Reef Rescue Marine Monitoring Program: using remote sensing for GBR wide water quality.

Final Report for 2009/10 Activities

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CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

Given the size and variability of conditions within the Great Barrier Reef (GBR) catchments and receiving waters, monitoring the water quality in the GBR lagoon waters is challenging. In situ monitoring data tends to be sparse in both space and time and as a result, remote sensing is now recognised as a suitable and cost-effective technique for the large-scale monitoring of coastal water quality. It is a particularly attractive alternative because it provides synoptic views of the spatial distribution of concentrations of chlorophyll-a (CHL) and total suspended solids (TSS), as well as the water clarity and the absorption by coloured dissolved organic matter (CDOM) of near-surface water. The daily frequency of satellite sensors improves our ability to identify patterns of spatial variation over scales of hundreds of meters to hundreds of kilometres and temporal scales of days to years. Yet, management-relevant products from remote sensing data that provide information beyond that of a simple concentrations map are needed by management agencies.

At present, MODIS Aqua represents a time series from November 2002 to present of water quality estimates with spatial coverage at 1 km resolution, nominally on a daily basis (except overcast days) for the whole-of-GBR lagoon. The water quality estimates were retrieved from the MODIS Aqua time series using two coupled physics-based inversion algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon (Brando et al. 2008a; Brando et al. 2010a; Brando et al. 2010b; Schroeder et al. 2008). This was necessary because Chlorophyll-a concentrations retrieved with the MODIS standard algorithms provided by NASA are inaccurate up to two-fold in GBR waters (Qin et al., 2007), while CSIRO’s regionally parameterised algorithms do account for the significant variation in concentrations of CDOM and TSS and achieve more accurate retrievals (Brando et al. 2010a; Brando et al. 2010b).

The results for the six reporting regions are presented as wet and dry season median maps of CHL, CDOM, TSS, water clarity expressed as Secchi Depth and the vertical attenuation coefficient of light. Also presented are maps reporting the number of valid pixels (i.e. cloud-free and error free) used for calculating the median values.

The number of available observation is significantly lower in the wet season than the dry season for all the regions. This is due to the higher cloud cover in the monsoonal season. It is possible that the cloud cover introduces a bias in the sampling that could affect the estimate of the median and mean concentration or any other statistical analysis of the imagery. The effect of cloud cover on the estimate of statistical parameters such as mean and median needs further investigation using time series data from moored sensors or the output from biogeochemical models.

The Great Barrier Reef Marine Park Authority (GBRMPA) has released in 2009 specific water quality guidelines for the Marine Park. These Guidelines provide triggers for management action where exceedance occurs and threshold levels for analysis of current condition as well as trend monitoring The exceedance of the Guidelines was assessed for two of the water quality variables that can be retrieved from remote sensing: CHL and TSS retrieved from MODIS Aqua using CSIRO’s algorithms.

The exceedance assessment results evaluated for CHL and TSS were presented as maps of exceedance as defined by the Guidelines, i.e. when mean values for the year (and seasons) exceed the thresholds, as well as the Exceedance Probability (EP) that provides the number of days where the concentration exceeded the threshold divided by number of days with (error-free) data for that period. The spatial patterns in exceedance were a function of the coastal to offshore gradients that can be observed in the median maps and of the different trigger values between the Midshelf and Offshore areas. For this report the metrics for the assessment of exceedance to the guideline values have been slightly modified compared to the Reef Rescue Marine Monitoring Program (MMP) report 2008/09 (Brando et al. 2010a). To enable a comparison of this study with the results of the 2008/09 reporting period, all assessment of exceedance tables (Tables 4-33) in the MMP report 2008/09 were recomputed and presented in Appendix 2.

For all reporting regions except Mackay Whitsunday the Open Coastal water body shows high areas of non compliance for Chlorophyll-a (56-83 % of relative area of the water body). The results of the previous reporting period presented a similar pattern of non compliance. The Open Coastal water body includes also all the Enclosed Coastal waters which have not been delineated by GBRMPA. As the guideline values for CHL and TSS for the Enclosed Coastal waters are higher than those for the Open Coastal water body the relative area of non-compliance for the Open Coastal is likely to be over-estimated. It is recommended to GBRMPA to delineate the Enclosed Coastal water body. The data used in this report will still be available and could be re-examined for consistency across both baseline reporting years as well as future years.

The freshwater plume extent into the lagoon during the wet season was estimated from MODIS measurements by applying a threshold to maps of aggregated seasonal maximum CDOM absorption at a reference wavelength of 443 nm. The freshwater extent based on the CDOM maximum provides a conservative estimate of the extent as the flood plumes could have extended further in cloudy or overcast days and hence not been captured with the satellite imagery. The extent and inter-annual variability of freshwater plumes in the Great Barrier Reef lagoon was found to be highly correlated with river flow data from stream gauges. The estimated freshwater extent the Fitzroy and Burnett Mary regions was higher than in 2008/2009 and comparable with the 2007/08 wet season when the largest flood since 1991 had occurred in the Fitzroy. For the Wet Tropics and Burdekin regions estimated freshwater extent was smaller than in the the previous wet season, reflecting flow conditions below or just above median levels.

Recommendations and future work

Comprehensive wet season studies carried out by CSIRO’s Environmental Earth Observation Group with DEWHA co-funding, has shown that considerable differences in optical properties and concentrations are found between the dry and wet season for the GBR lagoonal waters. In order to incorporate seasonal knowledge of variability in the specific inherent optical properties in the algorithms, a new comprehensive statistical analysis should be performed to include the optical characterizations carried out in the last two years, in particular those of the flood waters of the Fitzroy River in Keppel Bay (February 2008) and the wet season sampling of the wet tropics (April 2008).

CSIRO’s Environmental Earth Observation Group has been commissioning the Lucinda Jetty Coastal Observatory (LJCO), as part of the Australian National Mooring Network, one the facilities of Australia’s Integrated Marine Observing System (IMOS). LJCO aims to provide valuable data in tropical Queensland coastal waters to unravel the inaccuracies in remotely-sensed satellite ocean colour products due to the optical complexity in coastal waters and the overlying atmosphere. The LJCO data stream will increase the number of satellite vs. in situ match-ups assessment of normalized water-leaving radiances, water inherent optical properties and aerosol optical properties.

Meanwhile, AIMS is leading the setup of GBROOS (Great Barrier Reef Ocean Observing System). Several autonomous water quality loggers are being deployed in GBR waters with the support of MMP and IMOS. Also water quality data is provided by the flow-through system installed on the AIMS vessel RV Cape Ferguson. This dataset will provide insight in the spatial variability of water quality in the GBR waters. The value for remote sensing validation of the Chlorophyll-a data from GBROOS/IMOS sampling and moorings should be investigated as a priority over the next 24 months.

For this study a CDOM absorption threshold was established from visual inspection of a daily imagery, further work is needed to establish a threshold based on the relationship between measurements of salinity and CDOM absorption as proposed for the North and Baltic Seas (Astoreca et al. 2009; Ferrari and Dowell 1998). The high CDOM concentrations may also reflect other processes in occurring in near-shore waters, further work should also attempt to separate the “plumes” from non-plume effects .

The MMP water quality monitoring uses three complementary approaches to collect data at various spatial (site, location, region, and whole GBR lagoon) and temporal (snapshot, daily, 10-minutely) scales: traditional direct water sampling from research vessels, in situ data loggers at a small number of selected inshore reef locations and remote sensing techniques. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution. Given the spatial and temporal complexity of the data, the development of an integrated assessment and reporting framework is needed to provide a comprehensive and more easily interpretable assessment of GBR water quality.

The metrics used in this study to evaluate compliance are meant to provide a demonstration of the use of remotely sensed data in the assessment of exceedance to the Guidelines. These metrics are based on a high number of observations (ranging from hundreds of thousands valid observations for Open Coastal in the wet season to millions for the Offshore area in the dry season). Further work in designing the exceedance/compliance metrics and how to combine the assessment over more variables is needed to improve confidence in these results. This will enable these datasets to meet the requirements of the reasonable assurance statements and the monitoring and modelling strategies for the Paddock to Reef reporting.

INTRODUCTION

Water quality is a key issue for the health of the Great Barrier Reef (GBR), catchments and for the communities, industries and ecosystems that rely on good water quality in North Queensland.

The Great Barrier Reef Water Quality Protection Plan (GBRWQPP) was released by the Australian and Queensland Governments in October 2003 with the ultimate goal to 'halt and reverse the decline in water quality entering the Reef within 10 years'. The Reef Plan Marine Monitoring Program (now Reef Rescue Marine Monitoring Program, MMP thereafter) was established to assess the health of key marine ecosystems (inshore coral reefs and seagrasses), the condition of water quality in the inshore GBR lagoon and water quality of water masses entering the Great Barrier Reef during the wet season. The Marine Monitoring Program is now funded under the Australian Government's Reef Rescue initiative and is managed by the Reef and Rainforest Research Centre (RRRC).

This report will describe the activities carried out under RRRC Project 3.7.2 b (objective b) and RRRC Project 3.7.8 (objective b) on the use of Remote Sensing for reporting GBR wide water quality.

Underlying activity for both projects is the acquisition, processing with regionally valid algorithms, validation and transmission of geo-corrected MODIS ocean colour imagery. MODIS ocean colour imagery was used to quantify near-surface concentrations of total suspended solids (TSS), coloured dissolved organic matter (CDOM) and Chlorophyll-a (CHL) for the GBR.

Key Objectives of the two projects are:

- Provide medians and summary images derived for MODIS data for TSS CHL and CDOM within the inshore and offshore areas, during the wet and dry seasons.
- To assess the temporal and spatial variation in the extent of available 2009/10 river flood plumes across the 6 GBR natural resources manamegement (NRM) regions.
- To assess the exceedance of water quality guidelines for two of the water quality variables that can be retrieved from remote sensing: CHL and TSS retrieved from MODIS Aqua using CSIRO's algorithms.

METHODS

Given the size and variability of conditions within the GBR catchments, monitoring the water quality in the GBR lagoon waters is challenging. The MMP water quality monitoring uses three complementary approaches to collect data at various spatial (site, location, region, and whole GBR lagoon) and temporal (snapshot, daily, 10-minutely) scales: traditional direct water sampling from research vessels, in situ data loggers at a small number of selected inshore reef locations and satellite based remote sensing. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution.

Remote sensing is a suitable and cost-effective technique for the synoptic monitoring of coastal water quality, because it provides synoptic views of the spatial distribution of CHL, CDOM and TSS concentrations, and water clarity of near-surface water. The daily frequency of satellite sensors improves our ability to identify patterns of spatial variation over scales of hundreds of meters to hundreds of kilometres and temporal scales of days to years. Management-relevant products from remote sensing data that provide information beyond that of a simple concentrations map are needed by management agencies to make more informed decisions.

Regionally valid retrieval of water quality parameters from satellite imagery

Based on studies conducted in the Fitzroy Estuary (Brando et al. 2006; Oubelkheir et al. 2006) and the Mossman Daintree (Steven et al. 2007), it has been demonstrated that the NASA standard global Ocean Colour algorithms are inaccurate in nearshore GBR waters (Qin et al. 2007). Subsequently there has been considerable effort in developing regionally appropriate algorithms for these optically complex GBR waters. Studies commissioned by the Great Barrier Reef Marine Park Authority (GBRMPA) on water quality monitoring (Schaffelke et al. 2006) and optical characterisation of coastal waters (Blondeau-Patissier et al. 2009) have also been undertaken and contribute to the development of regionally appropriate algorithms using a semi-analytical physics-based approach parameterised and validated with local measurements (Brando et al. 2010a; Brando et al. 2010b).

In this work we coupled two physics-based inversion algorithms to improve the accuracy of water quality estimates from MODIS Aqua data in GBR Lagoon coastal waters. In a first step, an atmospheric correction algorithm based on inverse modelling of radiative transfer simulations and Artificial Neural Network (ANN) inversion, derives the remote sensing reflectance at mean sea level (Schroeder et al. 2007; Schroeder et al. 2008) Then, the inherent optical properties and the concentrations of the optically active constituents, namely Chlorophyll-a, non-algal particulate matter (NAP, as a measure of TSS) and CDOM, were retrieved using an enhancement of the Linear Matrix Inversion (LMI, Hoge and Lyon 1996) that incorporates regional and seasonal knowledge of specific Inherent Optical properties IOPs (Brando et al. 2008a).

The comparison of MODIS Aqua retrievals of Chlorophyll-a, CDOM and NAP with in situ data showed that the regional algorithm coupled with the ANN atmospheric correction is more accurate than NASA’s algorithms for GBR waters. The accuracy for the retrieval of Chlorophyll-a, CDOM and TSS with the coupled physics-based inversion algorithms was 58%, 57% and 66%, respectively. The parameterization and validation on the remote sensing retrievals was manily based on observations performed in coastal and lagoonal waters during the dry season between Keppel Bay and wet tropics. The accuracy of the retrieval is likely to likely to be lower in shallow and turbid waters systems such as Princess Charlotte Bay, Broad Sound, Shoalwater Bay where there is no data available for parameterization and validation. Details on the algorithm's theoretical basis, parameterization and validation are provided in Appendix 1.

Management relevant remote sensing products to monitor water quality in GBR

If environmental managers are to take full advantage of remote-sensing capabilities then products that translate remotely-sensed scenes into useful information for managers are required. From daily remote sensing data, it is possible to produce a number of derived products suited to the specific needs of end-users or to particular geographic regions, in a number of outputs. Maps are the most common and depending on user requirements, any number of variables or derived indices and attributes can be mapped over specified spatial aggregations or over timescales from days to years. A prime example of management relevant products are those providing water quality compliance information for environmental reporting.

Water quality maps

In this report, the results for the six reporting regions are presented as seasonal median maps for Chlorophyll-a, CDOM, Total Suspended Solids, and the vertical attenuation coefficient of light. The seasonal median values for the wet and dry seasons were calculated pixel by pixel based on the daily valid observations (i.e. cloud-free and error free). Also presented are seasonal maps that present the number of valid pixels (i.e. cloud-free and error free) used for calculating the median values.The wet and dry season median maps of water clarity expressed as Secchi Depth are presented as a demonstration product. This product is still in a development phase and should be validated using the water quality data sets used in recent studies on the spatial and temporal patterns of water quality of the Great Barrier Reef (De'ath 2007; De'ath and Fabricius 2008).

The maps depicting the number of image pixels per pixel location available for calculating the median values for each season show values varying from 30 to about 90 for each season for each pixel location. Theoretically about 180 images should be available for each season. For the data of dry season 2008 and wet season 2009/2010 there were 150-170 images available depending on the reporting region. The reason for the significantly less available pixels is the quality control criteria we applied: pixels with cloud or cloud shadow were flagged and dismissed; pixels where the atmospheric correction failed were dismissed too: this caused the dearth of pixels in the very near coastal areas. Also dismissed were the pixels where the error between modelled and measured spectra was too high indicating that the underlying inversion model was not able to retrieve meaningful concentrations.

For this report further masking for the quality flags was implemented for the solar zenith and observer zenith maximum 60 degrees, avoiding low view angles and pixels. As a result of this stricter quality control, the number of available observations for each pixel is lower than in previous reports.

The number of available observations is significantly lower in the wet season than the dry season for all the regions. This is due to higher cloud cover in the monsoonal season. It is possible that the cloud cover introduces a bias in the sampling that could affect the estimate of the median and mean concentration or any other statistical analysis of the imagery. The effect of cloud cover on the estimation of statistical parameters such as mean and median needs further investigation using time series data from moored sensors or the output from biogeochemical models.

Evaluation of compliance to guidelines

In addition to the median concentration maps, this year the exceedance of water quality guidelines was assessed for CHL and TSS retrieved from MODIS Aqua imagery using CSIRO’s algorithm. The exceedance could also be evaluated for the Secchi Depth imagery when accuracy of this retrieval is assessed with a match-up analysis of data recently made available by AIMS.

A set of water quality guideline values and objectives has been released in 2009 by federal and state legislation for the GBR, with an effort to avoid inconsistency in the regions of overlap. Version 3 of the Queensland Water Quality Guidelines (DERM 2009) was released to promote regionally and locally relevant guideline water quality values for Queensland coastal waters which extend up to 3 nautical miles offshore. Regionally specific environmental values and objectives have been set in some specific areas through the development of Water Quality Improvement Plans (WQIPs). The Great Barrier Reef Marine Park Authority (GBRMPA) has released the Water Quality Guidelines for the Marine Park Sea(hereafter called the Guidelines) nd has identified five water bodies: the Enclosed Coastal waters, the Open Coastal waters, the Midshelf waters, the Offshore waters, and the Coral Sea (GBRMPA 2009). Much of the Great Barrier Reef Marine Park lies beyond Queensland state waters but there is an area of overlap within the inshore coastal waters for which protocols have been agreed. Namely, Queensland guidelines are to be adopted for all waters inshore of and within the Enclosed Coastal zone. Offshore from the Enclosed Coastal zone and within waters of the GBR Marine Park, the Guidelines will apply, even if the boundary of the Enclosed Coastal zone lies inside the three nautical mile zone.

Figure 1 reports the regional and cross shelf boundaries defined by GBRMPA for the MMP 2008/09 reporting and used for this study. These boundaries were delineated by implementing in a GIS environment the "Approximate water body delineations of the Open Coastal, Midshelf and Offshore marine water bodies in the six NRM regions" of Table 1 at page 12 of the Guidelines (GBRMPA 2009). The Enclosed Coastal waters were not delineated, as according to GBRMPA they are likely to be a small area, especially in the context of GBR wide water bodies (Hugh Yorkstone, pers comm. 10 Aug 2010).

The exceedance assessment results were presented as maps of exceedance as defined by the Guidelines, i.e. when mean values for the year (and seasons) exceed the thresholds, as well as the Exceedance Probability (EP) that provide the number of days where the concentration exceeded the threshold divided by number of days with (error-free) data for that period. The GBRMPA guideline values used as triggers levels for the analysis of exceedance in this study are reported in Table 1 and Table 2. The maps will also be accompanied by two tables summarising the exceedance results for each variable for each reporting region: 1) the summary of the exceedance maps, providing the relative surface area in that resulted in exceedance of the trigger values; and 2) the summary of exceedance, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EP for that period.

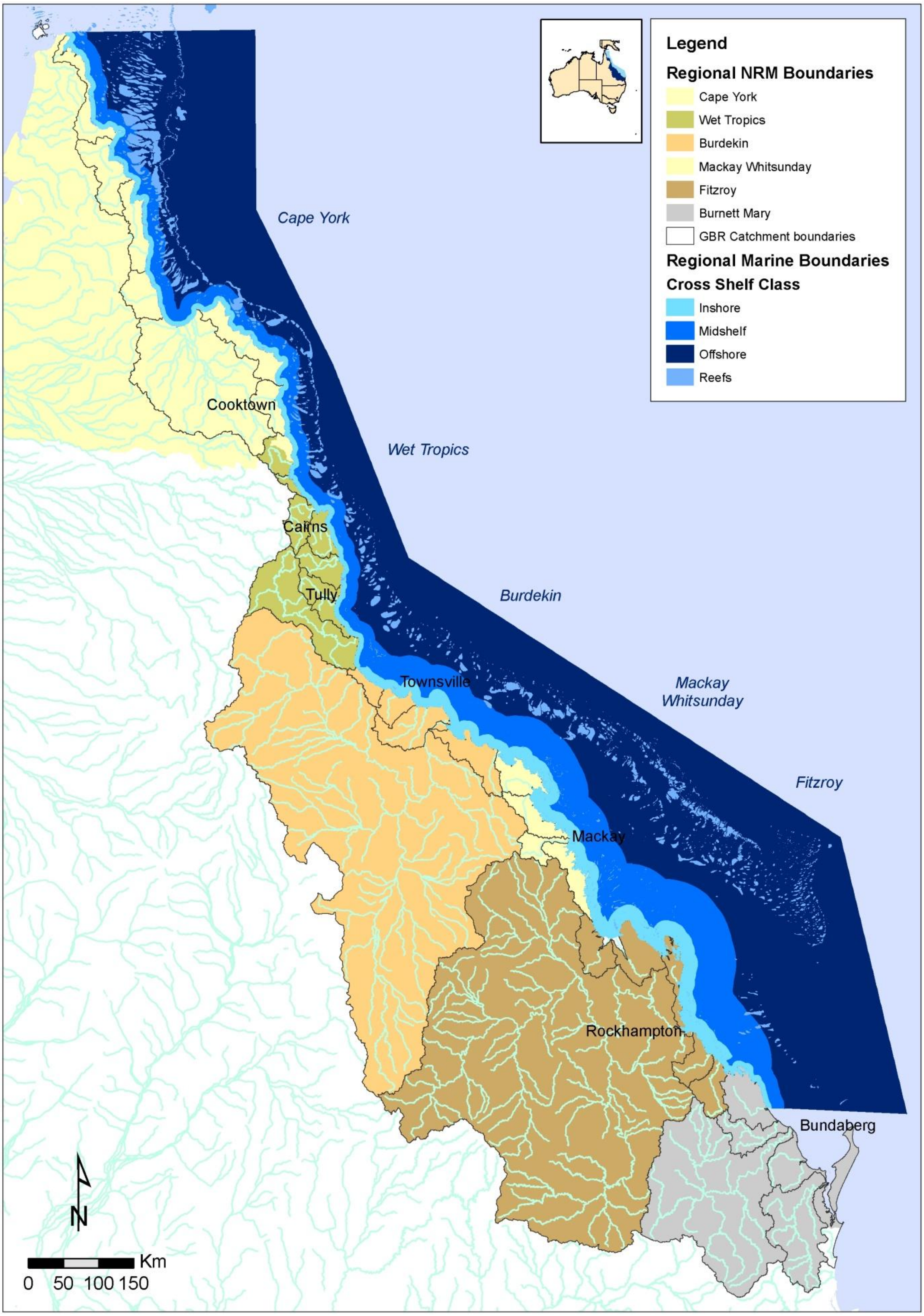


Figure 1. Regional and cross shelf boundaries defined by GBRMPA for the MMP 2008/09 reporting.

Table 1 Trigger values from the Great Barrier Reef Marine Park Authority Water Quality Guidelines (GBRMPA 2009). Guideline values for the assessment on annual basis. *:Geographical adjustment: Wet Tropics/Central Coast (see Figure 1).

	Water body			
Parameter	Enclosed Coastal	Open Coastal	Midshelf	Offshore
Chlorophyll-a (µg L^{-1})	2.0	0.45	0.45	0.40
Secchi Depth (m)	1.0/1.5*	10	10	17
Total Suspended Solids (mg L^{-1})	5.0/15*	2.0	2.0	0.7

Table 2 Trigger values from the Great Barrier Reef Marine Park Authority Water Quality Guidelines (GBRMPA 2009). Seasonally adjusted values for the assessment in dry/wet seasons.

	Water body			
Parameter	Enclosed Coastal	Open Coastal	Midshelf	Offshore
Chlorophyll-a (µg L^{-1})	2.0	0.32/0.63	0.32/0.63	0.28/0.56
Secchi Depth (m)	1.0/1.5	10	10	17
Total Suspended Solids (mg L^{-1})	5.0/15	1.6/2.4	1.6/2.4	0.6/0.8

The metrics used in this study to evaluate compliance were developed with DEWHA funding (Brando et al. 2010b), and implemented in the MMP report 2008/09 (Brando et al. 2010a) to provide a demonstration of the use of remotely sensed data in the assessment of exceedance to the Guidelines. These metrics are based on a high number of observations (ranging from hundreds of thousands valid observations for Open Coastal in the wet season to millions for the Offshore area in the dry season). Further work in designing the exceedance/compliance metrics and how to combine the assessment over more variables is needed to provide a high degree of confidence in these results. This will enable these datasets to meet the requirements of the reasonable assurance statements and the monitoring and modelling strategies for the WQIPs of the NRM regions.

For this report the metrics for the assessment of exceedance to the Guidelines have been modified compared to the MMP report 2008/09. The Surface Area in all tables now reports the actual number of pixels with valid observations for each reporting region instead of the surface area of the whole water body as resulting from GBRMPA's GIS layers. As a result of this change the reported Surface Areas are lower than last year (10-20% lower depending on the region) affecting in turn the reported relative areas for each water body where the mean or the median exceeded the trigger value. Also as a result of the stricter quality control of the imagery, the number of available observations for each pixel is lower than for the MMP report 2008/09. This affected the estimates of the annual and seasonal mean and median values for the reported variables. To enable a comparison with the results of the 2008/09 reporting period, all assessment of exceedance tables (Tables 4-33) in the MMP report 2008/09 were recomputed and presented in Appendix 2.

Flood plume mapping

The extent and duration of flood plumes can have significant implications for the health of marine ecosystems such as seagrasses and coral reefs. The dynamics of a flood plume as it moves from the river mouth into the marine environment can be described in terms of the hydrological and chemical behaviour. At first flood plumes contain elevated concentrations of sediments (and associated nutrients and pesticides). Later, when particulate matter falls out of the plume waters the plume is characterised mainly by presence of the dissolved materials and the associated nutrients (Devlin et al. in press)..

In flood plumes, CDOM concentrations are high and are largely derived from terrestrial sources, making CDOM a useful tracer of terrestrial discharge of low salinity waters. For this study, the extent of freshwaters was estimated by applying a threshold to the maps of CDOM maximum values for the wet season. A CDOM absorption threshold at 443 nm of 0.2 m^{-1} was established from visual inspection of a series of daily true-colour composites and associated CDOM maps. Further work is needed to establish a threshold based on the relationship between measurements of salinity and CDOM absorption as proposed for the North and Baltic Seas (Astoreca et al. 2009; Ferrari and Dowell 1998). The freshwater extents presented in this report are mainly influenced by flood waters during wet seasons but they may also reflect other processes occurring in near-shore waters.

Guide to interpreting the maps

All maps produced for this report have a similar template: land is presented as dark grey, the coastal boundary is based on a standard coastline vector. Main rivers are presented in blue lines. Coral reefs including a 1 km buffer zone (to avoid mixed land or reef and water pixels) are presented as white.

Several boundary lines are overlayed onto the maps to enable the identification of water bodies identified by the Guidelines (Open Coastal, Midshelf, and Offshore). The boundaries for the reporting region are presented in each map as defined by GBRMPA in accordance with the NRM boundaries for the catchment and marine extensions (Figure 1). The cross shelf boundaries were by defined by GBRMPA to implement the Guidelines: the thick white line defines the Open Coastal waters; the thick pink grey line defines the Midshelf waters while the thick gray line delineates the Offshore waters; the thick black lines to the East in all images represents the limit of the GBRWHA.

In the maps of exceedance as defined by the Guidelines, pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. The maps of the EP report in a continuous colour scale the EP ranging from 0-0.50 so that the pixels are mapped in dark red (EP>= 0.50) when the median values for the year (and seasons) exceed the thresholds reported in Table 1 and Table 2. The spatial patterns in the exceedance maps are a function of the coastal to offshore gradients that can be observed in the median maps and of the steep changes in trigger values between the Midshelf and Offshore areas. Hence most often the exceedance in the Offshore areas was present in clusters to the East of the thick gray line delineating the 'Offshore' waters.

RESULTS AND DISCUSSION

This section will provide an overview of the satellite- based monitoring results for the whole-of-GBR followed by a detailed regional report for each of the six reporting regions. For each region, wet and dry season median maps are presented for CHL, CDOM, TSS (as NAP), and the vertical attenuation coefficient of light. Also presented are maps that show the number of valid pixels (i.e. cloud-free and error free) used for calculating the seasonal median values. In addition to the median maps, the exceedance of the Guidelines was assessed for CHL and TSS and the wet season freshwater extent was estimated from CDOM maps.

Great Barrier Reef wide summary

Assessment of freshwater extent during the wet season

Wet season flood plume movements across Great Barrier Reef marine waters are a consequence of the volume and duration of river (flood) flows, wind direction and velocity, as well as the local marine currents and tidal dynamics. Figure 2 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the whole of the Great Barrier Reef World Heritage Area. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. Detailed maps for each region are presented in the regional reporting sections (Figure 18, Figure 30, Figure 42, Figure 54, Figure 66, Figure 78).

Freshwater discharge from the Great Barrier Reef catchment in 2009/10 was ~1.2 times the annual median flow, with the flow in the Burdekin sightly above the median values and the freshwater discharge for the Fitzroy River four times above the long term median flow. This is comparable with the flows of the 2007/08 wet season when the largest flood since 1991 occurred (Figure 3). In 2007/08, both the Burdekin and Fitzroy Rivers experienced extensive flooding, and the Burdekin River flooded again over the 2008/09 wet season (Figure 4). The flow conditions in the Russell, Johnstone, Tully and Herbert Rivers were below median levels (0.6 – 0.8 times median levels, Figure 3), while the freshwater discharge for the Proserpine, O'Connell, Pioneer and Plane Rivers were above median flows (Figure 3).

Flood plumes extended across inshore waters of the southern and northern Great Barrier Reef, but had a more limited influence on far northern Great Barrier Reef waters. The freshwater extent based on the CDOM maximum provides a conservative estimate of the extent as the flood plumes could have extended further in cloudy or overcast days and hence may not been captured with the satellite imagery.The extent and inter-annual variability of freshwater plumes in the Great Barrier Reef lagoon were found to be highly correlated with river flow data from stream gauges. The estimated freshwater extent the Fitzroy and Burnett Mary regions was higher than in 2008/2009 and comparable with the 2007/08 wet season when the largest flood since 1991 had occurred in the Fitzroy (Figure 4).. For the Wet Tropics and Burdekin regions estimated freshwater extent was smaller than in the the previous wet season, reflecting flow conditions below or just above median levels (Figure 4)..

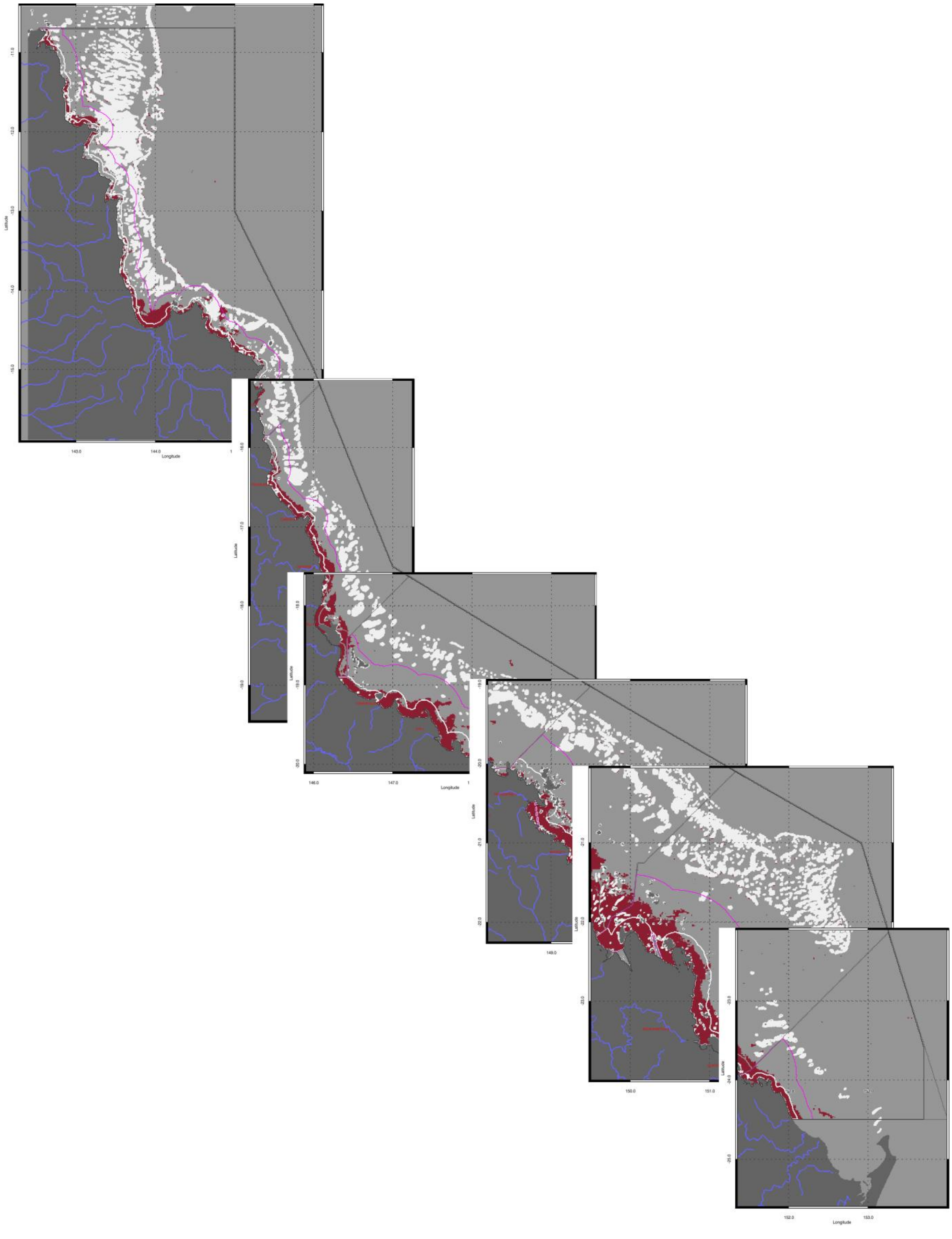


Figure 2. Collation of the freshwater extent maps for the wet season 2009/2010 (November 2009-April 2010) for the whole of the Great Barrier Reef World Heritage Area. Pixels are mapped in dark red when the CDOM seasonal maximum values for the year exceed the threshold of 0.2 m^{-1}. See text for annotation explanation.

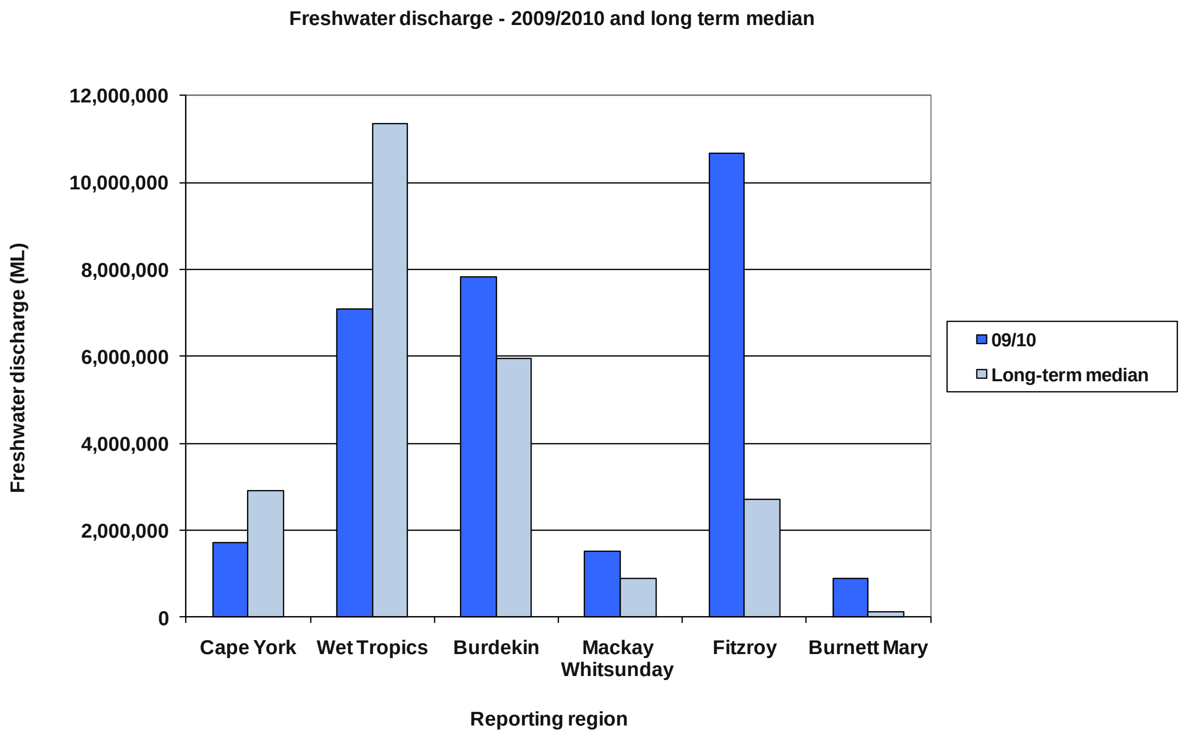


Figure 3. Comparison of fresh water discharge for 2009/2010 compared to the long term median for each reporting region of the Great Barrier Reef World Heritage Area. Data are aggregated from data supplied by the Queensland Department of the Environment and Resource Management for each river. Long-term medians were estimated from annual total flows (October to October).

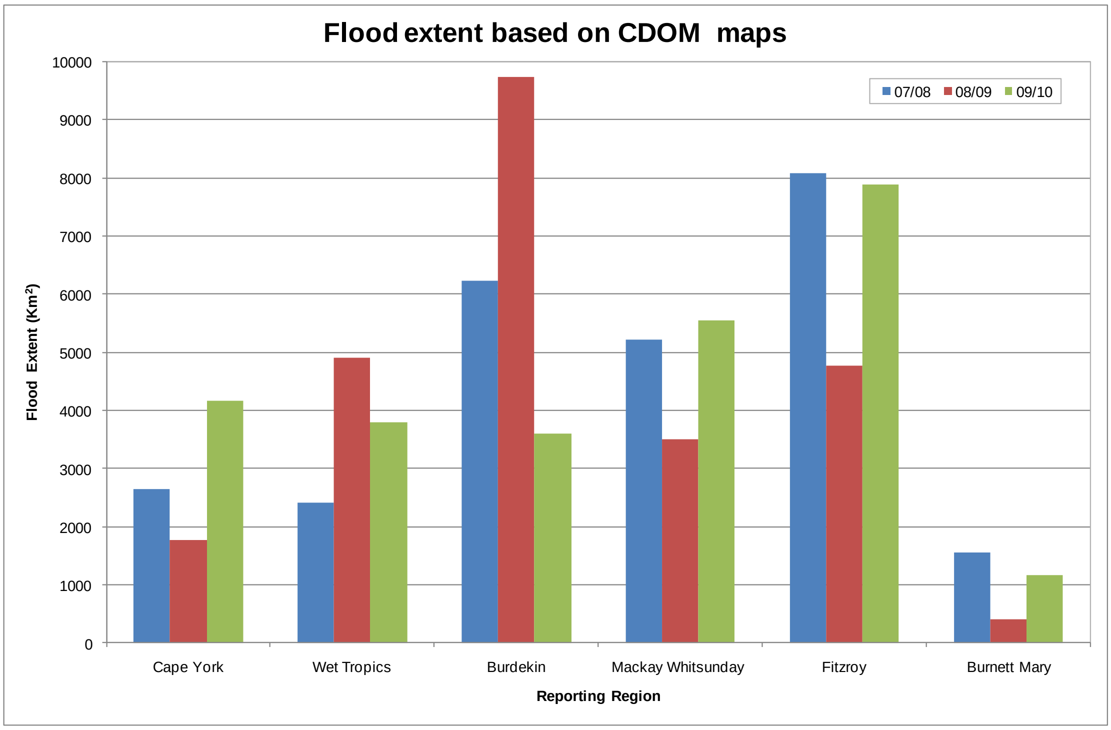


Figure 4. Comparison of freshwater extent for the wet seasons 2007/2008 (November 2007 - April 2008) 2008/2009 (November 2008- April 2009) and 2009/2010 (November 2009- April 2010) for each reporting region of the Great Barrier Reef World Heritage Area.

Assessment of the exceedance of water quality guidelines

Figure 5 is the map of the annual median for Chlorophyll-a 2009/2010 (1 May 2009 – 30 April 2010) for the whole of the Great Barrier Reef World Heritage Area. During the dry season a coastal to offshore gradient in Chlorophyll-a concentration was observed, with the inshore waters in the Wet Tropics and Burdekin Regions having elevated concentrations of Chlorophyll-a over the monitoring period. Detailed maps for the wet and dry season for each region are presented in the regional reporting sections.

Figure 6 shows the map of Exceedance of the mean annual Chlorophyll-a for the 2009/2010 reporting period (1 May 2009 – 30 April 2010) for the whole of the Great Barrier Reef World Heritage Area. For all reporting regions except Mackay Whitsunday the Open Coastal water body shows high areas of non compliance (56-83 % of relative area of the water body, Table 3). The results of the previous reporting period presented a similar pattern of high areas of non compliance (51-84% of relative area of the water body, Table 4). The assessment of the exceedance of the Guidelines is described in detail in the regional reporting sections with maps and tables summarising the exceedance results for CHL and TSS.

In this study the Open Coastal water body includes also all the Enclosed Coastal waters which have not been delineated by GBRMPA. As the guideline values for CHL and TSS for the Enclosed Coastal waters are higher than those for the Open Coastal water body (Table 1 and Table 2), the relative area of non-compliance for the Open Coastal is likely to be over-estimated.

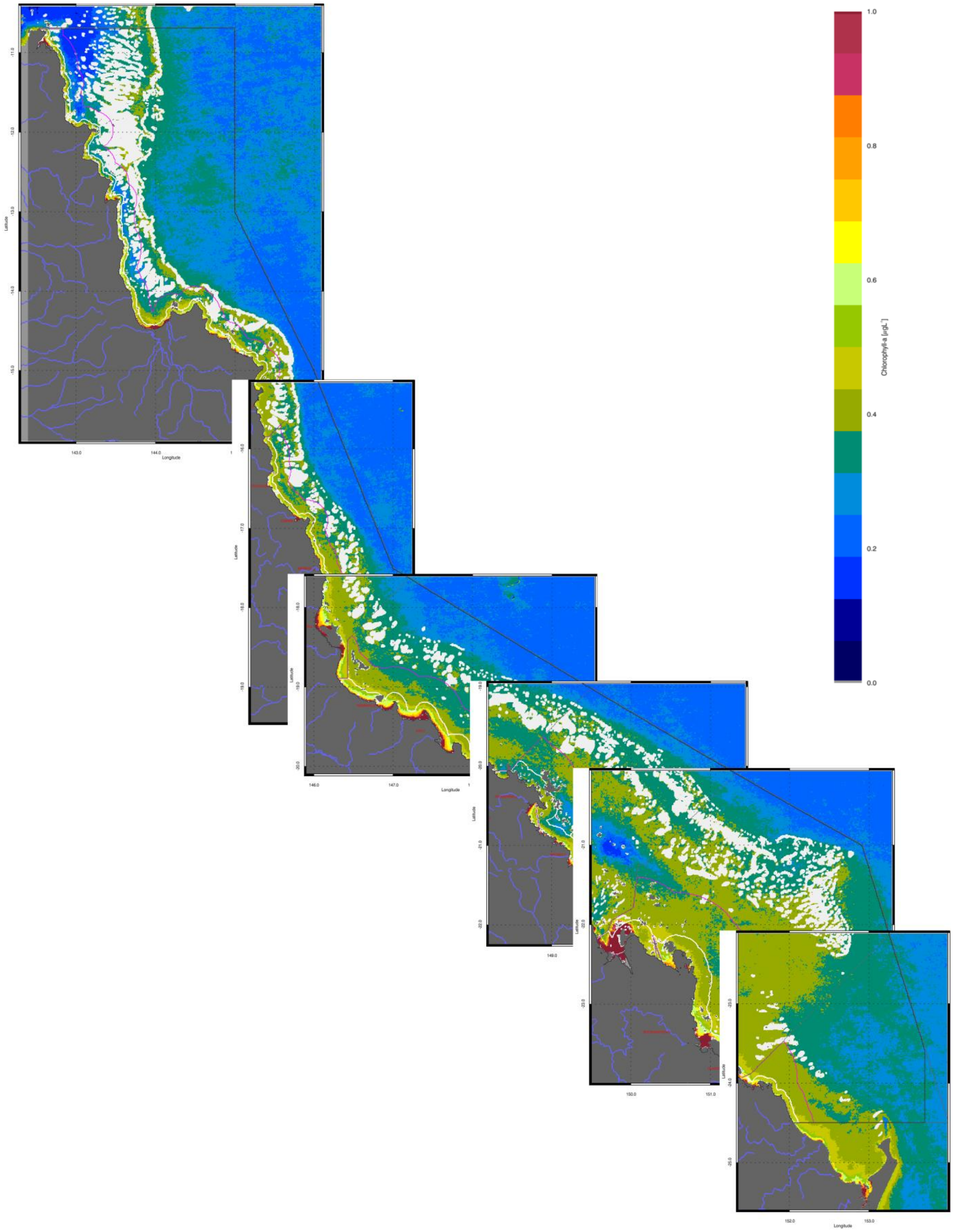


Figure 5. Collation of the Chlorophyll-a median maps for the 2009/2010 reporting period (May 2009 – April 2010) for the whole of the Great Barrier Reef World Heritage Area. See text for annotation explanation.

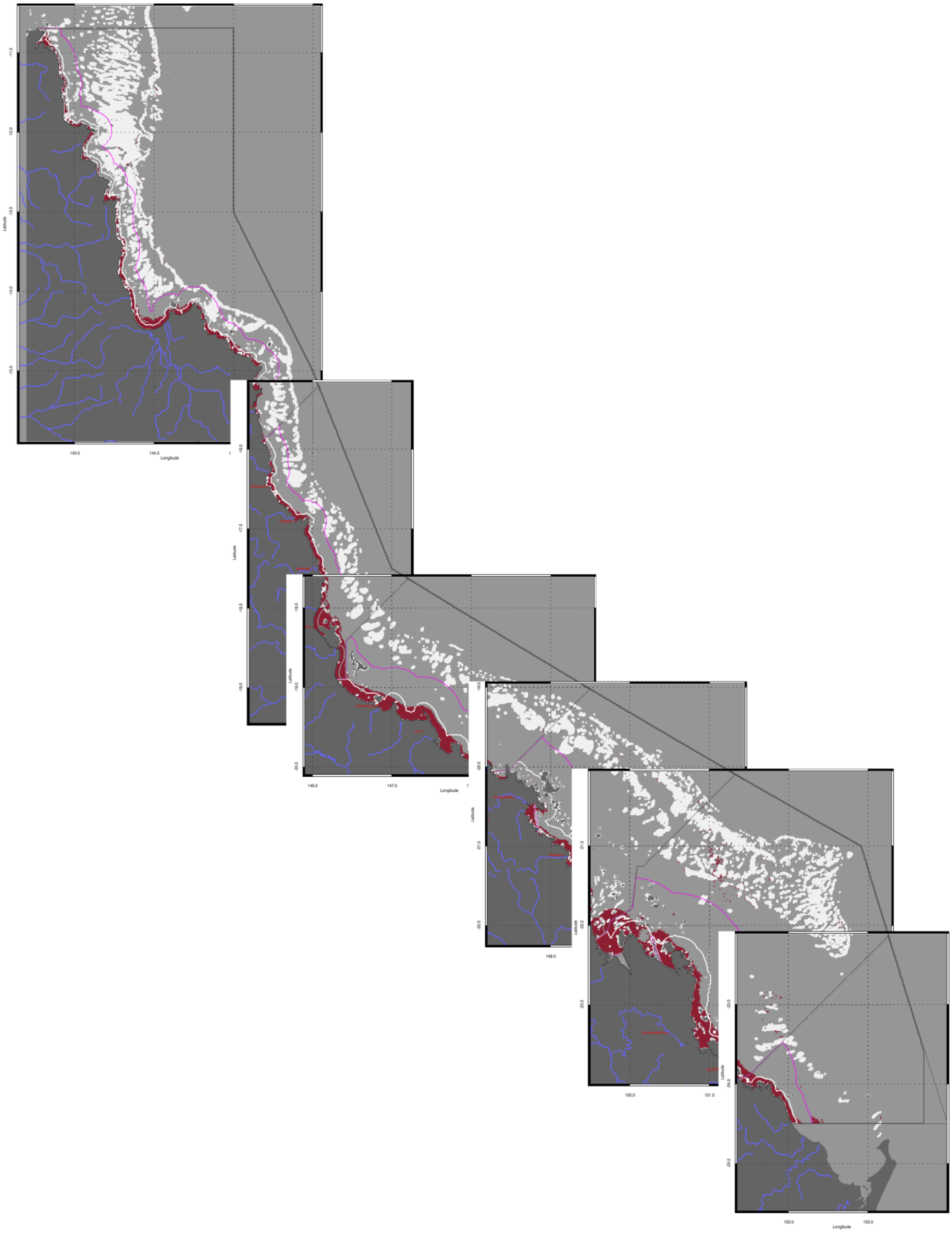


Figure 6. Collation of the exceedance maps of mean annual Chlorophyll-a for the 2009/2010 reporting period (1 May 2009 – 30 April 2010) for the whole of the Great Barrier Reef World Heritage Area. Pixels are mapped in dark red when mean values for the year exceed the thresholds. See text for annotation explanation.

Table 3. Summary of the exceedance of annual mean values of Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for this reporting period (1 May 2009 – 30 April 2010) for the Open Coastal, Mid-shelf and Offshore water bodies. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value			Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value		
	Open Coastal	Mid-shelf	Offshore	Open Coastal	Mid-shelf	Offshore
Cape York*	56	4	0	45	44	26
Wet Tropics	81	16	0	23	3	30
Burdekin	65	2	0	39	0	30
Mackay Whitsunday	32	3	0	69	40	64
Fitzroy	66	5	0	43	7	50
Burnett Mary *	83	4	0	12	0	48

Table 4. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the previous reporting period (1 May 2008 – 30 April 2009) for the Open Coastal, Mid-shelf and Offshore water bodies. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value			Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value		
	Open Coastal	Mid-shelf	Offshore	Open Coastal	Mid-shelf	Offshore
Cape York*	61	5	0	71	61	17
Wet Tropics	84	15	0	40	9	13
Burdekin	67	3	0	54	2	4
Mackay Whitsunday	33	2	0	84	42	63
Fitzroy	55	3	0	53	11	40
Burnett Mary*	51	4	0	10	0	1

Regional reports: Cape York region

Cape York Peninsula is the northernmost extremity of Australia. From its tip at Cape York it extends southward in Queensland for about 800km, widening to its base, which spans 650km from Cairns in the east to the Gilbert River in the west. The largest rivers in the Cape flow into the Gulf of Carpentaria, however there are several large catchments that drain into the GBR. The region has a monsoonal climate with distinct wet and dry seasons with mean annual rainfall ranging from 1715mm in the Starke region to 2159mm near the Lockhart River airport. Most rain falls between December and April. The Cape is an area of exceptional conservation value and has cultural value of great significance to both Indigenous and non-Indigenous communities. The majority of the land is relatively undeveloped, therefore water entering the lagoon is perceived to be of a high quality.

This system is characterized by shallow and turbid waters (e.g. in Princess Charlotte Bay) and a relatively narrow coastal water body. Caution should be used when interpreting the results for this region as limited field information was used for the parameterization and validation on the remote sensing retrievals.

The wet and dry season median maps for Chlorophyll-a, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of Chlorophyll-a (Figure 7) for the Cape York region show high CHL levels near the coast and in the estuary to lower concentrations towards the East. Median values of Chlorophyll-a to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.5 μgL^{-1}.

The wet and dry season median maps of CDOM (Figure 8) for the Cape York region show values higher than 0.20 m^{-1} for a coastal band ~5-10 km wide The wet and dry season median maps of NAP (as a measure of TSS) (Figure 9) for the Cape York region show similar gross patterns as for the CDOM distribution, with values higher than 3 mg/L in Princess Charlotte Bay.

The wet and dry season median maps of vertical attenuation of light (Figure 10) for the Cape York region show similar patterns as the Chlorophyll-a, coloured dissolved organic matter and non-algal particulate matter distribution. The difference in dark blue to light blue colours between the wet and dry season for K_d is due to the K_d being slightly dependent on average sun-angles during the satellite overpass. Sun light coming in at higher slant angles during the winter months is scattered more in the first meters of the water column. The wet and dry season median maps of water clarity expressed as Secchi Depth (Figure 11) for the Cape York region show similar gross patterns to the maps of vertical attenuation of light (Figure 10).

The maps in Figure 12 depict the number of image pixels per pixel location available for calculating the median values for each season. The maps show that this amount varies from 30 to 40 observations (out of 180) for the wet season and about 90 (out of 180) for the dry season for each pixel location.

Assessment of the exceedance of water quality guidelines

The exceedance of the Guidelines was assessed for CHL and TSS retrieved from MODIS Aqua using CSIRO’s algorithm.

Figure 13 presents the maps of Chlorophyll-a exceedance as defined by the Guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 14 presents the map of the EP for Chlorophyll-a.. Similar maps are presented for TSS, Figure 15and Figure 16).The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 7, Figure 9) and by the steep changes in trigger values between the Midshelf and Offshore areas. The mean values of Chlorophyll-a exceeded the Guidelines in the wet season and over the whole year only in river mouths and embayments (Figure 13, Figure 17). In the dry season the mean values of Chlorophyll-a exceed in most of the reef matrix and Offshore waters (Figure 13), while the EP ranged between 10-25 % indicating that median values did not exceed the Guidelines (Figure 14).

For the Cape York region the annual mean values of Chlorophyll-a exceeded the guideline values (0.45 µg/L) for 56% percent of the Open Coastal area, 4% of the Midshelf and none of the Offshore areas (Figure 17, Table 5). The mean values of Chlorophyll-a exceeded the Guidelines values for 94% of the Open Coastal area in the dry season and 24 % in the wet season. In the dry season Chlorophyll-a also exceeded the Guidelines for 63 % of the Midshelf and 70% of the Offshore areas (Figure 13, Table 6). Similar exceedance values were obtained if the median was used for the assessment (Figure 14, Table 6).

The mean values of TSS exceeded the Guidelines values for 56 % of the Open Coastal Area in the dry season and 39 % in the wet season, in the dry season the mean values of TSS also exceeded the Guidelines for 58 % of the Midshelf and 26% of the Offshore area. Over the whole year, exceedance of TSS Guideline values were recorded in 45% of Open Coastal, 44% of Midshelf and 26% of Offshore areas (Figure 17, Table 5). Almost no exceedance was recorded for the Midshelf and Offshore areas in both seasons if the median was used for the assessment, while the exceedance of the median values for the Open Coastal area were significantly lower than those for the mean values (36% for the dry season and 13% for the wet season, Figure 16, and Table 7).

Table 8 and Table 9 report the Summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EP for that period. These metrics are based on a high number of observations (ranging from 45 thousands valid observations for Open Coastal area in the wet season to over 1.6 million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal area in both seasons, while the mean values of TSS exceeded the Guidelines values for the Open Coastal area and Offshore area in both seasons.

The mean and median values for the TSS concentration differed substantially: the mean values were ~ 2-3 times higher than medians. The median values for the dry season (1.48 and 1.27 mg/L) are consistent with the long term mean annual values for Open Coastal and Midshelf waters in Cape York reported by De'ath and Fabricius (2008) (De'ath and Fabricius 2008) (2.24 and 1.39 mg/L SS, respectively).

Assessment of freshwater extent during the wet season

Figure 18 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the Cape York region. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum . For the Cape York region the freshwater extent for 2009/2010 was 4167 km^2 while in the wet season 2008/2009 it was 1775 km^2 (Figure 4). The annual flow data for the Normanby River for this year was incomplete and hence no comparison with the annual median flow can be made (Figure 3).

Table 5 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Cape York region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2009_30-Apr-2010		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	4295	177949	1232665	56%	49%	45%	20%
MS	10544	539903	3026128	4%	2%	44%	10%
OS	62344	2558809	17896612	0%	1%	26%	4%

Table 6 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Cape York region (Figure 13, Figure 14). Column and row labels are described in the legend of Table 5.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4295	132813	609890	94%	95%	45136	622775	24%	17%
MS	10544	386715	1497248	63%	72%	153188	1528880	1%	0%
OS	62344	1670341	8852848	70%	72%	888468	9039880	0%	0%

Table 7 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Cape York region (Figure 15, Figure 16). Column and row labels are described in the legend of Table 5.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4295	132813	609890	56%	36%	45136	622775	39%	13%
MS	10544	386715	1497248	58%	19%	153188	1528880	43%	14%
OS	62344	1670341	8852848	26%	5%	888468	9039880	41%	4%

Table 8. Summary of Chlorophyll-a exceedance for the dry and wet season for the Cape York region. Column and row labels are described in the legend of Table 5 Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	132813	609890	**0.54**	**0.45**	50%	45136	622775	**0.57**	**0.46**	53%
MS	386715	1497248	0.34	0.36	12%	153188	1528880	0.34	0.31	26%
OS	1670341	8852848	0.30	0.31	15%	888468	9039880	0.29	0.30	15%

Table 9 Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Cape York region. Column and row labels are described in the legend of Table 5. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	132813	609890	**2.22**	1.48	32%	45136	622775	**2.88**	1.27	33%
MS	386715	1497248	**2.02**	0.68	29%	153188	1528880	**2.76**	1.05	39%
OS	1670341	8852848	0.64	0.13	15%	888468	9039880	**0.92**	0.20	23%

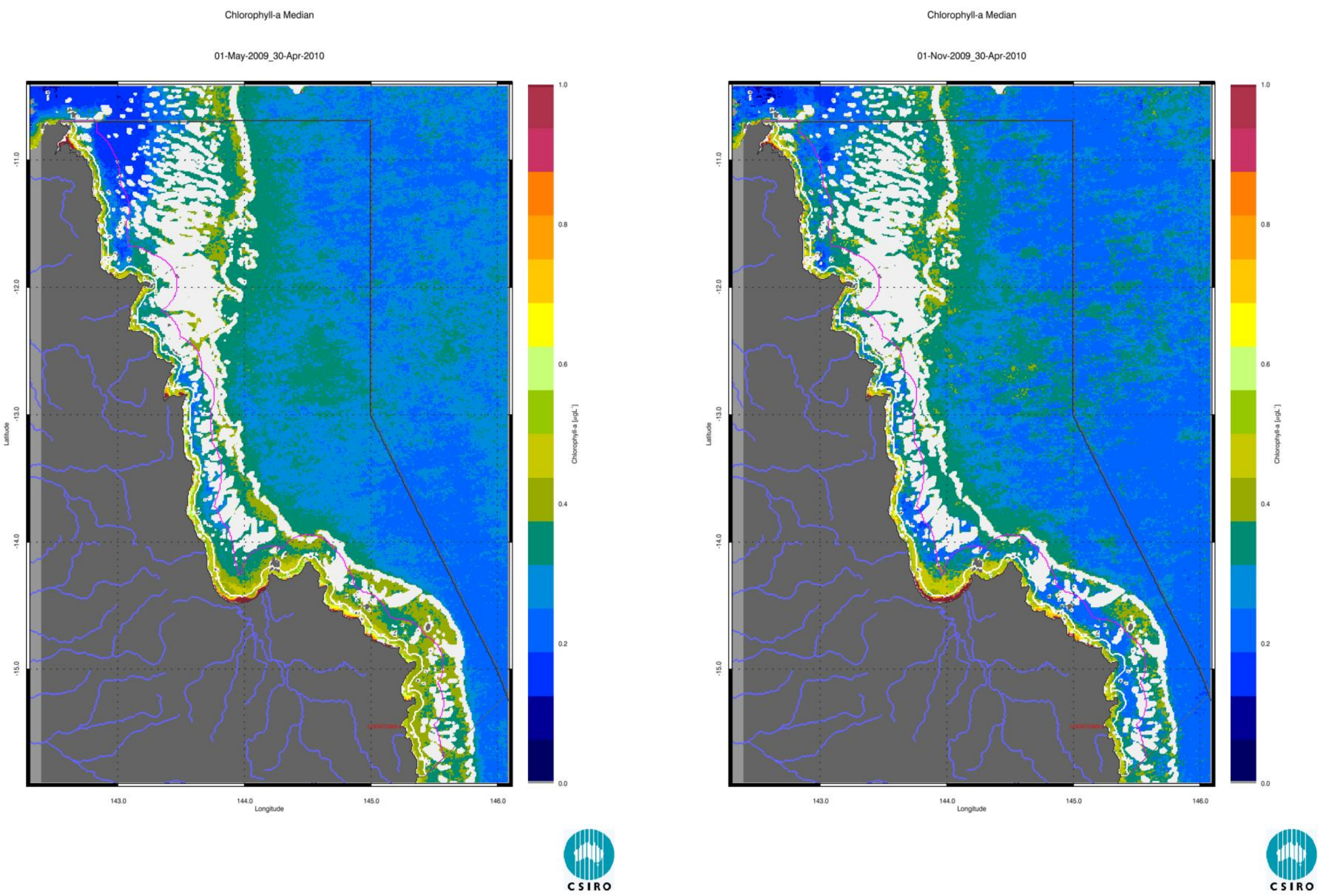


Figure 7. Chlorophyll-a median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

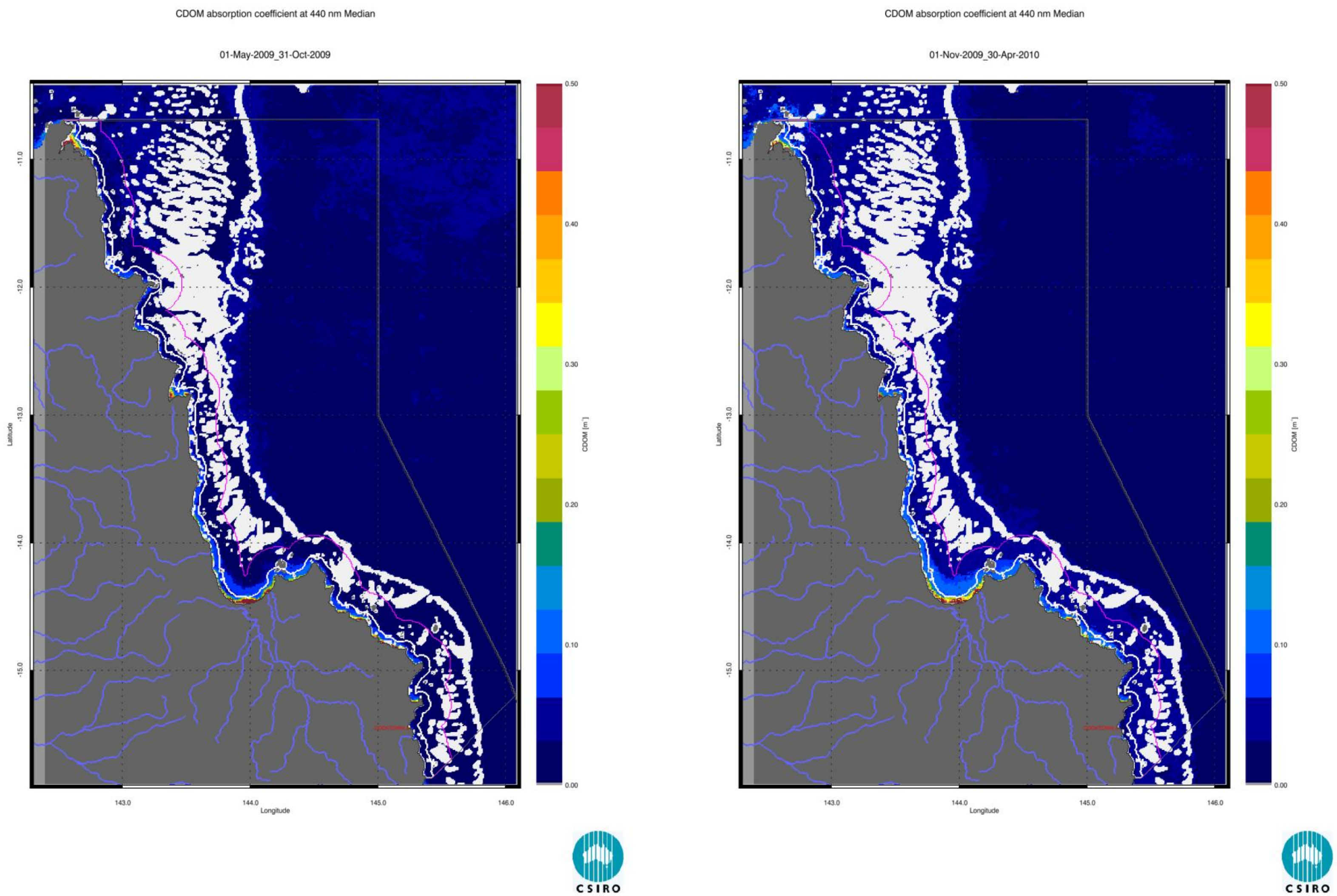


Figure 8. CDOM median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

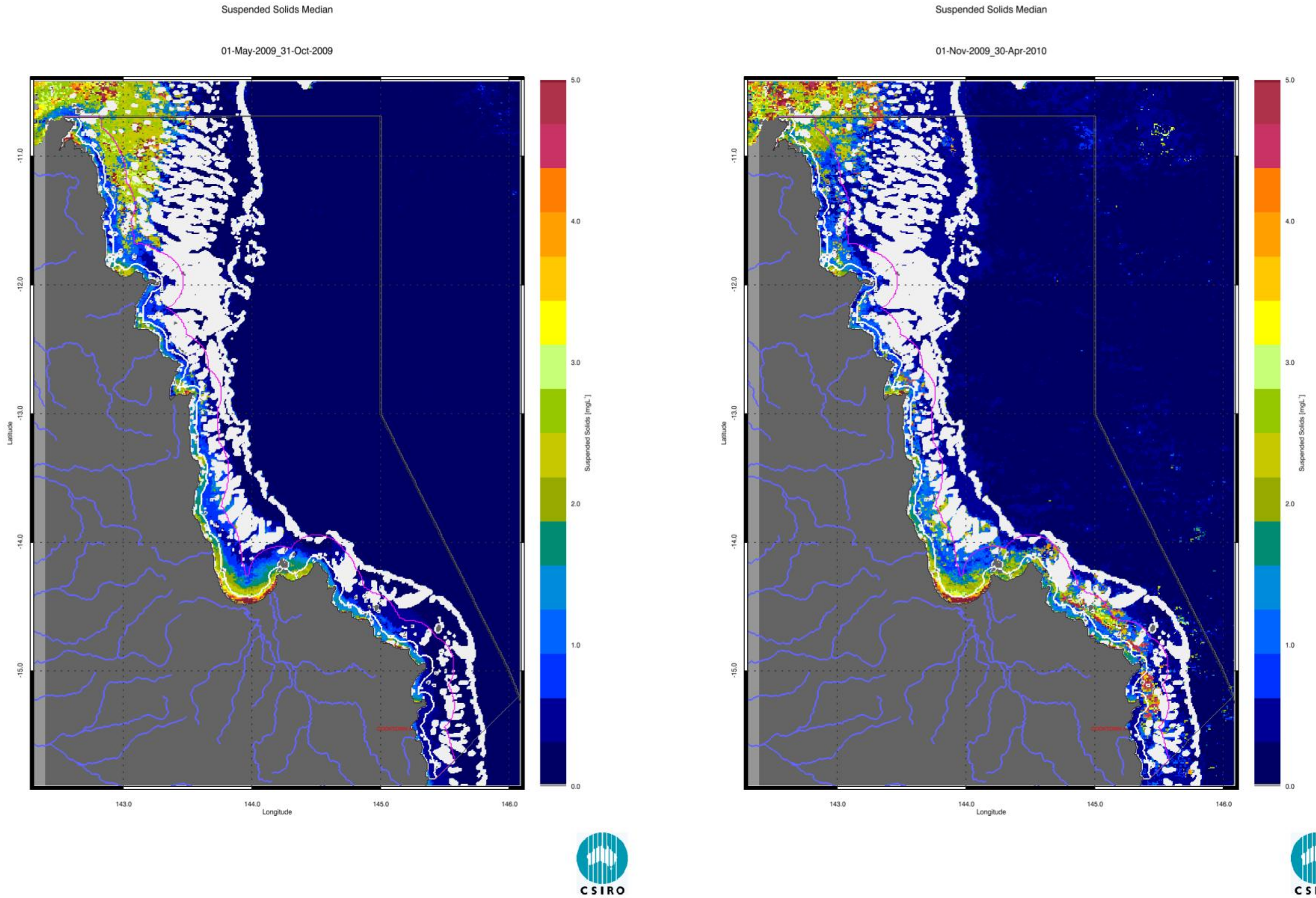


Figure 9. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

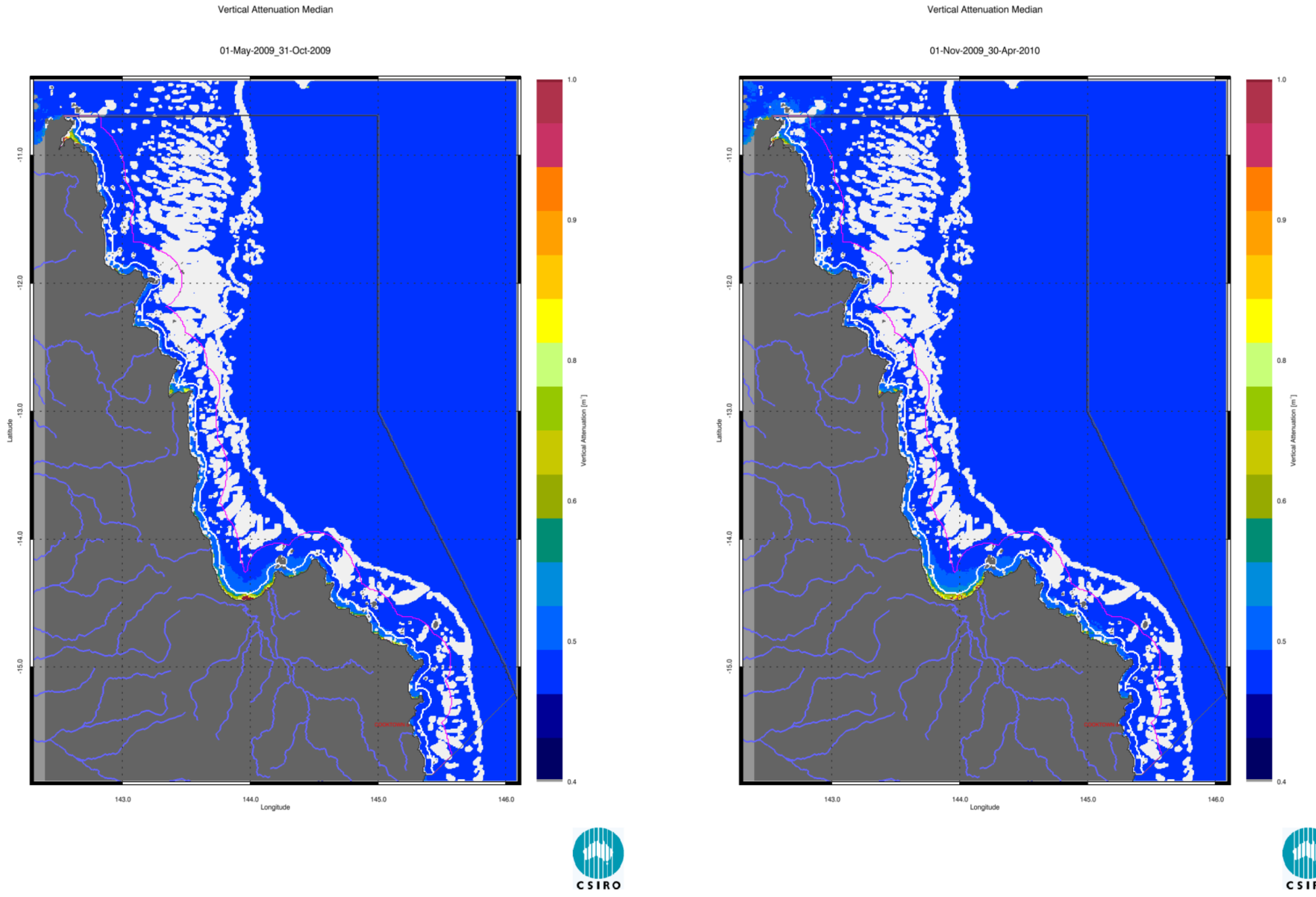


Figure 10. Vertical attenuation of light (Kd ,as estimate of water clarity) median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

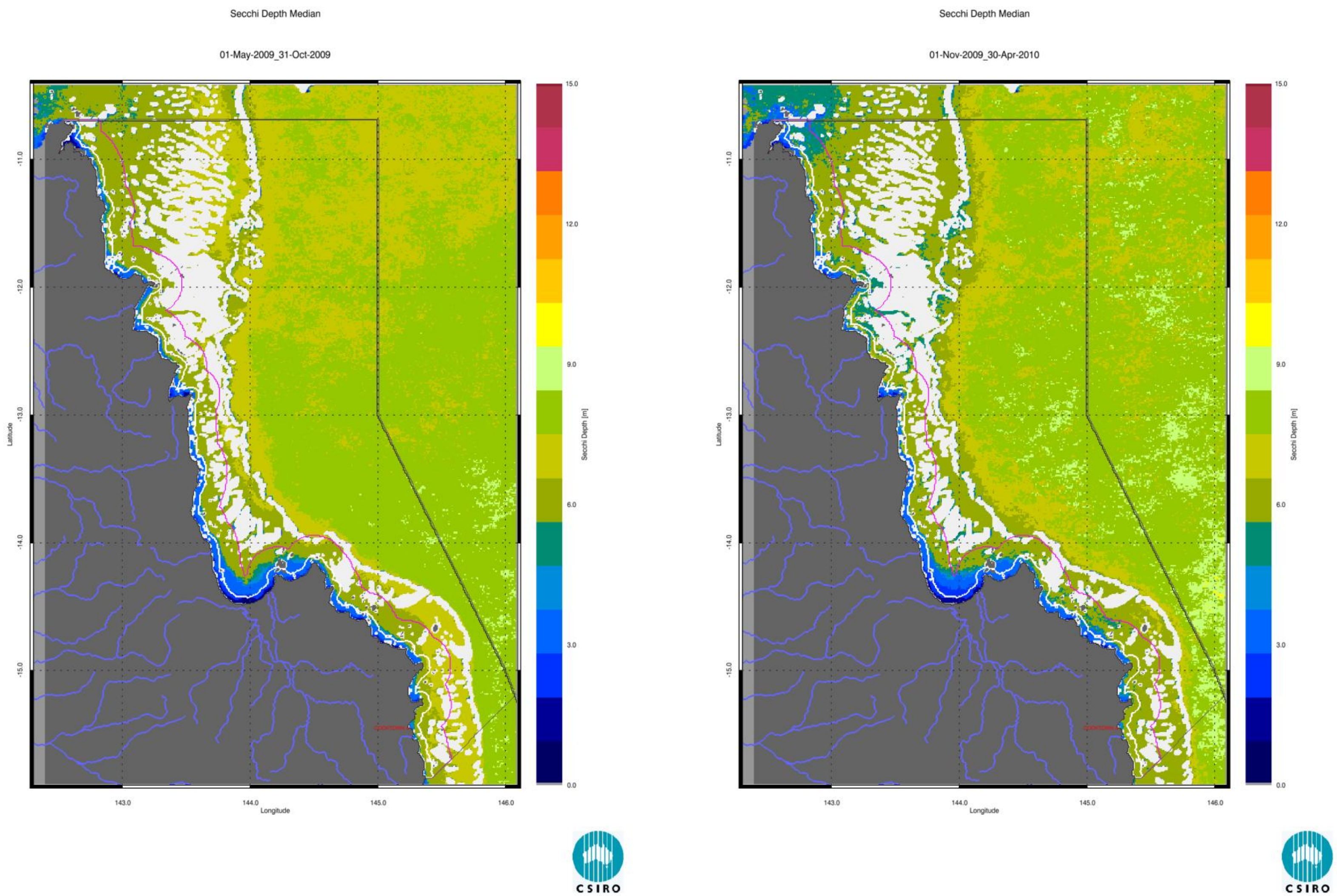


Figure 11. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

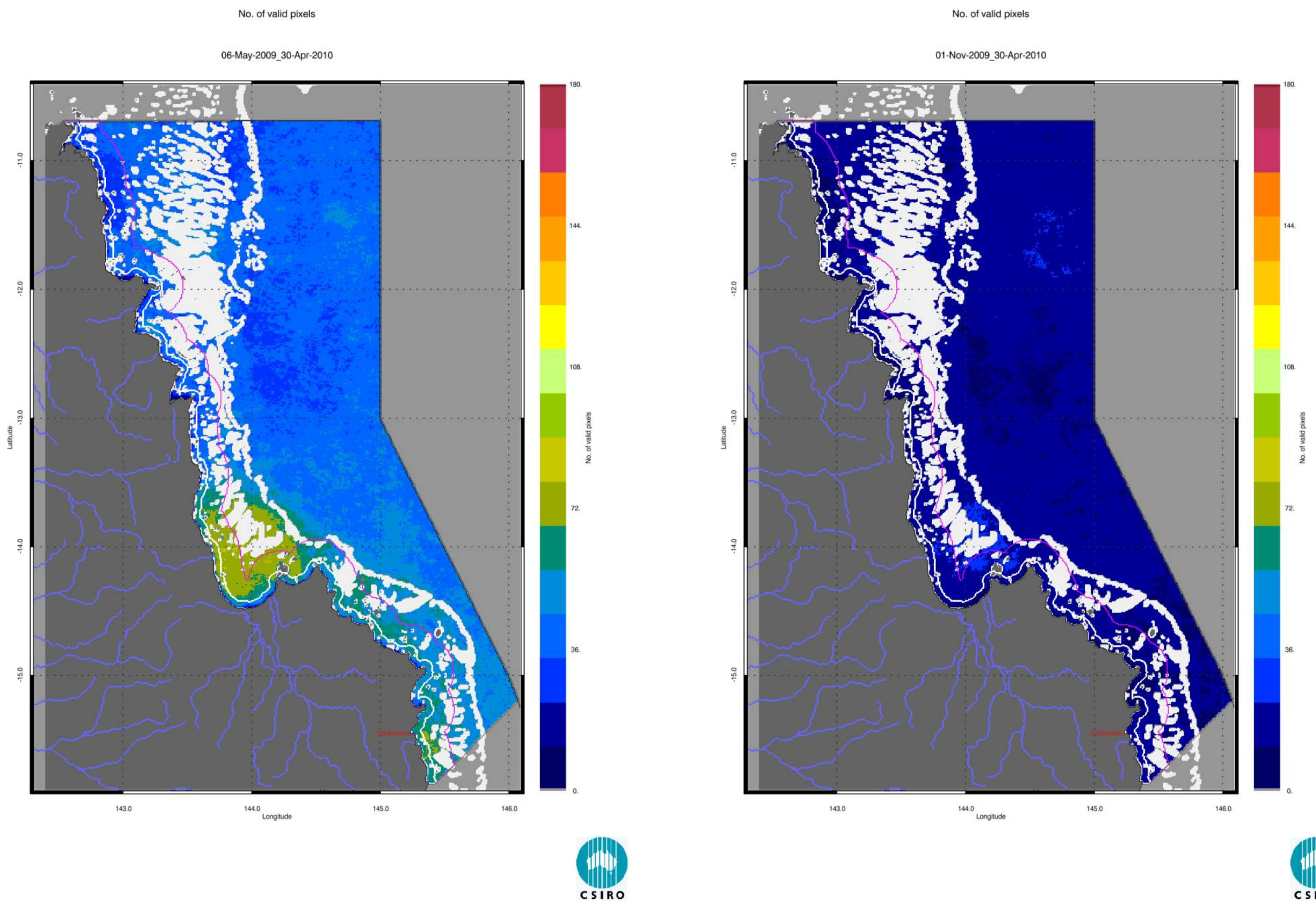


Figure 12. Number of pixels used to calculate the median maps (Figure 7 - Figure 11) for the dry and wet season for the Cape York region. The first map presents the number of pixels available for analysis in the dry season 2009 (May - October), while the second map presents the number of pixels available for analysis in the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

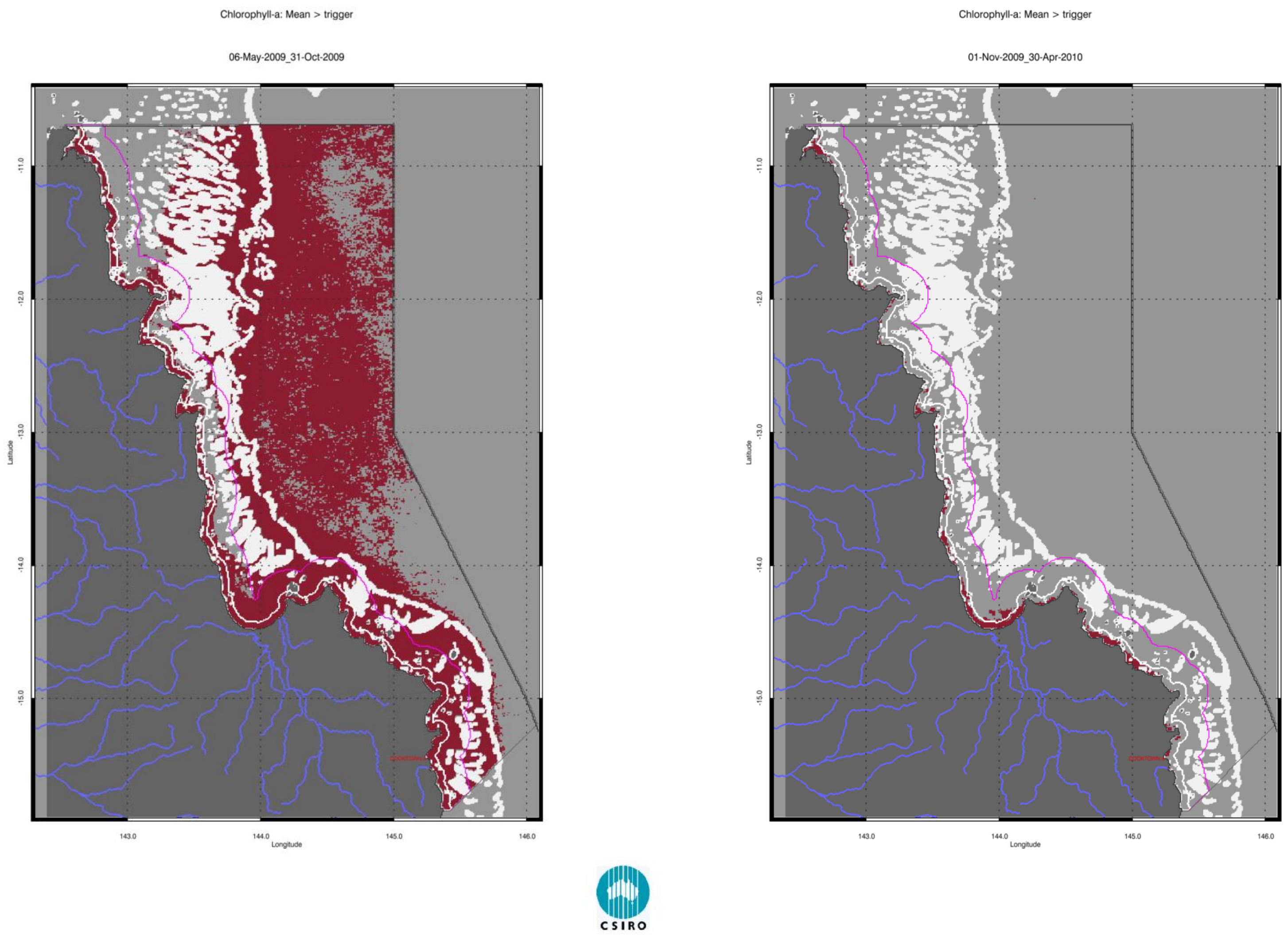


Figure 13. Chlorophyll-a exceedance maps for the dry and wet season for the Cape York region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

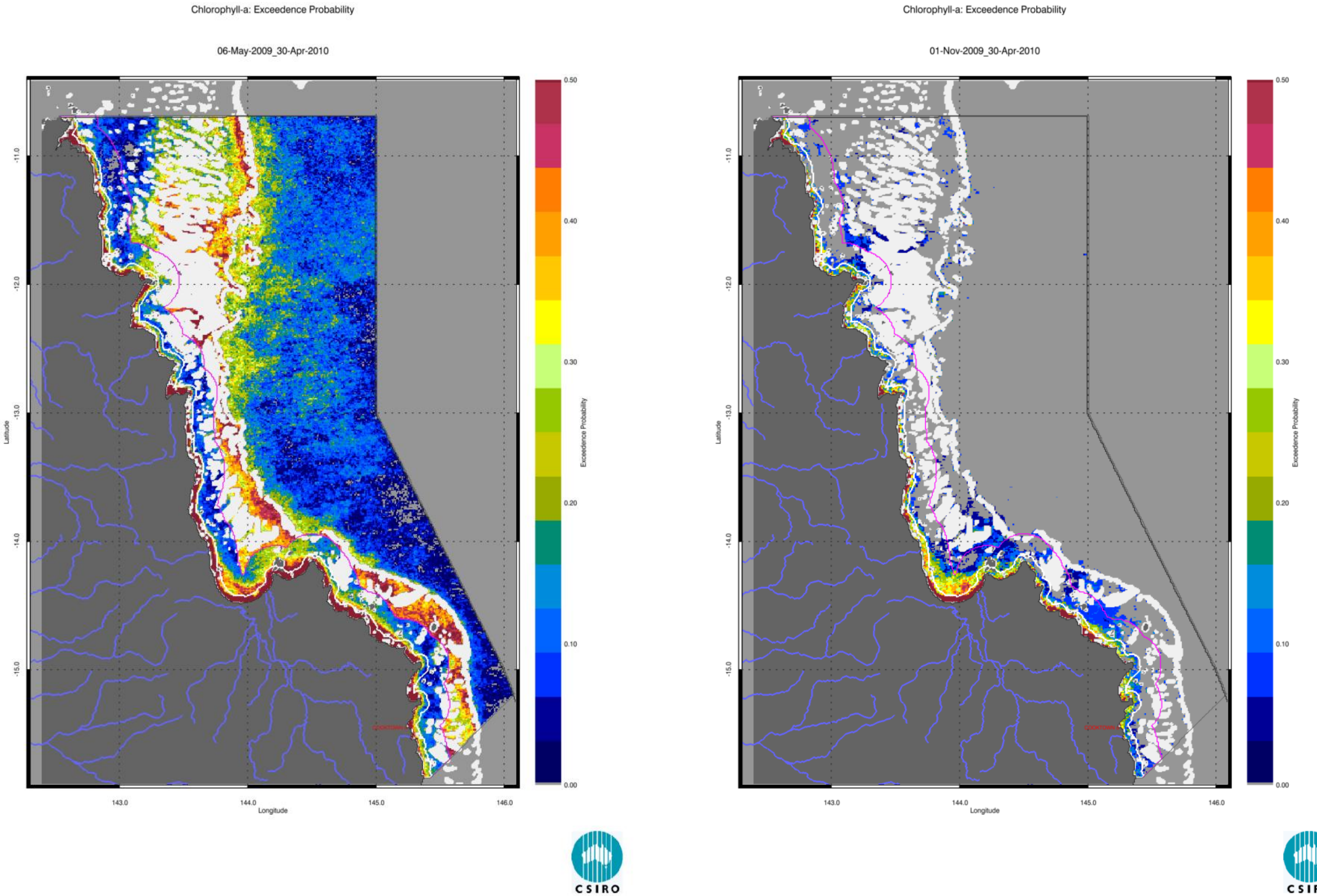
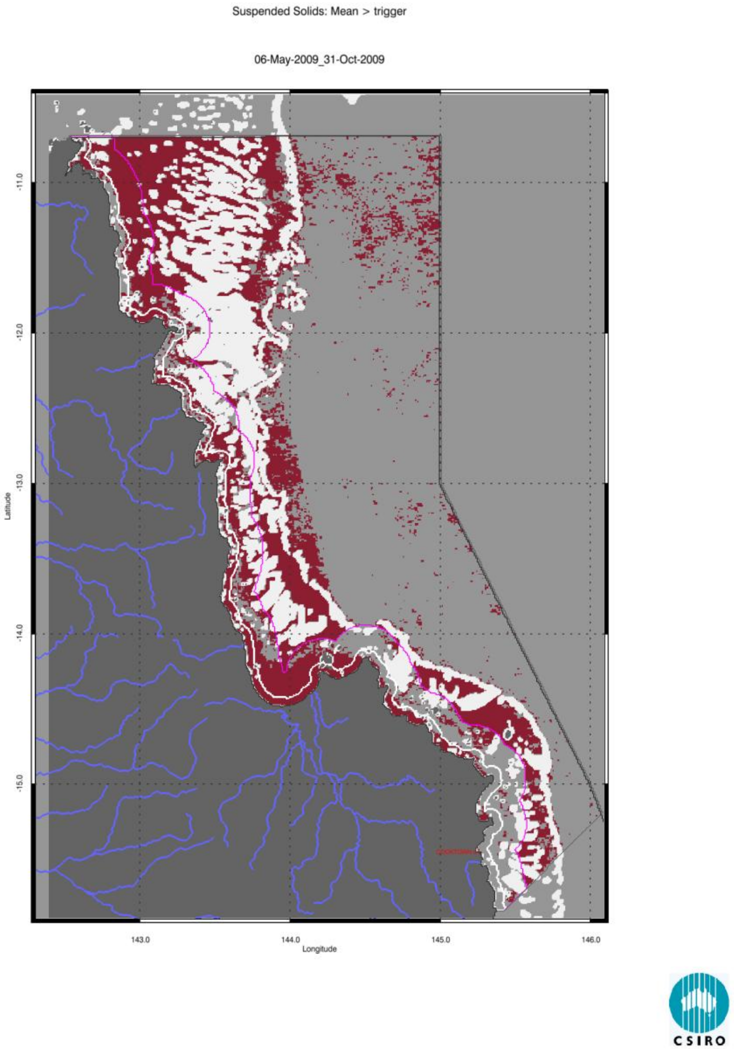


Figure 14. Chlorophyll-a exceedance probability maps for the dry and wet season for the Cape York region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



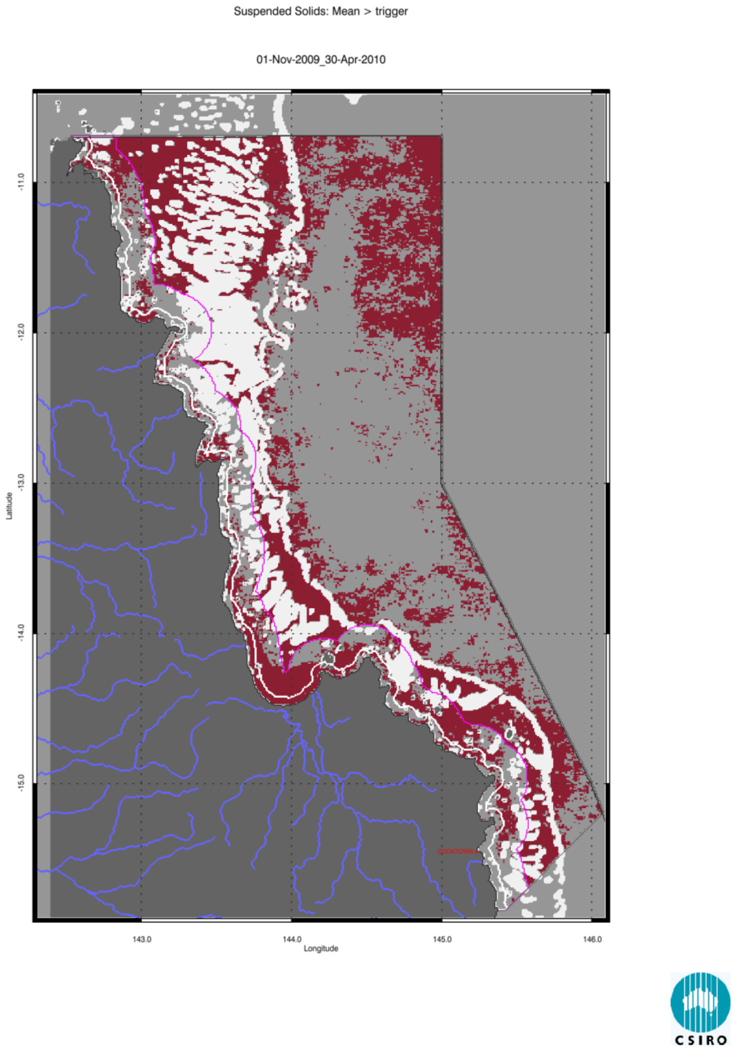


Figure 15. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance maps for the dry and wet season for the Cape York. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

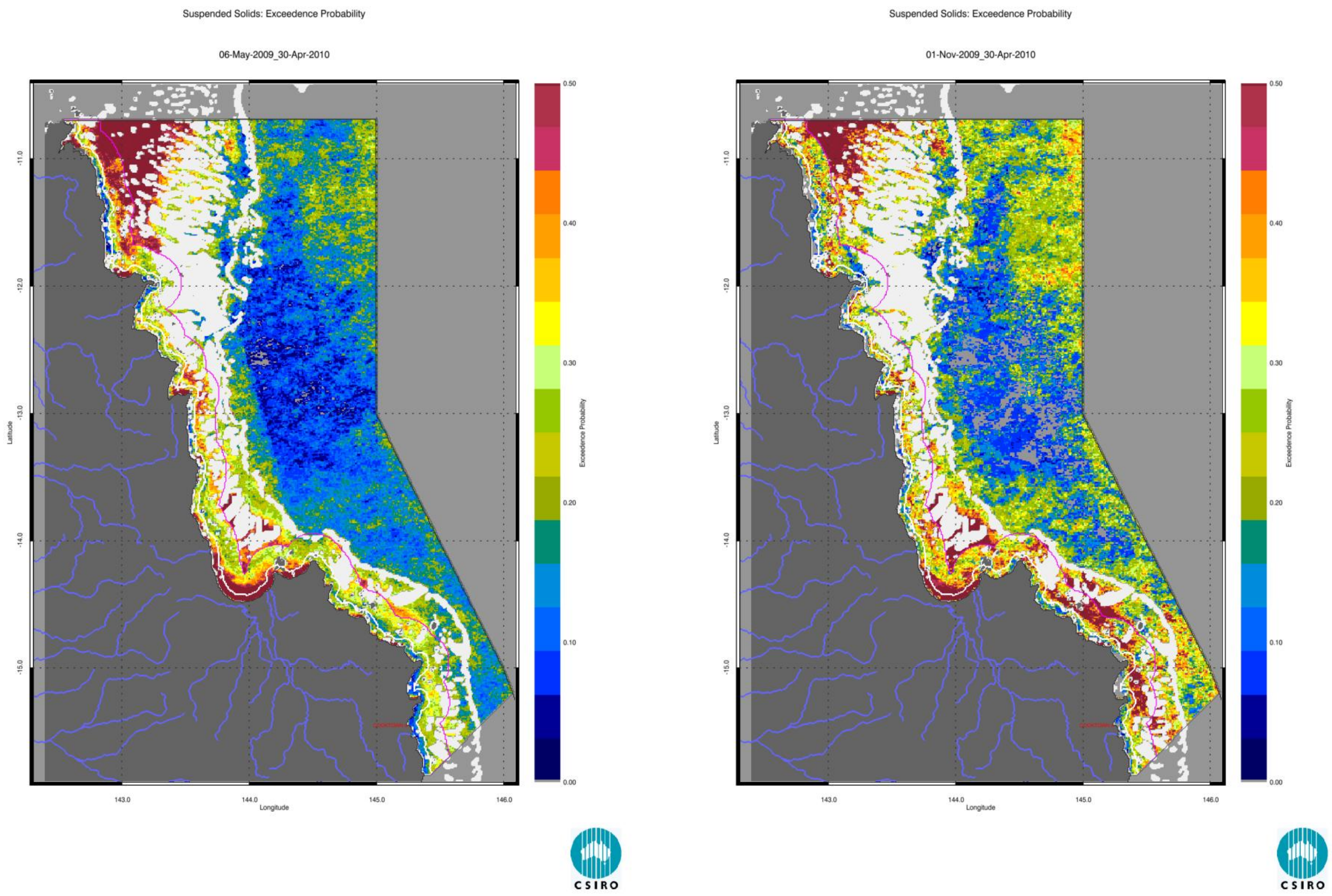


Figure 16. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance probability maps for the dry and wet season for the Cape York region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

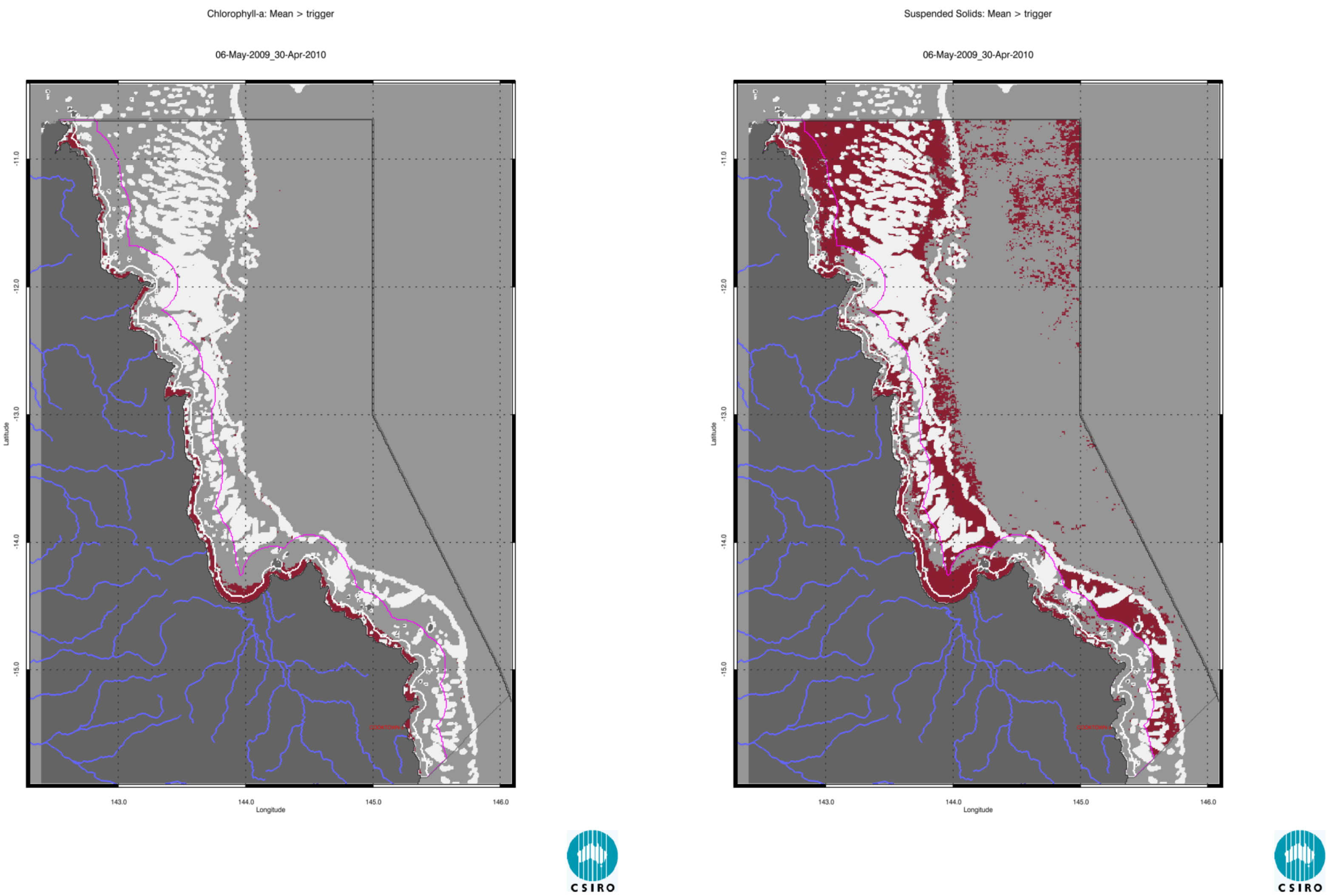


Figure 17. Exceedance maps for the Cape York region for the whole year (May 2009 –April 2010). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance map. See text for annotation explanation.

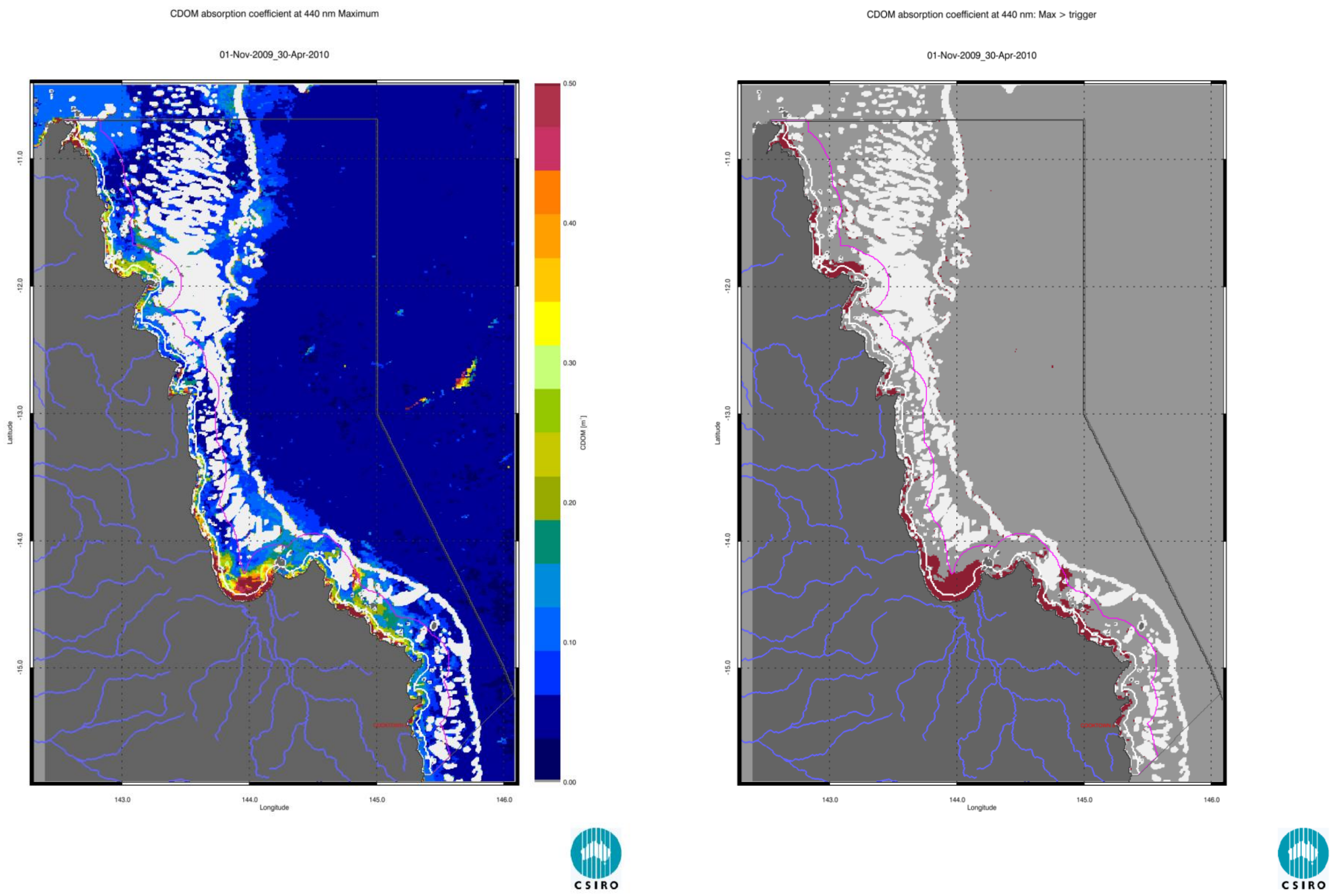


Figure 18. Map of freshwater extent for the wet season for the Cape York region. The first map presents the maximum value of CDOM for the wet season 2009/2010 (November 2009- April 2010), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m^{-1}. See text for annotation explanation.

Regional reports: Wet Tropics region

Land use practices within the wet tropics catchment include primary production such as sugar cane and banana farming, dairying, beef, cropping and tropical horticulture. Other uses within the region include fisheries, mining, and tourism. Declining water quality, due to sedimentation combined with other forms of pollutants, the disturbance of acid sulphate soils, and point source pollution have been identified as a major concern to the health of coastal and marine ecosystems. Major environmental controls in the wet tropics include pulsed terrigenous runoff, salinity and temperature extremes.

The wet and dry season median maps for Chlorophyll-a, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of Chlorophyll-a (Figure 19) for the Wet Tropics region show high Chlorophyll-a levels near the coast and in the estuary to lower concentrations towards the East. Median values of Chlorophyll-a up-to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the offshore region in the reef matrix ranged between 0.15-0.25 μgL^{-1}..

The wet and dry season median maps of coloured dissolved organic matter (CDOM, Figure 20) for the Wet Tropics region show values higher than 0.20 m^{-1} for a coastal band ~5-10 km wide with values higher than than 0.50 m^{-1} for in correspondence of the Barron, and Herbert rivers and in Rockingham Bay The wet and dry season median maps of non-algal particulate matter (as a measure of Total Suspended Solids) (Figure 21) for the Wet Tropics region show values higher than 3 mgL^{-1} in Rockingham Bay and Halifax Bay.

The wet and dry season median maps of vertical attenuation of light (Figure 22) for the Wet Tropics region show similar gross patterns as for the Chlorophyll-a, coloured dissolved organic matter and non-algal particulate matter distribution. Again, The difference in dark blue to light blue colours between the wet and dry season for K_d is due to the K_d being slightly dependent on average sun-angles during the satellite overpass-The wet and dry season median maps of water clarity expressed as Secchi Depth (Figure 23) for the Wet Tropics region show similar gross patterns to the maps of vertical attenuation of light (Figure 22).

The number of image pixels available for calculating the median values varies from 20 to 30 observations for the wet season and 60-70 for the dry season for each pixel location (Figure 24) .

Assessment of the exceedance of water quality guidelines

The exceedance of the Guidelines was assessed for Chlorophyll-a and Non-algal particulate matter (as measure for Total Suspended Solids) retrieved from MODIS Aqua using CSIRO's algorithm. Figure 25 presents the maps of Chlorophyll-a exceedance as defined by the Guidelines and Figure 26 presents the map of the EP for Chlorophyll-a. Similar maps are presented for TSS (Figure 27 and Figure 28).

The annual mean values of Chlorophyll-a exceeded the guideline value (0.45 µg/L) for 81% of the Open Coastal area, 16% of the Midshelf and none of the Offshore areas (Figure 29, Table 10). The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 19, Figure 21) and by the steep changes in trigger values between the

Midshelf and Offshore areas. The mean values of Chlorophyll-a exceeded the Guidelines values for 98% of the Open Coastal area in the dry season and 41 % in the wet season, in correspondence to the river mouths: Mossman –Daintree, Barron, Russell-Mulgrave, Johnstone, Tully, Murray and Herbert rivers and Hinchinbrook Channel (Figure 25). In the dry season Chlorophyll-a also exceeded the Guidelines for 99 % of the Midshelf and 48% of the Offshore areas mainly waters within and around the reef matrix (Figure 25, Table 11). Similar exceedance values were retrieved if the median was used for the assessment (Figure 26, Table 10, Table 11).

The mean values of TSS exceeded the Guidelines values for 44% of the Open Coastal Area in the dry season and 11 % in the wet season, in the dry season the mean values of TSS also exceeded the Guidelines for 8 % of the Midshelf and 30% of the Offshore area. Over the whole year, exceedance of TSS guideline values were recorded in 23% of the Open Coastal, 3% of the Midshelf and 30% of Offshore areas (Figure 29, Table 10). Almost no exceedance was recorded for the Midshelf and Offshore areas in both seasons ad over the year if the median was used for the assessment, while the exceedance of the median values for the Open Coastal area were significantly lower than those for the mean values (29% for the whole year, 17% for the dry season and 5% for the wet season, Figure 28, and Table 12).

Table 13 and Table 14 report the summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EPfor that period. These metrics are based on a high number of observations (ranging from 30 thousands valid observations for Open Coastal area in the wet season to over 770 thousands for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal area in both seasons, while the mean values of TSS exceeded the Guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of freshwater extent during the wet season

Figure 30 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the Wet Tropics region. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Wet Tropics region the freshwater extent for the wet season 2009/2010 (November 2009- April 2010) was 3786 km^2 while in the wet season 2008/2009 was 4898 km^2 (Figure 4). The lower freshwater extent was due to the to the flow conditions in the Russell, Johnstone, Tully and Herbert Rivers below median levels (0.6 – 0.8 times median levels, Figure 3).

Table 10 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Wet Tropics region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2009_30-Apr-2010		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	2044	118461	649992	81%	76%	23%	7%
MS	5859	399597	1863162	16%	14%	3%	1%
OS	19906	1107326	6330108	0%	3%	30%	0%

Table 11 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Wet Tropics region (Figure 25, Figure 26). Column and row labels are described in the legend of Table 10.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2044	87513	320908	98%	98%	30948	329084	41%	29%
MS	5859	287593	919863	99%	100%	112004	943299	4%	2%
OS	19906	772356	3125242	48%	57%	334970	3204866	0%	0%

Table 12 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Wet Tropics region (Figure 27, Figure 28). Column and row labels are described in the legend of Table 10.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2044	87513	320908	44%	17%	30948	329084	11%	5%
MS	5859	287593	919863	8%	2%	112004	943299	4%	1%
OS	19906	772356	3125242	30%	0%	334970	3204866	44%	0%

Table 13. Summary of Chlorophyll-a exceedance for the dry and wet season for the Wet Tropics region. Column and row labels are described in the legend of Table 10. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	87513	320908	**0.68**	**0.53**	68%	30948	329084	**0.72**	**0.51**	68%
MS	287593	919863	0.41	0.42	25%	112004	943299	0.41	0.39	41%
OS	772356	3125242	0.30	0.31	19%	334970	3204866	0.31	0.31	22%

Table 14 Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Wet Tropics region. Column and row labels are described in the legend of Table 10Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	87513	320908	1.85	1.19	20%	30948	329084	1.53	0.72	18%
MS	287593	919863	1.19	0.44	16%	112004	943299	1.63	0.48	28%
OS	772356	3125242	0.51	0.13	11%	334970	3204866	**0.90**	0.19	24%

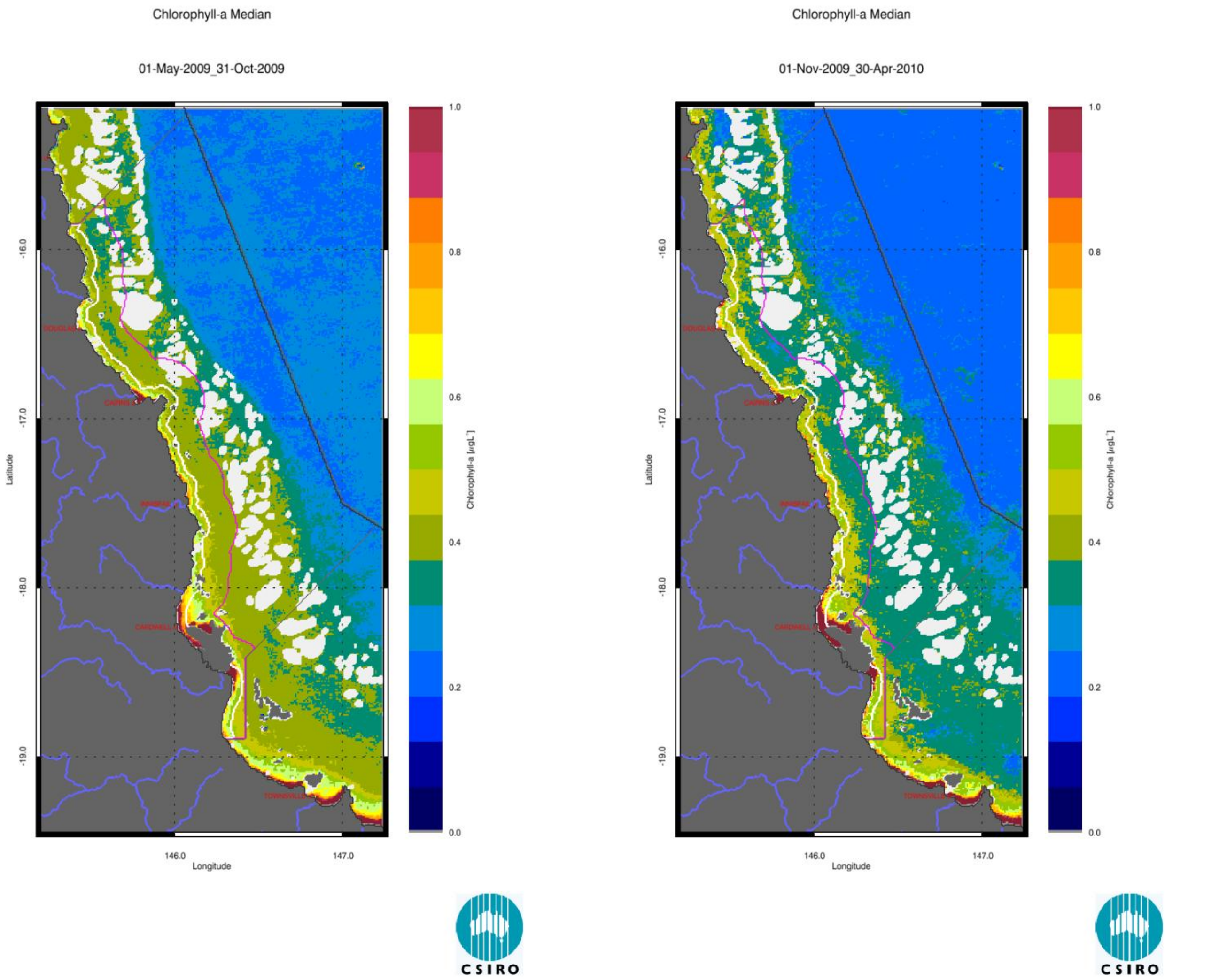
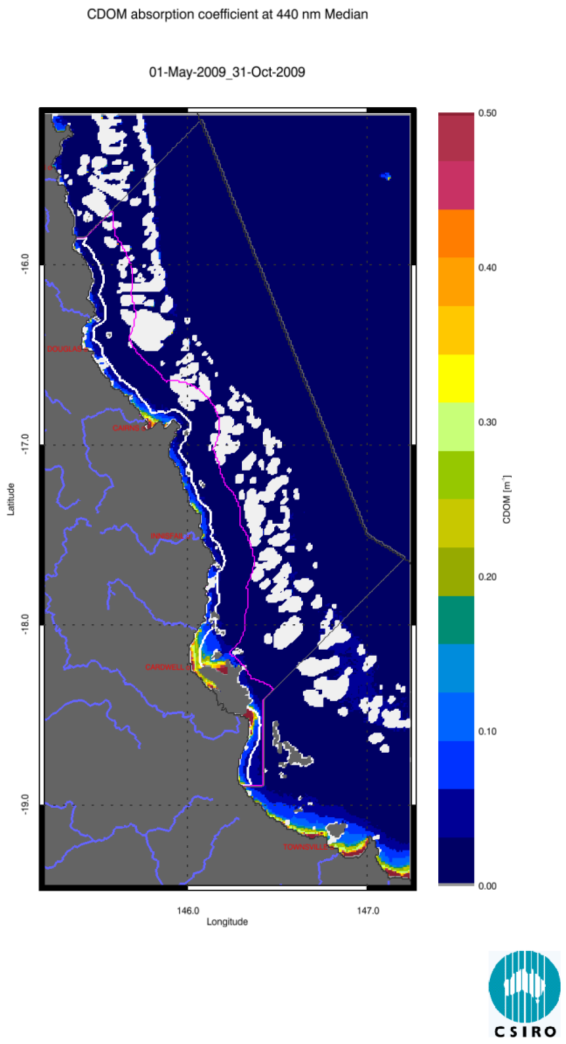


Figure 19. Chlorophyll-a median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



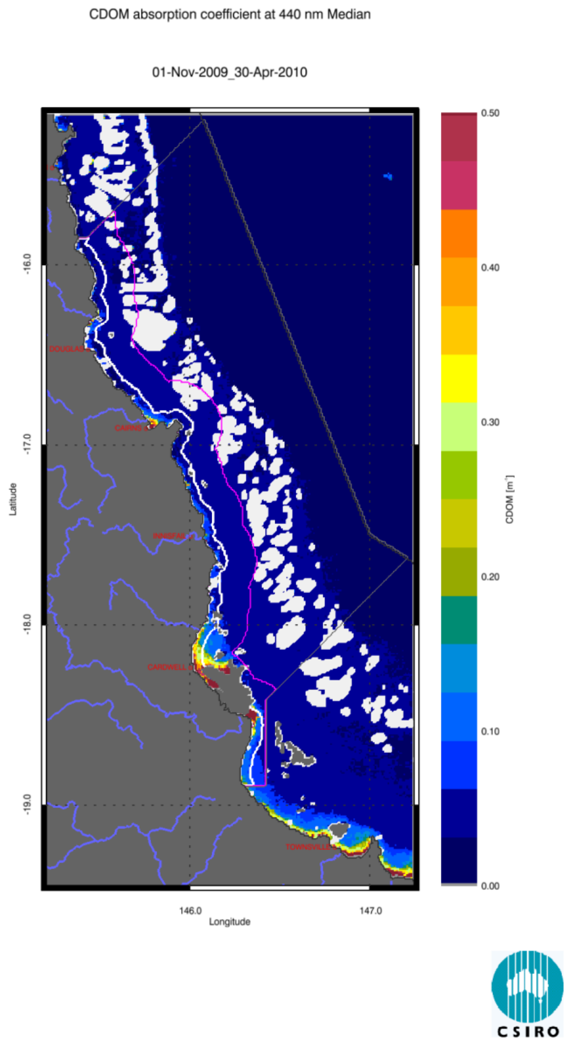


Figure 20. CDOM median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

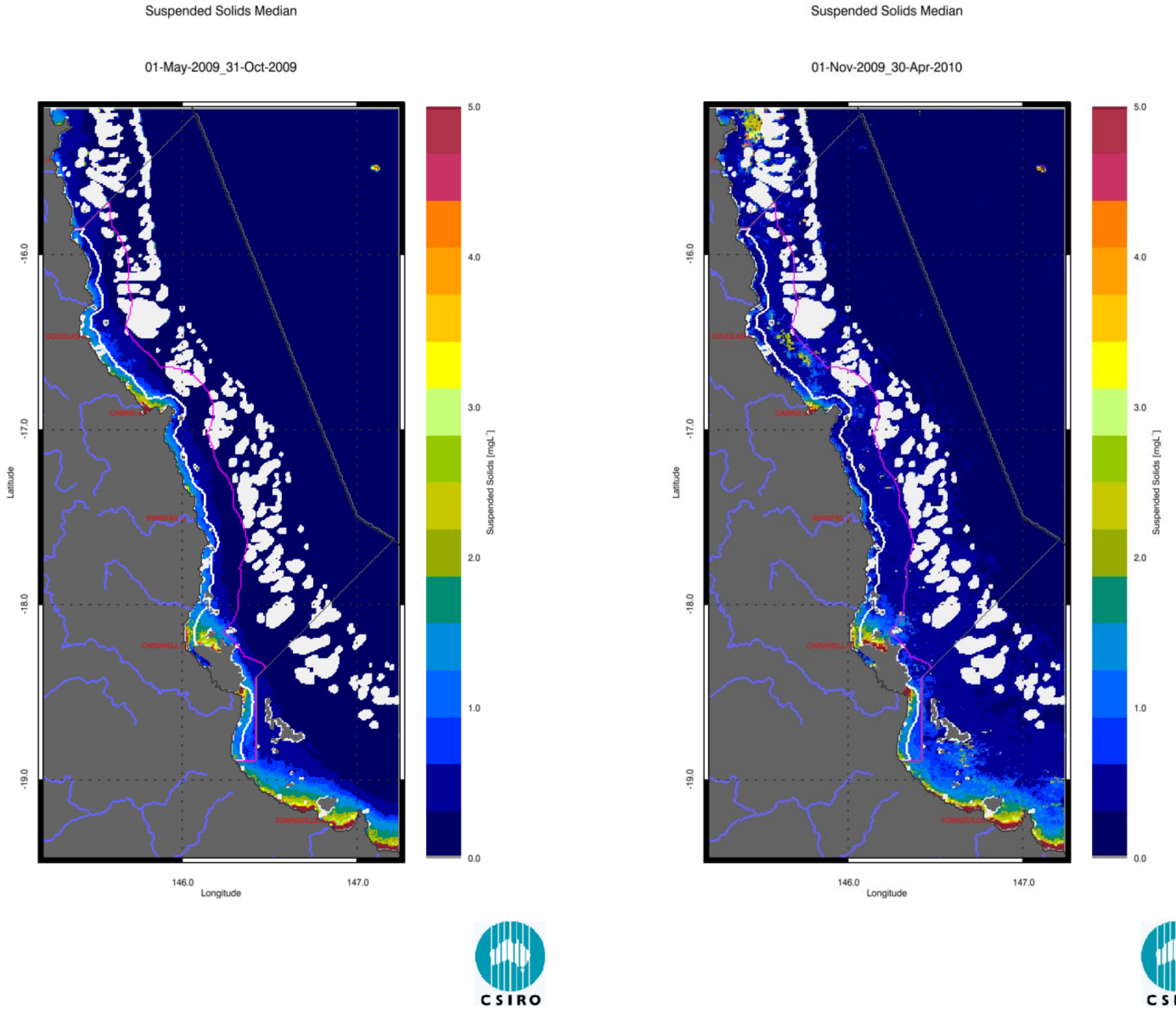


Figure 21. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

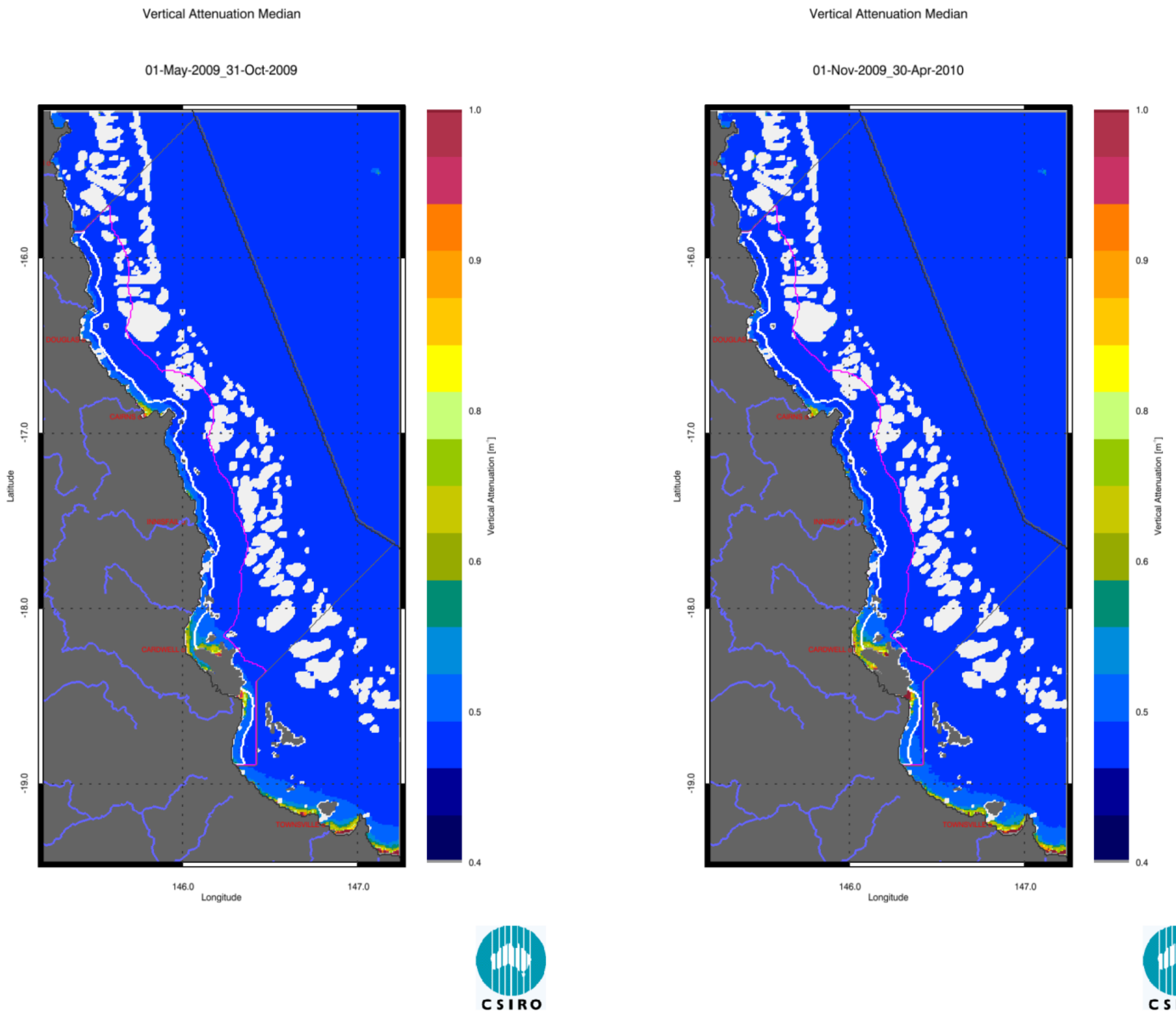


Figure 22. Vertical attenuation of light (Kd ,as estimate of water clarity) median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

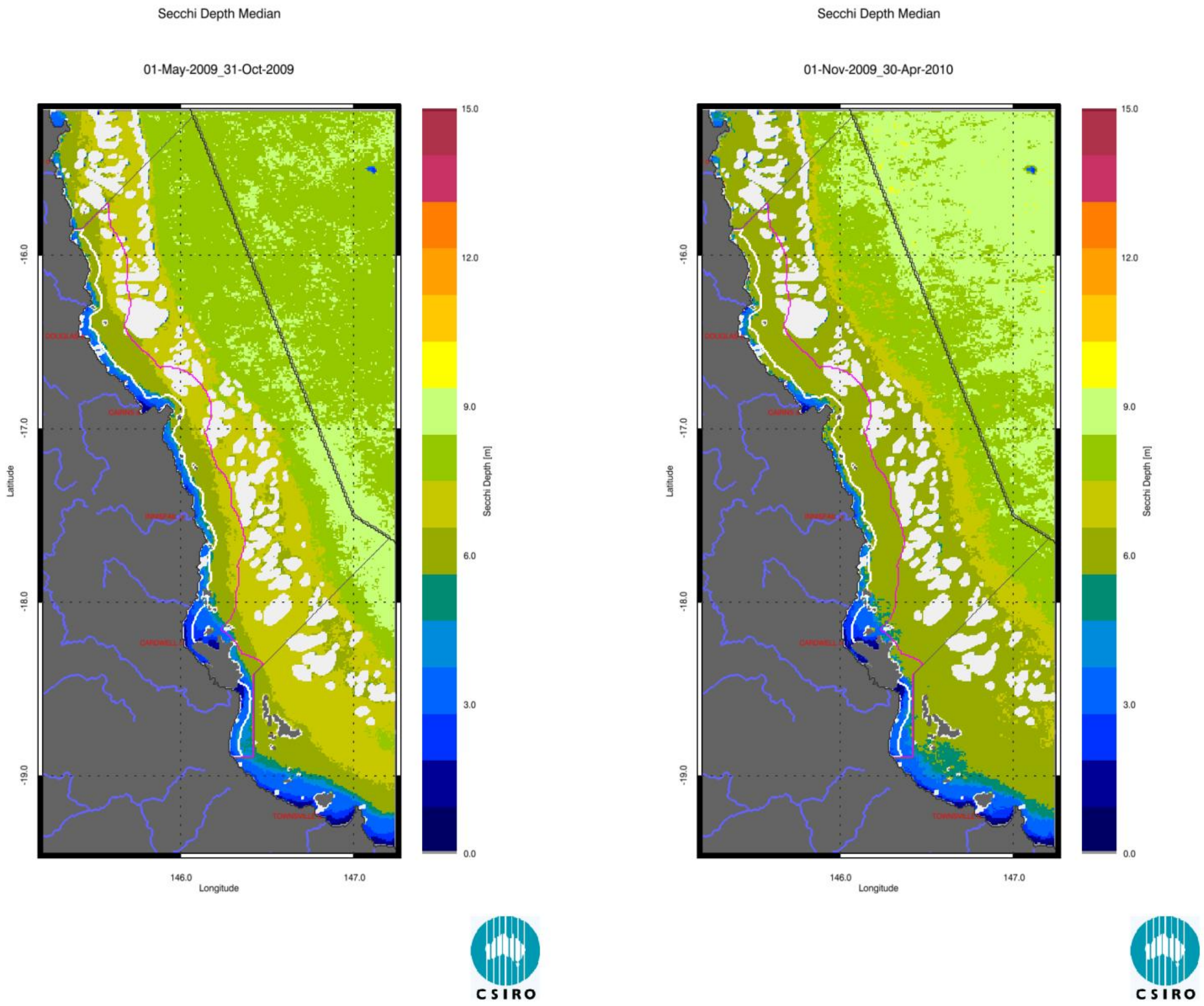


Figure 23. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

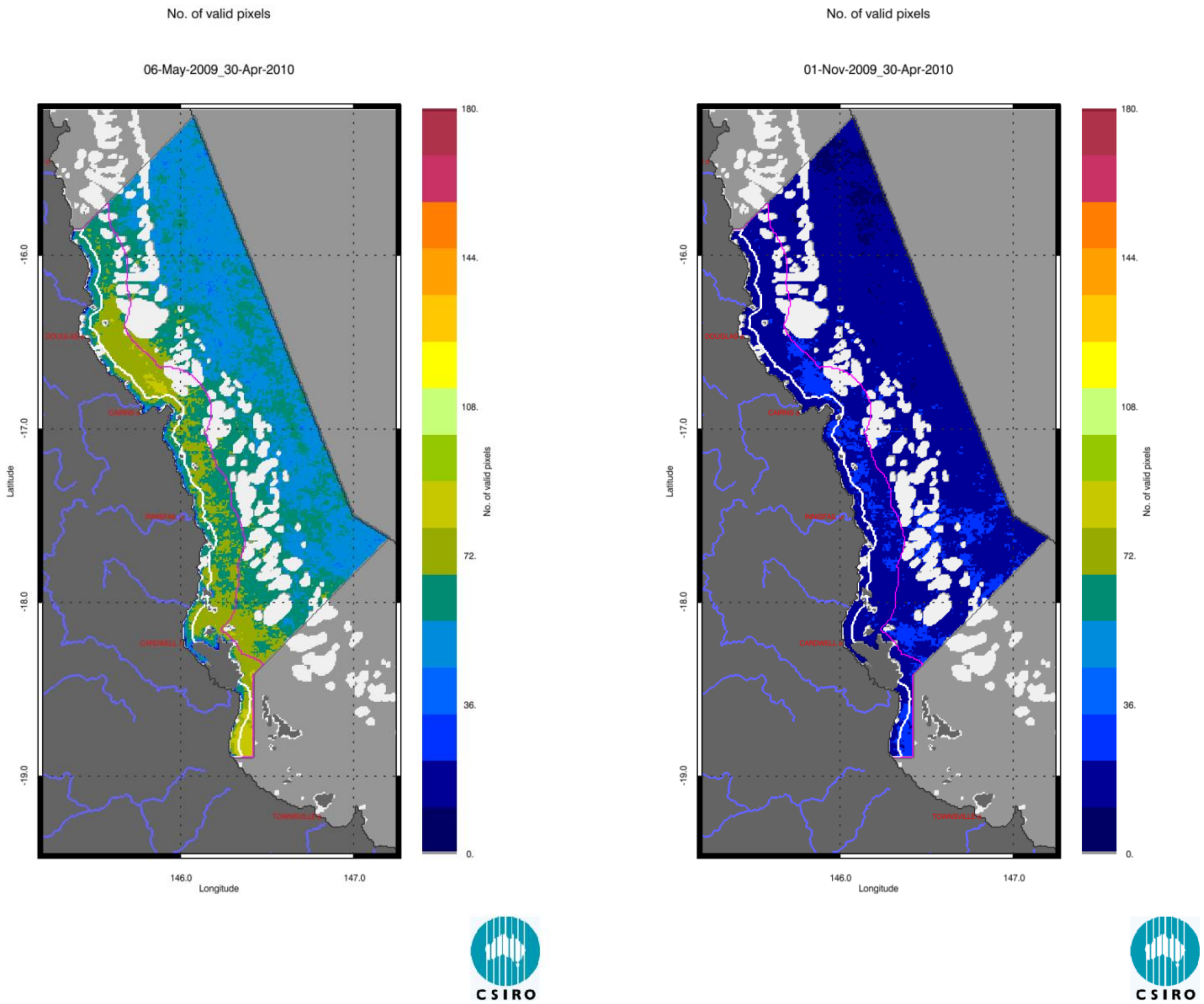


Figure 24. Number of pixels used to calculate the median maps (Figure 19- Figure 23) for the dry and wet season for the Wet Tropics region. The first map presents the number of pixels available for analysis in the dry season 2009 (May - October), while the second map presents the number of pixels available for analysis in the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

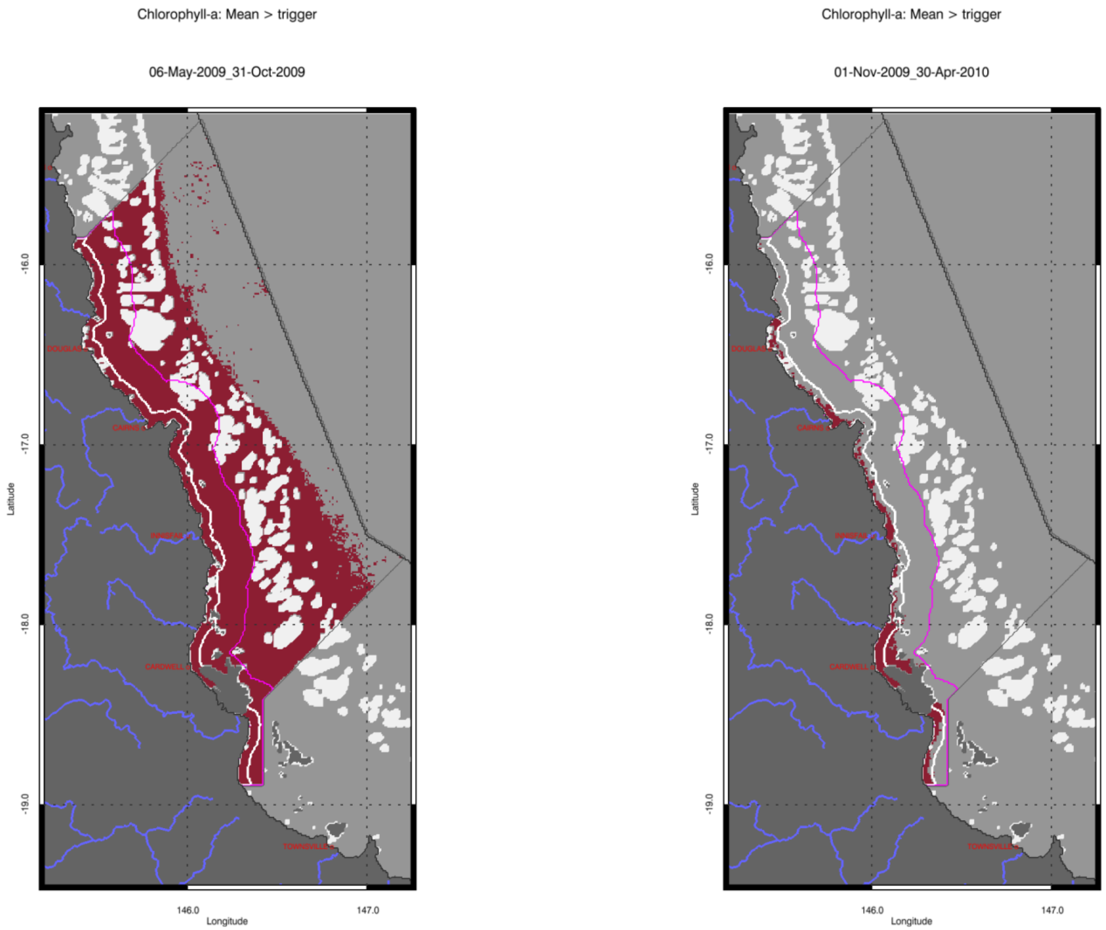


Figure 25. Chlorophyll-a exceedance maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

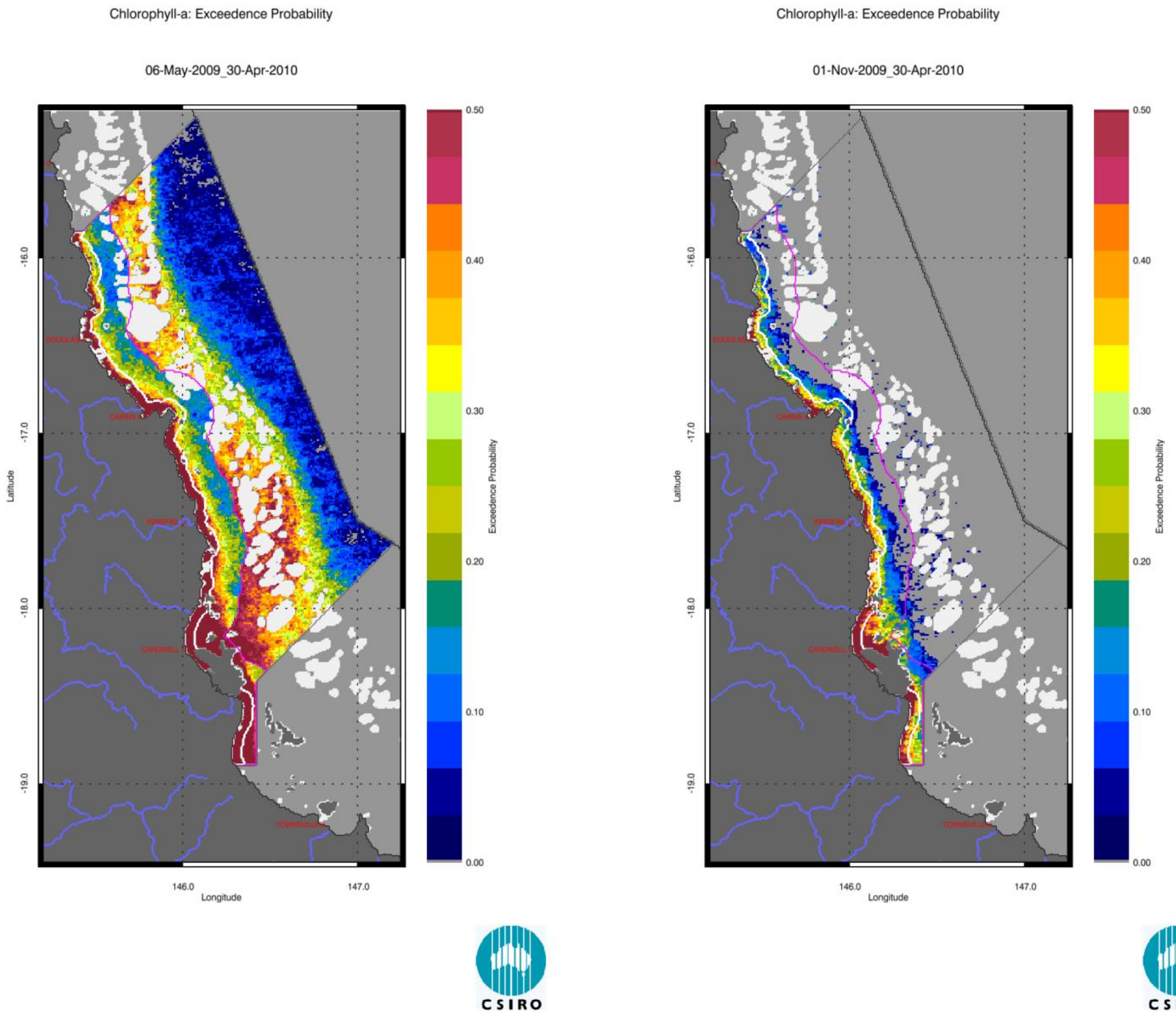
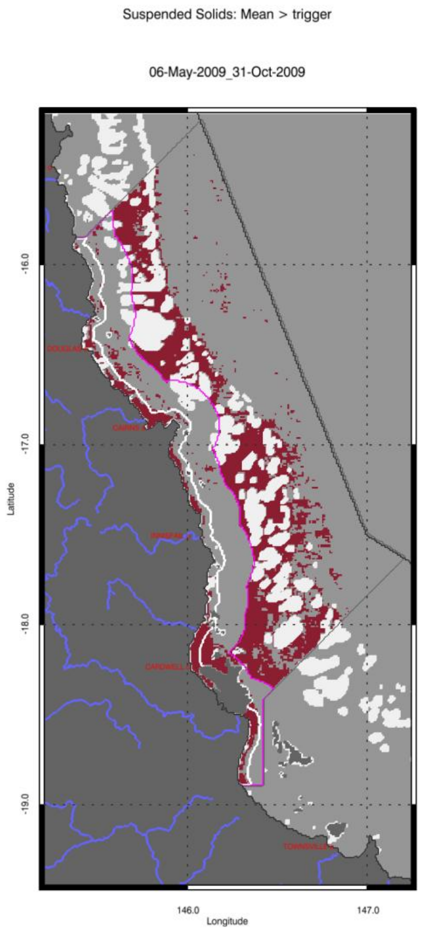


Figure 26. Chlorophyll-a exceedance probability maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



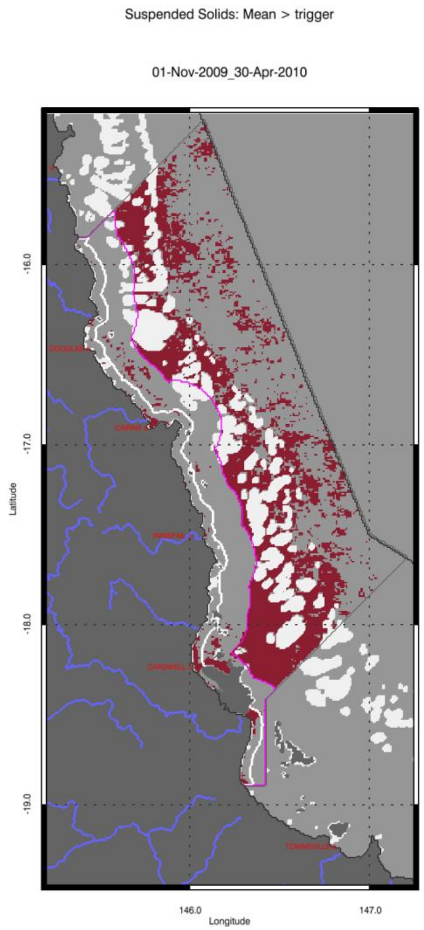


Figure 27. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

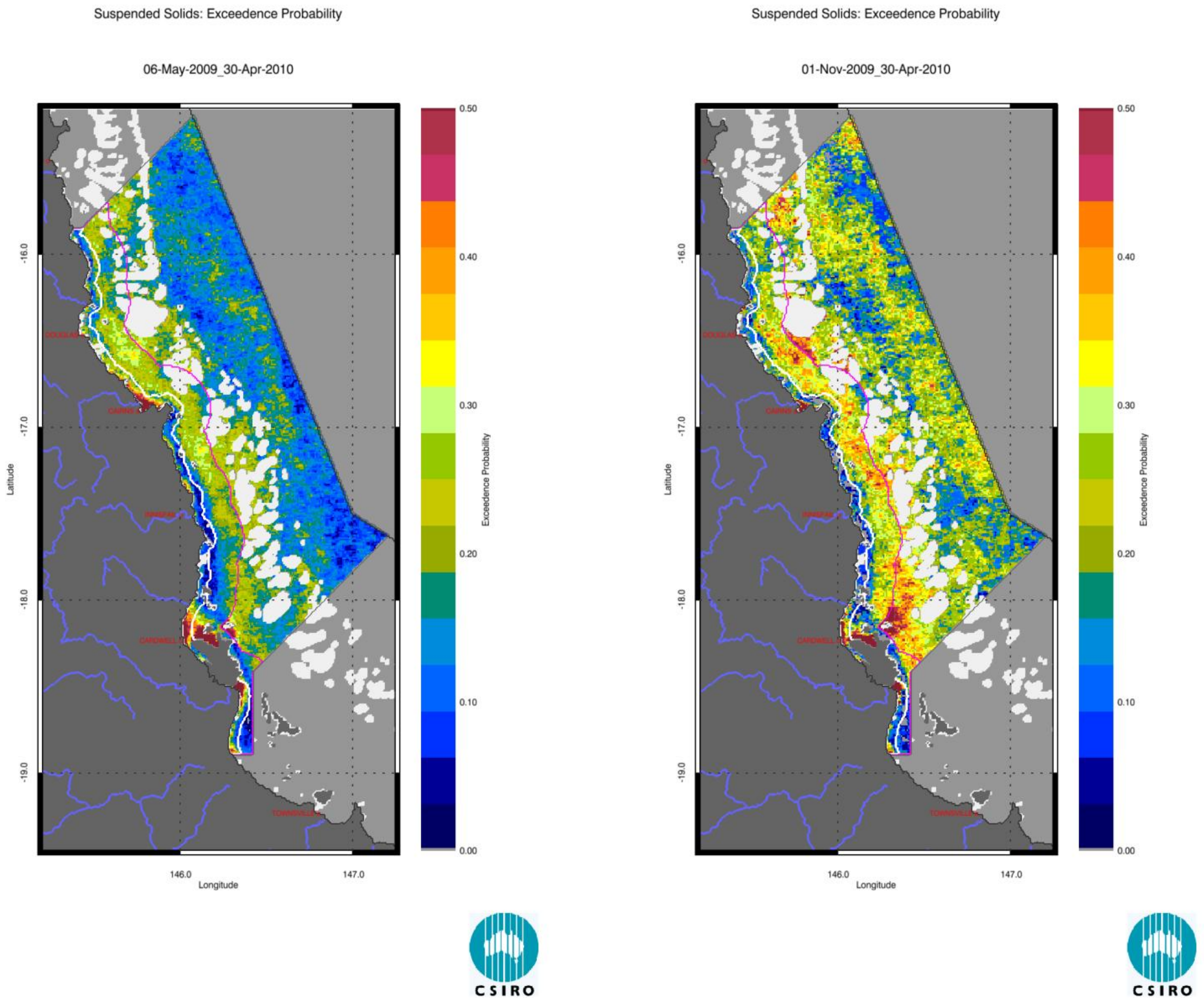
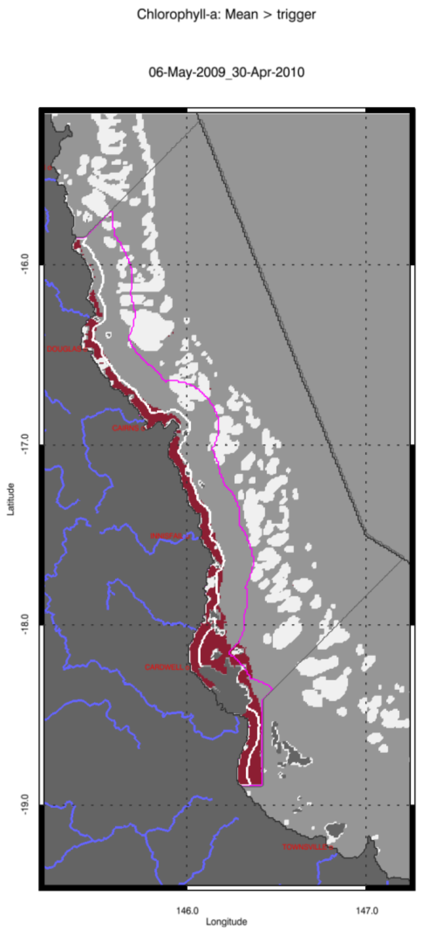


Figure 28. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance probability maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



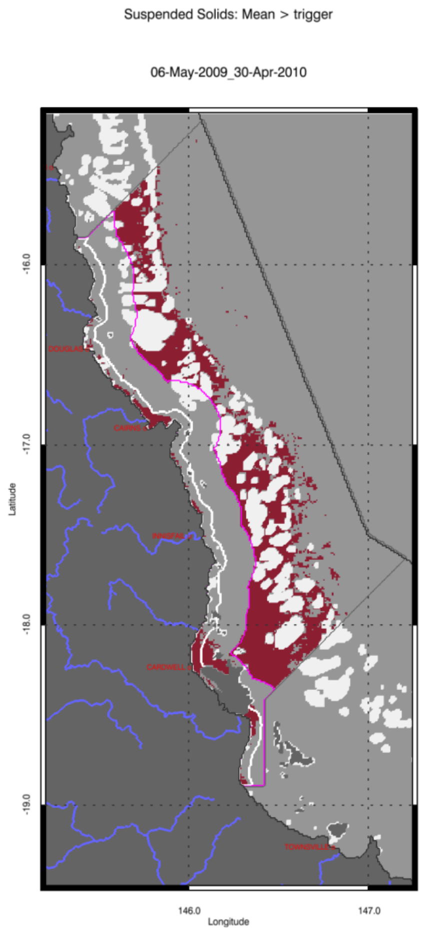


Figure 29. Exceedance maps for the Wet Tropics region for the whole year (May 2009 –April 2010). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance map. See text for annotation explanation.

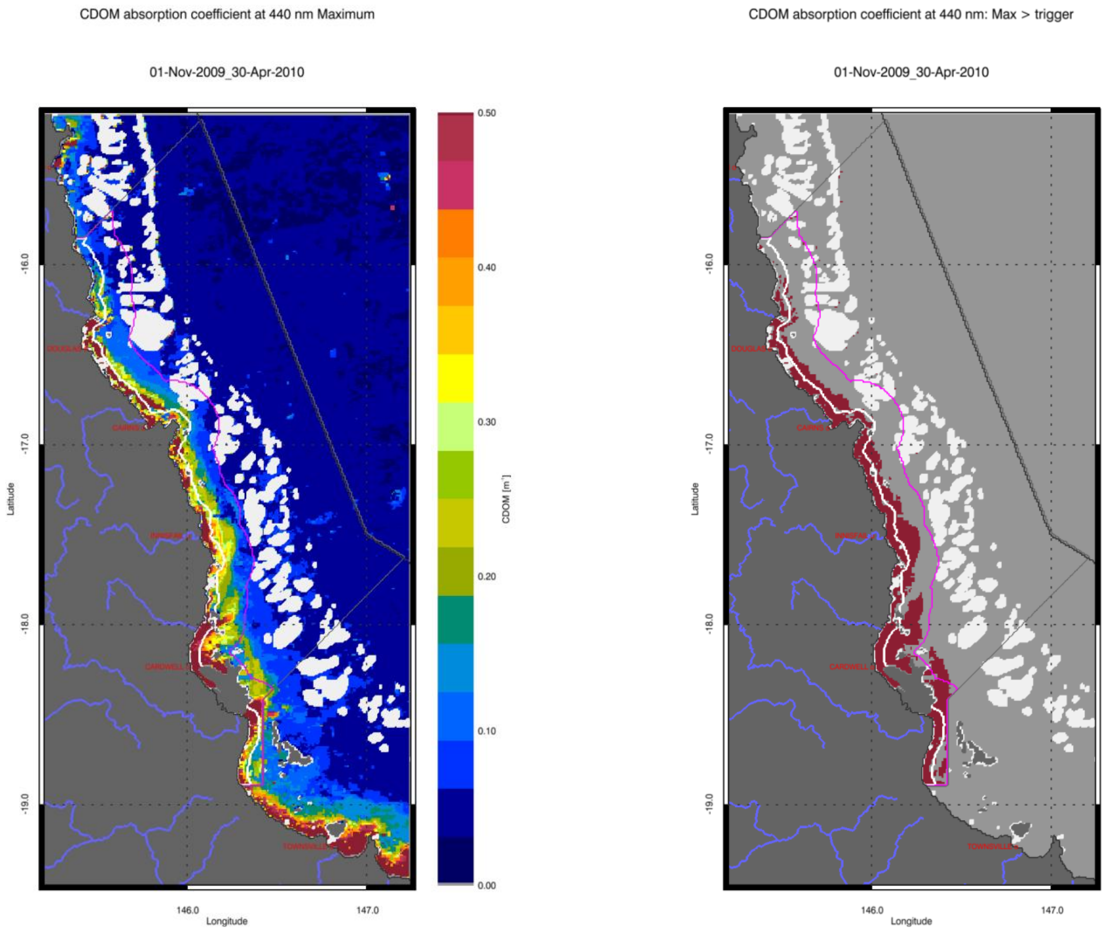


Figure 30. Map of freshwater extent for the wet season for the Wet Tropics region.. The first map presents the maximum value of CDOM for the wet season 2009/2010 (November 2009- April 2010), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m^{-1}. See text for annotation explanation.

Regional reports: Burdekin region

The Burdekin Dry Tropics region includes an aggregation of the Black, Burdekin, Don, Haughton and Ross River catchments and includes several smaller coastal catchments, all of which empty into the GBR lagoon. Because of its geographical location, rainfall in the region is lower than other regions within tropical Queensland, though there is considerable variation year to year with 75% of the annual rainfall received during December to March.

The wet and dry season median maps for Chlorophyll-a, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of Chlorophyll-a (Figure 31) for the Burdekin region show high Chlorophyll-a levels near the coast and in the estuary to lower concentrations towards the East. Median values of Chlorophyll-a up to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.25 μgL^{-1}. The lobe of relatively high Chlorophyll-a values (~0.3-0.4 μgL^{-1}) in dry season in the Midshelf and Offshore areas is possibly due to the occurrence of Trichodesmium blooms occurring in August/September/October.

The wet and dry season median maps of coloured dissolved organic matter (CDOM, Figure 32) for the Burdekin region show values higher than 0.20 m^{-1} for a coastal band ~10 km wide from Cape Upstart to Halifax Bay .The wet and dry season median maps of non-algal particulate matter (as a measure of Total Suspended Solids) show a simila r pattern, with values higher than 1.5 mgL^{-1} in all the open Coastal area in the wet season (Figure 33).

The wet and dry season median maps of vertical attenuation of light and of of water clarity expressed as Secchi Depth (Figure 34 and Figure 35) for the Burdekin region show similar gross patterns as for the Chlorophyll-a, coloured dissolved organic matter and non-algal particulate matter distribution. The maps in Figure 36 depict the number of image pixels available for calculating the median values for each season. This amount varies from 30 to 40 observations for the wet season and about 90 for the dry season for each pixel location.

Assessment of the exceedance of water quality guidelines

The exceedance of the Guidelines was assessed for Chlorophyll-a and Non-algal particulate matter (as measure for Total Suspended Solids) retrieved from MODIS Aqua using CSIRO's algorithm. Figure 37 presents the maps of Chlorophyll-a exceedance as defined by the Guidelines. Figure 38 presents the map of the EP for Chlorophyll-a.. Similar maps are presented for TSS (Figure 39 and Figure 40).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 31- Figure 33) and by the steep changes in trigger values between the Midshelf and Offshore areas.

The annual mean values of Chlorophyll-a exceeded the guideline value (0.45 ug/L) in 54% of the Open Coastal area, 1% of the Midshelf and none of the Offshore areas (Figure 41,Table 15). The mean values of Chlorophyll-a exceeded the Guidelines values for 76% of the Open Coastal Area in the dry season and 36 % in the wet season. In the dry season Chlorophyll-a also exceeded the Guidelines for

36 % of the Midshelf and 11% of the Offshore areas (Figure 37, Table 16). Similar exceedance values were retrieved if the median was used for the assessment (Figure 38, Table 16).

The mean values of TSS exceeded the Guidelines values for 75% of the Open Coastal Area in the dry season and 50 % in the wet season, while small exceedance levels were recorded for Midshelf and Offshore areas in both seasons (2-10%, Figure 39 and Table 17). Over the whole year, Exceedance of TSS Guideline values were recorded in 65% of the Open Coastal, 5% of the midshelf and 3% of offshore areas (Figure 41, Table 15). No exceedance was recorded for the Midshelf and Offshore areas in both seasons if the median was used for the assessment, while the exceedance of the median values for the Open Coastal Area where significantly lower (37% for the dry season and 10% for the wet season, Figure 40, and Table 17).

Table 18 and Table 19 report the Summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EP for that period. These metrics are based on a high number of observations (ranging from 90 thousands valid observations for Open Coastal in the wet season to over 1.1 million for the Offshore are in the dry season). According to these metrics both the mean and the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal area in both seasons. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of freshwater extent during the wet season

Figure 42 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the Burdekin region. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Burdekin region the freshwater extent for the wet season 2009/2010 (November 2009- April 2010) was 3599 km^2 while in the wet season 2008/2009 was 9733 km^2 (Figure 4).This reflects the high freshwater discharge from the Burdekin River that was sightly above the median values (~1.3) while the previous year flow was more than five times the annual median flow(Figure 3).

Table 15 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Burdekin region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2009_30-Apr-2010		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	3971	327698	1298517	65%	64%	39%	19%
MS	11065	924709	3618255	2%	2%	0%	0%
OS	26560	1619851	8685120	0%	0%	30%	0%

Table 16 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Burdekin region (Figure 37, Figure 38). Column and row labels are described in the legend of Table 15.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	3971	237099	639331	97%	98%	90599	659186	38%	27%
MS	11065	651416	1781465	99%	99%	273293	1836790	0%	0%
OS	26560	1101851	4276160	60%	63%	518000	4408960	0%	0%

Table 17 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Burdekin region (Figure 39, Figure 40). Column and row labels are described in the legend of Table 15.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	3971	237099	639331	50%	30%	90599	659186	46%	16%
MS	11065	651416	1781465	1%	0%	273293	1836790	5%	0%
OS	26560	1101851	4276160	30%	0%	518000	4408960	47%	0%

Table 18. Summary of Chlorophyll-a exceedance for the dry and wet season for the Burdekin region. Column and row labels are described in the legend of Table 15Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	237099	639331	**0.67**	**0.49**	61%	90599	659186	**0.65**	**0.50**	63%
MS	651416	1781465	0.37	0.39	12%	273293	1836790	0.33	0.32	24%
OS	1101851	4276160	0.31	0.32	18%	518000	4408960	0.29	0.28	17%

Table 19 Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Burdekin region. Column and row labels are described in the legend of Table 15. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	237099	639331	**2.11**	1.14	25%	90599	659186	**2.64**	1.47	35%
MS	651416	1781465	0.79	0.23	11%	273293	1836790	1.66	0.47	30%
OS	1101851	4276160	0.47	0.12	11%	518000	4408960	**0.88**	0.19	22%

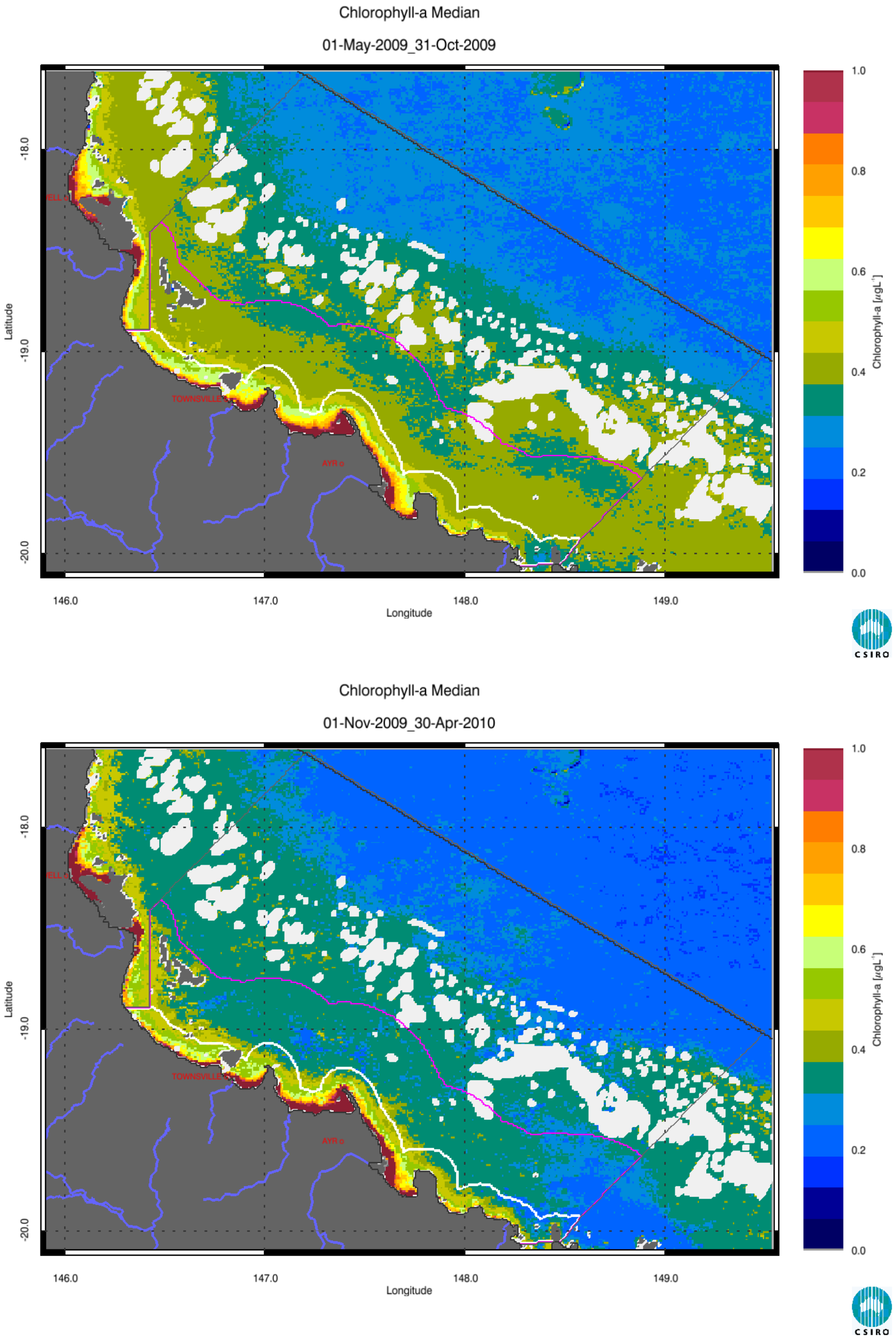
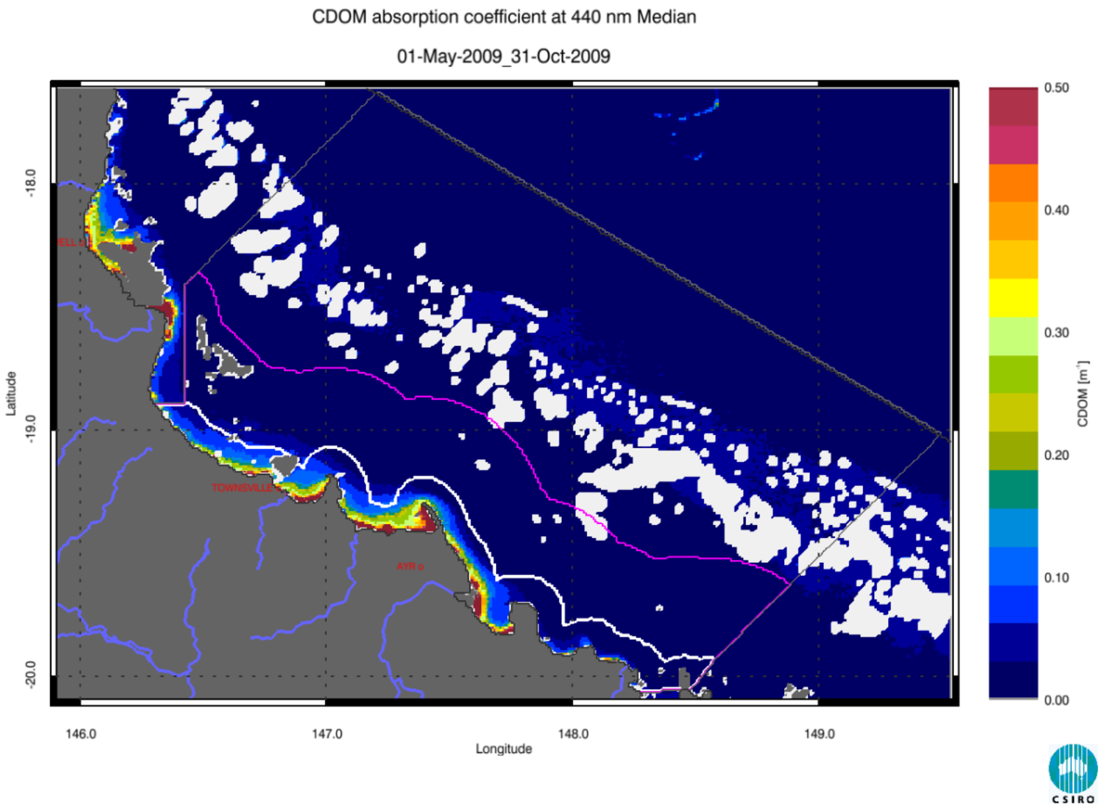


Figure 31. Chlorophyll-a median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



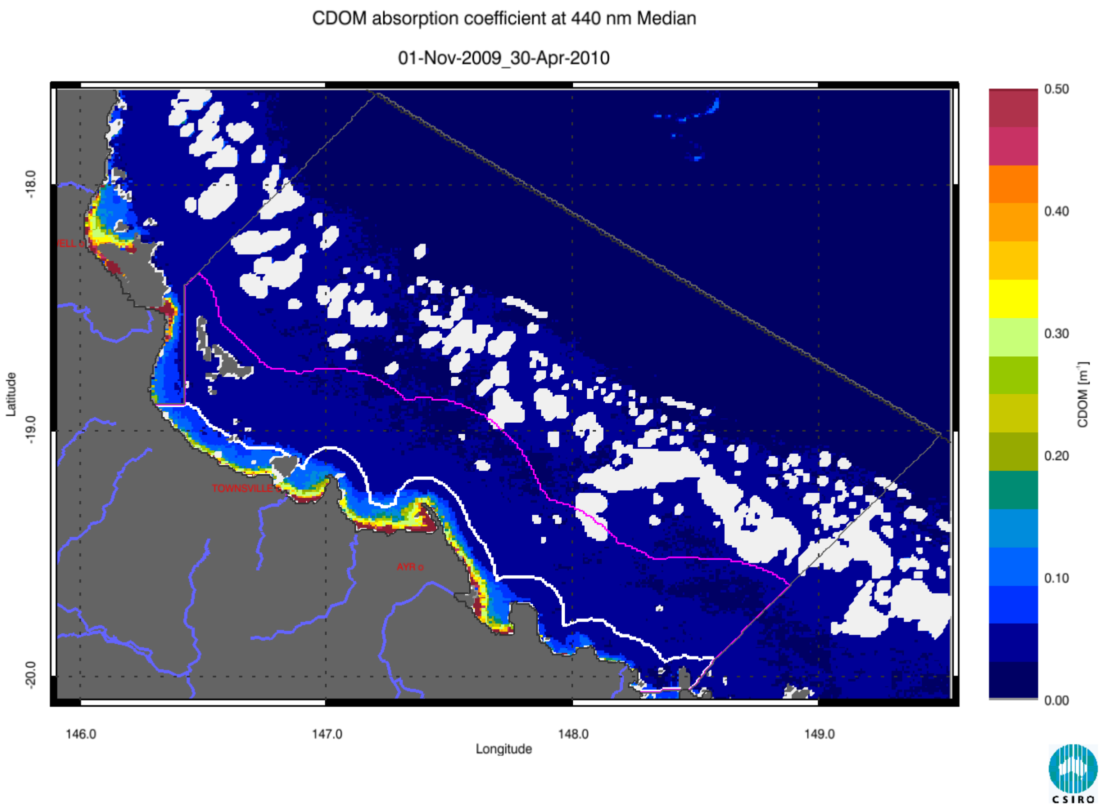


Figure 32. CDOM median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

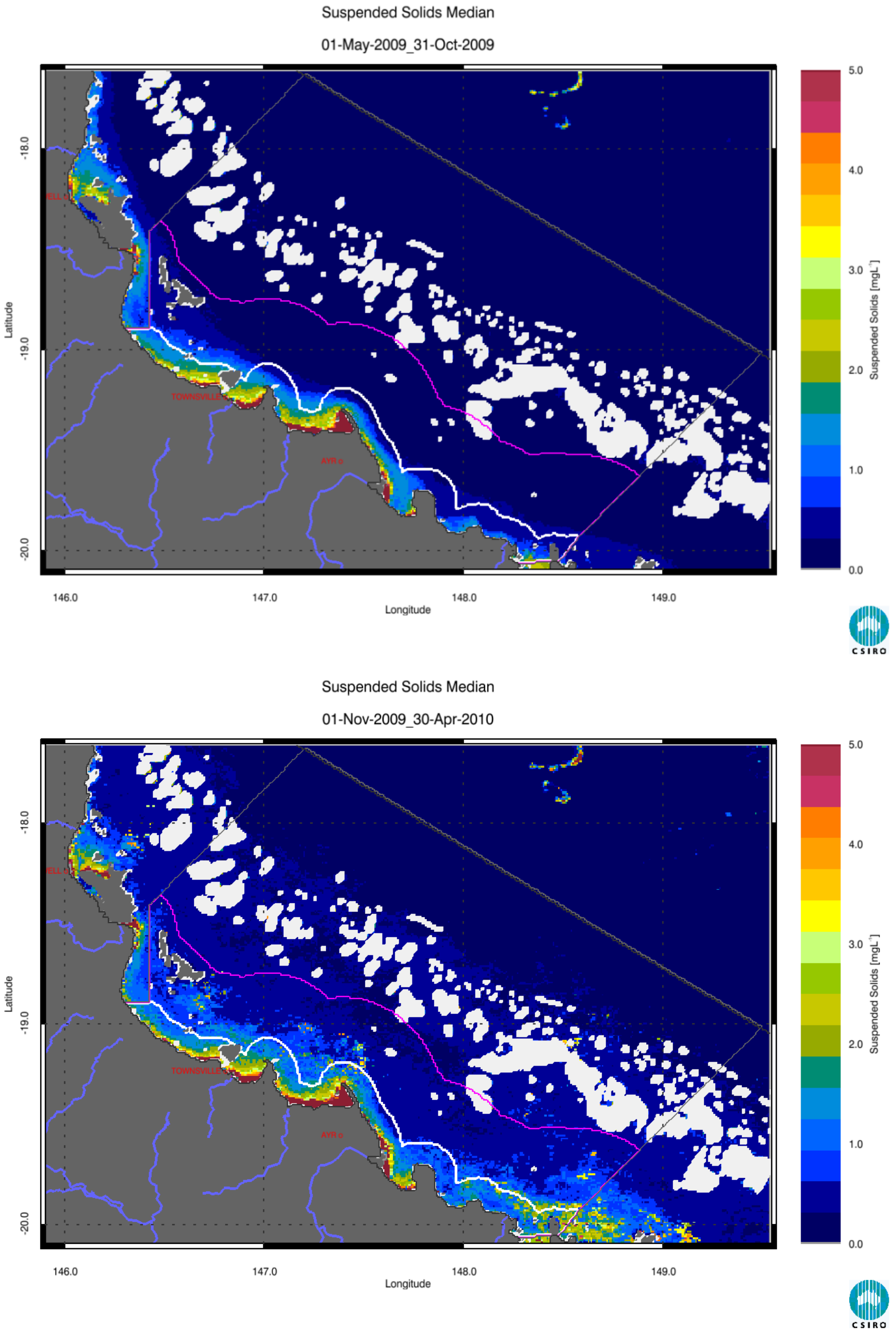
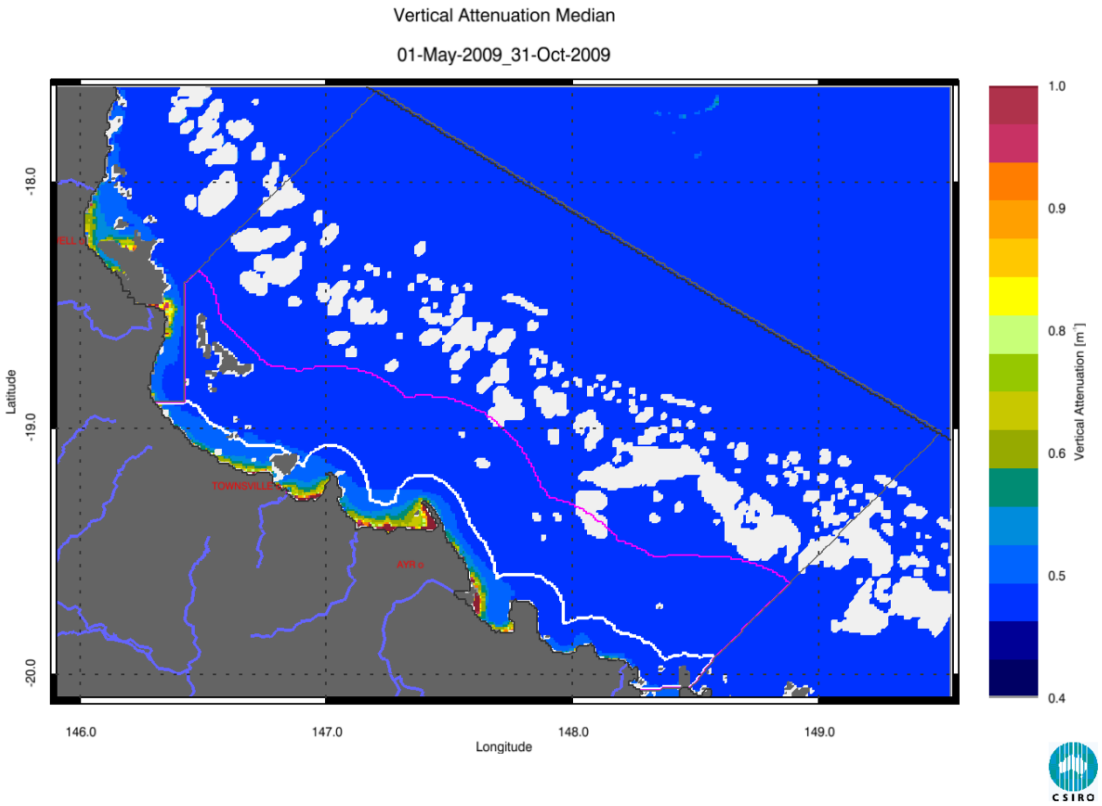


Figure 33. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



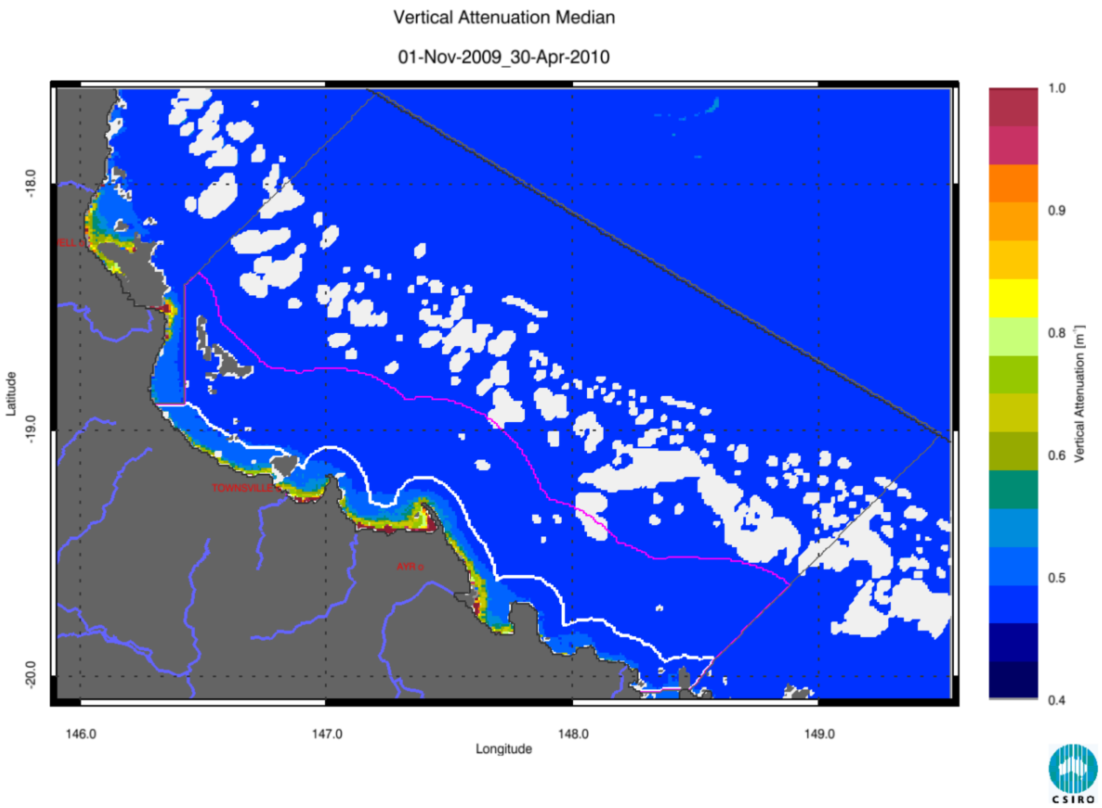


Figure 34. Vertical attenuation of light (Kd ,as estimate of water clarity) median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

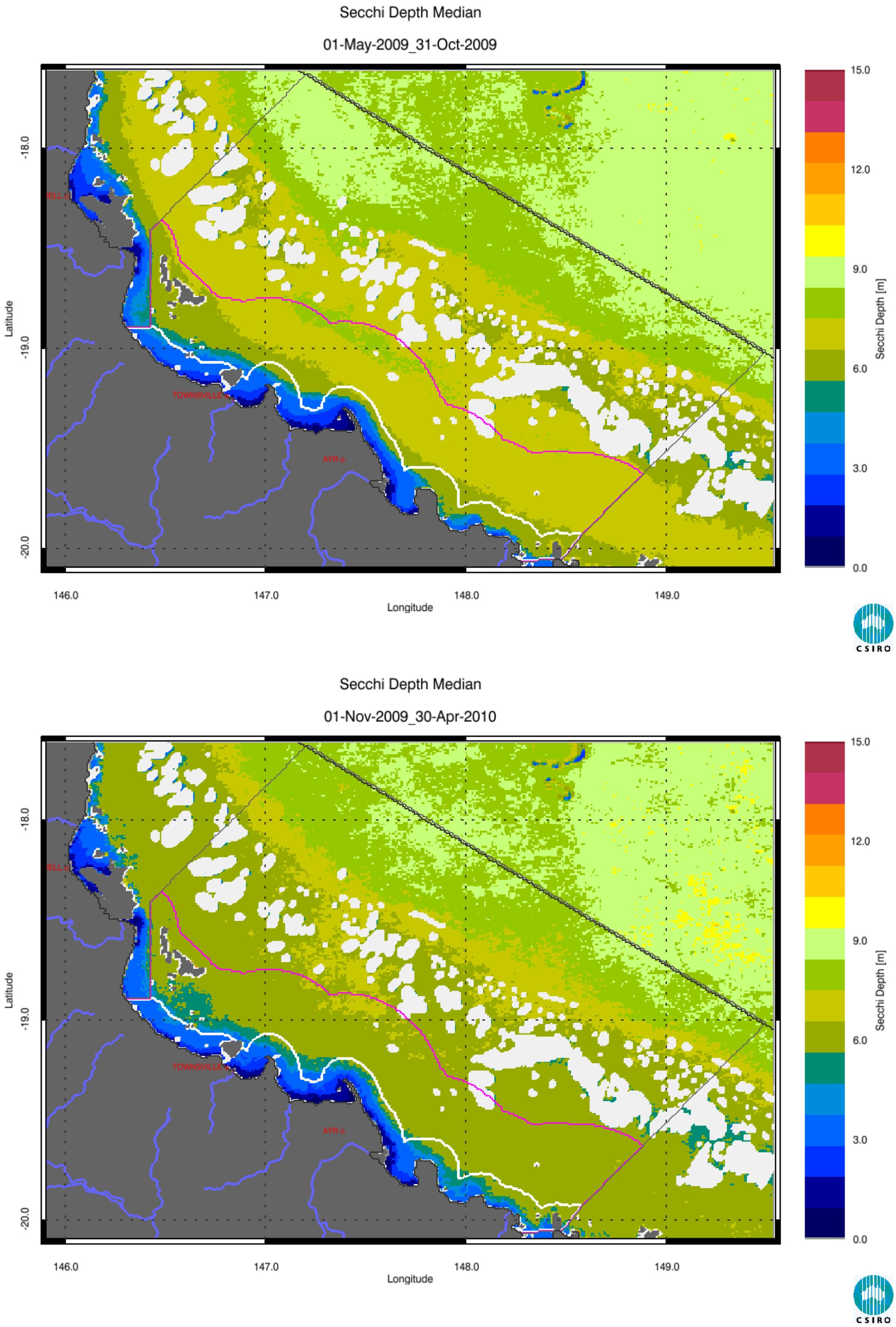


Figure 35. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

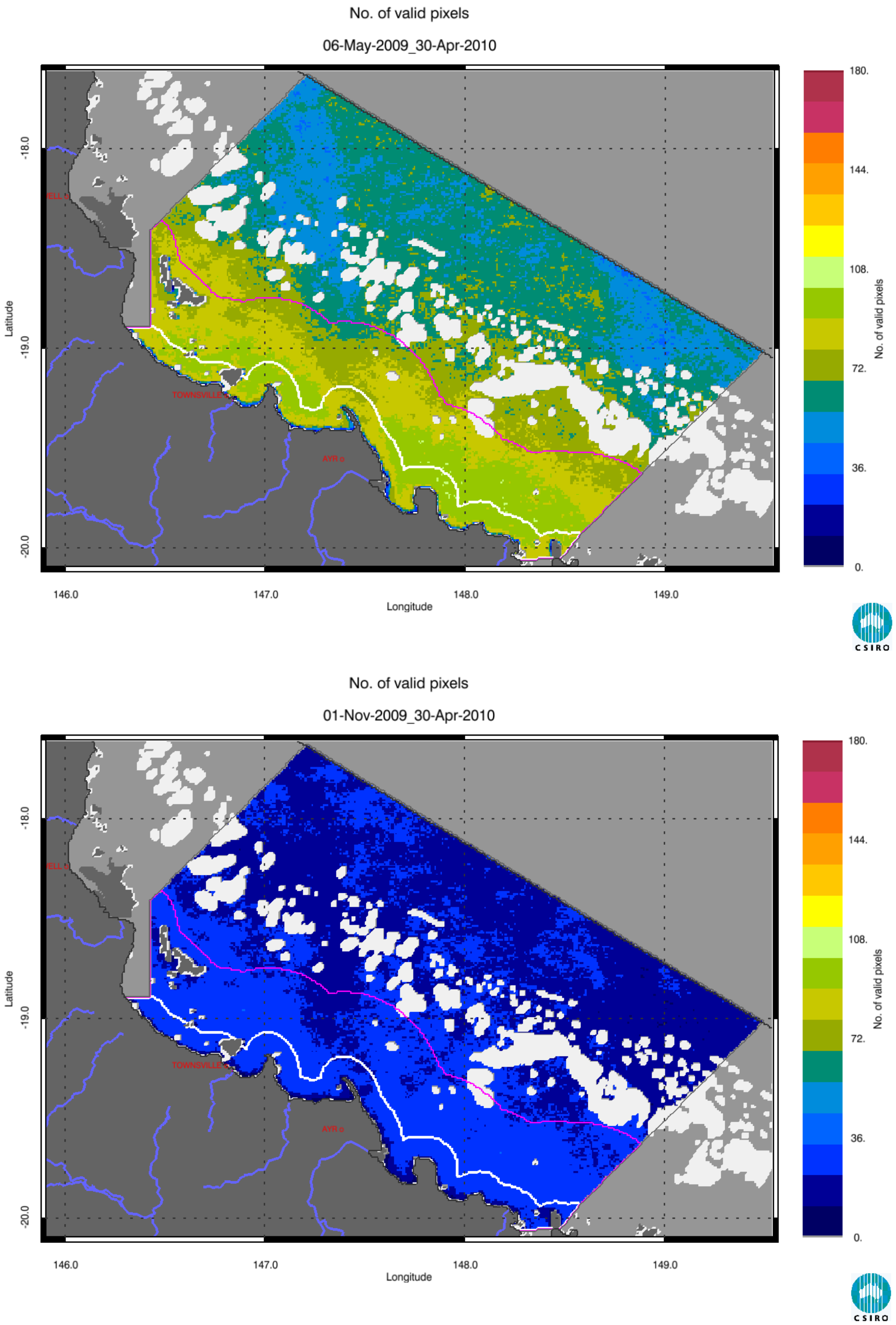
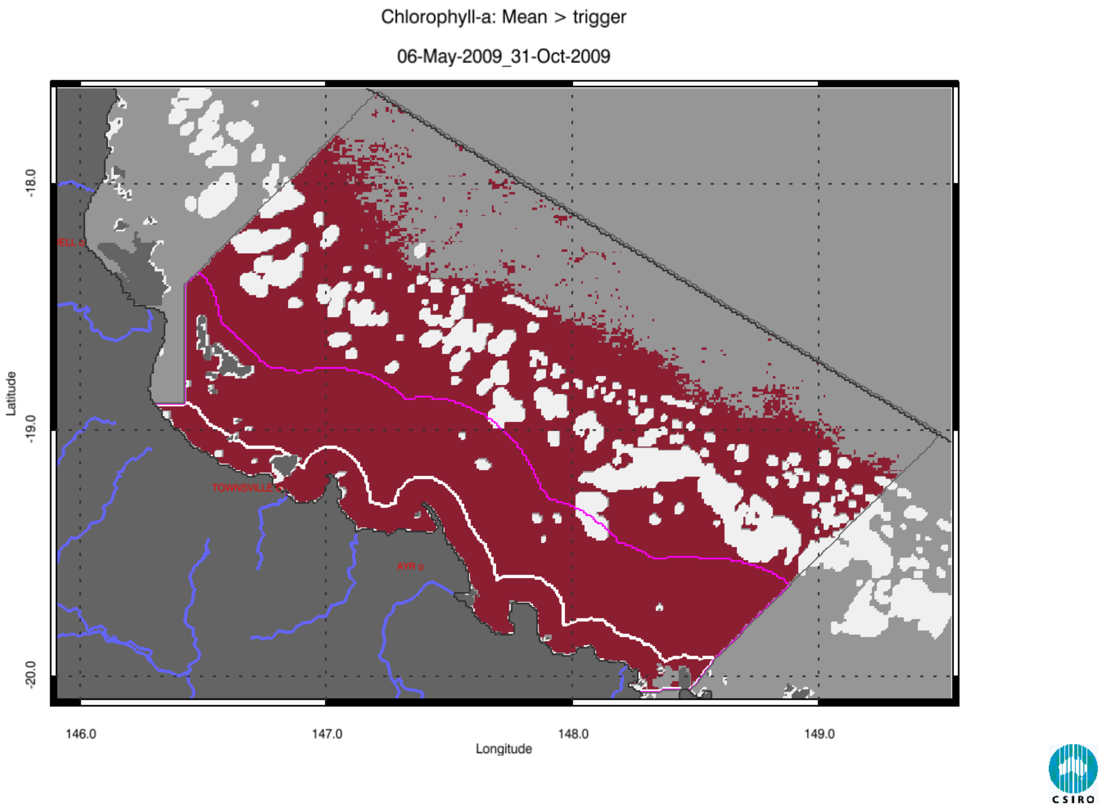


Figure 36. Number of pixels used to calculate the median maps (Figure 31- Figure 35) for the dry and wet season for the Burdekin region. The first map presents the number of pixels available for analysis in the dry season 2009 (May - October), while the second map presents the number of pixels available for analysis in the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



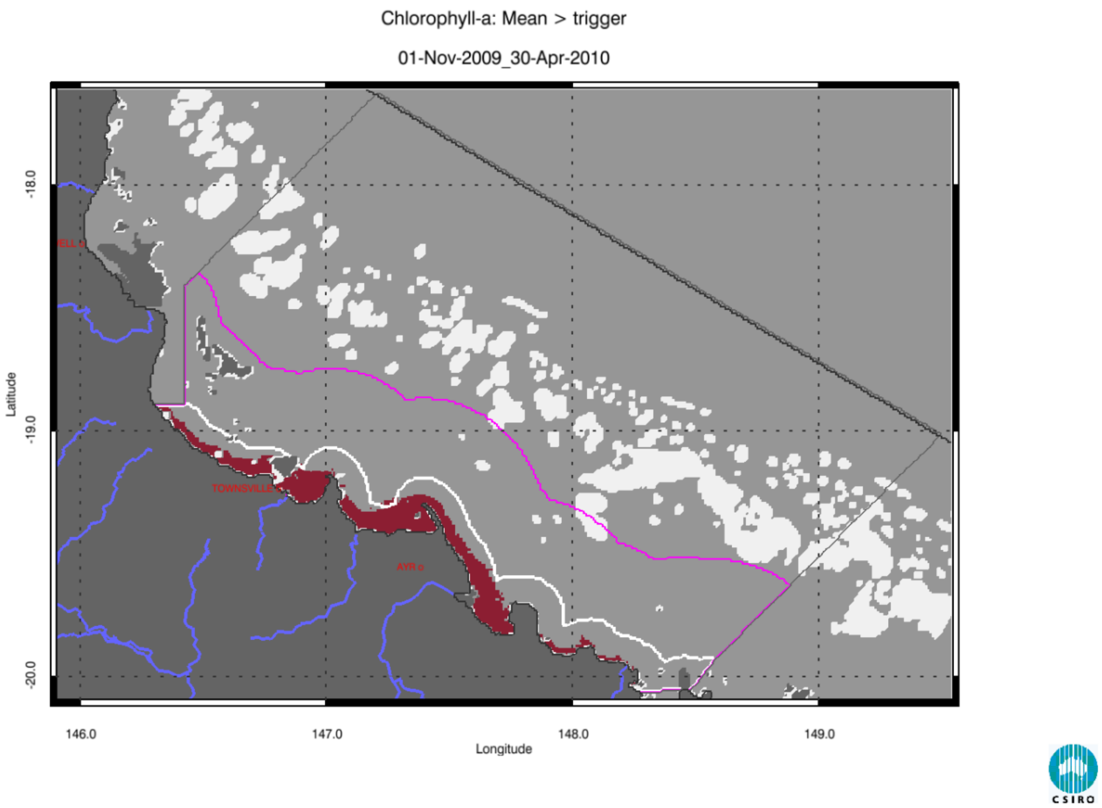
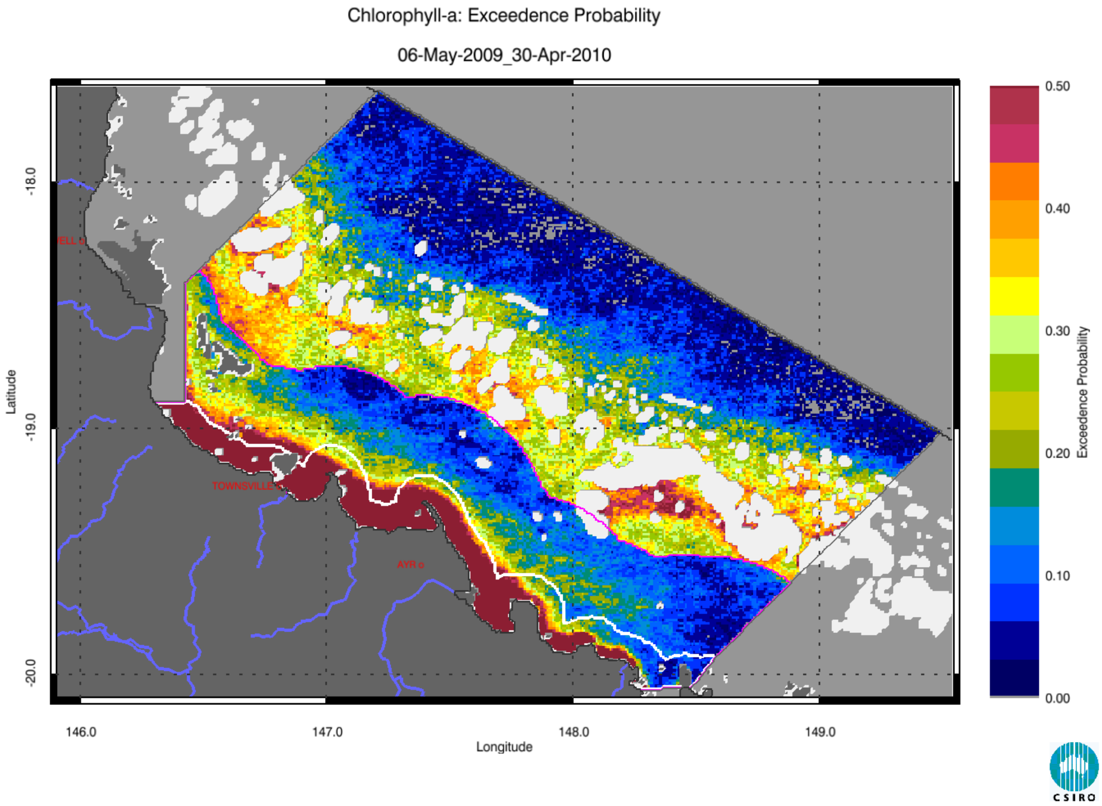


Figure 37. Chlorophyll-a exceedance maps for the dry and wet season for the Burdekin region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



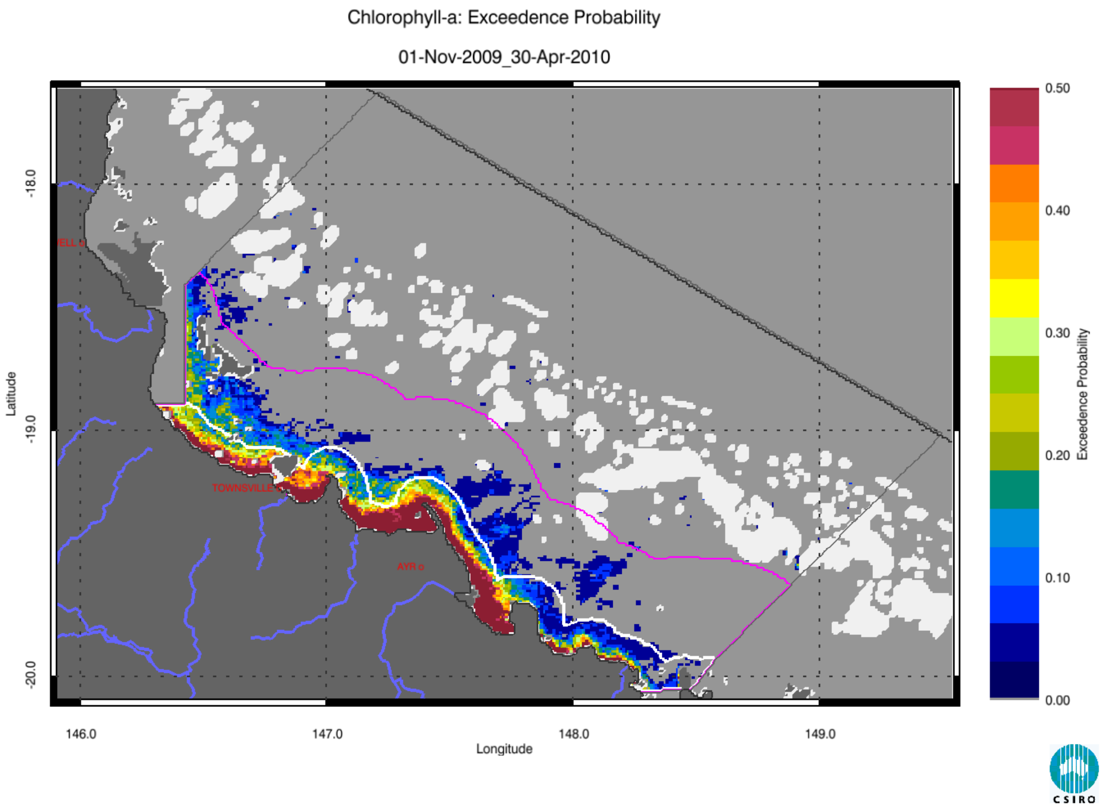
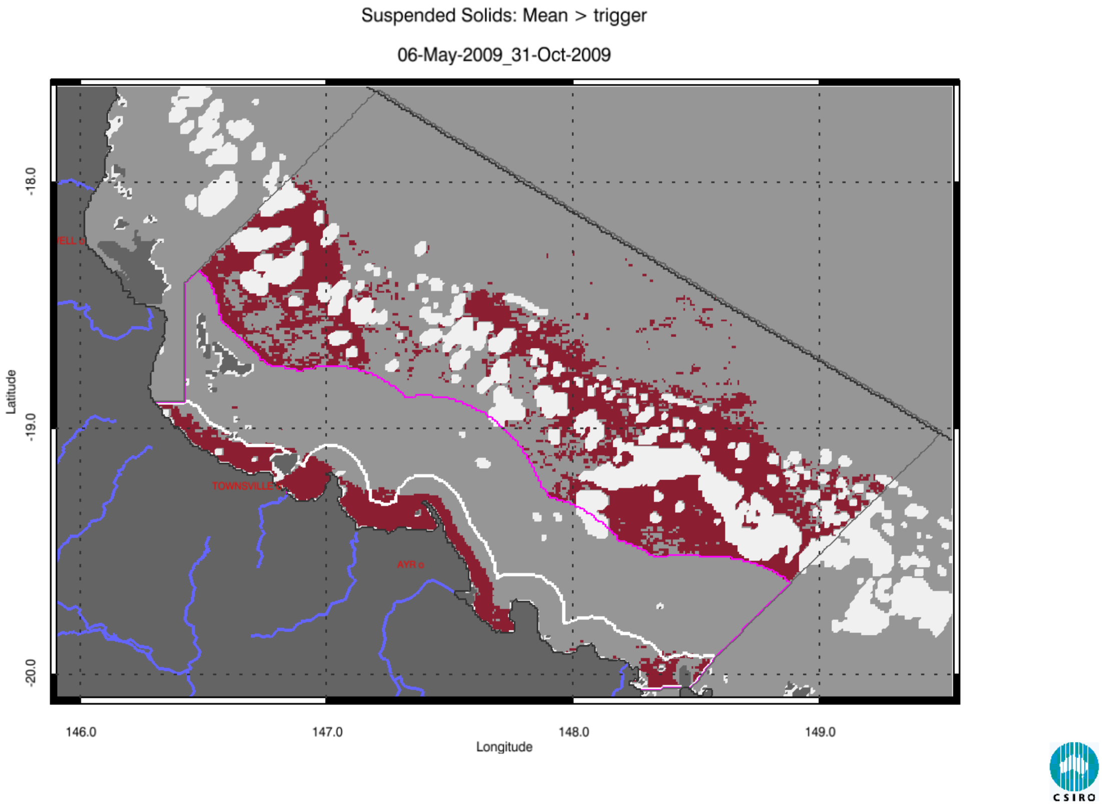


Figure 38. Chlorophyll-a exceedance probability maps for the dry and wet season for the Burdekin region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



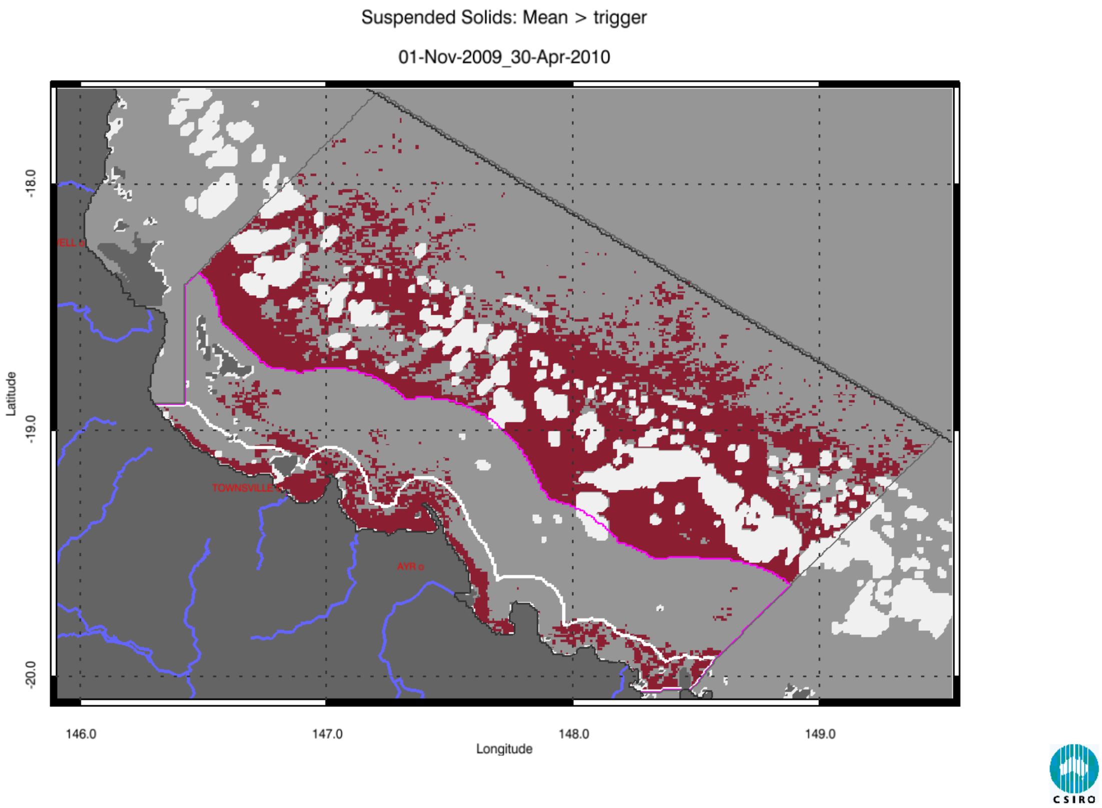


Figure 39. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance maps for the dry and wet season for the Burdekin region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

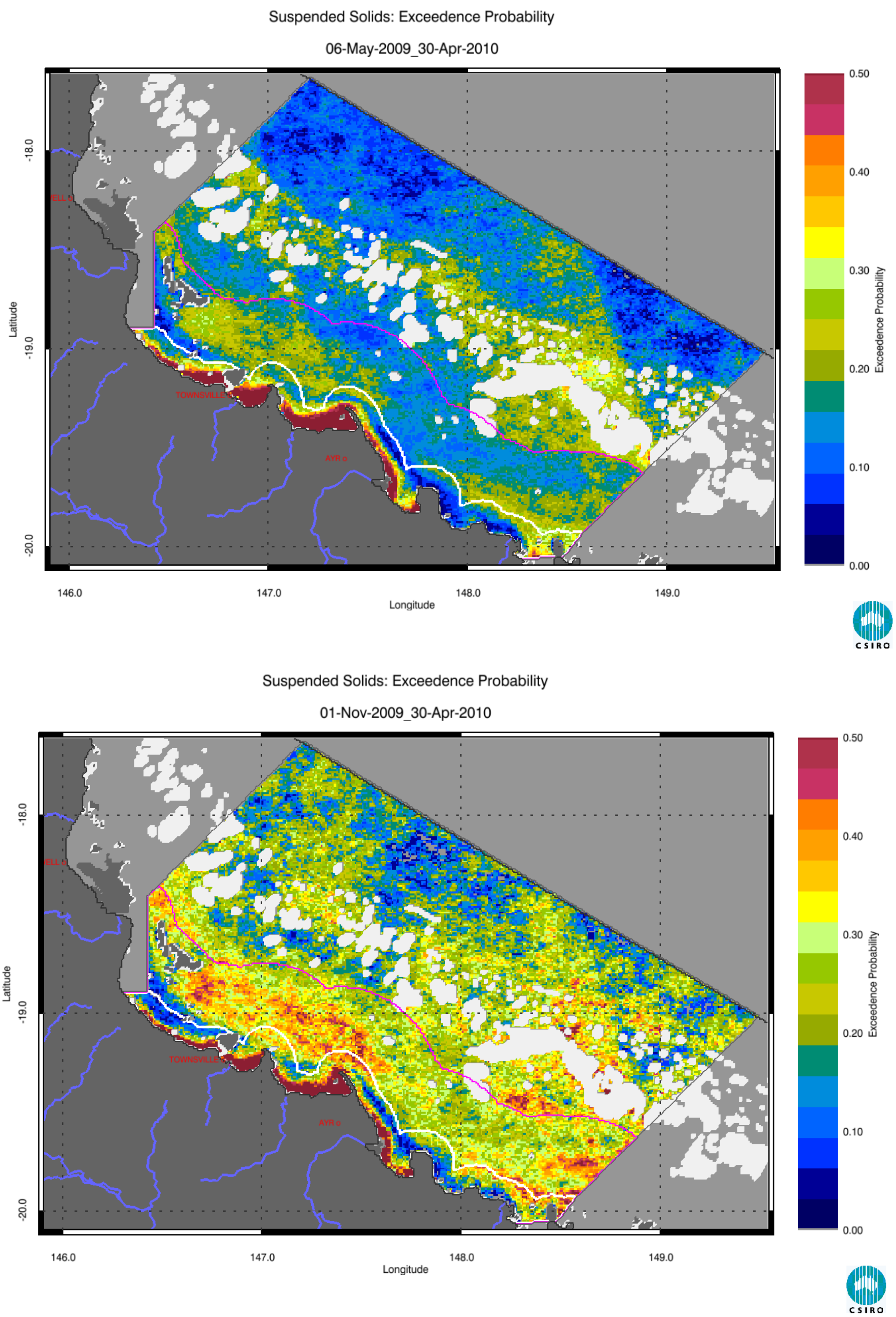
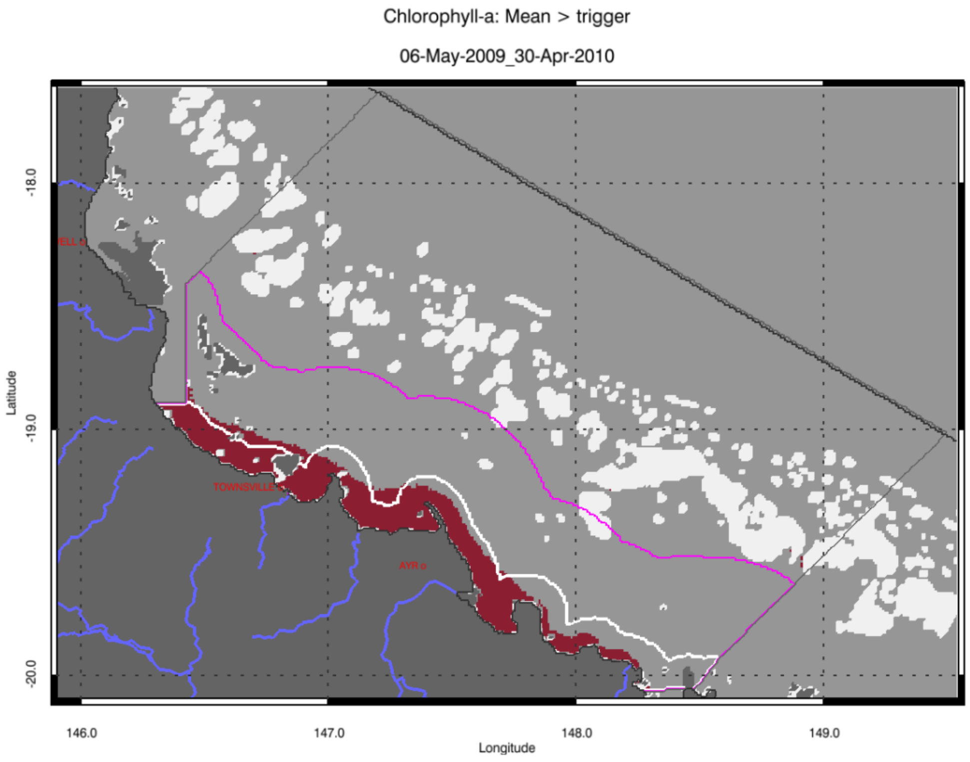


Figure 40. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance probability maps for the dry and wet season for the Burdekin region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



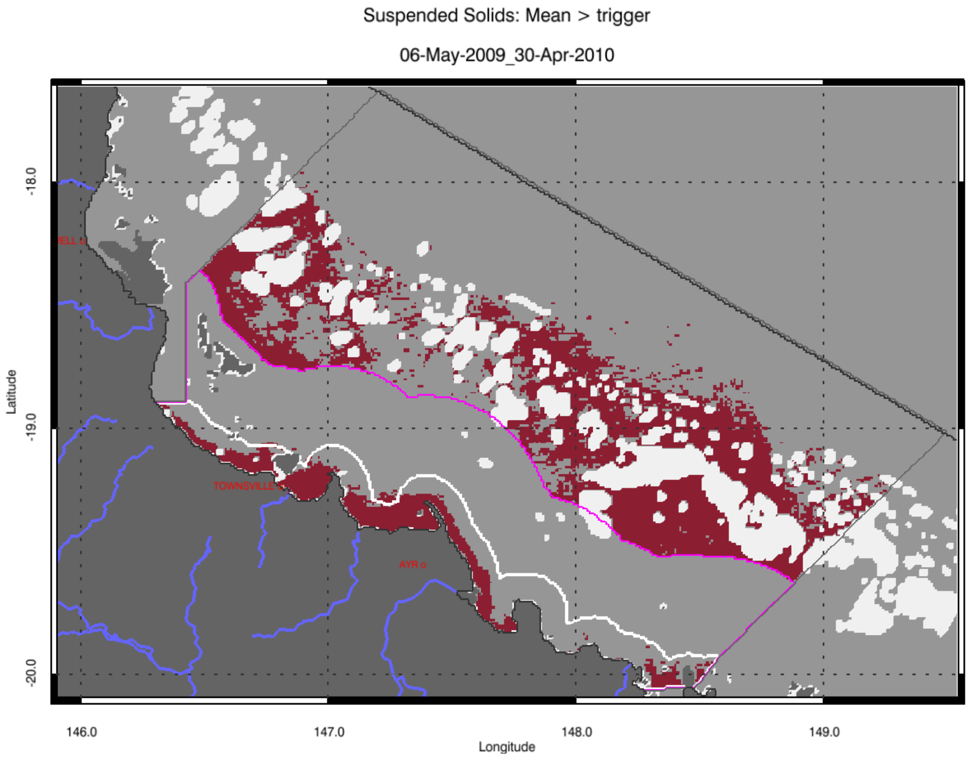
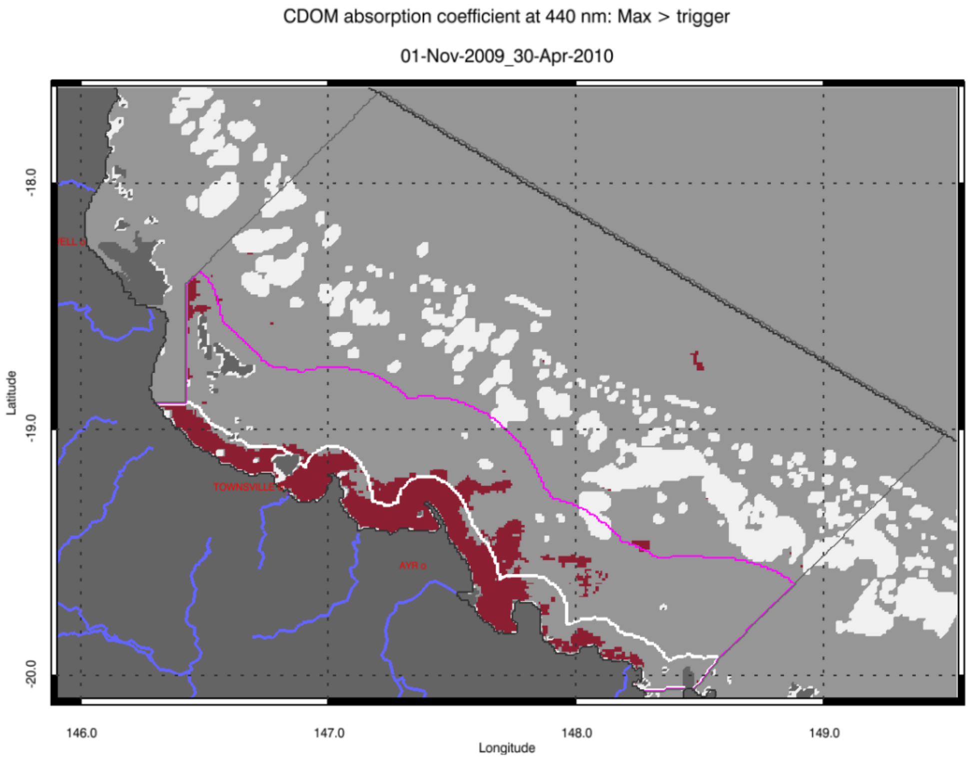


Figure 41. Exceedance maps for the Burdekin region for the whole year (May 2009 –April 2010). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance map. See text for annotation explanation.



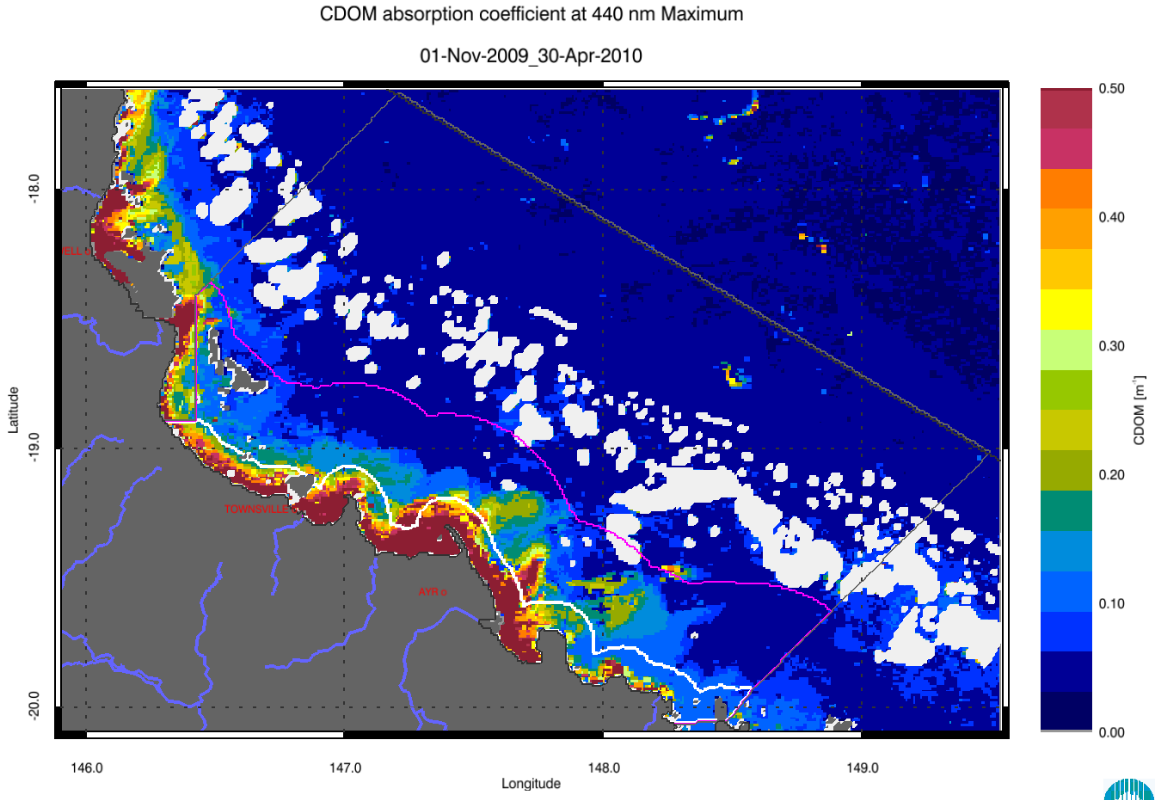


Figure 42. Map of freshwater extent for the wet season for the Burdekin region. The first map presents the maximum value of CDOM for the wet season 2009/2010 (November 2009- April 2010), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m^{-1}. See text for annotation explanation.

Mackay Whitsunday region

The Mackay Whitsunday Region is located in the central section of the GBR and comprises three major river catchments, the Proserpine, O'Connell (both flowing into Repulse Bay) and Pioneer catchments. The climate in this region is wet or mixed wet and dry and the catchment land use is dominated by agriculture such as grazing and cropping (mainly sugarcane on coastal plains), and minor urbanisation. The adjacent coastal and inshore marine areas have a large number of high continental islands with well-developed fringing reefs.

The wet and dry season median maps for Chlorophyll-a, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of Chlorophyll-a (Figure 43) for the Mackay Whitsunday region show high Chlorophyll-a levels near the coast and in the estuary to lower concentrations towards the East. Median values of Chlorophyll-a to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.25 μgL^{-1}. The lobe of relatively high Chlorophyll-a values (~0.3 μgL^{-1}) in dry season in the Midshelf and Offshore areas is possibly due to the occurrence of Tricodesmium blooms occurring in August/September/October.

The wet and dry season median maps of coloured dissolved organic matter (CDOM, Figure 44) for the Mackay Whitsunday region show values higher than 0.20 m^{-1} for a coastal band ~5-10 km wide. The wet and dry season median maps of non-algal particulate matter (as a measure of Total Suspended Solids) (Figure 45) for the Mackay Whitsunday region show similar gross patterns as for the CDOM distribution. The high concentrations shown Broad Sound and Shoalwater Bay are likely to be overestimated. The accuracy of the retrieval from MODIS imagery in these shallow and turbid waters systems cannot be assessed as there is no data available for parameterization and validation.

The wet and dry season median maps of vertical attenuation of light and of water clarity expressed as Secchi Depth (Figure 46a nd Figure 47) for the Mackay Whitsunday region show similar gross patterns as for the Chlorophyll-a, coloured dissolved organic matter and non-algal particulate matter distribution. The number of image pixels per pixel location available for calculating the median values varies from 30 to 40 observations for the wet season and about 90 for the dry season for each pixel location (Figure 48).

Assessment of the exceedance of water quality guidelines

The exceedance of the Guidelines was assessed for Chlorophyll-a and Non-algal particulate matter (as measure for Total Suspended Solids) retrieved from MODIS Aqua using CSIRO's algorithm. Figure 49 presents the maps of Chlorophyll-a exceedance as defined by the Guidelines. Figure 50 presents the map of the EP for Chlorophyll-a. Similar maps are presented for Total Suspended Solids (using Non-algal particulate matter as a measure of Total Suspended Solids, Figure 51 and Figure 52).

For the Mackay Whitsunday region the annual mean values of Chlorophyll-a exceeded the guideline value (0.45 µg/L) for 24% of the Open Coastal area, 3% of the Midshelf and none of the Offshore areas (Figure 53, Table 20). The mean values of Chlorophyll-a exceeded the Guidelines values for 67% of the Open Coastal area in the dry season and 12 % in the wet season. The mean values of Chlorophyll-a exceeded the Guidelines in the wet season only in correspondence to the river mouths: Proserpine and O'Connell, Pioneer and Plane Rivers In the dry season Chlorophyll-a also exceeded the Guidelines for 15 % of the Midshelf and 40% of the Offshore areas (Figure 49, Table 21). Similar exceedance values were retrieved if the median was used for the assessment (Figure 50, Table 20, Table 21).

The mean values of TSS exceeded the Guidelines values for 73 % of the Open Coastal area in the both seasons, for 59% of the Midshelf in the dry season and for 38% in the wet season, and 50% of the Offshore area in the dry season and for 53% in the wet season. The estimated exceedance for the all areas was significantly lower for the median values that those for the mean values (Figure 52, and Table 22). Over the whole year, Exceedance of TSS Guideline values were recorded in 74% of the Open Coastal, 42% of the Midshelf and 50% of Offshore areas (Figure 53, Table 20).

The spatial patterns in exceedance were affected by the coastal to offshore gradients that can be observed in the median maps (Figure 43, Figure 45) and by the steep changes in trigger values between the Midshelf and Offshore areas.

Table 23 and Table 24 report the Summary of exceedance for both variables , providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EP for that period. These metrics are based on a high number of observations (ranging from 90 thousand valid observations for Open Coastal area in the wet season to over 1.1 million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal area in both seasons, while the mean values of TSS exceeded the Guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of freshwater extent during the wet season

Figure 54 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the Mackay Whitsunday region. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Mackay-Whitsunday region the freshwater extent for the wet season 2009/2010 (November 2009- April 2010) was 5557 km^2 while in the wet season 2008/2009 was 3507 km^2 (Figure 4). The larger freshwater extent in 2009/10 correlates with a freshwater discharge for the Proserpine, O'Connell, Pioneer and Plane Rivers above median flows (Figure 3).

Table 20 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Mackay-Whitsunday region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2009_30-Apr-2010		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	4576	350234	1473472	32%	21%	69%	30%
MS	11389	855812	3667258	3%	0%	40%	10%
OS	25580	1639035	8236760	0%	2%	64%	3%

Table 21. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Mackay Whitsunday region (Figure 49, Figure 50). Column and row labels are described in the legend of Table 20.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4576	262132	713856	94%	96%	88102	759616	23%	8%
MS	11389	647455	1776684	67%	81%	208357	1890574	1%	0%
OS	25580	1190041	3990480	81%	88%	448994	4246280	0%	0%

Table 22. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Mackay Whitsunday region (Figure 51, Figure 52). Column and row labels are described in the legend of Table 20.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4576	262132	713856	75%	44%	88102	759616	72%	27%
MS	11389	647455	1776684	48%	12%	208357	1890574	46%	10%
OS	25580	1190041	3990480	69%	5%	448994	4246280	66%	11%

Table 23. Summary of Chlorophyll-a exceedance for the dry and wet season for the Mackay Whitsunday region. Column and row labels are described in the legend of Table 20. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	262132	713856	0.44	0.39	25%	88102	759616	**0.52**	0.44	47%
MS	647455	1776684	0.34	0.37	6%	208357	1890574	0.33	0.31	23%
OS	1190041	3990480	0.33	0.35	30%	448994	4246280	0.31	0.32	24%

Table 24. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Mackay Whitsunday region. Column and row labels are described in the legend of Table 20 Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	262132	713856	**2.56**	1.53	37%	88102	759616	**4.58**	2.02	50%
MS	647455	1776684	1.87	0.53	29%	208357	1890574	**2.87**	1.26	41%
OS	1190041	3990480	**0.92**	0.26	22%	448994	4246280	**1.20**	0.35	30%

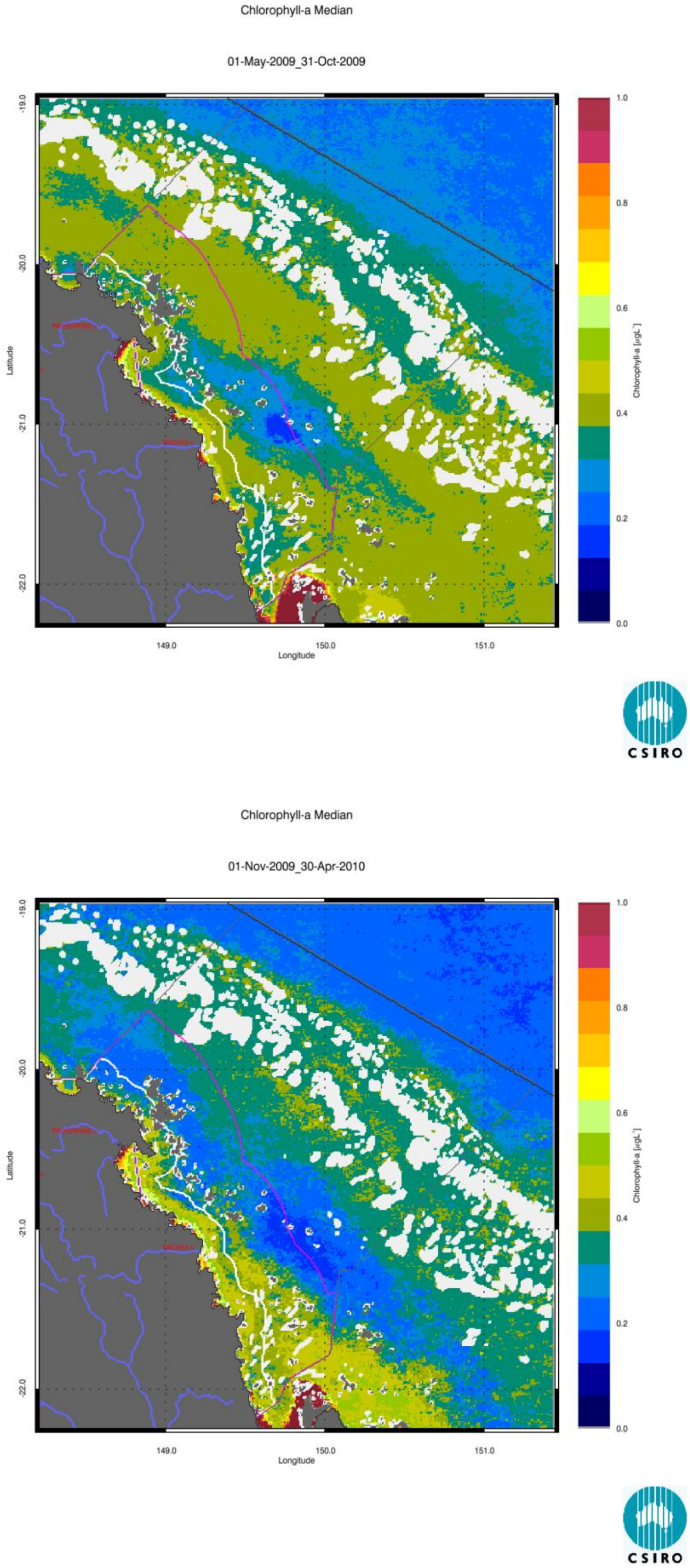
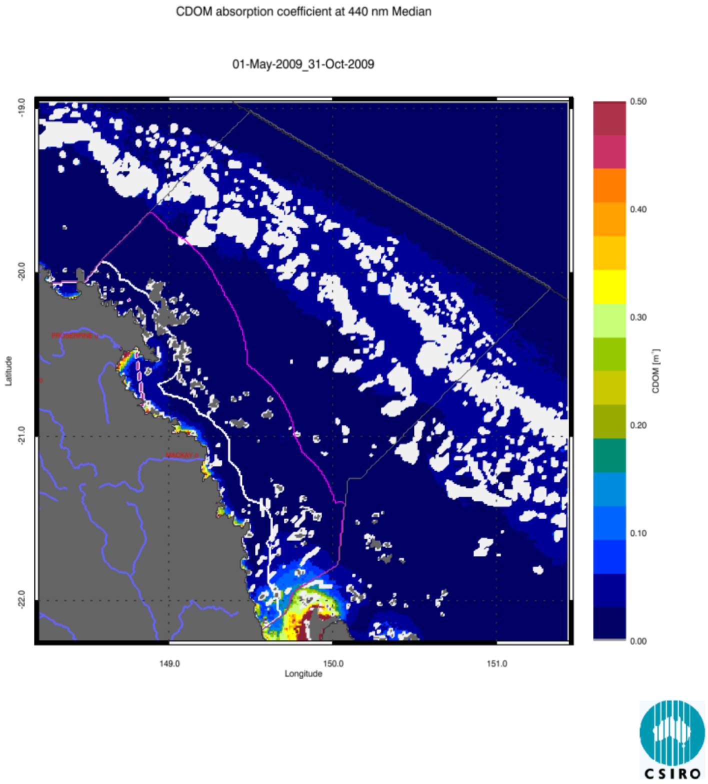


Figure 43. Chlorophyll-a median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



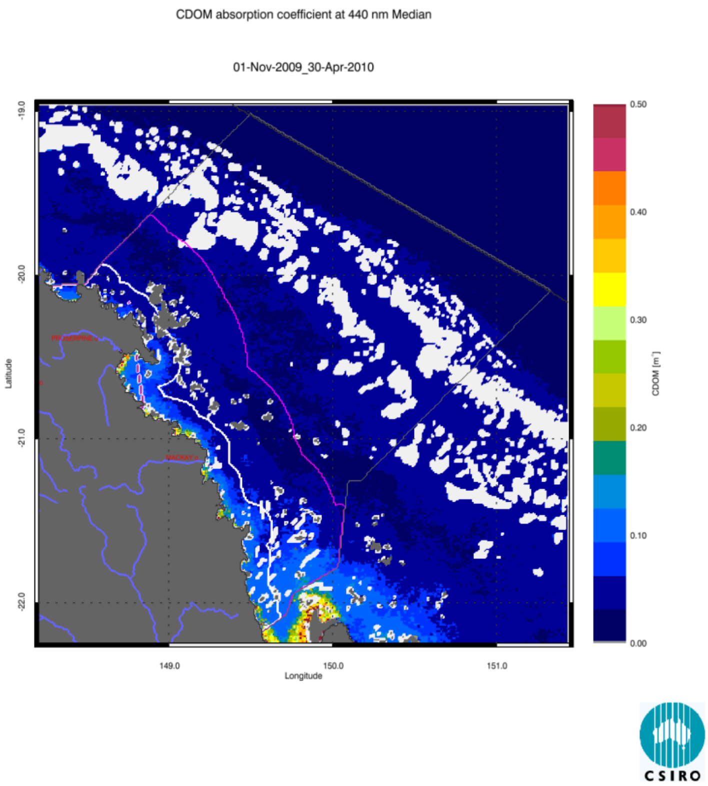


Figure 44. CDOM median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

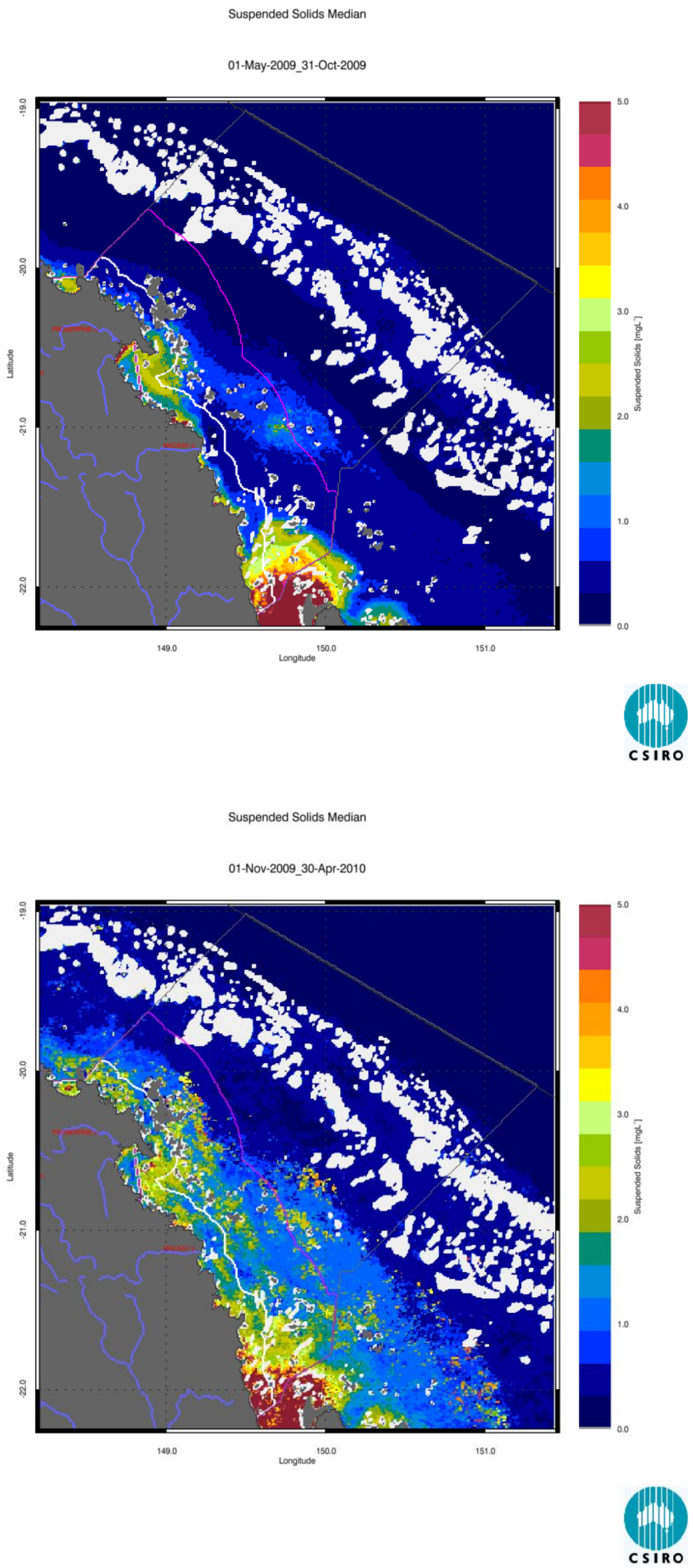
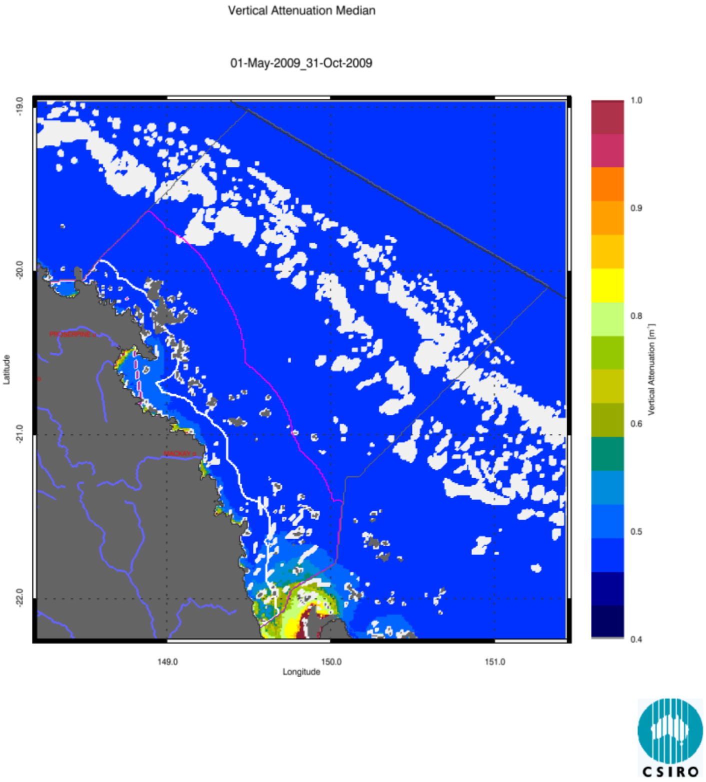


Figure 45. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



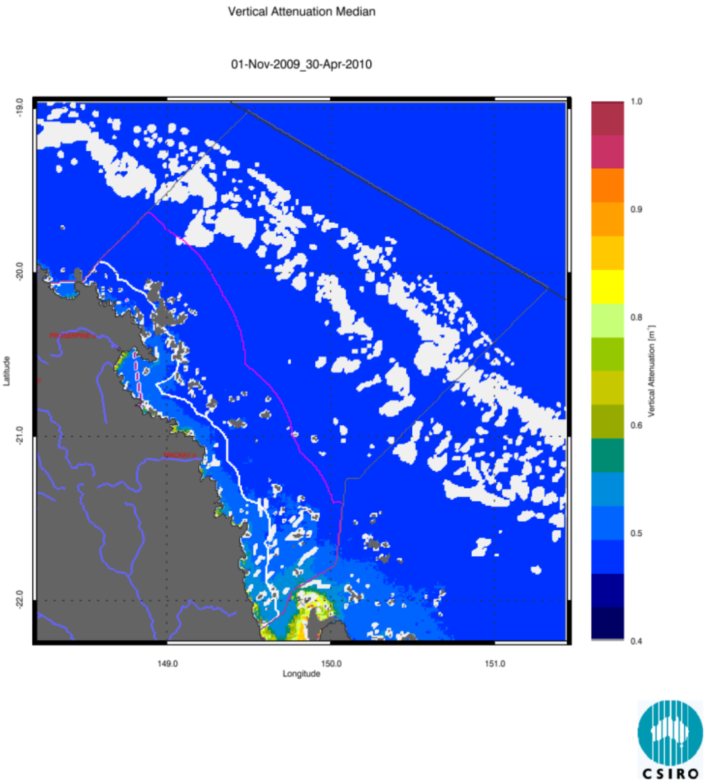
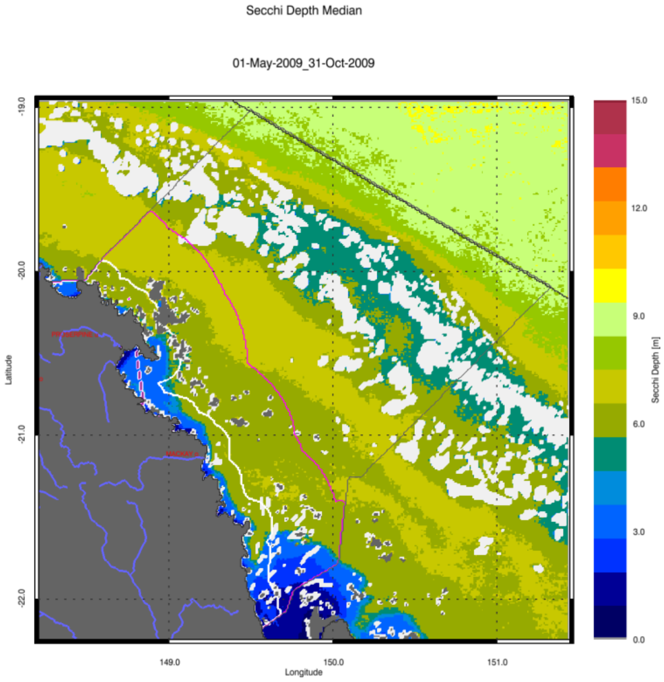


Figure 46. Vertical attenuation of light (Kd ,as estimate of water clarity) median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



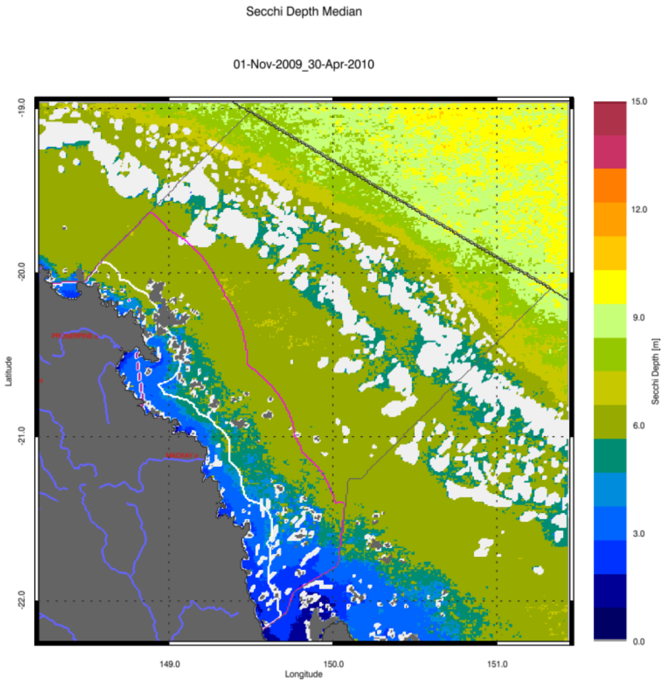
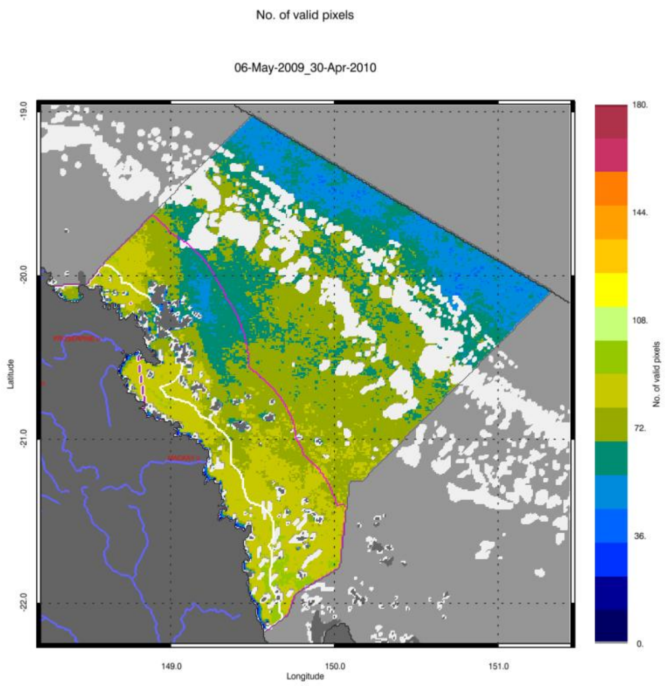


Figure 47. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009-April 2010). See text for annotation explanation.



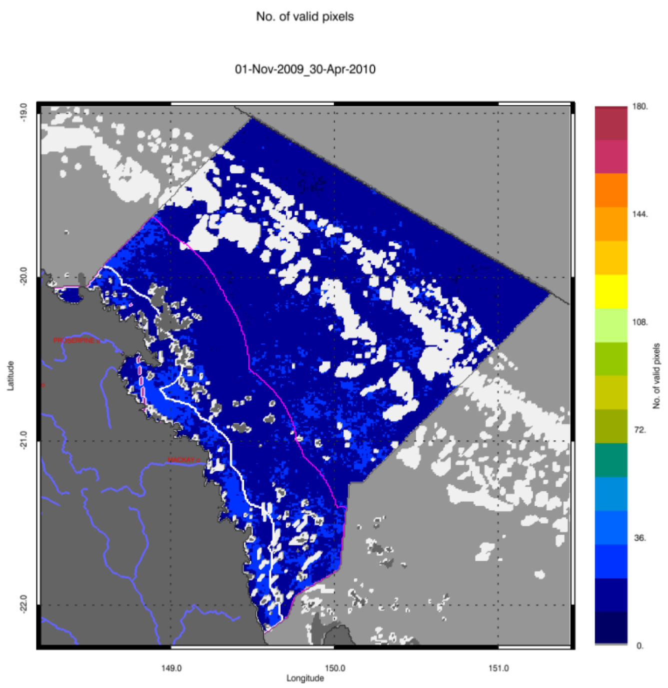
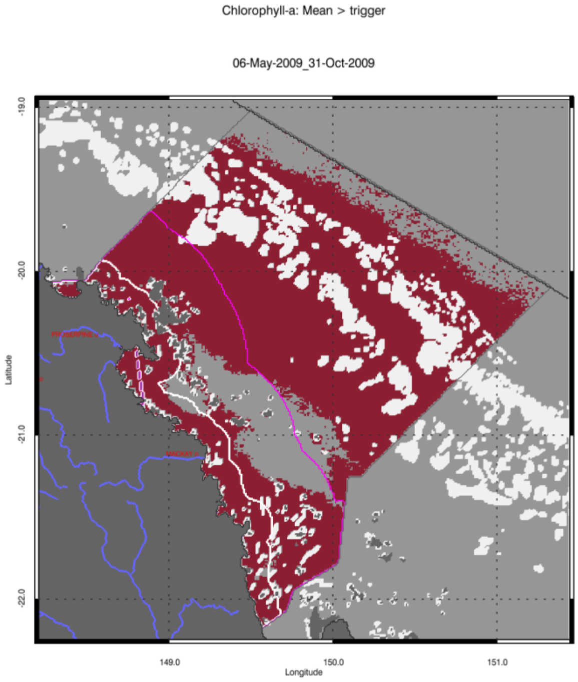


Figure 48. Number of pixels used to calculate the median maps (Figure 43 -Figure 47) for the dry and wet season for the Mackay Whitsunday region. The first map presents the number of pixels available for analysis in the dry season 2009 (May - October), while the second map presents the number of pixels available for analysis in the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



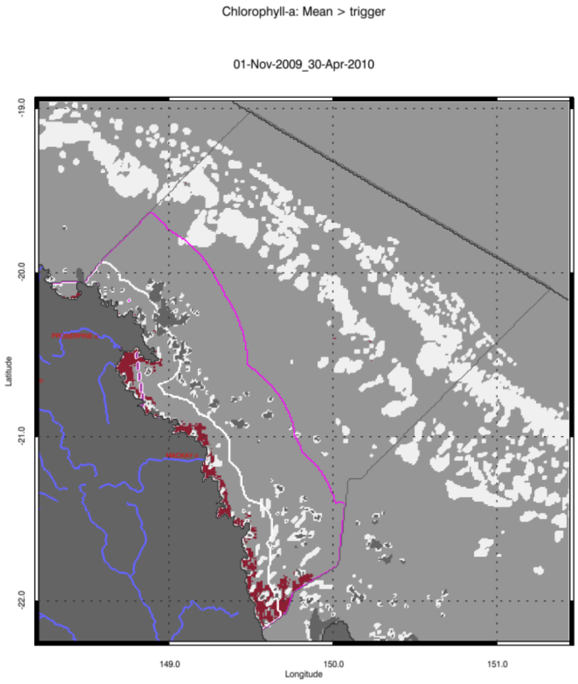
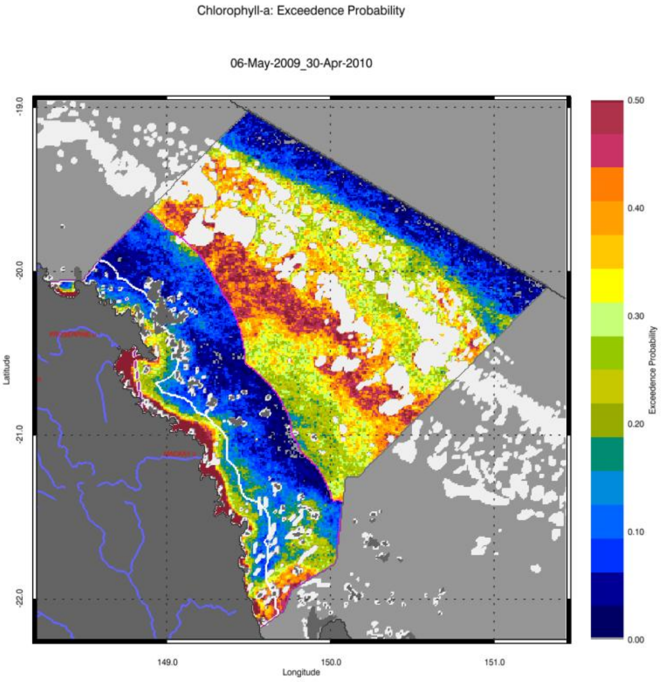


Figure 49. Chlorophyll-a exceedance maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



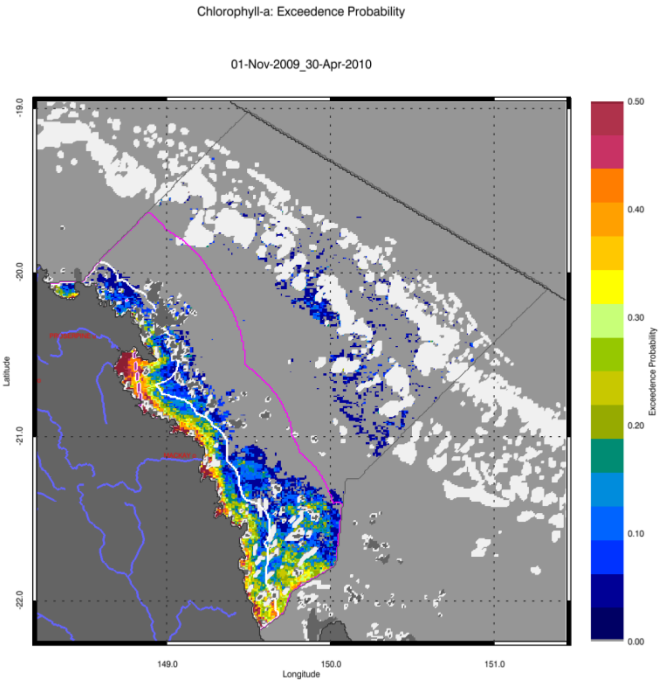
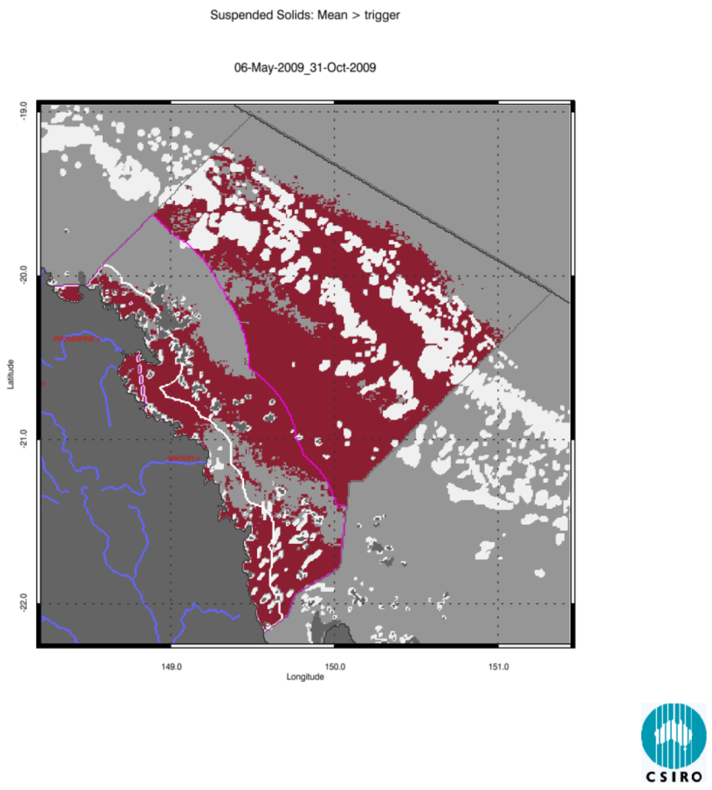


Figure 50. Chlorophyll-a exceedance probability maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



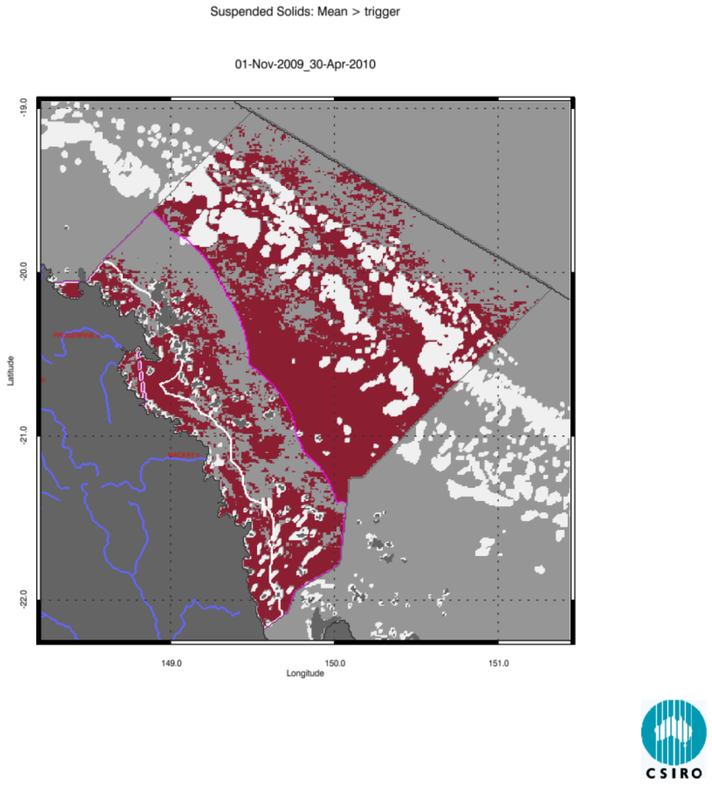
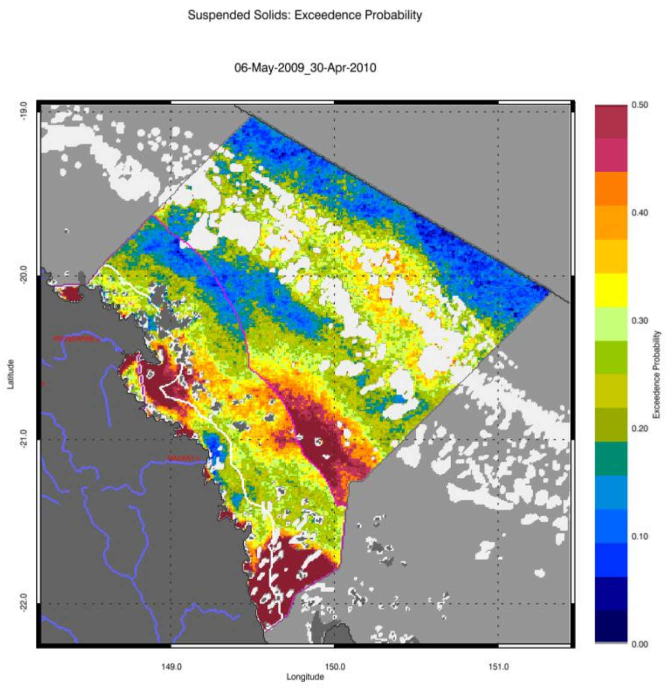


Figure 51. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



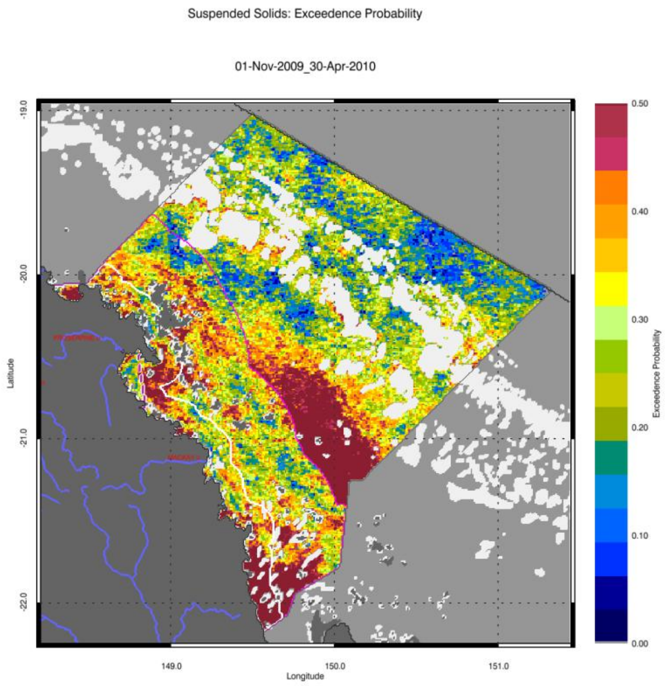
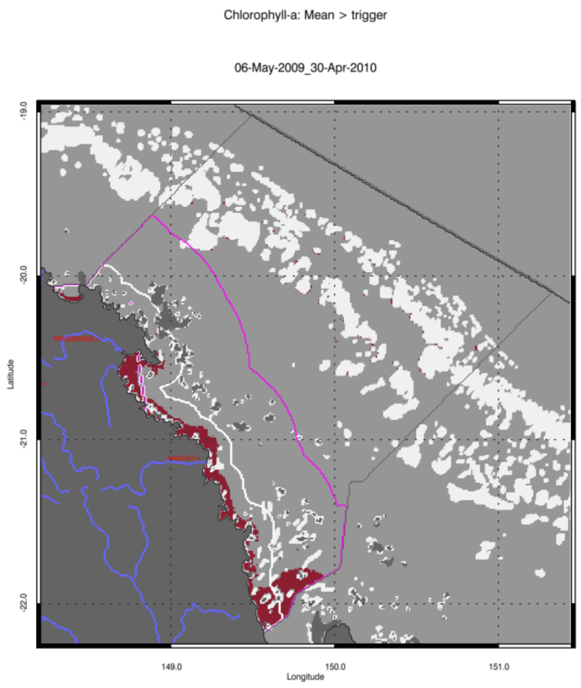


Figure 52. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance probability maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



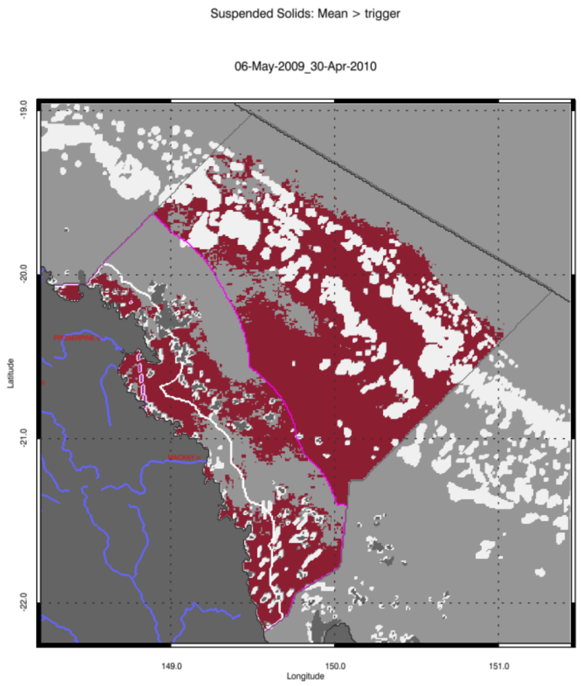
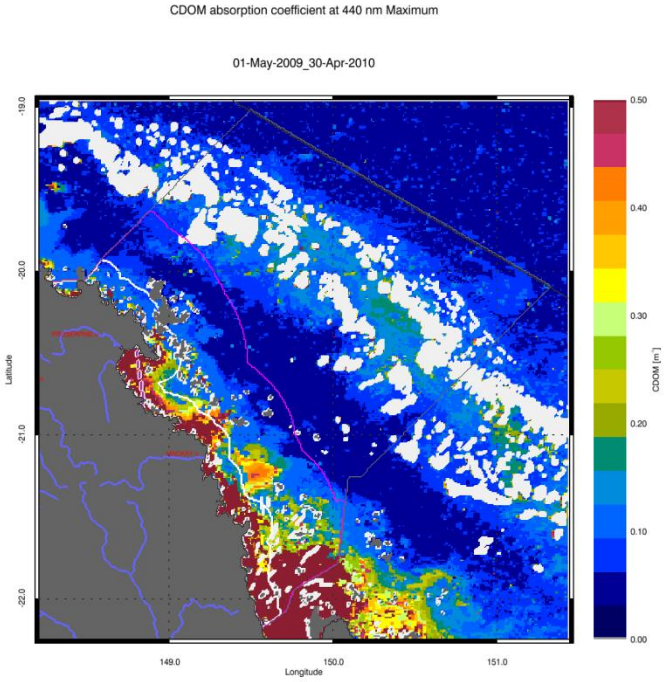


Figure 53. Exceedance maps for the Mackay Whitsunday region for the whole year (May 2009 –April 2010). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance map. See text for annotation explanation.



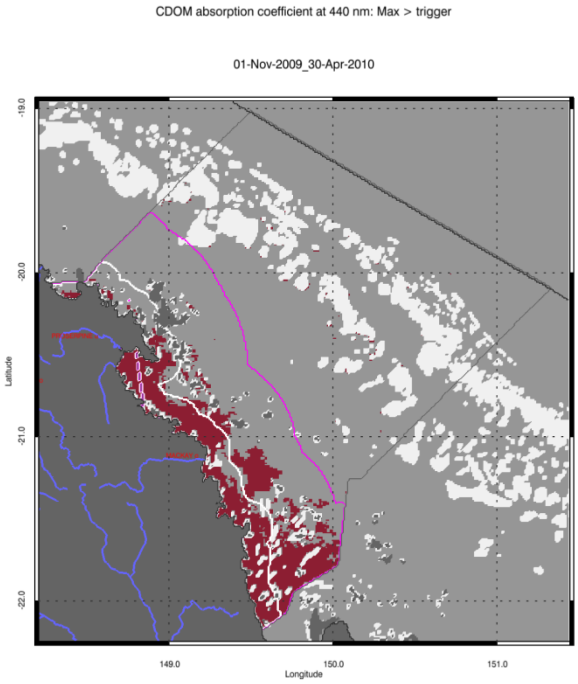


Figure 54. Map of freshwater extent for the wet season for the Mackay Whitsunday region. The first map presents the maximum value of CDOM for the wet season 2009/2010 (November 2009- April 2010), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m^{-1}. See text for annotation explanation.

Regional reports: Fitzroy region

The Fitzroy Region is one of the two large dry tropical catchment regions in the GBR Region with cattle grazing as the primary land use (Brodie et al. 2003). Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to runoff of suspended sediments and associated nutrients.

The main river system influencing the region is the Fitzroy River. The reefs in this group have the lowest clay & silt levels of all catchments. Levels of organic carbon are low, while nitrogen levels remain average with a modest increase in 2008, perhaps as a result of flooding in February 2008. A strong gradient in water quality exists between the reefs in this region with increasing distance from both the coast and Fitzroy river mouth.

The wet and dry season median maps for Chlorophyll-a, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of Chlorophyll-a (Figure 55) for the Fitzroy Estuary –Keppel Bay region show high Chlorophyll-a levels near the coast and in the estuary to lower concentrations towards the East. Median values of Chlorophyll-a to 0.5 μgL^{-1} extended as far as the Bunker group for both seasons. Median values of ~ 0.3 μgL^{-1} were observed in the offshore area particularly in the Swain group.

The wet and dry season median maps of coloured dissolved organic matter (CDOM, Figure 56) for the Fitzroy region show values higher than 0.20 m^{-1} for a coastal band ~10 km wide, up to 50 km north of the river mouth for the wet season, while during the dry season values were higher than 0.20 m^{-1} only for the area close to the river mouth.

The wet and dry season median maps of non-algal particulate matter (as a measure of Total Suspended Solids) (Figure 57) for the Fitzroy region show similar gross patterns as for the CDOM distribution, although locally there are differences such as in towards the northeast of Shoalwater Bay where increased levels of non-algal particulate matter reach out further into the lagoon. Care must be taken in interpreting the results for Shoalwater Bay and Broad Sound as the retrieval algorithm from the MODIS imagery was not parameterised nor validated for these waters . It is also likely that bottom visibility affects the accuracy of the retrieval for the shallow portion of these embayments.

The wet and dry season median maps of vertical attenuation of light ans the water clarity expressed as Secchi Depth (Figure 58, Figure 59) for the Fitzroy region show similar gross patterns as for the Chlorophyll-a, coloured dissolved organic matter and non-algal particulate matter distribution. The Secchi Depth product is still in development phase and should be validated using the water quality data sets used in recent studies on the spatial and temporal patterns of water quality of the Great Barrier Reef (De'ath 2007; De'ath and Fabricius 2008).

The maps in Figure 60 presents the number of image pixels available for calculating the median values for each season. This amount varies from 30 to about 90 for each season for each pixel location.

Assessment of the exceedance of water quality guidelines

Figure 61 presents the maps of Chlorophyll-a exceedance for the Fitzroy region as defined by the Guidelines. Figure 62 presents the map of the EP for Chlorophyll-a. Similar maps are presented for

Total Suspended Solids (using Non-algal particulate matter as a measure of Total Suspended Solids, Figure 63 and Figure 64).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 55, Figure 57) and by the steep changes in trigger values between the Midshelf and Offshore areas.

For the Fitzroy region the annual mean values of Chlorophyll-a exceeded the guideline value (0.45 µg/L) for 35% of the Open Coastal area, 2% of the Midshelf and none of the Offshore areas (Figure 65, Table 25). The mean values of Chlorophyll-a exceeded the Guidelines values for 74% of the Open Coastal Area in the dry season and 25 % in the wet season. In the dry season Chlorophyll-a also exceeded the Guidelines for 54 % of the Midshelf and 40% of the Offshore areas (Figure 61,Table 26). Similar exceedance values were retrieved if the median was used for the assessment (Figure 62, Table 25, Table 26). The mean values of TSS exceeded the Guidelines values for 46% of the Open Coastal Area in the dry season and 45 % in the wet season, and for 42 % for the Offshore areas in the dry season (Figure 63 and Table 27). Over the whole year, exceedance of TSS Guideline values were recorded in 45% of the Open Coastal, 12% of the Midshelf and 34% of Offshore areas (Figure 65, Table 25). Low exceedance was recorded for the Midshelf and Offshore areas in both seasons if the median was used for the assessment, while the exceedance of the median values for the Open Coastal Area where significantly lower (34% for the dry season and 25% for the wet season, Figure 64, and Table 27) when compared to exceedance of the mean..

Table 28 and Table 29 report the Summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EP for that period. These metrics are based on a high number of observations (ranging from 100 thousands valid observations for Open Coastal in the wet season to over 2.4 million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal area in the wet season while only the mean exceeded during the dry season.

The mean and median values for the TSS concentration differed substantially (Table 29) for all regions and seasons. The mean values were ~ 2-3 times higher than medians. Only the mean values of TSS exceeded the Guidelines values for the Open Coastal areas for both seasons.

Assessment of freshwater extent during the wet season

Figure 66 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the Fitzroy region. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Fitzroy region the freshwater extent for the wet season 2009/2010 (November 2009- April 2010) was 7882 km^2 ,4770 km^2w for the wet season 2008/09, while in the wet season 2007/08 was 8080 km^2 (Figure 4). Freshwater discharge was four times above the long term median flow for the Fitzroy River, and comparable with the flows of the 2007/08 wet season when the largest flood since 1991 had occurred.

Table 25 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Fitzroy region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2009_30-Apr-2010		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	5919	424705	1994703	66%	55%	43%	34%
MS	18421	1481564	6207877	5%	4%	7%	2%
OS	48664	3302918	16399768	0%	12%	50%	0%

Table 26 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Fitzroy region (Figure 61, Figure 62). Column and row labels are described in the legend of Table 25.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5919	322076	970716	99%	99%	102629	1023987	47%	33%
MS	18421	1129185	3021044	99%	100%	352379	3186833	2%	0%
OS	48664	2467471	7980896	92%	93%	835447	8418872	0%	0%

Table 27 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Fitzroy region (, Figure 63, Figure 64).). Column and row labels are described in the legend of Table 25.

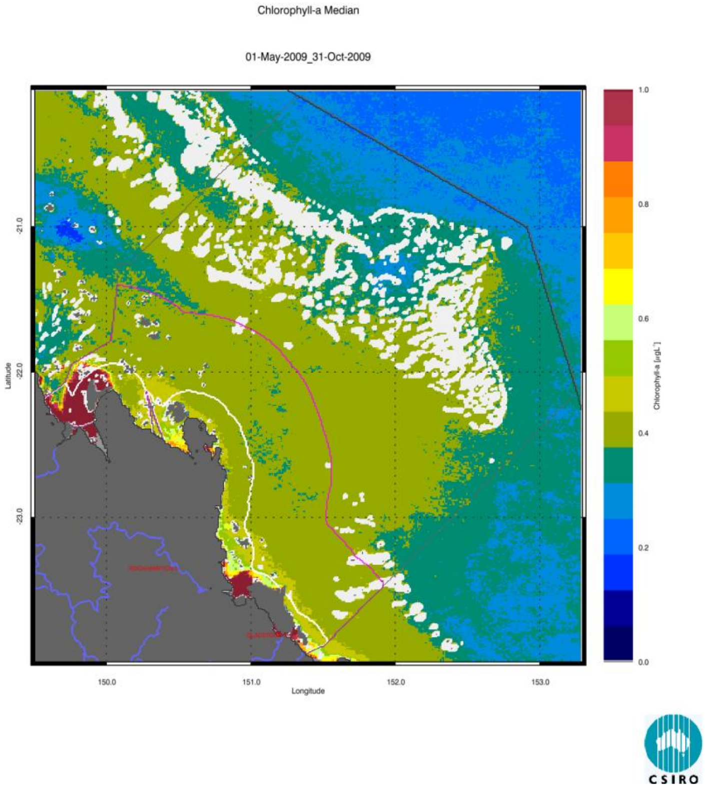
		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5919	322076	970716	46%	40%	102629	1023987	45%	31%
MS	18421	1129185	3021044	7%	3%	352379	3186833	21%	6%
OS	48664	2467471	7980896	67%	1%	835447	8418872	41%	3%

Table 28. Summary of Chlorophyll-a exceedance for the dry and wet season for the Fitzroy region.). Column and row labels are described in the legend of Table 25. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	322076	970716	**0.71**	**0.45**	51%	102629	1023987	**0.84**	**0.52**	66%
MS	1129185	3021044	0.38	0.40	18%	352379	3186833	0.37	0.35	29%
OS	2467471	7980896	0.35	0.36	37%	835447	8418872	0.32	0.33	26%

Table 29 Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Fitzroy region). Column and row labels are described in the legend of Table 25. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	322076	970716	**2.73**	1.04	33%	102629	1023987	**3.94**	1.58	41%
MS	1129185	3021044	1.01	0.27	15%	352379	3186833	1.91	0.56	28%
OS	2467471	7980896	**0.72**	0.23	18%	835447	8418872	**0.85**	0.24	19%



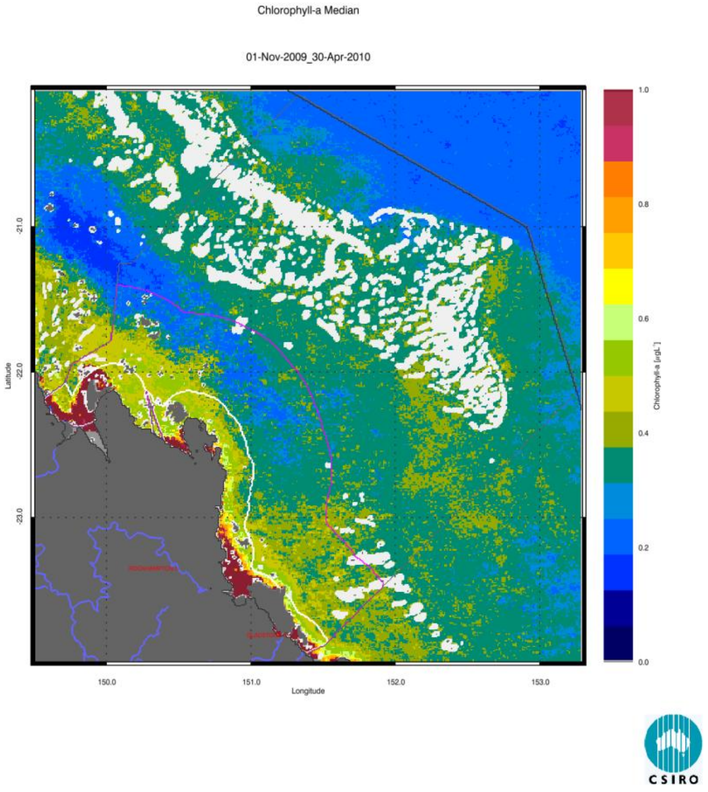
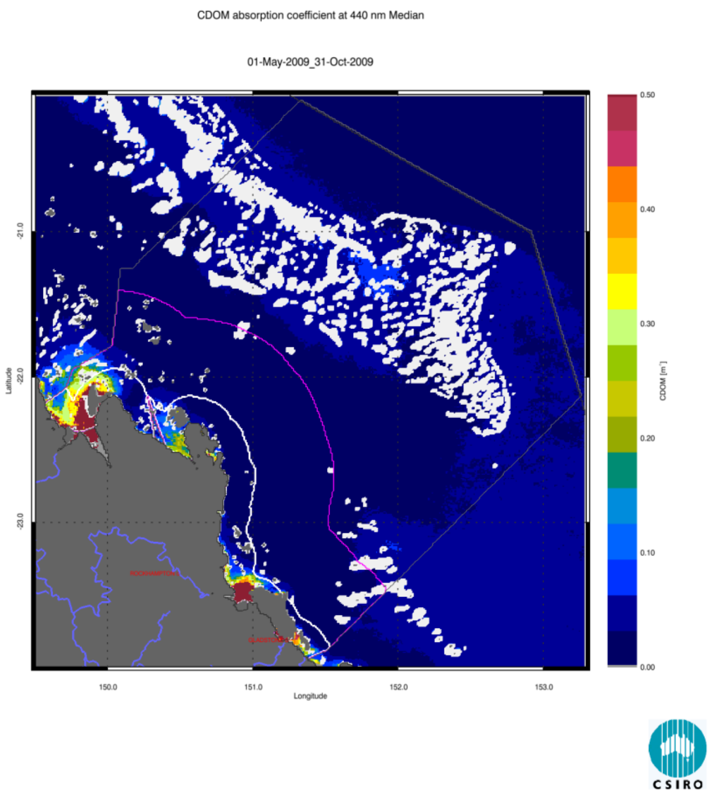


Figure 55. Chlorophyll-a median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



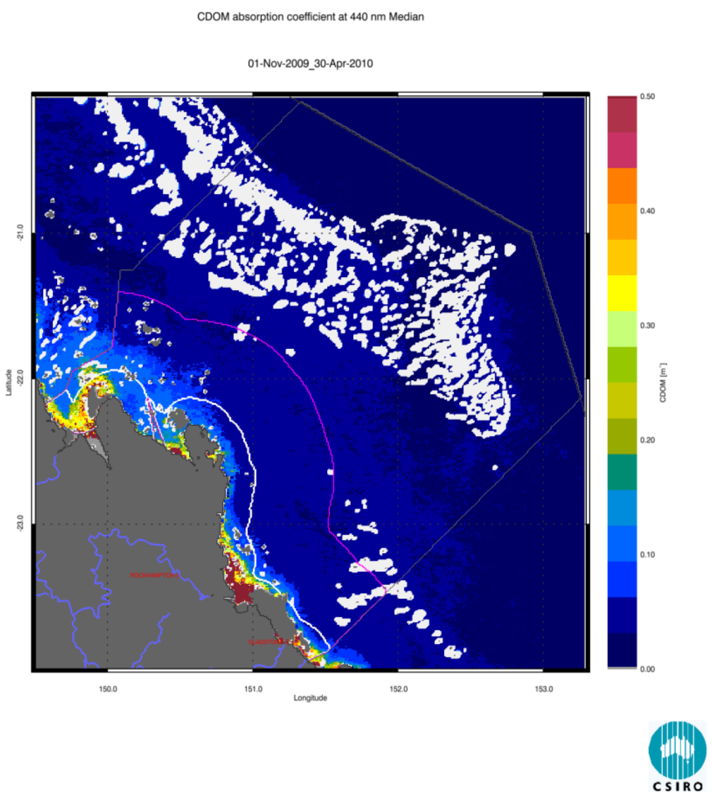
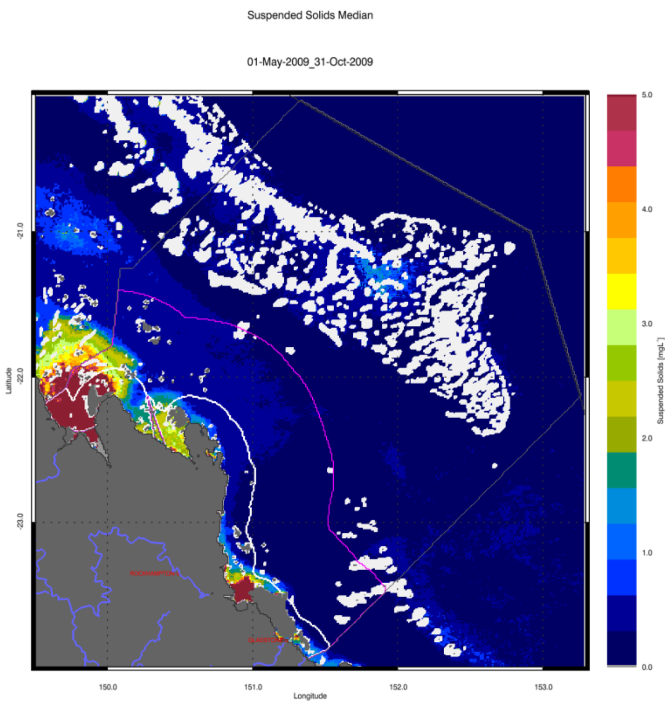


Figure 56. CDOM median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



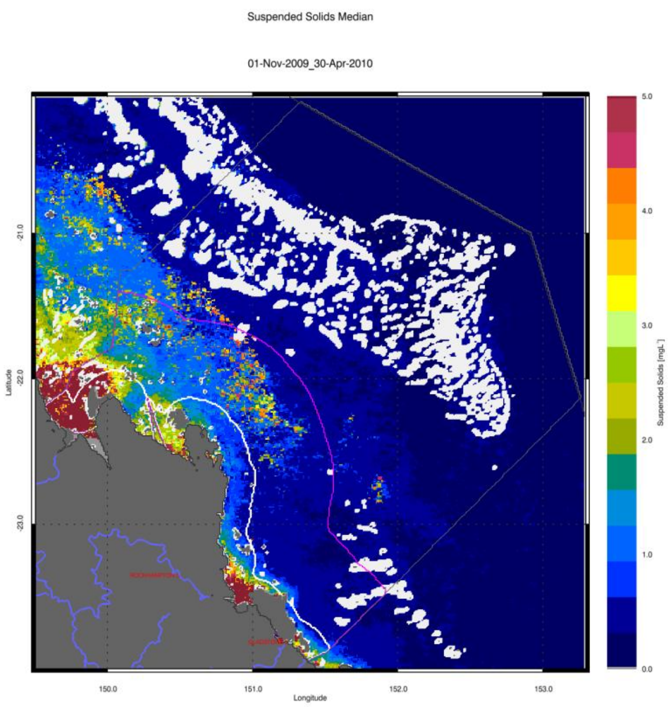


Figure 57. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

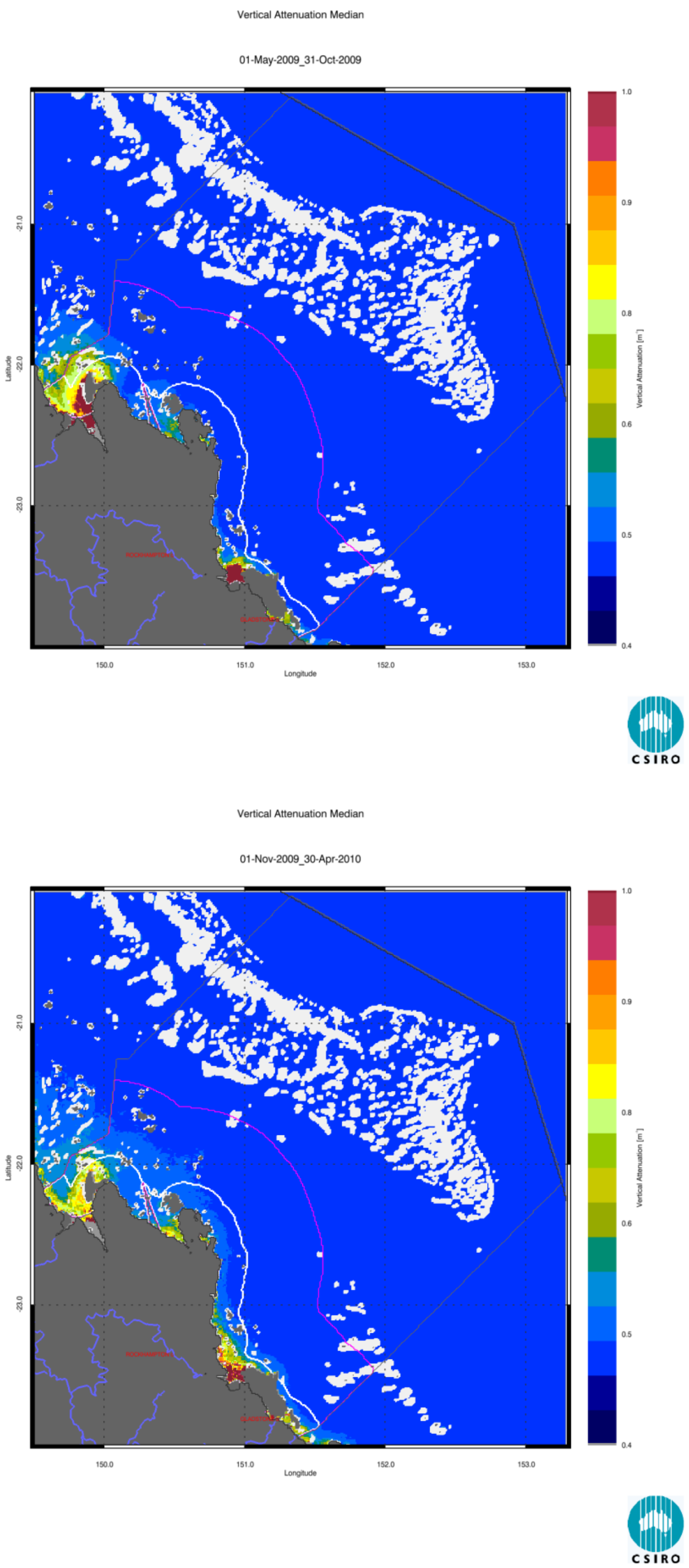
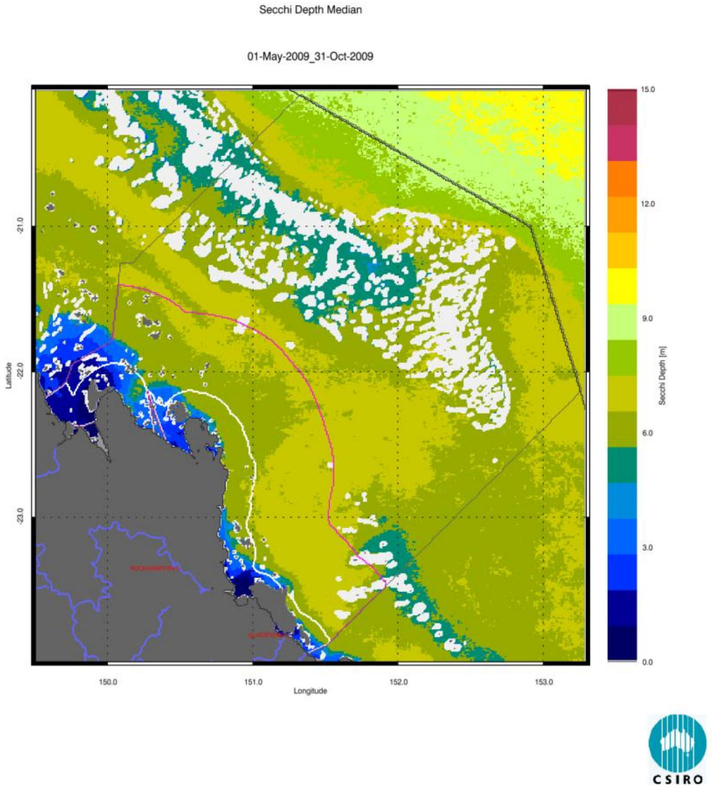


Figure 58. Vertical attenuation of light (Kd ,as estimate of water clarity) median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009-April 2010). See text for annotation explanation.



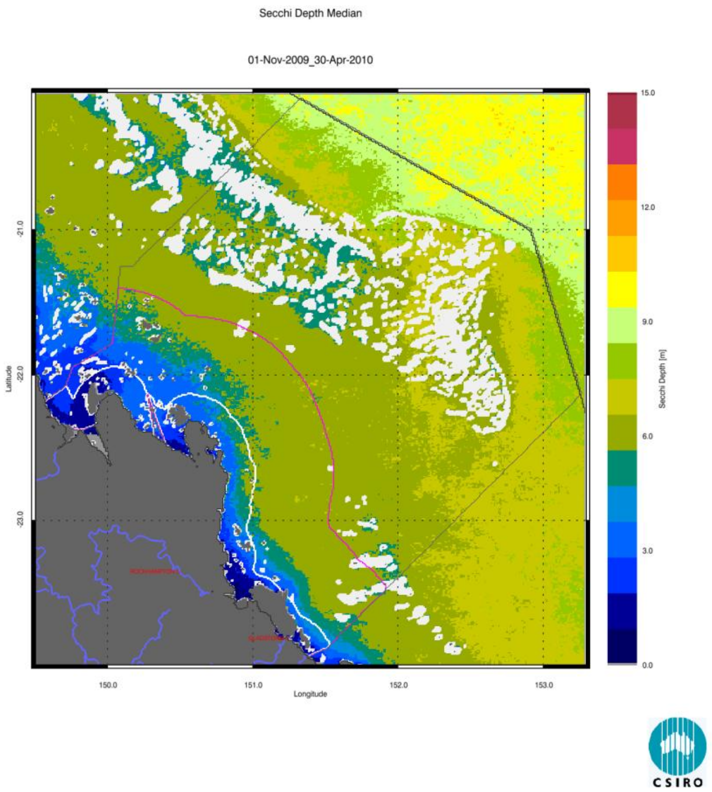
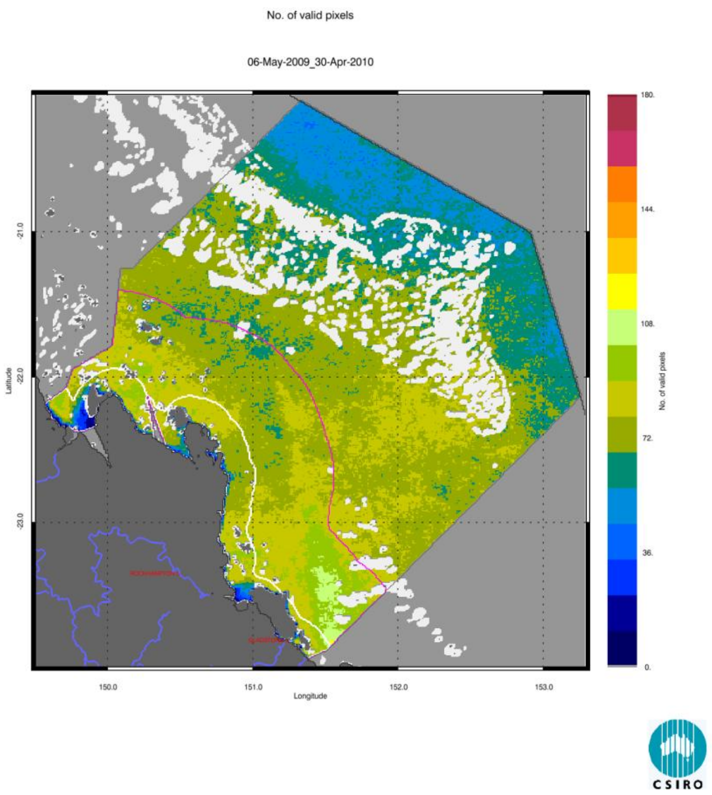


Figure 59. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



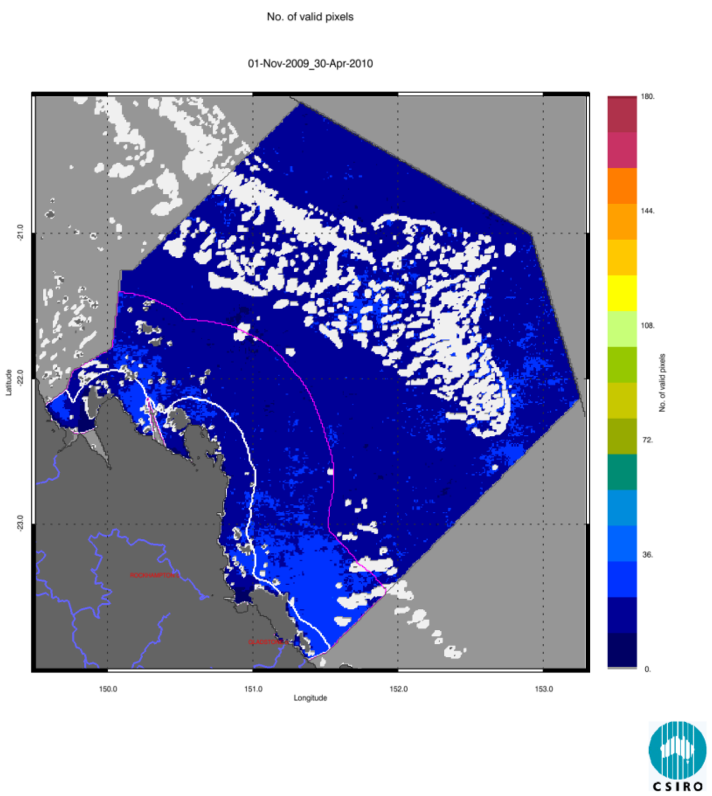


Figure 60. Number of pixels used to calculate the median maps (Figure 55 - Figure 59) for the dry and wet season for the Fitzroy region. The first map presents the number of pixels available for analysis in the dry season 2009 (May - October), while the second map presents the number of pixels available for analysis in the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

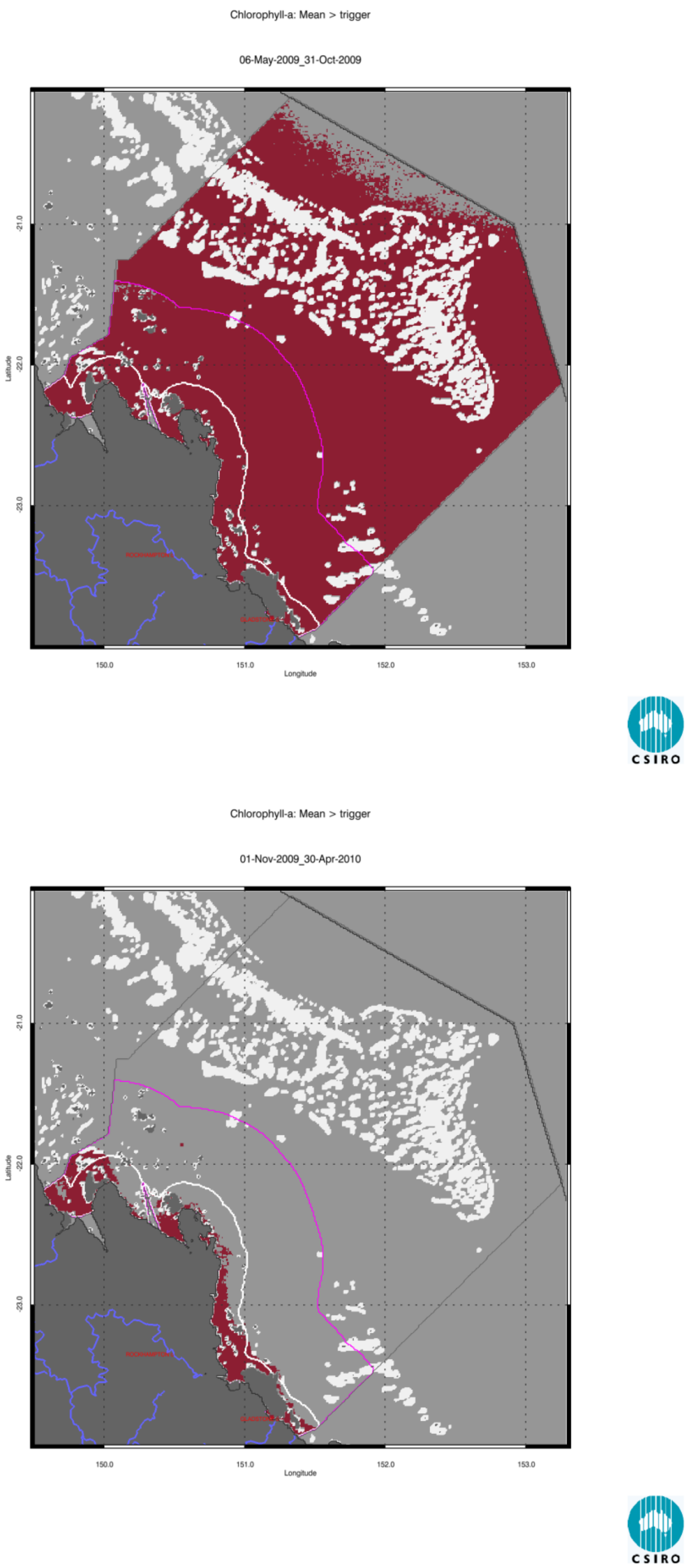
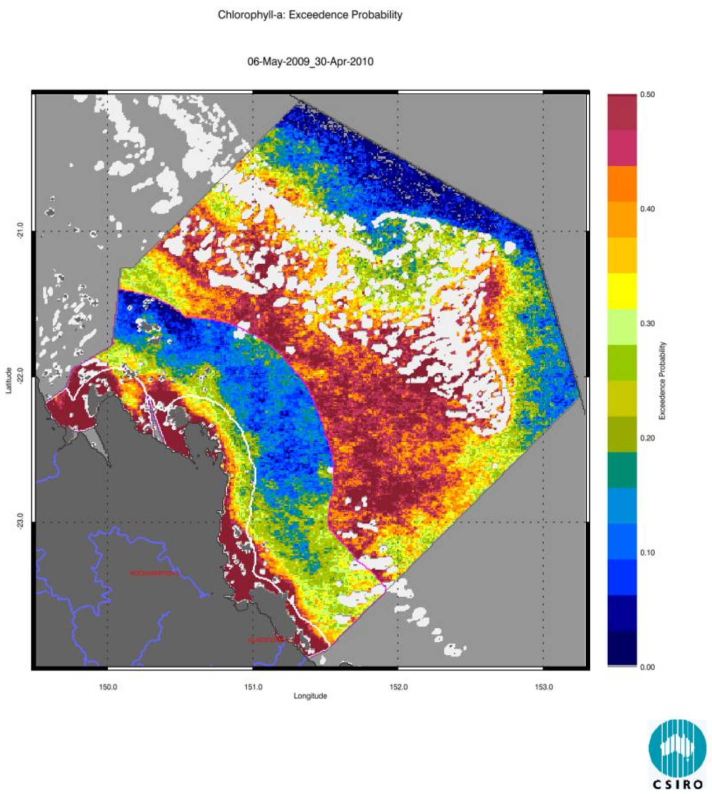


Figure 61. Chlorophyll-a exceedance maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



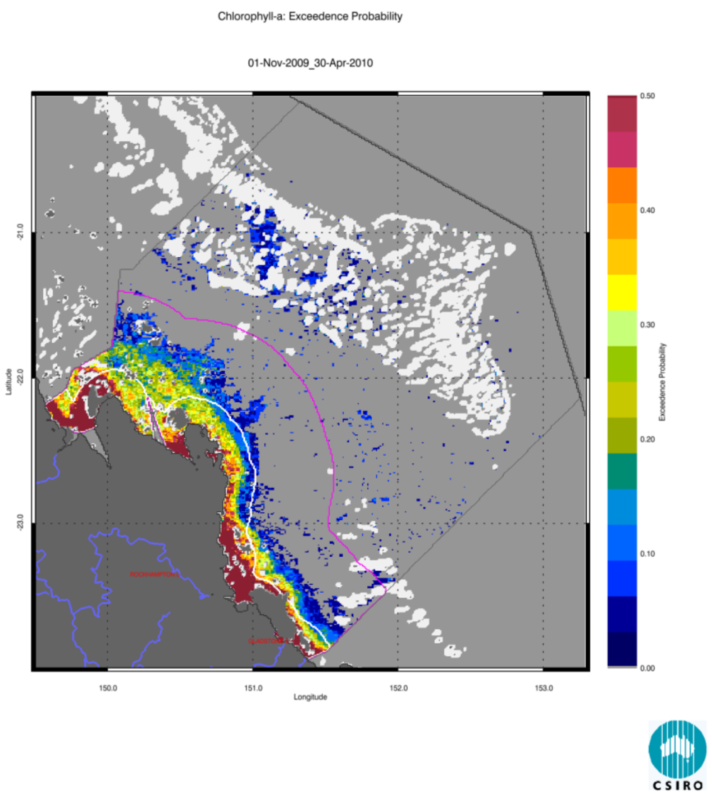
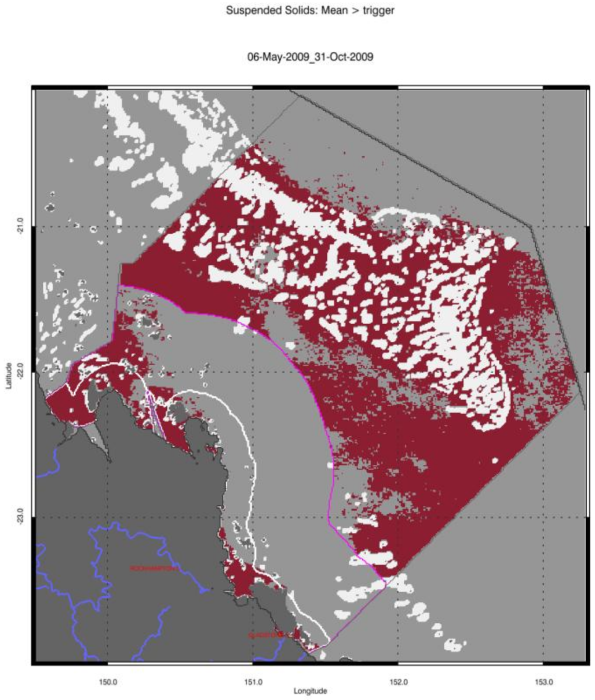


Figure 62. Chlorophyll-a exceedance probability maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



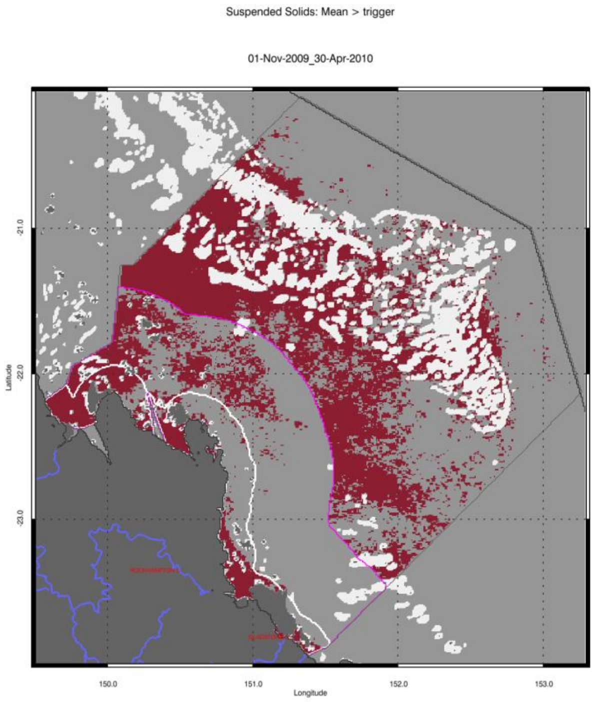
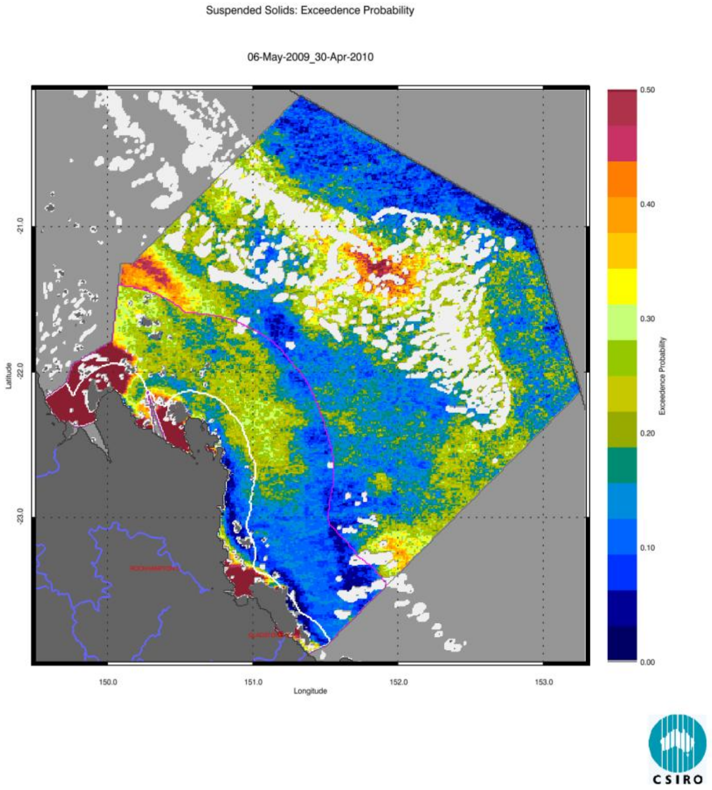


Figure 63. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



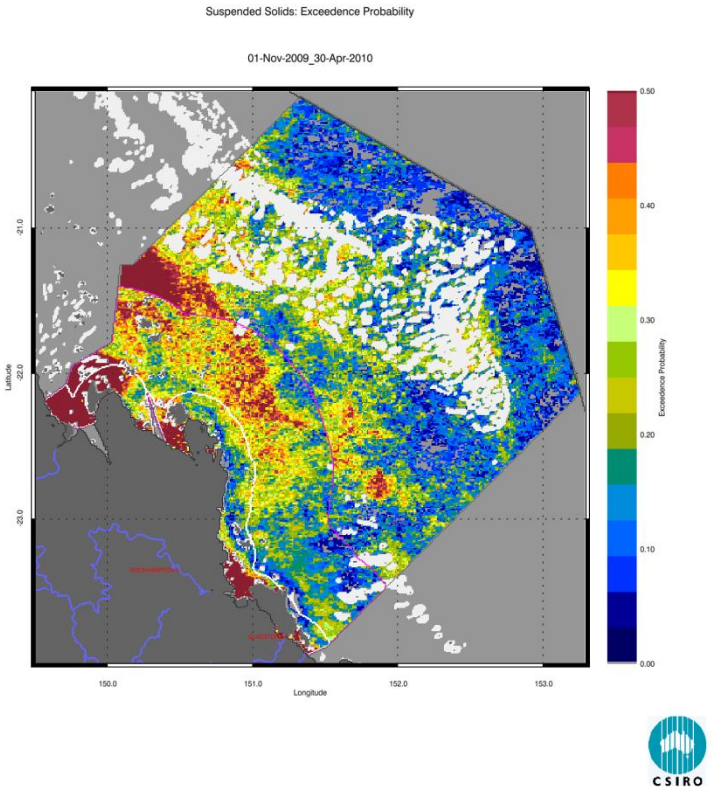
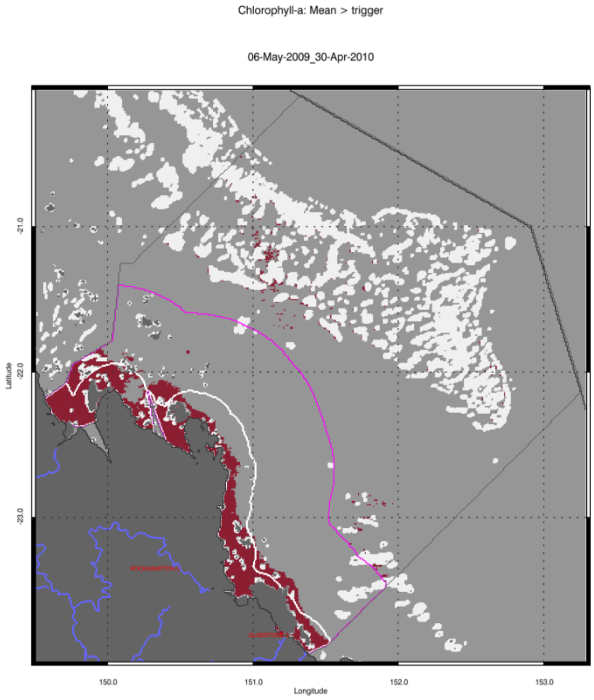


Figure 64. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance probability maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



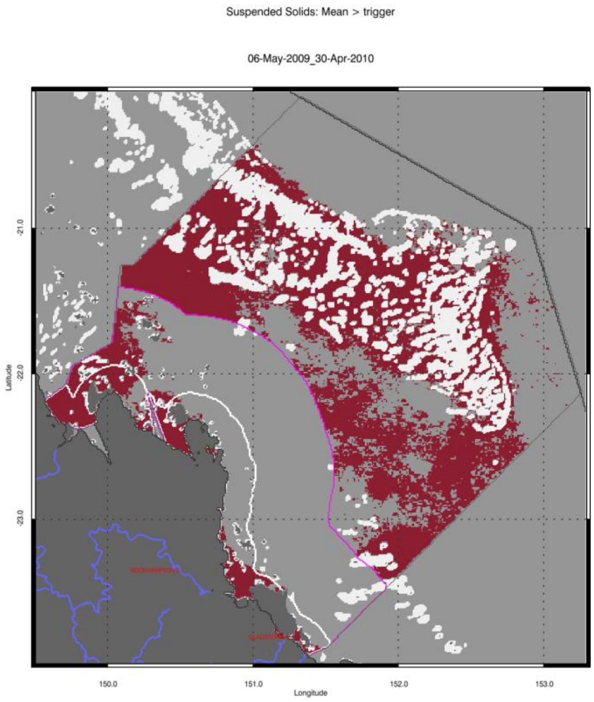


Figure 65. Exceedance maps for the Fitzroy region for the whole year (May 2009 –April 2010). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance map. See text for annotation explanation.

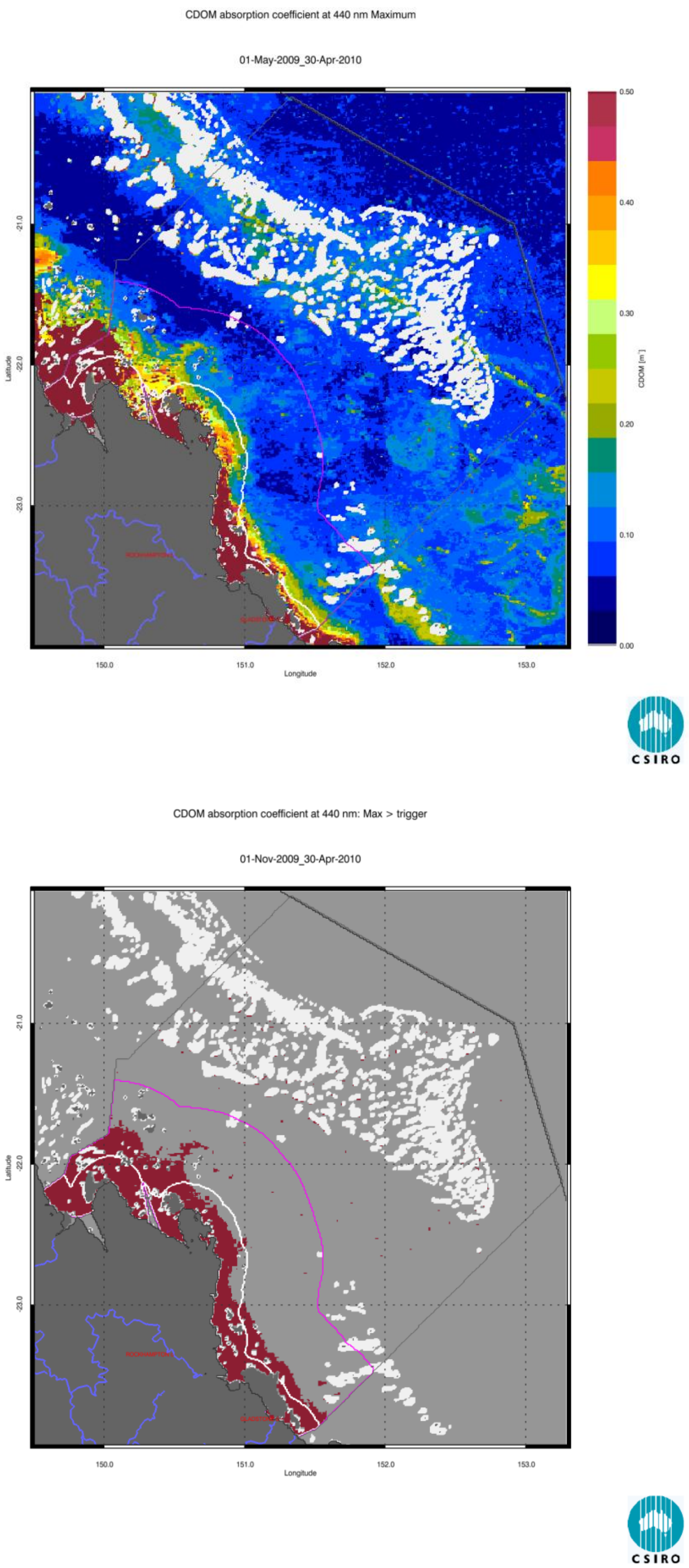


Figure 66. Map of freshwater extent for the wet season for the Fitzroy region. The first map presents the maximum value of CDOM for the wet season 2009/2010 (November 2009- April 2010), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m^{-1}. See text for annotation explanation.

Regional reports: Burnett Mary region

The Burnett Mary region is the southernmost in the GBR and is comprised of a number of catchments, though only the northernmost catchment, the Baffle Basin, is within the GBR.

The wet and dry season median maps for Chlorophyll-a, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of Chlorophyll-a (Figure 67) for the Burnett Mary region show high Chlorophyll-a levels near the coast and in the estuary to lower concentrations towards the East. Median values of Chlorophyll-a to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.25 μgL^{-1}. The lobe of relatively high Chlorophyll-a values (~0.3 μgL^{-1}) in dry season in the Midshelf and Offshore areas is possibly due to the occurrence of Tricodesmium blooms occurring in August/September/October.

The wet and dry season median maps of coloured dissolved organic matter (CDOM, Figure 68) for the Burnett Mary region show values higher than 0.20 m^{-1} for a coastal band ~5-10 km wide. The wet and dry season median maps of non-algal particulate matter (as a measure of Total Suspended Solids) (Figure 69) for the Burnett Mary region show similar gross patterns as for the CDOM distribution. The high concentrations shown near Breaksea Spit are likely to be overestimated. The accuracy of the retrieval from MODIS imagery in these shallow waters systems cannot be assessed as there is no data available for parameterization and validation.

The wet and dry season median maps of vertical attenuation of light (Figure 70) for the Burnett Mary region show similar gross patterns as for the Chlorophyll-a, coloured dissolved organic matter and non-algal particulate matter distribution. The difference in dark blue to light blue colours between the wet and dry season for K_d is due to the K_d being slightly dependent on average sun-angles during the satellite overpass- the reason is that sun light coming in at higher slant angles during the winter months is scattered more in the first meters of the water column. The wet and dry season median maps of water clarity expressed as Secchi Depth (Figure 71) for the Burnett Mary region show similar gross patterns to the maps of vertical attenuation of light (Figure 70).

The maps in Figure 72 depict the number of image pixels per pixel location available for calculating the median values for each season. The maps show that this amount varies from 30 to 40 observations for the wet season and about 90 for the dry season for each pixel location.

Caution should be used when interpreting the results for this region as limited field information was used for the parameterization and validation on the remote sensing retrievals.

Assessment of the exceedance of water quality guidelines

The exceedance of the Guidelines was assessed for Chlorophyll-a and Non-algal particulate matter (as measure for Total Suspended Solids) retrieved from MODIS Aqua using CSIRO’s algorithm (Figure 73, Figure 74 Figure 75, Figure 76).

Figure 73 presents the maps of Chlorophyll-a exceedance as defined by the Guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 74 presents the map of the EP for Chlorophyll-a. This map reports in a continuous colour scale the number of days where the concentration exceeded the threshold divided by number of days with (error-free) data for that period, hence pixels are mapped in dark red (EP>= 0.50) when median values for the year (and seasons) exceed the thresholds. Similar maps are presented for Total Suspended Solids (using Non-algal particulate matter as a measure of Total Suspended Solids, Figure 75 and Figure 76).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 67, Figure 69) and by the steep changes in trigger values between the Midshelf and Offshore areas.

For the Burnett Mary region the annual mean values of Chlorophyll-a exceeded the guideline values (0.45 µg/L) for 27% percent of the Open Coastal area, 2% of the midshelf and none of the offshore areas (Figure 77, Table 30).The mean values of Chlorophyll-a exceeded the Guidelines values for 77% of the Open Coastal area in the dry season and 17 % in the wet season. In the dry season Chlorophyll-a also exceeded the Guidelines for 76 % of the Midshelf and 13% of the Offshore areas (Figure 73, Table 31). Similar exceedance values were retrieved if the median was used for the assessment (Figure 74, Table 30, Table 31).

The mean values of TSS exceeded the Guidelines values for 14 % of the Open Coastal area in the dry season and for 13% in the wet season, while no exceedance was estimated for the Midshelf and the Offshore areas (Figure 76 , and Table 32). Over the whole year, exceedance of TSS guideline values were recorded in 13% of the Open Coastal, 2% of the Midshelf and 3% of Offshore areas (Figure 77, Table 30).The estimated exceedance for the all areas was significantly lower for the median values that those for the mean values (Figure 76 and Table 32).

Table 33 and Table 34 report the Summary of exceedance for both variables , providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EP for that period. These metrics are based on a high number of observations (ranging from 20 thousands valid observations for Open Coastal area in the wet season to over 1.7 million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal area in both seasons, while the mean values of Total Suspended Solids exceeded the Guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the TSS concentration differed substantially (for all regions and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of freshwater extent during the wet season

Figure 78 reports the freshwater extent for wet season 2009/2010 (November 2009- April 2010) for the Burnett Mary region. The freshwater extent was estimated by applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Burnett Mary region the freshwater extent for the wet season 2009/2010 (November 2009- April 2010) was 1170 km^2 , 399 km^2 for the wet season 2008/09, while in the wet season 2007/08 was 1549 km^2 (Figure 4). Freshwater discharge was seven times above the long term annual median flow in the region (Figure 3).

Table 30 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Mary-Burnett region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2009_30-Apr-2010		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	753	64423	234183	83%	60%	12%	0%
MS	3401	327125	1057711	4%	3%	0%	0%
OS	33928	2536234	10551608	0%	1%	48%	0%

Table 31 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Burnett Mary region (Figure 73, Figure 74). Column and row labels are described in the legend of Table 30.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	753	44934	110691	96%	97%	19489	123492	47%	29%
MS	3401	227429	499947	100%	100%	99696	557764	1%	0%
OS	33928	1777268	4987416	99%	92%	758966	5564192	0%	0%

Table 32 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Burnett Mary region (Figure 75, Figure 76). Column and row labels are described in the legend of Table 30.

		01-May-2009_31-Oct-2009				01-Nov-2009_30-Apr-2010			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	753	44934	110691	5%	0%	19489	123492	20%	3%
MS	3401	227429	499947	0%	0%	99696	557764	1%	0%
OS	33928	1777268	4987416	85%	3%	758966	5564192	17%	0%

Table 33. Summary of Chlorophyll-a exceedance for the dry and wet season for the Burnett Mary region. Column and row labels are described in the legend of Table 30. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	44934	110691	**0.51**	**0.46**	55%	19489	123492	**0.75**	**0.55**	73%
MS	227429	499947	0.40	0.41	25%	99696	557764	0.40	0.39	37%
OS	1777268	4987416	0.32	0.32	19%	758966	5564192	0.33	0.33	29%

Table 34 Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Burnett Mary region. Column and row labels are described in the legend of Table 30. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines.

	01-May-2009_31-Oct-2009					01-Nov-2009_30-Apr-2010				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	44934	110691	0.59	0.29	3%	19489	123492	1.60	0.66	19%
MS	227429	499947	0.41	0.18	5%	99696	557764	1.07	0.36	19%
OS	1777268	4987416	**0.77**	0.21	28%	758966	5564192	0.57	0.17	12%

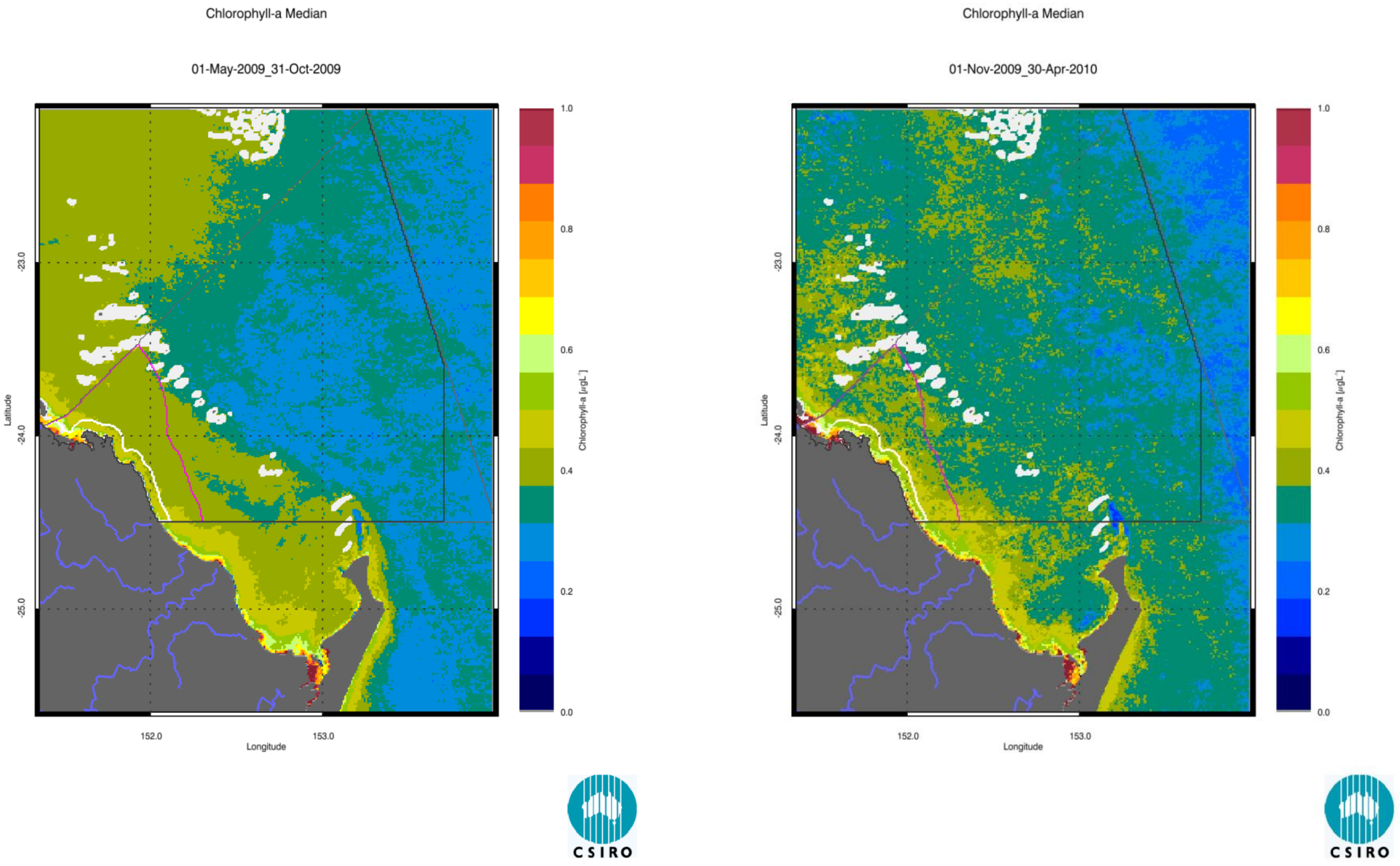


Figure 67. Chlorophyll-a median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

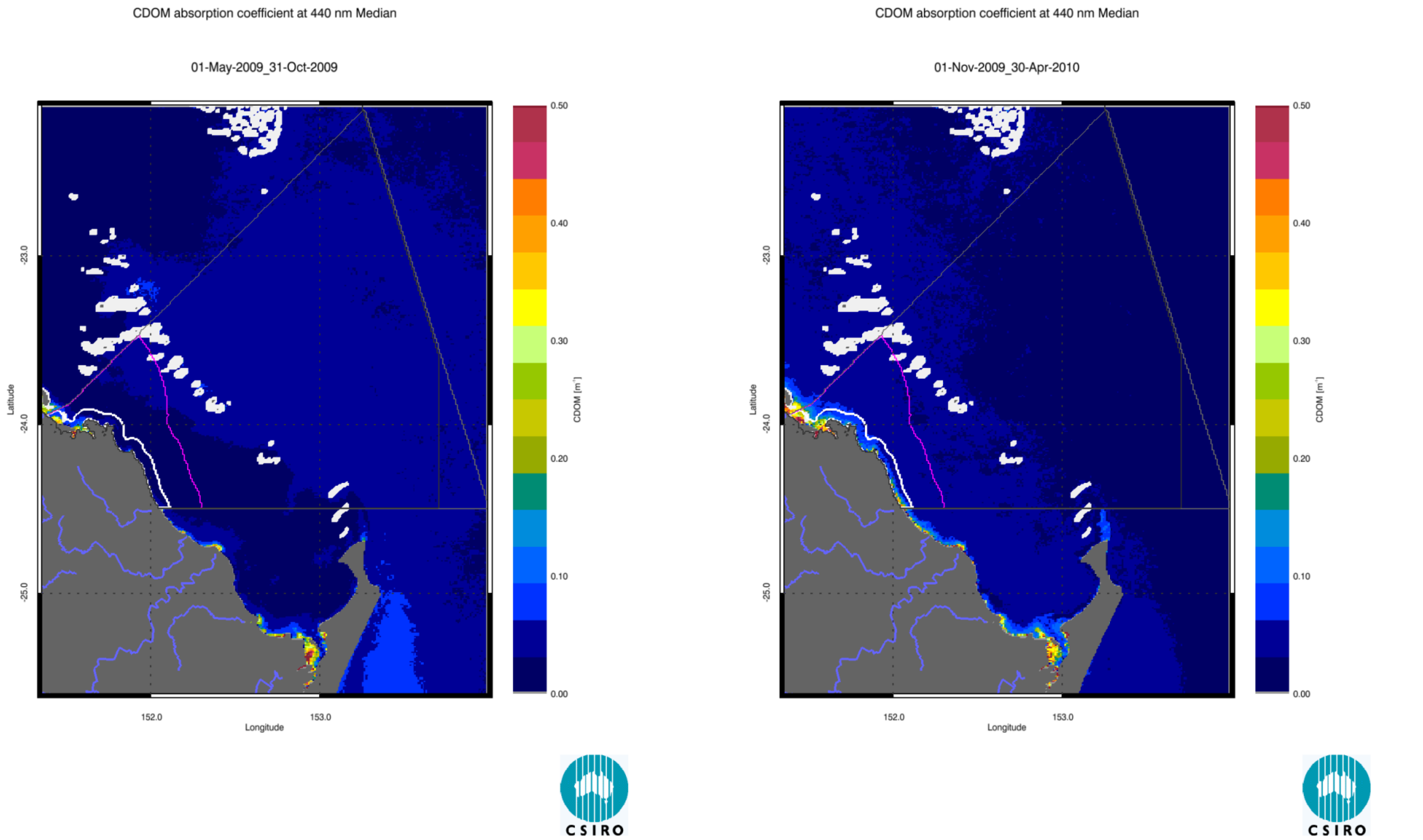


Figure 68. CDOM median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

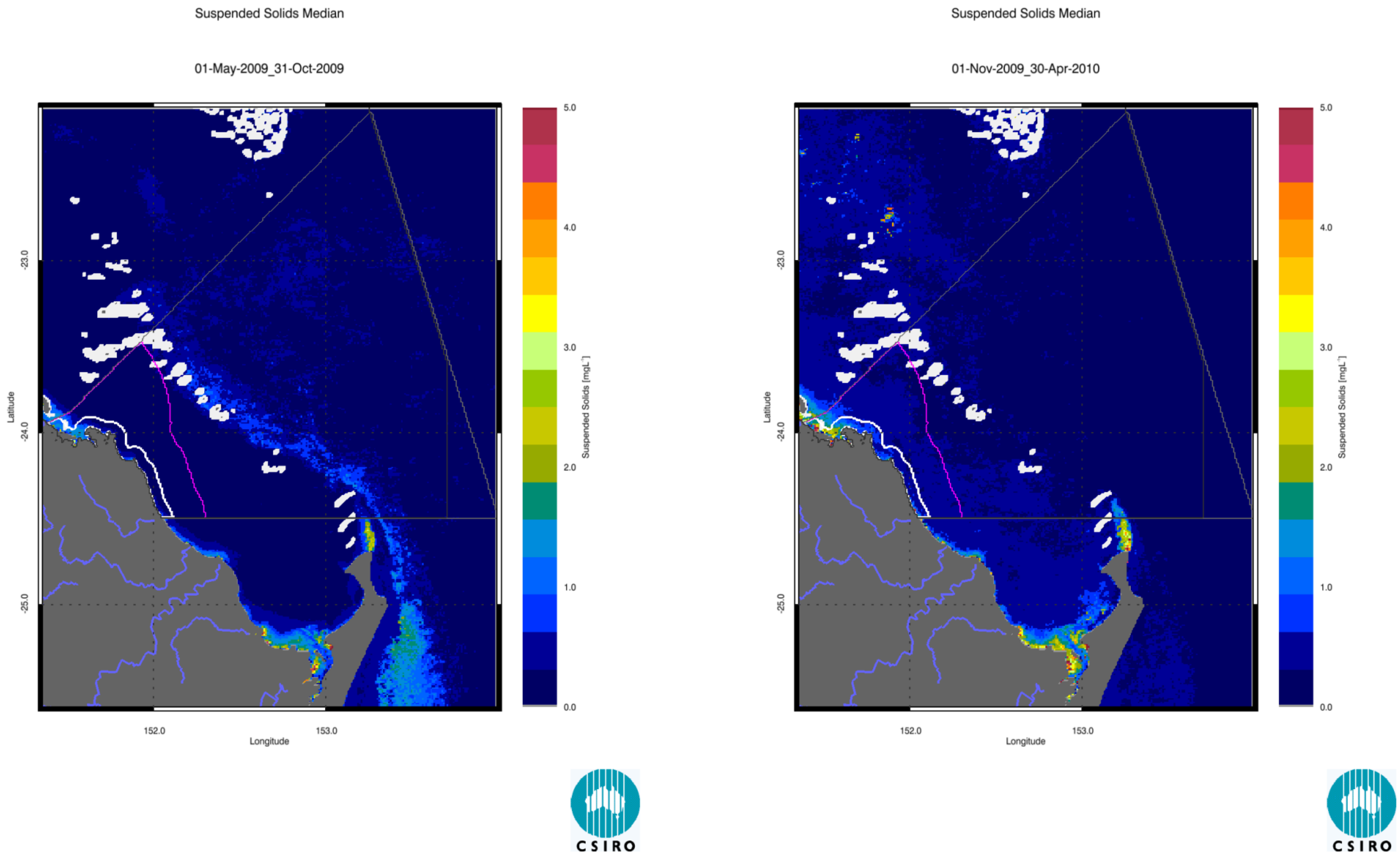


Figure 69. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

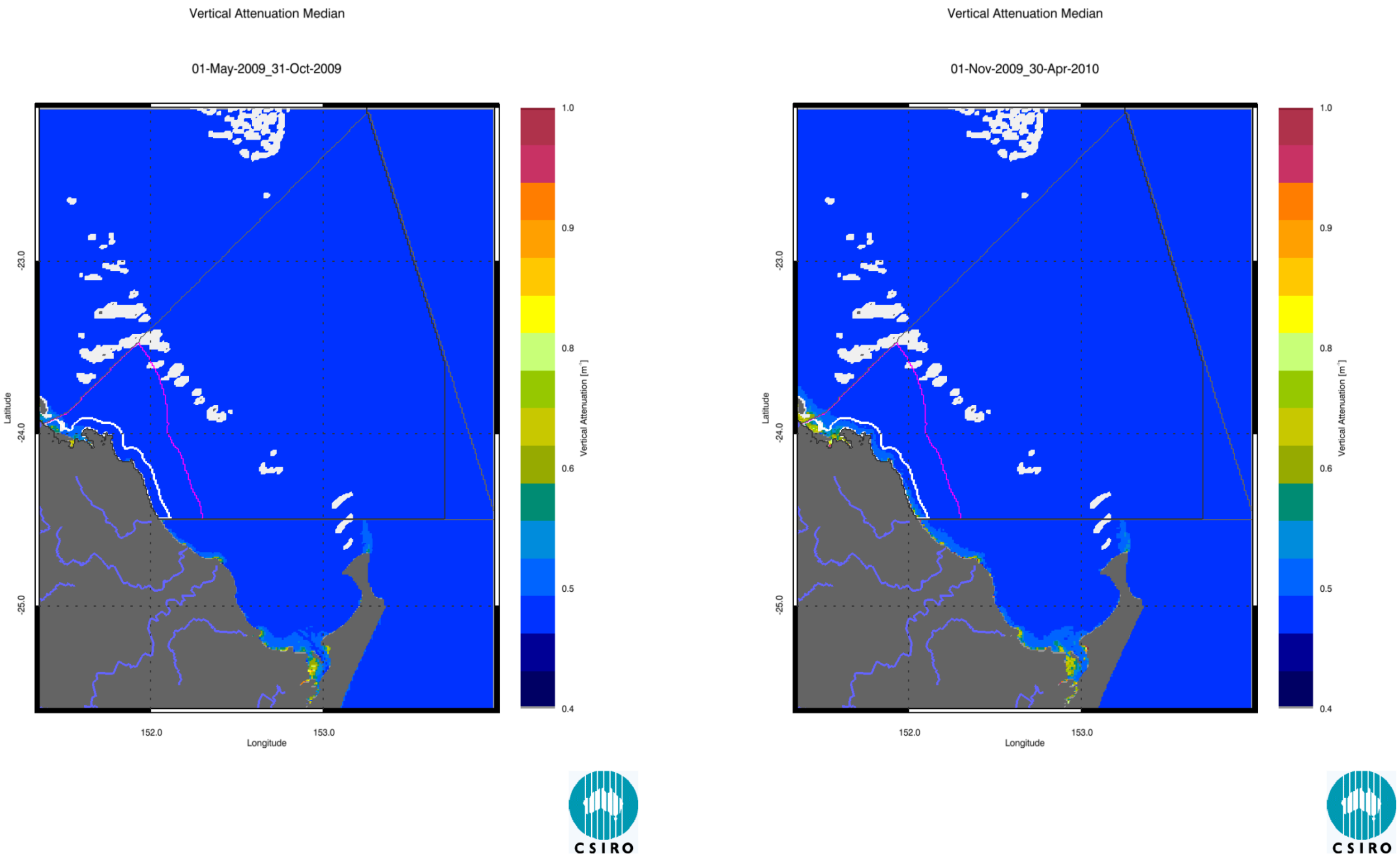
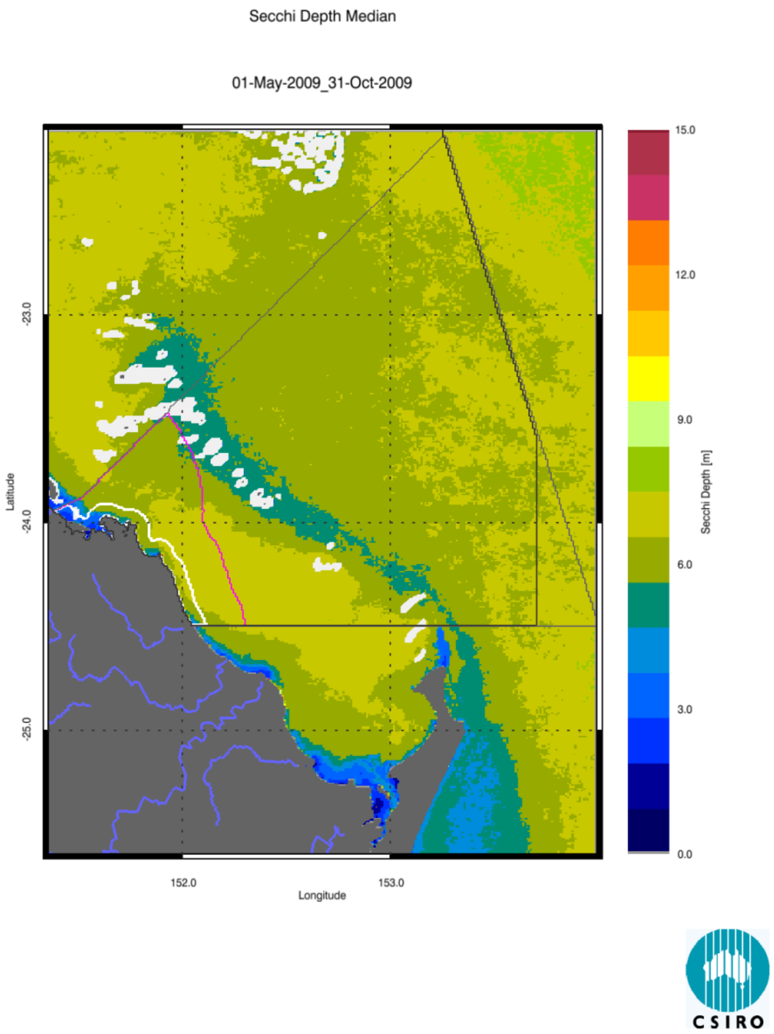


Figure 70. Vertical attenuation of light (Kd ,as estimate of water clarity) median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



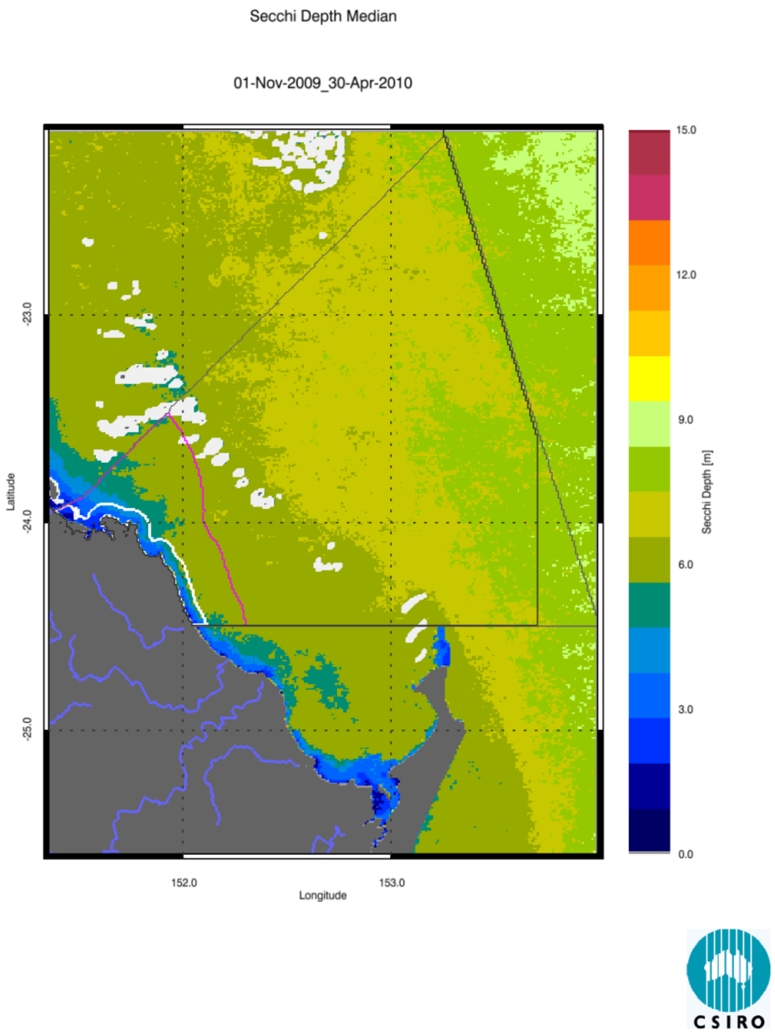


Figure 71. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2009 (May - October), while the second map presents the median for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

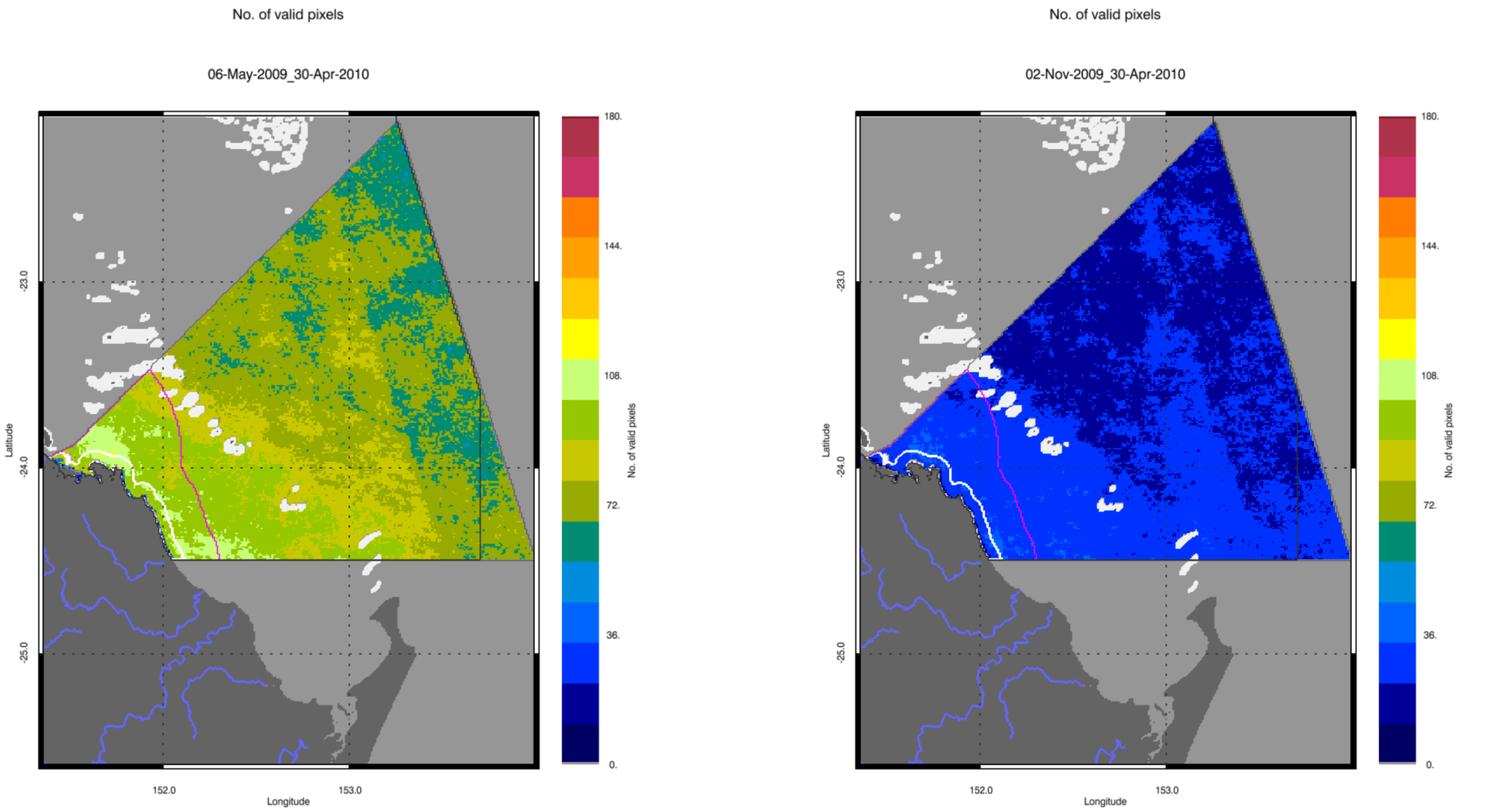


Figure 72. Number of pixels used to calculate the median maps (Figure 67 - Figure 71) for the dry and wet season for the Burnett Mary region. The first map presents the number of pixels available for analysis in the dry season 2009 (May - October), while the second map presents the number of pixels available for analysis in the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

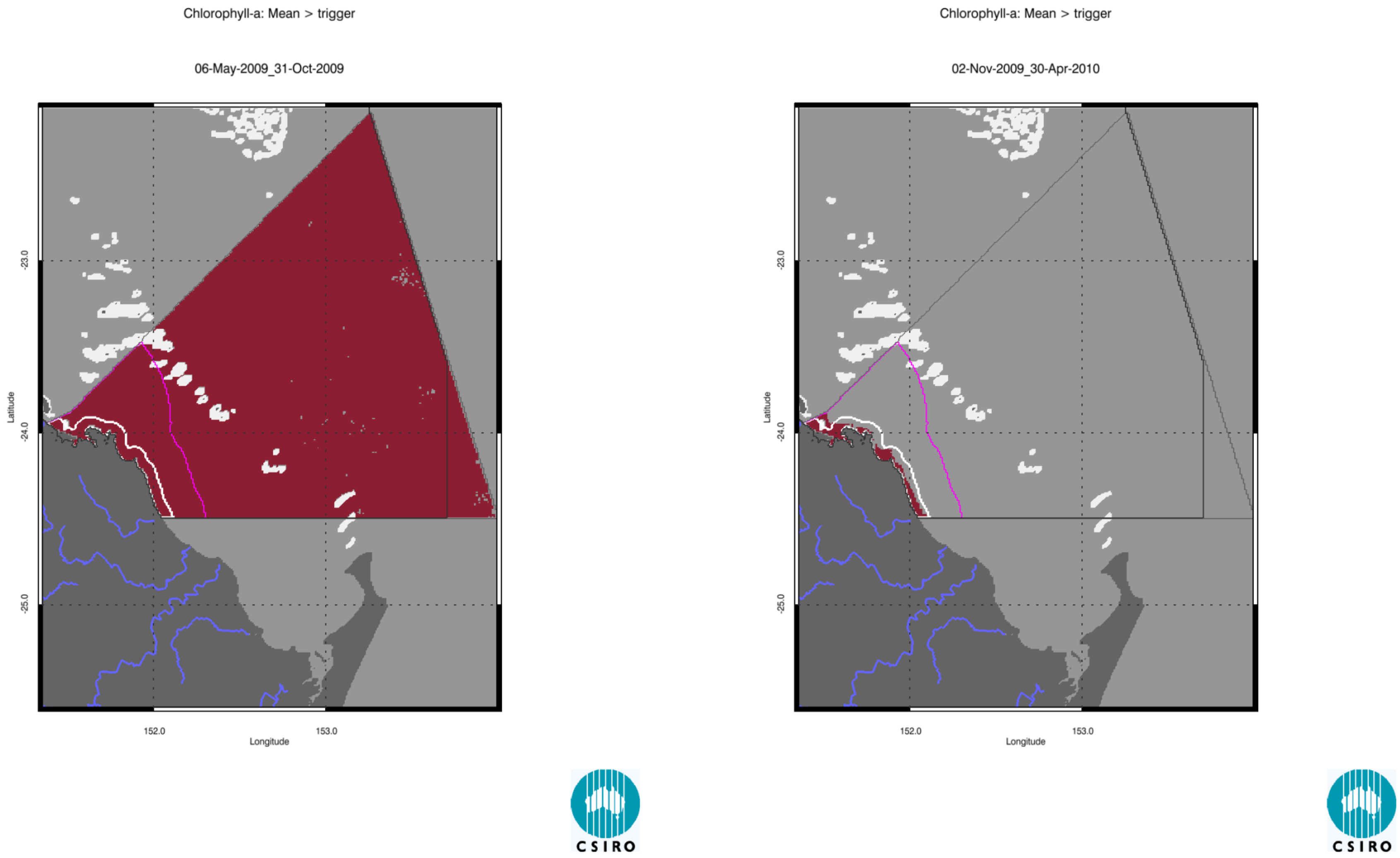
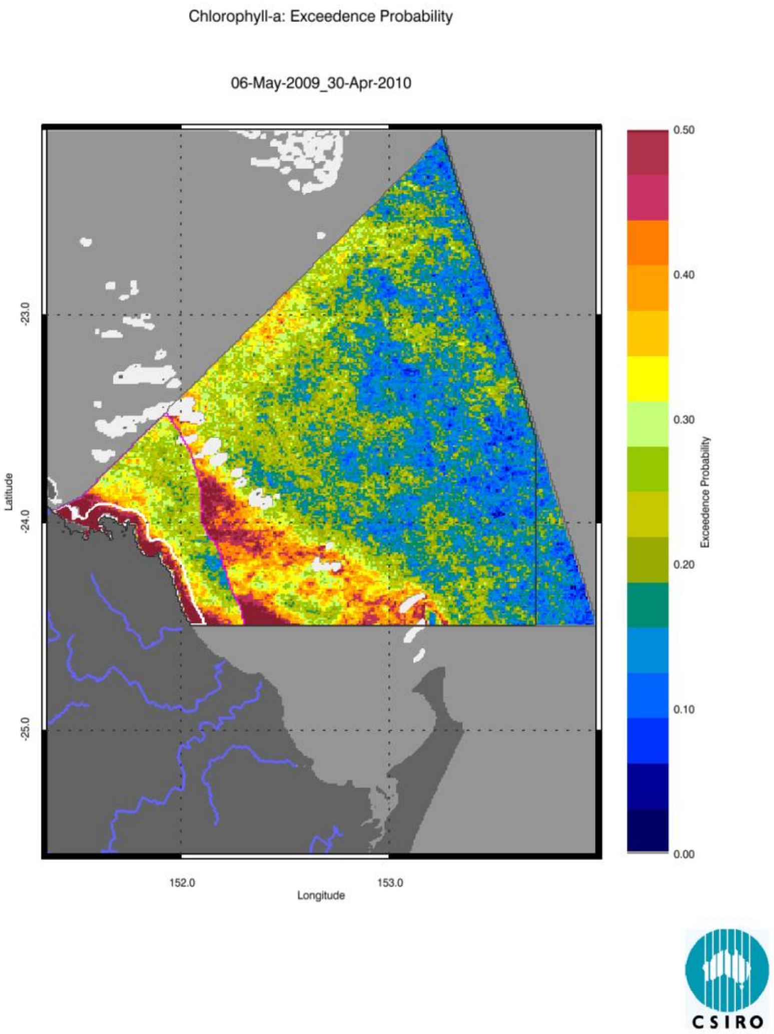


Figure 73. Chlorophyll-a exceedance maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



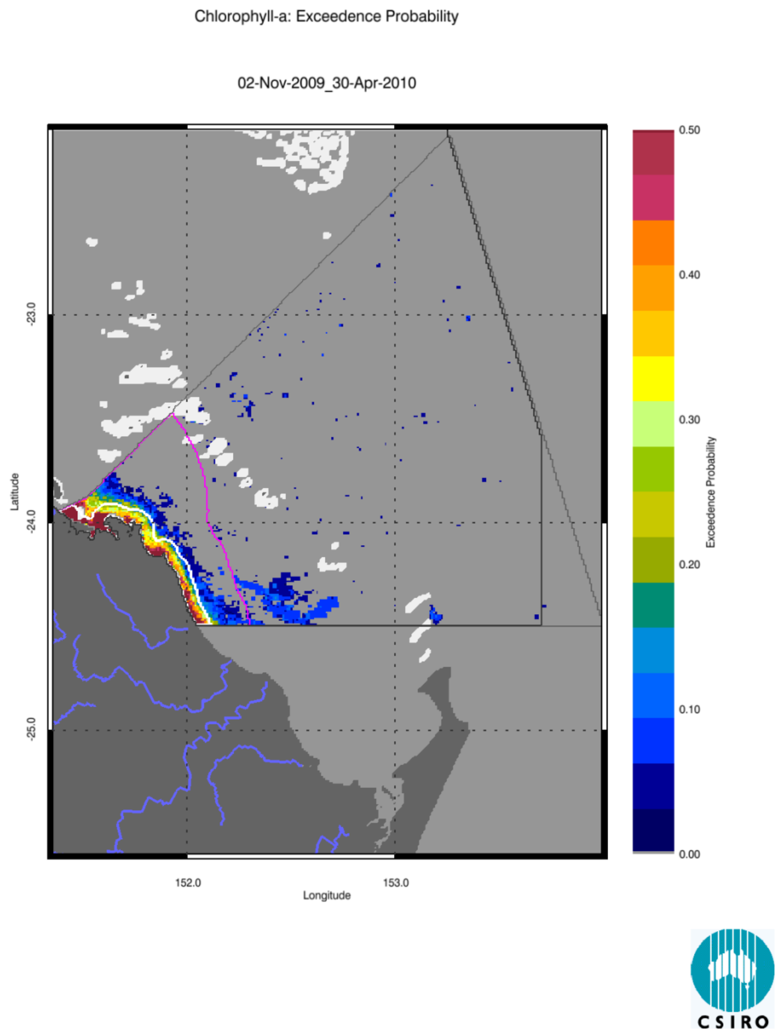
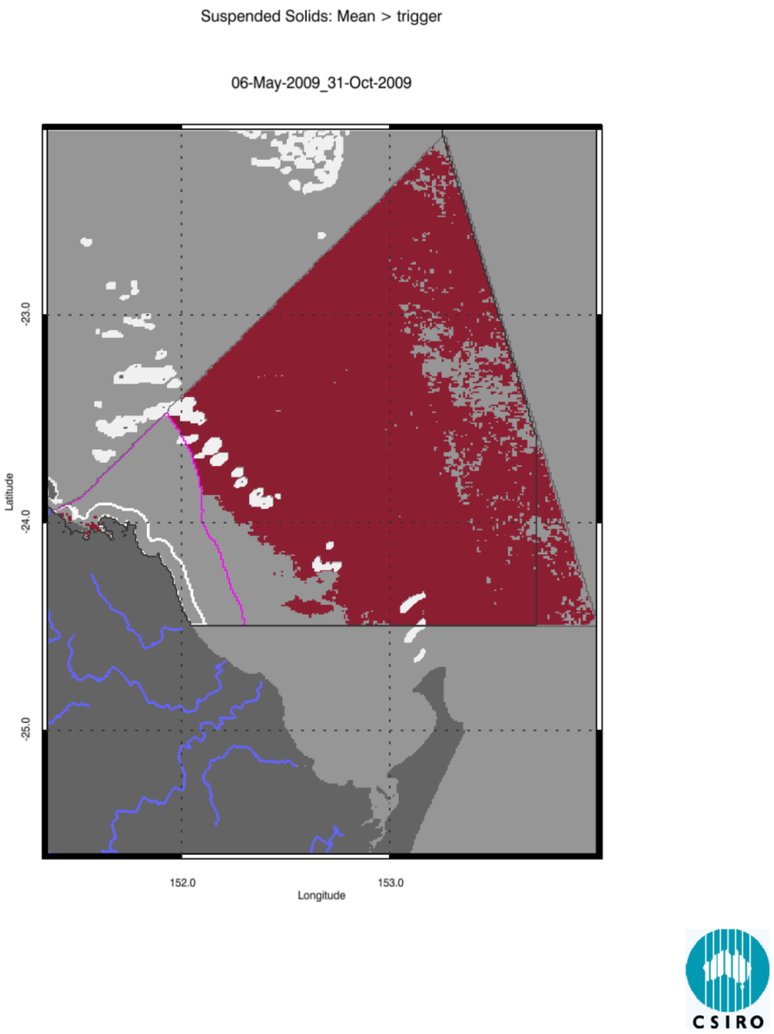


Figure 74. Chlorophyll-a exceedance probability maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



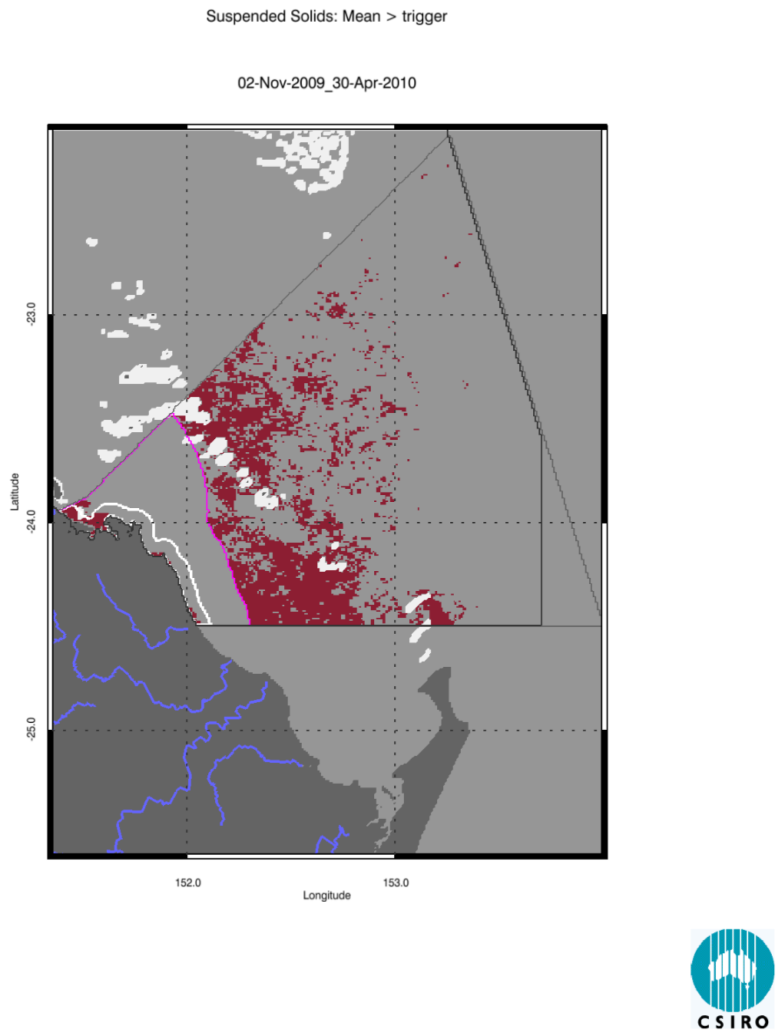


Figure 75. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance for the dry season 2009 (May - October), while the second map presents the exceedance for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.

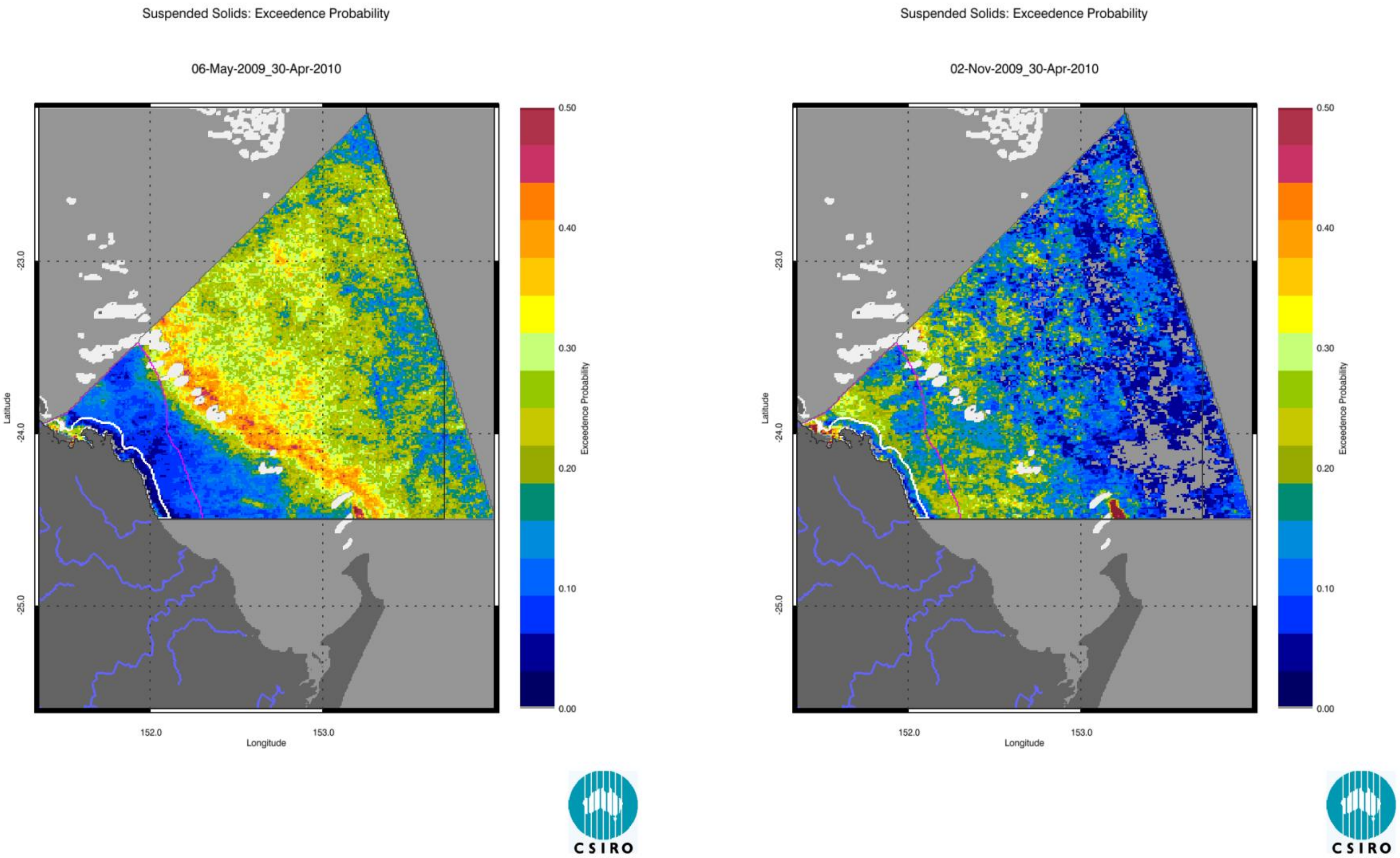
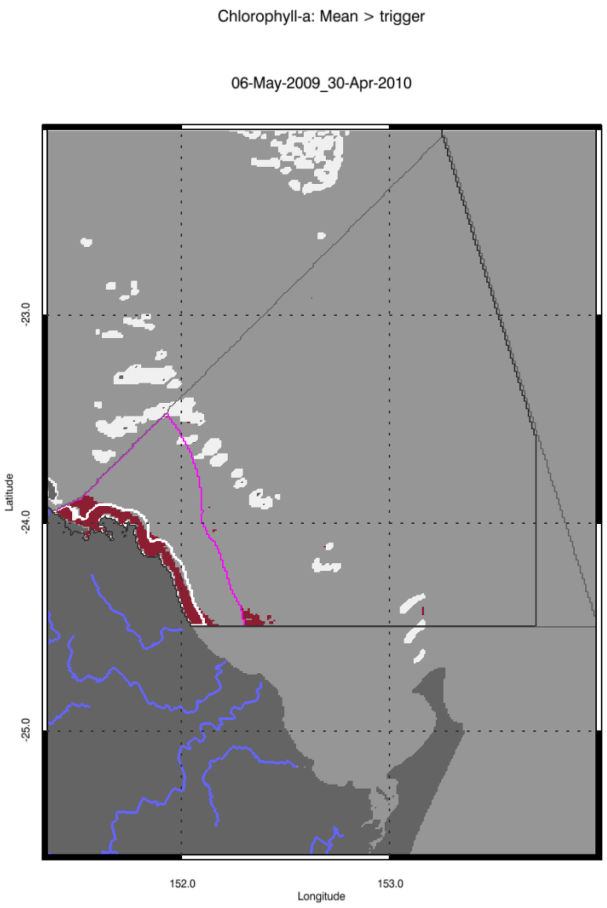


Figure 76. Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance probability maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance probability for the dry season 2009 (May - October), while the second map presents the exceedance probability for the wet season 2009/2010 (November 2009- April 2010). See text for annotation explanation.



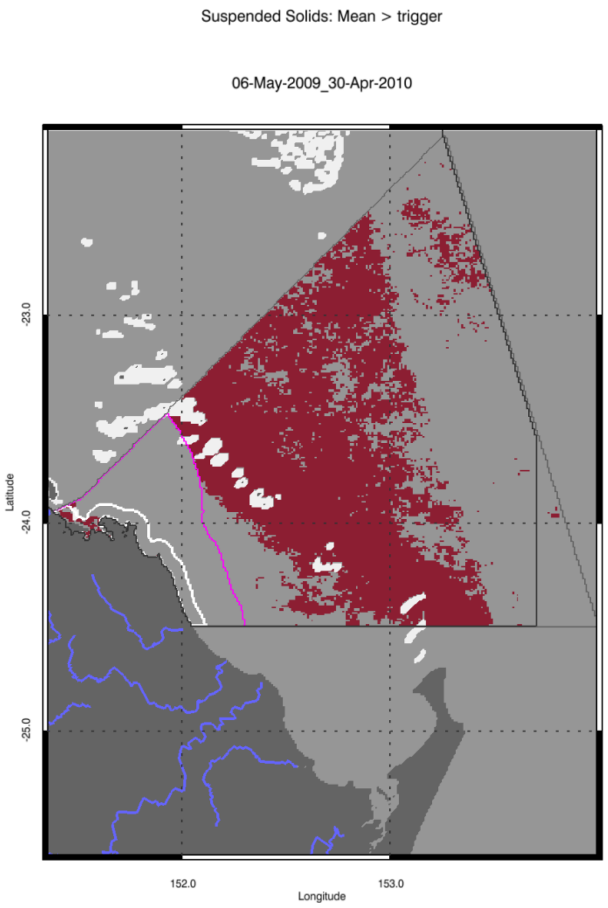
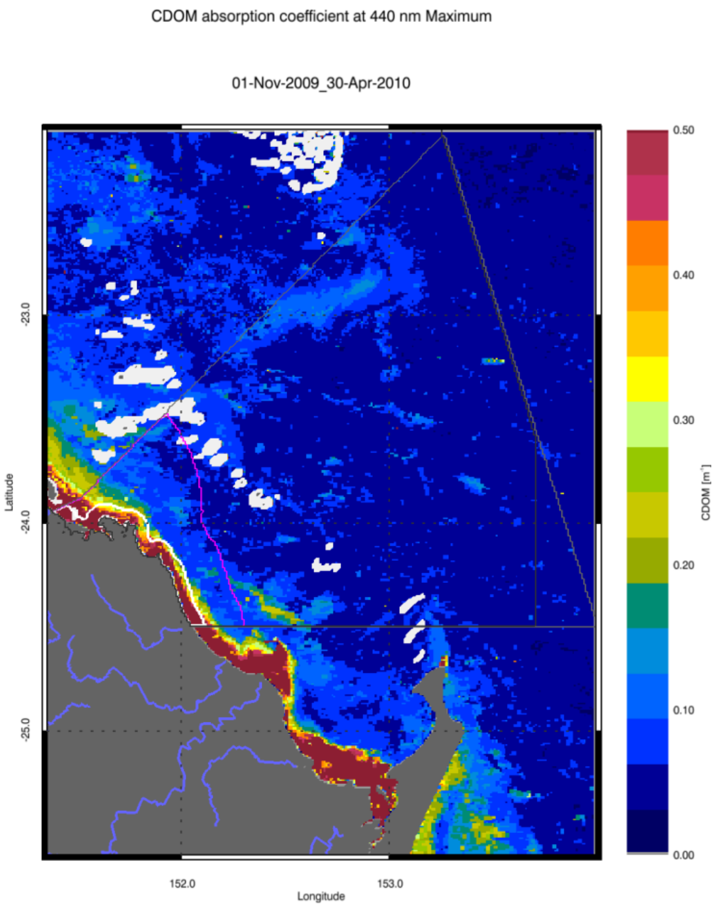


Figure 77. Exceedance maps for the Burnett Mary region for the whole year (May 2009 –April 2010). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance map. See text for annotation explanation.



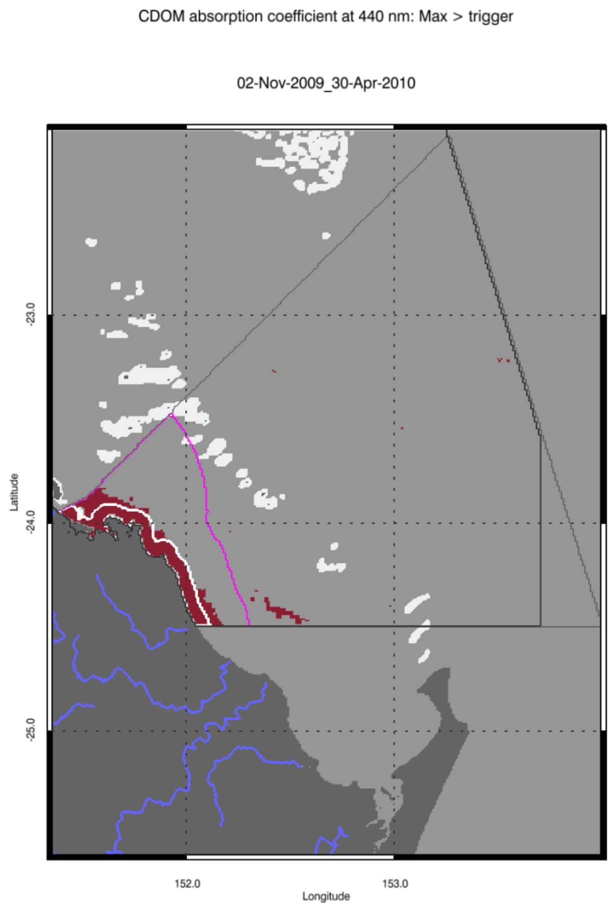


Figure 78. Map of freshwater extent for the wet season for Burnett Mary region. The first map presents the maximum value of CDOM for the wet season 2009/2010 (November 2009- April 2010), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m^{-1}. See text for annotation explanation.

CONCLUSION AND RECOMMENDATIONS

A cornerstone of the GBRWQPP and the WQIPs is the setting of regional water quality objectives against which to assess the success of the actions taken under Reef Rescue to mitigate the effects of nutrients and sediment from runoff and discharges. A key challenge is to detect and monitor the effect of the land management practices on the water quality in the GBR lagoon waters. In this system, the water quality is also influenced by the inter-annual weather variability induced by the *El Niño-Southern Oscillation* (ENSO) leading to large year to year variations in the distribution over the GBR catchments of rainfall events resulting in sediment laden river plumes and algal blooms.

Given the size and variability of conditions within the GBR, monitoring and assessment to meet these requirements is challenging. The MMP water quality monitoring uses three complementary approaches to collect data at various spatial (site, location, region, and whole GBR lagoon) and temporal (snapshot, daily, 10-minutely) scales: traditional direct water sampling from research vessels, in situ data loggers at a small number of selected inshore reef locations and remote sensing techniques. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution.

Remote sensing is a suitable and cost-effective technique for the large-scale monitoring of coastal water quality, because it provides synoptic views of the spatial distribution of Chlorophyll-a concentrations as well as CDOM, TSS and water clarity of near-surface water. At present, MODIS Aqua represents a time series from November 2002 to present of water quality estimates with spatial coverage at 1 km resolution, nominally on a daily basis (except overcast days) for the whole-of-GBR lagoon. The water quality estimates were retrieved from the MODIS Aqua time series using two coupled physics-based inversion algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon levelThis was necessary because Chlorophyll-a concentrations retrieved with the MODIS standard algorithms provided by NASA are inaccurate up two-fold in GBR waters (Qin et al., 2007), while regionally parameterised algorithms do account for the significant variation in concentrations of CDOM and TSS and achieve more accurate retrievals.

The comparison of MODIS Aqua retrievals of Chlorophyll-a, CDOM and NAP with in situ data showed that the regional algorithm coupled with the ANN atmospheric correction is more accurate than NASA's algorithms for GBR waters. The accuracy for the retrieval of Chlorophyll-a, CDOM and TSS with the coupled physics-based inversion algorithms was 58%, 57% and 66%, respectively. The parameterization and validation on the remote sensing retrievals was mainly based on observations performed in coastal and lagoonal waters during the dry season between Keppel Bay and the Wet Tropics. The accuracy of the retrieval is likely to likely to be lower in shallow and turbid waters systems such as Princess Charlotte Bay, Broad Sound, Shoalwater Bay where there was no data available for parameterization and validation.

The Secchi Depth product is still in development phase and should be validated using the water quality data sets used in recent studies on the spatial and temporal patterns of water quality of the Great Barrier Reef (De'ath 2007; De'ath and Fabricius 2008).

This report delivered management-relevant products from remote sensing data that provide information beyond that of a simple concentrations map to enable the relevant management agencies to make more informed management decisions.

The freshwater extent was estimated for each region from MODIS measurements within the wet season of each year by applying a threshold to maps of aggregated seasonal maximum CDOM concentrations. For this study a CDOM absorption threshold was established from visual inspection of a daily imagery, further work is needed to establish a threshold based on the relationship between measurements of salinity and CDOM absorption as proposed for the North and Baltic Seas (Astoreca et al. 2009; Ferrari and Dowell 1998). The high CDOM concentrations may also reflect other processes in occurring in near-shore waters, further work should also attempt to separate the plumes from non-plume effects.

The freshwater extent based on the CDOM maximum provides a conservative estimate of the extent as the flood plumes could have extended further in cloudy or overcast days and hence may not been captured with the satellite imagery. The extent and inter-annual variability of freshwater plumes in the Great Barrier Reef lagoon was found to be highly correlated with river flow data from stream gauges. The estimated freshwater extent the Fitzroy and Burnett Mary regions was higther than in 2008/2009 and comparable with the 2007/08 wet season when the largest flood since 1991 had occurred in the Fitzroy. For the Wet Tropics and Burdekin regions estimated freshwater extent was smaller than in the the previous wet seaon, reflecting flow conditions below or just above median levels.

The Guidelines provide triggers for management action where exceedance occurs and threshold levels for analysis of current condition as well as trend monitoring. The exceedance assessment results evaluated for CHL and TSS were presented as maps of exceedance as defined by the Guidelines, i.e. when mean values for the year (and seasons) exceed the thresholds, as well as the EP providing the number of days where the concentration exceeded the threshold divided by number of days with (error-free) data for that period. The spatial patterns in exceedance were function of the coastal to offshore gradients that can be observed in the median maps and of the steep changes in trigger values between the Midshelf and Offshore areas.

For all reporting region except Mackay Whitsunday the Open Coastal water body shows high areas of non compliance for Chlorophyll-a (56-83 % of relative area of the water body). The results of the previous reporting period presented a similar pattern of high areas of non compliance (51-84%). The Open Coastal water body includes also all the Enclosed coastal waters which have not been delineated by GBRMPA. As the guideline values for CHL and TSS for the Eenclosed Coastal waters are higher than those for the Open Coastal water body, the relative area of non-compliance for the Open Coastal is likely to be over-estimated. It is recommended to GBRMPA to delineate the Enclosed Coastal water body. The data used in this report will still be available and could be re-examined for consistency across both baseline reporting year as well as future out years.

For this report, a stricter quality control of the MODIS imagery was implemented, resulting lower number of available observations for each pixel than in previous reports. The number of available observation was significantly lower in the wet season than the dry season for all the regions. This is due to the higher cloud cover and aerosol concentration in the monsoonal season. It is possible that the cloud cover introduces a bias in the sampling if the remote sensing imagery does not capture effectively the extreme values in concentrations Chlorophyll-a and suspended solid during and following flood events. The estimate of the mean values for the wet season and to a lesser extent for the whole year are more likely to be affected than the estimate of the median values by the "non-sampling" of the higher values due to cloud cover. For this reason we have been reporting the evaluation of compliance using both the mean and the median values, even if the mean values are identified in the Guidelines. Also the effect of calculating a mean value for a given location based on

6-8 samples in a year or 100-200 values is quite different and it needs attention from a statistical sampling design perspective as the distribution of the effective sampling due to the cloud cover may bias the estimate of mean values. The effect of cloud cover and of a biased sampling for cloud free data needs further investigation using time series data from moored sensor or the output from biogeochemical models.

Given the spatial and temporal complexity of the water quality the GBR , the development of an integrated assessment and reporting framework is needed to provide a comprehensive and more easily interpretable assessment of GBR water quality. Further work in designing the exceedance/compliance metrics and how to combine the assessment over more variables is needed to provide a high degree of confidence in these results. This will enable these datasets to meet the requirements of the reasonable assurance statements and the monitoring and modelling strategies for the WQIPs of the NRM regions.

The spatial and temporal density of the MODIS Aqua time series should allow patterns in water quality to be evaluated across the whole of the GBR lagoon. These patterns may represent short-term trends in water quality related to meteorological variables, such as rainfall, while other patterns represent longer-term trends related to anthropogenic impacts such as land management practices. Separating the variability attributed to the ENSO-induced inter-annual weather variability from the anthropogenic factors is probably the central challenge to monitoring the condition of the GBR and of assessing the effectiveness of remediation measures. However, as the length of the data record grows, it will become easier to separate these sources of variability so that additional information can be obtained about the effects of land management practices and policy initiatives on water quality in the GBR lagoon and outer waters. Future work to achieve these results would include:

- Improving the accuracy of Chlorophyll-a detection in the wet season in the outer lagoon and reef matrix for both sensors. This will be based on a reanalysis of existing optical data sets for dry and wet season, combined with the data collected during at the Integrated Marine Observing System (IMOS) facilities: the Lucinda Jetty Coastal Observatory and the National Reference Station moored at the Yongala wreck.
- Assessing the value for remote sensing validation of Chlorophyll-a a data from GBROOS/IMOS underway sampling, and from the AIMS/MMP autonomous water quality loggers and moorings.
- Characterizing the detection limits for each of the water quality variables (Chlorophyll-a, TSS, CDOM and water clarity) for environmental conditions ranging from high flow turbid river plumes to dry season wind-driven resuspension to outer reef blue waters.

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APPENDIX 1 DETAILS OF ALGORITHM THEORETICAL BASIS FOR THE REGIONALLY VALID RETRIEVAL OF WATER QUALITY FROM SATELLITE IMAGERY

Regionally valid retrieval of water quality parameters from satellite imagery

Based on studies conducted in the Fitzroy Estuary (Brando et al. 2006; Oubelkheir et al. 2006) and the Mossman –Daintree (Steven et al. 2007), it has been demonstrated that the NASA standard global Ocean Colour algorithms are inaccurate in nearshore GBR waters (Qin et al. 2007). Subsequently there has been considerable effort in developing regionally appropriate algorithms for these optically complex GBR waters. Studies commissioned by GBRMPA on water quality monitoring (Schaffelke et al. 2006) and optical characterisation of coastal waters (Blondeau-Patissier et al. 2009) have also been undertaken and contributed to the development of regionally appropriate algorithms using a semi-analytical physics-based approach parameterised and validated with local measurements.

In this work we coupled two physics-based inversion algorithms with the objective to improve the accuracy of Chlorophyll-a and IOP estimates from MODIS Aqua data in GBR Lagoon coastal waters. In a first step, an atmospheric correction algorithm based on inverse modelling of radiative transfer simulations and Artificial Neural Network (ANN) inversion, derives the remote sensing reflectance at mean sea level (Schroeder et al. 2008). Then, the inherent optical properties and the concentrations of the optically active constituents, namely Chlorophyll-a, non-algal particulate matter (NAP) and coloured dissolved organic matter CDOM, were retrieved using an enhancement of the Linear Matrix Inversion (LMI, Hoge and Lyon 1996) that incorporates regional and seasonal knowledge of specific IOPs(Brando et al. 2008a).

Atmospheric correction

The application of NASA's atmospheric correction algorithm as implemented in SeaDAS v5.1.1 systematically retrieves unrealistic negative water-leaving radiances for the Great Barrier Reef coastal waters in the visible and NIR bands(Figure 79). A first step for accurate Chlorophyll-a retrievals in Great Barrier Reef coastal waters was thus to develop of a new atmospheric correction algorithm. Our new MODIS atmospheric correction algorithm was developed by inverse modelling of radiative transfer (RT) calculations within a coupled ocean–atmosphere system by utilizing an artificial neural network (ANN) technique.

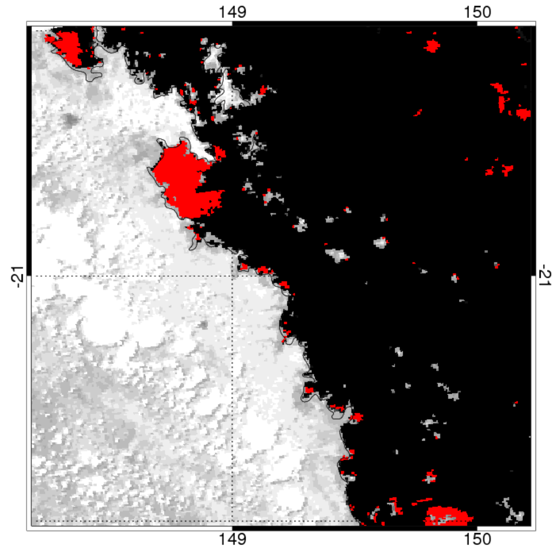	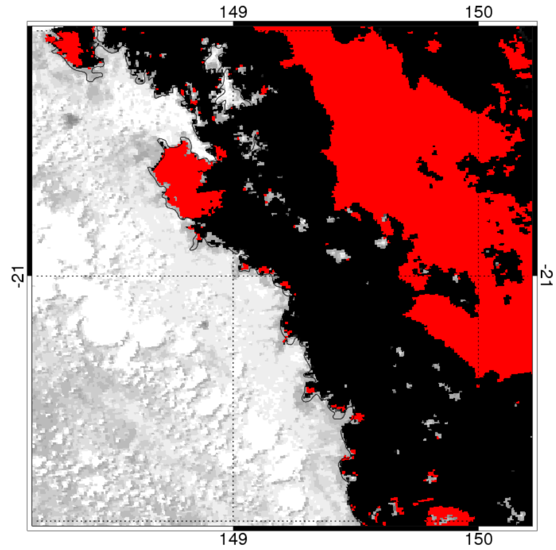
A) Pixels with negative values in the 412 – 678 nm spectral range	B) Pixels with negative values in the 412 – 748 nm spectral range

Figure 79 Atmospheric correction failure: negative reflectances retrieved by NASA algorithm for the Mackay – Whitsundays, QLD – 22 February 2008. Red areas are the pixels with negative values, i.e where the NASA's atmospheric correction algorithm failed for the visible spectral range (A) and the visible and NIR spectral range (B).

Artificial neural network atmospheric correction algorithm development

Our new MODIS atmospheric correction algorithm was developed by inverse modelling of radiative transfer (RT) calculations within a coupled ocean–atmosphere system by utilizing an artificial neural network (ANN) technique. The algorithm was implemented similar to an approach developed by Schroeder et al (2007) for MERIS, but with a different inverse model capable of generating more complex network architectures (Schroeder et al. 2008). Within this model-based approach, ANNs were found well suited models to deal with the optical-complex coastal waters because multilayer feed-forward networks with nonlinear transfer functions, as implemented in this work, are known as universal function approximators (Hornik et al. 1989).

By utilizing an established and validated radiative transfer code as a forward model (Fell and Fischer 2001; Fischer and Grassl 1984) , a large data base of azimuthally resolved upward radiances in the MODIS channels at the Bottom-Of-Atmosphere (BOA) and at the Top-Of-Atmosphere (TOA) was generated for a variety of sun and observing geometries as well as different types of atmospheric and oceanic constituents. Various ANNs serving as inverse models were trained under a supervised learning procedure by applying a non-linear optimisation routine on the basis of a randomly selected data subset of 100.000 spectra taken from the simulated data base. A detailed description of all inputs to the RT model can be found in Schroeder et al (2007).

In total 138 different networks were trained on basis of the simulated subset by applying different scaling and noise levels to the inputs as well as having the option of outputting additional aerosol optical thickness data. The learning was stopped for all networks after 1.000 iterations with the full subset of 100.000 simulated vectors. A single input vector contains the complete MODIS TOA reflectance spectrum of the bands 8-16, the sun and observing geometry and the surface pressure. The associated output vector consists of the reflectance spectrum at mean sea level (MSL) for the MODIS bands 8-15 (412-748 nm) with the output option of additional aerosol optical thickness data.

At the end of the training phase the accuracy of each network was accessed by inverting „real-world" MODIS data and comparing the outputs against in-situ data. Therefore, a match-up data base was compiled containing in-situ above water reflectance measurements collected by the GKSS Institute for Coastal Research and the Management Unit of the North Sea Mathematical Models (MUMM) during various MERIS Cal/Val field campaigns in North Sea turbid waters and by CSIRO in coastal waters of the Great Barrier Reef. The reflectances were measured according to the REVAMP protocols (Tilstone et al. 2004) using Trios RAMSES and SIMBADA spectrometers. The match-up criteria selected within this work was to allow a maximum time difference of ±60 min to the satellite over pass with all match-up area pixels not flagged by LAND, CLOUD/ICE or HIGHGLINT. From more than hundred in-situ spectra 31 finally met these criteria and were selected with their associated satellite data as match-up data set.

Artificial neural network atmospheric correction algorithm validation and application

The best overall performance was achieved by a 3-layer network with 20 neurons for the hidden layer using PCA for input spectra decorrelation and AOTs as additional outputs. Figure 80 shows the scatter plots of the in-situ reflectance measurements against the median reflectance values derived from the SeaDAS v5.1.1 atmospheric correction output and the values obtained from the ANN correction scheme. We found a lower RMSE of 0.0035, a lower BIAS of 0.0015 and a higher correlation of 0.98 for the proposed ANN algorithm compared to the SeaDAS output, with an overall RMSE of 0.0058 with a BIAS of 0.0029 and a correlation of 0.95. At four stations in North Sea turbid waters SeaDAS atmospheric correction retrieved negative reflectances at 412 nm from the match-up data (Figure 80). The error bars in Figure 80 indicate the simple standard deviation of the reflectances within the 3 x 3 pixel match-up area and of the in-situ measurements.

The spectral error show the largest differences in the blue part of the spectrum for both algorithms (Figure 81), where the SeaDAS atmospherically corrected data resulted in a mean absolute percentage error (MAPE) of up to 48% compared to 19% for the ANN algorithm.

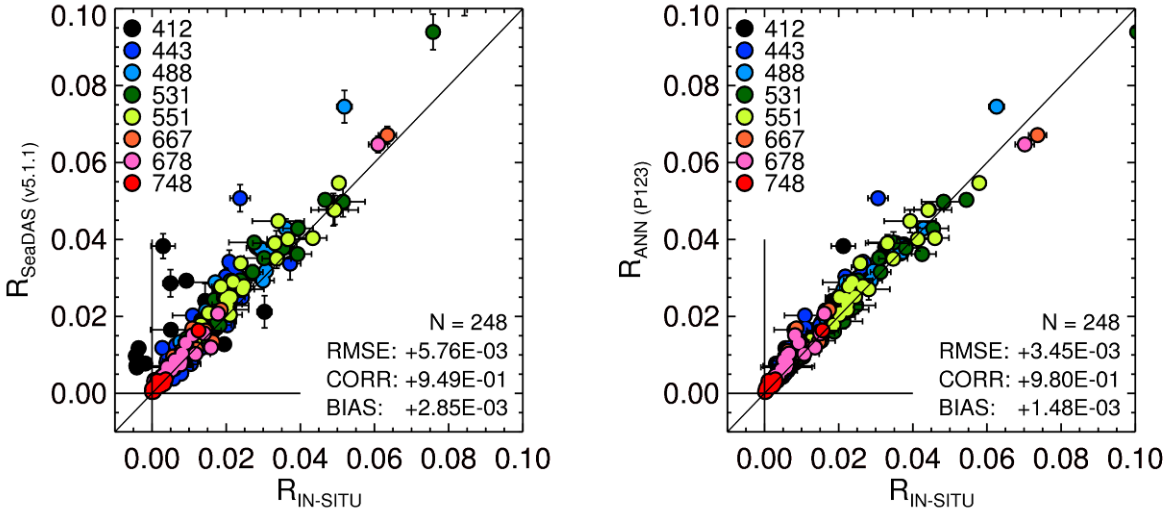

Figure 80: Scatter plots of the median reflectances of the MODIS Level2 product (left) and the proposed ANN atmospheric correction (right) compared to 31 in-situ reflectance measurements collected by GKSS, MUMM and CSIRO.

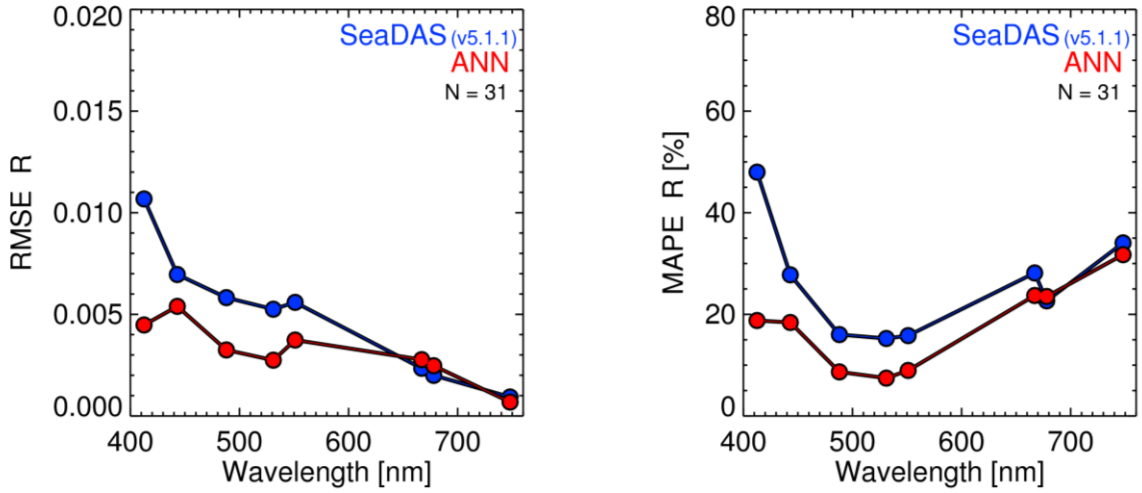

Figure 81: By comparison with in-situ reflectance measurements derived spectral slopes of RMSE (left) and MAPE (right) for the MODIS standard Level2 product generated with SeaDAS v5.1.1 (blue) and the proposed ANN algorithm (red).

The performance of the ANN algorithm is demonstrated and illustrated by comparing selected reflectance spectra with the reflectance output of SeaDAS v5.1.1 for a MODIS Aqua scene acquired on 22 February 2008 covering the Mackay – Whitsundays (Figure 82). Spectra from off-shore areas are in good agreement, while SeaDAS fails for most of the near-shore coastal areas by retrieving negative spectra.

To further illustrate the performance of the proposed ANN algorithm we shows map of the derived spatial reflectance distribution (Figure 83) for a MODIS Aqua scene acquired on 22 February 2008 covering the Mackay – Whitsundays coastal waters for the wavelengths 412 in comparison with the NASA's atmospheric correction algorithm Higher TSS and CDOM concentrations can be associated with the near coastal waters of Repulse Bay causing negative reflectance values at 412 nm.

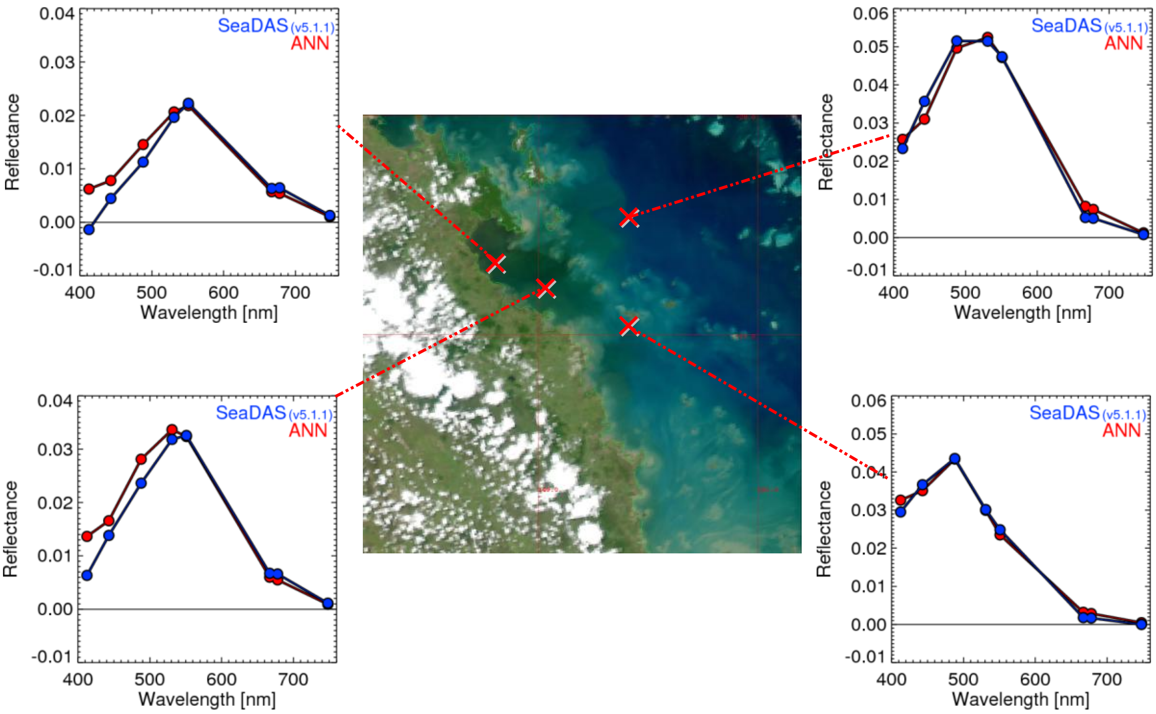

Figure 82: Comparison of SeaDAS v5.1.1 and ANN derived reflectance spectra for a MODIS Aqua scene acquired on 22 February 2008.

ANN atmospheric correction
Reflectance at 412 nm

NASA standard atmospheric correction
Reflectance at 412 nm

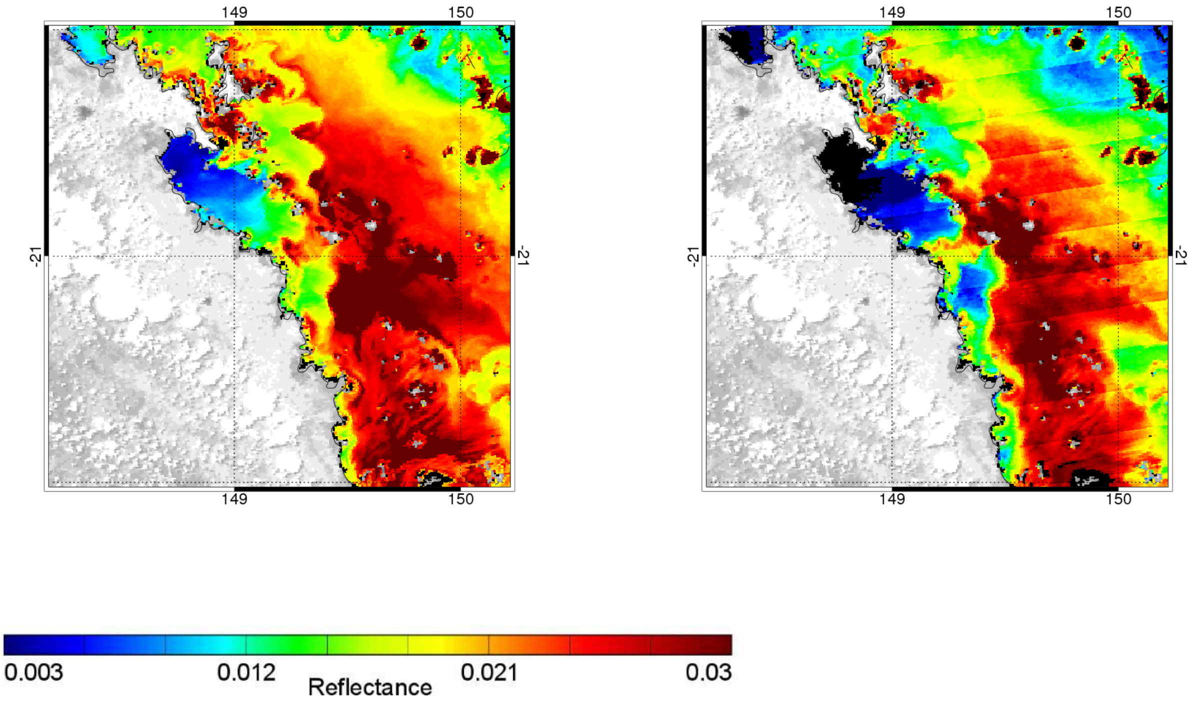

Figure 83 Spatial distribution of the reflectance at 412 551 nm as derived by the ANN algorithm and NASA standard algorithm from a MODIS Aqua scene acquired on 22 February 2008 (black areas=masked pixels).

The proposed atmospheric correction scheme provides a significant improvement in accuracy for the retrieval of reflectance data from MODIS Terra/Aqua measurements. From match-up analysis within coastal waters an overall mean absolute percentage error of 17.5% within the spectral range of 412-748 nm was derived. Compared to NASA's standard atmospheric correction implemented in SeaDAS v5.1.1., the proposed neural network approach showed a significant improvement in accuracy, especially in the blue part of the spectrum.

Future work for the validation of the atmospheric correction scheme will rely on the matchup analysis of the normalized water-leaving radiances data-stream acquired on a daily basis at the Lucinda Jetty Coastal Observatory (LJCO).

Optical water quality retrieval

In previous years CSIRO's Environmental Earth Observation Group assessed the performance for the local conditions of coastal GBR waters of the seven NASA global Chlorophyll-a (CHL) algorithms implemented in SeaDAS. The accuracy of CHL retrieval for the seven empirical and semi-analytical algorithms generally degraded rapidly with increasing coloured dissolved organic matter (CDOM) and non-algal particulate matter (NAP) concentrations (Qin et al. 2007). The level of disagreement is at least twofold for concentrations of Chlorophyll-a above 2 µg L^{-1}. The gsm01 (Maritorena et al. 2002) algorithm was shown to work relatively better in the widest range of CDOM and NAP concentrations, while the Carder (Carder et al. 2003) algorithm has the highest accuracy for low CDOM and NAP concentrations. For the retrieval of bulk IOP, Qin et al.(2007) found that the three semi-analytical algorithms Carder, gsm01 and QAA seem unable to break down the total absorption coefficient, a, into its components, aph (phytoplankton) and adg (CDOM + NAP). This is probably because the three algorithms used adg slopes (QAA: 0.015, gsm01: 0.0206 and Carder: 0.0225) that are different than the values of S_{NAP} and S_{CDOM} found in the GBR coastal waters. (Brando et al. 2008a) have shown that considerable differences in optical properties and concentrations are found between the dry and wet season for the GBR lagoonal waters.

IOP and concentrations retrieval - LMI

To improve the accuracy of Chlorophyll-a and IOP estimates from MODIS Aqua data in GBR Lagoon coastal waters, in this project an enhancement of the Linear Matrix Inversion (LMI, Hoge and Lyon 1996) was used to incorporates regional and seasonal knowledge of variability in the specific inherent optical properties of concentration specific light absorption and scattering encountered in GBR coastal waters. The algorithm estimates simultaneously the concentration of Chlorophyll-a, Total suspended sediment, CDOM and the water clarity expressed both as vertical attenuation coefficient (K_d) and as Secchi Depth.

LMI has been already successfully applied to retrieve the concentrations of the optically active constituents in inland and coastal waters with hyperspectral data (Brando and Dekker 2003; Giardino et al. 2007; Hoogenboom et al. 1998). This algorithm was adapted to MODIS for the Fitzroy River Estuary Keppel Bay (southern GBR) (Brando et al. 2006; Brando et al. 2007) and applied to the MODIS Aqua data for the whole GBRWHA (Brando et al. 2006; Schaffelke et al. 2006).The LMI method as outlined here uses the below-water remote sensing reflectance spectrum of the eight MODIS bands 8-15 (412-748 nm) as input to a semi-analytical model developed by Gordon et al. (1988) to simultaneously derive the three optically active constituents in an algebraic manner.

One of the major weaknesses of the LMI is the difficulty of parameterising a stable spectral shape for each SIOP to reflect the natural variability (Lyon and Hoge 2006). To overcome this, Wang et al. (2005) made use of an over-determined system (3x4, λ=410, 440, 490 and 550 nm) to explore the observed range of variability of the IOP shape factors. In this study, to incorporate regional knowledge of specific IOPs, the imagery inversion was performed while varying the SIOP shape parameters through a series of unique combinations of the shape parameters, i.e. SIOP sets. Each SIOP set correspond to a complete set of SIOP shape parameters ($a^*_{phy}(\lambda)$, S_{CDOM} , $a^*_{NAP}(440)$, S_{NAP} , $b^*_{bphy}(555)$, γ_{phy} , $b^*_{bNAP}(555)$, γ_{NAP}) as they were measured concurrently at a single station during a cruise. With this approach, no a priori assumptions are made on the locations of specific water types in the satellite imagery and unnatural combinations of the shape factors are avoided. The SIOP set, the IOPs and concentrations values associated with the best optical closure are retained for each pixel and used for the output maps (Figure 84).

The optical closure is measured with $relRMSE$, the relative Root Means Square Error between the input remote sensing reflectance and the inverse-forward simulated reflectance calculated for each input spectrum. $relRMSE$ provides a level of confidence of water quality parameter estimates. If the value of $relRMSE$ exceeds a threshold, or if the retrieved concentrations are negative, or if one or more of the spectral bands of the image gives anomalous values (perhaps due to sun glint or some atmospheric haze etc.) then the pixel is flagged as not mapped.

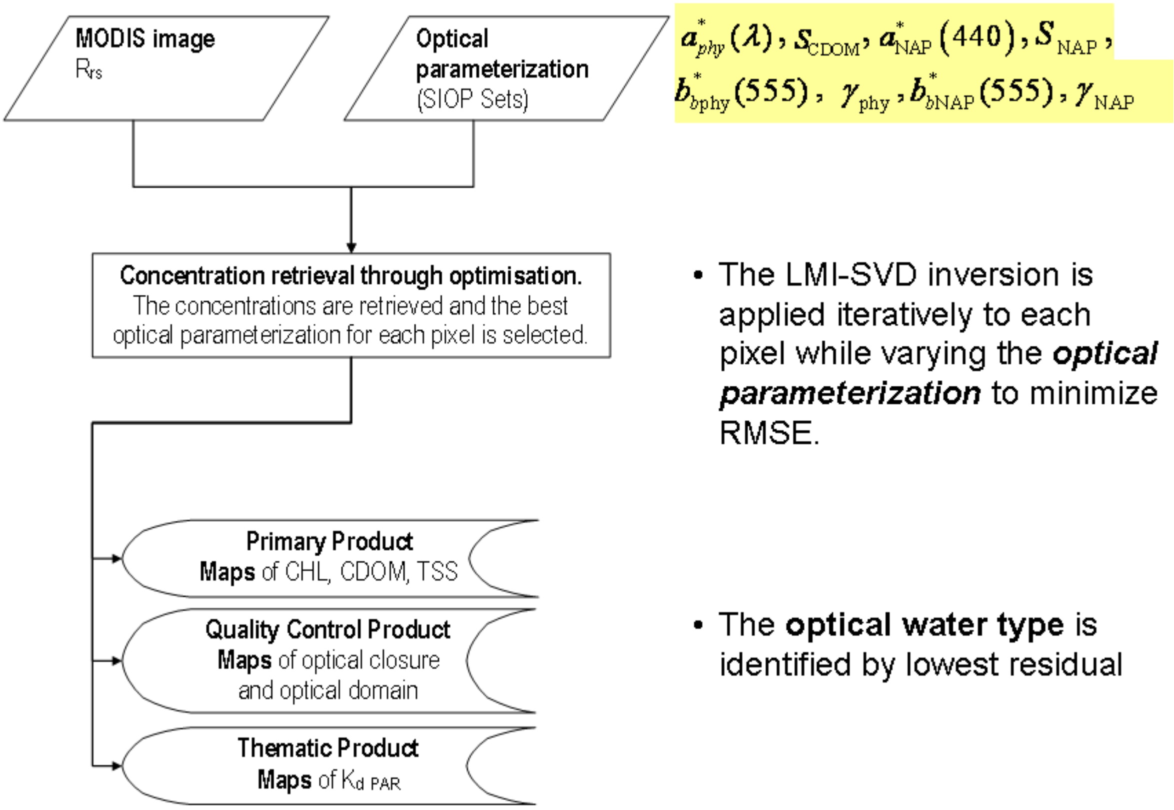

Figure 84. Conceptual diagram of the Linear Matrix Inversion approach adopted for the retrieval of Chlorophyll-a and IOPs from MODIS Aqua data.

Parameterization of LMI

The MMP 2006 report (Appendix 1 pages A40- A-57, Schaffelke et al. 2006) details how the most relevant SIOP sets of the GRBWHA were selected through a rigorous QA/QC and subsequent statistical analysis of the in situ datasets over the period 2002-2005 to adequately represented the full range of SIOPs measured from Cape Tribulation down to Port Curtis.

Subsequently, in the 2008 MMP report (Brando et al. 2008b)}, two adjustments were made to the original parameterization: 1) the value of $b^*_{bphy}(555)$ was fixed for all sites to 0.0006 m^{-1}; 2) the $a^*_{phy}(\lambda)$ spectrum was fixed to one value for the whole GBRWHA. This version of the LMI parameterization was labelled LMI_CLU4.

In 2009, a full re-analysis of the the $a_{phy}*$ spectra for the GBR was performed to overcome the contamination in the UV-blue and NIR ends of the spectra by residual non algal particulate absorption that occurred in the 2006 and 2008 parameterizations (Figure 85 and Figure 86, respectively). Table 35 reports the values needed to parameterize LMI algorithm to estimate simultaneously the concentration of Chlorophyll-a, total suspended sediment, CDOM and expressed both as vertical attenuation coefficient (K_d) and as Secchi Depth (Brando et al. 2010a).

A new statistical analysis comprehensive of Hierarchical clustering, Principal Component Analysis and Multi-Dimensional Scaling, should be performed to incorporate the new optical characterizations carried out in the last two years, in particular the flood waters of the Fitzroy River in Keppel Bay (February 2008) and the wet season sampling of the wet tropics (April 2008).

Table 35 The final centroids identifying the most representative SIOP sets that were used in the regional algorithm parameterization of LMI_CLU4.

Cluster	Site	bb_phy_slope	Bb_phy_555nm	a_cdom_slope	a_tr_slope	a_tr_440nm	bb_tr_slope	bb_tr_555nm
1	AS05_WQN026	0.6649	0.0006	0.0336	0.0115	0.0188	0.6649	0.0064
2	MD 7D	0.7735	0.0006	0.0171	0.0119	0.0401	0.7735	0.0084
3	FK30	0.9882	0.0006	0.0146	0.0136	0.0391	0.9882	0.0452
4	FK35	0.421	0.0006	0.0116	0.0099	0.0281	0.421	0.0063
5	FK2-30	0.6065	0.0006	0.0181	0.0148	0.0271	0.6065	0.0128
6	FK2-23	0.8579	0.0006	0.0192	0.0118	0.0438	0.8579	0.0145
7	AA05_WQS008	0.7859	0.0006	0.012	0.011	0.0029	0.7859	0.001
8	MD 15D	0.8393	0.0006	0.0144	0.0115	0.0266	0.8393	0.008
9	AA05_WQS015	0.6003	0.0006	0.0105	0.0119	0.0057	0.6003	0.0028
10	AO02_SAT0021	1.3086	0.0006	0.0145	0.0124	0.0118	1.3086	0.0049

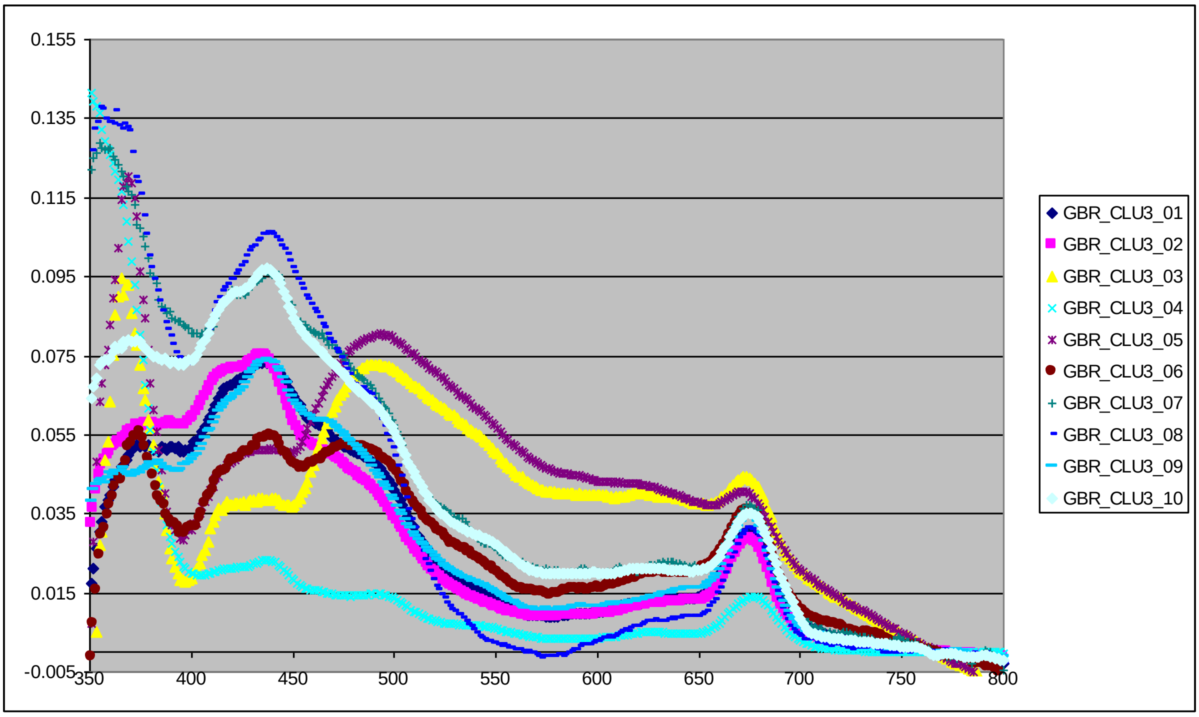

Figure 85 aphy* spectra for LMI inversion in the parameterization for 2006 MMP report

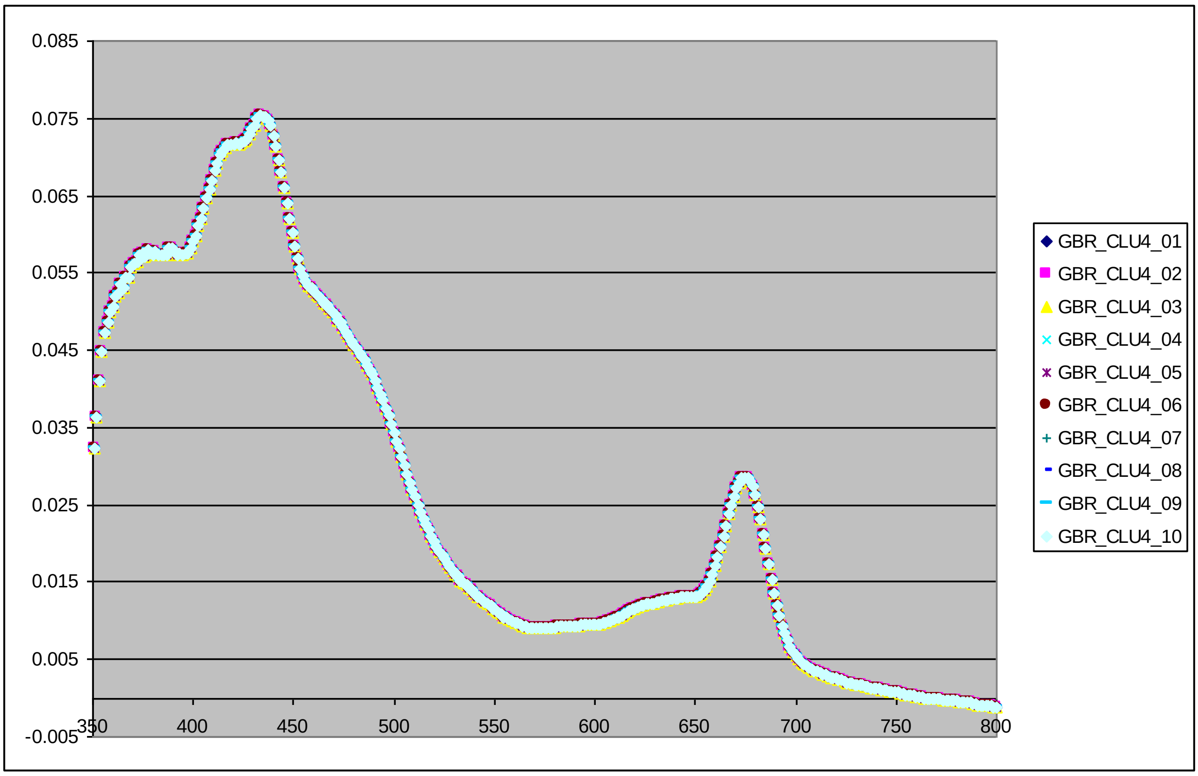

Figure 86 aphy* spectra for LMI inversion in the 2008 MMP version of the parameterization (LMI_CLU4). Note different scale range for Y axis.

Algorithm validation

In the remote sensing literature *validation* refers to the independent verification of the physical measurements made by a sensor as well as of the derived geophysical variables. Validation allows for the verification and improvement of the algorithms used (e.g. for atmospheric correction and retrieval of water quality variables). To achieve this, conventional, ground-based observations are required using calibrated and traceable field instrumentation and associated methods.

In previous MMP reports, we used for validation the GBR Long Term Monitoring Program (GBR-LTMP) dataset. The GBR- LTMP dataset includes Chlorophyll-a measurements going back as far as 1992 (thus including the start of the first contemporary ocean colour sensor SeaWiFS, launched in 1997). This monitoring program was designed to monitor water quality status at regional spatial scales (Brodie et al. 2007). The sampling stations for GBR-LTMP were situated some distance (~1-2 km) from the edge of nearby reefs to avoid confounding influences from biological activity on the reef itself (Brodie et al. 2007) Chlorophyll-a and phaeophytin concentrations were determined fluorometrically, and a suite of site variables (water depth, presence of Trichodesmium and weather conditions) was measured to aid interpretation of the Chlorophyll-a a data (Brodie et al. 2007).

In this study, Chlorophyll-a data from the Cairns transect collected by Miles Furnas and co-workers (AIMS) between 1988 and 2006 as well as data collected by ACTFR during flood monitoring projects and data collected by CSIRO during the optical characterization projects were added to the validation database. The match-up data base included 1787 data points measured by 4 institutions. The measurement campaigns for GBR-LTMP, AIMS and ACTFR data sets were not designed for remote sensing validation purposes and thus the sampling protocols do not follow remote sensing validation guidelines (e-g minimum distance of 5 km from land or islands, HPLC estimate of Chlorophyll-a a, collection within 3 hour from overpass, etc.).

The Chlorophyll-a, TSS (or NAP) and CDOM measurements of the combined validation database were used to validate the retrieval of these water quality variables as retrieved with the algorithms implemented in SeaDAS, NASA's processing software for MODIS imagery, and by the regionally parameterized algorithm (LMI_CLU4) coupled with the Artificial Neural Network atmospheric correction. For this comparison, we extracted from the remote sensing data the average value of the nine pixels (a square of 3x3 pixels) centred at the GPS location of the in situ measurements, for each available date. Only those measurements collected within ±3 hours of the satellite overpass were used in this analysis. Quality flags were checked and masks applied for land, glint, cloud, atmospheric correction failure and for solar zenith and observer zenith above a maximum of 60 degree.

The *in situ* Chlorophyll-a data were used to evaluate the Chlorophyll-a retrievals by the LMI_CLU4 and gsm01 algorithms, as the gsm01 (Maritorena et al. 2002) algorithm was shown to work relatively better in the widest range of CDOM and NAP concentrations for these coastal waters (Qin et al. 2007). Figure 87 presents the results of the MODIS Aqua Chlorophyll-a retrieval comparison with *in situ* data in logarithmic scale. LMI and gsm01 have a similar RMSE, and LMI has lower MAPE (Table 2). These results are consistent with the findings of the sensitivity analysis carried out for these coastal waters (Qin et al. 2007).

The in situ TSS data were used to evaluate the TSS retrieval by LMI_CLU4 and the Clark algorithms, as it is the only one currently implemented in SEADAS for the retrieval of TSS. Figure 11 presents the matchup for MODIS Aqua TSS retrieval vs. in situ data. Only the measurements collected with 3 hours of the overpass were plotted. Although with a limited number of matching measurements (24 for

LMI and 33 for NASA's Clark algorithm) LMI shows a lower bias and MAPE that Clarks algorithm (Table 2).

The in situ CDOM data were used to evaluate the CDOM retrieval by LMI_CLU4 and the QAA algorithms, as the QAA algorithm was shown to work relatively better than others for these coastal waters (Qin et al., 2007). Figure 89 presents the matchup for MODIS Aqua aCDOM (443) retrieval vs. in situ data. Only the measurements collected with 3 hours of the overpass were plotted. The number of matchups are 18 for LMI and 27 for adg (443) (QAA). QAA acdm overestimates CDOM in situ data as it provides an estimate of the absorption due to Coloured Dissoleved Organic Matter as well as particulate matter (Table 36).

The comparison of MODIS Aqua retrievals of Chlorophyll-a, CDOM and NAP with in situ data showed that revised parameterization of regional algorithm coupled with the Artificial Neural Network atmospheric correction led to an improvement in accuracy since the previous report. The results of the matchup analysis for Chlorophyll-a, CDOM and TSS are consistent with the findings of the sensitivity analysis based on radiative transfer modelling that was carried out for these coastal waters (Qin et al., 2007).

To strengthen the validation of remote sensing data, the validation database should be extended to include water quality data sets used in recent studies on the spatial and temporal patterns of water quality of the Great Barrier Reef (De'ath 2007; De'ath and Fabricius 2008). The Secchi Depth database would allow a direct validation the Secchi Depth estimates done from remote sensing data.

It should be noted that most of this matchup analysis is based mainly on dry season observations, and so it is currently not possible to assess whether the retrieval of water quality variables for the wet season estimates have the same level of accuracy or not. This year CSIRO has been commissioning the Lucinda Jetty Coastal Observatory (LJCO), with the support of Australia's Integrated Marine Observing System (IMOS). The LJCO data streams will increase the number of satellite vs. in situ match-ups assessment of normalized water-leaving radiances, water inherent optical properties and aerosol optical properties for the GBR. Also the data collected at the IMOS National Reference Station moored at the Yongala wreck will provide further data to extend the match-up database for the validation of the retrieval of bio-optical and biogeochemical quantities.

Table 36 Validation statistics for the measurements collected with 3 hours of the overpass. RMSE is the root mean square error, MAPE the mean absolute percentage error.

Variable	Algorithm	N	RMSE	MAPE	Bias
Chlorophyll-a	LMI	108	0.79446	58.49%	0.1496
Chlorophyll-a	GSM	110	0.82066	89.50%	-0.0572
TSS (NAP)	LMI	24	5.62293	57.29%	-2.3648
TSS	Clark	38	7.55040	61.33%	-4.2467
CDOM	LMI	18	0.05709	66.88%	-0.0007
a_{dg} (CDOM + NAP)	QAA	27	0.15944	216.2%	0.07921

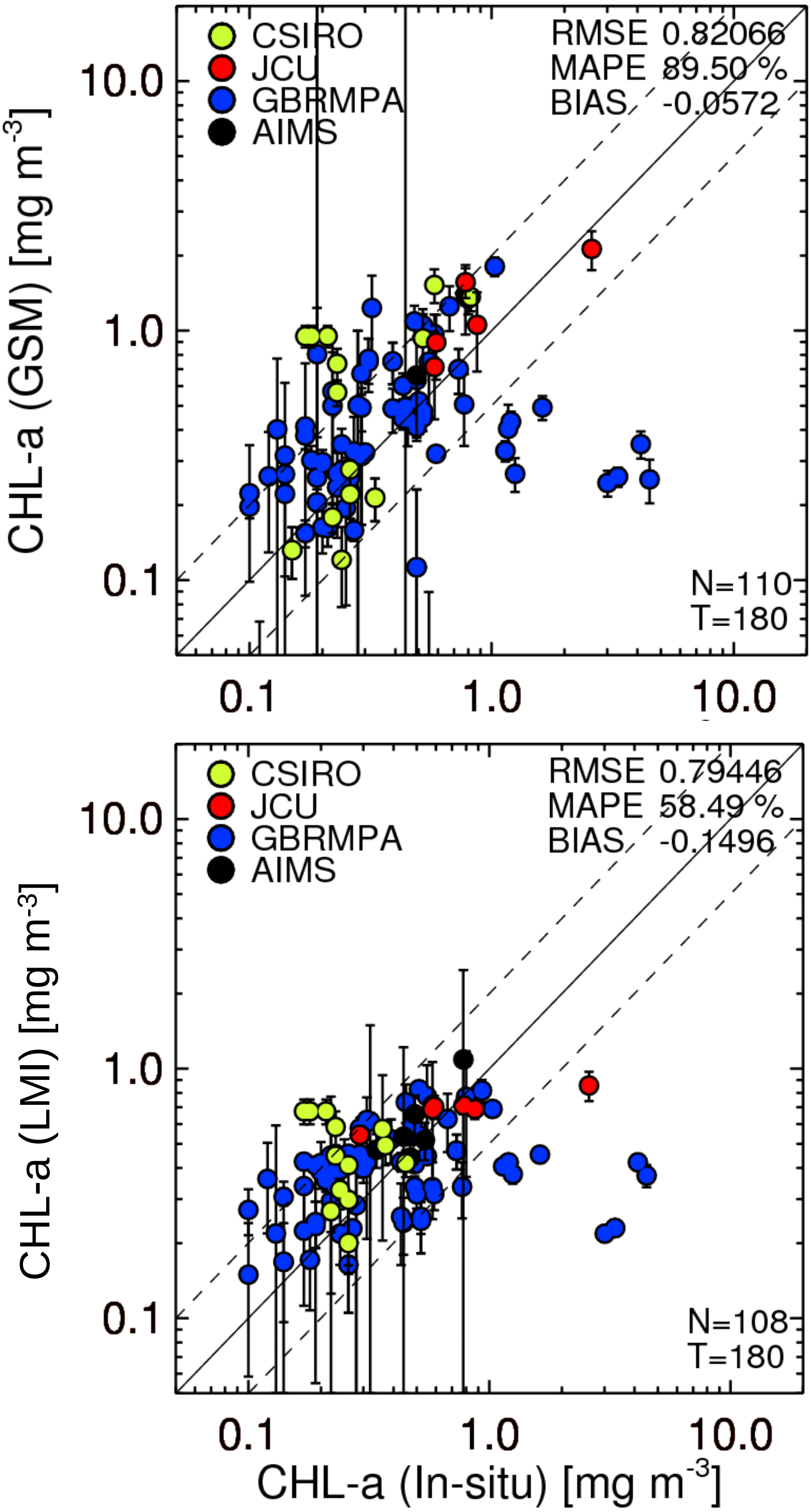

Figure 87: MODIS Aqua Chlorophyll-a retrieval vs. in situ data. Only the measurements collected within ±3 hours time difference to the overpass were plotted. Number of matchups are 108 for LMI and 110 for gsm.

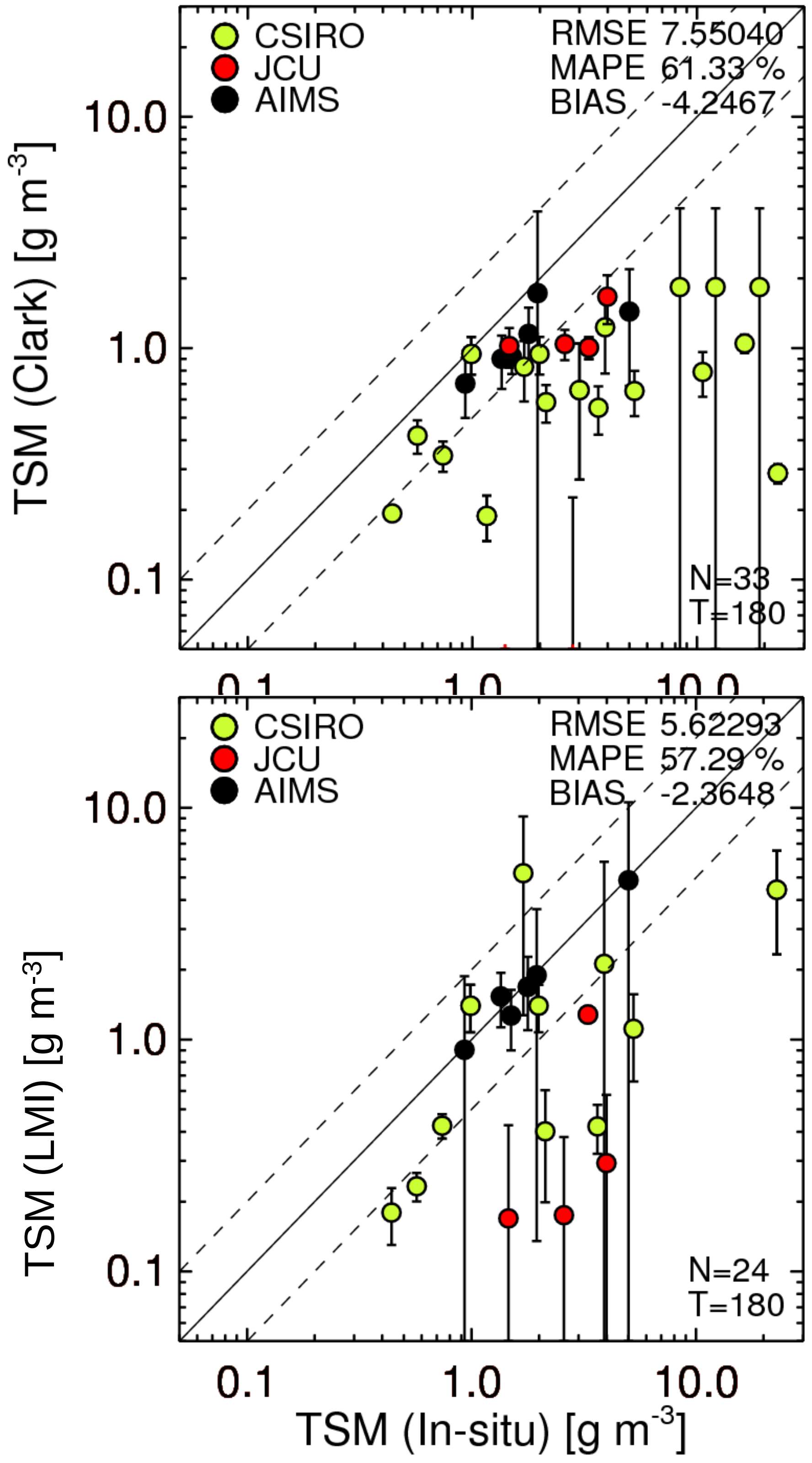

Figure 88: MODIS Aqua TSS retrieval vs. in situ data. Only the measurements collected within ±3 hours time difference to the overpass were plotted. Number of matchups are 24 for LMI and 33 for Clark.

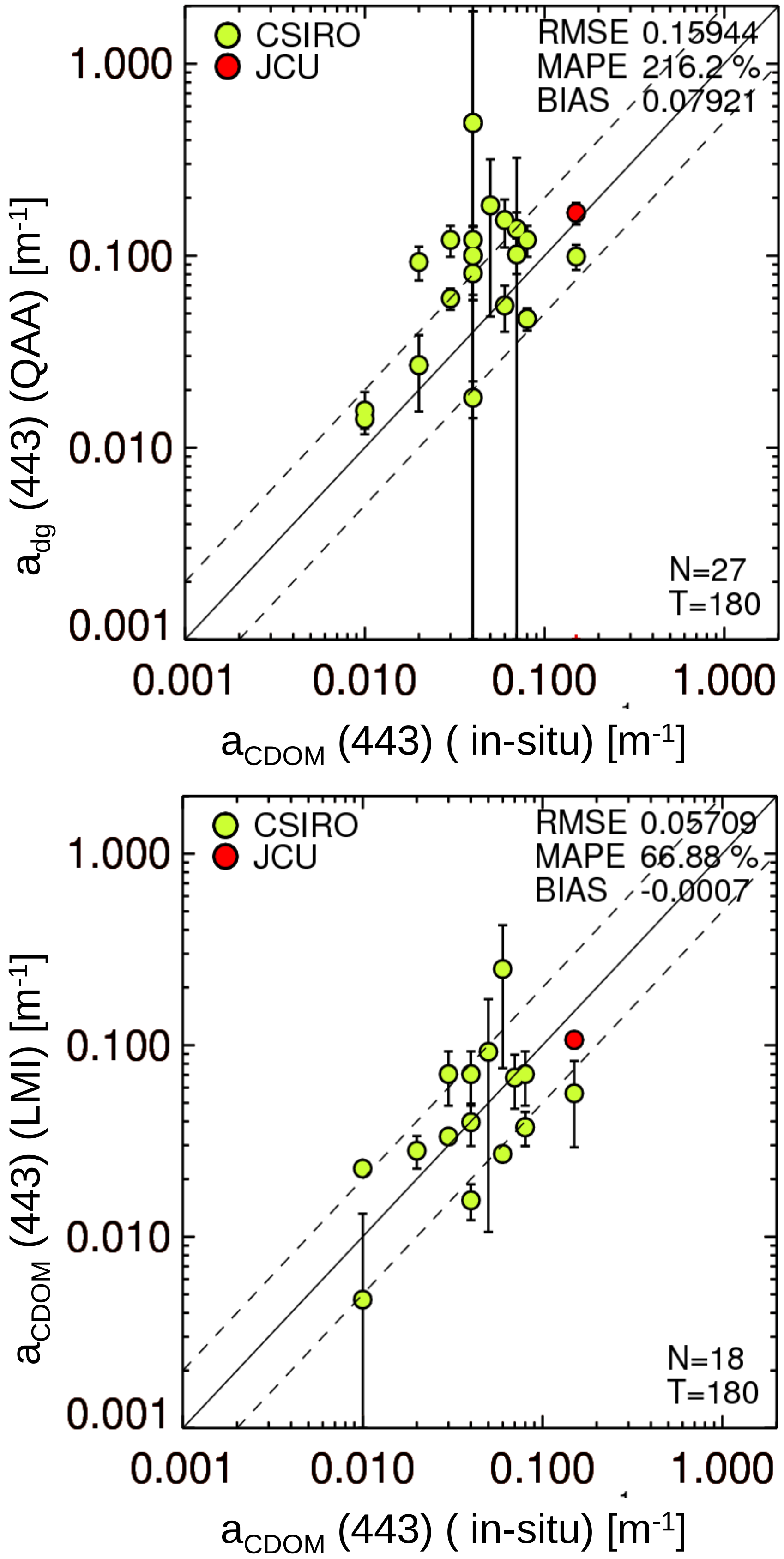

Figure 89: MODIS Aqua aCDOM (443) retrieval vs. in situ data. Only the measurements collected within ±3 hours time difference to the overpass were plotted. Number of matchups are 18 for LMI and 27 for a_{dg} (443) (QAA).

Comparison of the in situ data distributions of the long term monitoring plan with the remote sensing data distributions

In previous reports a comparison of the statistical distributions of the Chlorophyll-a –a from the in-situ data from the GBR LTMP and those retrieved with the algorithm from MODIS Aqua data was presented as box-whiskers plots for each region for the wet and dry season.

The GBR LTMP program was downscaled to a reduced number of sites in 2005 and in 2008. Due to logistical constraints, some sampling locations were different from the locations sampled under the previous long-term program. In 2008/09 and 2009/10 the sampling under the Long-term Chlorophyll-a monitoring component has generally been very unsuccessful (see Tables 2.6 and 2.7 of the AIMS 2008/09 report for details). The results from this sampling were deemed to be too sparse to warrant presentation as graphs or tables. Hence no comparison to this dataset will be presented in this report.

Several autonomous water quality loggers are being deployed in GBR waters by AIMS with MMP, MTSRF and IMOS support. Also water quality data is provided by the flow-through system installed on the AIMS vessel RV Cape Ferguson. The fluorescence and turbidity sensors on these water quality loggers provide continuous estimates of Chlorophyll-a and suspended sediments that are calibrated using water samples collected on a monthly basis. This dataset will provide insight in the short term temporal variability of water quality in the GBR waters. The value for remote sensing validation of these Chlorophyll-a a data streams should be investigated.

APPENDIX 2 RECOMPUTED EXCEEDANCE TABLES FOR THE REPORTING PERIOD 2008/09

For this report the metrics for the assessment of exceedance to the Guidelines have been modified compared to the MMP report 2008/09. The Surface Area in all tables now reports the actual number of pixels with valid observations for each reporting region instead of the surface area of the whole water body as resulting from GBRMPA’s GIS layers. As a result of this change the reported Surface Areas are lower than last year (of ~ 10-20% depending of the region) affecting in turn the reported relative areas for each water body where the mean or the median exceeded the trigger value. Also as a result of the stricter quality control of the imagery, the number of available observations for each pixel is lower than for the MMP report 2008/09. This affected the estimates of the annual and seasonal mean and median values for the reported variables.

To enable a comparison with the results of the current reporting period, all assessment of exceedance tables (Tables 4-33) in the MMP report 2008/09 were recomputed and presented here. The table numbers in this appendix are the same of the corresponding table in the report for 2008/09

For all tables "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for the region: (OC: Open Coastal, MS: Midshelf, OS: Offshore), “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value. "Mean" and “Median” report the mean and median concentrations computed on all the valid observations, “EP” provides the Exceedance Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period.

Cape York region

Table 4. Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Cape York region

	01-May-2008_30-Apr-2009			Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	4295	172254	1241255	61%	62%	71%	26%
MS	10544	533431	3047216	5%	6%	61%	7%
OS	62344	2244612	18013124	0%	0%	17%	5%

Table 5. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Cape York region

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4295	127453	661430	86%	89%	44801	579825	27%	28%
MS	10544	388483	1623776	42%	50%	144948	1423440	0%	0%
OS	62344	1437281	9600976	15%	15%	807331	8416440	0%	0%

Table 6. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Cape York region.

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4295	127453	661430	87%	54%	44801	579825	23%	9%
MS	10544	388483	1623776	82%	24%	144948	1423440	24%	6%
OS	62344	1437281	9600976	17%	6%	807331	8416440	19%	5%

Table 7. Summary of Chlorophyll-a exceedance for the dry and wet season for the Cape York region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	127453	661430	0.62	0.48	60%	44801	579825	0.57	0.50	64%
MS	388483	1623776	0.32	0.32	19%	144948	1423440	0.34	0.33	24%
OS	1437281	9600976	0.22	0.19	6%	807331	8416440	0.23	0.20	8%

Table 8. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Cape York region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	127453	661430	3.65	1.89	46%	44801	579825	2.17	1.16	25%
MS	388483	1623776	2.95	1.17	36%	144948	1423440	2.10	0.70	30%
OS	1437281	9600976	0.52	0.15	18%	807331	8416440	0.66	0.14	21%

Wet Tropics region

Table 9. Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Wet Tropics region

	01-May-2008_30-Apr-2009			Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	2044	125719	676564	84%	85%	40%	12%
MS	5859	420243	1939329	15%	15%	9%	1%
OS	19906	1070308	6588886	0%	0%	13%	0%

Table 10. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Wet Tropics region.

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2044	88814	357700	98%	99%	36905	318864	40%	32%
MS	5859	290484	1025325	94%	97%	129759	914004	5%	4%
OS	19906	696424	3483550	27%	26%	373884	3105336	0%	0%

Table 11. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Wet Tropics region.

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2044	88814	357700	64%	30%	36905	318864	12%	3%
MS	5859	290484	1025325	24%	3%	129759	914004	2%	0%
OS	19906	696424	3483550	15%	0%	373884	3105336	16%	0%

Table 12. Summary of Chlorophyll-a exceedance for the dry and wet season for the Wet Tropics region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	88814	357700	0.77	0.55	76%	36905	318864	0.77	0.56	71%
MS	290484	1025325	0.39	0.38	26%	129759	914004	0.45	0.42	41%
OS	696424	3483550	0.24	0.21	7%	373884	3105336	0.26	0.23	14%

Table 13. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Wet Tropics region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	88814	357700	2.39	1.27	27%	36905	318864	1.61	0.77	16%
MS	290484	1025325	1.34	0.46	19%	129759	914004	1.25	0.42	20%
OS	696424	3483550	0.37	0.09	15%	373884	3105336	0.58	0.13	19%

Burdekin region

Table 14. Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Burdekin region.

	01-May-2008_30-Apr-2009			Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	3971	367188	1346169	67%	63%	54%	18%
MS	11065	1024239	3751035	3%	3%	2%	0%
OS	26560	1561426	9003840	0%	0%	4%	0%

Table 15. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Burdekin region

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	3971	254874	718751	92%	98%	112314	627418	44%	27%
MS	11065	705299	2002765	67%	85%	318940	1748270	1%	0%
OS	26560	1026704	4807360	24%	25%	534722	4196480	0%	0%

Table 16. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Burdekin region

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	3971	254874	718751	75%	36%	112314	627418	33%	10%
MS	11065	705299	2002765	10%	0%	318940	1748270	0%	0%
OS	26560	1026704	4807360	5%	0%	534722	4196480	12%	0%

Table 17. Summary of Chlorophyll-a exceedance for the dry and wet season for the Burdekin region

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	254874	718751	0.69	0.50	62%	112314	627418	0.72	0.51	62%
MS	705299	2002765	0.33	0.34	11%	318940	1748270	0.37	0.33	17%
OS	1026704	4807360	0.23	0.21	5%	534722	4196480	0.25	0.22	8%

Table 18. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Burdekin region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	254874	718751	2.58	1.28	32%	112314	627418	2.48	1.16	31%
MS	705299	2002765	0.86	0.21	13%	318940	1748270	1.12	0.28	21%
OS	1026704	4807360	0.28	0.07	12%	534722	4196480	0.48	0.12	19%

Mackay Whitsunday region

Table 19. Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Mackay-Whitsunday region.

	01-May-2008_30-Apr-2009			Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	4576	417815	1542112	33%	28%	84%	30%
MS	11389	990864	3838093	2%	0%	42%	11%
OS	25580	1829690	8620460	0%	0%	63%	1%

Table 20. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Mackay Whitsunday region

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4576	285941	814528	94%	98%	131874	727584	15%	8%
MS	11389	678876	2027242	54%	75%	311988	1810851	0%	0%
OS	25580	1244710	4553240	66%	57%	584980	4067220	0%	0%

Table 21. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Mackay Whitsunday region.

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4576	285941	814528	89%	52%	131874	727584	79%	28%
MS	11389	678876	2027242	66%	15%	311988	1810851	39%	9%
OS	25580	1244710	4553240	62%	2%	584980	4067220	68%	12%

Table 22. Summary of Chlorophyll-a exceedance for the dry and wet season for the Mackay Whitsunday region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	285941	814528	0.47	0.42	36%	131874	727584	0.47	0.41	41%
MS	678876	2027242	0.33	0.34	10%	311988	1810851	0.30	0.27	13%
OS	1244710	4553240	0.29	0.27	19%	584980	4067220	0.28	0.24	18%

Table 23. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Mackay Whitsunday region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	285941	814528	3.23	1.68	39%	131874	727584	5.08	2.06	51%
MS	678876	2027242	2.23	0.74	32%	311988	1810851	3.03	1.17	35%
OS	1244710	4553240	0.75	0.21	25%	584980	4067220	1.17	0.35	38%

Fitzroy region

Table 24. Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Fitzroy region.

	01-May-2008_30-Apr-2009			Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	5919	493271	2195949	55%	54%	53%	37%
MS	18421	1782838	6834191	3%	3%	11%	3%
OS	48664	3731178	18057784	0%	0%	40%	0%

Table 25. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Fitzroy region .

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5919	334324	1166043	99%	99%	158947	1029906	36%	23%
MS	18421	1199214	3628937	98%	99%	583624	3205254	1%	0%
OS	48664	2578604	9586808	63%	57%	1152574	8467536	0%	0%

Table 26. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Fitzroy region

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5919	334324	1166043	59%	44%	158947	1029906	49%	31%
MS	18421	1199214	3628937	14%	5%	583624	3205254	13%	3%
OS	48664	2578604	9586808	49%	0%	1152574	8467536	41%	2%

Table 27. Summary of Chlorophyll-a exceedance for the dry and wet season for the Fitzroy region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	334324	1166043	0.78	0.45	50%	158947	1029906	0.65	0.48	55%
MS	1199214	3628937	0.36	0.36	14%	583624	3205254	0.33	0.33	20%
OS	2578604	9586808	0.30	0.28	20%	1152574	8467536	0.28	0.25	16%

Table 28. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Fitzroy region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	334324	1166043	3.18	1.30	37%	158947	1029906	4.24	1.78	45%
MS	1199214	3628937	1.10	0.23	18%	583624	3205254	1.80	0.45	30%
OS	2578604	9586808	0.57	0.17	18%	1152574	8467536	0.86	0.24	27%

Burnett Mary region

Table 29. Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Mary-Burnett region.

	01-May-2008_30-Apr-2009			Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
OC	753	76689	265809	51%	52%	10%	0%
MS	3401	372562	1200553	4%	5%	0%	0%
OS	33928	2957418	11976584	0%	0%	1%	0%

Table 30. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Burnett Mary region.

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	753	51746	141564	97%	97%	24943	124245	22%	19%
MS	3401	252365	639388	99%	99%	120197	561165	0%	0%
OS	33928	2104386	6378464	16%	15%	853032	5598120	0%	0%

Table 31. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Total Suspended Solids) for the dry and wet season for the Burnett Mary region.

		01-May-2008_31-Oct-2008				01-Nov-2008_30-Apr-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	753	51746	141564	12%	1%	24943	124245	12%	0%
MS	3401	252365	639388	0%	0%	120197	561165	0%	0%
OS	33928	2104386	6378464	1%	0%	853032	5598120	12%	0%

Table 32. Summary of Chlorophyll-a exceedance for the dry and wet season for the Burnett Mary region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	51746	141564	0.52	0.47	56%	24943	124245	0.54	0.48	58%
MS	252365	639388	0.38	0.37	19%	120197	561165	0.37	0.36	26%
OS	2104386	6378464	0.25	0.23	4%	853032	5598120	0.25	0.23	7%

Table 33. Summary of Non-algal particulate matter (Nap as a measure of Total Suspended Solids) exceedance for the dry and wet season for the Burnett Mary region.

	01-May-2008_31-Oct-2008					01-Nov-2008_30-Apr-2009				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
OC	51746	141564	0.83	0.29	9%	24943	124245	1.35	0.48	19%
MS	252365	639388	0.49	0.14	8%	120197	561165	0.94	0.30	20%
OS	2104386	6378464	0.26	0.09	11%	853032	5598120	0.61	0.15	24%

ATTACHMENTS

List of publications and presentations associated with the MMP

Journal Papers

Blondeau-Patissier, D., V.E. Brando, K. Oubelkheir, A.G. Dekker, L.A. Clementson, and P. Daniel, Bio-optical variability of the absorption and scattering properties of the Queensland inshore and reef waters, Australia. J. Geophys. Res., 2009. 114.

Brodie, J., T. Schroeder, K. Rohde, J. Faithful, B. Masters, A. Dekker, V. Brando and M. Maughan (2010). "Dispersal of suspended sediments and nutrients in the Great Barrier Reef lagoon during river-discharge events: conclusions from satellite remote sensing and concurrent flood-plume sampling." Marine and Freshwater Research 61(6): 651-664.

Book Chapters

Devlin, M., T. Schroeder, L. McKinna, J. Brodie, V. Brando and A. Dekker (in press). Monitoring and mapping of flood plumes in the Great Barrier Reef based on in-situ and remote sensing observations. Advances in Environmental Remote Sensing to Monitor Global Changes. N.-B. Chang.

Conference Papers

Blondeau-Patissier, D., V,E. Brando, A.G. Dekker, S.R. Phinn, S.J. Weeks, T. Schroeder, Y.J. Park, 2010, Phytoplankton response to episodic events and long-term trends in the Great Barrier Reef lagoonal waters: towards a regional characterisation. Proceedings of Ocean Optics Conference XX 2010

Conference presentations

Brando, V.E., A.G. Dekker, T. Schroeder, D. Blondeau-Patissier, Y.J. Park, L.A. Clementson, N.R.C. Cherukuru, P. Daniel, “Optical complexity of the coastal waters of the Great Barrier Reef: Strategies to incorporate regional and seasonal knowledge of optical properties”, Invited Talk at the session on “Development, Validation, and Uncertainty Analysis of Optical Remote Sensing Algorithms for the Coastal Ocean” of the AGU/ASLO 2010 Ocean Sciences Meeting in Portland, USA (21-26 February 2010).

Devlin, M., L McKinna, T. Schroeder, B. Schaffelke, V.E Brando, J. Brodie, Riverine plumes in the Great Barrier Reef: Mapping plume extent and composition using remote sensing imagery. 2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF), 18- 20 May 2010 Cairns.

Brando, V.E., T. Schroeder, A.G. Dekker, B. Schaffelke, M. Devlin. Delivering accurate water quality information for the Great Barrier Reef lagoon using regionally valid satellite remote sensing data. 2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF), 18- 20 May 2010 Cairns.

Schaffelke, B., M. Devlin, V.E Brando, T. Schroeder, From measurements to metrics: a case for the development of an improved reporting system for marine water quality. 2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF), 18- 20 May 2010 Cairns.

Mueller, J.F., K.Kennedy, C. Paxman, A. Dunn, T. Schroeder, V. Brando, A. Dekker, Comparing time integrated herbicide concentrations with remote sensing data. 2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF), 18- 20 May 2010 Cairns.

Workshops and seminars

Dekker, A.G., et al, Earth Observation for shallow marine parks habitats and coastal water quality. (past), Present and Future. Oct 2009, Goungzhou, China.

Dekker, A.G., et al, Earth Observation for shallow marine parks habitats and coastal water quality. (past), Present and Future. Oct 2009, Xiamen, China.

Dekker, A.G., et al, A Coastal Observatory for Australia, National Estuaries Network Meeting November 2009

Dekker, A.G., et al, CoastColour Australian perspective as "user", European Space Agency, Feb 2nd 2010, Italy

Dekker, A.G., et al, NOAA-CSIRO Ocean Colour & Coral Reefs- NOAA-UQ Coral Reef Workshop. Brisbane, 13 th Feb 2010

Dekker, A.G., et al, Earth Observation for Marine Aquatic Ecosystems in Australia Overview Current and Near Future Capabilities, Presented at the India-Australia Workshop on Ocean Colour Remote Sensing, ISRO Space Applications Centre, March 18-19 2010, Ahmedabad, India

Schroeder, T., Brando, V.E., Cherukuru, N., Park, Y.J., Clementson, L., Blondeau-Patissier, D., Dekker, A.G., and Steven, A., (2010), "CSIRO's new remote sensing algorithms for water quality assessment in optically complex waters", Presented at the India-Australia Workshop on Ocean Colour Remote Sensing, ISRO Space Applications Centre, March 18-19 2010, Ahmedabad, India.

Schroeder, T., Brando, V.E., Clementson, L., Park, Y.J., Blondeau-Patissier, D., and Dekker A.G., (2010), "Remote sensing and mapping of water quality in optically complex waters", Presented at the SeaHARRE-5 workshop, 13-16 April 2010, Hobart, Australia.

Dekker, A.G., et al, Inland, Estuarine, Coastal and Coral Reef Remote Sensing in Australia: from Science to Management. Singapore Centre for Remote Sensing. Singapore 16th march, 2010.

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