

## Acknowledgements

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*Cover Photo: 3-day mean remote sea surface temperature image of the Bay of Plenty for the 5 November 2003 (data provided by NIWA).*



## Executive Summary

A study of the Bay of Plenty's coastal shelf waters was undertaken to collect data for the support of modelling and estimating the sustainability and carrying capacity of aquaculture. The study included physical and chemical analysis of the waters, quantification of phytoplankton communities, current measurements and temperature profiling of the water column and the use of remote sensing to provide a synopsis of seasonal and spatial patterns of sea surface temperature and chlorophyll-a concentrations. This report presents results gained from development and processing of remote sensing data.

10 years of NOAA satellite sea surface temperature data from 1993 – 2004 was used to produce climatological monthly means and standard deviations for the entire Bay of Plenty. Results provide excellent data on the seasonal and spatial patterns which includes the effect of the East Auckland current in the off-shore waters and up-welling of cooler water along the inshore coastal margins.

7 years of SeaWiFS satellite data from 1997 – 2004 were used to produce climatological monthly means and standard deviation estimates of chlorophyll-a concentrations for the entire Bay of Plenty. Both Case-1 (offshore waters) and case-2 (inshore waters) algorithms were used to produce the estimates. The case-2 algorithm was developed using an optical calibration survey in the Bay of Plenty (contracted to NIWA). Case-2 algorithms attempt to adjust for the presences of high levels of suspended sediments and coloured organic matter in inshore waters which result in over estimates when using case-1 algorithms. Climatological monthly means of chlorophyll-a were lower for case-2 values compared to case-1. Results show clear seasonal and spatial patterns with highest chlorophyll-a concentrations occurring in late winter and spring with peak values inshore near the coast.

Comparison of 3-day composite estimates of chlorophyll-a concentrations with sea surface temperature (both 1 km<sup>2</sup> resolution) clearly shows the dynamic links between the hydrodynamics of the bay and primary productivity in terms of nutrient inputs and phytoplankton growth. The satellite derived graphics also show the shorter term hydrodynamic features present in the bay at times in terms of eddies and inshore intrusions of warmer water etc.

3-day 1 km<sup>2</sup> case-1 and case-2 chlorophyll-a estimates were correlated with measurements (fluorometer) of point sampling data derived from corresponding sites gathered over the duration of the field sampling. Due to high variability of chlorophyll-a at small scales it was not surprising that correlation coefficients were relatively low when measured against the remote sensing estimates which represent a mean value from a square kilometre of ocean surface. The best correlation results were gained using mean chlorophyll-a values from the 5 – 10 m depth interval against the case-1 algorithm estimates ( $r^2 = 0.647$  on log transformed data).



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# Chapter 1: Introduction

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## 1.1 Scope

This report presents the results from an analysis by Environment Bay of Plenty of remote sensing data provided by NIWA. The work was part of the Aquaculture Management Areas (AMA) science project which has also included collection of physical and biological data (Oct 2003 – May 2004) to support assessment of the productivity and sustainability of coastal shelf waters within the Bay of Plenty. The specific objectives of the remote sensing module of this project were;

- Conduct a bio-optical survey cruise in the Bay of Plenty to allow validation measurements for development of region specific case-2 algorithms for chlorophyll-a estimation.
- Provide a remote sensing analysis of the climatological seasonal and spatial patterns of chlorophyll-a abundance in the Bay of Plenty.
- Provide a remote sensing analysis of the climatological seasonal and spatial patterns of sea-surface temperature (SST) in the Bay of Plenty.
- Provide a remote sensing analysis of the short term (3 day) SST state of the Bay of Plenty over the duration of field sampling for the AMA science project.
- Provide a remote sensing analysis of the short term (3 day) case-1 and case-2 chlorophyll-a estimates for the Bay of Plenty over the duration of field sampling for the AMA science project.
- Assess the relationship between field measurements and remote sensing data.

The field survey measurements including currents, temperature, plankton, nutrients, sediments, benthic biota and other physical water quality parameters collected by staff of Environment Bay of Plenty and ASR Ltd have been published in the following reports:

- Bay of Plenty shelf Physical and Chemical Properties 2003-2004. (Longdill *et al* 2005)
- Bay of Plenty Coastal Water Quality, 2003 – 2004. (Park 2005)
- Current and Temperature measurements, Aquaculture Management Areas. (Black *et al* 2005)
- Bay of Plenty Sediment Characteristics: Aquaculture Management Areas. (Longdill *et al* 2005)

- Bay of Plenty Biological Survey: Aquaculture Management Areas. (Mead *et al* 2005)

## 1.2 AMA Project background

Aquaculture as an industry in New Zealand has been growing rapidly in recent years and has become a substantial producer and export earner. The industry is still largely dominated by green lipped mussel and salmon farming but has the potential to produce a very wide range of product. In some areas such as the Marlborough Sounds suitable farming space has become limited and is considered a valuable asset. In the Bay of Plenty only around 4 ha of aquaculture existed up until May 2001 at which time it then received two large applications for a total of 8,760 ha.

In March 2002 the government imposed a moratorium on the granting of marine space for the purposes of aquaculture due to the explosion of demand and the complicated and sometimes adhoc approach to the processing of consents. The moratorium was “.to provide Regional Councils with the opportunity to plan for Aquaculture Management Areas”. It was also intended to remove much of the dual process that currently exists to make it more straight forward and easier for industry to establish.

The moratorium has now meant that regional councils must work out where to allow aquaculture to take place and how much. Environment Bay of Plenty is dealing with this task under both a science and planning project. The planning project is defining areas that will be most suitable. The approach taken is to define and map the various values of the marine environment that may potentially clash with aquaculture. This includes ecological, cultural, recreational fishing, commercial fishing, recreational activities, navigation, landscape and water quality values and issues.

Aquaculture can put considerable pressure on some components of the marine environment. Mussel farming for instance can cause phytoplankton depletion, change plankton species composition, result in nutrient changes, deposition of shell and faeces, impacts on water quality and a range of other actual or potential impacts. One of the most important questions is that of sustainability from a productivity view point. For example how much mussel farming could the Bay of Plenty coastal shelf waters support without such farms depleting phytoplankton levels to an extent that other inshore shellfish beds may be impacted in their ability to grow.

The aquaculture industry growth and moratorium has imposed an urgent need to obtain a sound understanding of the oceanographic processes, productivity and carrying capacity of the Bay of Plenty coastal waters. The science project being run as part of the whole AMA project is intended to address many of the issues and knowledge gaps mentioned above. It was started in July 2003 and will be concluded at the end of 2005 with a final report in March 2006.

The science project in its first year (2003/4) set up a wave buoy, current meter and gathered data from field surveys on the physical and biological status of the coastal waters during each season of the year. In addition remote sensing data is being used to assist in defining the seasonal and spatial status of Bay of Plenty waters for sea surface temperature and chlorophyll-a levels.

A large component of the science project is the development of hydrological and productivity models of the Bay of Plenty. Plankton, nutrient, physical and remote sensing data will all help in developing and calibrating numerical models aimed at estimating impacts, carrying capacity and sustainability of marine farming. Overall the project is primarily aimed at providing information needed to assist Environment Bay of Plenty's planning responsibilities in a way which will also help to safeguard the regions natural marine resources and ecosystems.



## Chapter 2: Methods

### 2.1 Location and physical environment

Field sampling for the AMA science project builds upon a previous survey of the coastal shelf waters undertaken in 1996/97 (Park 1998). In Figure 1 below the three transects in the centre of the bay (Pukehina, Whakatane and Opotiki) running from shore (10m depth) out to the edge of the continental shelf (200m depth) were used for the 2003/2004 field surveys. The Tauranga and Whakatane transects were both used in the 1996/97 survey. Grid references for the sampling points along each of these transects are provided in Appendix 1.

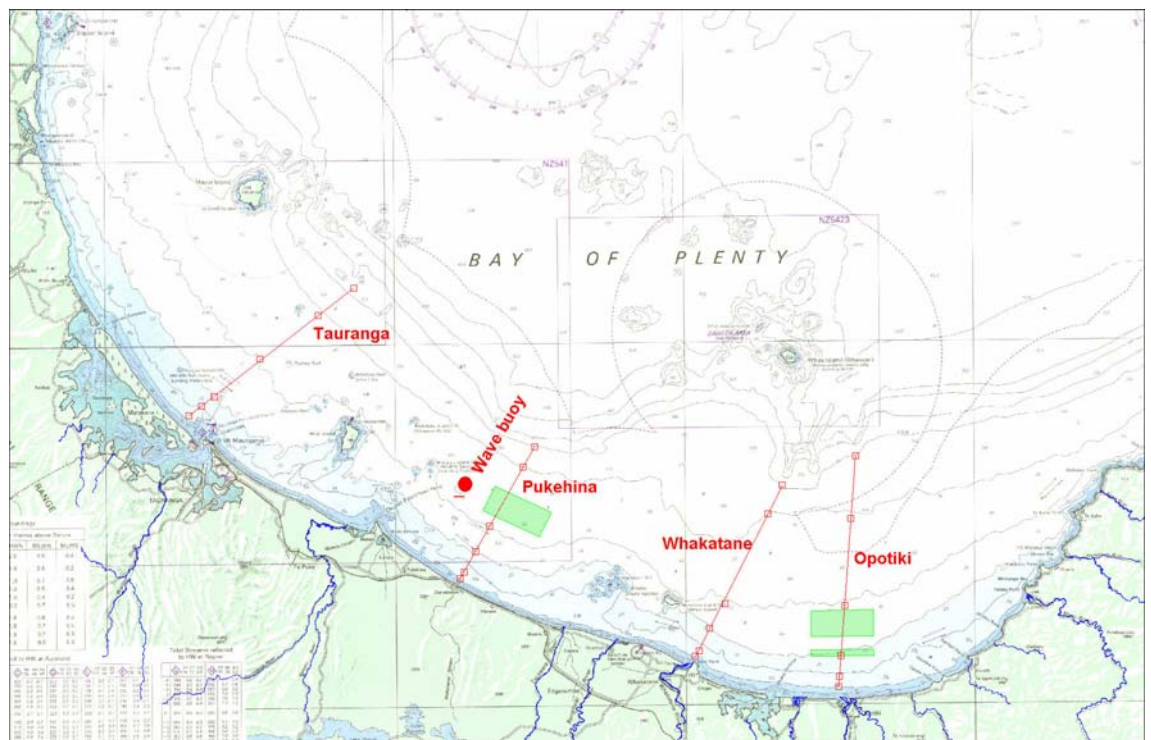


Figure 1 Location of transect sampling sites and the wave buoy in the Bay of Plenty coastal shelf waters

The Bay of Plenty coastline is exposed to wind and waves from the northwest to easterly directions and is a lee shore in respect of the Bay of Plenty's prevailing south-westerly wind flows (Iremonger and Stringfellow 2001). Offshore waters are predominantly influenced by the East Auckland Current, which flows south-eastward along the north-east coast of the North Island to East Cape where the main core of the current turns north-eastward (Ridgway and Greig 1986). Influence of the current is thought to be variable with limited penetration inshore.

Inshore currents are highly variable responding to both tidal effects and wind forcing (Healy *et al*, 1988, Harms 1989). During periods of high wind strengths, currents were observed to flow in the direction of the wind with velocities of up to 40 cm sec<sup>-1</sup>. In addition, periods of onshore bottom current occurred with offshore wind and the reverse with onshore winds. Residual current flows during periods of weak and variable winds appear to be to the south, possibly as an inshore influence of the East Auckland Current. Similar residual currents have been observed from a long-term current observation on the east Coromandel shelf (Bradshaw *et al* 1991). Results collected from this project also support this synopsis and show a high degree of water structure complexity and variability over short and long periods of time (Black *et al* 2005).

The inshore end of the Tauranga transect is influenced by tidal currents and flushing associated with the southern entrance of Tauranga Harbour. A similar situation exists with the Whakatane transect and estuary.

The southern entrance to Tauranga Harbour has a recorded flow of 153 x10<sup>6</sup> m<sup>3</sup> with maximum current speeds of 2.65 m.s<sup>-1</sup> (Beca Carter Hollings and Ferner Ltd 1978). Freshwater inflows to the southern harbour have been estimated to be around 30.5 m<sup>3</sup>s<sup>-1</sup> (<1% of tidal compartment) with the Wairoa River contributing 58% of the total (McIntosh 1994). The catchment of the northern Tauranga Harbour basin is much smaller with total freshwater inflow of around 4.6 m<sup>3</sup>s<sup>-1</sup>.

In contrast to the Tauranga situation Whakatane Estuary is much smaller with a high riverine influence. The Whakatane River, which flows into the estuary, has a mean flow of 57 m<sup>3</sup>s<sup>-1</sup>. Peak ebb-tide flows from the estuary have been gauged at 140 m<sup>3</sup>s<sup>-1</sup> during river flows of 18 m<sup>3</sup>s<sup>-1</sup> (Healy 1983). Catchment soils are still influenced by volcanic ash but most soils are derived from weathering of the underlying greywacke rocks.

Offshore of Opotiki the situation is similar to that of Whakatane, especially regarding the catchment geology. Opotiki estuary is even smaller measuring only 0.6 km<sup>2</sup>. The freshwater inflow from the Waioeka and Otara Rivers combined is also slightly less with a mean annual flow of 44m<sup>3</sup> s<sup>-1</sup>. Both these rivers flow through Opotiki Estuary.

At the Pukehina transect there is not a lot of freshwater influence even at the inshore 10m depth site. The Waitahanui Stream is around 1 km away and has a mean annual flow of 6 m<sup>3</sup> s<sup>-1</sup>. The Kaituna River is 15 km to the northwest and has a mean annual flow of 39 m<sup>3</sup> s<sup>-1</sup>, but due to the distance it has only a very diffuse effect on salinity.

## 2.2 Sampling program

### 2.2.1 Transect water quality sampling

Field sampling was conducted at sites along each of the Pukehina, Whakatane and Opotiki transects shown in Figure 1. Surveys were conducted four times within a year to obtain data on seasonal variations in water quality and plankton assemblages. Each transect has sampling sites set at the 10, 20, 30, 50, 100 and 200m depth contours with samples obtained within a day of the following dates 17 October 2003, 3 December 2003, 18 March 2004, 25 May 2004, 1 August 2004.

An additional set of transects were surveyed with CTD instruments on 7-9 December 2004.

At each of the sampling sites chemical, physical, and biological sampling was conducted at set depths (detail provided in Park 2005). Instruments readings at each site were taken with a SBE 19plus SEACAT Profiler from the surface down to the seabed. This probe recorded temperature, conductivity, pressure (depth), Oxygen (SBE 43), PAR (LI-COR LI-193SA), fluorometer (Turner SCUFA), and OBS (turbidity – Turner SCUFA).

## 2.2.2 Bio-optical validation survey

NIWA personnel carried out six days of bio-optical measurements at 24 coastal stations between Tauranga and the Motu River in June 2004. Measurements of spectral properties included radiometric measurements of the above-surface and underwater light field were made to obtain water leaving radiance, incident irradiance, diffuse attenuation, scattering and attenuation coefficients. In addition bio-geophysical and vertical water column structure measurements were taken. Details of the work are described in Richardson *et al* 2005.

## 2.3 Methods

### 2.3.1 SST climate synopsis

The NIWA SST archive comprises 1 km spatial resolution data from 1993 derived from NOAA (AVHRR) satellite measurements which provide up to eight observations per day. Climatological monthly means and standard deviations for the Bay of Plenty area were based on the period January 1993 to August 2004. Details of cloud detection algorithm, SST retrieval equations, validation and compositing are described in Uddstrom *et al* 1999.

Three-day 1 km spatial resolution SST temporal composites were produced for the period June 2003 – December 2004.

### 2.3.2 Chlorophyll-a climate synopsis

Ocean colour surface data with which to estimate chlorophyll-a levels were derived from the SeaWiFS satellite and obtained from NASA. Launched in September 1997, the satellite provides about two passes of New Zealand waters around noon each day.

Open ocean chlorophyll-a estimates (case 1 waters) were estimated using the SeaWiFS processing software SeaDAS using an empirical blue-green ratio algorithm. Climatological monthly means and standard deviations for the Bay of Plenty area using 4 km spatial resolution data were based on the period September 1997 to August 2004. Case 1 chlorophyll-a estimates can have a significant bias in inshore waters.

Three-day 1 km spatial resolution case 1 composites (means) were produced for the period June 2003 – December 2004.

The generation of case 2 (inshore waters which generally have high levels of suspended matter and coloured organic material present) chlorophyll-a estimates used results from the bio-optical measurements in the Bay of Plenty to calibrate the NIWA IOP algorithm. Details are described in Richardson *et al*, 2005. Climatological monthly means for the Bay of Plenty area using 4 km spatial resolution data were based on the period September 1997 to August 2004. Not all inshore coastal water will be “case 2” and will vary according to conditions at the time.

Three-day 1 km spatial resolution case two composites (means) were produced for the period June 2003 – December 2004.

## Chapter 3: Results

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### 3.1 Sea surface temperature

#### 3.1.1 Monthly mean

Results of long-term mean (10 yr) sea surface temperature for the whole of the Bay of Plenty as derived from remote sensing are presented for each calendar month in Figures 2a and 2b. The maximum temperature range of the means at 13.6 (August) – 22°C (February) is similar to previously recorded data. Minimum and maximum temperatures will be higher and lower than the mean values at each end of the range. The amount of variability about the mean values is shown in the plots of the standard deviation of the data (Figures 3a and 3b).

There are consistent spatial patterns showing features such as the East-Auckland current which flows down the north-east coast of the North Island to the Bay of Plenty before being deflected out to the east off the East Cape area. This current brings warmer water from the north and is clearly reflected in the zone of higher average temperature in the off-shore waters. The current appears to show up more prominently over the warmer months of the year.

Across the shelf and out into the offshore waters of the Bay of Plenty there is also a consistent spatial pattern showing that inshore waters are generally cooler than the offshore water mass. This difference in surface temperature can be up to 3°C. However, on a much finer scale than the resolution possible with the remote sensing data there will at times be warmer surface waters in the harbours and estuaries, particularly during summer.

Variability of the mean surface water temperatures throughout the Bay of Plenty also show distinct seasonal and spatial patterns (Figures 3a and 3b). Variability tends to be greatest in summer and inshore and is most likely the result of coastal up-welling of colder, deeper waters when the difference in temperature is greatest.

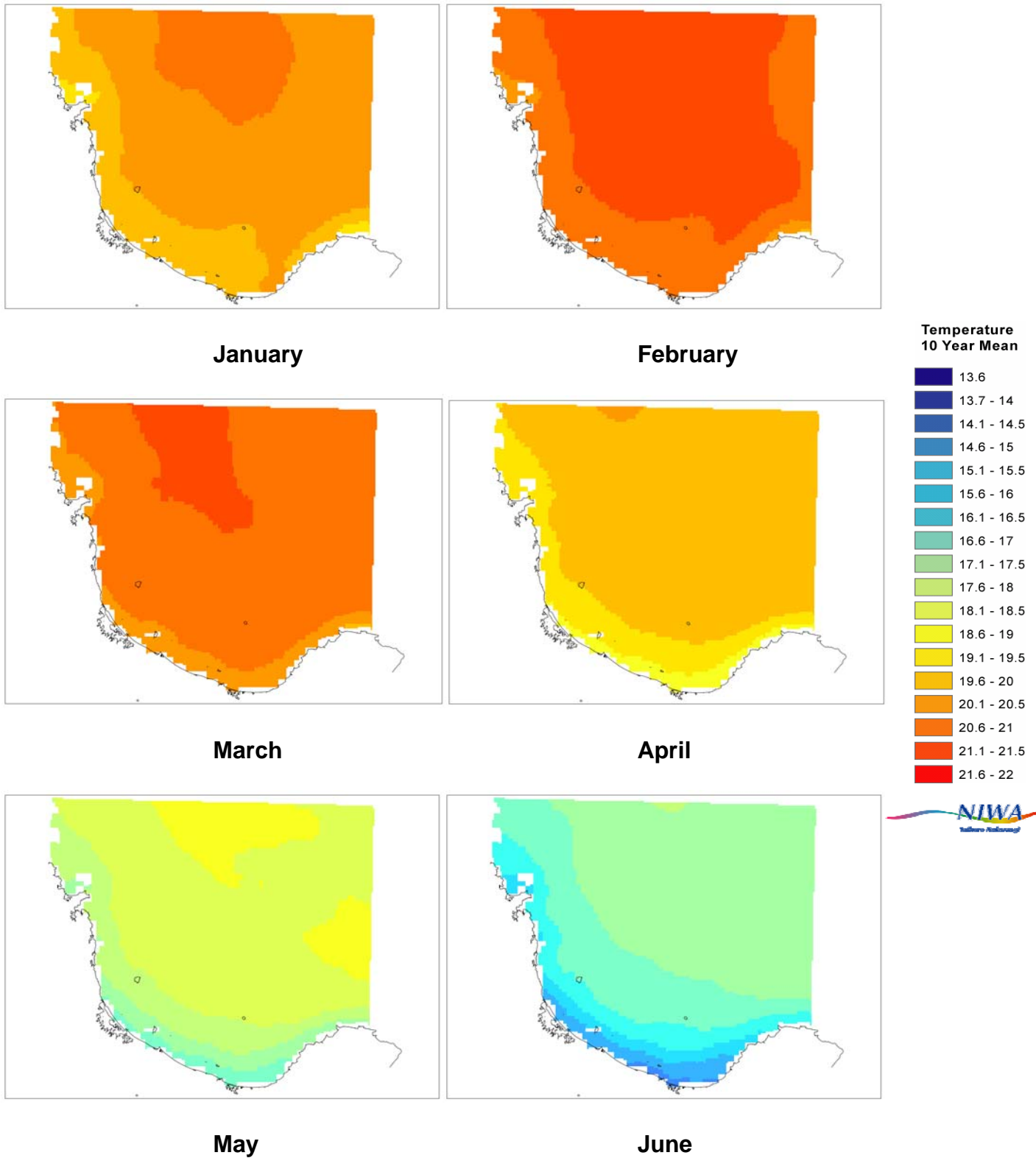


Figure 2a Mean sea surface temperature (°C) in the Bay of Plenty for the calendar months from January to June based on 10 years data from 1993 – 2004.

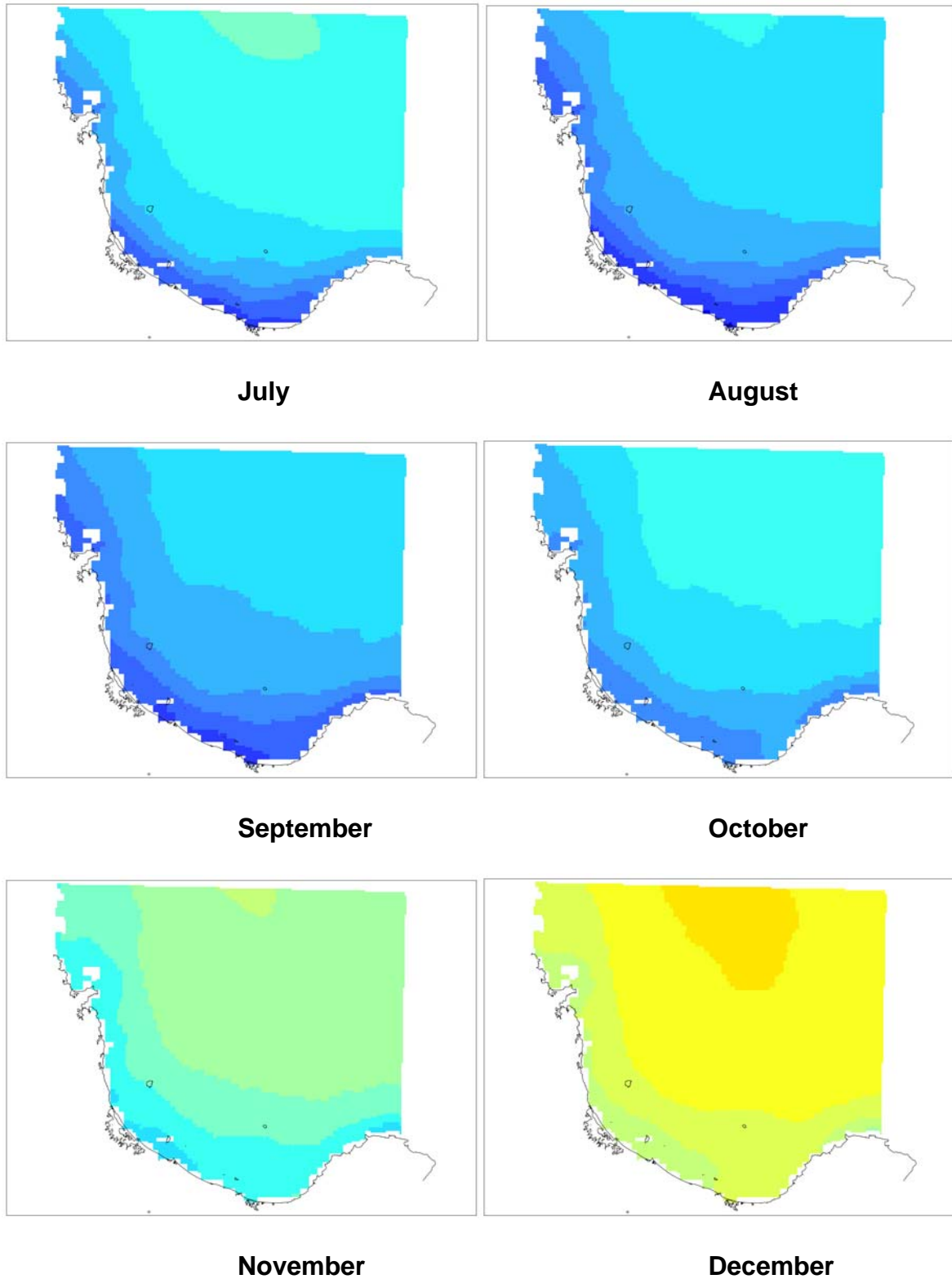


Figure 2b Mean sea surface temperature (°C) in the Bay of Plenty for the calendar months from July to December based on 10 years data from 1993 – 2004.

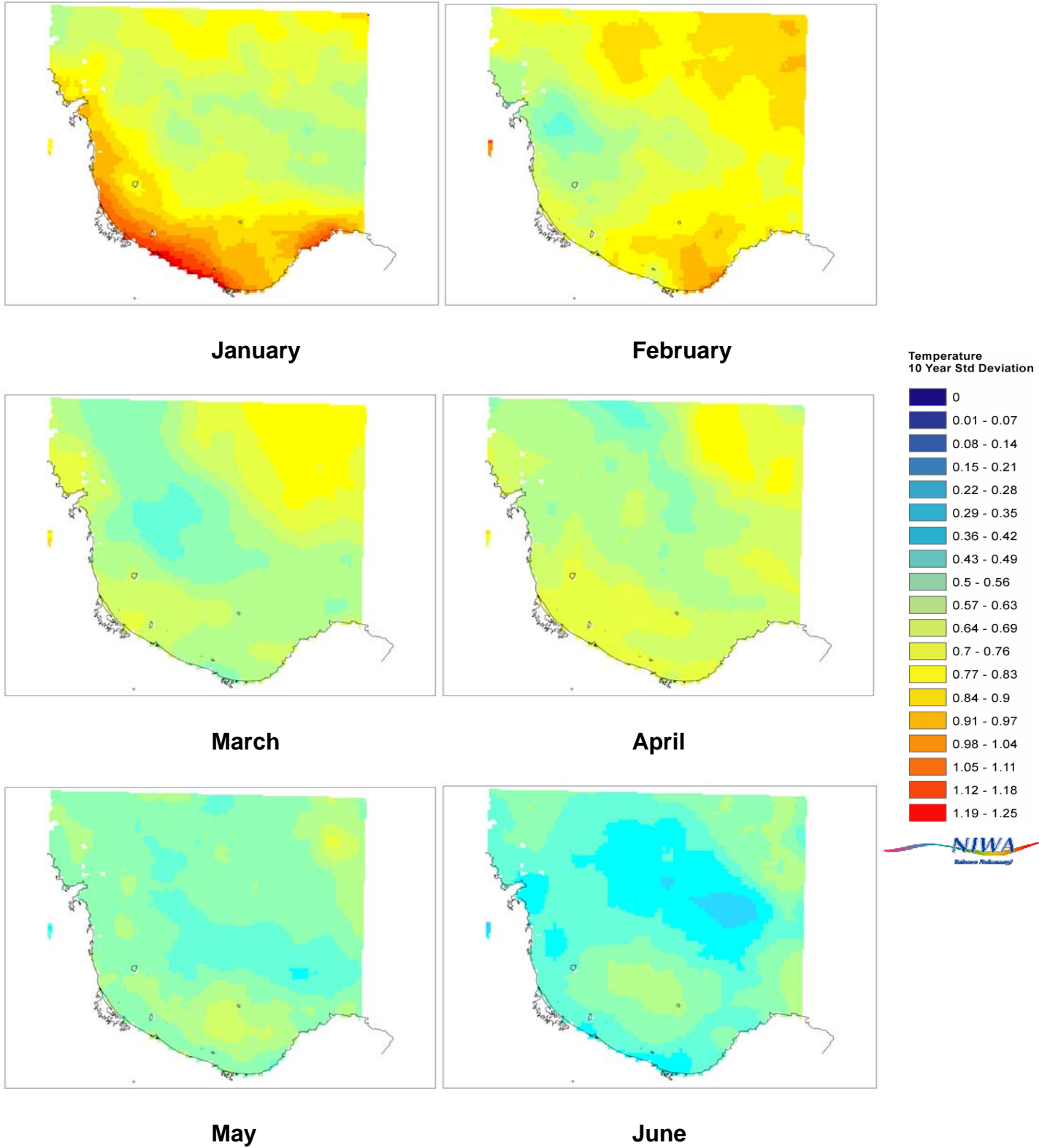


Figure 3a Standard deviation of mean sea surface temperature (°C) in the Bay of Plenty for the calendar months from January to June based on 10 years data from 1993 – 2004.

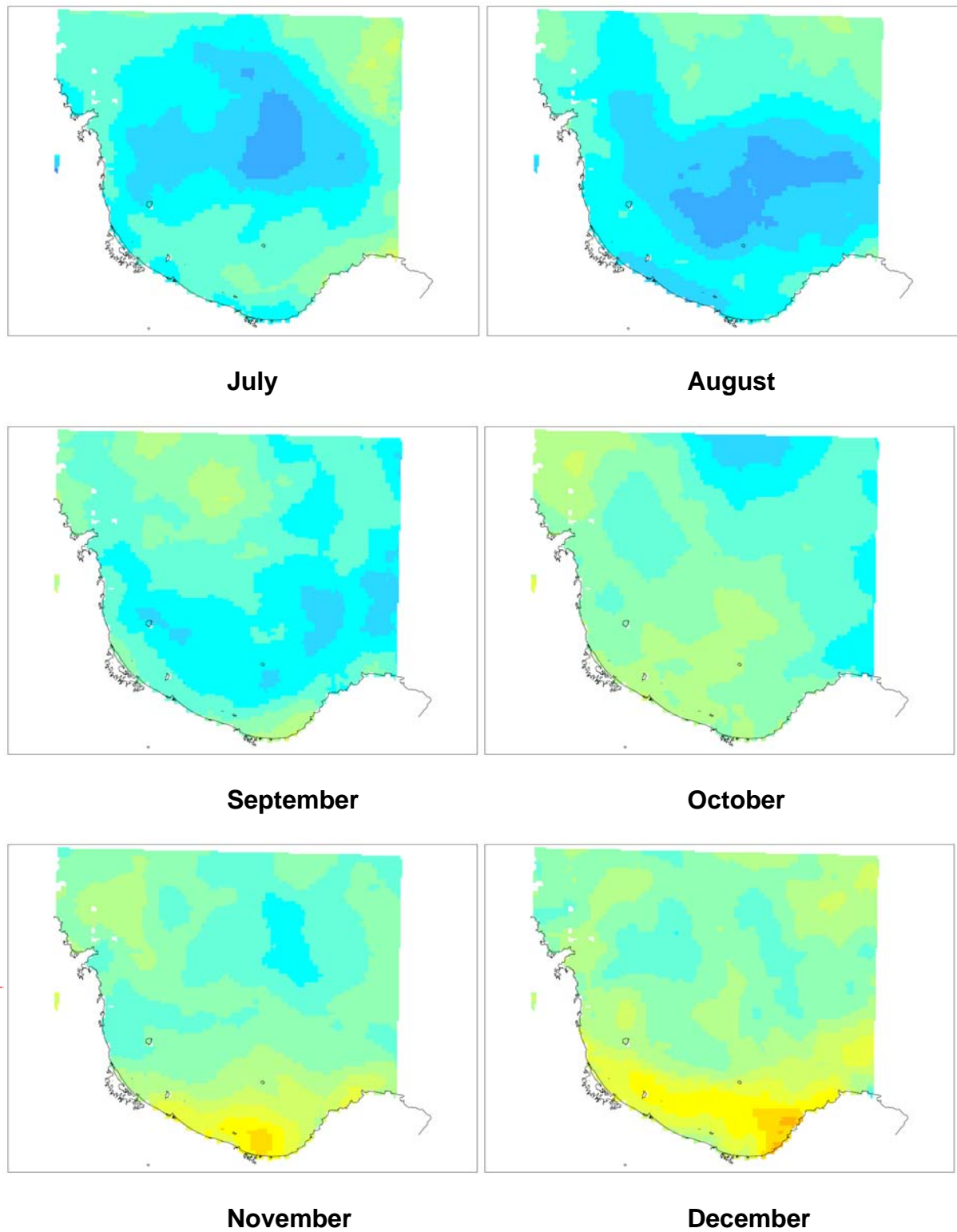


Figure 3b Standard deviation of mean sea surface temperature (°C) in the Bay of Plenty for the calendar months from July to December based on 10 years data from 1993 – 2004.

## 3.2 Chlorophyll-a

### 3.2.1 Case-1 algorithms

Mean concentrations of chlorophyll-a for each month of the year as derived from remote sensing data using case 1 algorithms are shown in Figures 4a and 4b. There are consistent spatial patterns showing that highest levels of estimated chlorophyll-a occur inshore very close to the coastline and decrease markedly in the offshore waters well out to sea. There also appear to be slightly higher chlorophyll-a concentrations along the central Bay of Plenty coastline compared to the western or eastern areas of the bay.

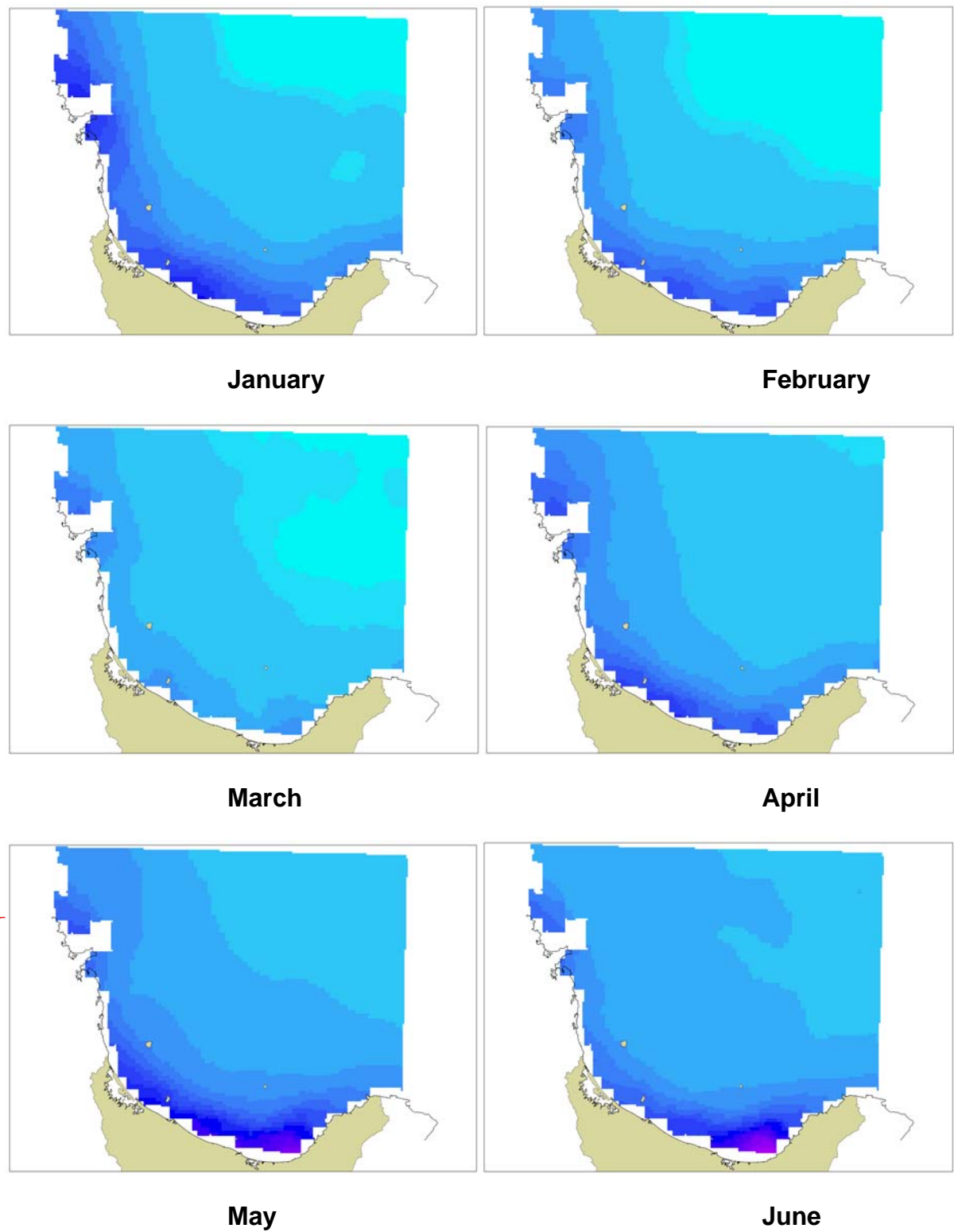
In addition to the spatial pattern of chlorophyll-a concentrations, there is a clear seasonal pattern with low mean monthly values of 0.5 µg/l inshore during late summer in March. Peak concentrations of up to 2.0 µg/l or more occur in late winter and spring.

Variability of chlorophyll-a concentrations as measured by the standard deviation of the monthly means (Figures 5a and 5b) shows very similar spatial and seasonal patterns as displayed by the monthly means.

### 3.2.2 Case-2 algorithms

Only monthly means were derived using the case-2 algorithms and the results are shown in Figure 6a and 6b. Spatial and seasonal patterns of chlorophyll-a concentrations are very similar to the results derived using the case-1 algorithms. The difference between the two is that concentrations of chlorophyll-a estimated using the case-2 algorithms are lower as they take into account the suspended sediment and coloured organic matter in the water column and attempt to correct for this.

During late summer when chlorophyll-a concentrations are lowest, the inshore case-2 algorithm estimates give peak monthly mean values around 0.35 µg/l and winter highs of 1.5 µg/l.



*Figure 4a Mean SeaWiFS chlorophyll-a concentration ( $\mu\text{g/l}$ ,  $4\text{km}^2$  resolution, case 1 retrieval algorithm) in the Bay of Plenty for the calendar months from January to June based on 7 years data from 1997 – 2004.*

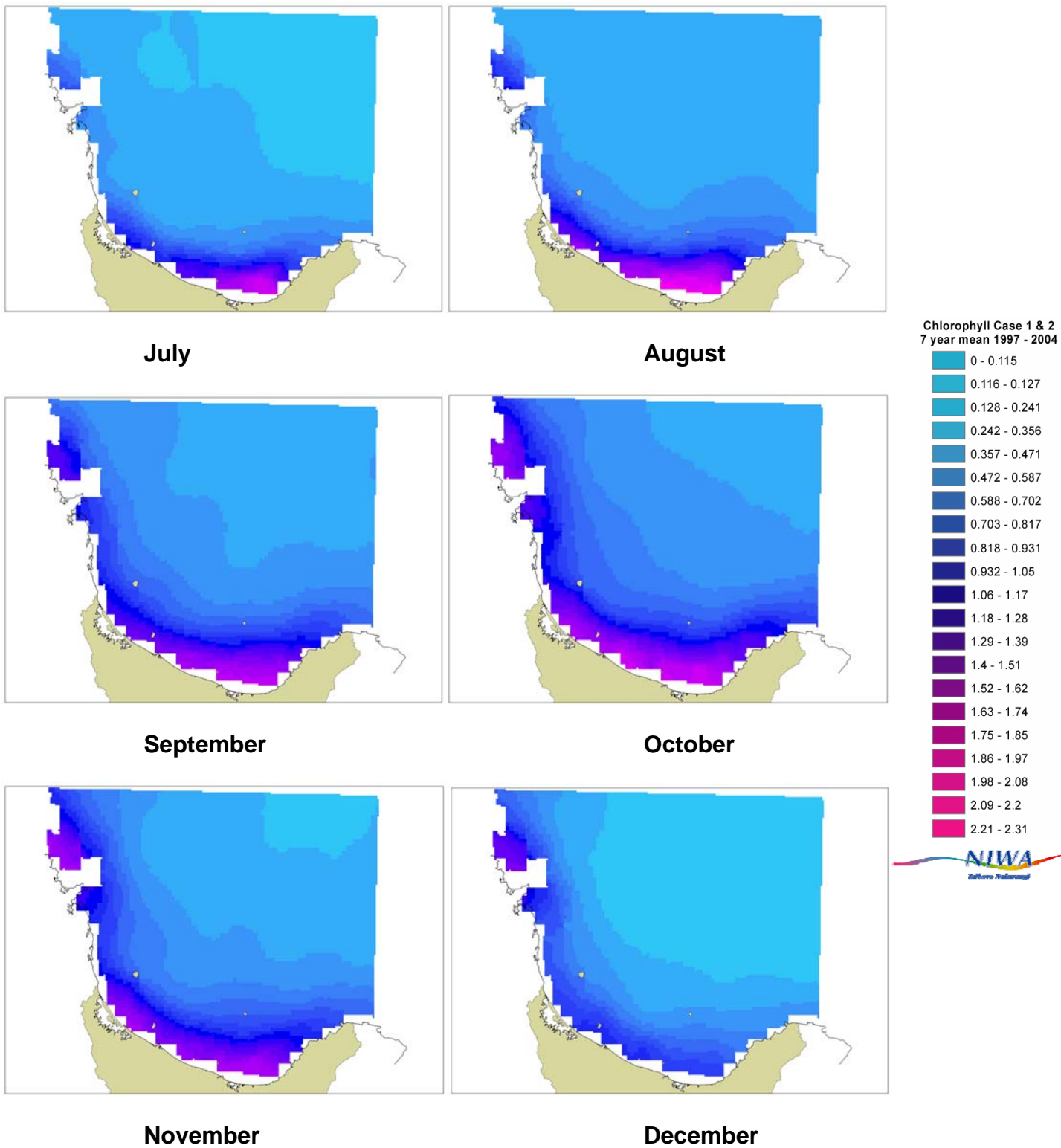


Figure 4b Mean SeaWiFS chlorophyll-a concentration ( $\mu\text{g/l}$ ,  $4\text{km}^2$  resolution, case 1 retrieval algorithm) in the Bay of Plenty for the calendar months from July to December based on 7 years data from 1997 – 2004.

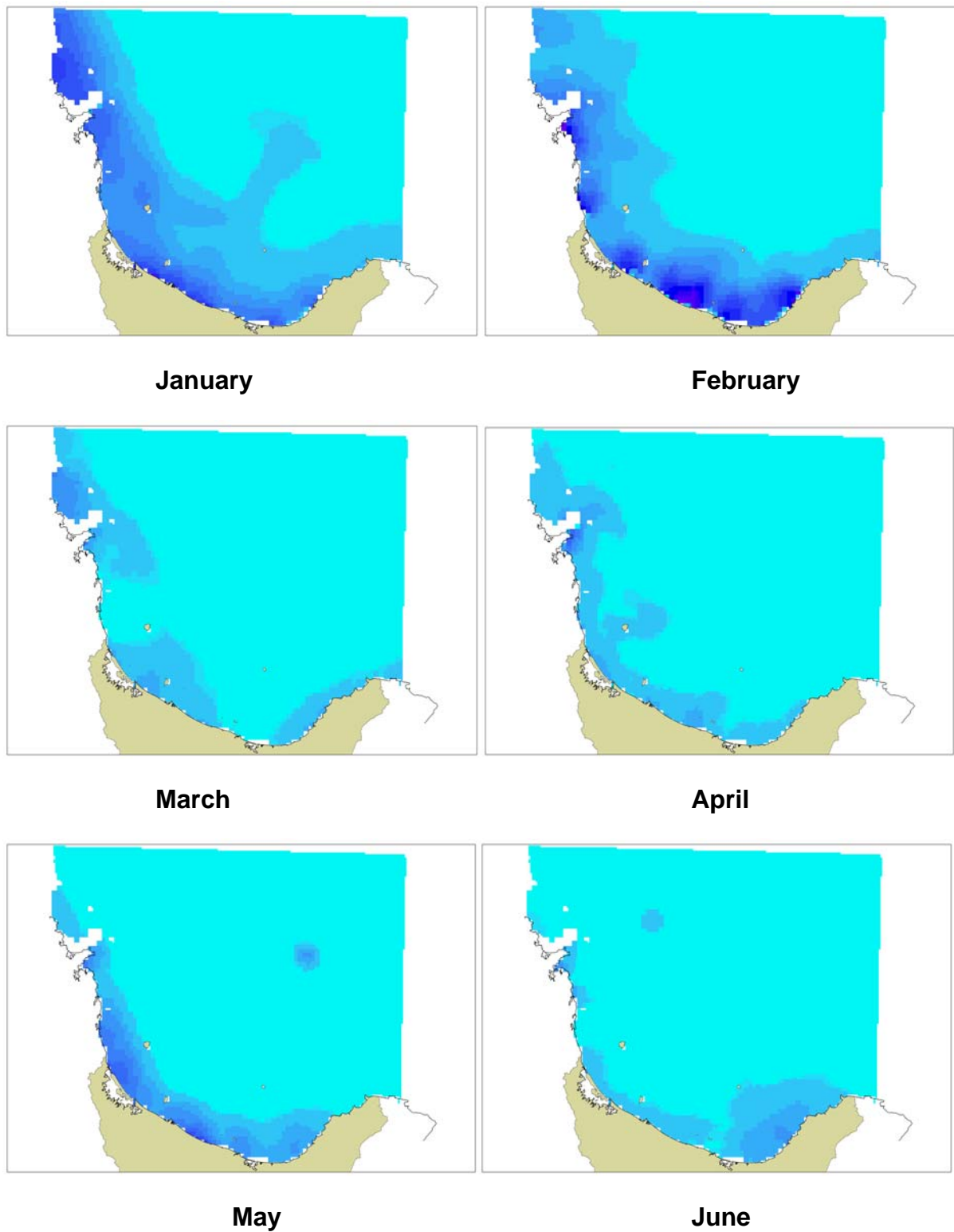


Figure 5a Standard deviation of mean SeaWiFS chlorophyll-a concentration ( $\mu\text{g/l}$ ,  $4\text{km}^2$  resolution, case 1 retrieval algorithm) in the Bay of Plenty for the calendar months from January to June based on 7 years data from 1997 – 2004.

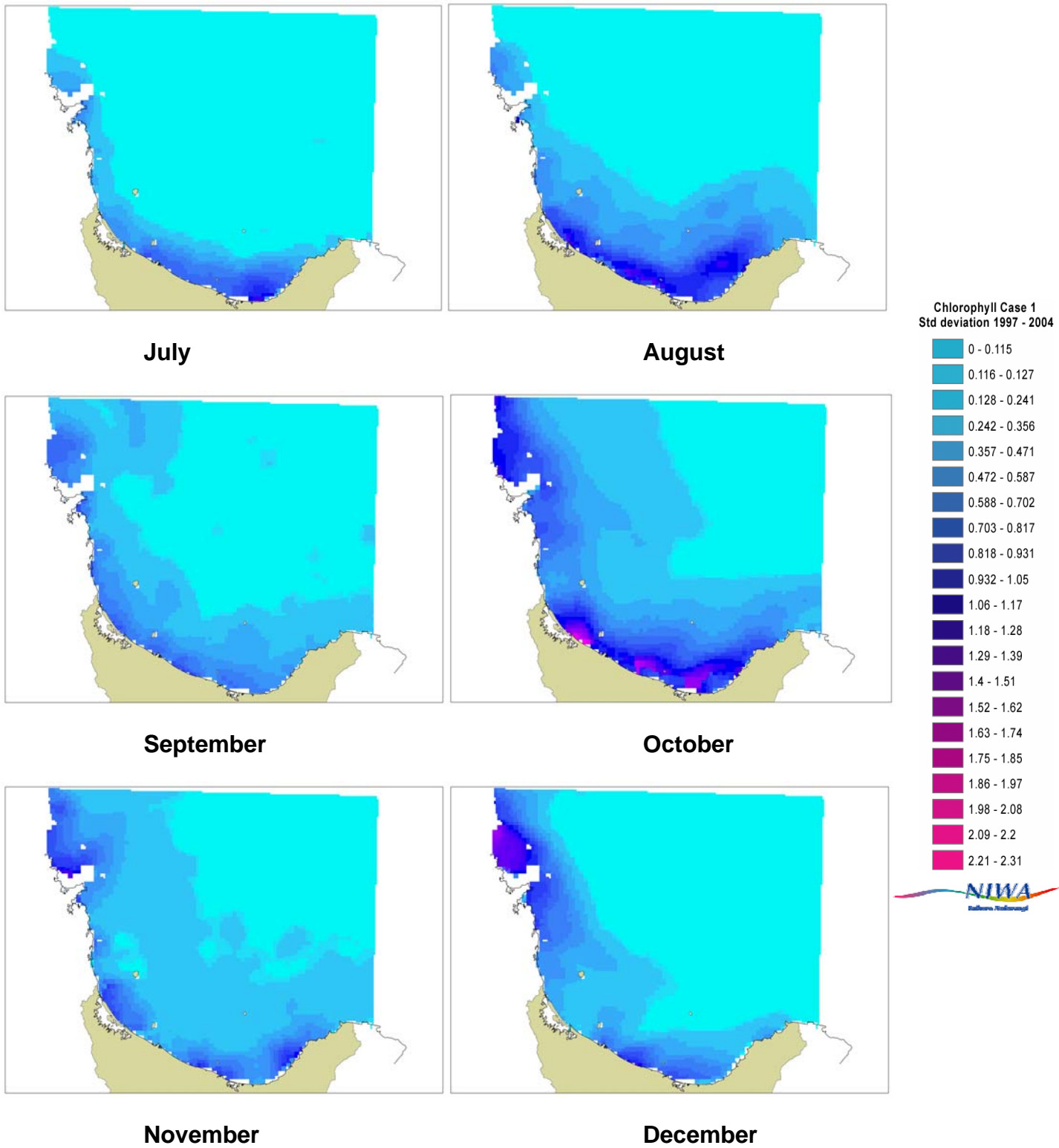
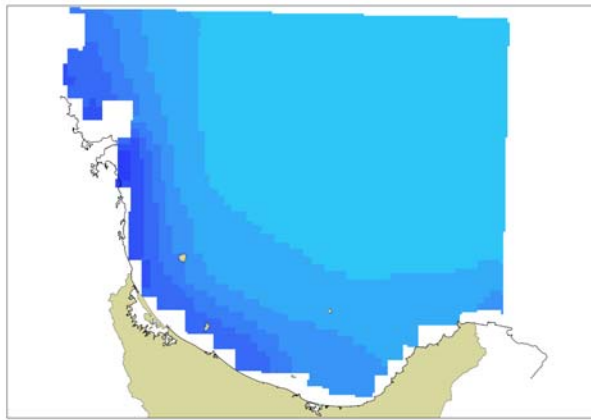
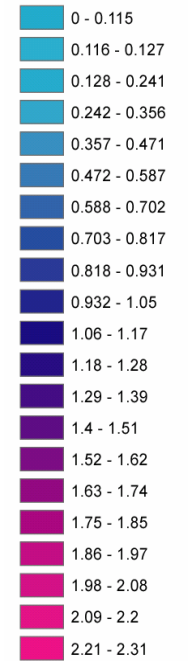
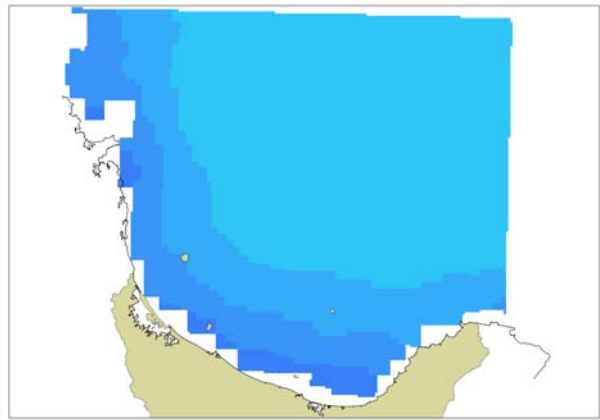


Figure 5b Standard deviation of mean SeaWiFS chlorophyll-a concentration ( $\mu\text{g/l}$ ,  $4\text{km}^2$  resolution, case 1 retrieval algorithm) in the Bay of Plenty for the calendar months from July to December based on 7 years data from 1997 – 2004.

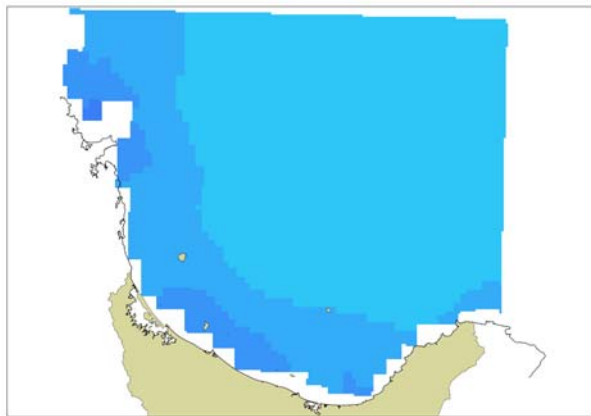
Chlorophyll Case 1 & 2  
7 year mean 1997 - 2004



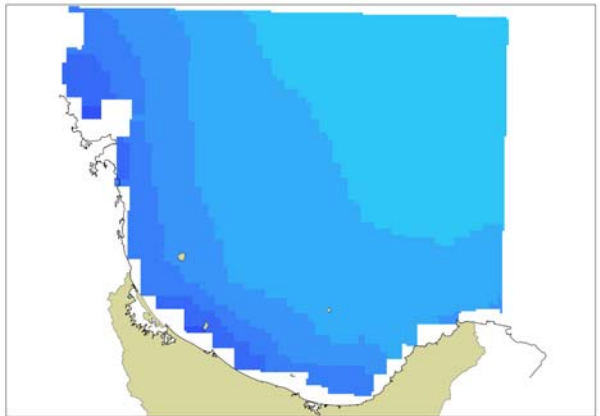
January



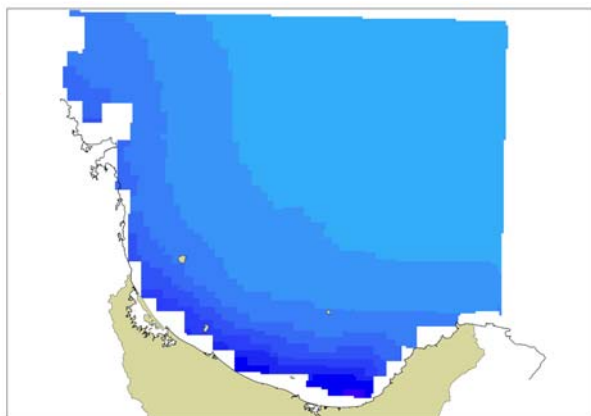
February



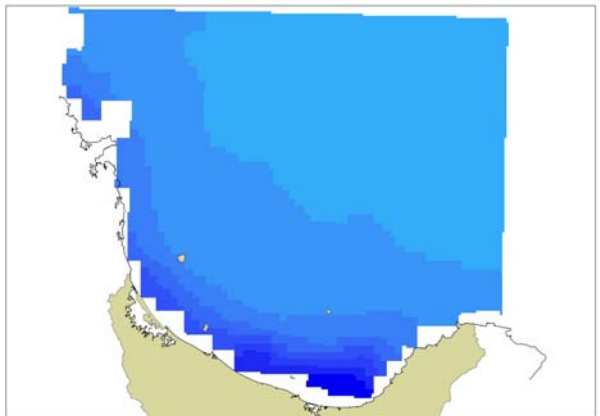
March



April



May



June



Figure 6a Mean SeaWiFS chlorophyll-a concentration ( $\mu\text{g/l}$ ,  $4\text{km}^2$  resolution, case 2 retrieval algorithm) in the Bay of Plenty for the calendar months from January to June based on 7 years data from 1997 – 2004.

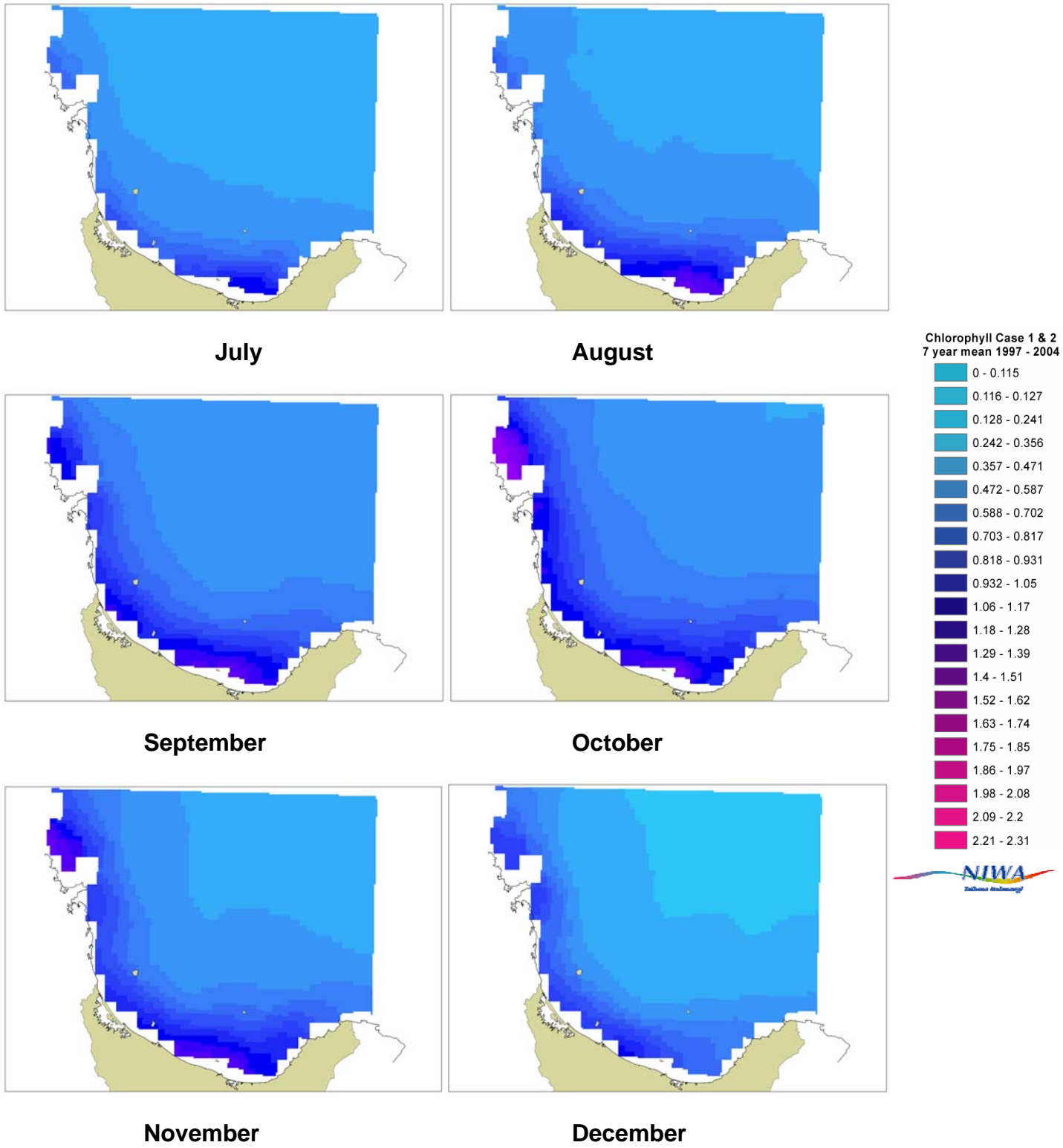


Figure 6b Mean SeaWiFS chlorophyll-a concentration ( $\mu\text{g/l}$ ,  $4\text{km}^2$  resolution, case 2 retrieval algorithm) in the Bay of Plenty for the calendar months from July to December based on 7 years data from 1997 – 2004.

### 3.3 Comparison of 3-day SST, case-1 and case-2 chlorophyll-a images

A number of 3-day SST and chlorophyll-a remote sensing images were selected as examples to show the relationships between each of the products and the hydrodynamics. Selection was simply based on those images that did not have too much cloud cover and appeared to show both the general spatial patterns observed in the Bay of Plenty and more detailed features related to prevailing conditions.

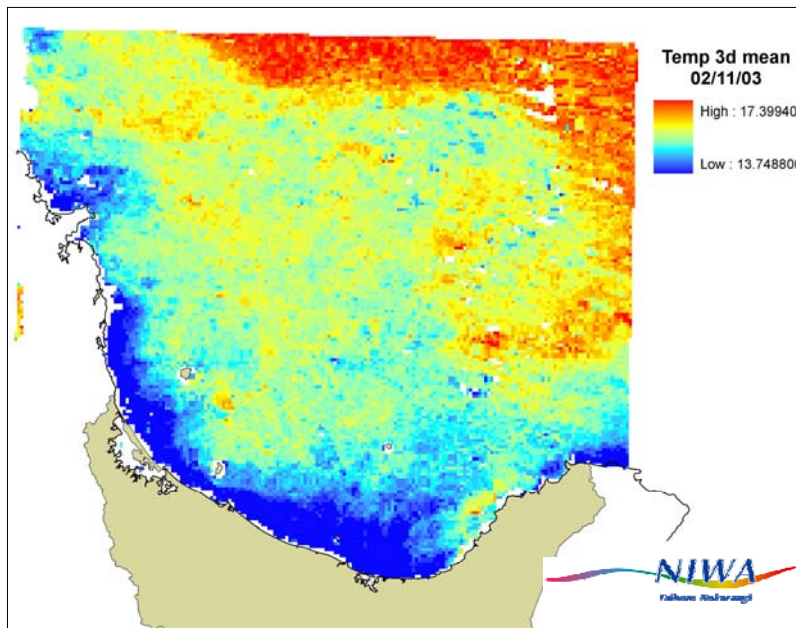
These comparisons are shown in Figures 7 – 10. Each set of case-1 and case-2 chlorophyll-a images have been plotted using the same scale which excludes high outlying values. In many of the images the highest values were often observed to be associated with areas of cloud and probably erroneous. This problem is worse for chlorophyll-a than SST data retrievals.

Figures 7 and 8 are only three days apart (1 and 4 November 2003) and show very similar characteristics. The SST plots indicate possible coastal up-welling of cooler, deeper oceanic water inshore. As the cooler inshore surface has moved offshore it has clearly formed an eddy pattern. The cooler up-welled water would have higher nutrient levels and the same pattern seen in the SST plots is reflected in the chlorophyll-a levels. In the ten days leading up to the 1 November 2003 moderate winds from the south to south west had been blowing up to the 26 November, then apart from one day (28 November ) of north easterly winds, the winds were of moderate strength from the west to northwest. These winds were of suitable strength and direction to drive upwelling.

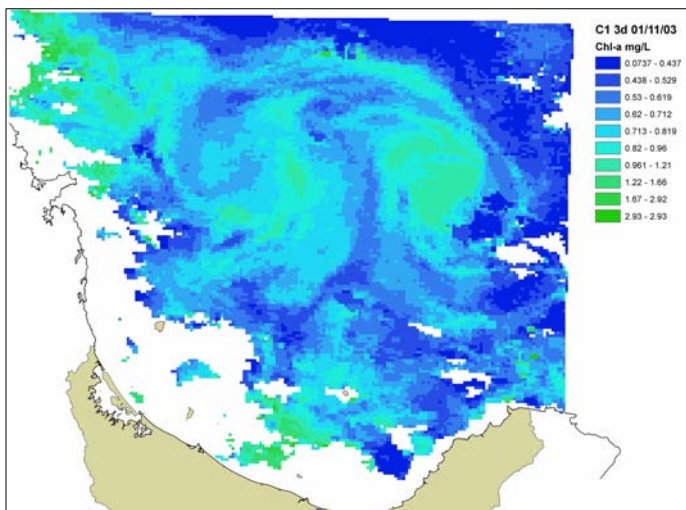
In Figure 7 the case-1 chlorophyll-a algorithm product has marginally higher values than the case-2 algorithm. Results in Figure 8 three days later show the reverse with the case-2 product showing marginally higher values.

In Figure 9 for the 21 March 2004 the SST plot indicates that there may be some coastal up-welling in the western area of the Bay of Plenty with warm water intruding or remaining inshore in the central to eastern area of coast. Once again the higher chlorophyll-a levels closely match the areas of cooler water.

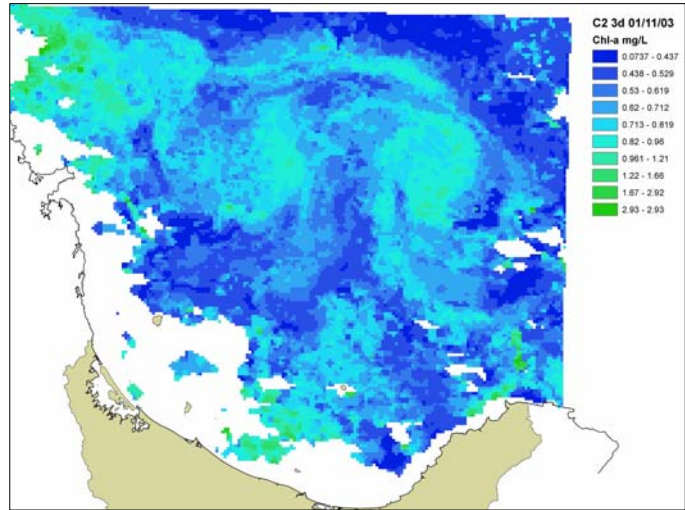
In the last comparison (Figure 10) on 14 October 2004 there again appears to be a degree of coastal up-welling taking place with an area of cooler water having moved well out offshore. As with all the other plots the higher chlorophyll-a levels closely match the areas of cooler water. In the case-1 and case-2 comparisons it is evident that in this example that the case-1 algorithm product has higher chlorophyll-a values than the case-2 inshore but lower values offshore.



(A)



(B)

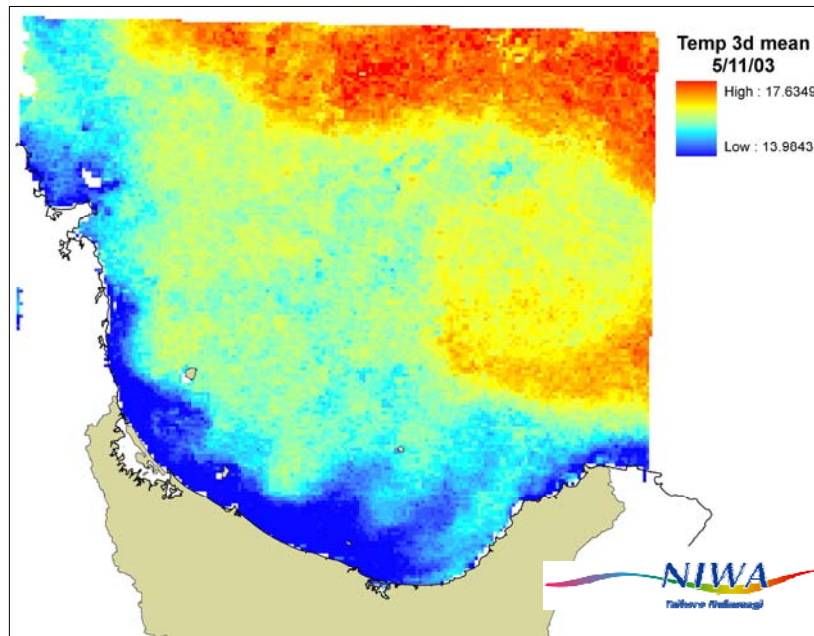


(C)

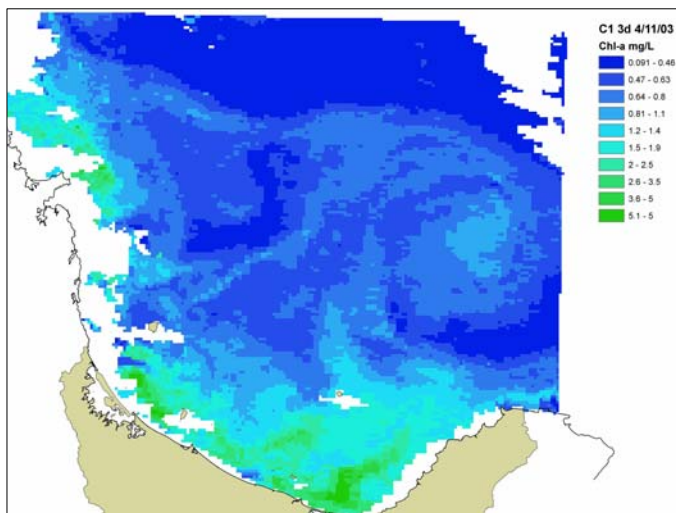
Figure 7 Comparison of 3-day mean sea surface temperature (A), case-1 (B) and case-2 (C) chlorophyll-a ( $\mu\text{g/l}$ ) using NIWA processing results of 1km resolution remote sensing data for the 1/11/03.

Prevailing winds in the period 31 October to 1 November 2003 prior to the recorded SST and chlorophyll-a levels were moderate west to north-westerly winds while earlier significant winds (24–26) were moderate south to south westerlies.

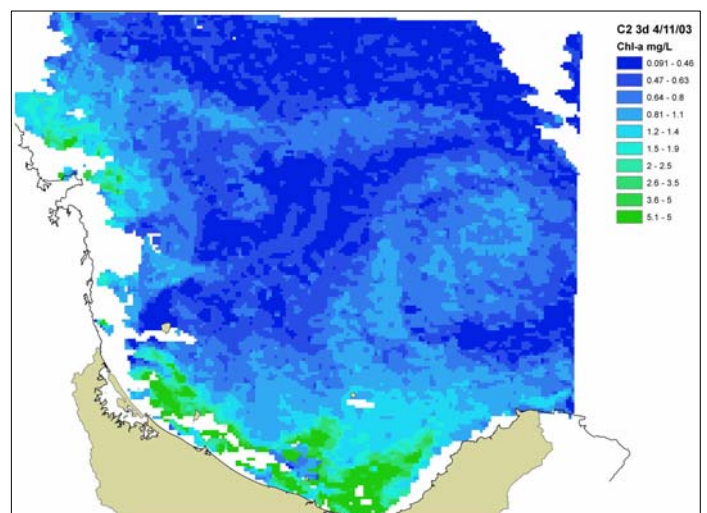
Maximum chlorophyll-a values for the 1 November 2003 images were 11.5  $\mu\text{g/l}$  for the Case-1 and 17  $\mu\text{g/l}$  for Case-2 algorithm product while the maximum value of the plotted scale range is 3.



(A)



(B)

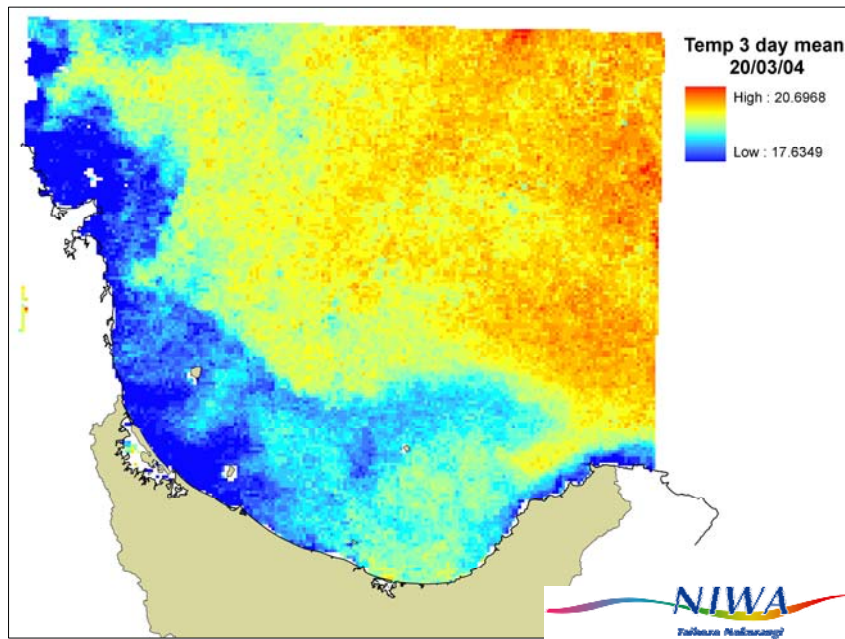


(C)

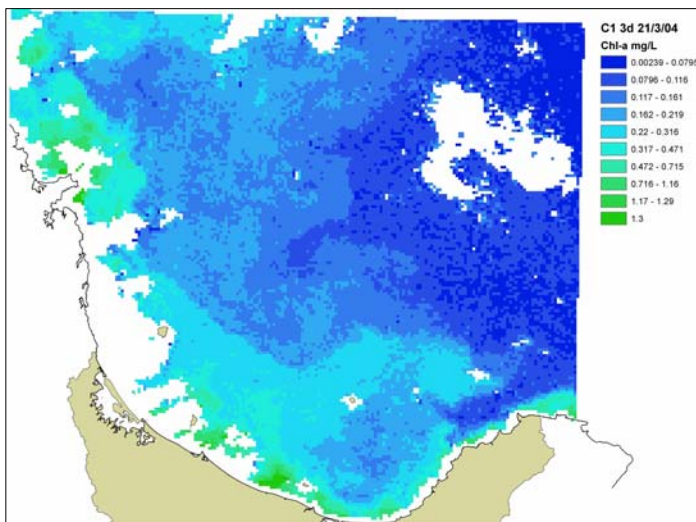
**Figure 8** Comparison of 3-day mean sea surface temperature (A), case-1 (B) and case-2 (C) chlorophyll-a ( $\mu\text{g/l}$ ) using NIWA processing results of 1km resolution remote sensing data for the 4/11/03.

Prevailing winds in the period 1 November to 4 November 2003 prior to the recorded SST and chlorophyll-a levels were strong - moderate west to north-westerly winds.

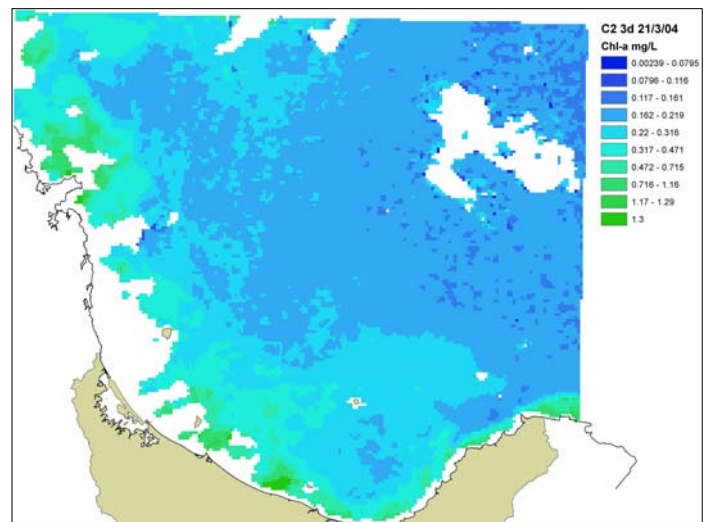
On the 4 November the case-1 case-2 maximums were 9.2 and 42 respectively. The case-2 had a small secondary peak in the data distribution around 14  $\mu\text{g/l}$  and the maximum value of the plotted scale range for both is 5.



(A)



(B)

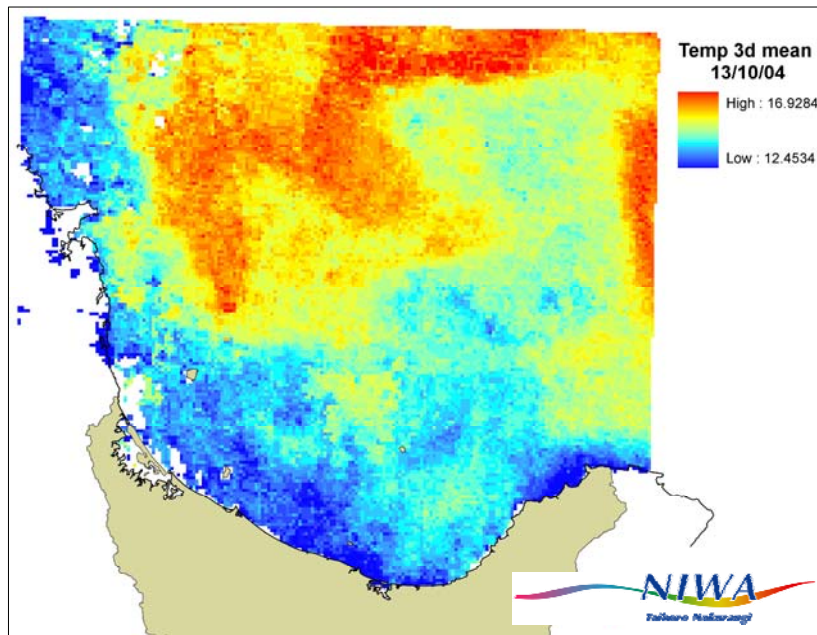


(C)

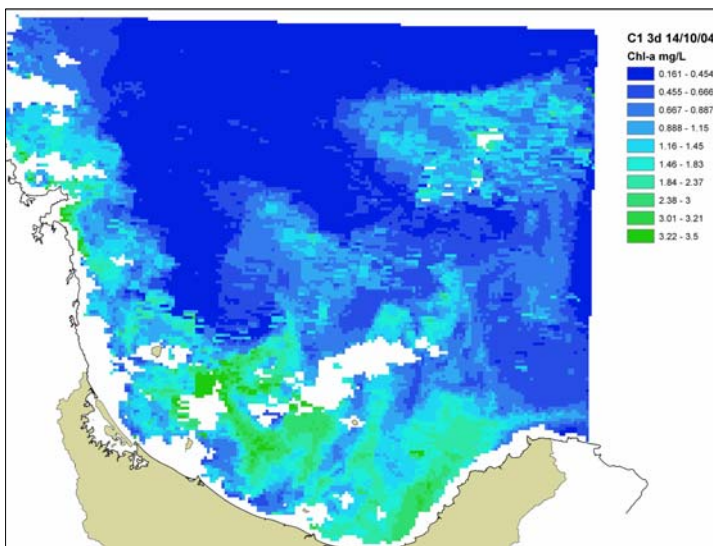
Figure 9 Comparison of 3-day mean sea surface temperature (A), case-1 (B) and case-2 (C) chlorophyll-a ( $\mu\text{g/l}$ ) using NIWA processing results of 1km resolution remote sensing data for the 21/3/04.

Prevailing winds in the period 19 March to 21 March 2004 prior to the recorded SST and chlorophyll-a levels were moderate west to north-westerly winds.

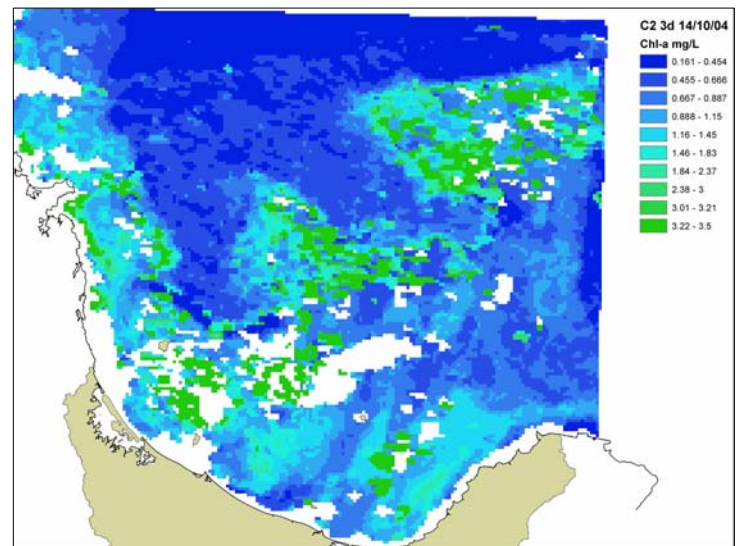
Maximum chlorophyll-a values for the 21 March 2004 images were 5.2  $\mu\text{g/L}$  for the Case-1 and 4.1  $\mu\text{g/L}$  for Case-2 algorithm product while the maximum value of the plotted scale range is 1.3.



(A)



(B)



(C)

Figure 10 Comparison of 3-day mean sea surface temperature (A), case-1 (B) and case-2 (C) chlorophyll-a ( $\mu\text{g/l}$ ) using NIWA processing results of 1km resolution remote sensing data for the 14/10/04.

Prevailing winds in the period 11<sup>th</sup> October to 14 October 2004 prior to the recorded SST and chlorophyll-a levels were strong - moderate westerly winds.

Maximum chlorophyll-a values for the 14 October 2004 images were 14.7  $\mu\text{g/L}$  for the Case-1 and 44  $\mu\text{g/L}$  for Case-2 algorithm product while the maximum value of the plotted scale range is 3.5.

### 3.4 Correlation of field and remote sensing data

#### 3.4.1 Sea Surface temperatures

Data from all field sampling of transects throughout the term of the project was compared to corresponding remote sensing results for sea surface temperature where possible. Results are shown in Figures 11 – 14 below. Remote sensing data was based on the NIWA provided 3-day mean value for a square kilometre of the sea surface, while the temperature readings from the CTD instrument are from a single point at the time of sampling.

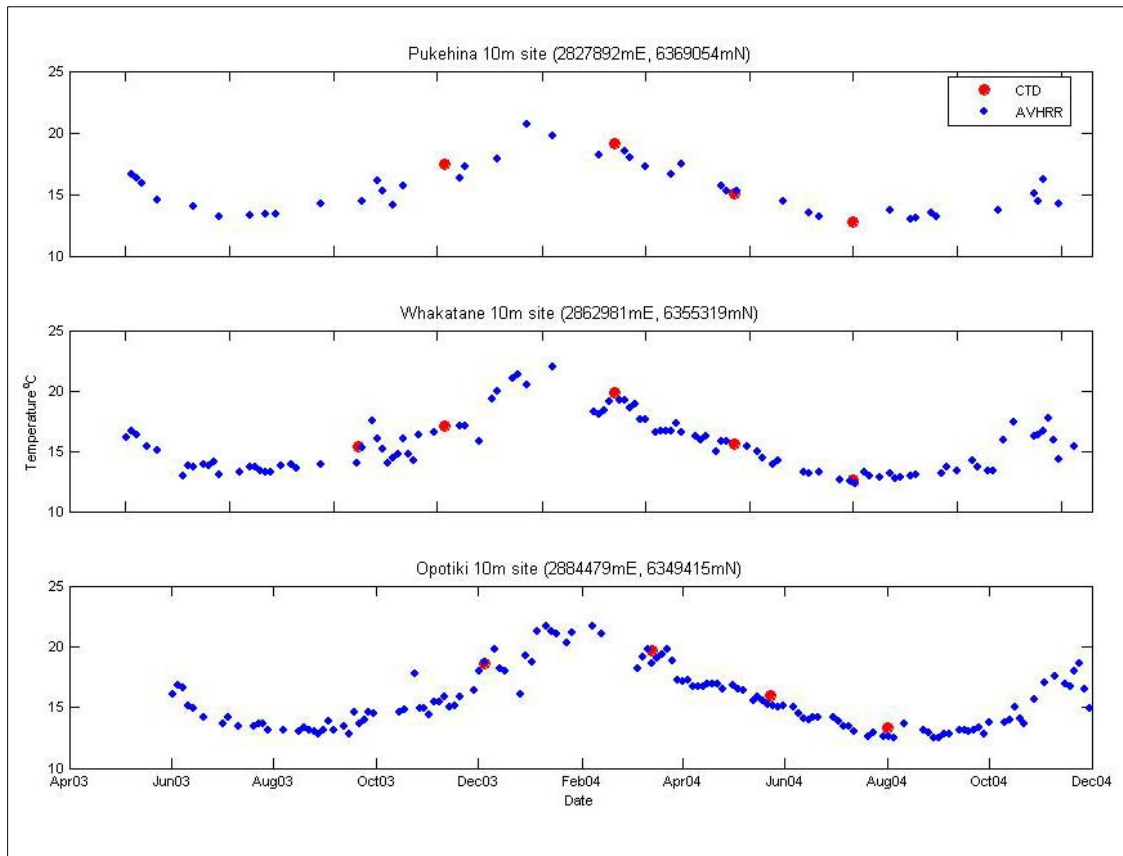


Figure 11 Plots of remote sensing (AVHRR - 1 km<sup>2</sup>) and field measurements (CTD – point sample) of Sea Surface Temperatures measured at the 10m depth contour sites on the transects in the Bay of Plenty.

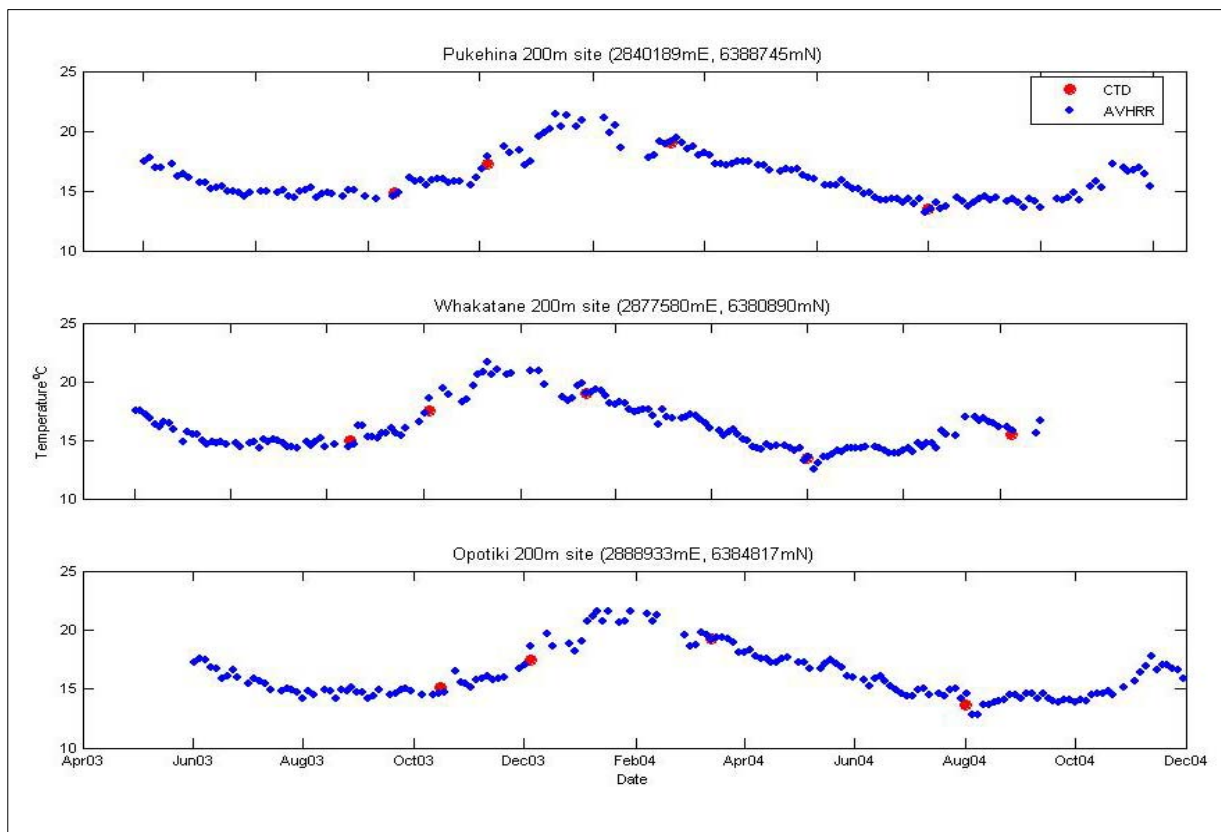


Figure 12 Plots of remote sensing (AVHRR - 1 km<sup>2</sup>) and field measurements (CTD – point sample) of Sea Surface Temperatures measured at the 200m depth contour sites on the transects in the Bay of Plenty.

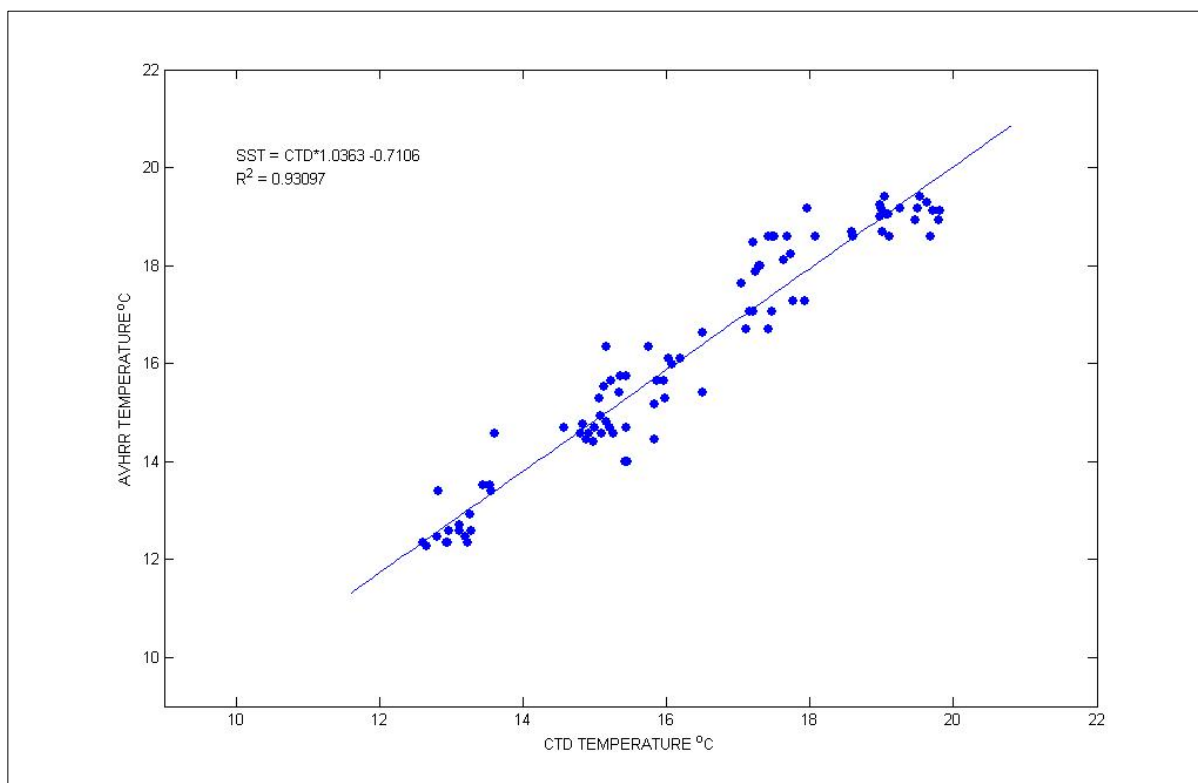


Figure 13 Correlation between remote sensing (AVHRR - 1 km<sup>2</sup>) and field measurements (CTD – point sample) of Sea Surface Temperatures measured at sites in the Bay of Plenty.

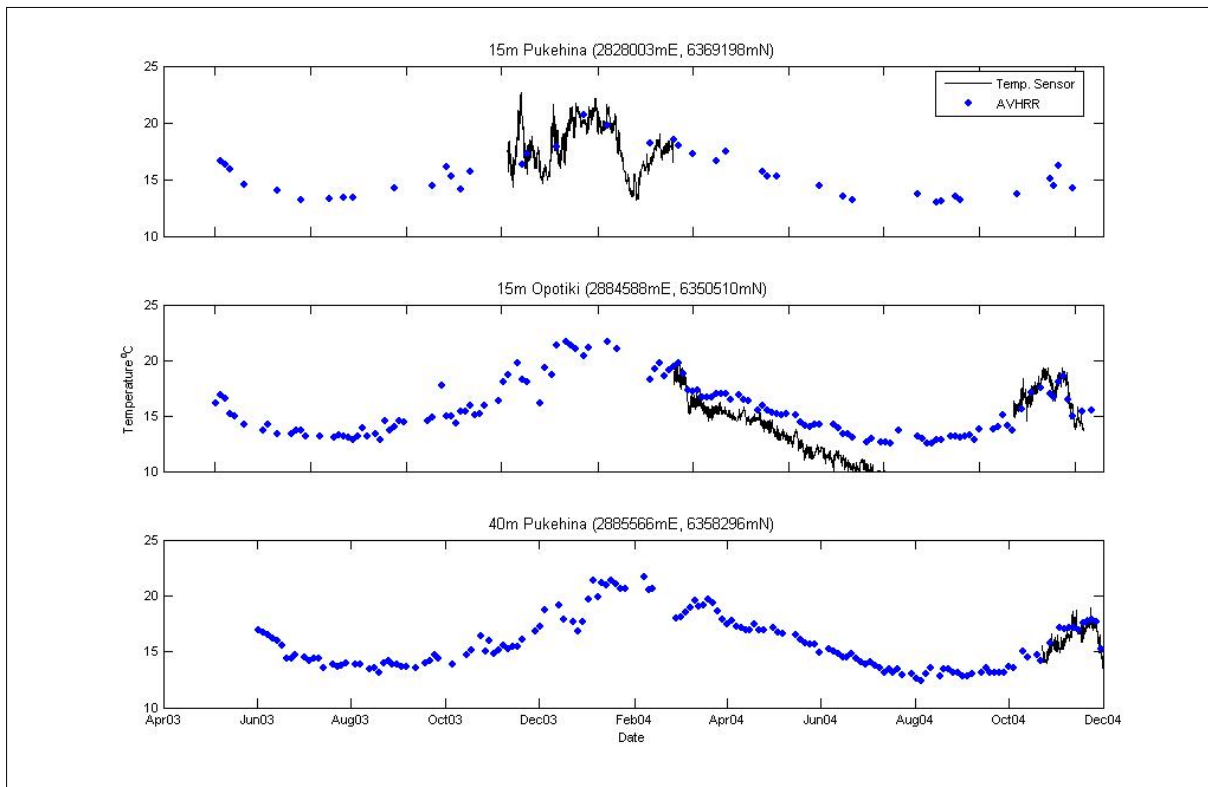


Figure 14 Plots showing relationship between temperature sensor data from defined water depths and remote sensing sea surface temperature data.

### 3.4.2 Chlorophyll-a

Data from all field sampling of transects throughout the term of the project was compared to corresponding remote sensing results for estimates of chlorophyll-a concentration where possible. Remote sensing data was based on the mean daily value for a square kilometre of the sea surface, while the field readings from the fluorometer are from a single point at the time of sampling.

Comparisons were made using several different depth range mean values of fluorometer chlorophyll-a estimates against the case-1 and case-2 remote sensing estimates. Both the fluorometer and remote sensing estimates of Chlorophyll-a concentration were log transformed for the correlations. Only the best correlation results are shown in Figures 15 – 18 below. To obtain field estimates of chlorophyll-a concentration, 29 field samples taken for laboratory analysis were also measured on the fluorometer and then used to calculate a conversion equation (presented in Park 2005). This conversion equation was applied to all the field data obtained with the fluorometer.

Overall the best correlation coefficient values were obtained between the case-1 and the fluorometer estimates of chlorophyll-a. Also the mean fluorometer value from 5-10m water depth was better than the 0-5m average or any single depth point chosen.

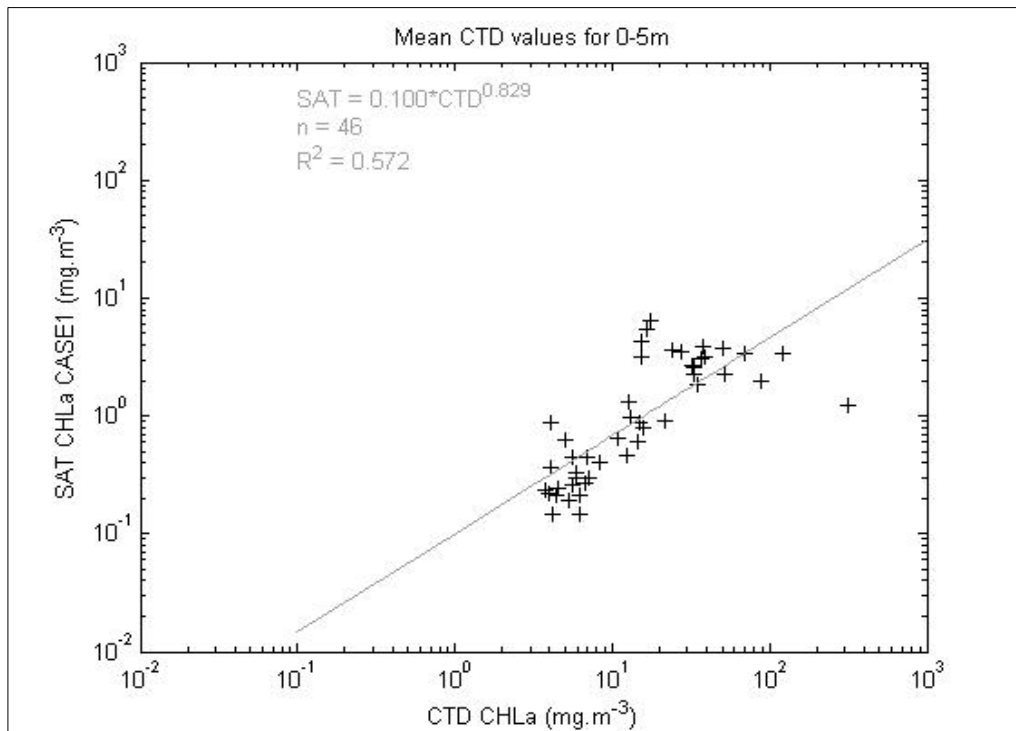


Figure 15 Correlation of remote sensing (case-1, 1km<sup>2</sup>) and fluorometer (mean value for 0-5m water depth) estimates of chlorophyll-a concentrations measured at corresponding points in the Bay of Plenty.

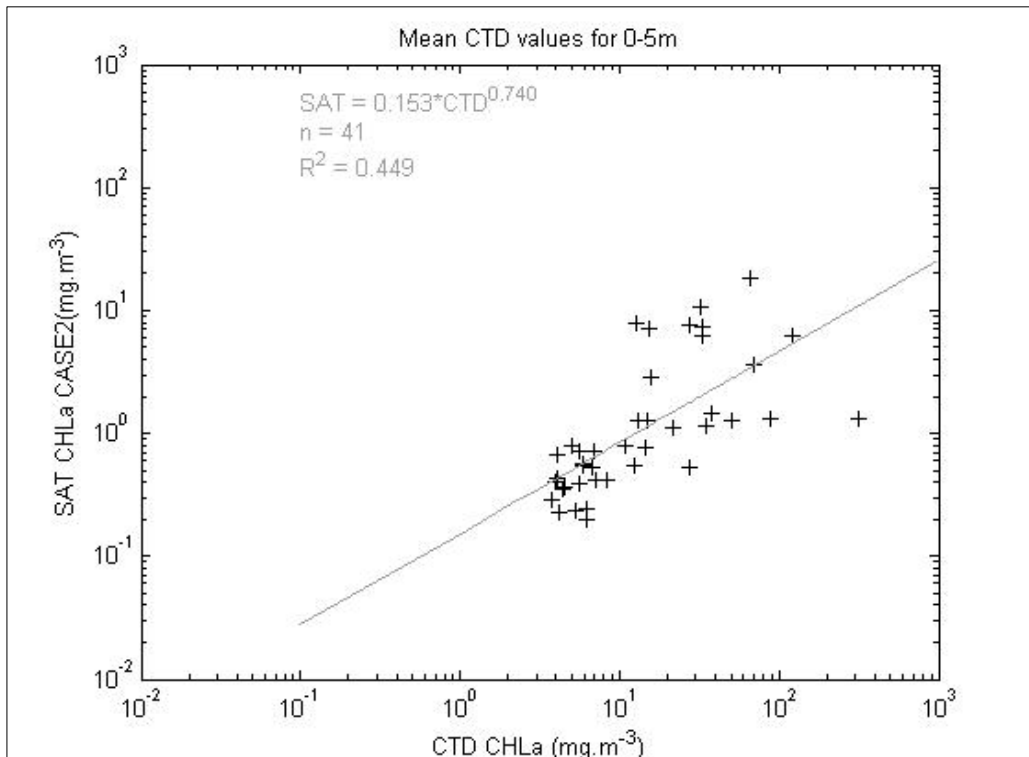


Figure 16 Correlation of remote sensing (case-2, 1km<sup>2</sup>) and fluorometer (mean value for 0-5m water depth) estimates of chlorophyll-a concentrations measured at corresponding points in the Bay of Plenty.

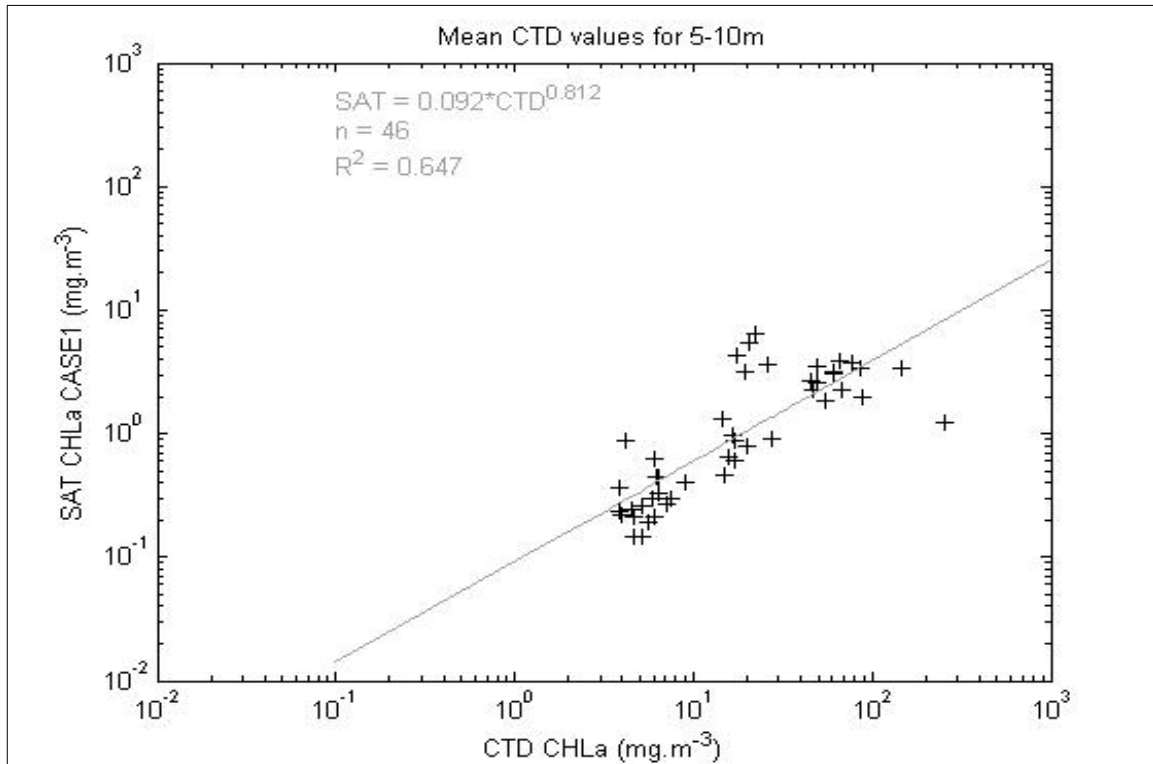


Figure 17 Correlation of remote sensing (case-1, 1km<sup>2</sup>) and fluorometer (mean value for 5-10m water depth) estimates of chlorophyll-a concentrations measured at corresponding points in the Bay of Plenty.

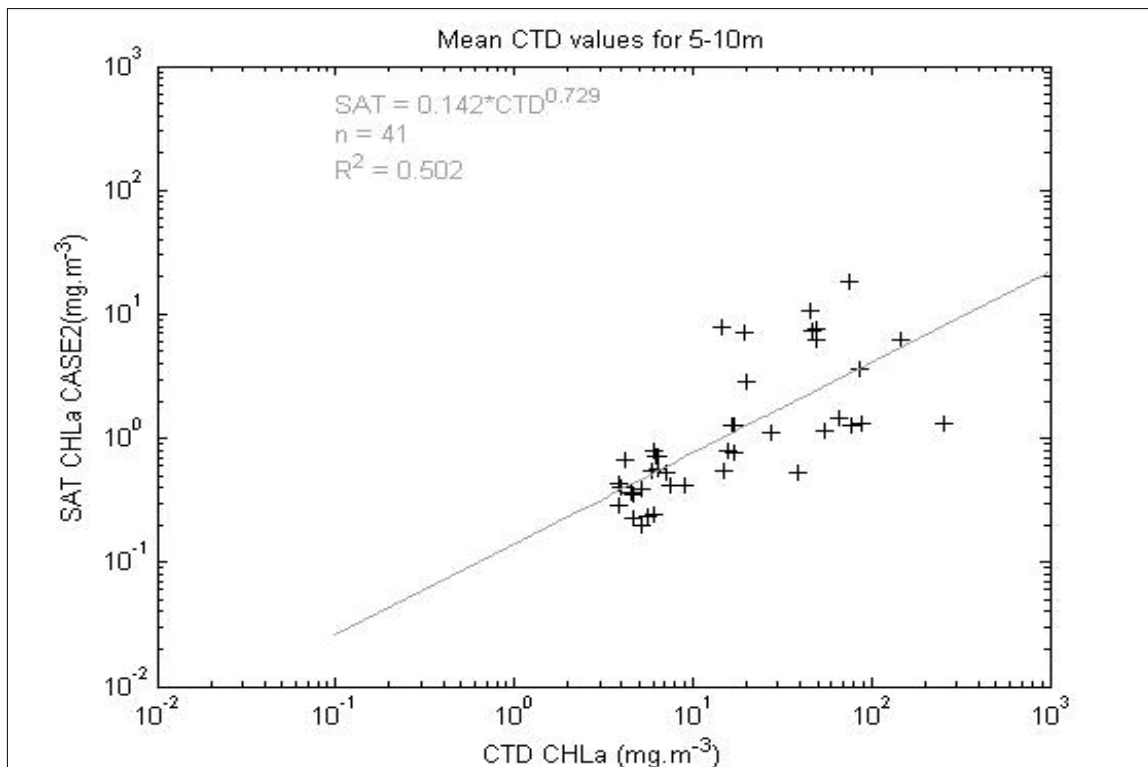


Figure 18 Correlation of remote sensing (case-2, 1km<sup>2</sup>) and fluorometer (mean value for 0-5m water depth) estimates of chlorophyll-a concentrations measured at corresponding points in the Bay of Plenty.

## Chapter 4: Discussion

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Remote sensing data of sea surface temperatures and chlorophyll-a estimates proved to be a very good method for determining spatial patterns of these parameters throughout the Bay of Plenty. Sea surface temperature as measured by satellite provided accurate values that correspond well with data collected in the field.

The main feature dominating the offshore Bay of Plenty waters on long term time scales as represented by the 10-year monthly means was the East Auckland current which flows down the north-east coast bringing warm water with it. This helps maintain a year-round temperature gradient with lower temperatures on average being recorded inshore close to the coast.

The other mechanism by which temperatures are lowered close to the coast is up-welling which is suggested in some of the high resolution 3-day composites. The high resolution 3-day composites of sea surface temperature also highlight some of the smaller and short-term hydrodynamic features which develop in the form of eddies and inshore intrusions etc.

Comparing 3-day composites of both sea surface temperature and chlorophyll-a estimates clearly shows the dynamic links between the hydrodynamics of the bay and surface biomass in terms of nutrient inputs and phytoplankton growth.

Use of an algorithm developed specifically for estimating chlorophyll-a concentrations in the inshore waters (case-2) of the Bay of Plenty from remote sensing data showed a high degree of accuracy for the conditions present at the time the calibration survey was made (Richardson *et al.* 2005). However, as stated in that report the algorithm ideally needs to be calibrated against a range of conditions which could occur.

Attempts to correlate remote sensing chlorophyll-a estimates with field data are not easy because of the differences in the scale of the measurements (km<sup>2</sup> vs. point sample) and high spatial variability, particularly over small distances. Results did show that case-1 estimates of chlorophyll-a had higher correlation coefficients than the case-2 estimates. The 3-day composites show that under some conditions the case-2 algorithm will produce higher values (due to cloud contamination) than case-1. On the basis of long-term means the case-2 algorithm must be returning lower values as shown by the 7-year monthly means.



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## Appendices

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### Appendix I Site location and sampling program



## Appendix I – Site location and Sampling program

### Sampling Sites

	Latitude	Longitude	NZMS 260 Grid ref. (m)		labstar #
<b>Tauranga Transect</b>					
10 m depth	37 35 40.9	176 08 34.8	2787737	6395999	730031
20 m	37 34 53.4	176 09 54.0	2789731	6397394	730032
30m	37 34 05.5	176 11 13.2	2791725	6398800	730033
50m	37 31 00.0	176 16 00.0	2798966	6404261	730034
100m	37 27 45.0	176 22 21.0	2808542	6409921	730035
200m	37 25 12.0	176 25 43.0	2813682	6414446	730036
<b>Pukehina Transect</b>					
10m	37 49 25.3	176 36 34.8	2827892	6369054	730043
20m	37 48 51.6	176 36 59.3	2828533	6370066	730044
30m	37 47 11.5	176 38 10.8	2830408	6373078	730045
50m	37 45 05.0	176 39 41.1	2832774	6376884	730046
100m	37 40 12.4	176 43 10.9	2838278	6385687	730047
200m	37 38 30.7	176 44 23.6	2840189	6388745	730048
<b>Whakatane Transect</b>					
10m	37 56 02.0	177 00 53.3	2862982	6355319	730037
20 m	37 55 35.4	177 01 17.3	2863604	6356112	730038
30m	37 53 43.1	177 02 22.4	2865348	6359500	730039
50m	37 51 41.9	177 04 00.0	2867899	6363125	730040
100m	37 44 12.9	177 08 30.5	2875141	6376649	730041
200m	37 41 51.9	177 10 02.0	2877580	6380891	730042
<b>Opotiki Transect</b>					
10m	37 58 41.4	177 15 44.1	2884479	6349415	730049
20m	37 57 50.0	177 15 47.5	2884636	6350990	730050
30m	37 56 04.3	177 15 58.0	2885047	6354233	730051
50m	37 51 55.7	177 16 23.1	2886021	6361859	730052
100m	37 44 42.6	177 17 06.2	2887710	6375147	730053
200m	37 39 27.4	177 17 37.3	2888933	6384817	730054

## Sampling program

At each sampling station the following parameters were recorded; vertical light attenuation, secchi depth, and dissolved oxygen, temperature, fluorescence, turbidity and salinity/conductivity profiles. These profiles are based on the down-cast recordings from the SBE 19 Plus probe.

Surface sampling (0-5m) in the plans below is an integrated tube sample except for the Enterococcal samples.

Sampling plan for phytoplankton identification and enumeration, 168 spot samples (14 per transect)

Sample Depth (m)	Sampling Station (depth contour m)					
	10	20	30	50	100	200
0-5 .	x	x	x	x	.	x
10 ..	.	.	.	.	.	.
20 ....	.	x	x	x	.	x
30 .....	.	.	.	x	.	x
50 .....	.	.	.	x	.	x
100 .....	.	.	.	x	.	.
200 .....	.	.	.	.	.	.

Sampling plan for phytoplankton size fractionation (Chl-a), 144 spot samples (9 per transect)

Sample Depth (m)	Sampling Station (depth contour m)					
	10	20	30	50	100	200
0-5 .	.	x	.	x	.	x
10 ..	.	.	.	.	.	.
20 ....	.	x	.	x	.	.
30 .....	.	.	.	x	.	x
50 .....	.	.	.	x	.	.
100 .....	.	.	.	x	.	.
200 .....	.	.	.	.	.	.

Sampling plan for dissolved nutrients DRP, NH<sub>4</sub>, NO<sub>3</sub>, 288 spot samples (18 per transect)

Sample Depth (m)	Sampling Station (depth contour m)					
	10	20	30	50	100	200
0-5 .	x	x	x	x	x	x
10 ..	.	.	.	.	.	.
20 ...	x	x	x	.	x	.
30 ....	.	.	x	x	.	x
50 .....	.	.	.	x	x	x
100 .....	.	.	.	.	x	.
200 .....	.	.	.	.	.	x

Sampling plan for TN, TP, SS, DRSi, DFe and TOC/DOC, 192 spot samples (16 per transect).

Sample Depth (m)	Sampling Station (depth contour m)					
	10	20	30	50	100	200
0-5 .	x	x	x	x	x	x
10 ...	.	.	.	.	.	.
20 ....	.	x	x	x	.	.
30 ....	.	.	x	x	.	x

50 . . . . .	x	x	.
100 . . . . .		x	.
200 . . . . .			x

Sampling plan for Enterococci bacteria, 96 spot samples (6 per transect).

**Sample Sampling Station** (depth contour m)

<b>Depth (m)</b>	10	20	30	50	100	200
0 . . .	x	x	x	x	x	x