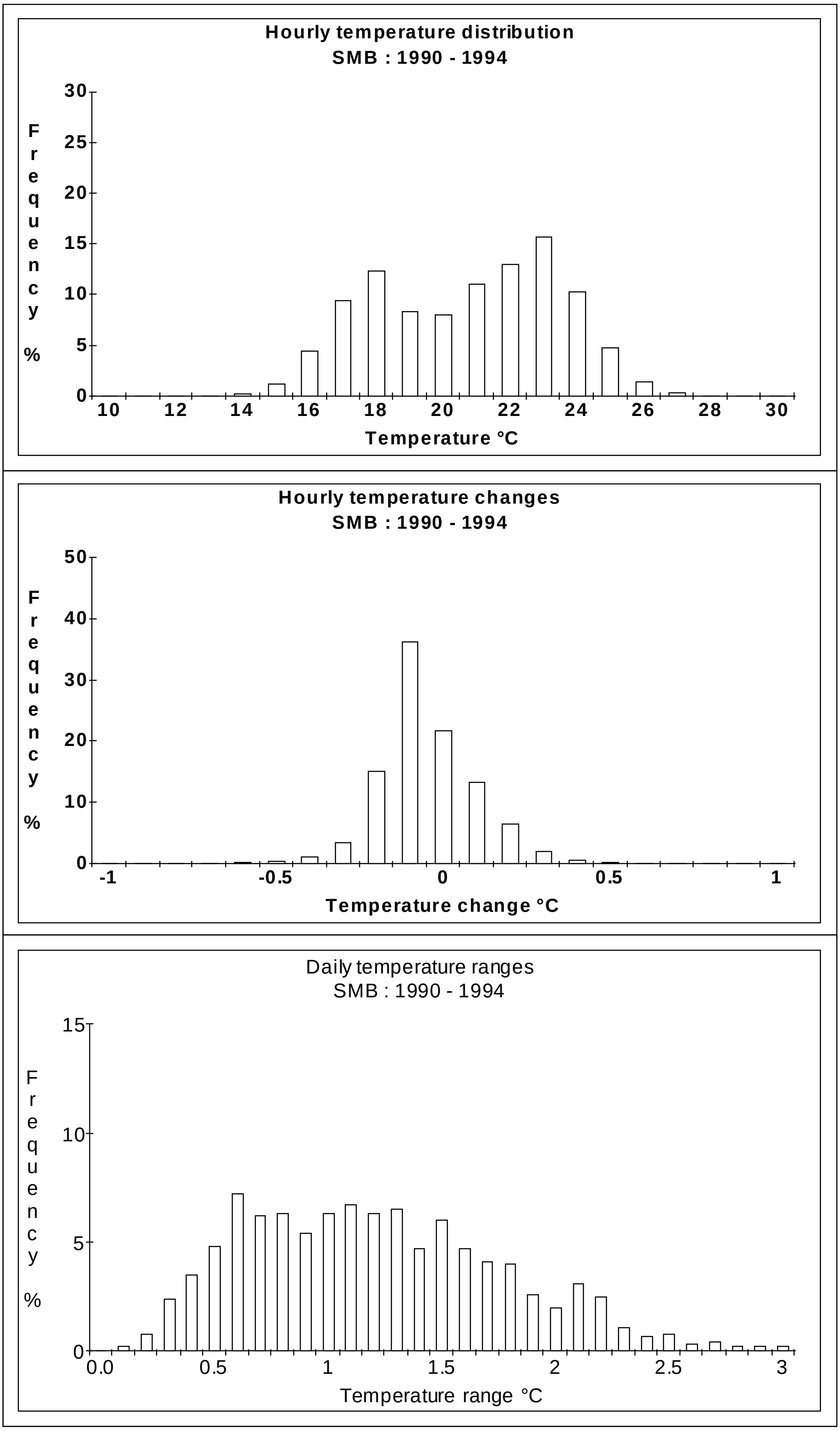


Figure 19 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) at Seven Mile Beach (Dongara).

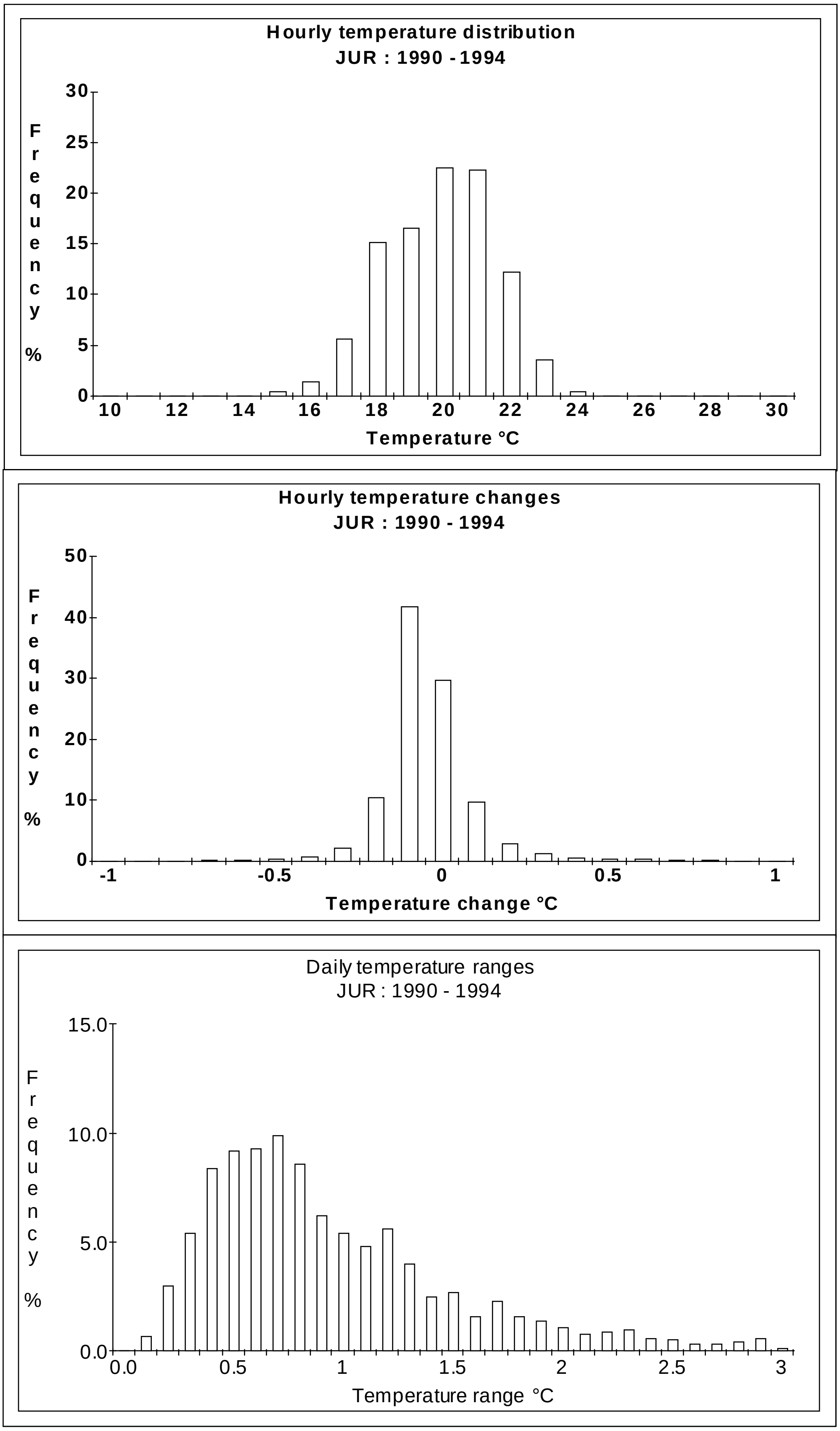


Figure 20 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) at Jurien.

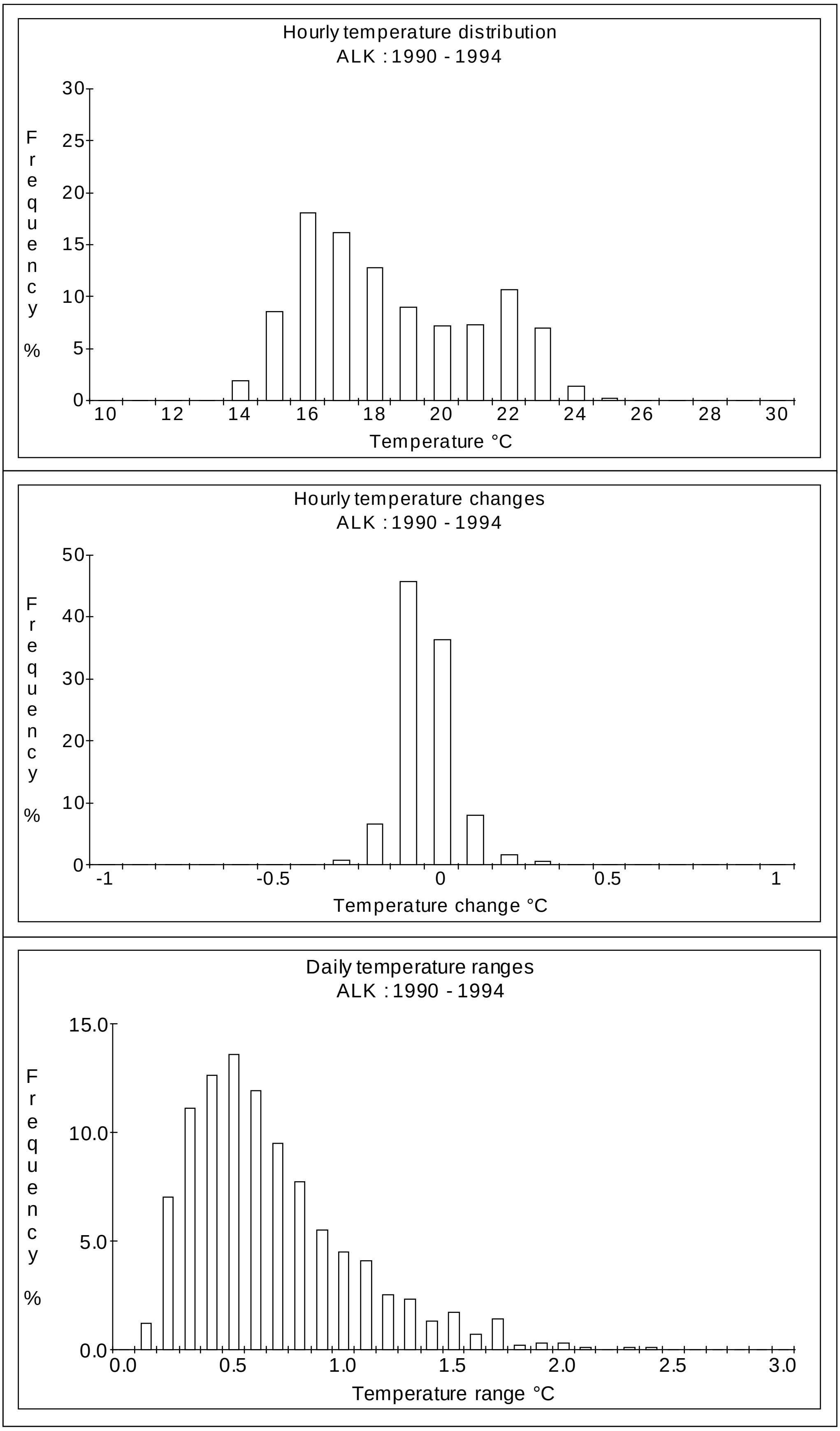


Figure 21 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) at Alkimos.

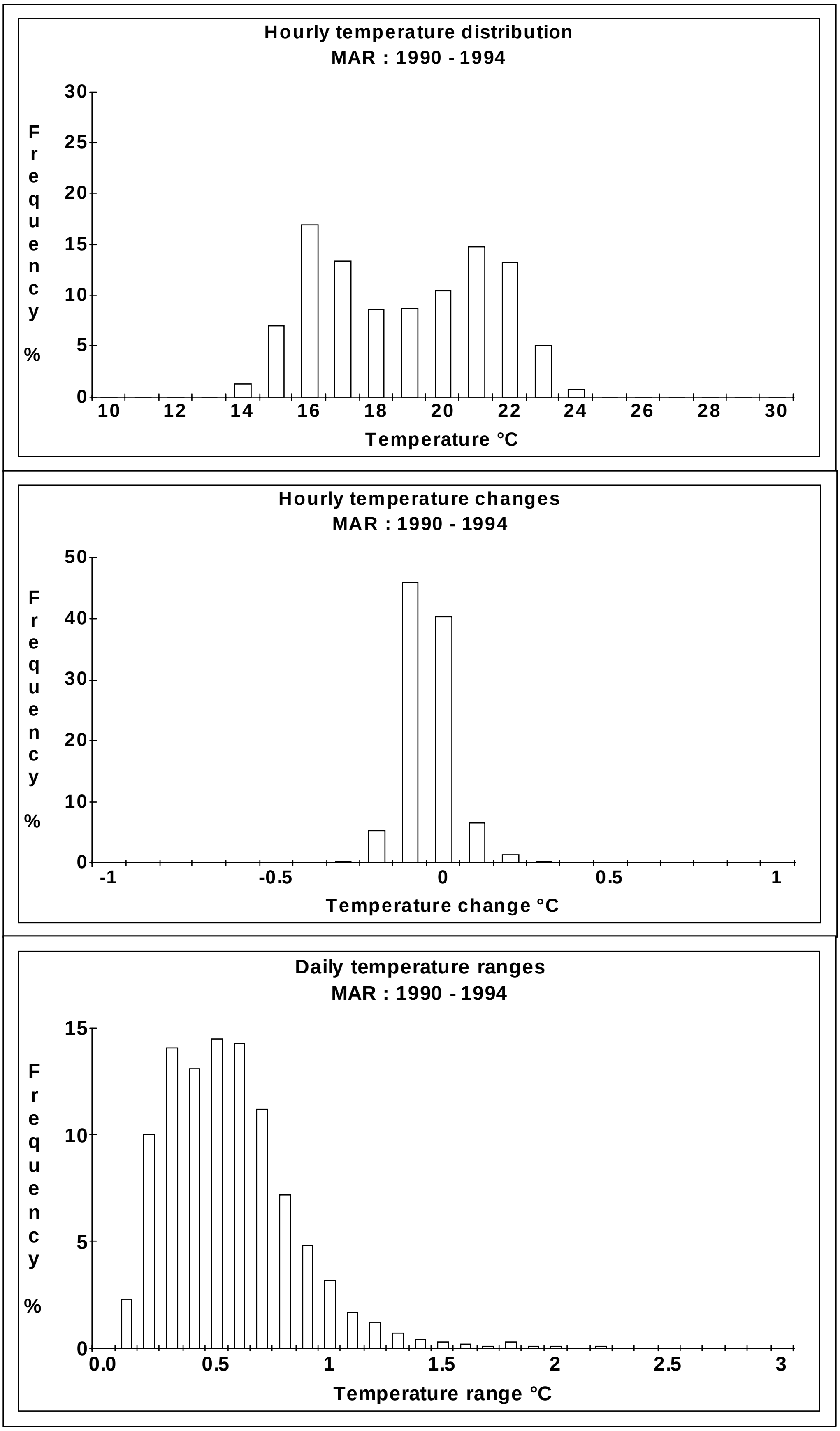


Figure 22 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) in Marmion Lagoon.

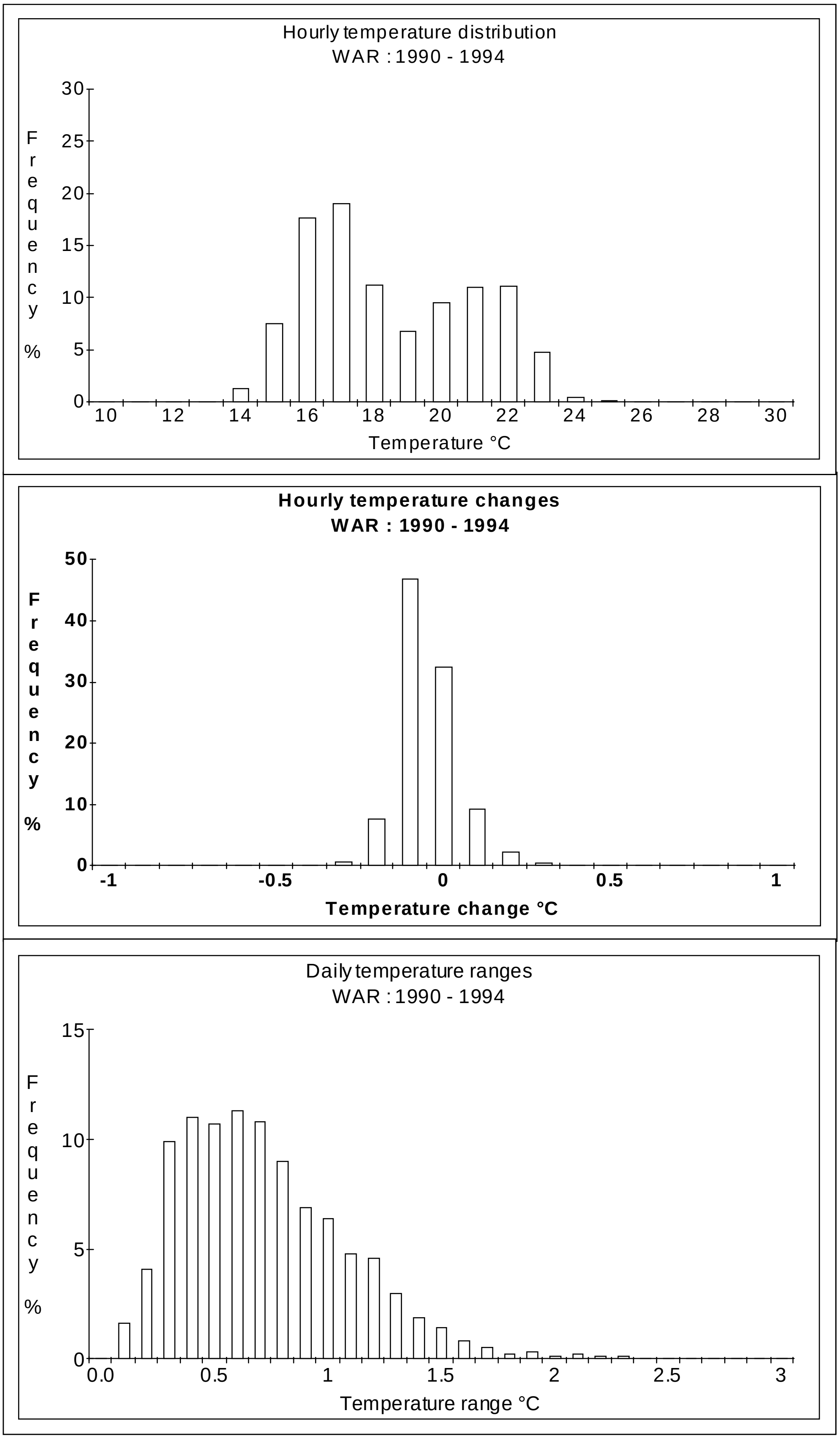


Figure 23 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) in Warnbro Sound.

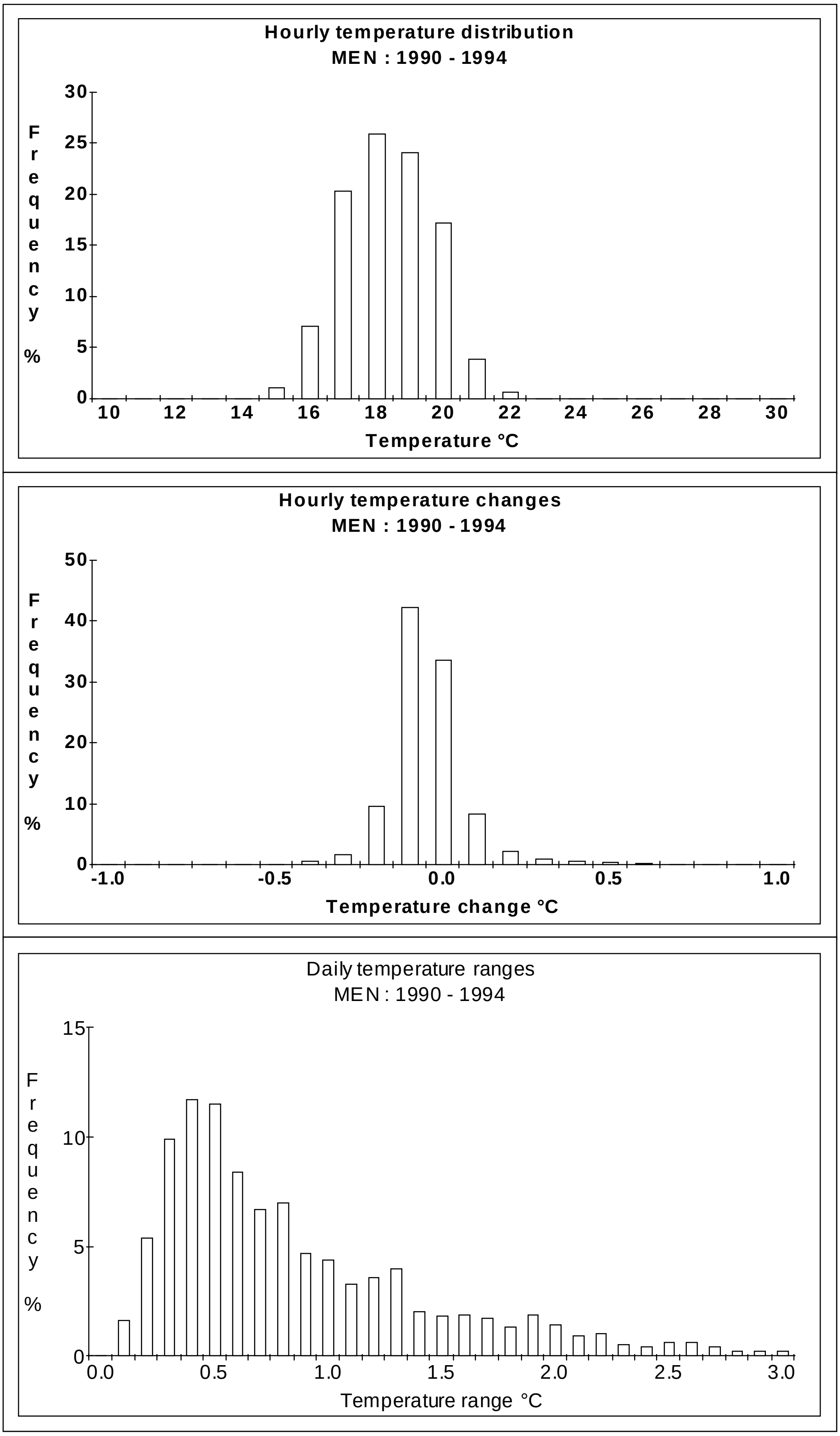


Figure 24 Histograms of hourly temperatures (upper panel), hourly temperature changes (centre panel) and daily temperature ranges (daily maximum to minimum) (lower panel) at Cape Mentelle.

Appendix 1 - Summary of temperature logger deployments.

For each table: Start = the dates when the loggers were deployed; End = the dates when the loggers were recovered; HgTemp = the mercury thermometer temperature check; TLTemp = the corresponding temperature logger value; and Code = a reliability index (see text).

Appendix Table 1 Summary of temperature logger deployments at South Passage.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
SPB90068	9/03/90	25.5	25.3	8/06/90	22.8	22.7	AA
SPB90159	8/06/90	22.8	22.8	8/08/90	20.2	20.4	AA
SPB90276	3/10/90	22.0	21.5	4/12/90	22.5	21.3	AC
SPB91029	29/01/91	23.0	23.8	28/03/91	23.4	24.1	BB
SPB91087	28/03/91	23.4	23.3	12/04/91		24.0	AC
SPB91189	8/07/91	20.7	21.9	28/07/91	22.0	22.6	CB
SPB91209	28/07/91	22.0	22.8	3/10/91	20.3	20.5	BA
SPB91276	3/10/91	20.3	20.7	24/11/91	21.0	20.6	AA
SPB92025	25/01/92	24.3	22.6	16/03/92	24.0	24.9	CB
SPB92076	16/03/92	24.0	25.1	19/05/92	22.2	23.4	CC
SPB92140	19/05/92	22.2	23.4	14/07/92	22.9	24.4	CC
SPB92196	14/07/92	22.9	23.0	10/09/92	20.5	20.8	AA
SPB93040	9/02/93	22.7	23.5	7/05/93	23.0	22.5	BA
SPB93127	7/05/93	23.0	22.4	26/05/93		22.1	BC
SPB93217	26/05/93		22.1	1/08/93	20.6	20.6	CA
SPB93213	1/08/93	20.6	20.8	1/10/93	20.2	20.1	AA
SPB93274	1/10/93	20.2	20.6	28/11/93	21.0	21.1	AA
SPB93332	28/11/93	21.0	20.9	1/03/94	23.5	23.1	AA
SPB94060	1/03/94	23.5	23.2	15/05/94			AC
SPB94142	22/05/94	25.1	25.9	16/09/94	22.3	21.9	BA
SPB94259	16/09/94	22.3	21.9	1/02/95		21.8	AC

Appendix Table 2 Summary of temperature logger deployments at Rat Island.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
RAT93039	8/02/93	22.6	22.8	8/05/93	22.2	22.1	AA
RAT93128	8/05/93	22.2	22.1	4/07/93	21.0	21.0	AA
RAT93185	4/07/93	21.0	21.0	5/09/93	19.9	20.0	AA
RAT93248	5/09/93	19.9	19.7	30/11/93	21.3	20.8	AA
RAT93334	30/11/93	21.3	21.1	2/03/94	23.9	24.0	AA
RAT94061	2/03/94	23.9	23.6	24/05/94	23.4	23.1	AA
RAT94144	24/05/94	23.4	23.5	23/07/94			AC
RAT94263	20/09/94	20.9	21.2	18/12/94	22.6	22.5	AA
RAT94352	18/12/94	22.6	22.6	16/02/95	23.7		AC

Appendix Table 3 Summary of temperature logger deployments at Seven-Mile Beach.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
SMB90015	15/01/90	23.3	22.5	11/03/90	25.8	25.2	BB
SMB90070	11/03/90	25.8	24.4	9/04/90		19.8	CC
SMB90157	6/06/94	18.9	19.3	3/08/90	17.3	17.6	AA
SMB90215	3/08/90	17.3	18.1	5/10/90	20.1	20.6	BA
SMB90278	5/10/90	20.1	19.8	7/12/90	21.7	21.2	AA
SMB90341	7/12/90	21.7	23.0	30/01/91	25.3	25.7	CA
SMB91030	30/01/91	25.3	25.2	4/04/91	22.2	22.6	AA
SMB91266	23/09/91	18.6	19.3	22/11/91	20.8	22.4	BC
SMB91326	22/11/91	20.8	22.5	18/01/92	23.6	24.8	CC
SMB92018	18/01/92	23.6	23.8	19/03/92	23.1	23.1	AA
SMB92199	17/07/92	18.8	18.6	11/09/92	18.0	17.6	AA
SMB92346	11/12/92	22.3	22.5	7/02/93	23.7	22.9	AB
SMB93038	7/02/93	23.7	23.6	7/05/93	19.8	20.2	AA
SMB93127	7/05/93	19.8	20.4	31/05/93		18.4	BC
SMB93184	3/07/94	17.6	18.0	9/08/93	17.0	17.5	AA
SMB93251	8/09/93	17.0	17.4	29/11/93	22.6	22.9	AA
SMB93333	29/11/93	22.6	22.8	1/03/94	22.1	22.1	AA
SMB94060	1/03/94	22.1	22.2	26/05/94	20.9	21.4	AA
SMB94146	26/05/94	20.9	20.9	22/07/94	19.2	18.9	AA
SMB94203	22/07/94	19.2	19.3	19/09/94	19.5	19.3	AA
SMB94262	19/09/94	19.5	19.5	17/12/94	24.5	24.2	AA
SMB94351	17/12/94	24.5	24.6	14/02/95	23.6	23.8	AA

Appendix Table 4 Summary of temperature logger deployments at Greenhead (upper).

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
GHT89271	28/09/89	24.4	20.7	1/05/90		24.3	CC
GHT90143	23/05/90	26.0	27.7	10/11/90		17.6	CC
GHT90314	10/11/90	20.7	20.7	21/06/91		22.9	AC
GHT91147	27/05/91	20.6	22.9	6/07/91			CC
GHT91224	12/08/91	22.7	20.9	6/02/92		21.5	CC
GHT92037	6/02/92	21.3	23.5	5/07/92		21.2	CC
GHT92345	21/11/92		19.3	5/07/93			
GHT93158	5/11/93	20.3	19.3	1/06/94	22.3	22.0	BA
GHT94344	1/06/94	22.3	21.5	10/12/94	21.0	20.3	BB

Appendix Table 5 Summary of temperature logger deployments at Green Head (lower).

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
GHB89271	28/09/89		17.8	1/05/90		20.8	CC
GHB90143	23/05/90		20.3	10/11/90		17.6	CC
GHB90314	10/11/90		18.0	21/06/91		20.9	CC
GHB91244	1/09/91		19.8	6/02/92		18.0	CC
GHB92037	6/02/92		22.1	5/07/92	20.4	20.1	CA
GHB92187	5/07/92		19.0	10/12/92	21.2	20.1	CC
GHB92345	21/11/92		20.2	5/07/93	21.1	20.0	CC
GHB93186	5/07/93	21.1	19.3	22/11/93		19.7	CC
GHB93158	5/11/93	20.3	18.9	1/06/94	22.3	21.7	CB
GHB94344	1/06/94	22.3	21.5	10/12/94	21.0	20.3	BB

Appendix Table 6 Summary of temperature logger deployments at Jurien.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
JBB90336	2/12/90	21.6	22.4	29/01/91	23.2	23.6	BA
JBB91029	29/01/91	23.2	22.7	3/04/91	22.0	22.1	AA
JBB91093	3/04/91	22.0	22.4	26/05/91	21.0	21.5	AA
JBB91146	26/05/91	21.0	20.8	26/07/91	20.0	19.8	AA
JBB91265	22/09/91	18.8	18.4	21/11/91	21.0	19.9	AC
JBB92080	20/03/92	22.0	22.6	18/05/92	20.1	20.1	BA
JBB92139	18/05/92	20.1	20.5	16/07/92	17.9	18.2	AA
JBB92198	16/07/92	17.9	18.0	10/09/92	18.6	18.5	AA
JBB92250	10/09/92	18.6	18.6	10/12/92	21.2	21.6	AA
JBB92345	10/12/92	21.2	21.2	10/03/93	21.2	21.2	AA
JBB93069	10/03/93	21.2	21.4	5/05/93	20.6	20.5	AA
JBB93183	2/07/93	19.2	19.3	3/09/93	17.6	17.7	AA
JBB93246	3/09/93	17.6	17.3	28/11/93	21.1	21.3	AA
JBB93332	28/11/93	21.1	21.2	28/02/94		22.7	AC
JBB94059	28/02/94		23.3	27/05/94	21.4	21.5	CA
JBB94147	27/05/94	21.4	21.3	21/07/94	19.4	19.3	AA
JBB94202	21/07/94	19.4	19.5	18/09/94	18.9	19.0	AA
JBB94261	18/09/94	18.9	19.1	16/12/94	22.9	22.9	AA
JBB95350	16/12/94	22.9	22.5	13/02/95	23.6	23.2	AA

Appendix Table 7 Summary of temperature logger deployments at Alkimos.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
ALB90071	12/03/90	24.0	23.3	4/07/90	16.6	15.6	BB
ALB90185	4/07/90	16.6	15.6	30/07/90	14.8	14.2	BB
ALB90211	30/07/90	14.8	15.0	28/09/90	18.5	17.3	AC
ALB90333	29/11/90	21.4	21.6	25/01/91	22.3	22.4	AA
ALB91085	26/03/91	20.8	20.5	22/05/91	19.9	19.5	AA
ALB91142	22/05/91	19.9	20.4	23/07/91	16.7	17.0	AA
ALB91204	23/07/91	16.7	16.8	18/09/91	17.2	17.1	AA
ALB91261	18/09/91	17.2	17.2	18/11/91	19.8	20.3	AA
ALB92014	14/01/92	22.9	23.7	23/03/92	22.5	22.2	BA
ALB92134	13/05/92	19.5	19.5	14/07/92	17.2	17.3	AA
ALB92196	14/07/92	17.2	17.4	9/09/92	16.0	16.3	AA
ALB92253	9/09/92	16.0	15.7	8/12/92	21.5	21.4	AA
ALB92343	8/12/92	21.5	21.7	4/02/93	23.7	23.8	AA
ALB93124	4/05/93	19.4	19.5	2/06/93	17.5	17.7	AA
ALB93153	2/06/93	17.5	17.9	30/07/93	16.9	17.0	AA
ALB93211	30/07/93	16.9	17.0	31/08/93	15.6	15.7	AA
ALB93243	31/08/93	15.6	15.6	26/11/93	21.1	20.9	AA
ALB93330	26/11/93	21.1	21.3	25/02/94	22.9	23.1	AA
ALB94056	25/02/94	22.9	22.9	18/05/94	21.1	21.1	AA
ALB94141	21/05/94	19.8	19.8	19/07/94	17.8		AC
ALB94200	19/07/94	17.8	18.1	16/09/94	17.1	17.6	AA
ALB94348	14/12/94	22.1	22.1	11/02/95	23.6	23.9	AA

Appendix Table 8 Summary of temperature logger deployments at Marmion.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
MAB89283	10/10/89	18.2	17.1	15/01/90	23.1	22.0	AA
MAB90015	15/01/90	23.1	23.5	11/05/90		19.8	AC
MAB90156	5/06/90	17.0	16.5	5/09/90	17.3	17.0	AA
MAB90248	5/09/90	17.3	19.8	30/11/90		23.0	CC
MAB91044	13/02/91	22.5	22.3	18/04/91	20.2	20.0	AA
MAB91190	9/07/91	16.3	16.8	7/10/91		18.2	AC
MAB91280	7/10/91		17.6	25/12/91		22.5	CC
MAB92006	6/01/92	22.4	22.7	3/04/92	22.1	22.3	AA
MAB92191	9/07/92		17.4	14/09/92	16.0	17.2	CC
MAB92258	14/09/92	16.0	16.2	30/11/92	19.5	19.4	AA
MAB92335	30/11/92	19.5	19.8	5/02/93	22.6	22.9	AA
MAB93036	5/02/93	22.6	22.9	3/05/93		19.6	AC
MAB93123	3/05/93		20.1	1/09/93	15.6	15.7	CA
MAB93244	1/09/93	15.6	15.7	1/02/94	22.0	22.9	AB
MAB94042	1/02/94	22.0	22.4	27/07/94		18.5	AC
MAB94229	27/07/94	16.7	16.5	21/12/94	22.6	22.3	AA

Appendix Table 9 Summary of temperature logger deployments at Warnbro Sound.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
WSB90094	4/04/90	21.6	20.5	15/06/90	16.6	15.9	CB
WSB90166	15/06/90	16.6	17.0	31/07/90	14.9	15.4	AA
WSB90212	31/07/90	14.9	15.4	2/10/90	17.8	18.2	AA
WSB90275	2/10/90	17.8	17.8	30/11/90	21.2	21.4	AA
WSB90334	30/11/90	21.2	21.8	24/01/91	22.6	23.3	BB
WSB91024	24/01/91	22.6	23.0	27/03/91	21.0	21.2	AA
WSB91203	22/07/91	15.9	16.7	19/09/91	16.5	17.1	BB
WSB91262	19/09/91	16.5	16.2	19/11/91	19.1	19.1	AA
WSB92114	23/04/92	20.2	20.1	12/05/92	18.6	17.9	AB
WSB92133	12/05/92	18.6	18.8	10/07/92	16.8	17.2	AA
WSB92192	10/07/92	16.8	17.3	8/09/92	15.5	15.7	AA
WSB92342	7/12/92	21.3	21.2	3/02/93	23.7	23.5	AA
WSB93034	3/02/93	23.7	23.3	1/06/93	17.8	21.3	AC
WSB93152	1/06/93	17.8	18.2	1/09/93	15.4	15.6	AA
WSB93244	1/09/93	15.4	15.6	25/11/93	20.9	21.3	AA
WSB93329	25/11/93	20.9	20.9	24/02/94	22.7	22.8	AA
WSB94055	24/02/94	22.7	22.8	18/06/94	18.2	18.2	AA
WSB94169	18/06/94	18.2	18.2	18/07/94	16.7	17.0	AA
WSB94199	18/07/94	16.7		15/09/94	17.1		CC
WSB94258	15/09/94	17.1	16.9	13/12/94	21.9	21.8	AA
WSB94347	13/12/94	21.9	21.8	10/02/95	23.5	23.4	AA

Appendix Table 10 Summary of temperature logger deployments at Cape Mentelle.

File	Start	HgTemp	TLTemp	End	HgTemp	TLTemp	Code
CMB90073	14/03/90	22.3	21.2	5/07/90	19.0	18.2	CB
CMB90186	5/07/90	19.0	18.5	6/08/90	16.0	15.2	AB
CMB90279	6/10/90	17.3	16.6	1/12/90	18.5	18.0	BA
CMB91031	31/01/91	20.4	20.3	3/04/91	20.7	20.0	AB
CMB91152	1/06/91	19.3	19.2	23/07/91	17.0	17.9	AB
CMB91204	23/07/91	17.0	17.5	26/09/91	17.8	17.3	AA
CMB92023	23/01/92	18.9	19.4	23/03/92	21.1	21.1	AA
CMB92083	23/03/92	21.1	20.9	19/05/92	19.7	19.5	AA
CMB92140	19/05/92	19.7	19.1	18/07/92	18.1	17.3	BB
CMB92200	18/07/92	18.1	17.8	18/09/92		16.3	AC
CMB92350	15/12/92	17.8	19.3	9/02/93	20.1	21.2	CC
CMB93040	9/02/93	20.1	20.1	10/07/93	17.2		AC
CMB93330	26/11/93	18.0	18.5	3/03/94	20.7	20.7	AA
CMB94176	25/06/94	17.9	17.7	27/07/94	18.0	18.0	AA
CMB94208	27/07/94	18.0	18.5	21/09/94	17.7	18.4	AB
CMB94354	20/12/94	19.5	19.7	17/02/95	19.9	20.2	AA