Reference WP 1614 CP

Review of the climate and physical oceanography of the Recherché Archipelago and adjacent waters

Jonathon van Hazel, Charitha Pattiaratchi and Nick D'Adamo

A report prepared for the Department of Conservation and Land Management of Western Australia under funding from the Commonwealth Government Natural Heritage Trust to assist in conservation of the marine environment of the south coast of Western Australia

June 2001

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REVIEW OF THE CLIMATE AND PHYSICAL OCEANOGRAPHY OF THE RECHERCHÉ ARCHIPELAGO AND ADJACENT WATERS

By

JONATHAN VAN HAZEL, CHARITHA PATTIARATCHI AND NICK D'ADAMO

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EXECUTIVE SUMMARY

This report presents a review of the climate and oceanography of the south coast of Western Australia, focussing on the Recherché Archipelago region and neighbouring Stokes Inlet. The study region consists of a number of areas that have been highlighted as worthy of consideration as possible marine conservation reserves under the Conservation and Land Management Act 1984 by the Marine Parks and Reserves Selection Working Group (CALM, 1994). Furthermore, in recognition of the current and projected pressures on the Recherché Archipelago's rich and diverse ecological and social values, the Marine Parks and Reserves Authority (MPRA) recently highlighted the region as one which it considers should receive high priority for investigation as a possible marine conservation reserve.

The oceanography of the region is yet to be studied in any great detail, either through field, analytical or numerical modelling methods. Accordingly, this review provides a significant contribution to furthering the understanding of the broad-scale oceanography and, in turn, provides insight into physical factors that may have an influence and control on the biology. The review will provide a platform from which to plan more detailed investigations of the oceanography, as may be relevant to the possible establishment of a marine conservation reserve in the future.

The review was initiated by the Marine Conservation Branch (MCB) of CALM and is being funded through the joint resources of MCB and the Commonwealth Government's Marine Protected Areas program (Natural Heritage Trust). The Department of Environmental Engineering (DEE) at The University of Western Australia has contributed significant in-kind resources to the preparation of this report.

One of the authors (van Hazel) is continuing this work as an Honours Thesis at DEE which will examine the hydrodynamic processes in detail through the use of a 3-dimensional numerical model of circulation patterns within the study region. The Honours thesis will be available through the Department of Environmental Engineering.

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1 INTRODUCTION

In 1986, in recognition of the need to conserve the State's biodiversity, the Minister for the Environment established the Marine Parks and Reserves Selection Working Group to identify representative and unique areas, worthy of reservation for conservation, scientific, or public recreational purposes. The report was released in June 1994 and identified over seventy candidate areas around Western Australia (CALM, 1994) (Figure 1.1).

Marine conservation reserves are vested in the Marine Parks and Reserves Authority (MPRA). The MPRA has prioritised the various areas that are under consideration to be established as marine conservation reserves. The Recherché Archipelago was identified by the MPRA as one area that should be considered for investigation as a high priority, following the current set of areas currently under formal planning.

The State Government's strategy for marine conservation, as outlined in *New Horizons – The way ahead in marine conservation and management*, indicates a requirement for:

"*Extensive assessment, community consultation and management planning before a new marine conservation reserve is established*"

In view of the priority that has been assigned to this region, an application was made by CALM to Environment Australia to fund biological and oceanographic studies of the region. That application was successful and a component of those funds received have been used to support this review.

1.1 Objective

The objective of this report is to provide an overview of the climate and oceanography of the South Coast of Western Australia, focusing on the Recherché Archipelago and neighbouring Stokes Inlet.

1.2 Study Boundary

The study area for this survey includes the WA State waters stretching from Margaret Cove, west of Stokes Inlet to Gegelup Point, east of Israelite Bay (Figure 1.2). The Archipelago contains over 150 islands and stretches well over 200km, with many of the islands lying beyond the 3 nautical mile coastal water boundary that defines the State's territorial waters limit. However, because the islands are State territory, they each have their own shore lines surrounded by State territorial waters, again defined by the 3 nautical mile offshore limit. In combination, the territorial waters surrounding the archipelago's islands effectively extend Western Australia's territorial waters off the south coast to over 25nm offshore in the Recherché Archipelago.

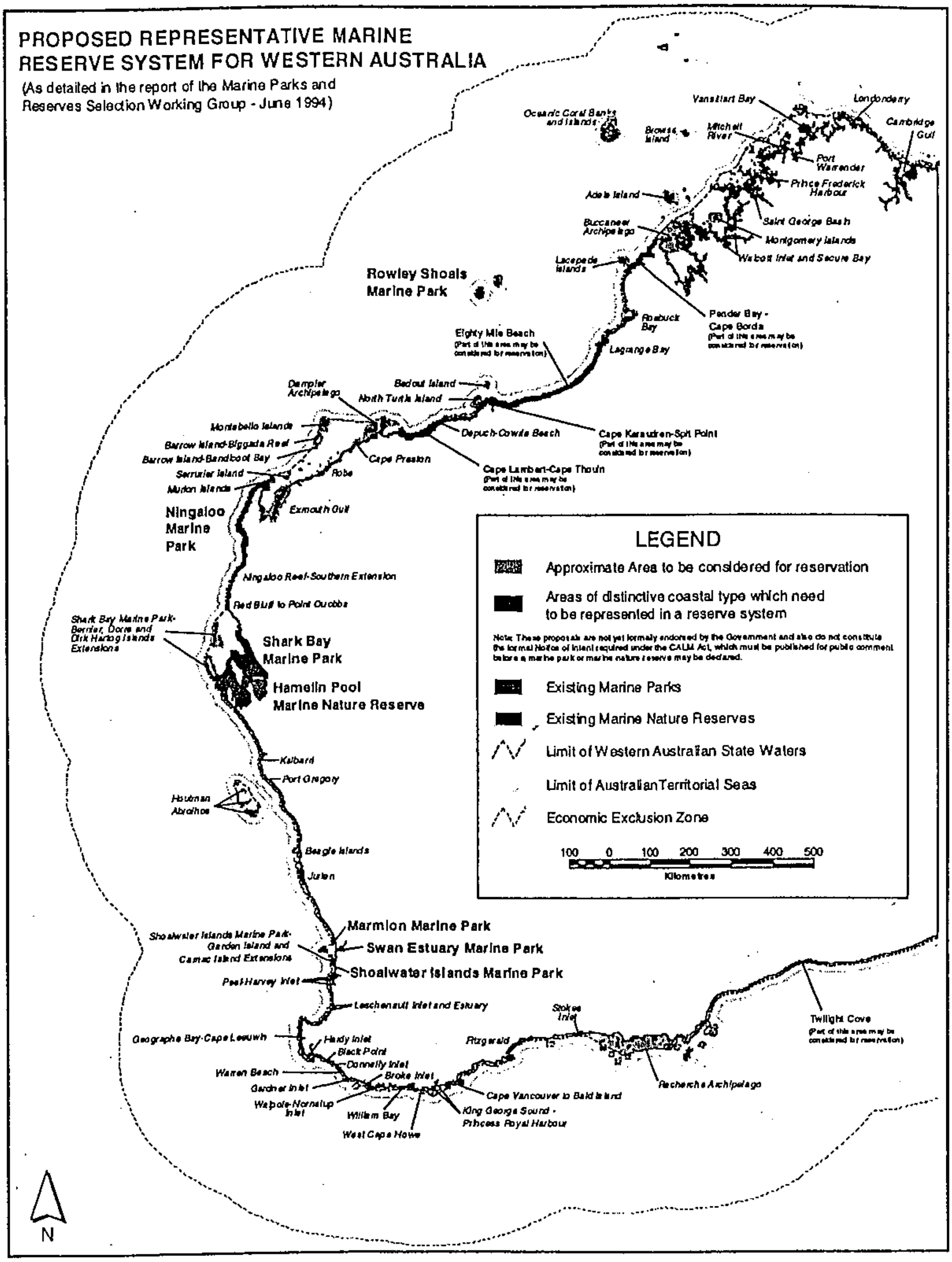


Figure 1.1: Map showing areas recommended as worthy of marine reservation in the Report of the Marine Parks and Reserves Selection Working Group (CALM, 1994)

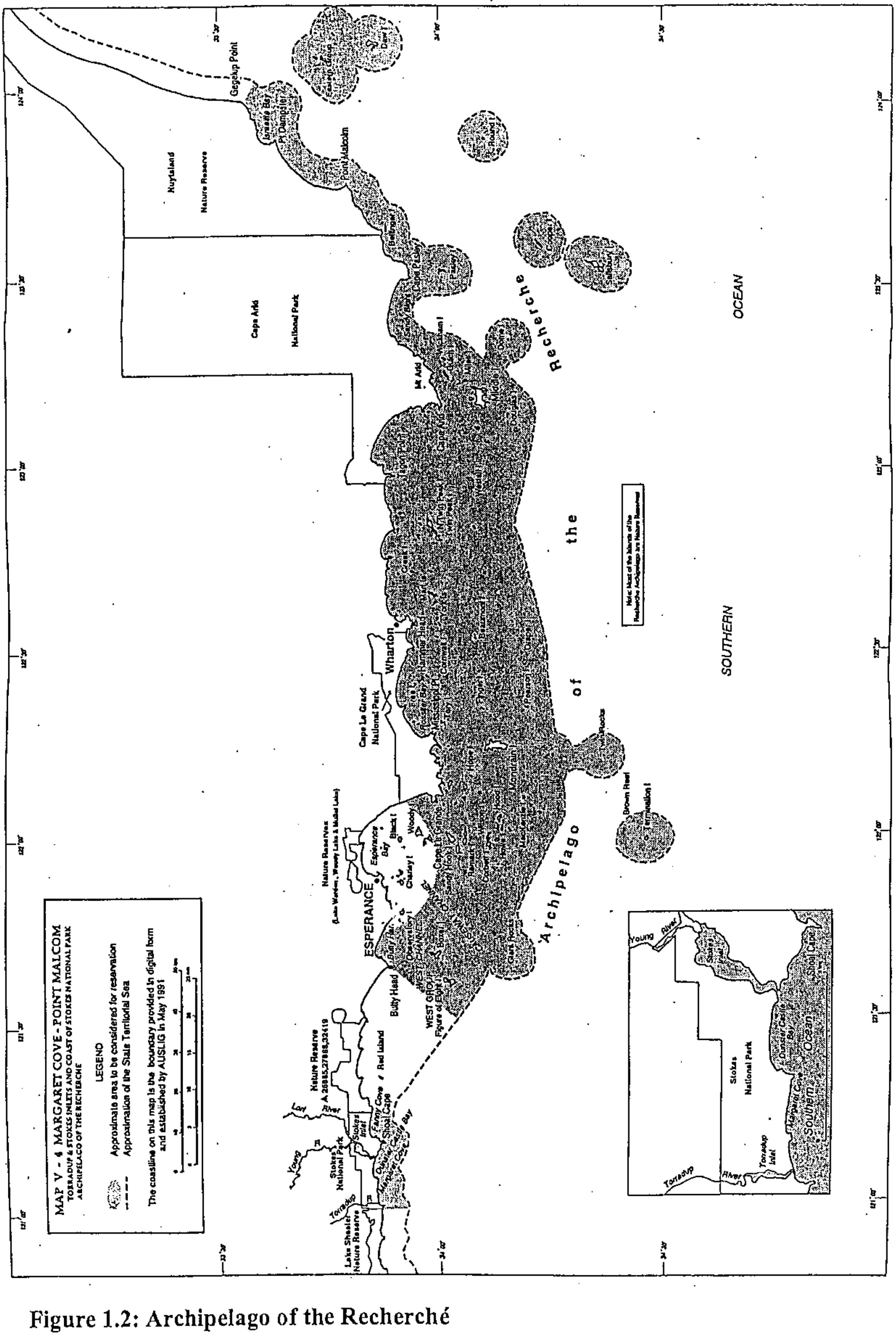


Figure 1.2: Archipelago of the Recherché

2 PHYSICAL SETTING

2.1 Bathymetry

Numerous islands dominate the bathymetry of the region and a relatively narrow (40-80km) continental shelf with depth contours generally parallel to the coastline. Beyond the continental shelf the depths increase rapidly to 4000m

2.2 Large scale coastal geomorphology

The continental shelf along this section of the coast is relatively narrow. In some places it is only 35km from the shore. The islands off the headlands represent the high points of the Albany-Frazer Oregon, now flooded by the ocean. The depth of the sea floor within the archipelago averages about 40m. Most of the islands are within the 50m bathymetric contour although some of the outer islands rise from depths of 70m or more.

In form and character the islands resemble the granitic headlands of the mainland coast. The rocky shores fall steeply in to the ocean till they reach the sandy floor where the substrate changes abruptly (CALM, 1994).

3 METEOROLOGY

3.1 Climate

The climate of southwest Australia is typically Mediterranean with hot dry summers and cool wet winters. The major controlling factor of these seasons is the north-south migration of the 'subtropical baric ridge' that is formed by high-pressure cells moving west to east across Australia. During summer the ridge at it's southernmost, bringing hot dry weather to the south. During winter the belt lies at its northernmost allowing rain-bearing depressions to move eastwards across the south of the state (Figure 3.1). The counterclockwise direction of the winds around the high pressure systems means that Esperance witnesses a reversal in wind direction from summer to winter as the baric ridge moves north (Figure 3.1).

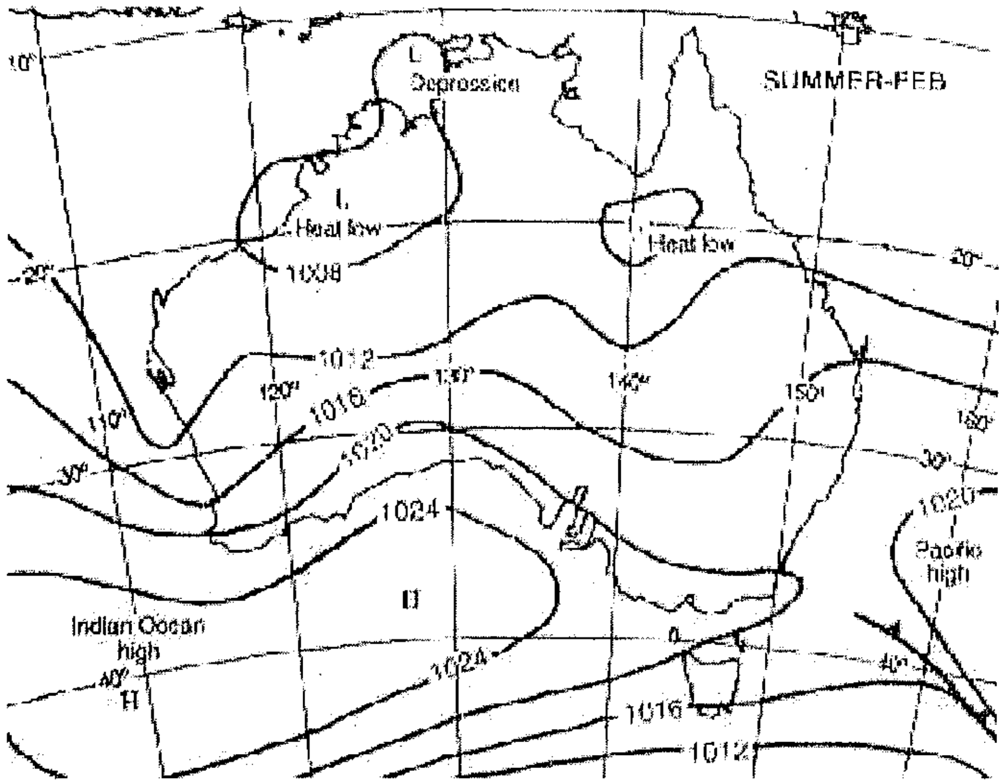


Figure 3.1(a): Typical Summer pressure distribution over Australia. Note the presence of the high in the Great Australian Bight

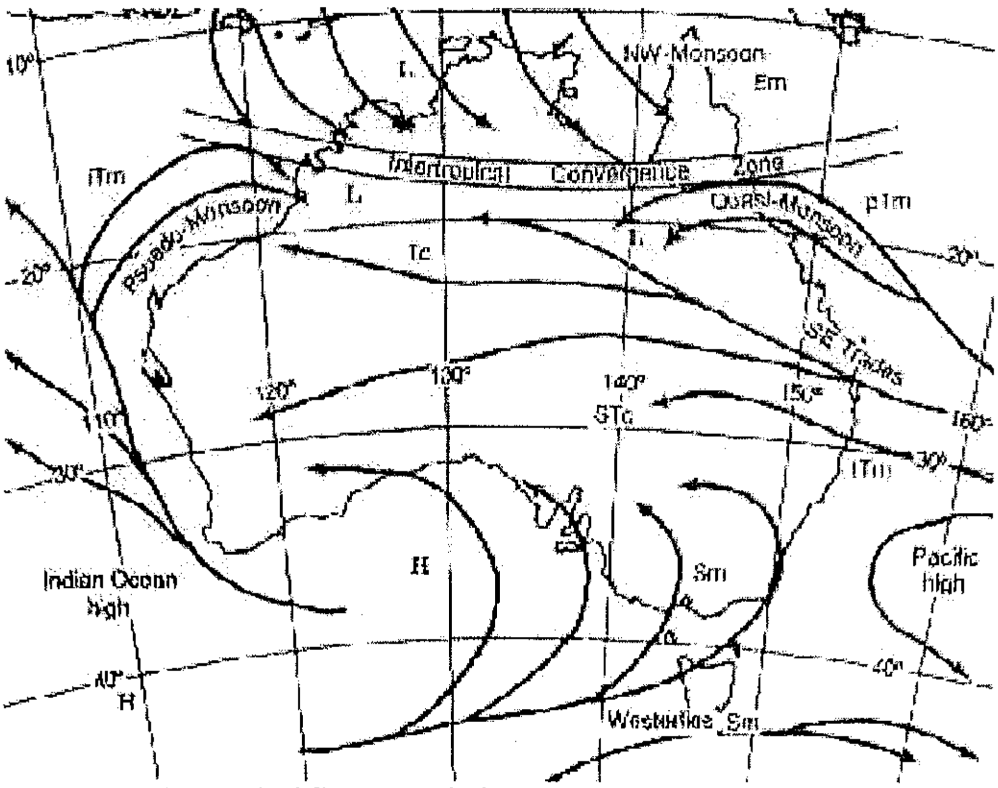


Figure 3.1(b): Typical Summer wind pattern over Australia. The prevailing winds are easterly over the Recherché.

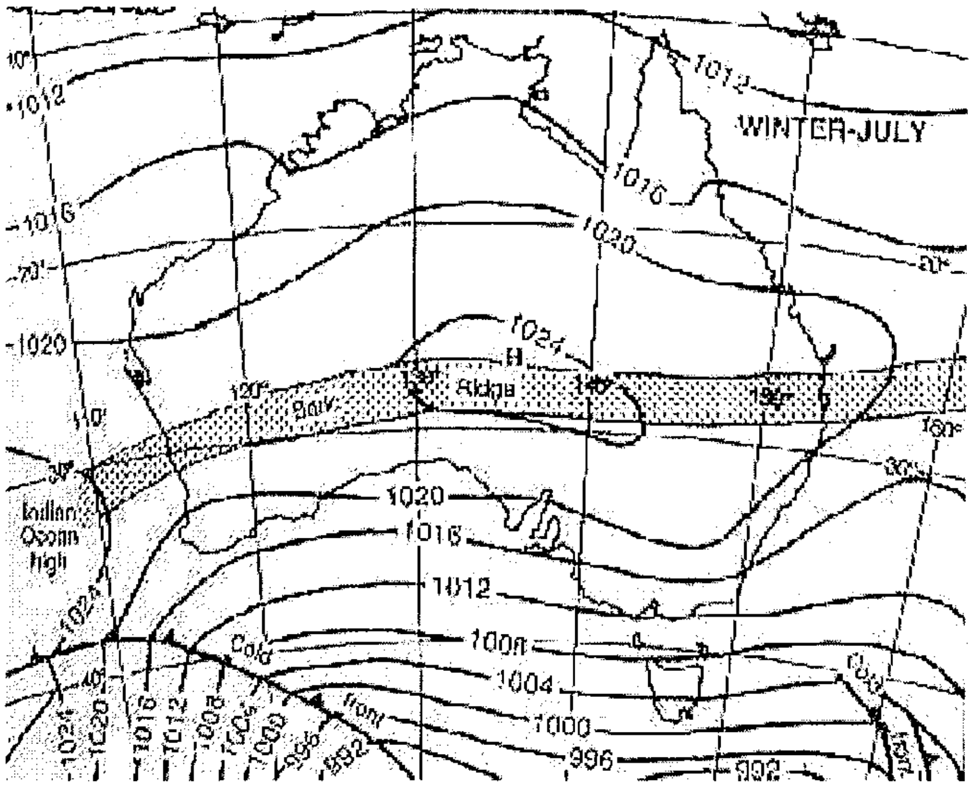


Figure 3.2(a): Typical Winter pressure distribution over Australia. Note the baric ridge has moved north.

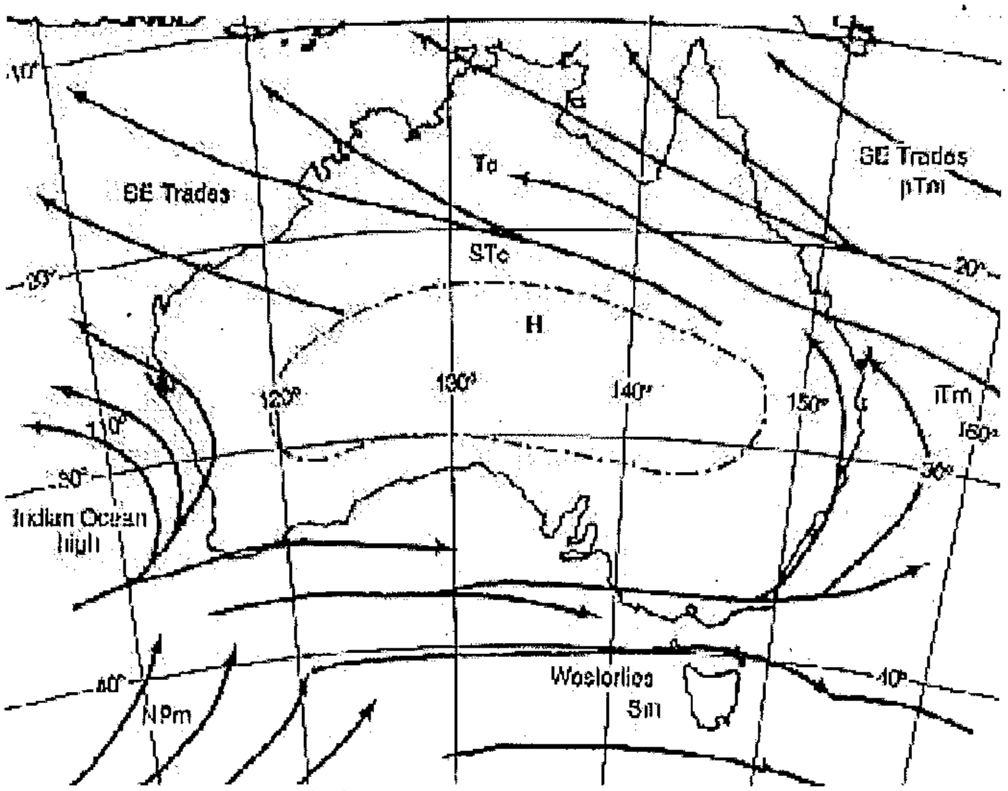


Figure 3.2(b): Typical Winter wind pattern over Australia. The prevailing winds are now more westerly over the Recherché.

3.2 Wind Regime

Two years (1995 and 2000) of wind speed and direction data collected by the Bureau of Meteorology at hourly (1995) and half-hourly (2000) intervals was analysed as part of this study. For both years, the annual wind roses (Figure 3.2 and 3.3) indicate that the majority of winds come from the northwest and southeast quadrants. In 1995 the highest occurrences of winds are easterly and the strongest winds are from the north and west (Figure 3.2). In 2000, the winds were strongest and most frequent from the northwest (Figure 3.3). However, the data for the year 2000 is missing the majority of December, creating a skewed frequency in favour of the northeast (winter) winds. For both years, the highest recorded wind speed (averaged over 1 hour) was 17.5 ms^{-1}.

The seasonality in the wind direction is shown by the seasonal wind roses (Figure 3.2 and 3.3). During summer (December-February) the winds are predominantly from the east and southeast direction. These seabreezes are relatively strong for the year, rivalling the strength of the winter winds. Figure 3.4 shows four wind roses for summer 2000 (3am, 9am, 3pm, and 9pm). The figures indicate the strongest winds are in the evening from the east (17ms^{-1}). They tend to weaken overnight, before swinging southeast in the morning. During the day the southeasterly winds strengthen before turning east again in the evening.

The autumn winds (March-May) maintain the east and southeast component but an increase in the north and northwest winds can be identified. They are generally weak except for some evidence of strong northerly winds in 2000.

Winter winds (June-August) dominate the northwest quadrant and are the strongest of the year. Throughout winter the winds are likely from all directions in the northwest quadrant.

During spring (September-November) the winds are generally weaker and there appears to be no dominant direction.

Figure: 3.2: Percentage frequency of wind occurrence and wind strength (1995)

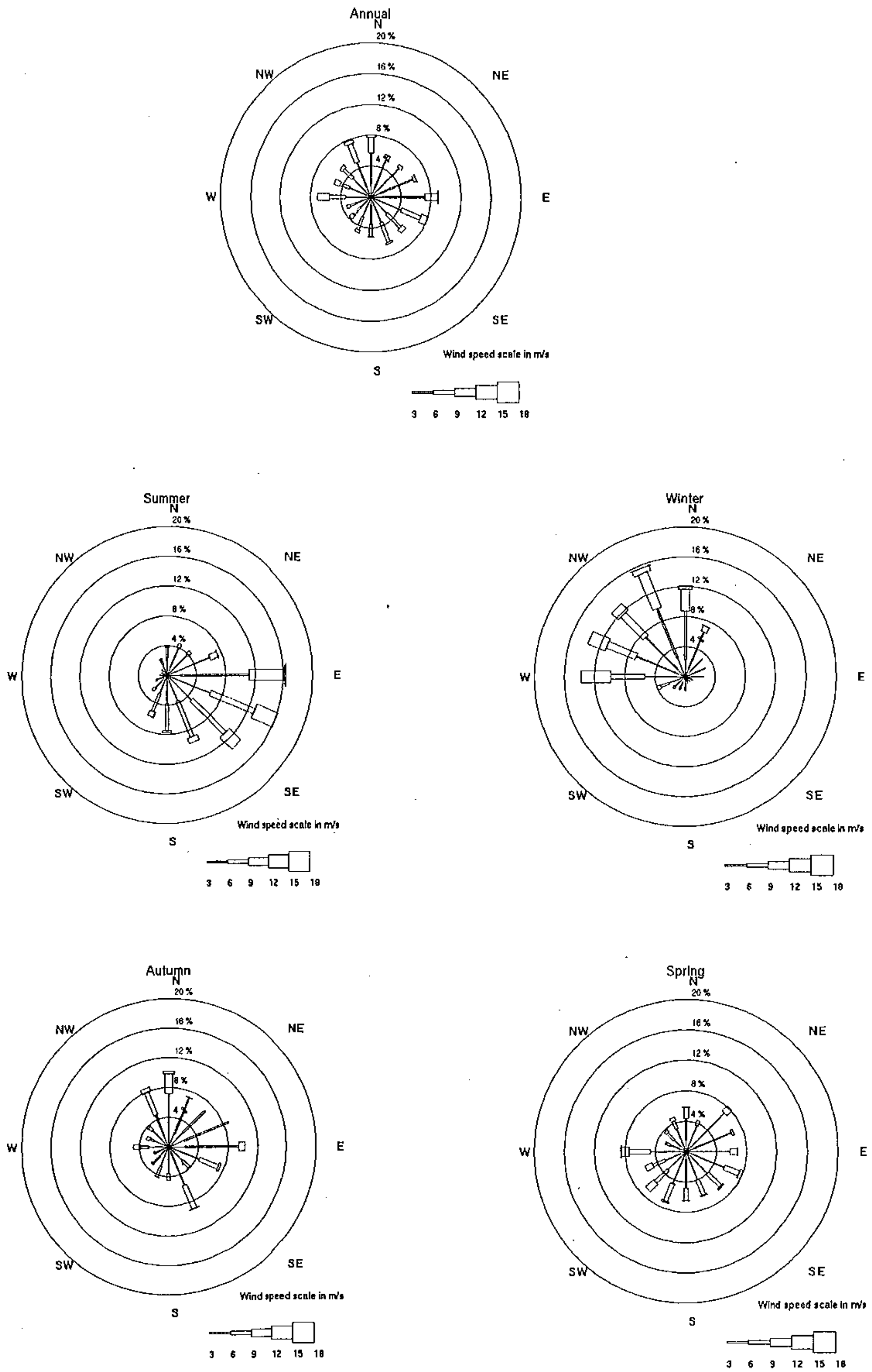


Figure: 3.3: Percentage frequency of wind occurrence and wind strength (2000)

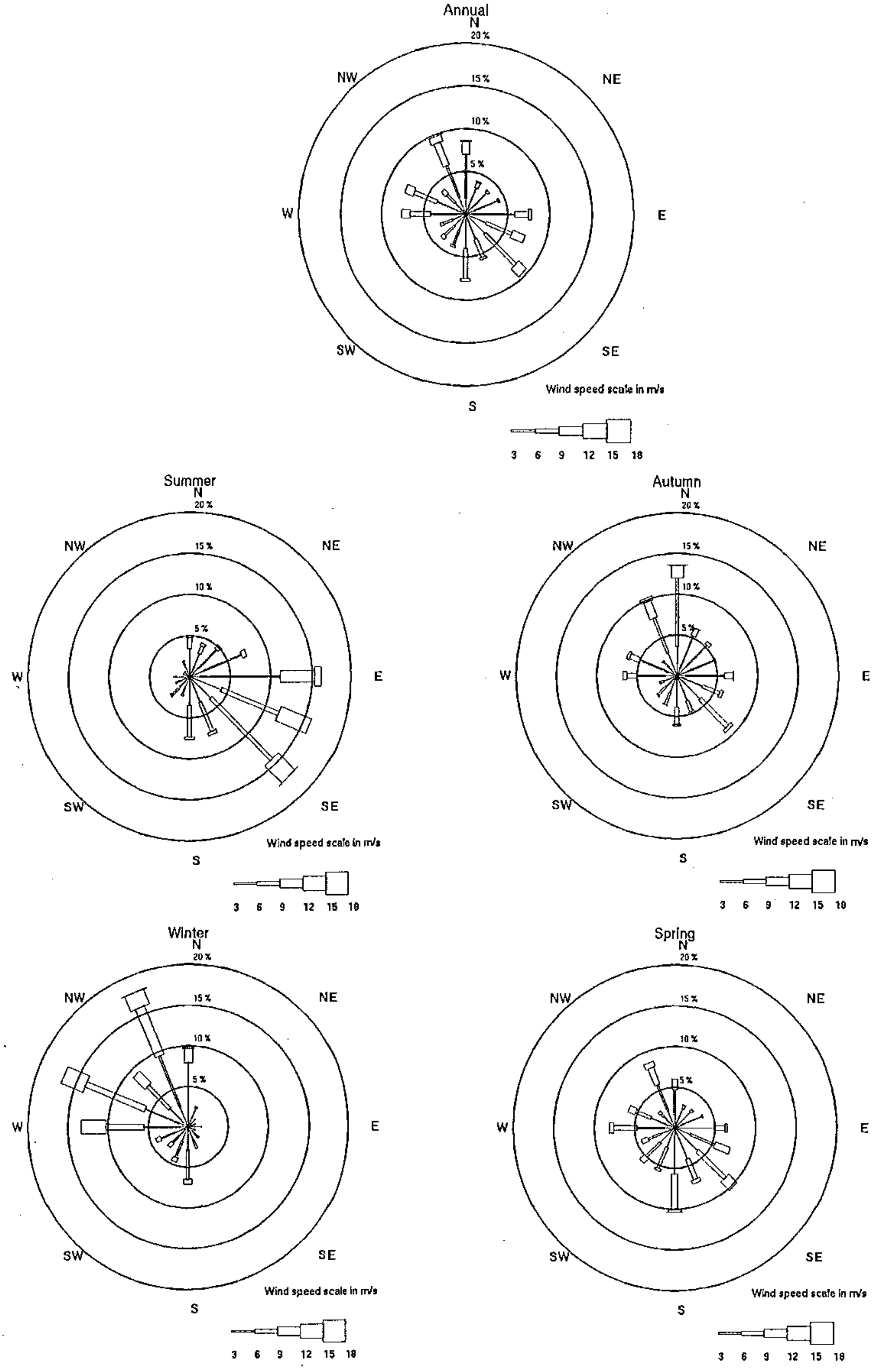
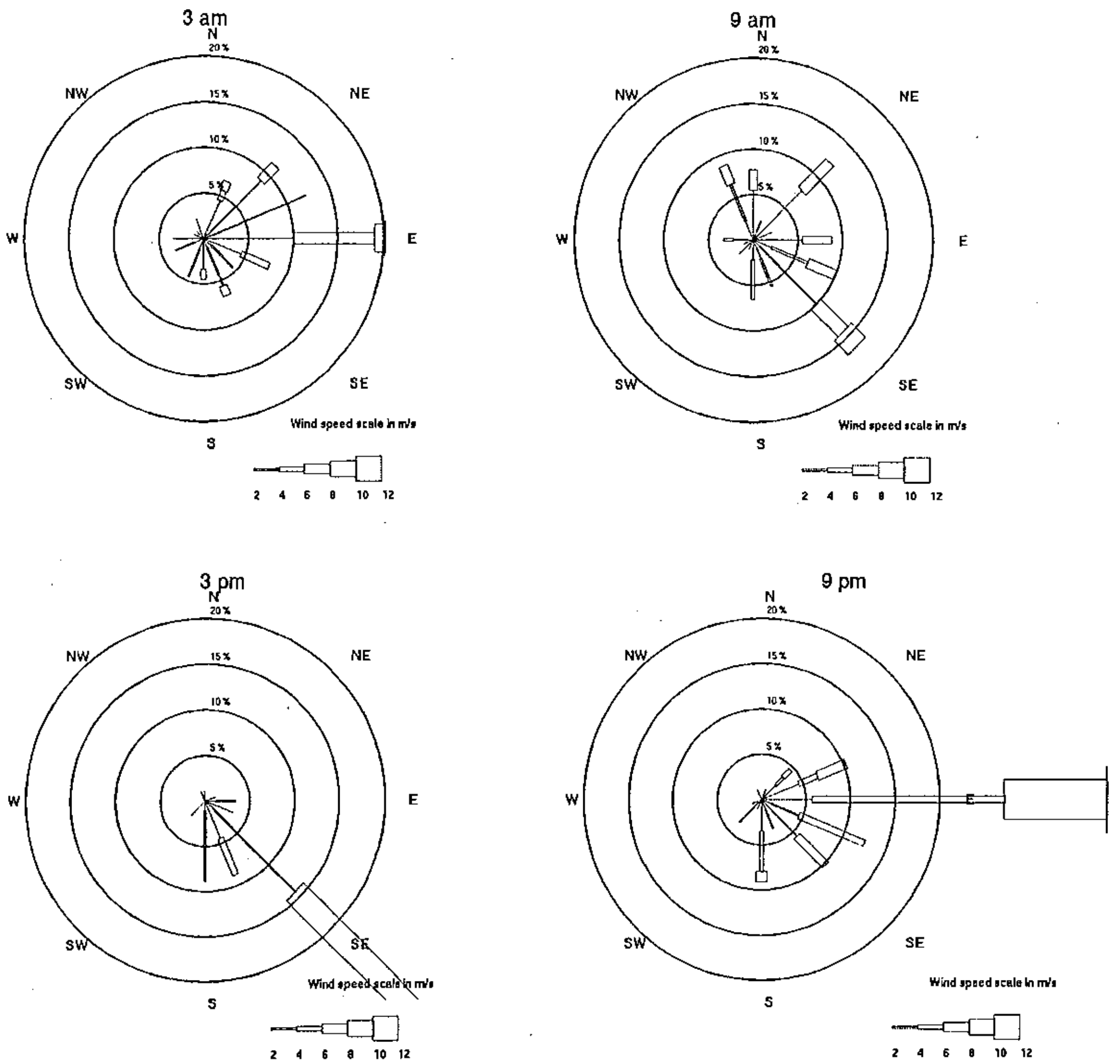


Figure: 3.4: Percentage frequency of wind occurrence and wind strength (Summer 2000)



3.3 Rainfall

The rainfall in the Recherché region is that of a typical temperate climate. The relatively dry summers experience an average monthly rainfall of around 20mm and have approximately 5 raindays per month. At the peak of winter in July, the average monthly rainfall almost exceeds 100mm and the number of raindays is around 17 for the month (Figure 3.5).

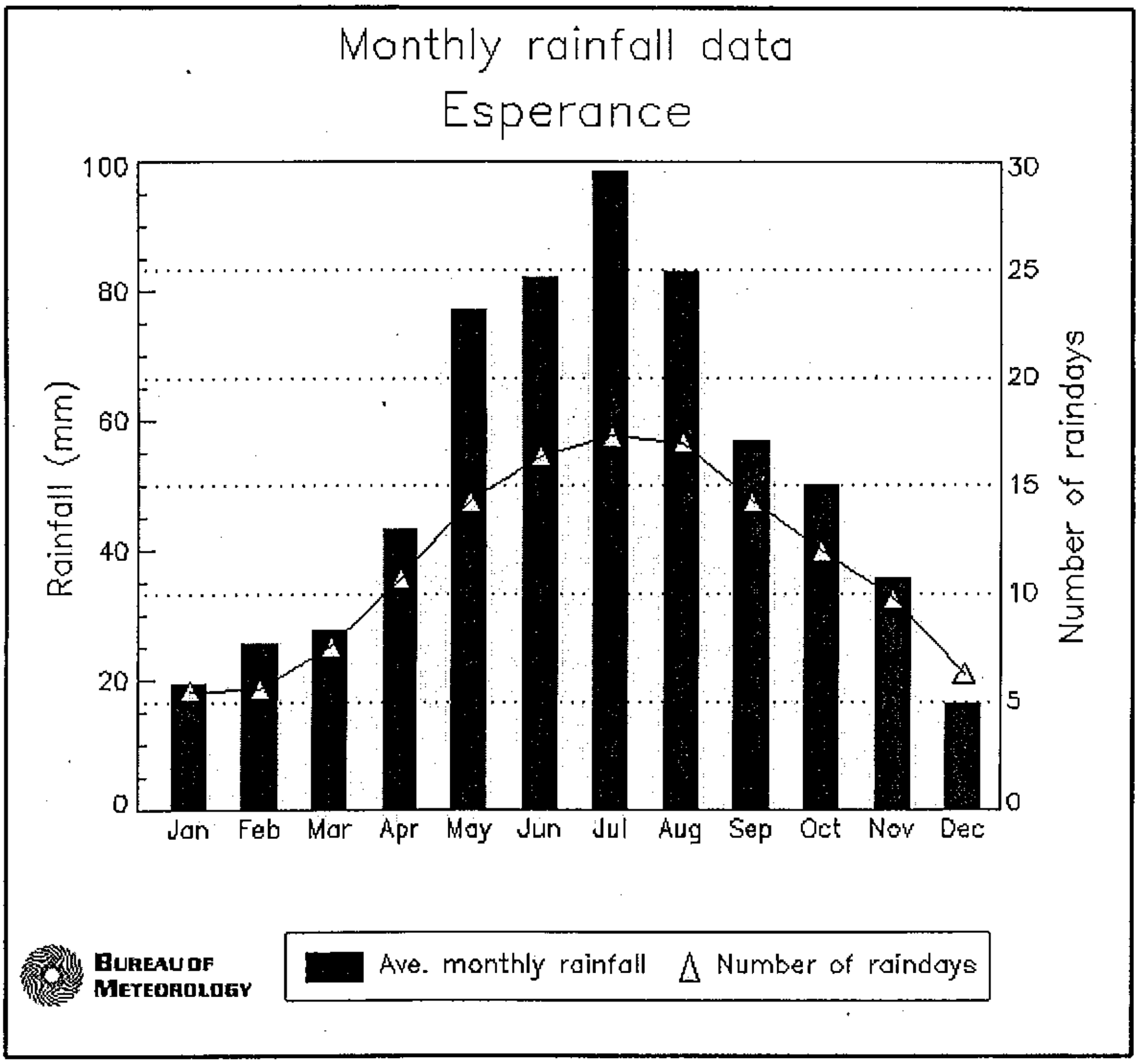
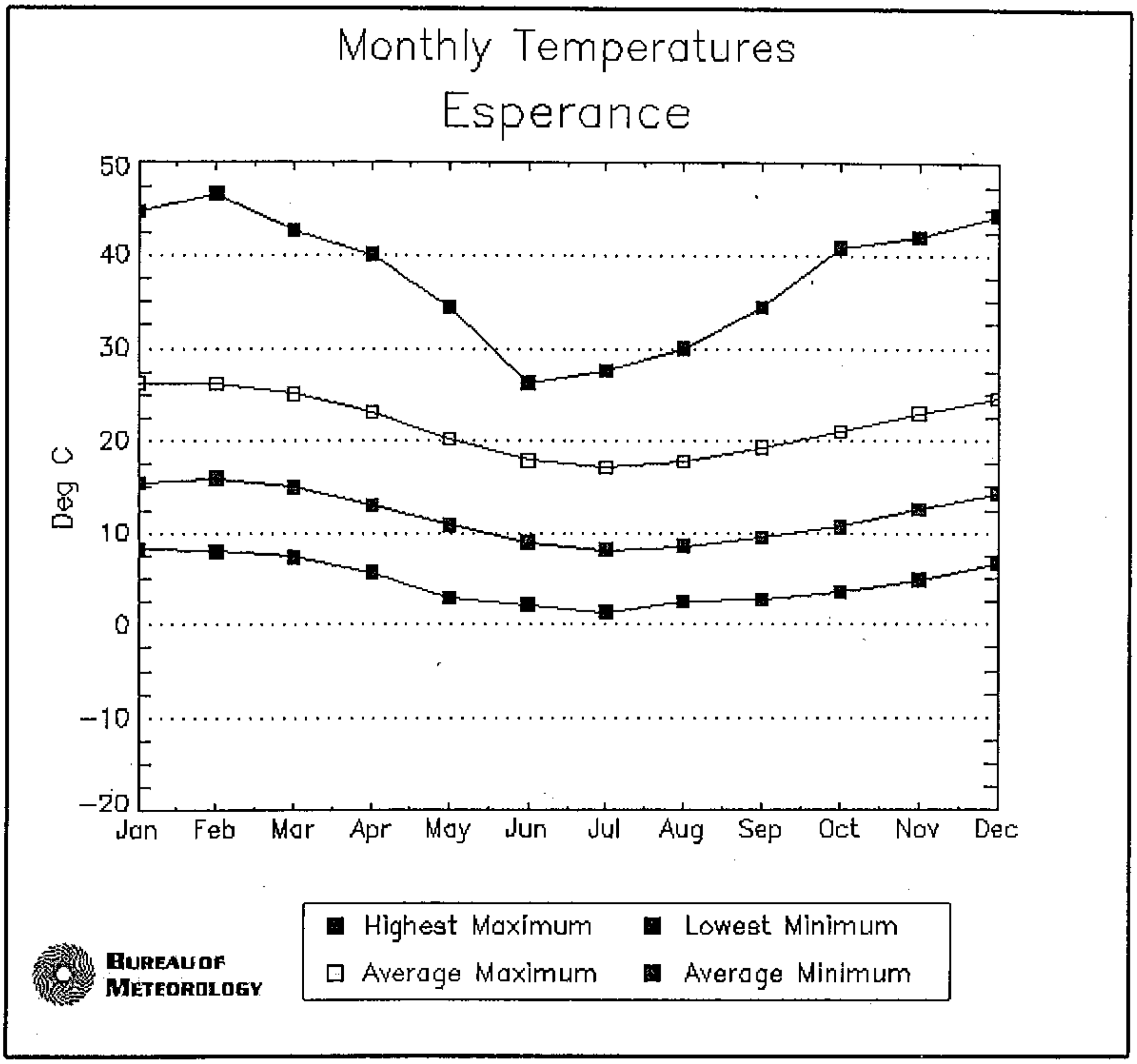


Figure 3.5: Monthly Rainfall Data for Esperance

3.4 Temperature

The temperature variation in the Recherché is shown in Figure 3.6. The graph indicates that the average summer range is from 27°C to 15°C and the winter ranges from around 17°C to 8°C. The graph also shows the maximum and minimum temperatures recorded and it is interesting to note the range that has been experienced. At some stage Esperance has recorded a blistering 47°C day and has been as low as 2°C.

Figure 3.6: Monthly Temperature Data for Esperance



3.5 Freshwater Inflows

Stokes Inlet, which is situated 100 km to the west of the easternmost island of the Recherché Archipelago, is the only significant source of freshwater inflows to the archipelago region. However, the sand bar at the mouth is closed most of the time rendering the inlet fairly ineffectual as an inflow source. Hodgkin and Clark (1989) have researched the ecology of Stokes Inlet in more detail, and found that the inlet had only been reported open six times between 1968 and 1989.

When the Inlet does open, the resulting outflow into the ocean is generally hyper-saline. The salinity of the Inlet is rarely less than 35ppt during the year. Little stratification is present in the Inlet as a result of wind mixing.

The temperature range is slightly greater than the ocean, reaching a high of approximately 25°C in summer and a low of about 12°C in winter.

4 WATER LEVEL FLUCTUATIONS

Water level fluctuations are a combination of several factors, some random, others more deterministic. A spectral plot of the water level data is shown in Figure 4.1. This data was collected from the Esperance Harbour in 1991. Some of the various contributing components are noted on the figure and are discussed in more detail below. The relative importance of each of the components can also be seen on the spectral plot. Clearly the diurnal astronomic tide component is the most important, but the semi-diurnal astronomic tide component and the long period component seem to be of relatively similar strength. Interestingly, a seiche seems to be present at a frequency of about 7 cycles per day (period of 3.4 hours).

4.1 Surface Gravity Waves

Surface gravity waves are a combination of swell developed in the Southern Oceans and locally generated wind waves. Raw data collected between 13/12/82 and 20/12/83 was analysed using spectral methods by WNI Science and Engineering. The resulting time series was then analysed by Pattiaratchi (1998).

Maximum significant wave heights of up to 4.5m were associated with storm events. Storms occurred most frequently from autumn (mid April) and continued into spring. Storm frequency is about 8-10 day^{-1} reducing to about 5 day^{-1} during winter. Relatively high waves are experienced for about 1-2 days during a storm event (Pattiaratchi, 1998).

Time series show the mean swell wave period to be around 8sec with a maximum mean period of around 10sec. The sea wave component has a mean of about 4sec and a maximum period of about 5sec.

A percentage occurrence histogram of Significant Wave Height at Magistrate Rock shows 1m waves have the highest occurrence (Figure 4.2). The exceedence curve shows that 50% of waves are larger than 1.45m and 20% are larger than 2m (Figure 4.3). Seasonal percentage occurrence histograms show that the highest waves occur in autumn and spring but the mean height is largest during winter (Figure 4.4).

The refraction/diffraction patterns for waves approaching the Bay from an angle of 240° are shown in Figure 4.5. This is the most dominant direction of wave approach.

Significant Wave heights of 0.65 m and peak periods of 3.3 s were found for typical winter storm events with locally generated winds for duration of 48hrs and mean wind speeds of 10 $ms^{-1}$from the north-northeast in a mean water depth of 35m (Pattiaratchi, 1998).

Figure 4.1: Spectral plot of Esperance tidal data

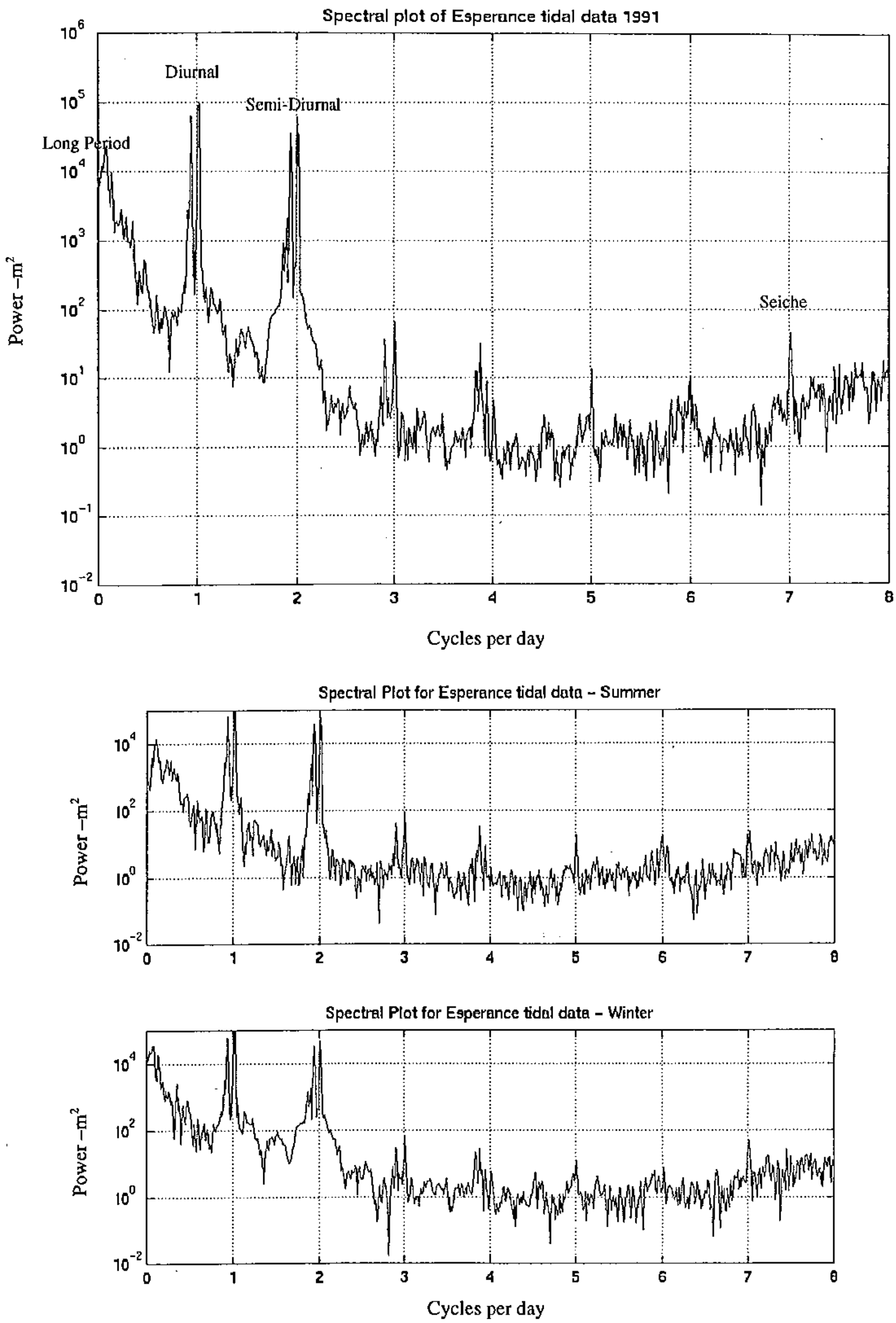
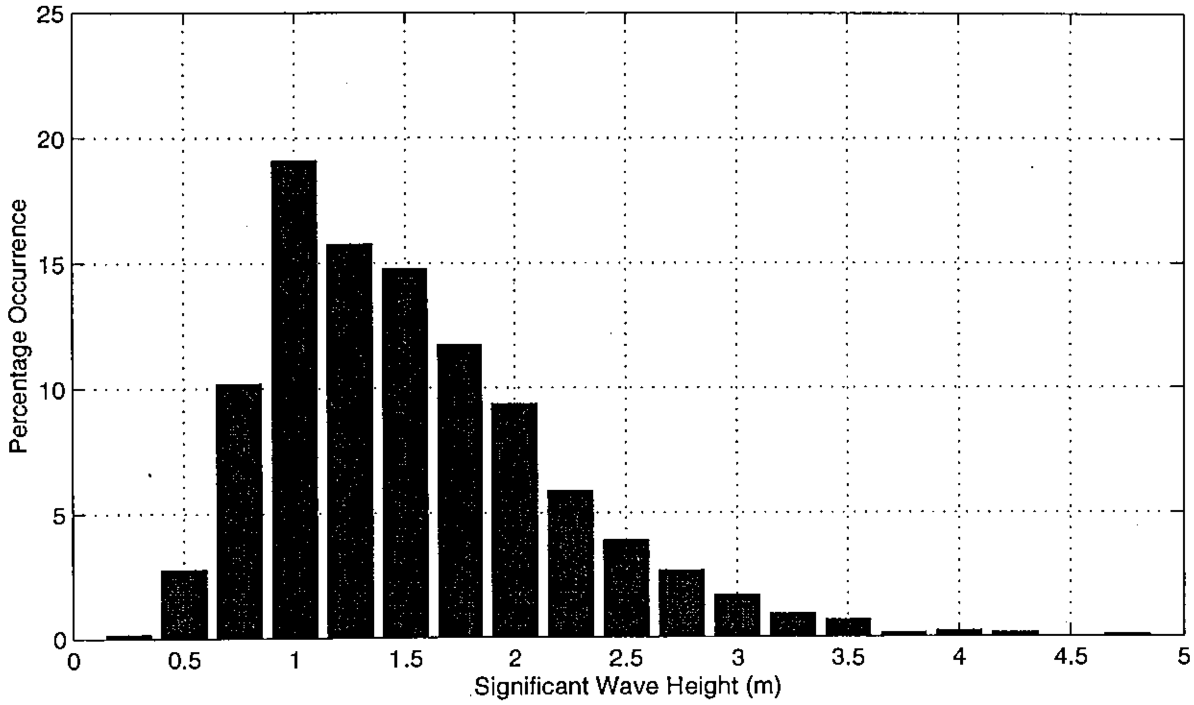


Figure 4.2 and 4.3: Percentage Occurrence Histogram and Exceedence Curve (1982-1983)

Magistrate Rock: Observed Data



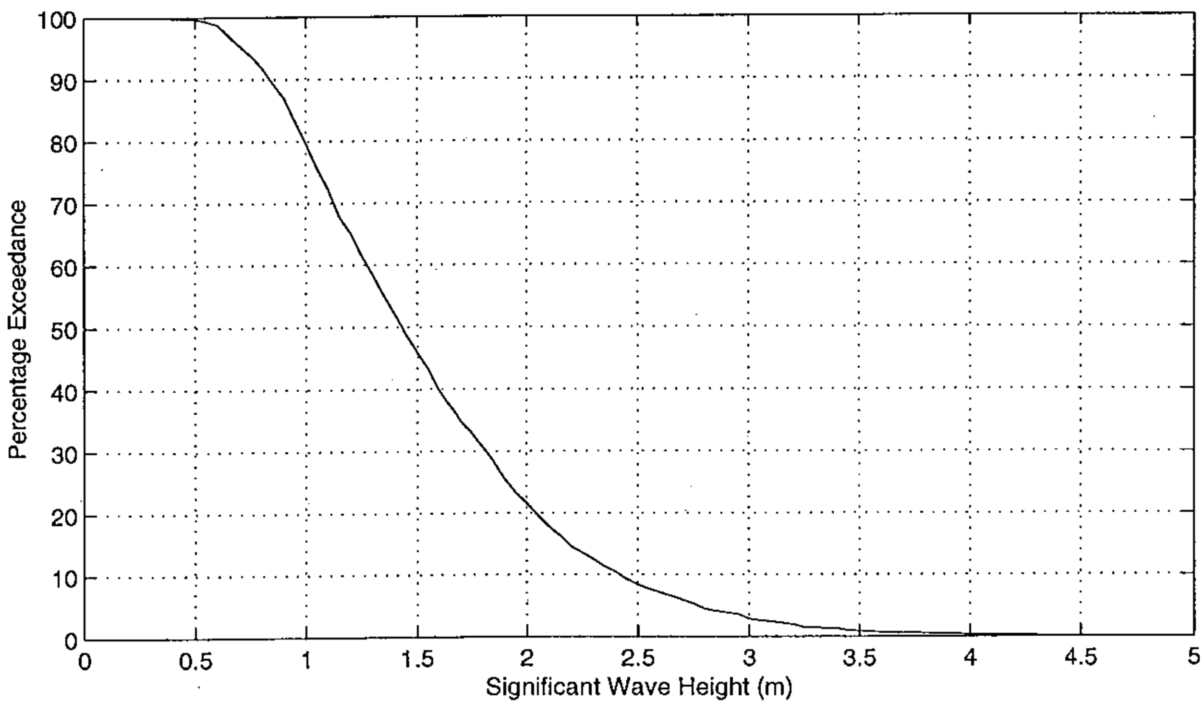


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Figure 4.4: Seasonal Percentage Occurrence Histogram (1982-1983)

Magistrate Rock: Observed Data

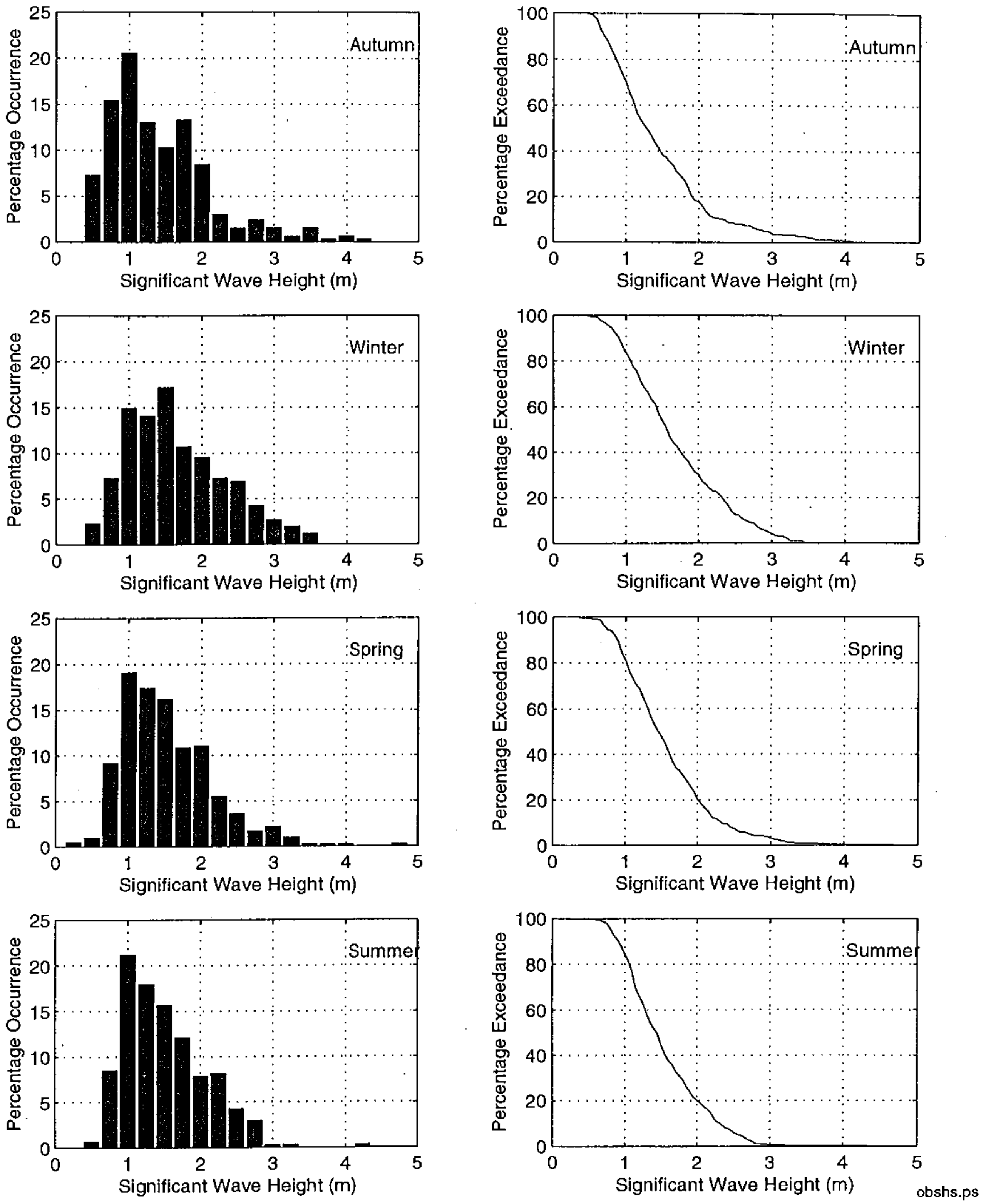
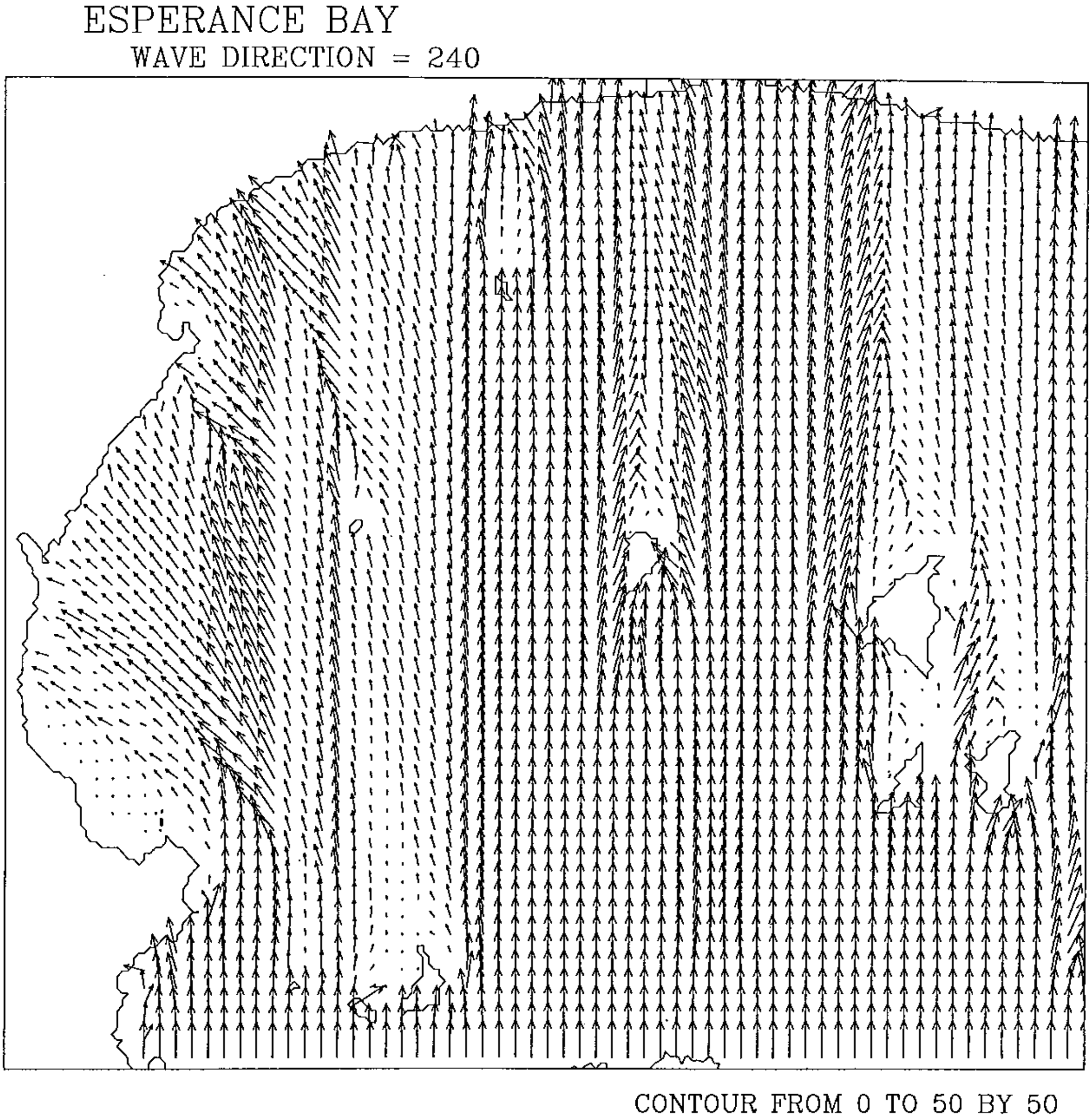


Figure 4.5: Refraction/Diffraction pattern of waves approaching from direction 240°C (Note: the figure needs to be rotated 60° in a clockwise direction)



4.2 Seiches

Enclosed or semi-enclosed bodies of water can be prompted into resonant motions, or seiches, at a set of natural periods of oscillation. The period of these motions is dependent on the depth and horizontal dimensions of the water body. Once established the seiche may last for several hours. For semi-enclosed water bodies, the seiche can be considered as a standing wave with no vertical motion at the open end (node) and maximum vertical motion at the other end (anti-node). The Recherché Archipelago is an example of a semi-enclosed water body.

The spectral plot in Figure 4.1 confirms the existence of a seiche. Instead of tapering away after the diurnal and semi-diurnal peaks like a normal series of harmonics, the spectrum shows a power peak. The peak suggests that the seiche has a period around 3.4 hrs.

4.3 Astronomic Tides

Tides forced by the combined gravitational and centrifugal forces of the earth-moon and earth-sun systems are termed astronomic tides. These tides are highly predictable because of the deterministic nature of the force exerted by the sun and the moon. The observed tide is the sum of a number of partial tides, each whose period corresponds with the period of the astronomical motion responsible for the forcing. Although over 100 of these tidal constituents exist, there are several that dominate. These are shown in Table 4.1. The predicted tidal data for Esperance is shown in Figure 4.6.

Table 4.1 - Average Tidal Constituents of the World

Constituent	Name	Period (hours)	Relative Magnitude
Semidiurnal			
M_2	Principal lunar	12.42	100
S_2	Principal solar	12.00	47
N_2	Lunar elliptic	12.66	19
K_2	Luni-solar semidiurnal	11.97	13
Diurnal			
K_1	Soli-lunar	23.93	58
O_1	Principal lunar	25.82	42
P_1	Principal solar	24.07	19
Q_1	Lunar elliptic	26.87	8
Long Period			
M_f	Lunar fortnightly	327.8	17
M_m	Lunar monthly	661.3	9
S_{sa}	Solar semiannual	4383.3	8

Tidal oscillations consist of a line spectrum of numerous semidiurnal, diurnal and long period constituents (Wright, 1995). The most pronounced is the semidiurnal moon constituent, M_2. The relative importance, to M_2, of the various tidal constituents is shown in Table 4.2. To determine the relative importance of the diurnal and semidiurnal constituents the form factor, F, is used:

$$F = \frac{H_{K_1} + H_{O_1}}{H_{M_2} + H_{S_2}}$$

Where H_n is defined as the amplitude of the tidal constituent n.

Table 4.2: Tidal Constituent Data for Esperance (Department of Defence, 1996)

	Name	H (amplitude, cm)	G(phase)
Semidiurnal			
M_2	Principle Lunar	0.103	320.1
S_2	Principle Solar	0.133	335.6
Diurnal			
K_1	Luni-solar diurnal	0.179	336.4
O_1	Principle lunar diurnal	0.133	314.2

$$F = 1.322$$

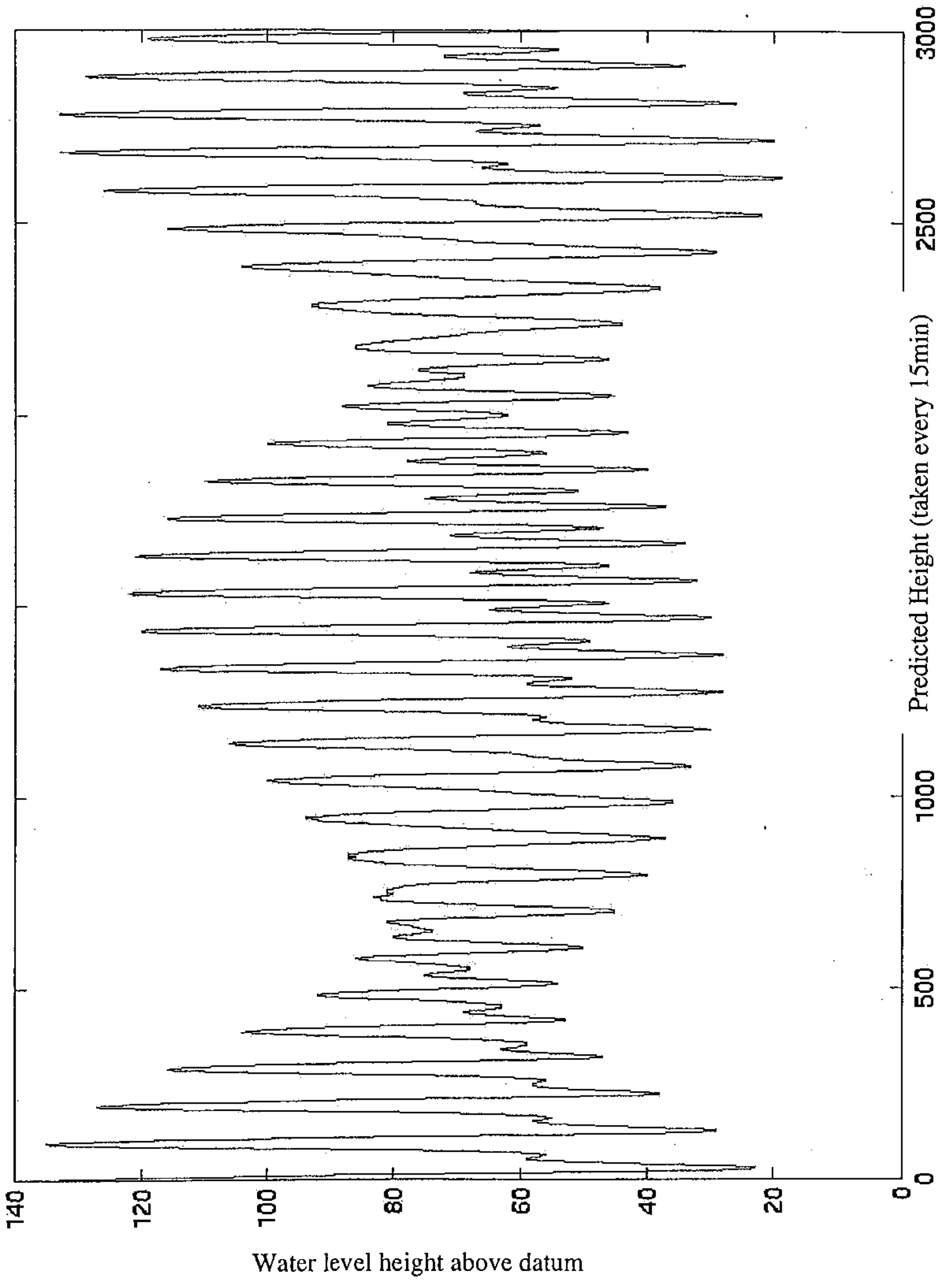
The form factor is interpreted as:

F = 0.25 to 1.5 Mixed, mainly semi diurnal tides.
F = 1.5 to 3.0 Mixed, mainly diurnal tides.

According to the form factor, the tidal character of Esperance is mixed but mainly semi-diurnal. This is inconsistent with the initial findings of the report. The reason for this inconsistency lies in the arbitrary definition of the form factor's transition from semi-diurnal to diurnal. The form factor boundary between diurnal and semi-diurnal is shown above to be 1.5. This value is not definitive. Because the Esperance tides have a form factor close to 1.5 only indicates that the tidal characteristics are highly mixed.

Figure 4.6 shows the typical tidal characteristics for the region. It is clear form this plot that the diurnal tides dominate. While the semi-diurnal peaks are clear (the smaller local peaks), they are of smaller magnitude than the diurnal peaks.

Figure 4.6: Predicted Tidal Data for January 1991



4.4 Non-tidal Changes

4.4.1 Continental Shelf Waves

The existence of long period waves with a period of about ten days is seen on the spectral plot (Figure 4.1). These most likely correspond to continental shelf waves that are formed by barotropic pressure changes at the air/sea interface far from the Esperance coast (Provis and Radok, 1979). Tropical cyclones generated along the north-west continental shelf off Western Australia are an example of such a pressure change. By looking at the residuals of five different tidal stations along the Western Australian coast, the presence of continental shelf waves can be identified. Data for stations from Geraldton to Esperance shown in Figure 4.7 indicate that variations of up to 0.5m are possible. Travel times from Dampier to Fremantle are of the order of 5-6 days (Fahrner & Pattiaratchi, 1994). However, long period waves can also be generated locally in the same manner. These may be out of phase with the continental shelf waves but will still have similar frequencies.

4.4.2 Storm Surge

A storm surge is a meteorological tide with an abnormal rise of seawater and is mainly induced by strong winds (wind set-up) and abrupt atmospheric change (inverse barometric effect) (Horikawa, 1978). In the Recherché region the effect of storm surge can be seen in the same residual plots that continental waves can be observed in (Figure 4.7). More recent data of Esperance shows that the effect of storm surge is significant in the region. Figure 4.8 shows a month of data for three tidal stations, indicating the propagation of continental waves down the coast as the effects of storm surge. Three peaks are highlighted in Figure 4.8, A, B, and C. Peak A is clearly in the middle of the 31st of January, peak B is in between the 31st of January and the 1st of February, and peak C is in the middle of the 1st of February. Clearly the sea-level anomaly is propagating around the coast.

Figure 4.7: Residual plots for five WA tidal stations 1991

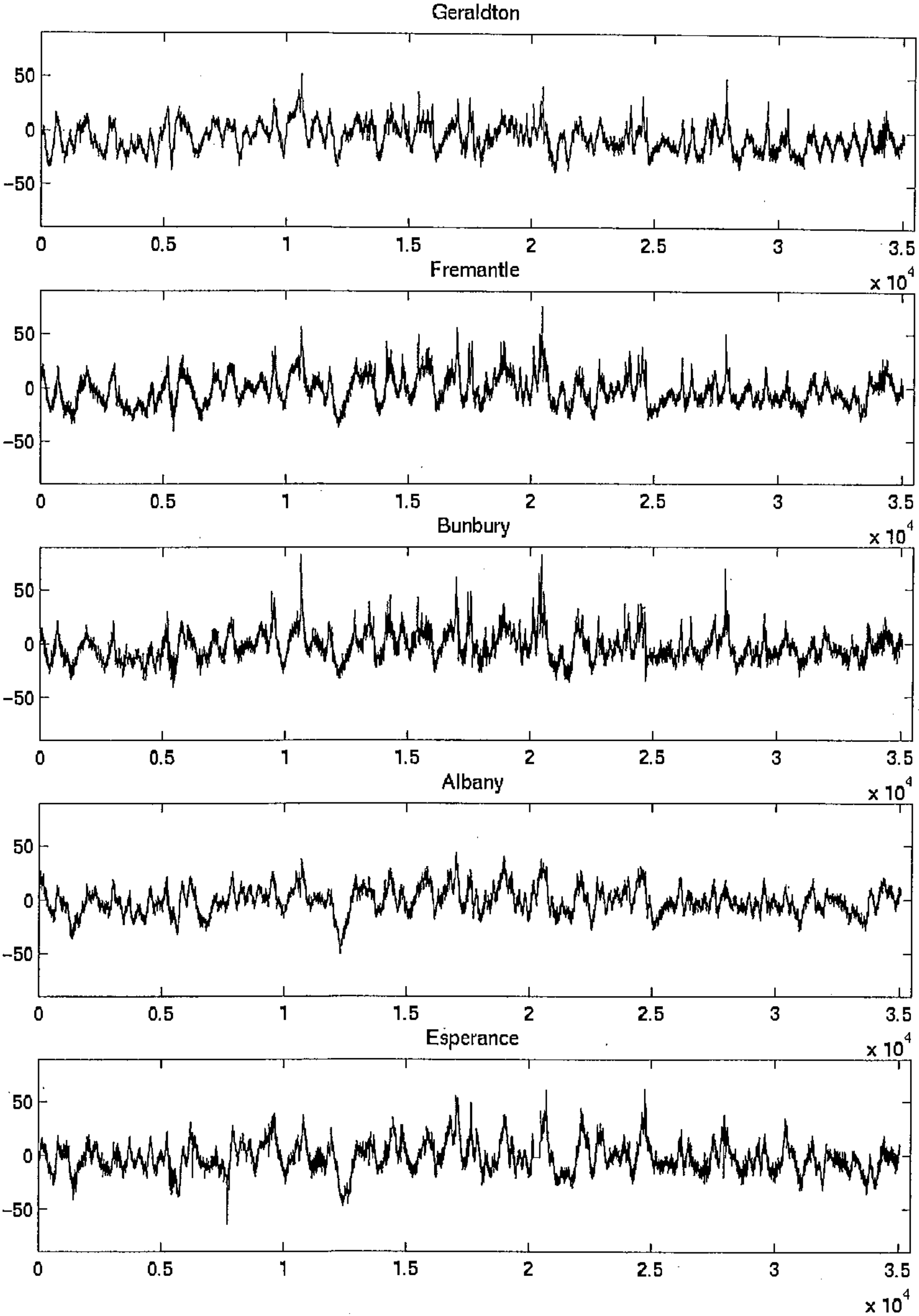
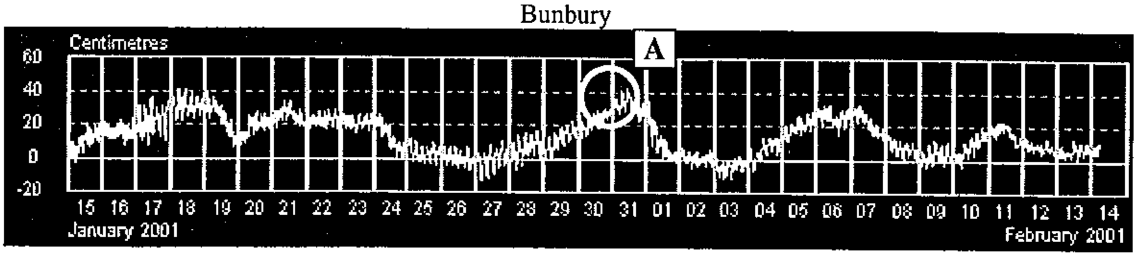
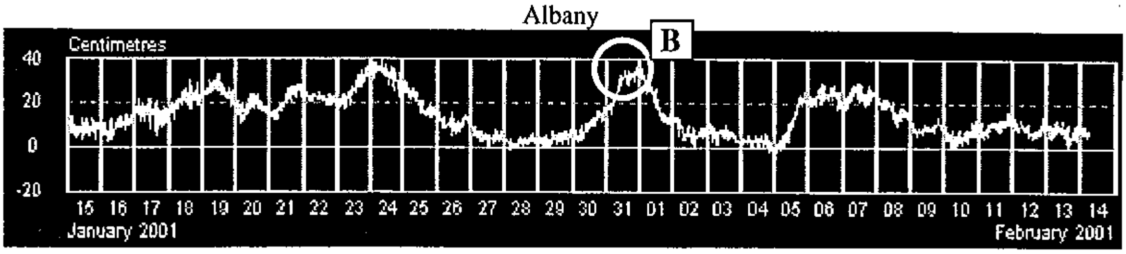


Figure 4.8: Residual Plots of three tidal stations showing the evidence of Storm Surge





4.5 Annual/inter-annual variations

4.5.1 Annual Variations

The variation in the monthly mean sea level at Esperance has amplitude of up to 30 cm during the year (Figure 4.9). It reaches a maximum during July, the middle of winter, and a minimum during the two summers (90/91 and 91/92) that are present in the data. This variation is consistent with the strong seasonality of the Leeuwin current. The Leeuwin flows all year but is significantly stronger in the winter months and weaker during summer. Hence the sea level reaches a maximum over May-June and a minimum during December-January (Pattiaratchi and Buchan, 1991).

4.5.2 Inter-annual Variations

The variations in the average monthly sea level at Esperance from 1966 to 1996 are shown in Figure 4.10. The first six or seven years of sampling were corrupted by a datum shift and have been disregarded. Between 1974 and 1996, the average sea level fluctuates about 130mm. These fluctuations have a period of approximately 5 years. The cause of the inter-annual fluctuations is due mainly to the varying strength of the Leeuwin current. The strength of the Leeuwin is in turn driven by more global forcing effects such as the El Nino/La Nina phenomenon.

Figure 4.9: Intra-annual Mean Monthly Sea Level 1991

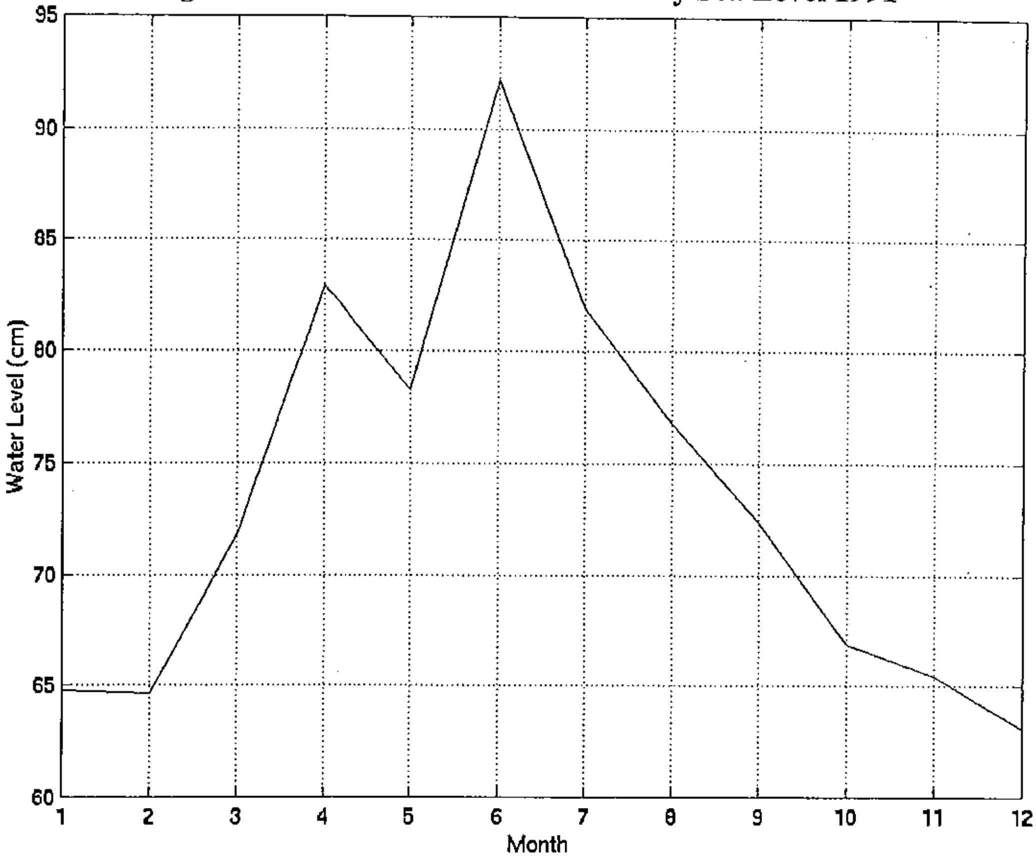
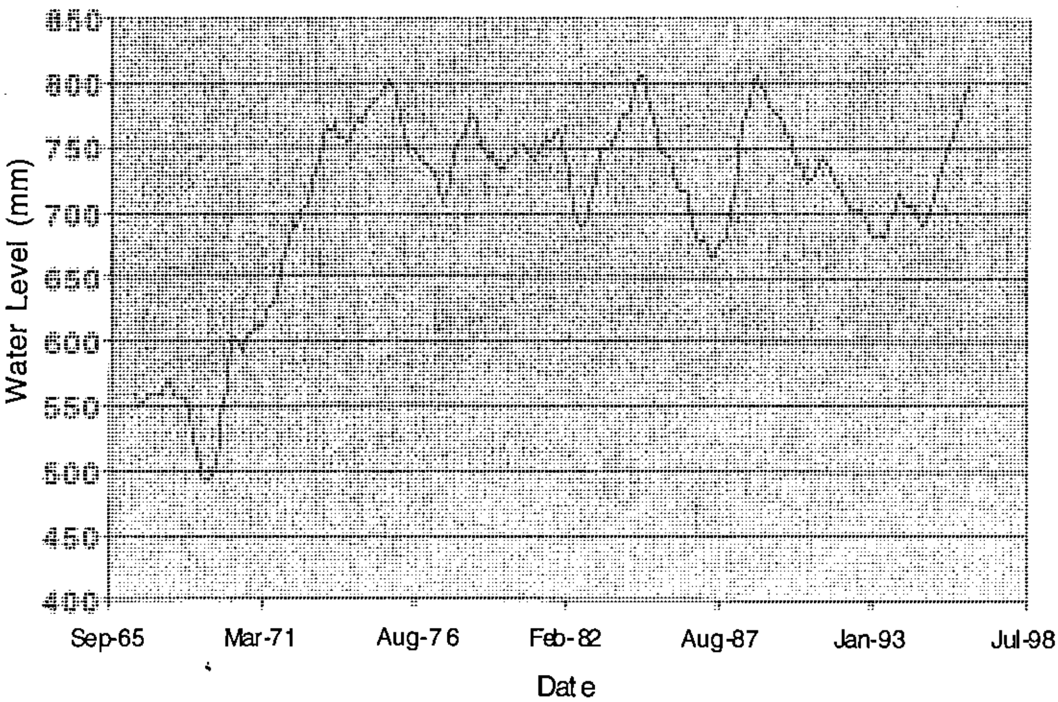


Figure 4.10: Inter-annual Mean Monthly Sea Level



5 PHYSICAL OCEANOGRAPHY

5.1 Seasonal changes in Salinity/Temperature

The seasonal variation in mean sea surface temperature (SST) and salinity are shown in Figures 5.1 and 5.2. These were approximated from data presented on the IRI/LDEO Climate Data Library web site. The surface temperature reaches a maximum during March of approximately 20.8 ^{0}C and a minimum during September of 15.8 ^{0}C whilst the salinity range from a maximum of 36.10 during the summer to 35.65 during the winter.

The observed changes in salinity and temperature may be described as follows: due to increased solar heating, the SST's increase from October reaching a maximum during March. In general, there is lag in the SST with the solar heating with maximum SST's occurring after the maxima in solar heating. Here, it is also possible that southeasterly winds during the summer results in upwelling which will counter the solar heating. Salinity is also higher during the summer months due to evaporation. During the winter months, the salinity decreases due to the presence of the Leeuwin Current (advection of low salinity water into the region) and the Leeuwin Current also prevents cooling of the shelf through advection of higher temperature water.

Some sea-surface temperature satellite imagery of the Southwest coast is shown in Figure 5.3, illustrating the effect of the Leeuwin Current on the temperature in the Recherché region. The data in Figure 5.1 shows that the water temperature varies seasonally so it is difficult to assess the effect that the warmer Leeuwin Current waters.

Figure 5.2: Intra-annual Salinity Variation

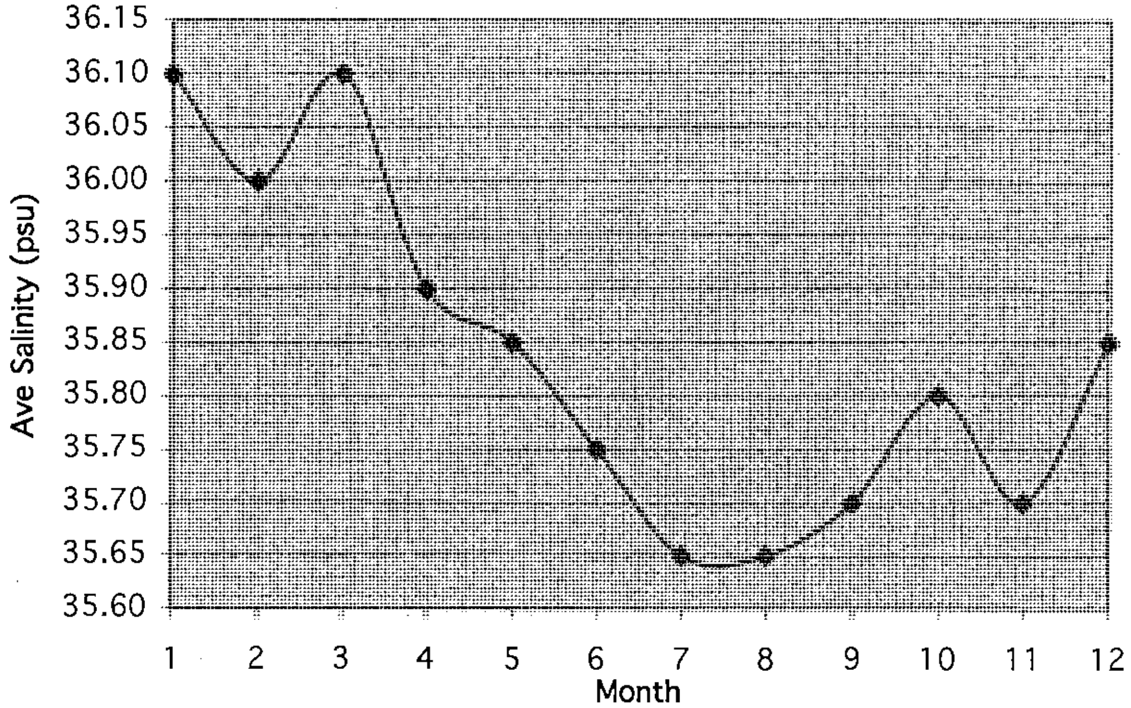
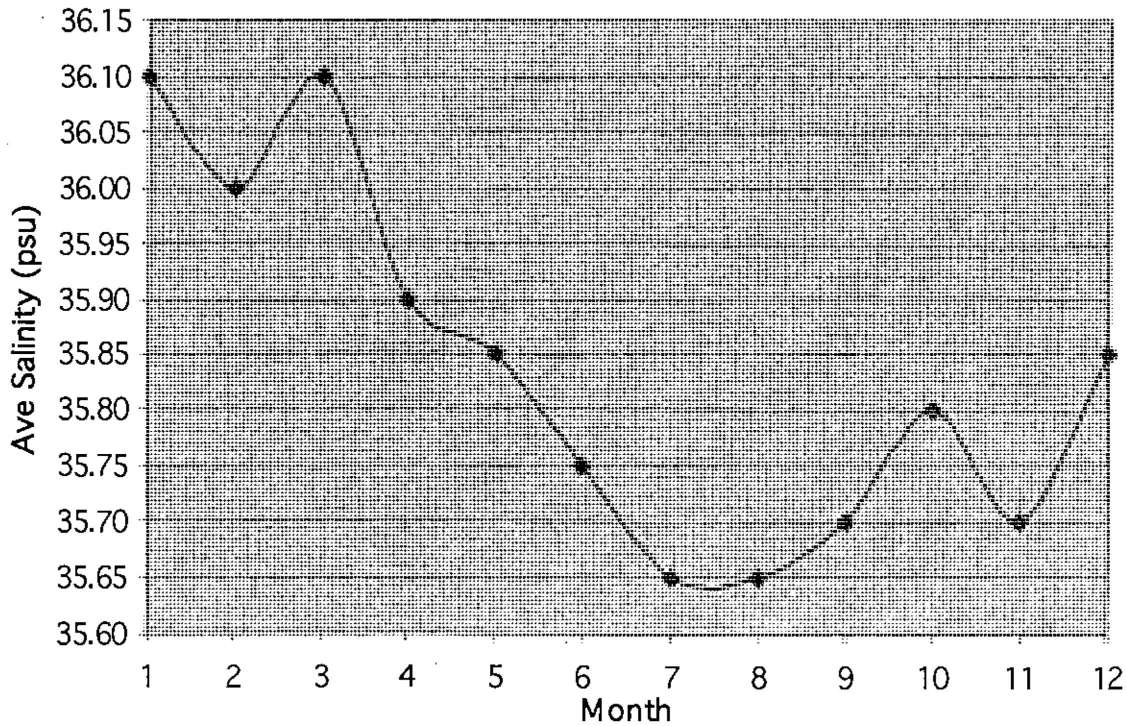


Figure 5.2: Intra-annual Salinity Variation



5.2 Chlorophyll / Phytoplankton Levels

Using satellite imagery of chlorophyll and phytoplankton levels in the near shore can be very useful in analysing the physical oceanography of a region. Subtle changes in ocean colour signify various types and quantities of marine chlorophyll and phytoplankton. The changes in chlorophyll and phytoplankton can therefore act as a tracer to help determine circulation patterns in the world's oceans.

The Recherché region can be viewed with two satellites, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and the Coastal Zone Colour Scanner (CZCS). Both satellites are capable of resolution images but often have their views restricted by cloud cover. A selection of relatively good images for one particular year is displayed in Figures 5.4(SeaWiFS) and 5.5(CZCS).

The images show a seasonally varying band of higher concentration chlorophyll and phytoplankton close to shore. The concentration levels and the width of this band are shown in Figures 5.6 and 5.7. While the SeaWiFS curve is smoother than the CZCS satellite, they both indicate annual peaks of concentration and bandwidth around April and yearly lows around November. These patterns are similar to those observed off the Western coast of WA and is attributed the changes in nutrients and light climate. It is highly likely that in these clear oceanic waters a sub-surface chlorophyll maximum to be present thus the actual concentrations of chlorophyll through the water column is higher than those measured by the satellites. This helps to explain the chlorophyll high in April, which may be due to the upwelling favourably conditions created with the predominant easterly and southeasterly winds over summer.

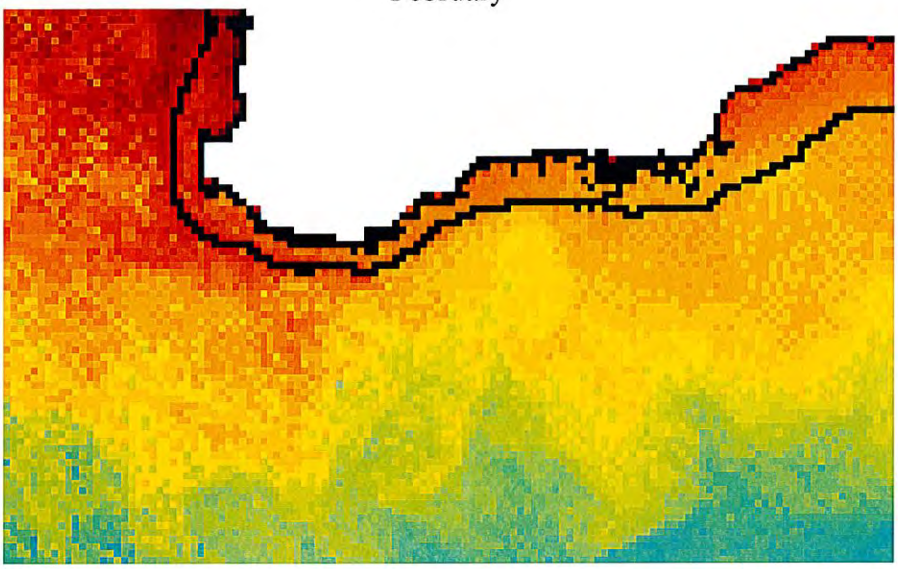
5.3 Nutrient Levels

Figure 5.9 has point marked X (-34 36', 122 00') on it. Nutrient levels were taken at this location during the CSIRO Franklin cruise 9507 and are shown below. Further analysis of the nutrient levels in the region will be conducted in the Honours study.

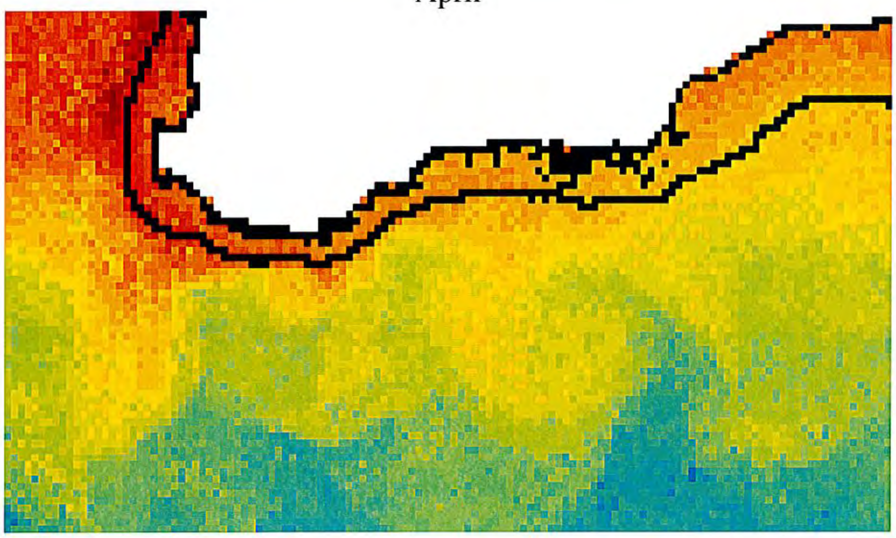
Point X	mmol/L
Phosphate	0.110
Nitrate	0.30
Silicate	2.0

Figure 5.3: Mean Sea Surface Temperatures for Southwest Australia

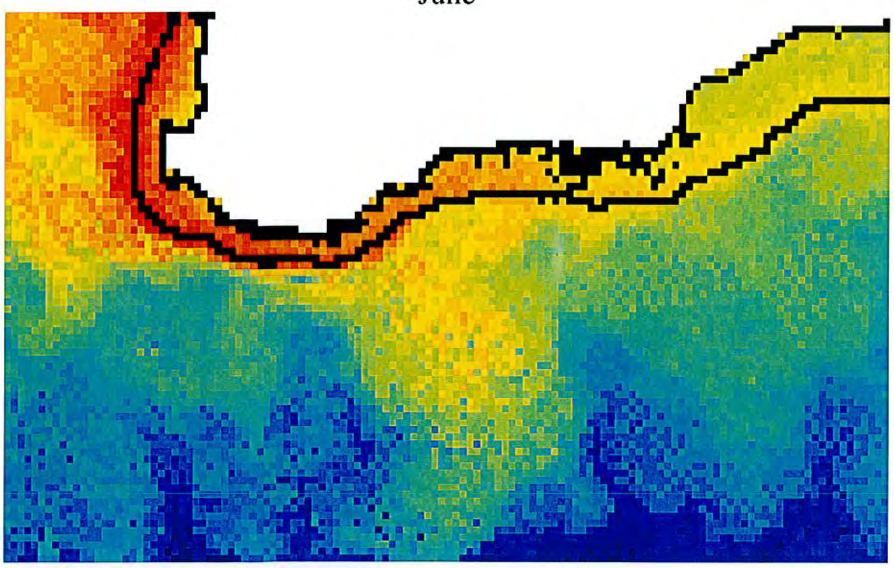
February



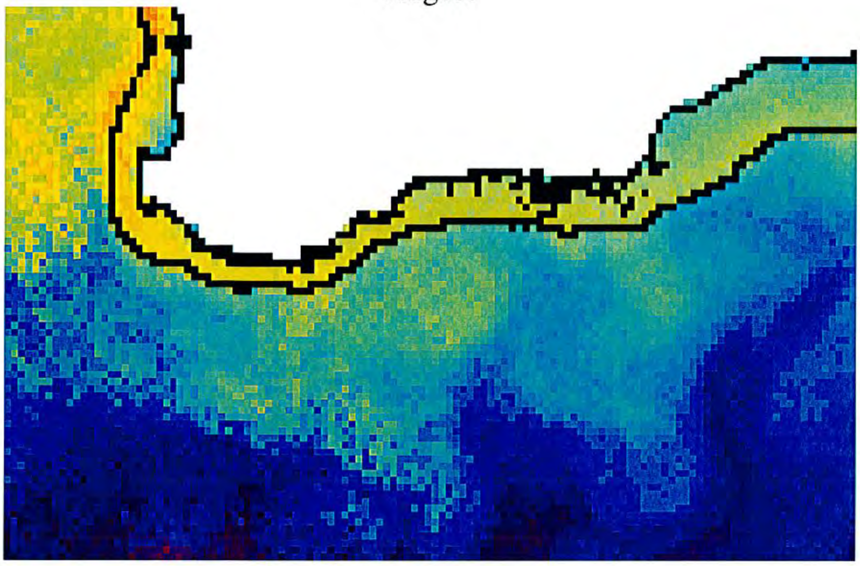
April



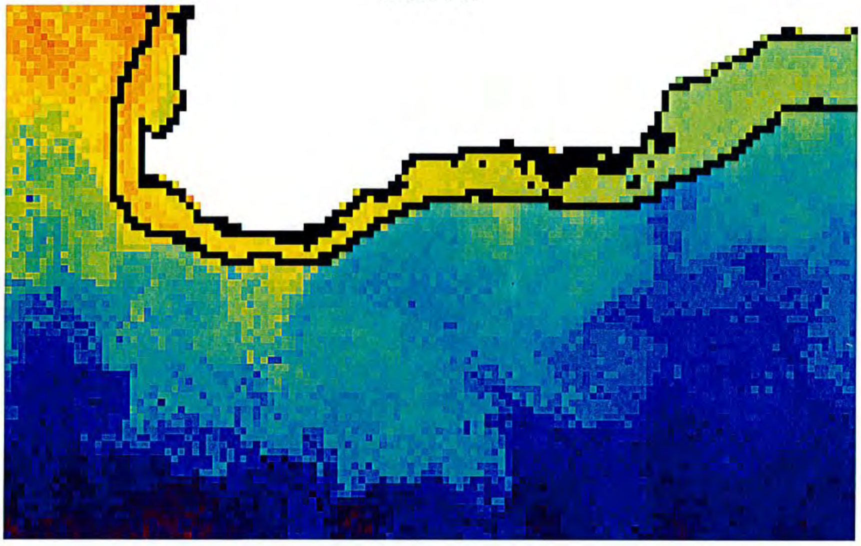
June



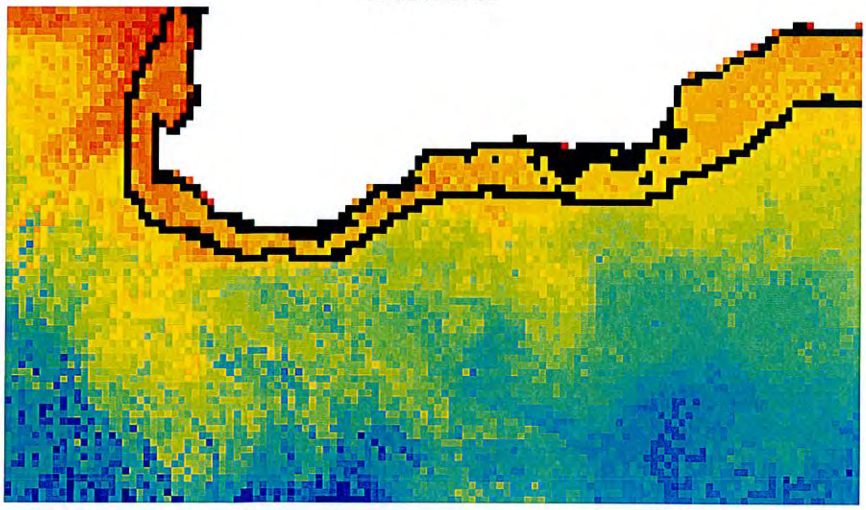
August



October



December



5.4 Circulation patterns

The satellite imagery of the Recherché (Figures 5.4 and 5.5) indicates that the Leeuwin current has a large influence on the circulation (and therefore physical characteristics) of the region. As mentioned above, the Leeuwin's seasonally varying strength has an influence on sea levels. It also causes a decrease in salinity during winter. The effect on chlorophyll and phytoplankton has also been mentioned, showing another close relationship with the Current. The effect of the Leeuwin on temperature was unclear from the data. However, the sea-surface temperature images do show that the Leeuwin imports warmer waters.

While the Leeuwin Current is visible in the images, during the summer months there is some evidence of a counter-current that acts closer to shore. The satellite images are not very clear on this issue so some further examination is required. Whether this current acts in a similar way as the Capes Current (Pearce and Pattiaratchi, 1999) remains to be seen. The prevailing winds certainly indicate that a similar forcing to the Capes Current is present. The Capes Current is set up and is driven by persistent southerly winds (i.e. blowing parallel to the coast). During summer, the Recherché has predominant winds from the east and southeast, indicating that a similar along-shore current could be set up.

Figure 5.8 shows the possible summer counter-current acting during summer, while the Leeuwin dominates during winter (Figure 5.9).

Figure 5.4: Satellite Images of the Recherché from the Coastal Zone Colour Scanner

Figure A: 1/5/80
Mid/End-Autumn

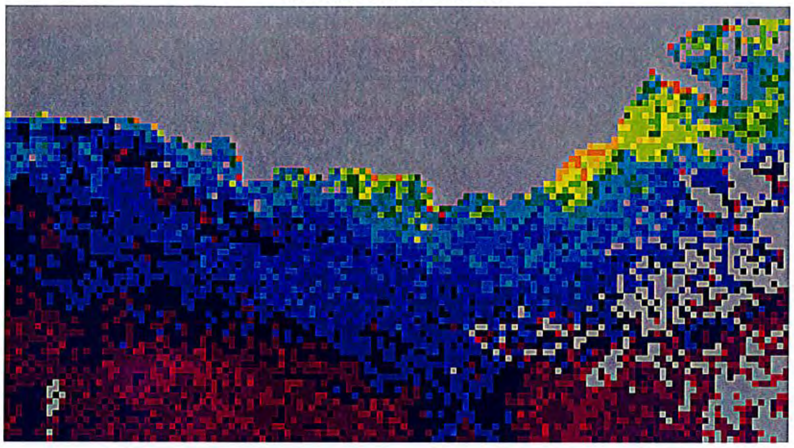


Figure B: 12/9/80
Start Spring

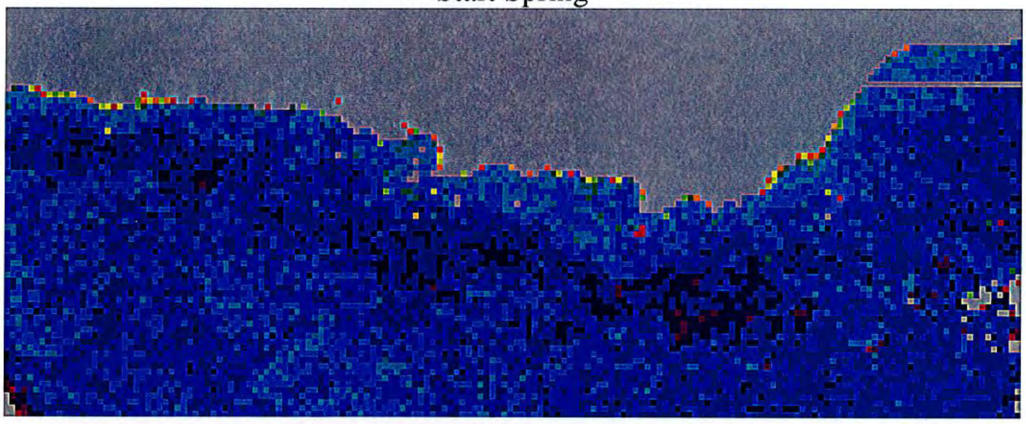


Figure C: 3/10/80
Mid-Spring

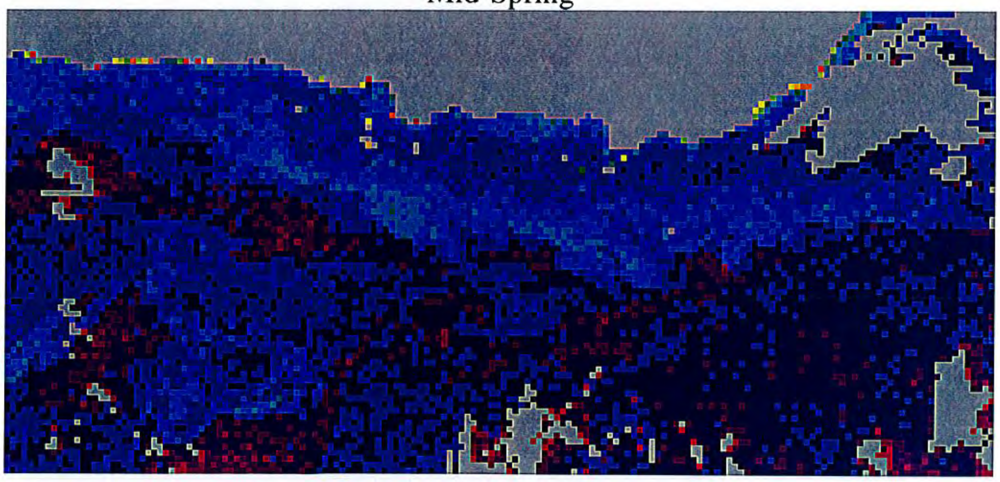


Figure D: 20/10/80
Mid-Spring

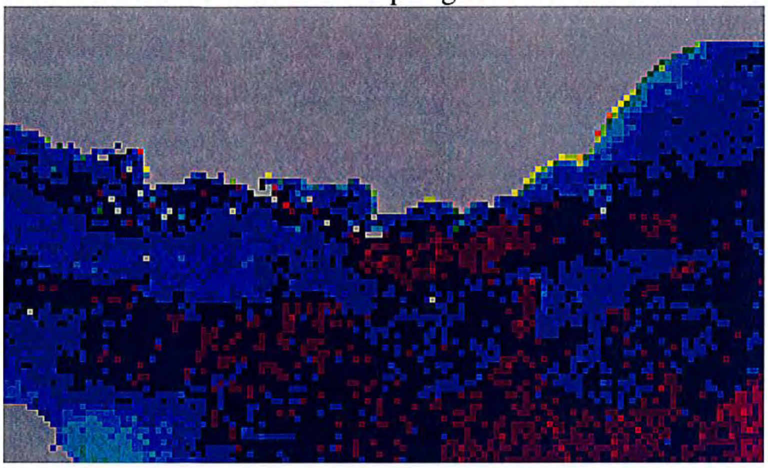


Figure E: 1/11/80
End-Spring

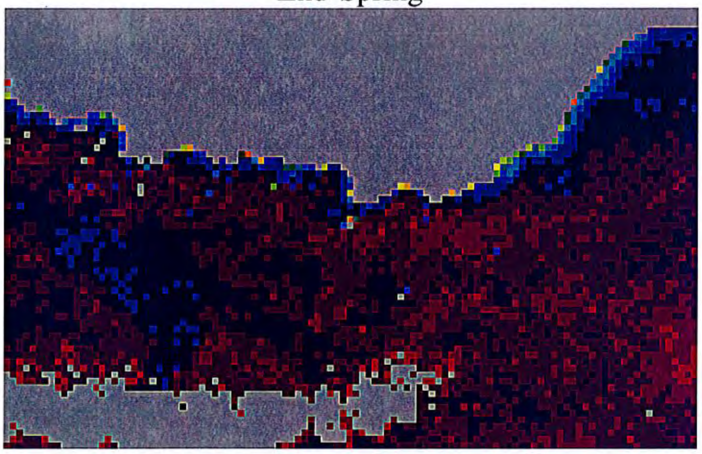


Figure F: 11/1/81
Mid-Summer

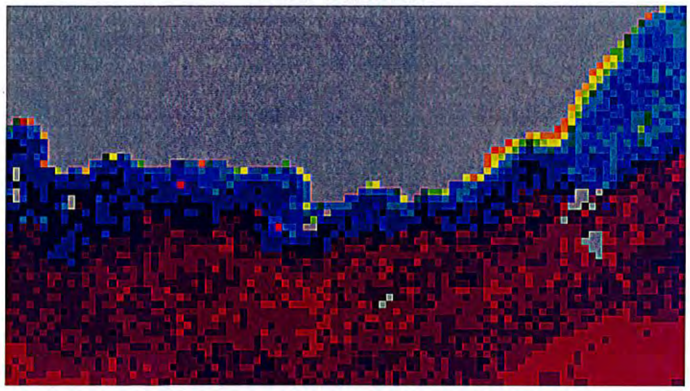


Figure G: 3/3/81
End-Summer/Start-Autumn

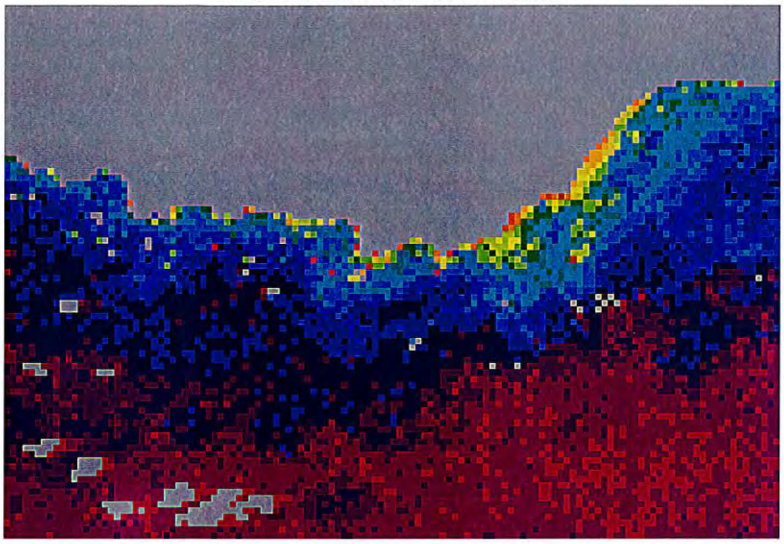


Figure H: 13/3/81
Start-Autumn

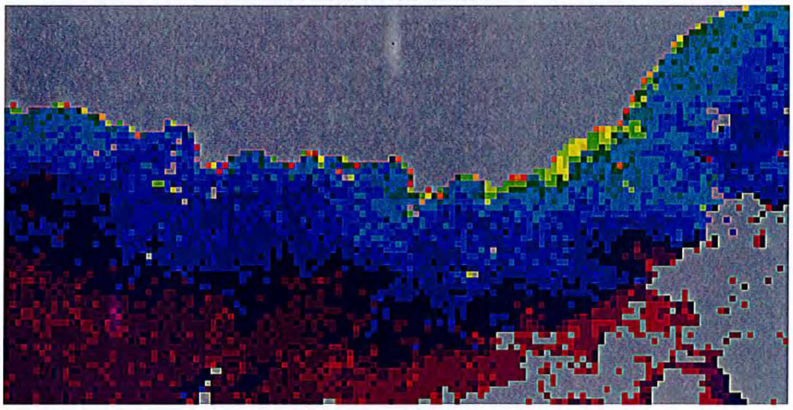


Figure I: 20/4/81
Mid-Autumn

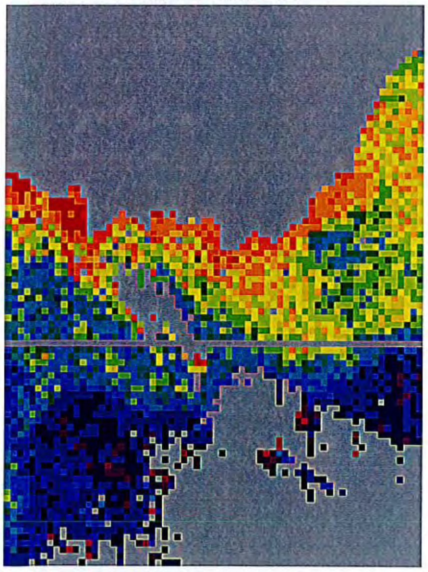


Figure J: 10/5/81
End-Autumn

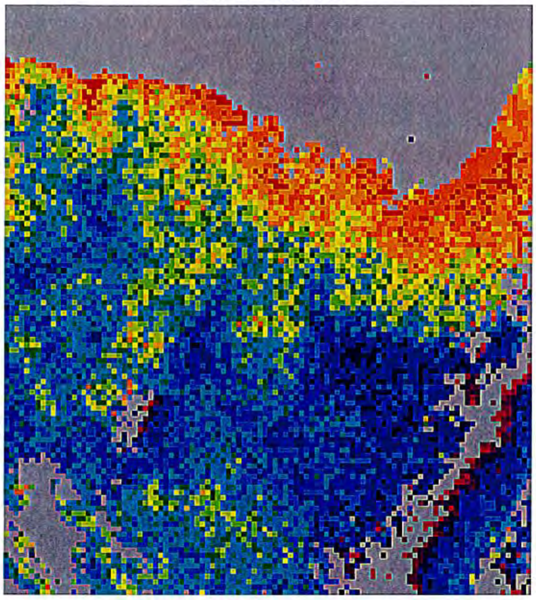


Figure K: 4/1//82
Mid-Summer

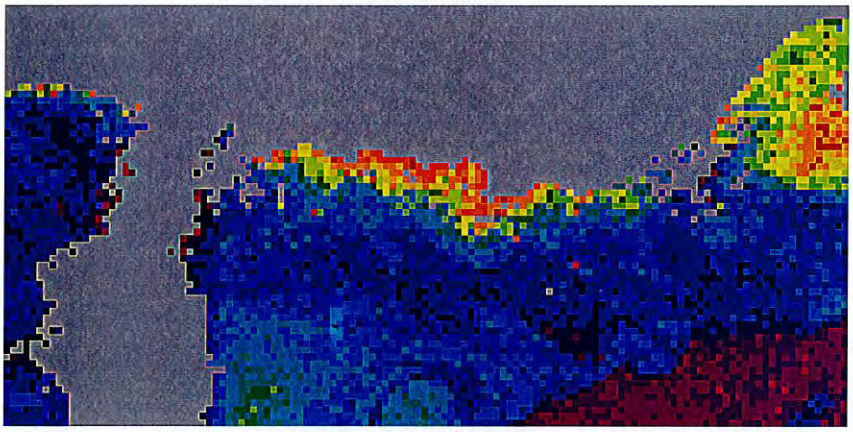


Figure L: 29/3/82
Start/Mid-Autumn

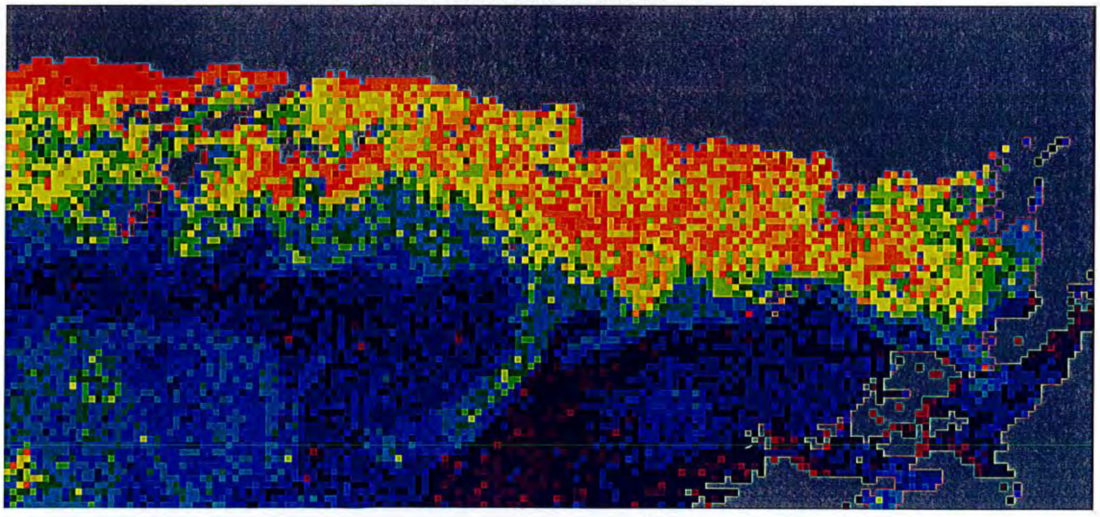
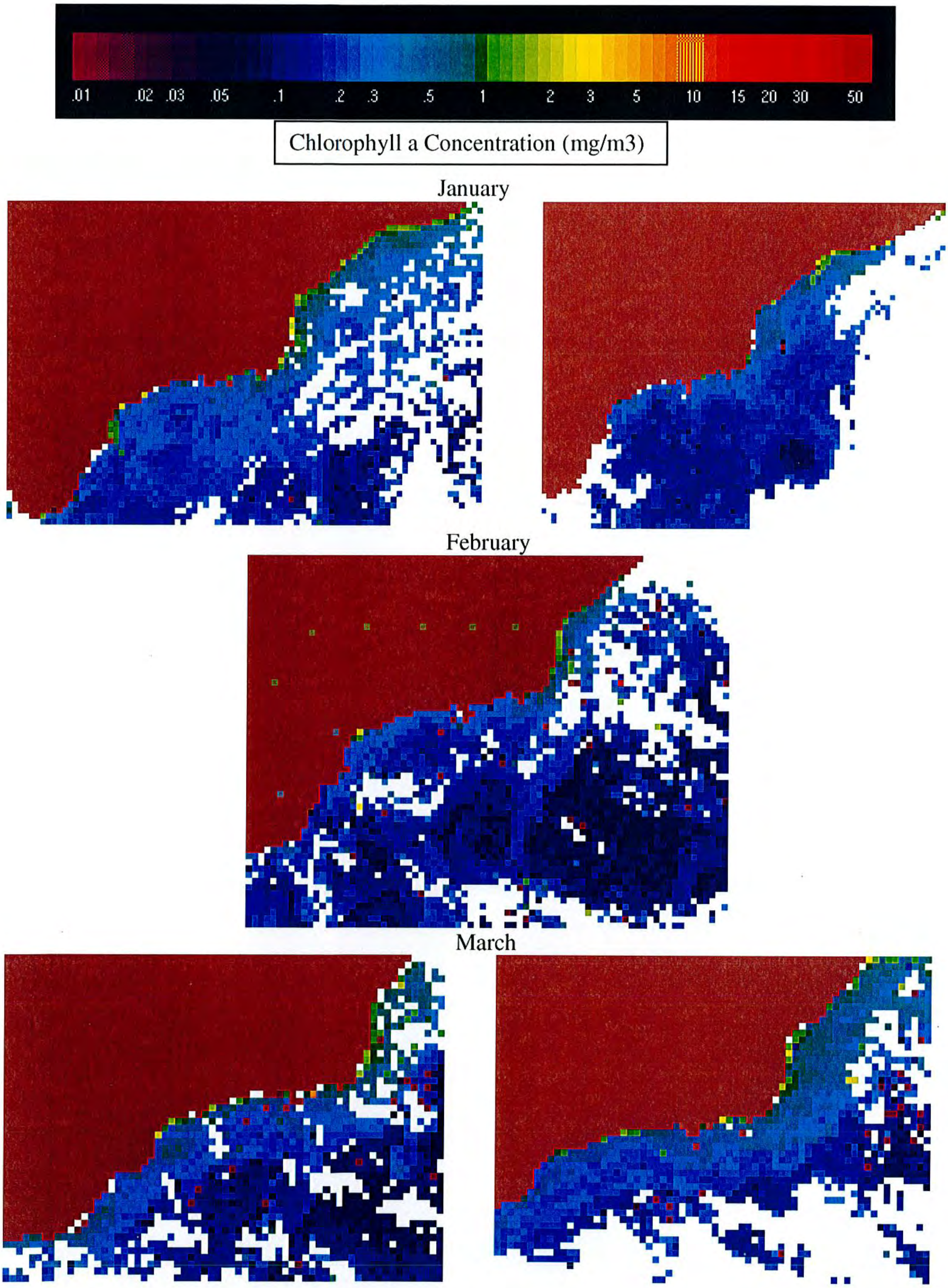
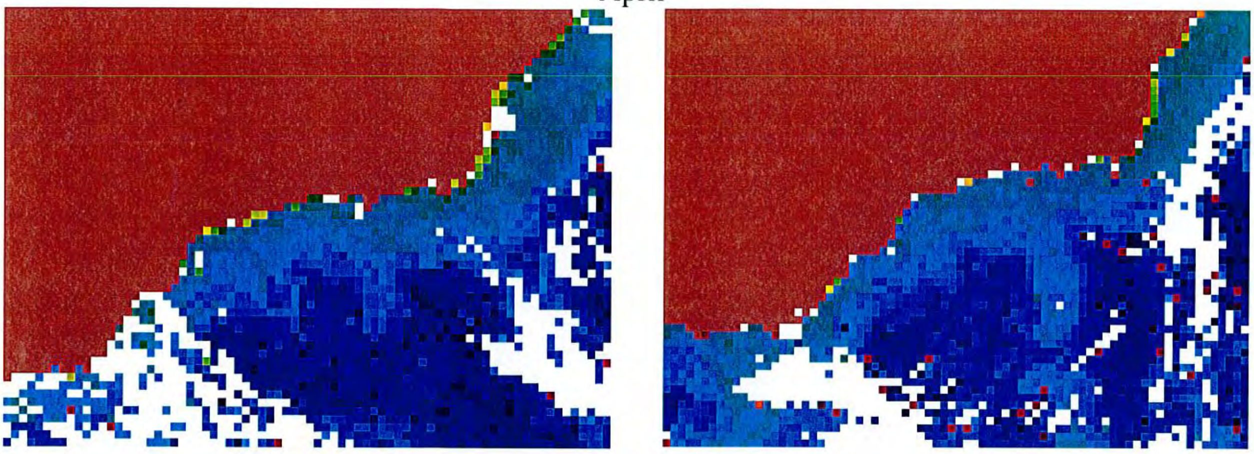


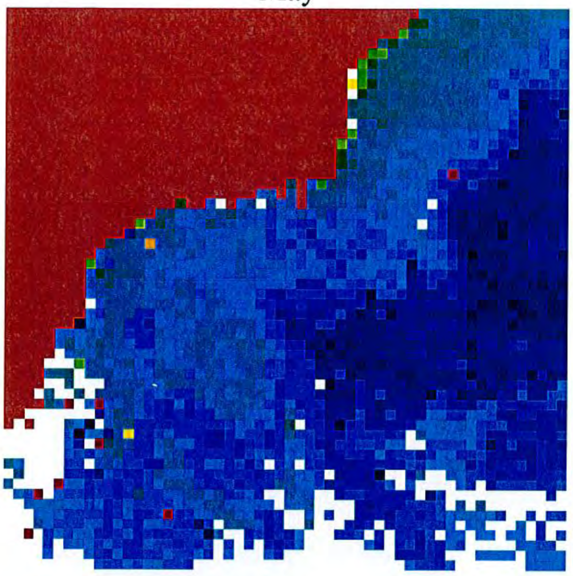
Figure 5.5: SeaWiFS Satellite Images Year 2000



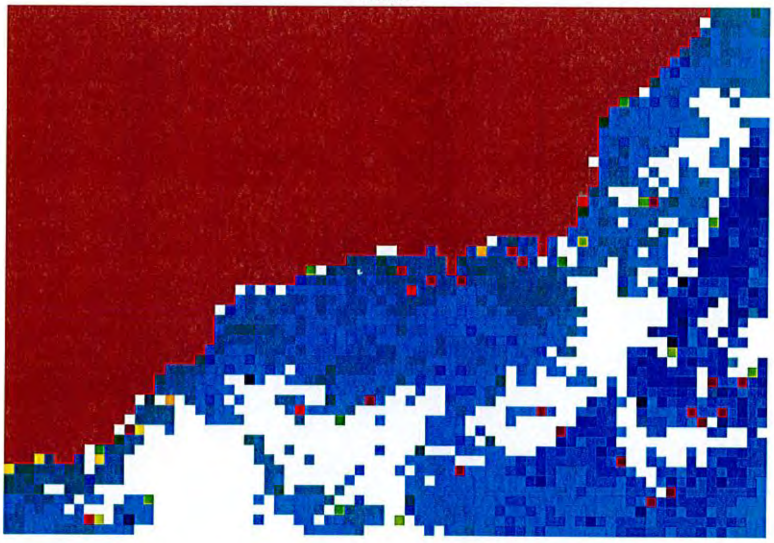
April



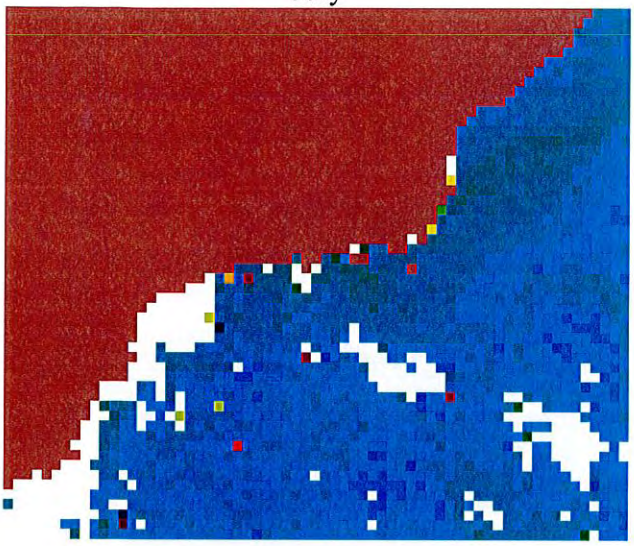
May



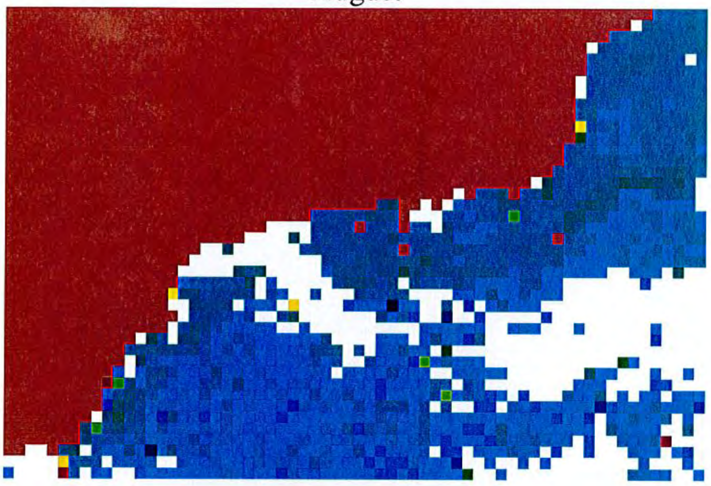
June



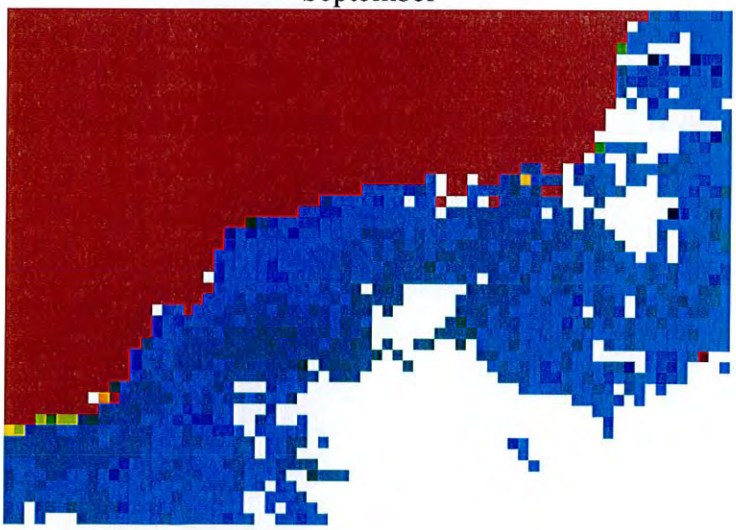
July



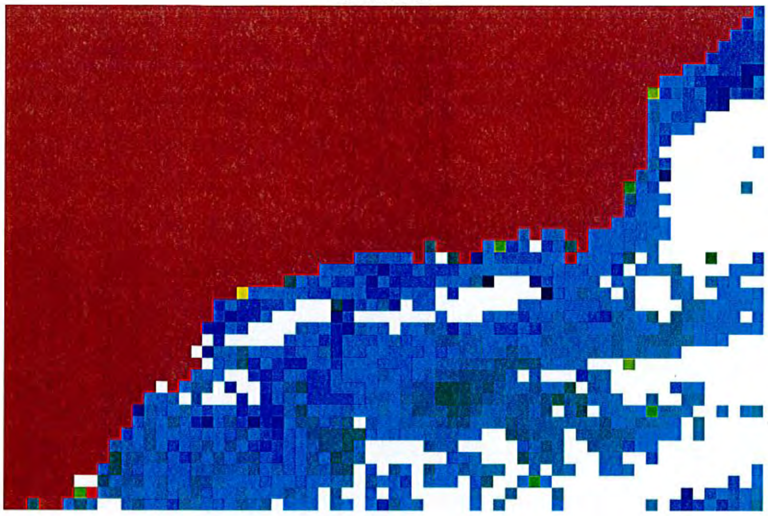
August



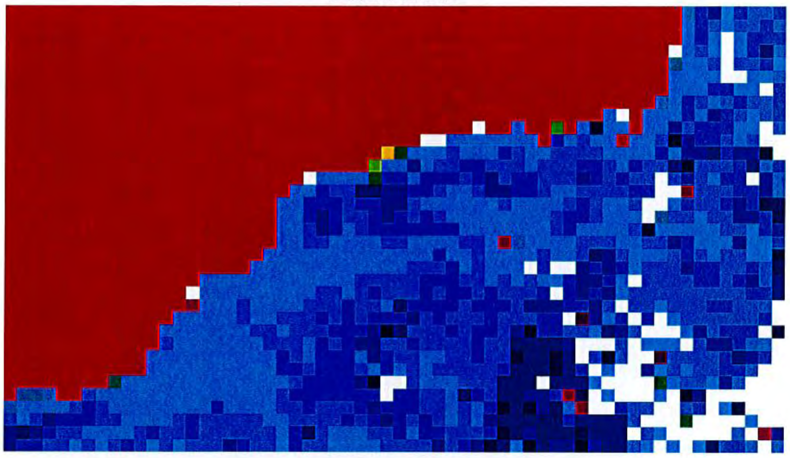
September



October



November



December

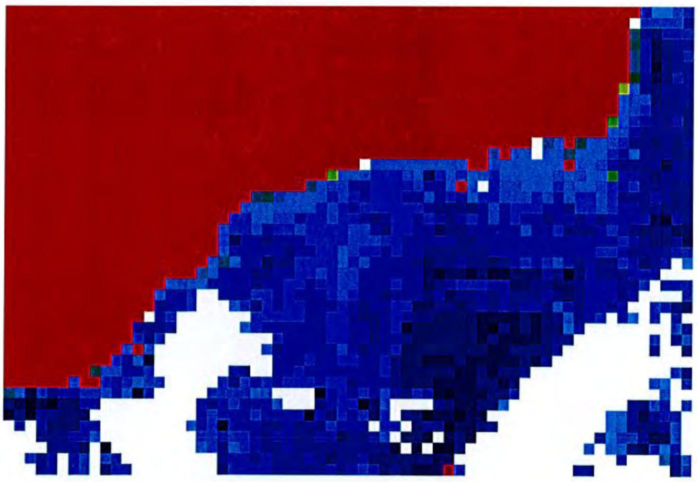
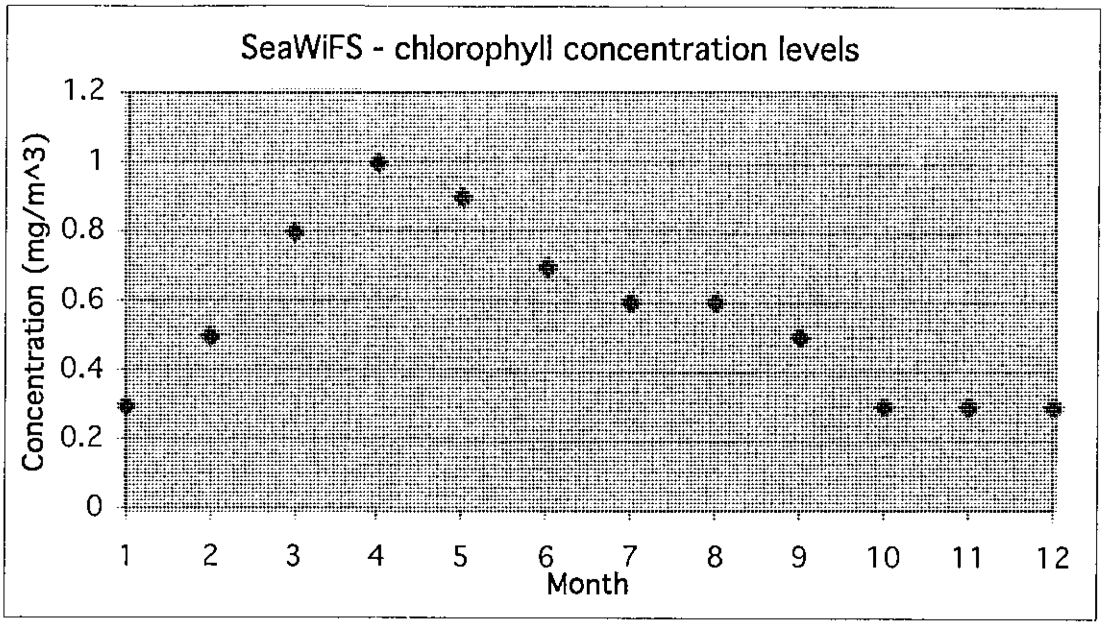


Figure 5.6: Chlorophyll concentration levels and distance offshore



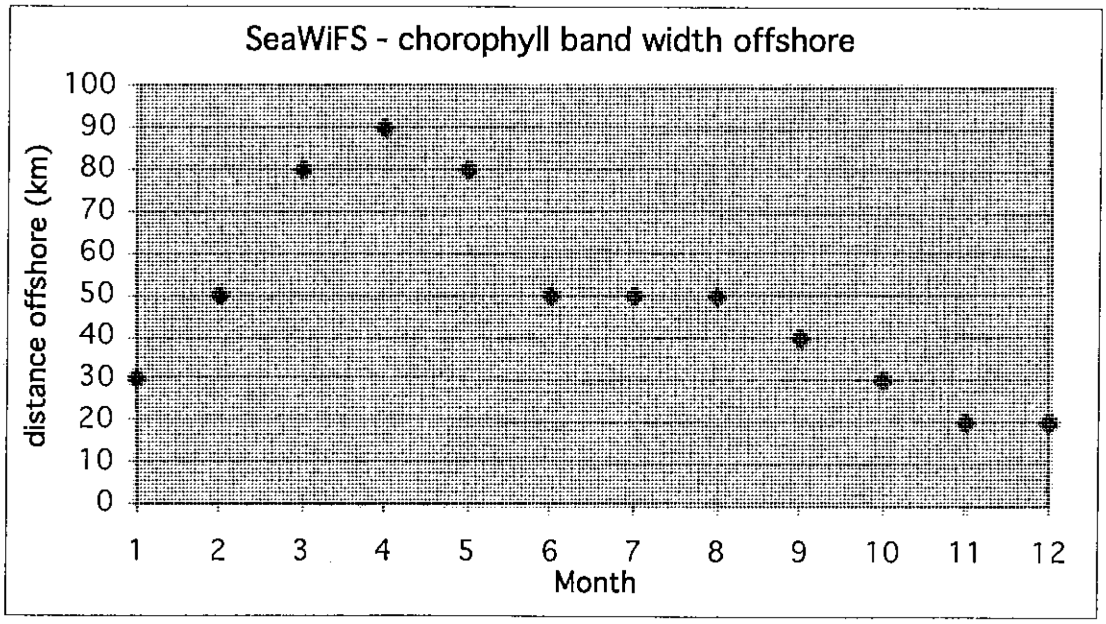
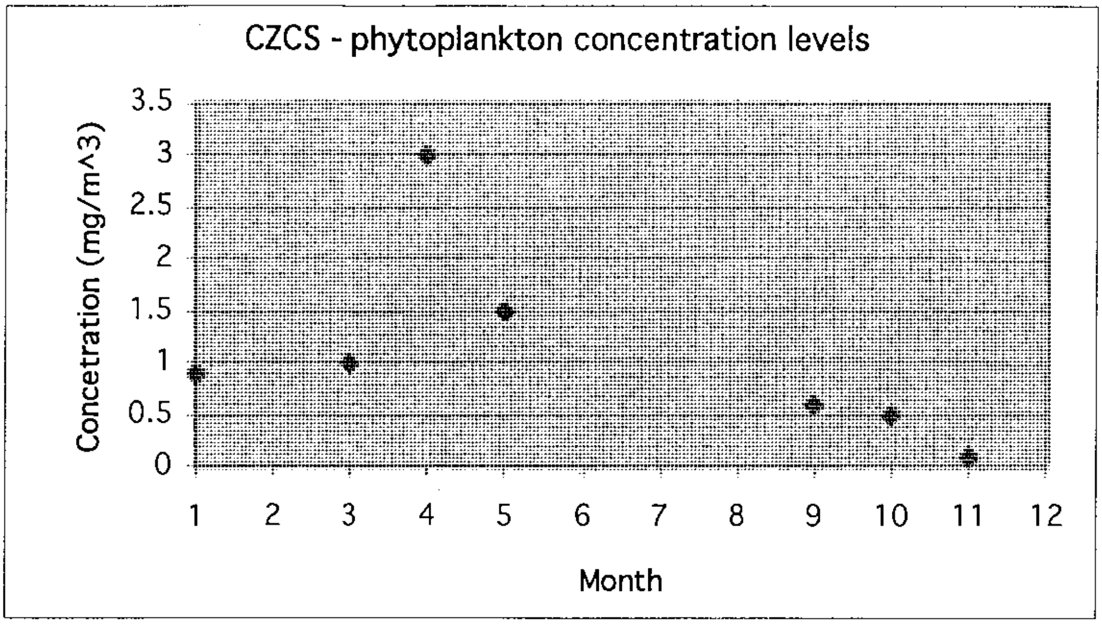


Figure 5.7: Phytoplankton concentration levels and distance offshore



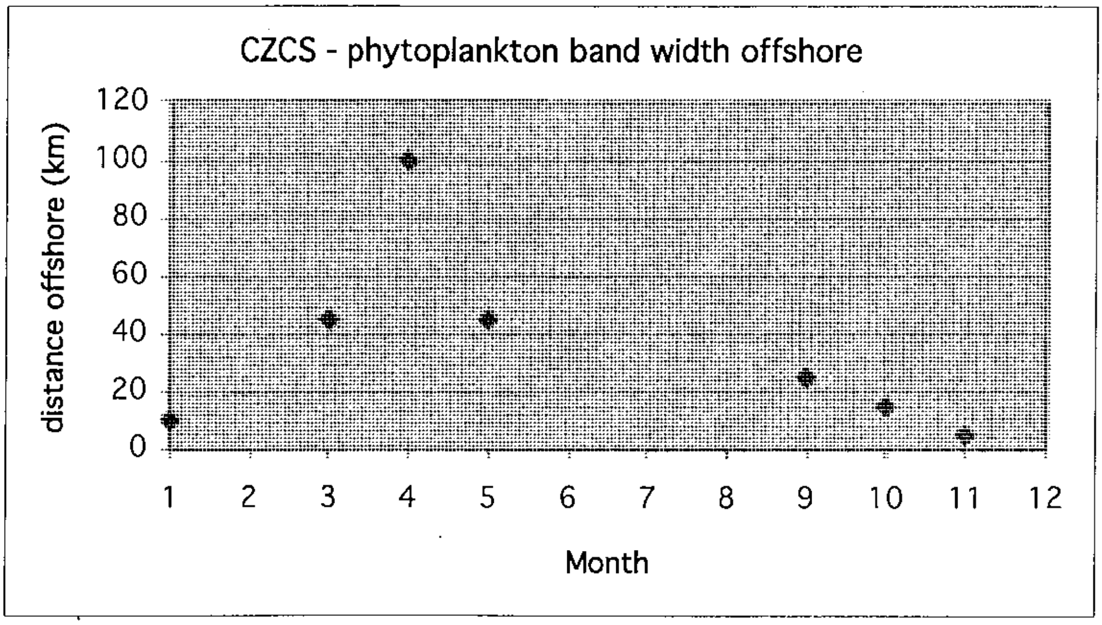


Figure 5.8: The bathymetry of the Recherché and the major summer currents of the region

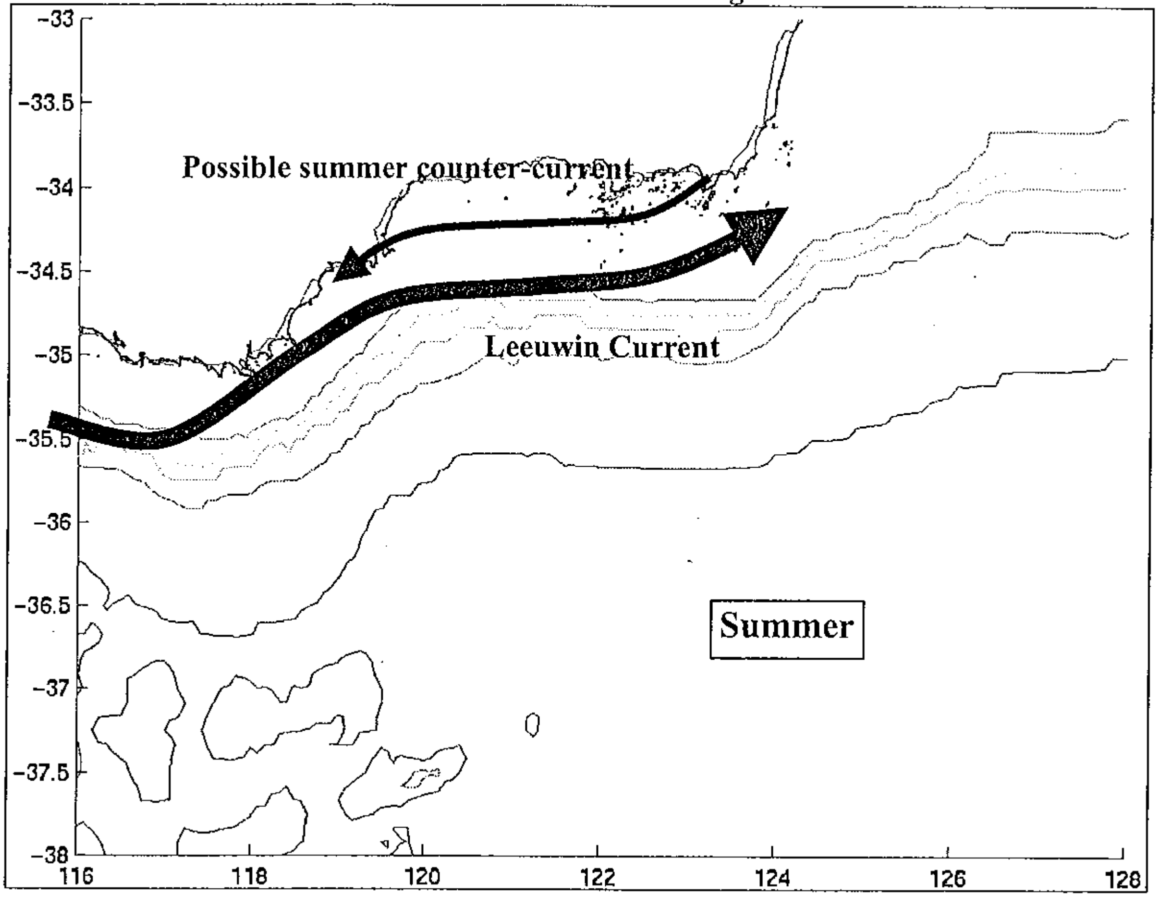
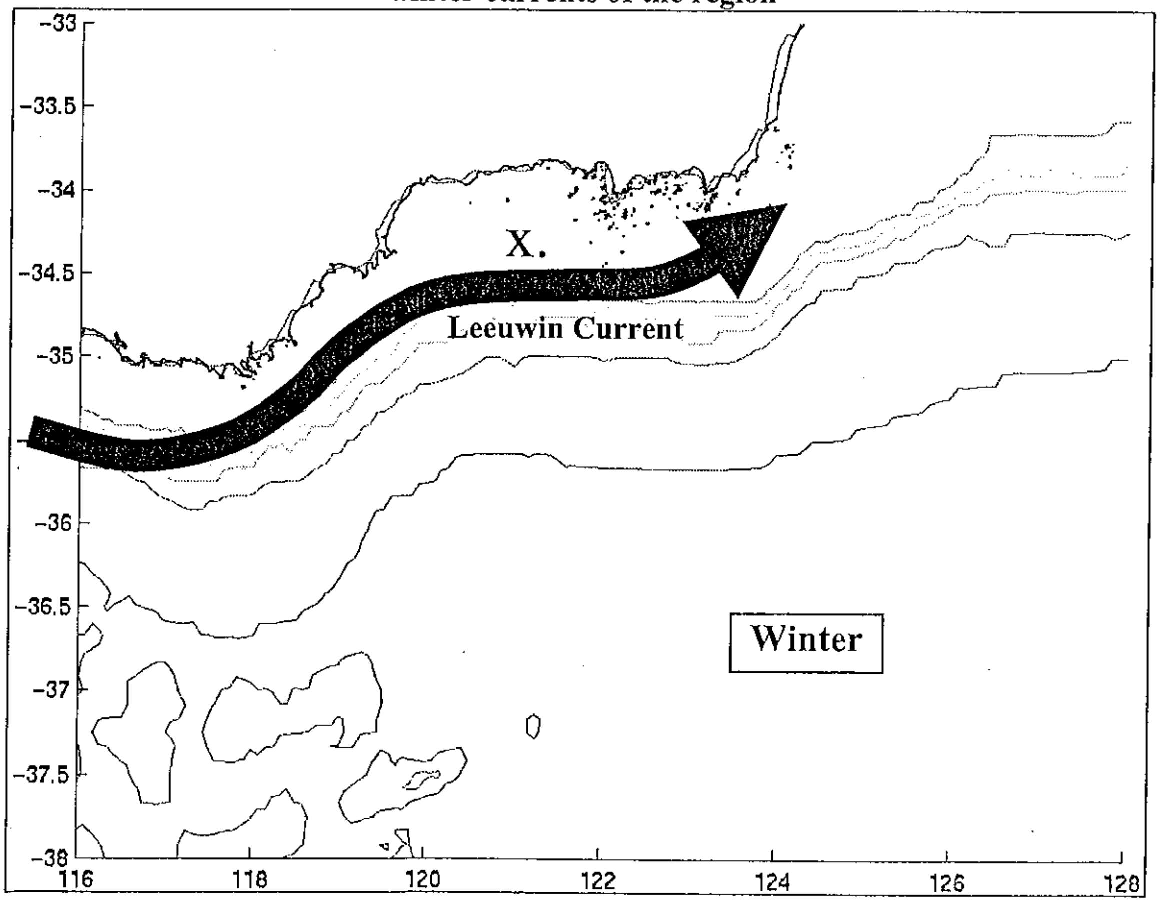


Figure 5.9: The bathymetry of the Recherché and the major winter currents of the region



6 CONCLUSIONS

The Recherché Archipelago region has predominately northwest winds during the winter, and winds from the east and southeast during the summer. The summer winds create upwelling favourable conditions at a time when the Leeuwin Current is at its weakest. The presence of these upwelling favourable summer conditions has been raised as a possible explanation for relatively high levels of chlorophyll (over twice the background) revealed by the satellite images. The summer winds may also contribute to the formation of a nearshore wind-driven counter current similar to the Capes Current. Hopefully further study of the hydrodynamics of this region will show the existence or otherwise of this counter current.

The rainfall and air temperature patterns for the region are typical for a temperate climate, experiencing relatively hot, dry summers and cool, wet winters.

The Archipelago experiences minimal freshwater inflow, with the only major source being Stokes Inlet. However due to high levels of evaporation, the salinity of the Inlet is rarely less than 35ppt during the year.

The wave climate of the Recherché region has been analysed to show that 50% of waves are larger than 1.45m but only 20% are larger than 2m. The highest waves occur during autumn and spring but mean wave height is larger during winter.

Storm surge can also cause significant changes in water levels along the Western Australian coast. Variations of up to 50cm have been shown propagating down the coast and around into the Recherché region.

The strong winter Leeuwin Current greatly influences the surface water temperature and salinity in the Recherché. The temperature is raised higher than it would otherwise be without the Leeuwin in winter, while the salinity decreases due to the importation of the lower salinity waters of the Leeuwin current.

Hopefully this report provides sufficient background to support planning for further investigations into the oceanography of the Recherché. This report and any other further studies that it may contribute to, assist in planning for the establishment of a marine conservation reserve in the area.

7 REFERENCES

Anon. (1997) Great Australian Bight Marine Park Draft Management Plan, Part B-Resource Information, Natural Resources Group, Department of Environmental and Natural Resources

CALM (1994) A Representative Marine Reserve System for Western Australia, Report of the Marine Parks and Reserves Selection Working Group, Department of Conservation and Land Management, Perth, Western Australia.

D'Adamo, N (1997) A Strategic Plan for Oceanographic Information Requirements in Marine Reserve Implementation, Management, Policy and Co-ordination in Western Australia, Marine Conservation Branch, Department of Conservation and Land Management, Report MCB-01/97

D'Adamo, N (1997) Oceanographic Requirements for the Establishment and Management of Marine Reserves in Western Australia, Marine Conservation Branch, Department of Conservation and Land Management, Report MCB-02/97

D'Adamo, N and Mamaev, A (1999). An overview of the oceanography of the proposed Geographe Bay-Capes-Hardy Inlet marine conservation reserve, Literature Review MRI/CF/GBC-28/1999, Marine Conservation Branch, Department of Conservation and Land Management, Fremantle, Western Australia

Fahner, C. and Pattiaratchi, C. (1994) The physical oceanography of Geographe Bay, Western Australia, Centre for Water Research, University of Western Australia, Reference WP 898 CF

Green, T (1998) Hydrodynamics Study of Van Diemen Gulf, Centre for Water Research, University of Western Australia, Perth, Western Australia

Herzfeld, M (1997) The annual cycle of sea surface temperatures in the Great Australian Bight, Centre for Water Research, University of Western Australia, Perth, Western Australia

Kantha, L Clayson, C (2000) Numerical Models of Oceans and Oceanic Processes, Academic Press, London

Knauss, J (1978) Introduction to Physical Oceanography, Prentice-Hall Inc., Englewood Cliffs, New Jersey

Mellor, G (1996) Introduction to Physical Oceanography, Princeton University, Princeton, New Jersey

Pattiaratchi, C. and Buchan, S (1991) Implications of long-term climate change for the Leeuwin Current. J. Roy. Soc. WA 74

Pattiaratchi, C. (1998) Assessment and Modelling of Oceanographic Conditions at Four Potential Sites for Tuna Fattening in Esperence Centre for Water Research, University of Western Australia, Reference WP 1391 CP

Pearce A. and Pattiaratchi C.B. 1999. The Capes Current: a summer counter-current flowing past Cape Leeuwin and Cape Naturaliste, Western Australia. Continental Shelf Research, 19, 401-420.

Tapper, N and Hurry, L (1993) Australia's Weather Patterns, An Introductory Guide, Dellasta Pty Ltd, Mount Waverley, Victoria

WA Government (undated) New Horizons, The way ahead in marine conservation and management, Prepared for the Western Australia Government by the Department of Conservation and Land Management, Perth, Western Australia

Wright, L (1995) Morphodynamics of Intercontinental Shelves, CRC Press, Boca Raton, Florida