Reef Rescue Marine Monitoring Program: using Remote Sensing for GBR wide water quality. Final Report for 2008/09 Activities

Vittorio E. Brando, Thomas Schroeder, Arnold G. Dekker

CSIRO Land & Water
30 March 2010

CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

Given the size and variability of conditions within the Great Barrier Reef (GBR) catchments, monitoring the water quality in the GBR lagoon waters is challenging. 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 chlorophyll-a concentrations as well as total suspended sediment (TSS), water clarity and the 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 to decades. Yet, management-relevant products from remote sensing data that provide information beyond that of a simple concentrations map are needed by relevant management agencies so that they may make more informed management decisions.

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 regionally appropriate algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon (Brando et al 2009, Brando et al 2010). This 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 (Brando et al 2009, Brando et al 2010).

The application of NASA's atmospheric correction algorithm as implemented in SeaDAS v5.1.1 systematically retrieves negative water-leaving radiances for the Great Barrier Reef coastal waters . A first step for accurate chlorophyll 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 (Schroeder et al., 2008).

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 (Schroeder et al., 2008).

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 (Qin et al., 2007). To improve the accuracy of chlorophyll and IOP estimates from MODIS AQUA data in GBR Lagoon coastal waters an enhancement of the Linear Matrix Inversion (LMI, Hoge and Lyon, 1996) was used to incorporate regional and seasonal knowledge of variability in the specific inherent optical properties of concentration specific light absorption and scattering encountered in GBR coastal waters (Brando et al 2008). The algorithm estimates simultaneously the concentration of Chlorophyll, Total suspended sediment, CDOM and the vertical attenuation coefficient, Kd.

The comparison of MODIS Aqua retrievals of chlorophyll, CDOM and Suspended solids 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, CDOM and suspended solids 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).

The results for the six reporting regions are presented as wet and dry season median maps of chlorophyll, coloured dissolved organic matter (CDOM), total suspended matter (as non algal

particulate matter), and the vertical attenuation coefficient of light. Also presented are maps for these dry and wet periods 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 was presented as a demonstration product. This 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, 2008).

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 and aerosol concentration in the monsoonal season. It is possible that the cloud cover introduces a bias in the sampling. This in turn will affect the estimate of the median and mean concentration or any other statistical analysis of the imagery. 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.

Further than the median maps, this year the exceedance of water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA 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.

The GBRMPA guidelines provide triggers for management action where exceedance occurs and current condition and trend monitoring threshold levels for analysis. The exceedance assessment results was 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 Exceedence Probability (EP) that provide the Number of day 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.

The freshwater extent during the wet season was estimated from MODIS measurements by applying a threshold to maps of aggregated seasonal maximum CDOM concentrations. 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. These data sets were made available to Michelle Devlin (ACTFR) to carry out further research activities to within another MTSRF project

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 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.

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 the flood waters of the Fitzroy River in Keppel Bay (February 2008) and the wet season sampling of the wet tropics (April 2008).

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, 2008). The Secchi depth (m) database would allow a direct validation the Secchi Depth estimates done from remote sensing data.

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.

In the 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 chlorophyll *a* data from GBROOS/IMOS underway sampling and moorings should be investigated as a priority over the next 24 months.

CSIRO's Environmental Earth Observation Group is currently exploring avenues for assimilation of satellite observational data with biogeochemical and sediment transport models in Keppel Bay, within a collaborative project funded by CSIRO's "Water for an Healthy Country" Flagship. An improved model for light attenuation based on the specific optical characteristics of dissolved and particulate substances in Keppel Bay was developed based on the local optical measurements and remotely sensed light attenuation estimate. Currently the group is evaluating the use of satellite observations to supplement in situ data to improve calibration and parameterisation of the model for the estimate of fluxes to the GBR. Assimilation of satellite observations with biogeochemical and sediment transport models is likely to become increasingly important in the near future, as it combines the merits of both tools.

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.

INTRODUCTION

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

The Reef Water Quality Protection Plan 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 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. Remote sensing derived information is a cost-effective method to determine spatial and temporal information on near-surface concentrations of suspended solids (as non-algal particulate matter), turbidity (as vertical attenuation of light coefficients Kd), chlorophyll a (CHL) and colored dissolved organic matter (CDOM) for the GBR.

Underlying activity for both projects is the acquisition, processing with regionally valid algorithms, validation and transmission of geo-corrected ocean colour imagery and data sets derived from MODIS imagery. Key Objectives of the two projects are:

Project 3.7.2 b:

- Assess the temporal and spatial variation in the extent of available 2008/09 river flood plumes across the 6 GBR NRM regions was used to quantify near-surface concentrations of suspended solids, turbidity, CDOM and chlorophyll a.

Project 3.7.8:

- Development of new analytical tools for understanding the trends and anomalies of these waters (specifically wet season to dry season variability) based on the characteristics of optical satellite remote sensing data.
- Remote sensing data was processed to provide monthly medians and summary images (by NRM region) for suspended solids, turbidity, chlorophyll a (chl) and colored dissolved organic matter (CDOM) within the inshore and offshore areas, during the wet and dry seasons.
- analysis of how remote sensing can contribute to improvements of the 'in situ' water quality monitoring

METHODS

Given the size and variability of conditions within the Great Barrier Reef (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 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 total suspended sediment (TSS), water clarity and the 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 to decades. Yet, management-relevant products from remote sensing data that provide information beyond that of a simple concentrations map are needed by relevant management agencies so that they may make more informed management decisions.

Regionally valid retrieval of water quality parameters from satellite imagery

Based on studies conducted in the Fitzroy Estuary (Brando et al., 2006b; 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 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.

In this work we coupled two physics-based inversion algorithms with the objective to improve the accuracy of chlorophyll 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 2008).

Atmospheric correction

The application of NASA's atmospheric correction algorithm as implemented in SeaDAS v5.1.1 systematically retrieves negative water-leaving radiances for the Great Barrier Reef coastal waters (Figure 1). A first step for accurate chlorophyll 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.

Pixels with negative values in the 412 – 678 nm	Pixels with negative values in the 412 – 748 nm

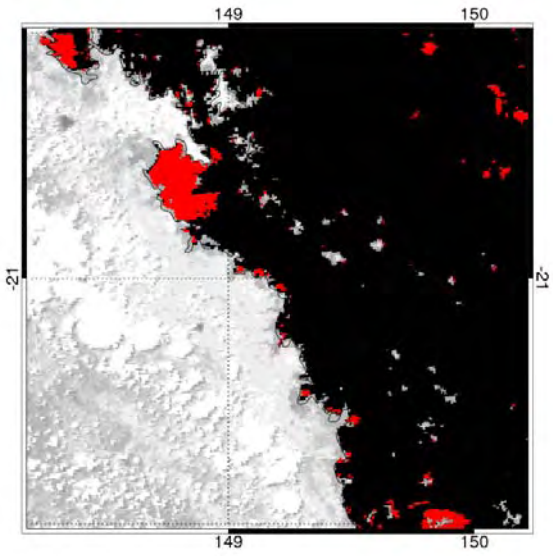
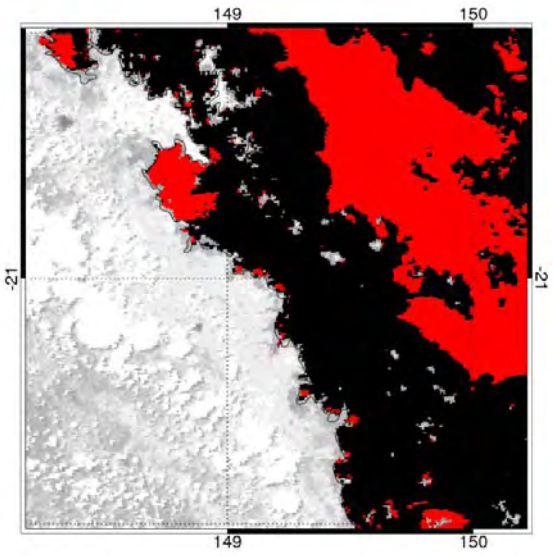
spectral range	spectral range
	

Figure 1 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)

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. (2007a) for MERIS, but with a different inverse model capable of generating more complex network architectures. 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 (Fischer and Grassl 1984; Fell and Fischer 2001), 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. 2007a, 2007b.

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.

.t 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, 2002) 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 2 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 2). The error bars in Figure 2 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 3), 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.

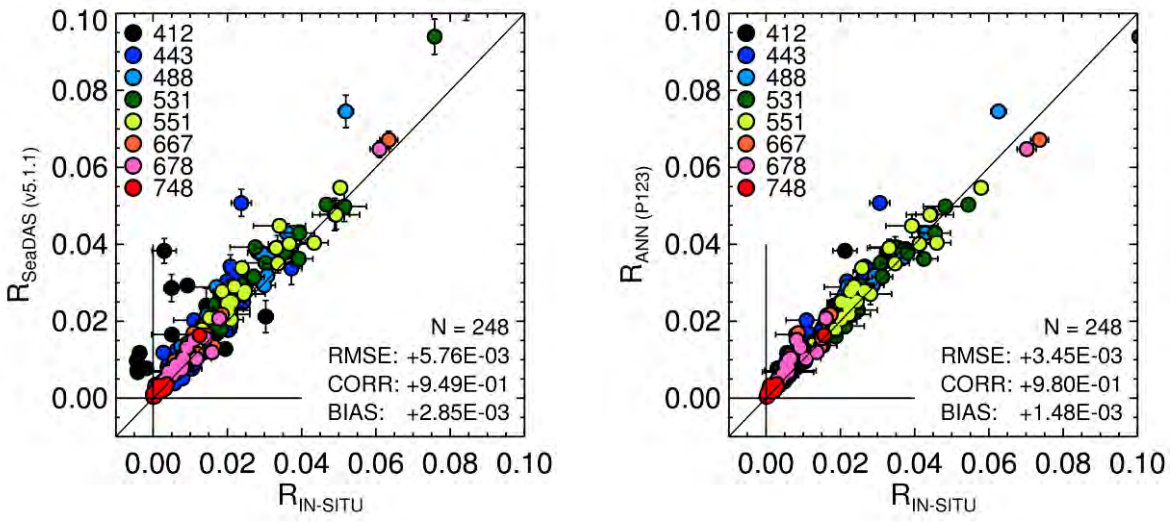


Figure 2: Scatter plots of the median reflectances of the MODIS Level2 product (left) and the proposed ANN atmospheric correction (right) compared to 31 in-situ reflectance measurements collected by GKSS, MUMM and CSIRO.

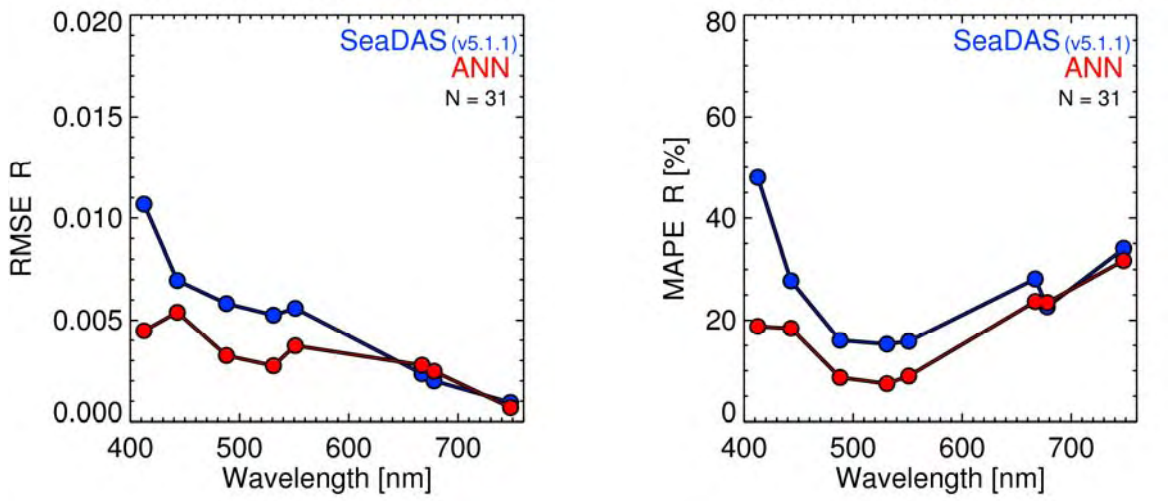


Figure 3: By comparison with in-situ reflectance measurements derived spectral slopes of RMSE (left) and MAPE (right) for the MODIS standard Level2 product generated with SeaDAS v5.1.1 (blue) and the proposed ANN algorithm (red).

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 4). 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 5) 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 Suspended solids and CDOM concentrations can be associated with the near coastal waters of Repulse Bay causing negative reflectance values at 412 nm.

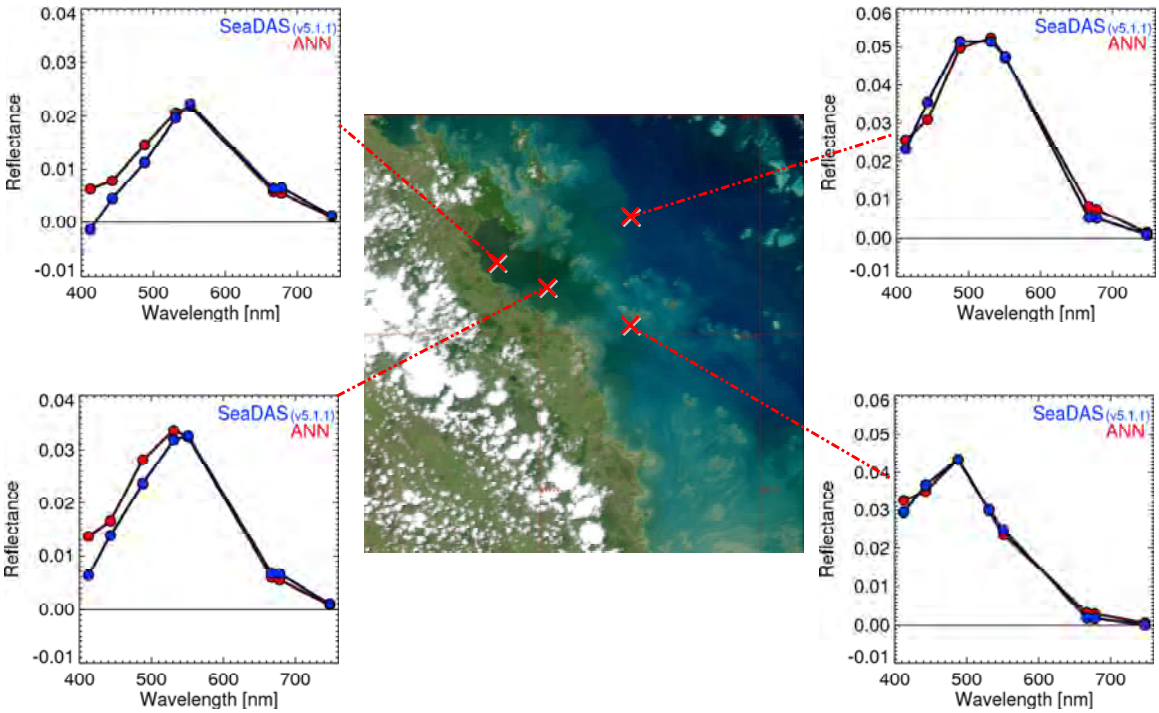


Figure 4: Comparison of SeaDAS v5.1.1 and ANN derived reflectance spectra for a MODIS Aqua scene acquired on 22 February 2008.

ANN atmospheric correction
Reflectance at 412 nm

NASA standard atmospheric correction
Reflectance at 412 nm

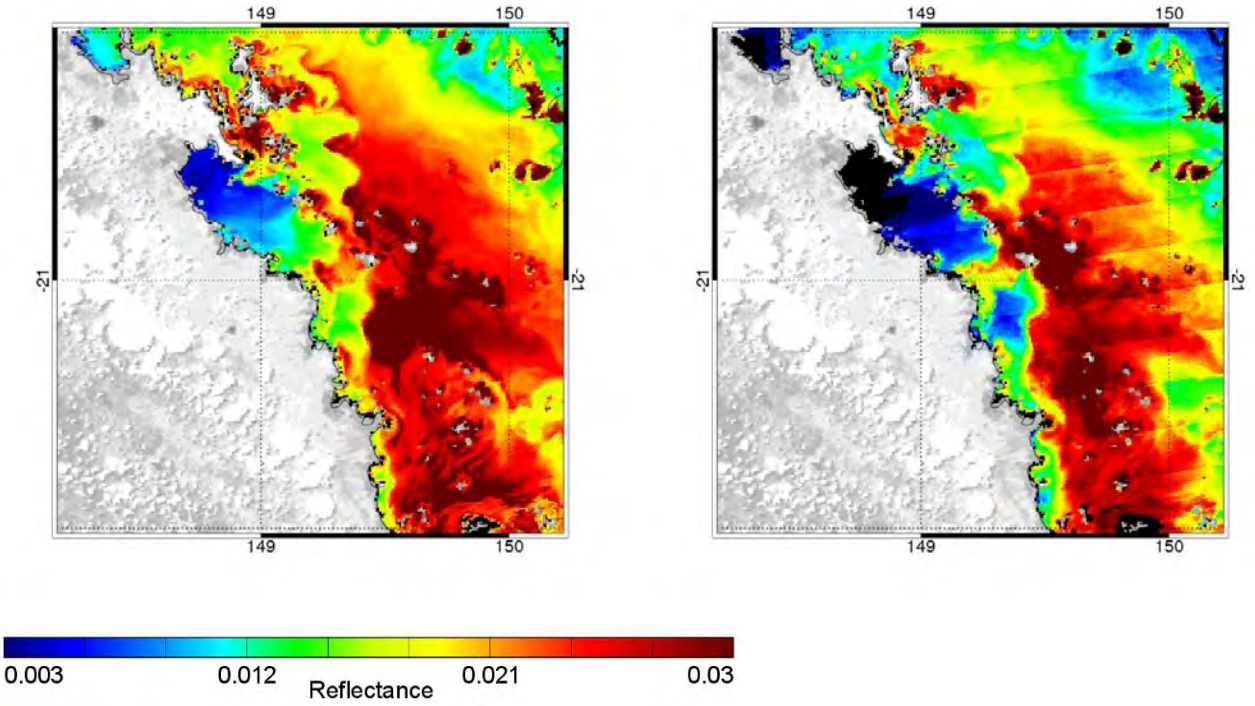


Figure 5 Spatial distribution of the reflectance at 412 551 nm as derived by the ANN algorithm and NASA standard algorithm from a MODIS Aqua scene acquired on 22 February 2008 (black areas=masked pixels).

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 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., 2008) 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 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, 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., 2006b; Brando et al., 2007) and applied to the MODIS-AQUA data for the whole GBRWHA (Brando et al., 2006a; 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}, $a^*_{\mathrm{NAP}}(440)$, S_{NAP}, $b^*_{b\mathrm{phy}}(555)$, γ_{phy}, $b^*_{b\mathrm{NAP}}(555)$, 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 6).

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.

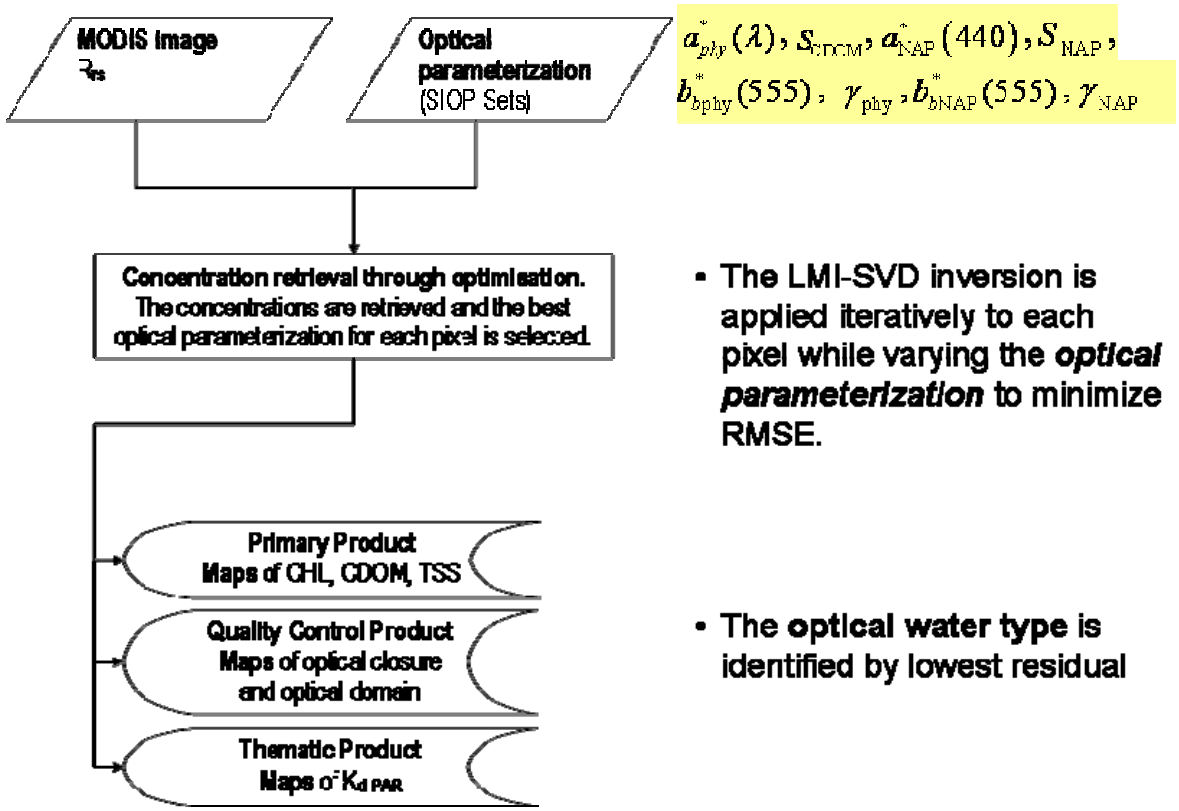


Figure 6. Conceptual diagram of the Linear Matrix Inversion approach adopted for the retrieval of chlorophyll and IOPs from MODIS AQUA data.

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, 2009}, 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 7 and Figure 8, respectively). Table 1 reports the values needed to parameterize LMI algorithm to estimate simultaneously the concentration of chlorophyll, total suspended sediment, CDOM and expressed both as vertical attenuation coefficient (K_d) and as Secchi Depth.

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 1 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

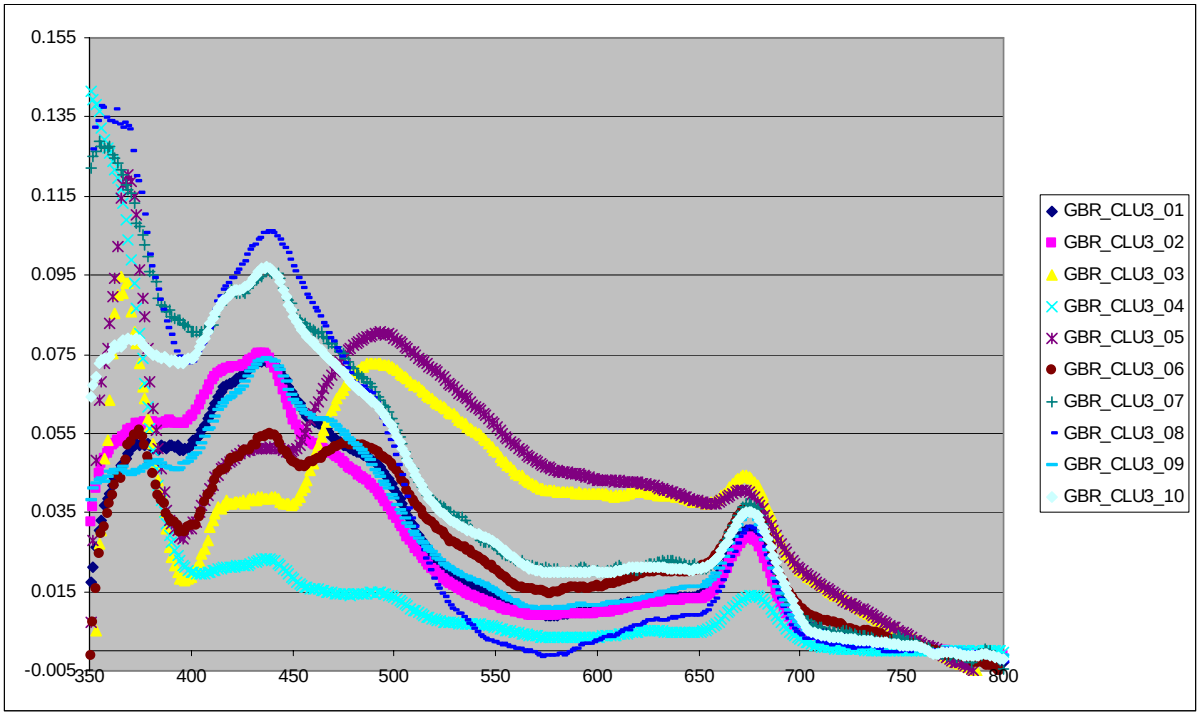


Figure 7 aphy* spectra for LMI inversion in the parameterization for 2006 MMP report

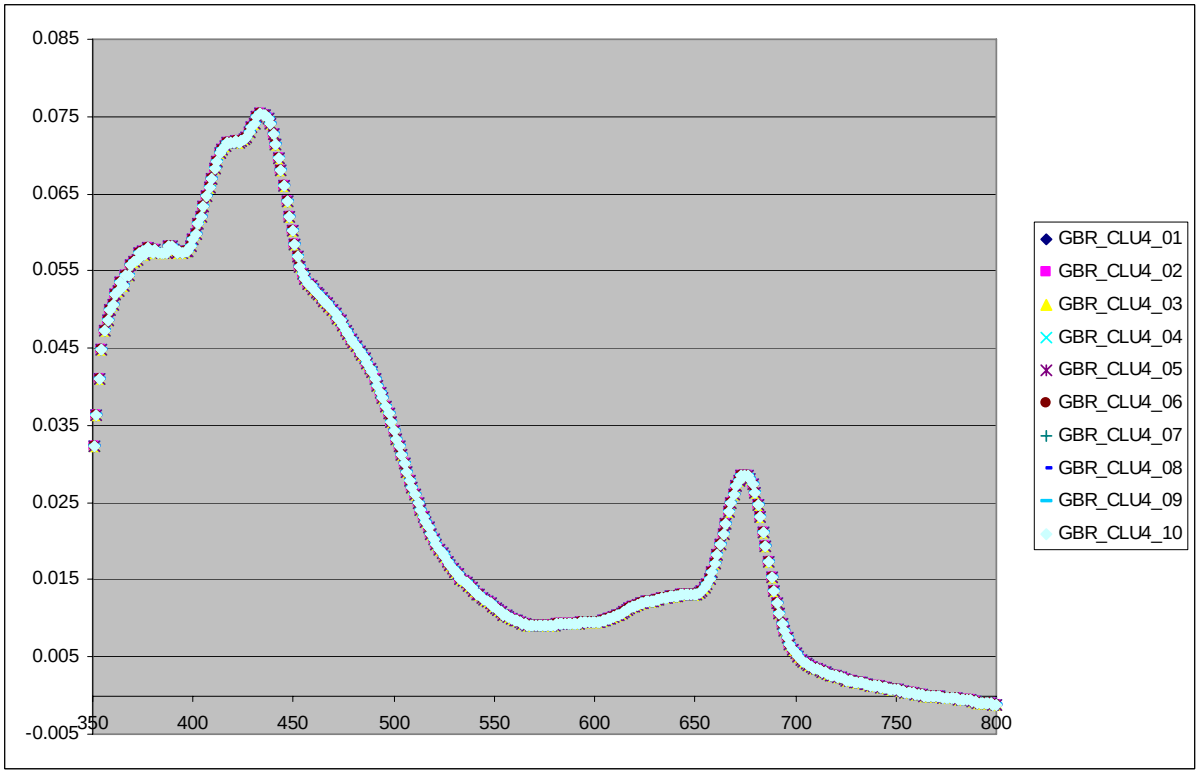


Figure 8 aphy* spectra for LMI inversion in the 2008 MMP version of the parameterization (LMI_CLU4).

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 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 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 data (Brodie et al 2007).

In this study, Chlorophyll data from the Cairns transect of 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 also 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, collection within 3 hour from overpass, etc.).

The chlorophyll, TSS 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 the measurements collected with 3 hours of the overpass were used in this analysis. Quality flags were checked for land, glint, cloud, atmospheric correction failure and for solar zenith and observer zenith maximum 60 degree. A Reduced Major Axis regression (Model II, Sokal) was applied to the data as both the MODIS Aqua retrievals and the in situ data are affected by measurement errors (Table 2).

The *in situ* chlorophyll data were used to evaluate the chlorophyll 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 9 presents the results of the MODIS Aqua chlorophyll retrieval comparison with *in situ* data in logarithmic scale. LMI and gsm01 have a similare 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 Suspended solids retrieval vs. in situ data. Only the measurements collected with 3 hours of the overpass were plotted. Altough wit ha 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 12 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. 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 and detrital matter (Table 2).

The comparison of MODIS Aqua retrievals of chlorophyll, CDOM and Suspended solids 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, CDOM and suspended solids 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, 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. CSIRO is currently setting up 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.

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, 2008). The Secchi depth database would allow a direct validation the Secchi Depth estimates done from remote sensing data.

Table 2 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	LMI	108	0.79446	58.49%	0.1496
Chlorophyll	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

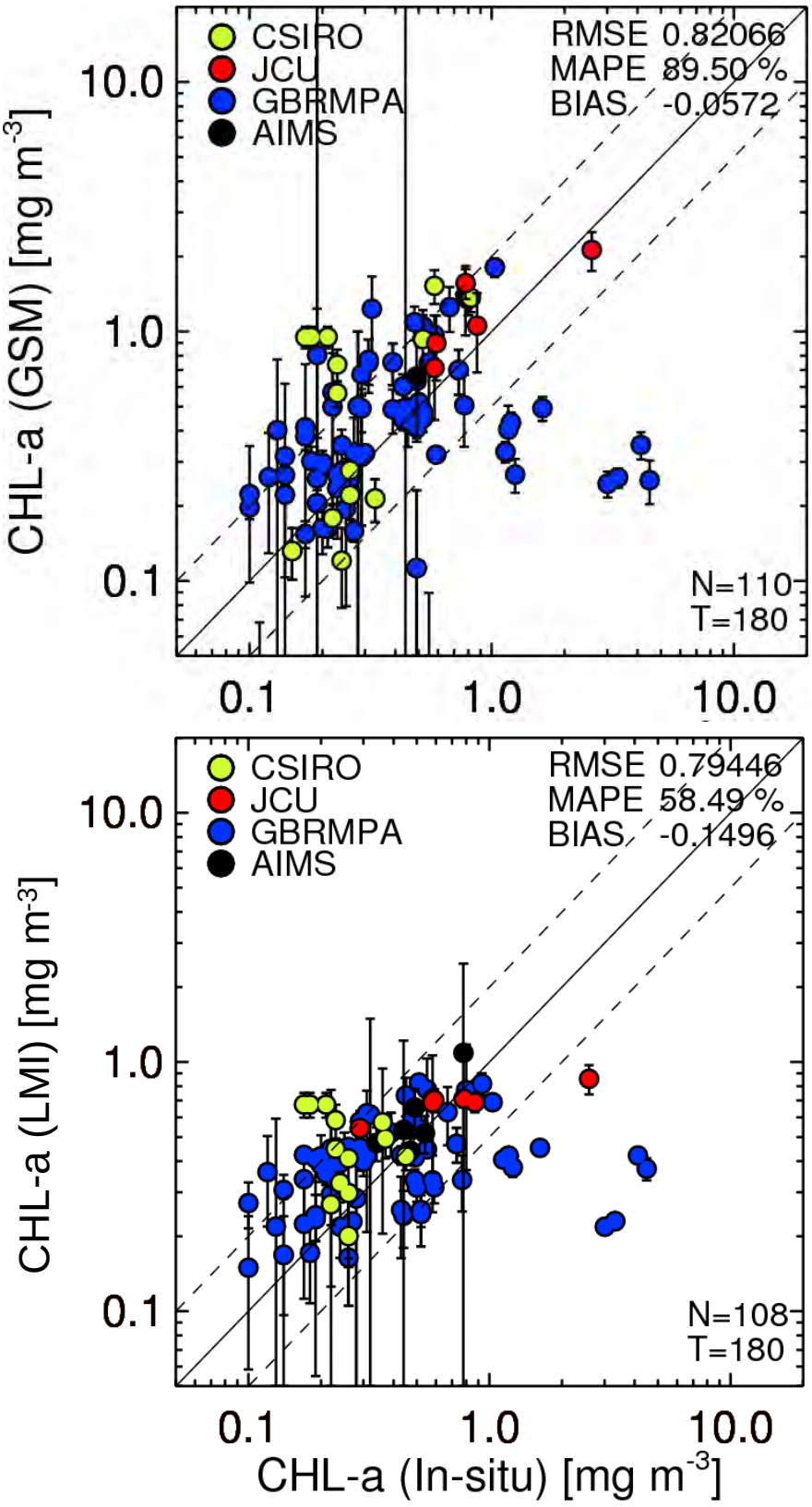


Figure 9: MODIS Aqua chlorophyll retrieval vs. in situ data. Only the measurements collected with 3 hours of the overpass were plotted. Number of matchups are 108 for LMI and 110 for gsm..

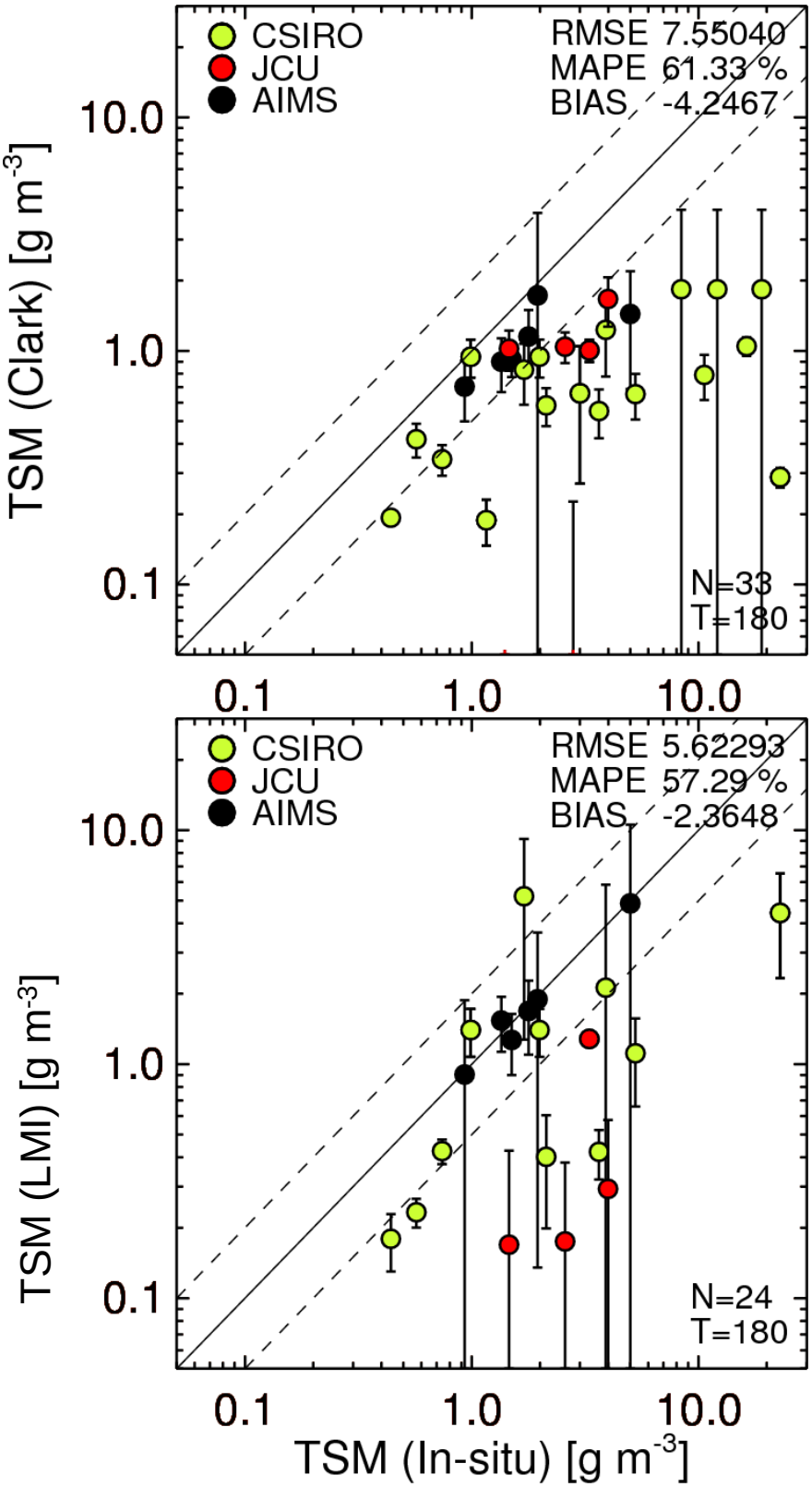


Figure 10: MODIS Aqua Suspended solids retrieval vs. in situ data. Only the measurements collected with 3 hours of the overpass were plotted. Number of matchups are 24 for LMI and 33 for Clark.

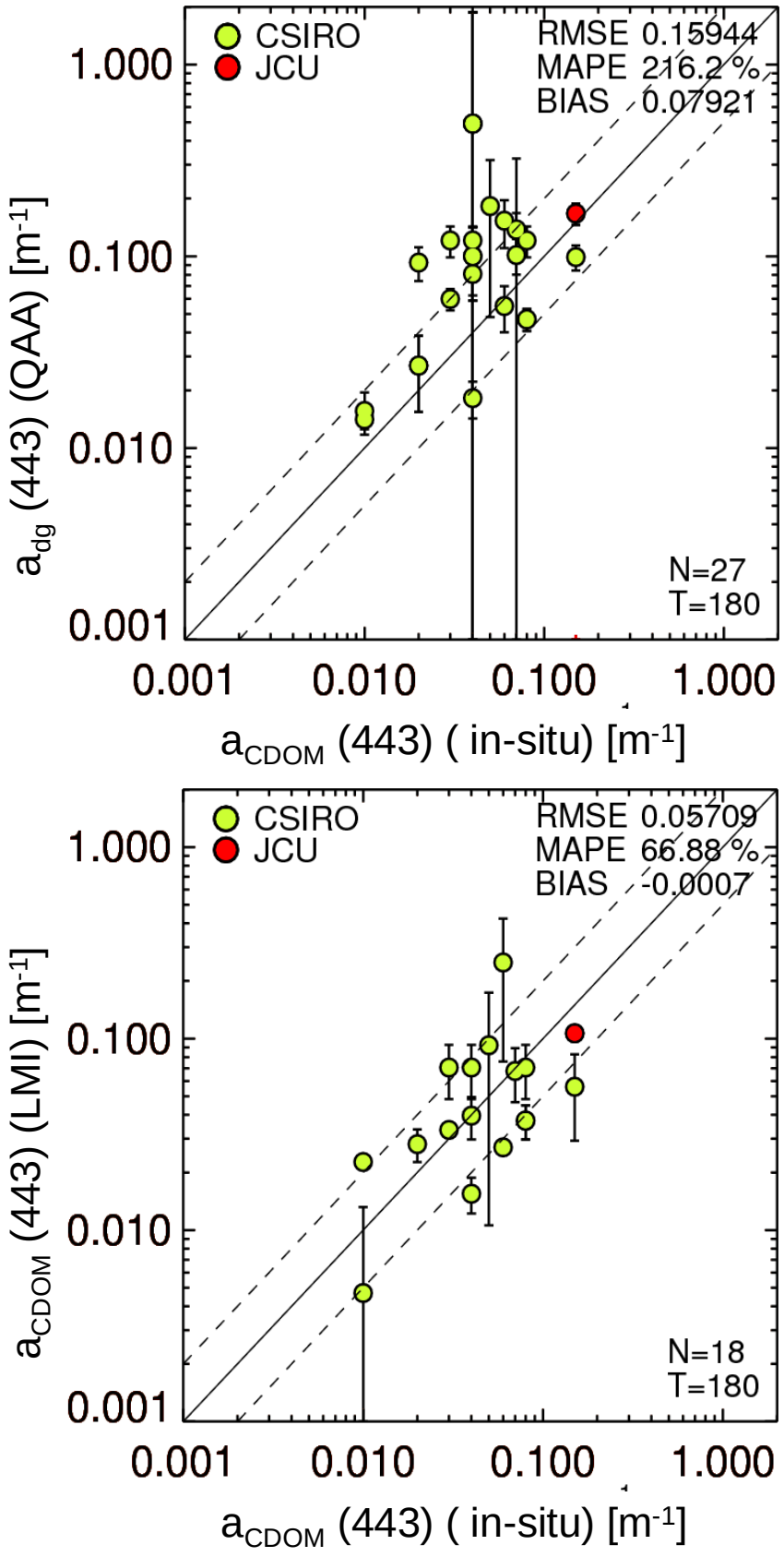


Figure 11: MODIS Aqua aCDOM (443) retrieval vs. in situ data. Only the measurements collected with 3 hours of the overpass were plotted. Number of matchups are 18 for LMI and 27 for a_{dg} (443) (QAA).

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 from the in-situ data from the GBR LTMP and 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 the sampling under the Long-term chlorophyll monitoring component has generally been very unsuccessful (see Tables 2.6 and 2.7 of the AIMS 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 sensor on these water quality loggers provide continuous estimates of chlorophyll 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 data streams should be investigated.

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 primary 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 primary 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 compliance information for environmental reporting.

CSIRO's Environmental Earth Observation Group developed a software suite to produce from daily remote sensed data a number of derived products suited to the specific needs of end-users, in a number of outputs, including maps, animations, statistical compliance assessments and alert or anomaly systems. The software suite enables the production of maps of:

- Min, Max, Median, Logmean, Mean, STD of Chlorophyll, Suspended solids, CDOM and Kd for the GBRWHA.
- Maps of 5^{th}, 25^{th}, 75^{th} and 95^{th} of Chlorophyll, Suspended solids, CDOM and Kd for the GBRWHA.
- Weekly, monthly, seasonal, and yearly and long term statistics
- Assessment of the nature of the exceedance of water quality guidelines for water quality variables

All the maps and comparisons with in situ data presented in this report were produced using the above mentioned software suite. The software suite will be made available in the coming future to the GBRWHA management and research community.

Water quality maps

In this report, the results for the six reporting regions are presented as wet and dry season median maps of chlorophyll, coloured dissolved organic matter (CDOM), total suspended matter (as non algal particulate matter), and the vertical attenuation coefficient of light. Also presented are maps for these dry and wet periods 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 was presented as a demonstration product. This 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, 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 2008/2009 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.

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 and aerosol concentration in the monsoonal season. It is possible that the cloud cover introduces a bias in the sampling. This in turn will affect the estimate of the median and mean concentration or any other statistical analysis of the imagery. 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.

Evaluation of compliance to guidelines

Further than the median maps, this year the exceedance of water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA 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.

A set of water quality guideline values and objectives have been released in 2009 by federal and state legislation for the GBR, with an effort avoid conflict 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 waters and apply to the state coastal waters which extend up to 3 nautical miles. Regionally specific environmental values and objectives have been set in some specific areas through the development of WQIPs, notably for this study the Douglas Shire coastal waters. The Great Barrier Reef Marine Park Authority (GBRMPA) has released specific water quality guidelines for the Marine Park and has identified five water bodies: the 'enclosed coastal' waters, the 'open coastal' waters, the 'inshore' waters, the 'offshore' waters, and the Coral Sea (GBRMPA, 2009). Much of the Great Barrier Reef Marine Park lies beyond Queensland state waters but, in inshore coastal waters, there is an area of overlap, for which protocols have been agreed. Namely, Queensland guidelines are to be adopted for all waters inshore of and within the Enclosed Coastal zone; and offshore from the 'enclosed coastal' zone and within waters of the GBR Marine Park, the GBR guidelines will apply, even if the boundary of the 'enclosed coastal' zone lies inside the three nautical mile zone.

The GBRMPA guidelines provide triggers for management action where exceedance occurs and current condition and trend monitoring threshold levels for analysis (Table 3). The exceedance assessment results was 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 Exceedence Probability (EP)

that provide the Number of day where the concentration exceeded the threshold divided by number of days with (error-free) data for that period. 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 Exceedence Probability for that period.

The metrics used in this study to evaluate compliance were developed with DEWHA funding {Brando, 2010}, and 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 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.

Table 3 Trigger values from the Great Barrier Reef Marine Park Authority Water Quality Guidelines (GBRMPA 2009). *:Seasonal adjustment: Dry/Wet, **:Geographical adjustment: Wet Tropics/Central Coast

	Water body			
Parameter	Enclosed coastal	Open Coastal	Midshelf	Offshore
Chlorophyll (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
Suspended solids (mg L^{-1})	5.0/15**	1.6/2.4*	1.6/2.4*	0.6/0.8*
Particulate nitrogen (µg L^{-1})	Not available	16/24*	16/24*	13.6/20.4*
Particulate phosphorus (µg L^{-1})	Not available	2.2/3.4*	20./3.0*	1.5/2.3*

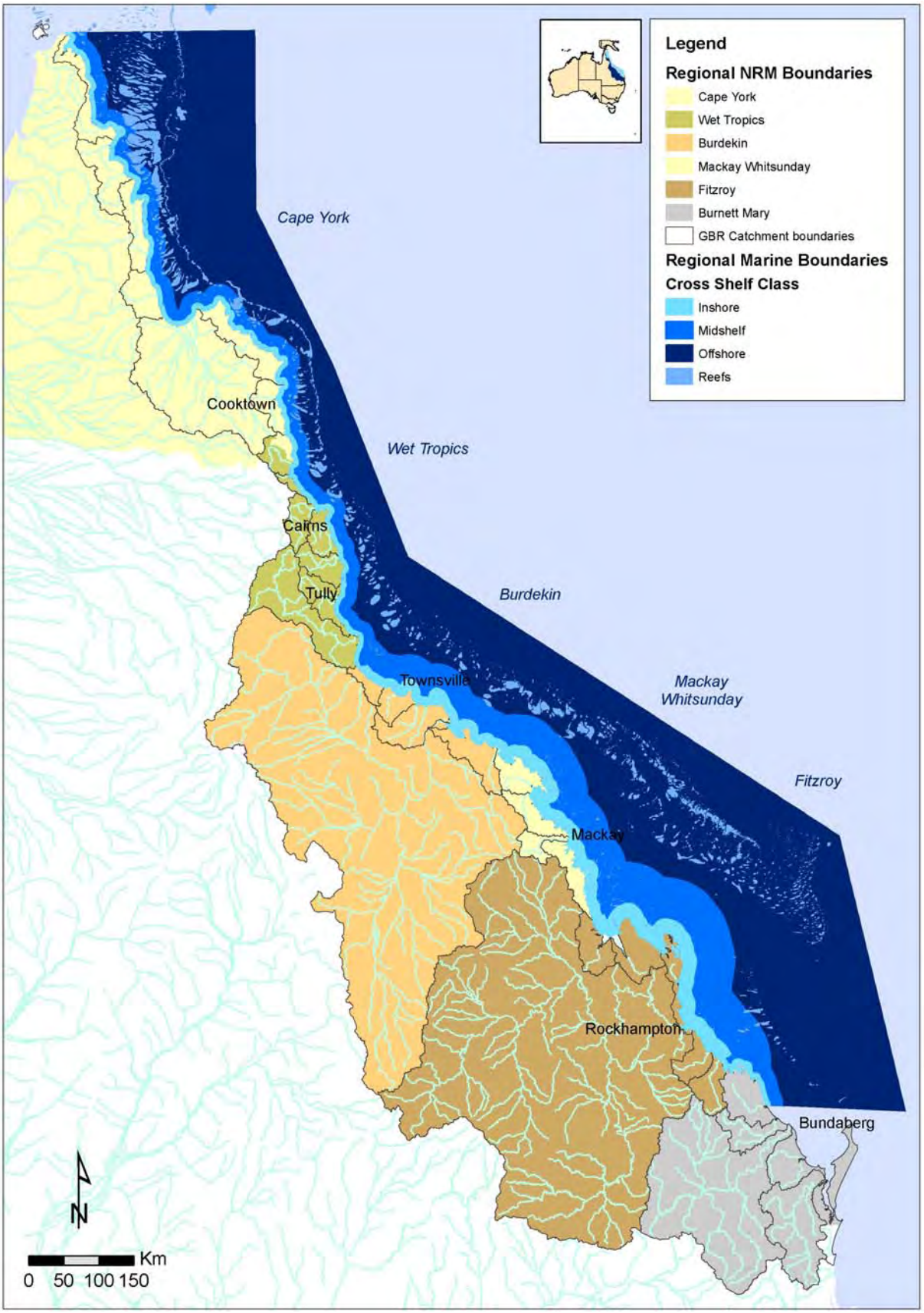


Figure 12: Regional and cross shelf boundaries defined for the MMP 2008/09 reporting.

Flood plume mapping

The extent and duration of flood plumes can have significant implications for the health of inshore 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).

In flood plumes, coloured dissolved organic matter (CDOM) concentrations are high and are largely derived from terrestrial sources, making CDOM a useful tracer of terrestrial discharge of low salinity waters. The flood extent can be estimated by applying a threshold to the maps of CDOM seasonal maximum values. For this study, a CDOM threshold of 0.2 m^{-1} was derived by performing a qualitative analysis of the relationship between in-situ CDOM absorption and salinity, excluding data from around reefs which would include marine-derived CDOM.

The maps of CDOM seasonal maximum values and estimated flood extent were made available to Michelle Devlin (ACTFR) to carry out further research in mapping extent and duration of the primary and secondary plumes within a companion MMP activity.

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 to the maps to enable the identification of water bodies identified by GBRMPA guidelines (Open coastal, Midshelf, and Offshore). The boundaries for the reporting region presented in each map as defined by GBRMPA in accordance with the NRM boundaries for the catchment and marine extensions. The cross shelf boundaries are defined in accordance with the Great Barrier Reef Water Quality Guidelines 2009: The thick white line is defines the ‘open coastal’ waters; the thick pink grey line defines the ‘inshore’ waters while the thick gray line delineate the ‘offshore’ waters; the thick black lines to the East in all images is 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, while the maps of the Exceedence Probability report in a continuous colour scale the Exceedence Probability ranging 0-0.50 so that the pixels are mapped in dark red (EP>= 0.50) when median values for the year (and seasons) exceed the thresholds. The spatial patterns in the exceedance maps are 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 thick gray line delineating the ‘Offshore’ waters.

The final information in the maps are the long term monitoring stations, presented as pink numbers. The images show that many of these stations are situated very near to islands or coral reefs, rendering them less suitable for remote sensing product validation as all international remote sensing product validation protocols stipulate that validation match-ups will only be accepted if they are at least 5 km away from the nearest exposed land mass or submerged but still visible substratum.

RESULTS AND DISCUSSION

This section will provide an overview of the monitoring results for the whole-of-GBR followed by a detailed regional report for each of the six reporting regions.

For each regions are presented the wet and dry season median maps of chlorophyll, coloured dissolved organic matter (CDOM), total suspended matter (as non algal particulate matter), and the vertical attenuation coefficient of light. Also presented are maps for these dry and wet periods that present the number of valid pixels (i.e. cloud-free and error free) used for calculating the median values. Further than the median maps, the exceedance of water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA using CSIRO's algorithm.

Great Barrier Reef Wide Summary

Flood plume movement across Great Barrier Reef marine waters is a consequence of the volume and duration of river (flood) flows, wind direction and velocity, as well as local marine current and tidal dynamics. Figure 13 reports the flood plume extent for wet Season 2008/2009 (November 2008- April 2009) for the whole of the Great Barrier Reef World heritage Area. The flood extent was estimated 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 27, Figure 38, Figure 49, Figure 60, Figure 71, Figure 82).

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 Flood 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. Freshwater discharge from the Great Barrier Reef catchment in 2008/09 was ~2.2 times the annual median flow, with the flow in the Burdekin River more than five times the annual median flow. (Figure 14). 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 15). In contrast, during the same two year period, rivers of the Wet Tropics and Mackay Whitsunday Regions (with the exception of the Herbert River) only experienced slightly above-average flow conditions without significant flooding occurring (Figure 15, Figure 14).

Figure 16 presents the Chlorophyll Median map for the Dry Season 2008 (May - October) for the whole of the Great Barrier Reef World heritage Area. During the dry season the coastal to offshore gradient in chlorophyll concentration was observed, with the inshore waters in the Wet Tropics and Burdekin Regions having elevated concentrations of chlorophyll over the monitoring period. Detailed maps for the wet and dry season for each region are presented in the regional reporting sections. These median maps form the basis for the assessment of the exceedance of water quality guidelines that is described in details regional reporting sections by tables summarising the exceedance results for each variable.

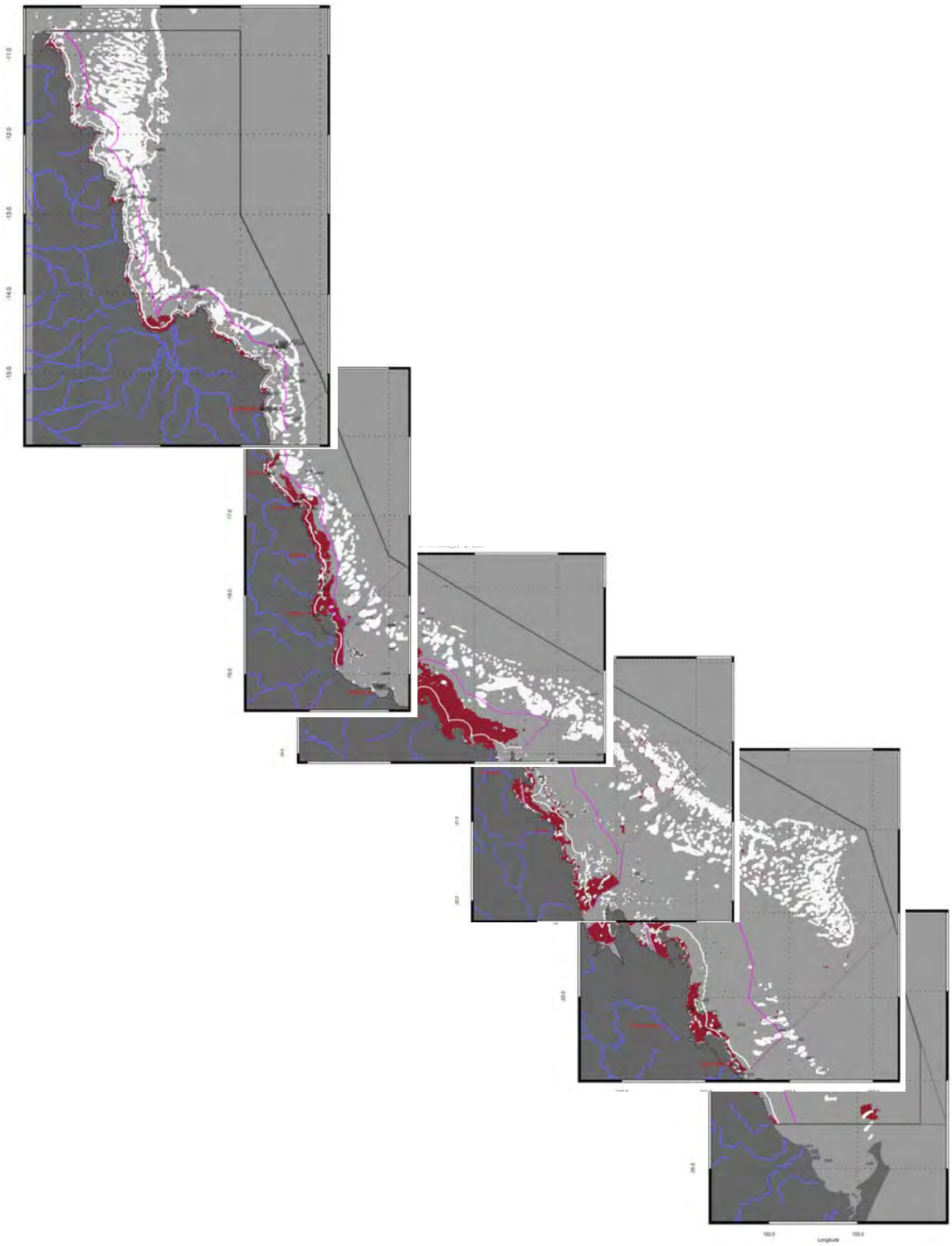


Figure 13. Collation of the Flood extent maps for the Wet Season 2008/2009 (November 2008- April 2009) for the whole of the Great Barrier Reef World Heritage Area. See text for annotation explanation.

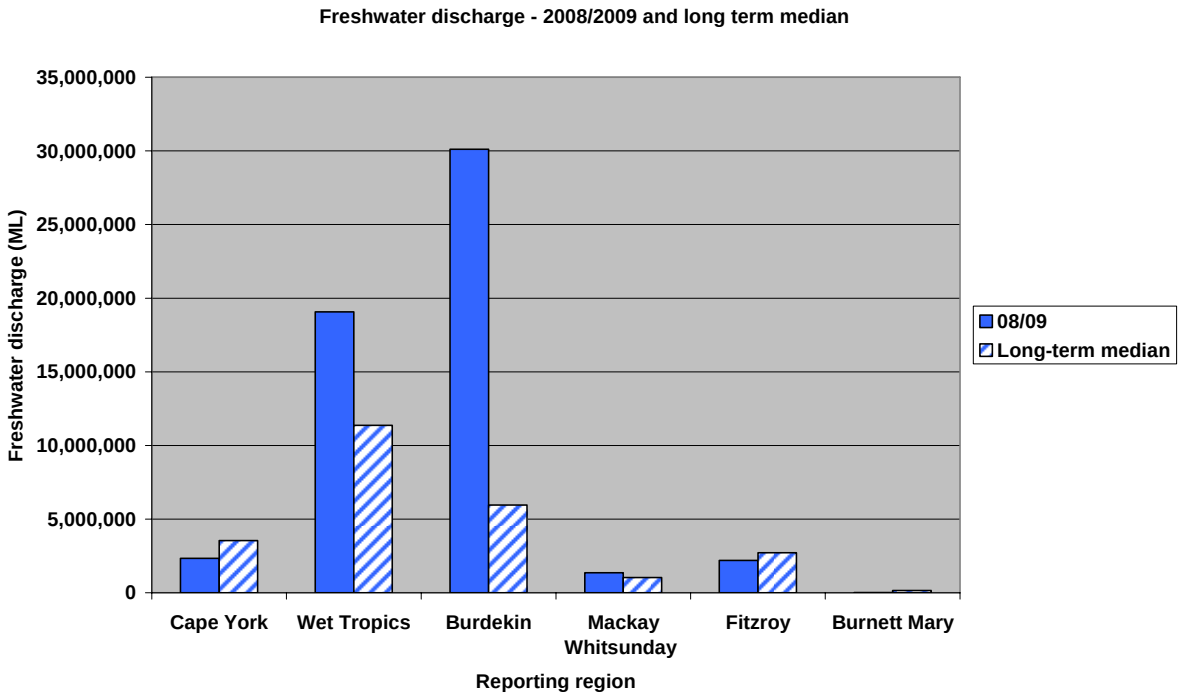


Figure 14. Comparison of fresh water discharge the year 2008/2009 compared to the long term median for each reporting region of the Great Barrier Reef World Heritage Area. Data are aggregated from data supplied by the Queensland Department of the Environment and Resource Management for each river. Long-term medians were estimated from annual total flows (October to October) available on: www.nrw.qld.gov.au/precomp.

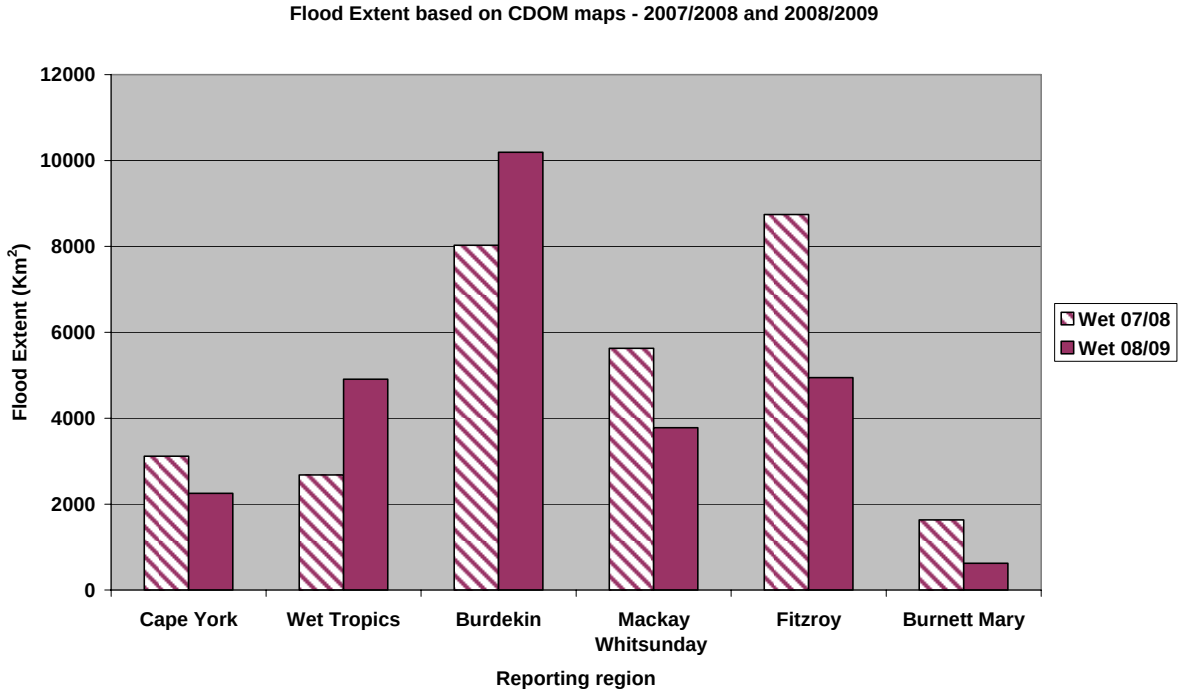


Figure 15. Comparison of flood extent for the Wet Seasons 2007/2008 and (November 2007 - April 2008) 2008/2009 (November 2008- April 2009) for each reporting region of the Great Barrier Reef World Heritage Area.

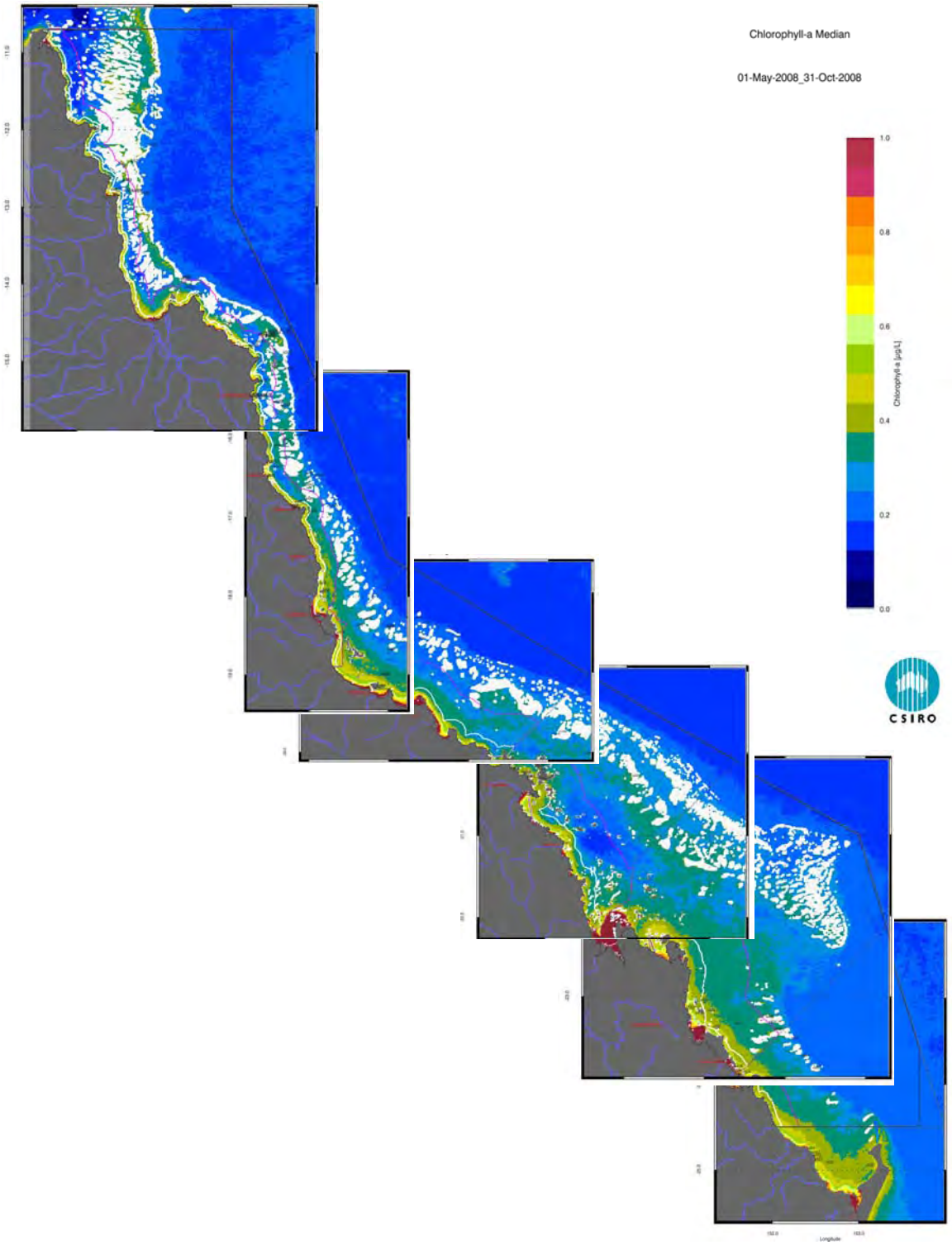


Figure 16. Collation of the Chlorophyll Median maps for the Dry Season 2008 (May - October) for the whole of the Great Barrier Reef World heritage Area. Several boundary lines are overlayed to the maps to enable the identification of water bodies identified by GBRMPA guidelines (Open coastal, Midshelf, and Offshore). The boundaries for the reporting region presented in each map as defined by GBRMPA in accordance with the NRM boundaries for the catchment and marine extensions. The cross shelf boundaries are defined in accordance with the Great Barrier Reef Water Quality Guidelines 2009: The thick white line is defines the 'open coastal' waters; the thick pink grey line defines the 'inshore' waters while the thick gray line delineate the 'offshore' waters; the thick black lines to the East in all images is the limit of the GBRWHA.

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 empty into the Gulf of Carpentaria, however there are several large catchments that empty 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.

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

The wet and dry season median maps of chlorophyll (Figure 17) for the Cape York region show high chlorophyll 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 reef matrix ranged ~0.15-0.5 μgL^{-1}.

The wet and dry season median maps of coloured dissolved organic matter (CDOM, Figure 18) for the Wet Tropics region show values higher than 0.20 m^{-1} in for a costal band ~5-10 km wide.

The wet and dry season median maps of non-algal particulate matter (as a measure of total suspended matter) (Figure 19) 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 20) for the Wet Tropics region show similar gross patterns as for the chlorophyll, 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 21) for the Wet Tropics region show similar gross patterns to the maps of vertical attenuation of light (Figure 20).

The maps in Figure 22depict 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 water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA using CSIRO's algorithm.

Figure 23 presents the maps of Chlorophyll exceedance as defined by the guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 24 presents the map of the Exceedence Probability for Chlorophyll. This map reports in a continuous colour scale the Number of day 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 Suspended solids (using Non-algal particulate matter as a measure of Suspended Solids, Figure 25and Figure 26).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 17, Figure 19) and by the steep changes in trigger values between the Midshelf and Offshore areas. The mean values of Chlorophyll exceeded the guidelines in the wet season only in correspondence to the river mouths.

For the Cape York region the mean values of Chlorophyll exceeded the guidelines values for 58% of the Open Coastal area in the dry season and14 % in the wet season. In the dry season Chlorophyll also exceeded the guidelines for 20 % of the Midshelf and 12% of the Offshore areas (Figure 23, Table 5). Similar exceedance values were retrieved if the median was used for the assessment (Figure 24, Table 5).

The mean values of Suspended solids exceeded the guidelines values for 63% of the Open Coastal Area in the dry season and 24 % in the wet season, In the dry season the mean values of Suspended solids also exceeded the guidelines for 55 % of the Midshelf and 13% of the Offshore area. 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 values for the Open Coastal area where significantly lower that those for the mean values (40% for the dry season and 6% for the wet season, Figure 26, and Table 6).

Table 7 and Table 8 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 Exceedence Probability for that period. These metrics are based on a high number of observations (ranging from 75 Thousands valid observations for Open Coastal area in the wet season to over 2.2 Million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll exceeded the guidelines values for the Open Coastal area in both seasons, while the mean values of Suspended solids exceeded the guidelines values for the Open Coastal area and Offshore area in both seasons.

The mean and median values for the Suspended solids concentration differed substantially: the mean values were ~ 2-3 times higher than medians. The median values for the dry season (1.96 and 1.23 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) (2.24 and 1.39 mg/L SS, respectively).

Assessment of flood extent during the wet season

Figure 27 reports the flood extent for wet Season 2008/2009 (November 2008- April 2009) for the Cape York region. The flood extent was estimated applying a threshold of 0.2 m-1 for the CDOM seasonal maximum.

For the Cape York region the flood extent for 2008/2009 (November 2008- April 2009) was 2255 km^2 while in the Wet Seasons 2007/2008 (November 2007 - April 2008) was 3116 km^2 (Figure 15). . This reflects the freshwater discharge from the Normanby River that was below the annual median flow (Figure 14).

Table 4 Summary of the annual exceedance maps for Chlorophyll 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-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	6001	222281	1221535	41%	41%
MS	15603	705210	3047216	2%	2%
OS	78347	2829184	18013124	0%	0%

Table 5 Summary of the exceedance maps for Chlorophyll for the dry and wet season for the Cape York region (Figure 23, Figure 24). "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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	6001	160071	646085	58%	61%	61983	562009	14%	15%
MS	15603	493680	1623776	20%	26%	211530	1423440	0%	0%
OS	78347	1731943	9600976	12%	11%	1097241	8416440	0%	0%

Table 6 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Suspended solids) for the dry and wet season for the Cape York region (Figure 25, Figure 26). "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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	6001	160071	646085	63%	40%	61983	562009	24%	6%
MS	15603	493680	1623776	55%	16%	211530	1423440	14%	0%
OS	78347	1731943	9600976	13%	6%	1097241	8416440	14%	5%

Table 7. Summary of Chlorophyll exceedance for the dry and wet season 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" and “Median” report the mean and median concentrations computed on all the valid observations, “EP” provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	190785	924154	**0.60**	**0.47**	57%	75102	810135	**0.54**	**0.48**	57%
MS	658693	2402862	0.34	0.31	20%	296781	2106405	0.35	0.32	25%
OS	2213450	12065438	0.26	0.20	13%	1373050	10576845	0.25	0.20	13%

Table 8 Summary of Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	190785	924154	**4.11**	1.96	49%	75102	810135	**2.73**	1.17	26%
MS	658693	2402862	**3.48**	1.23	38%	296781	2106405	**2.76**	0.97	30%
OS	2213450	12065438	**1.16**	0.22	26%	1373050	10576845	**1.17**	0.27	30%

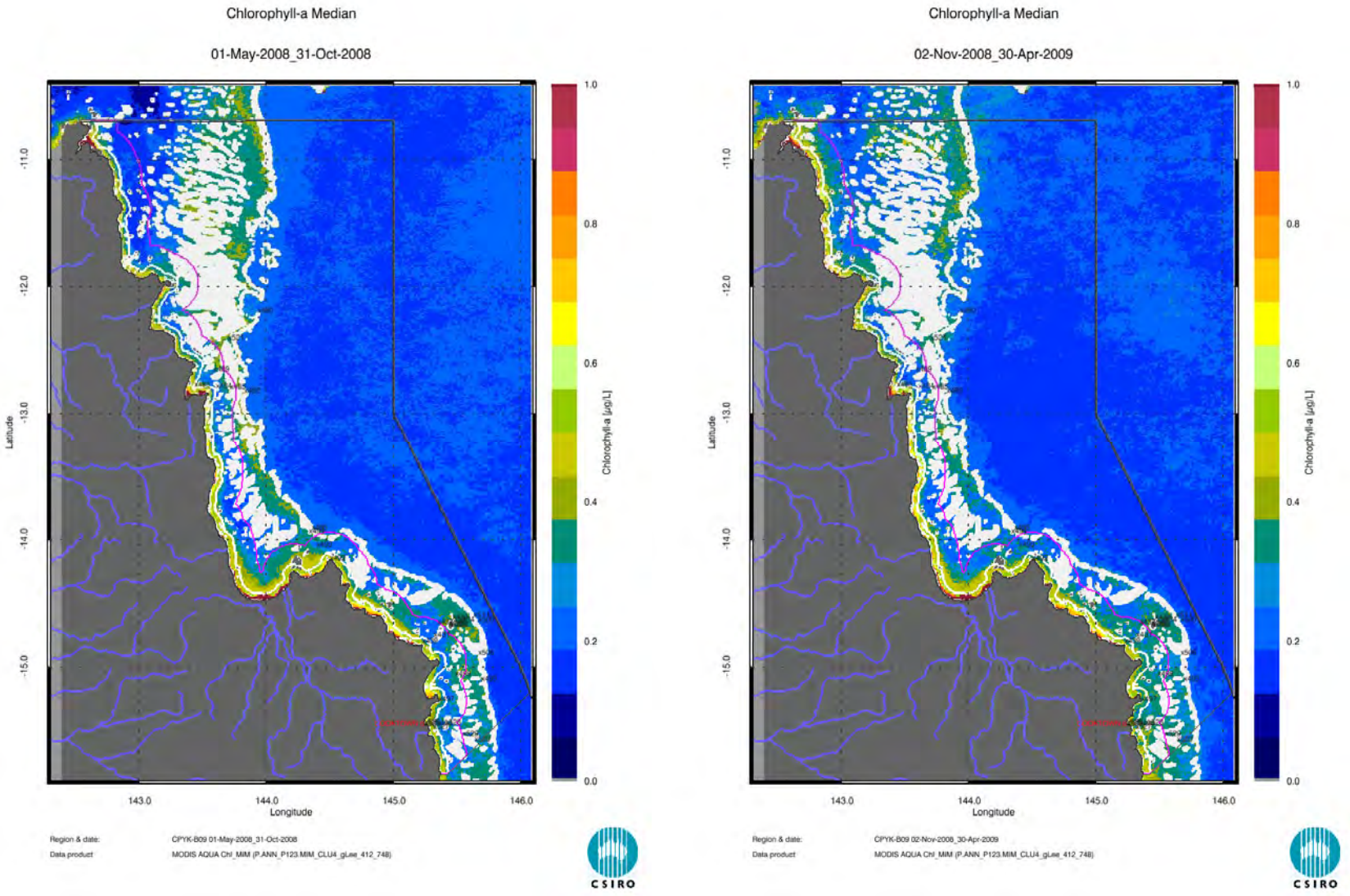


Figure 17. Chlorophyll Median maps for the dry and wet season for the Cape York region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

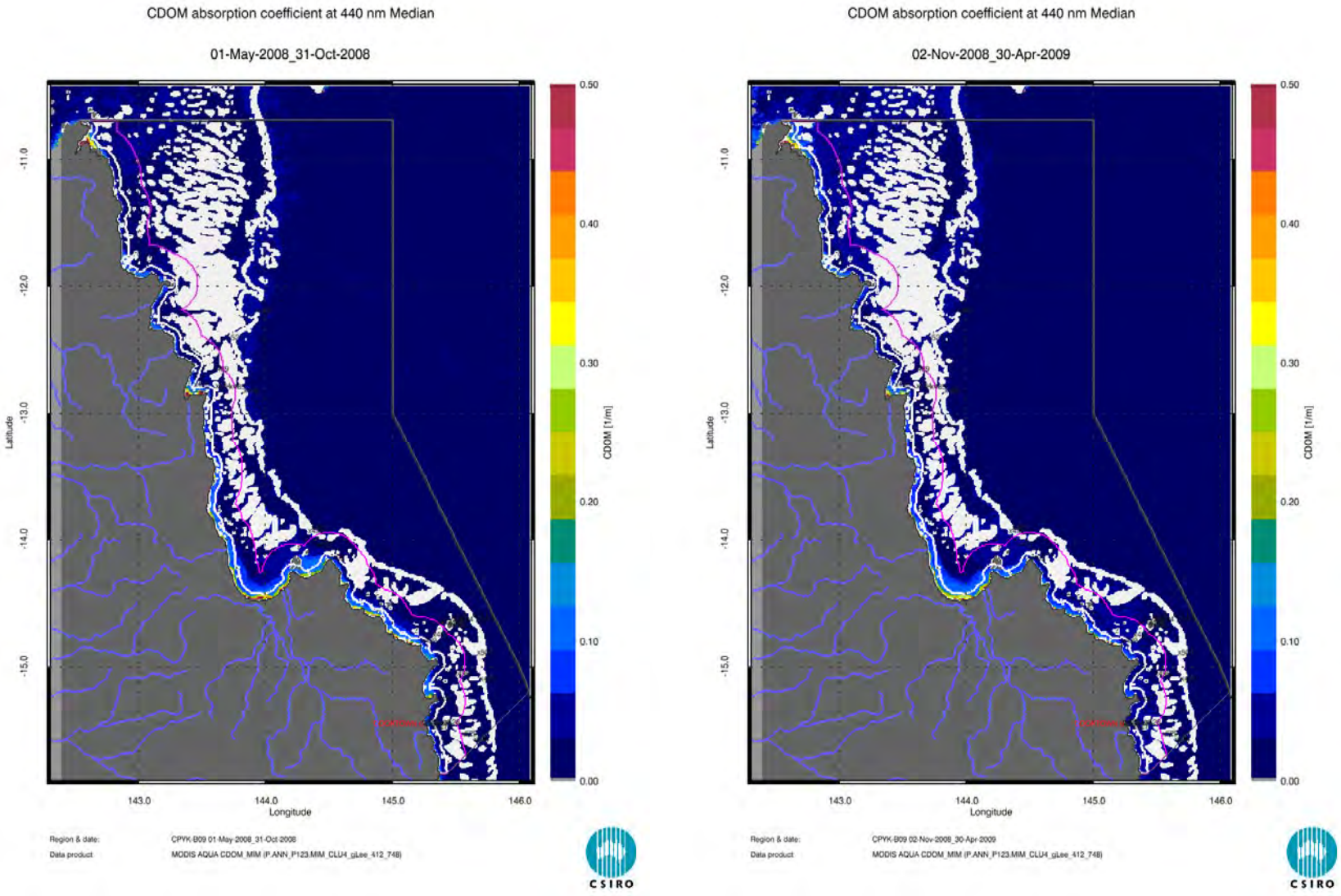


Figure 18. CDOM Median maps for the dry and wet season for the Cape York region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

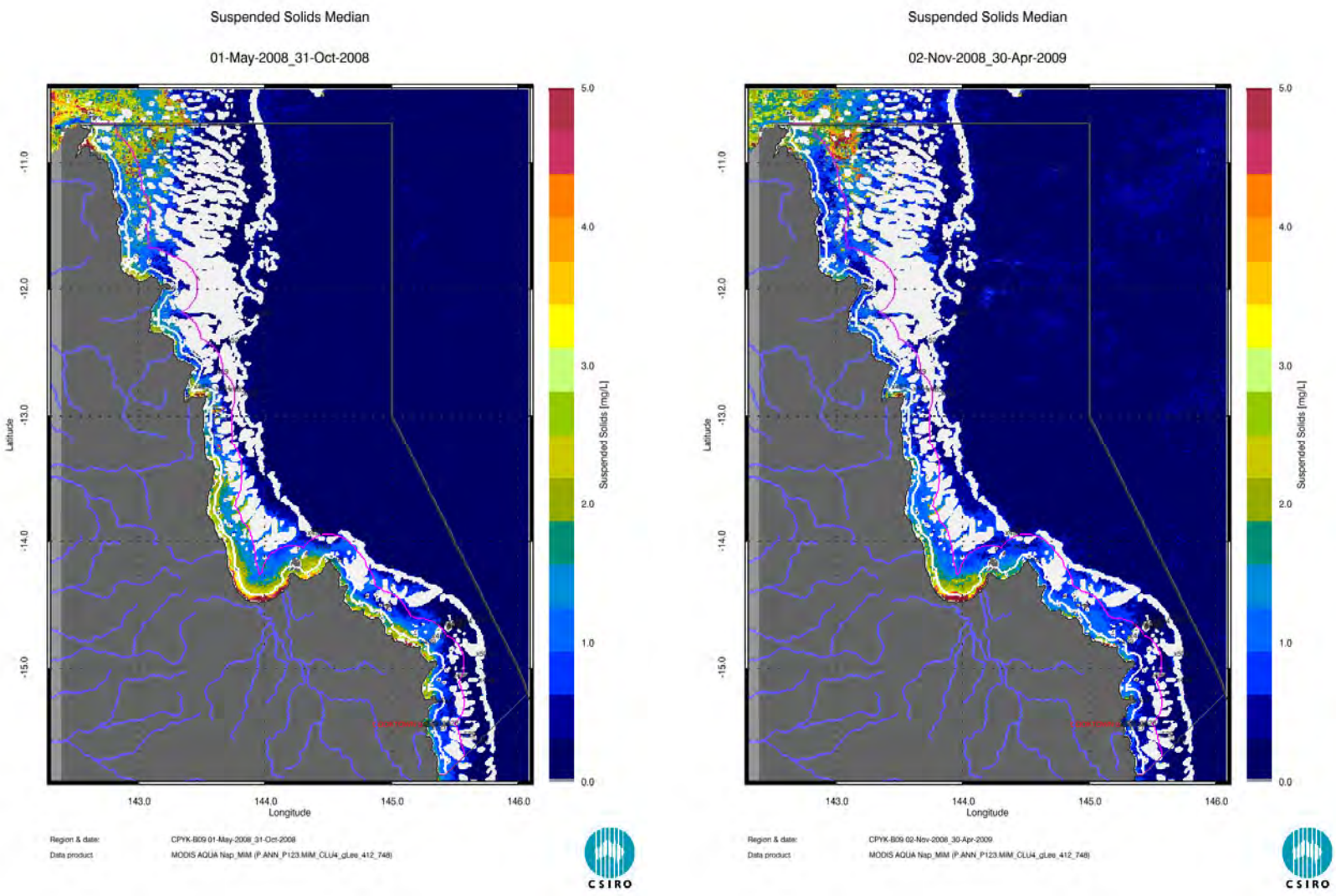


Figure 19. Non-algal particulate matter (Nap as a measure of Suspended solids) Median maps for the dry and wet season for the Cape York region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

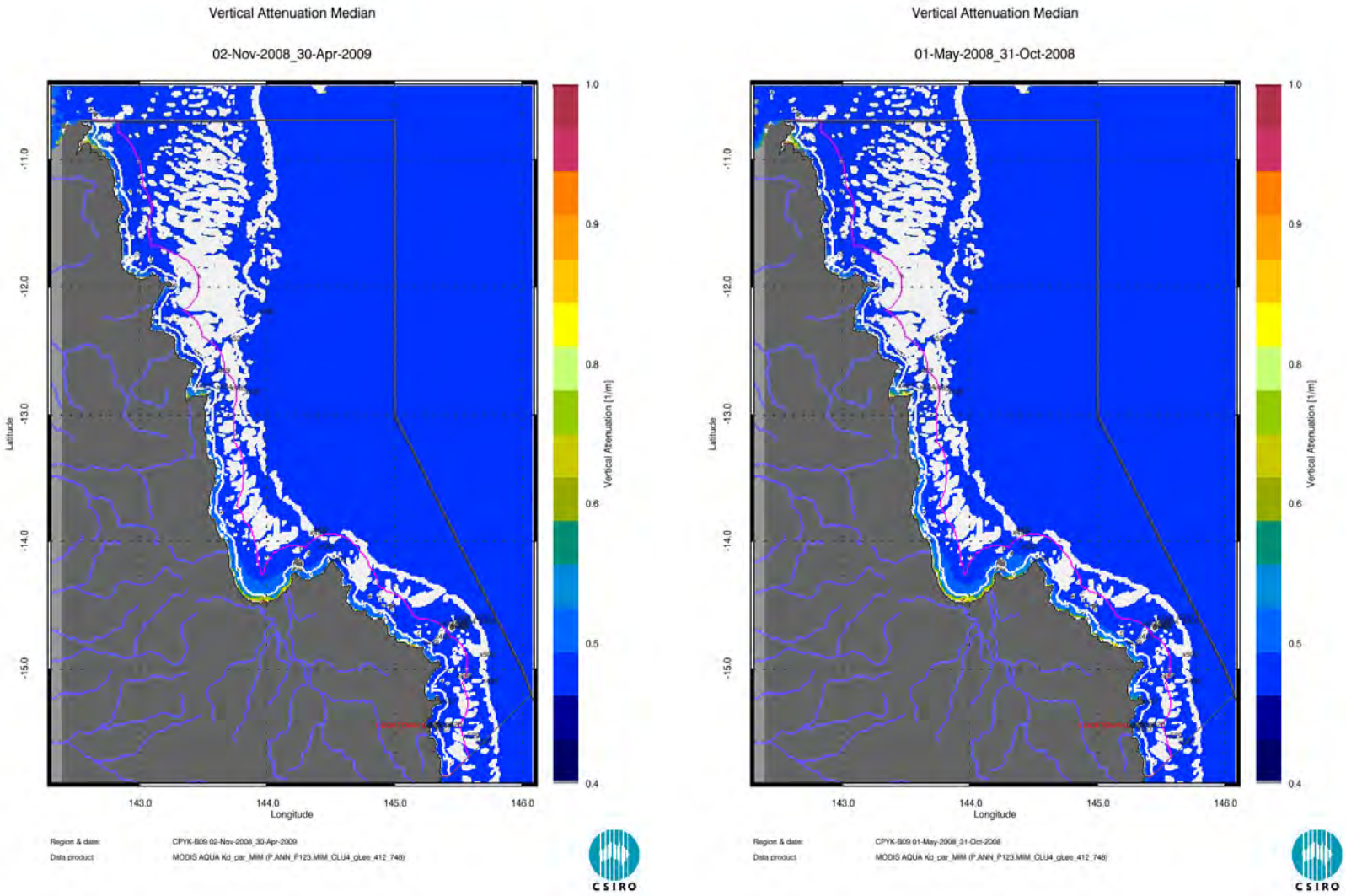


Figure 20. Vertical attenuation of light (Kd ,as estimate of water clarity) Median maps for the dry and wet season for the Cape York region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

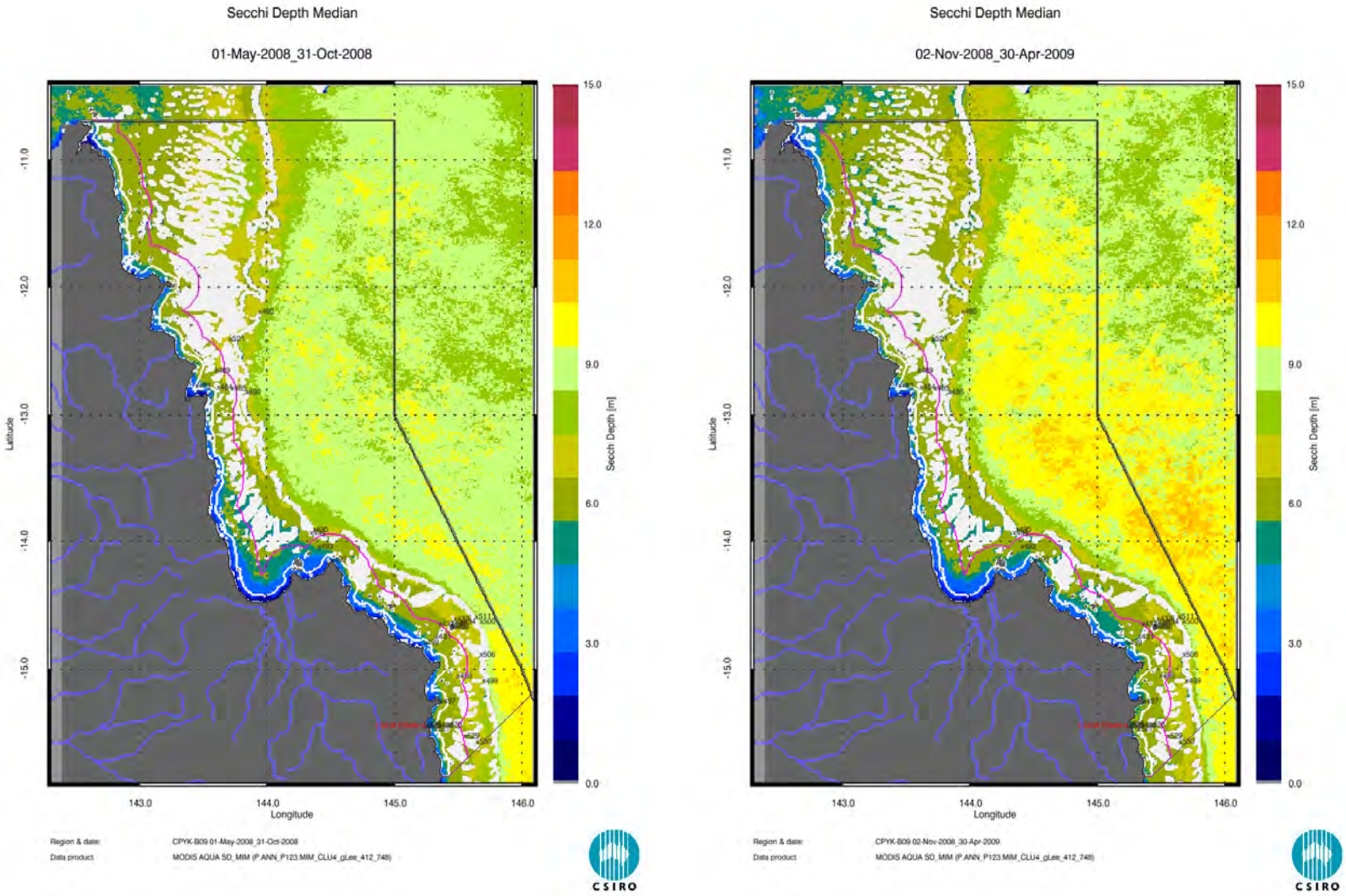


Figure 21. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Cape York region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

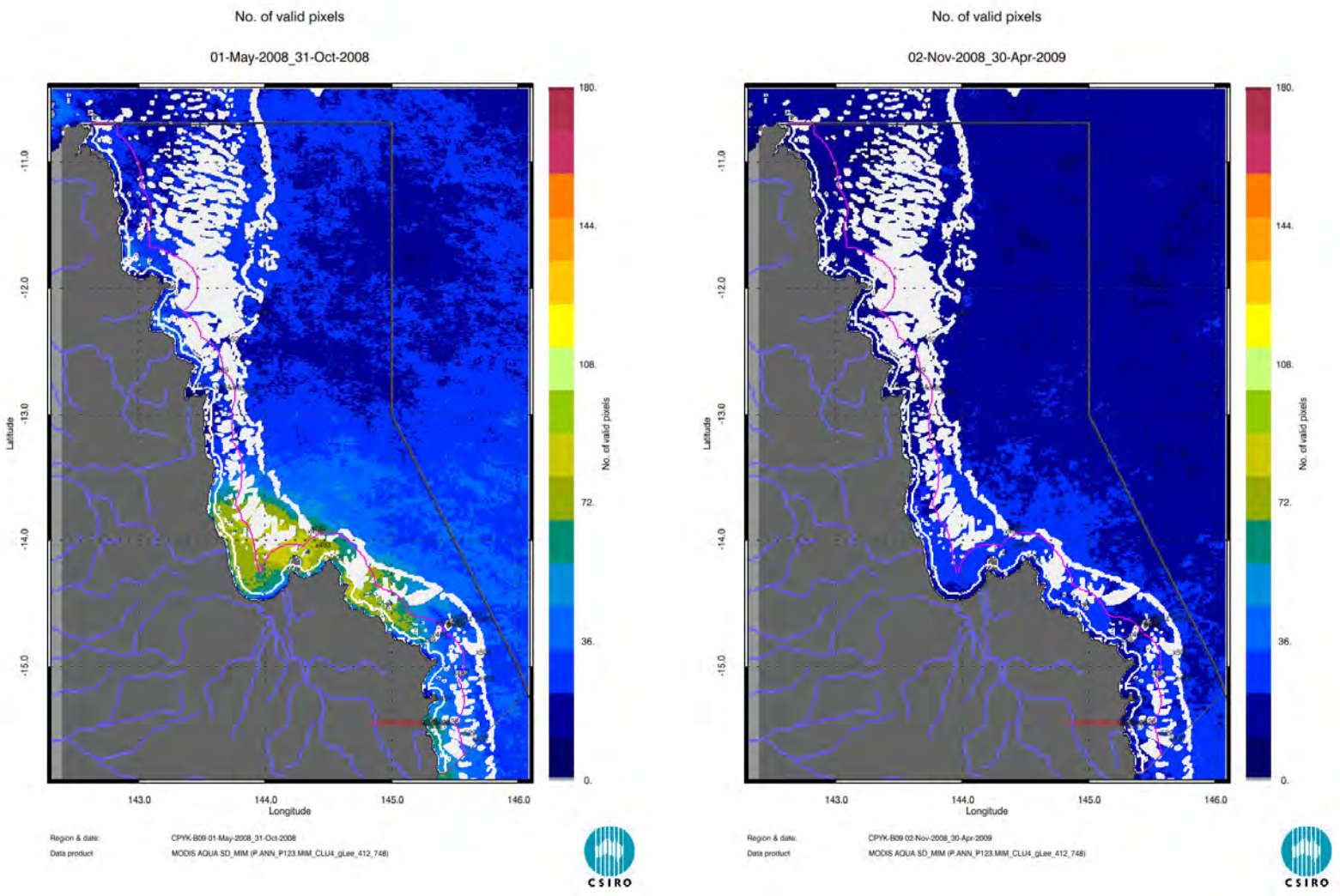


Figure 22. Number of pixels used to calculate the Median maps (Figure 17 - Figure 21) for the dry and wet season for the Cape York region. The first map presents the number of pixels available for analysis in the Dry Season 2008 (May - October), while the second map presents the number of pixels available for analysis in the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

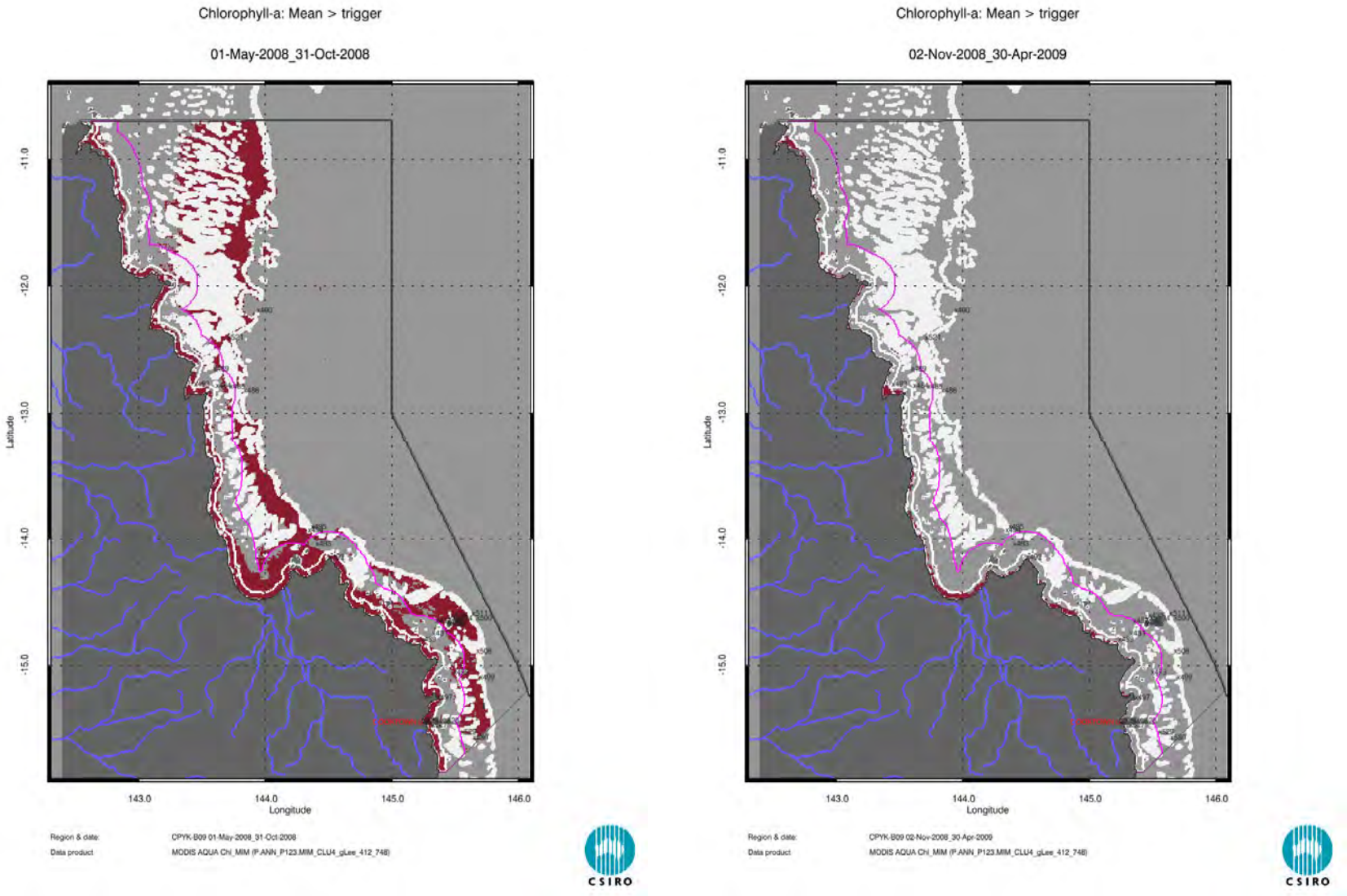


Figure 23. Chlorophyll exceedance maps for the dry and wet season for the Cape York region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

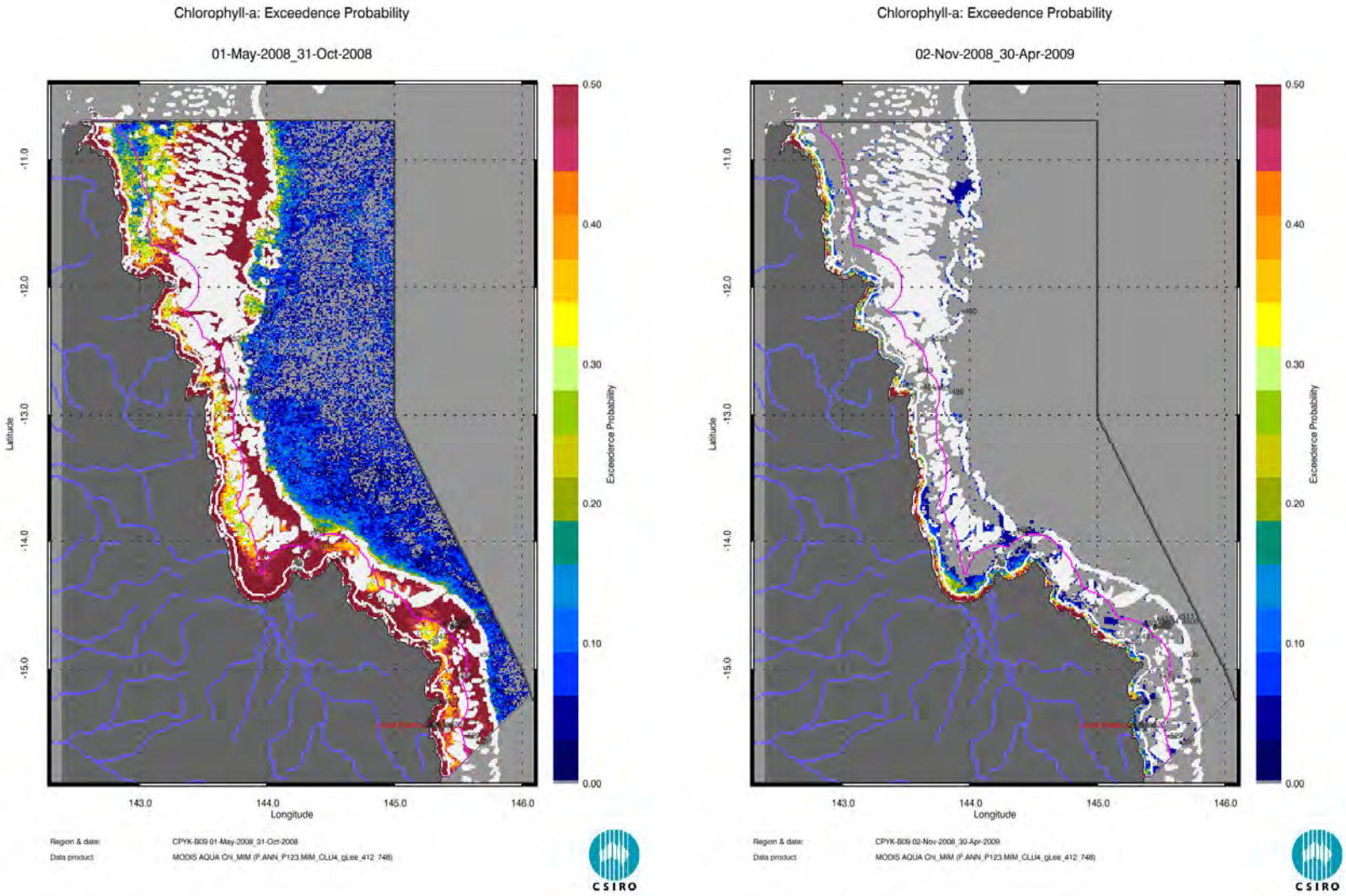


Figure 24. Chlorophyll exceedance probability maps for the dry and wet season for the Cape York region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

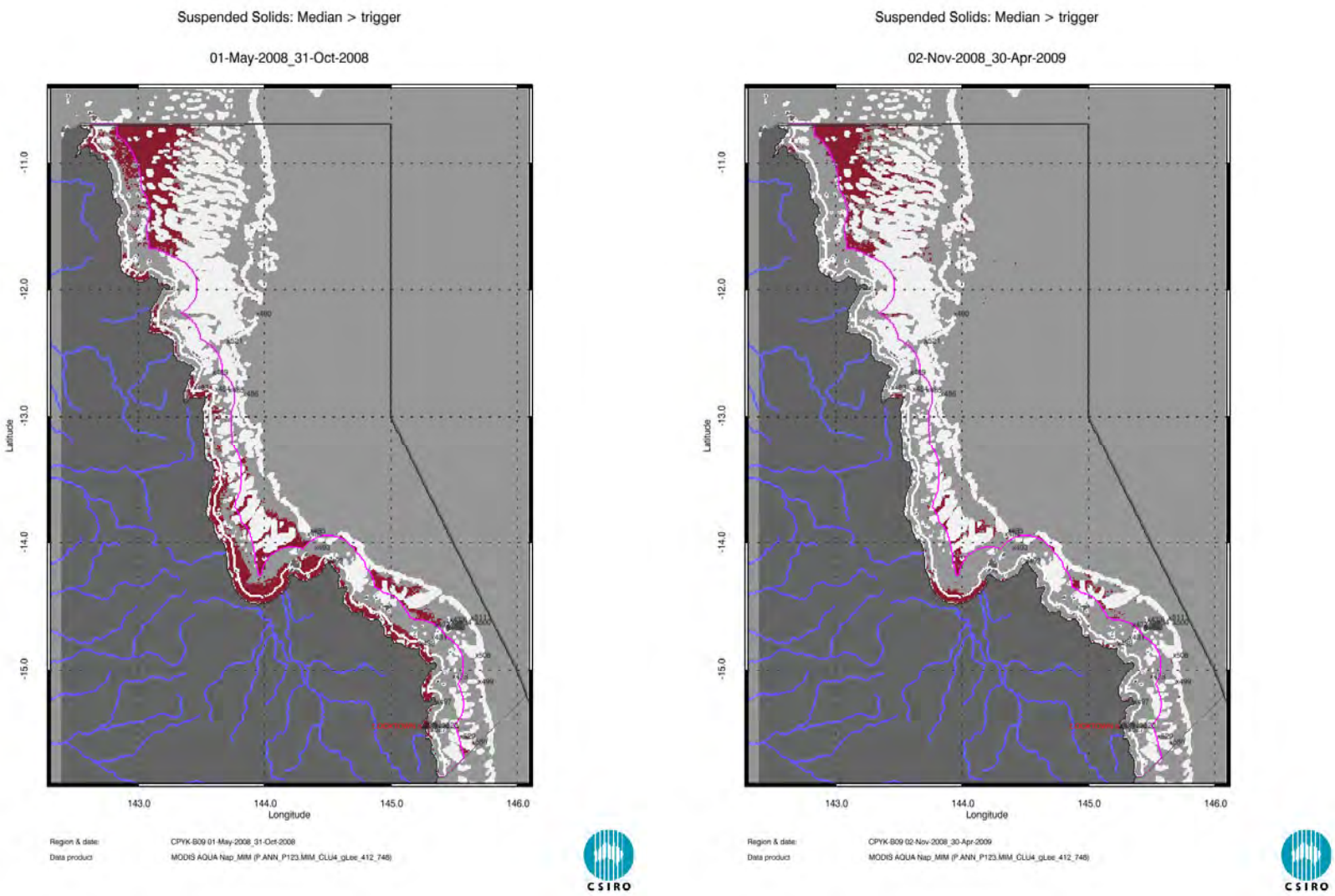


Figure 25. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance maps for the dry and wet season for the Cape York. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

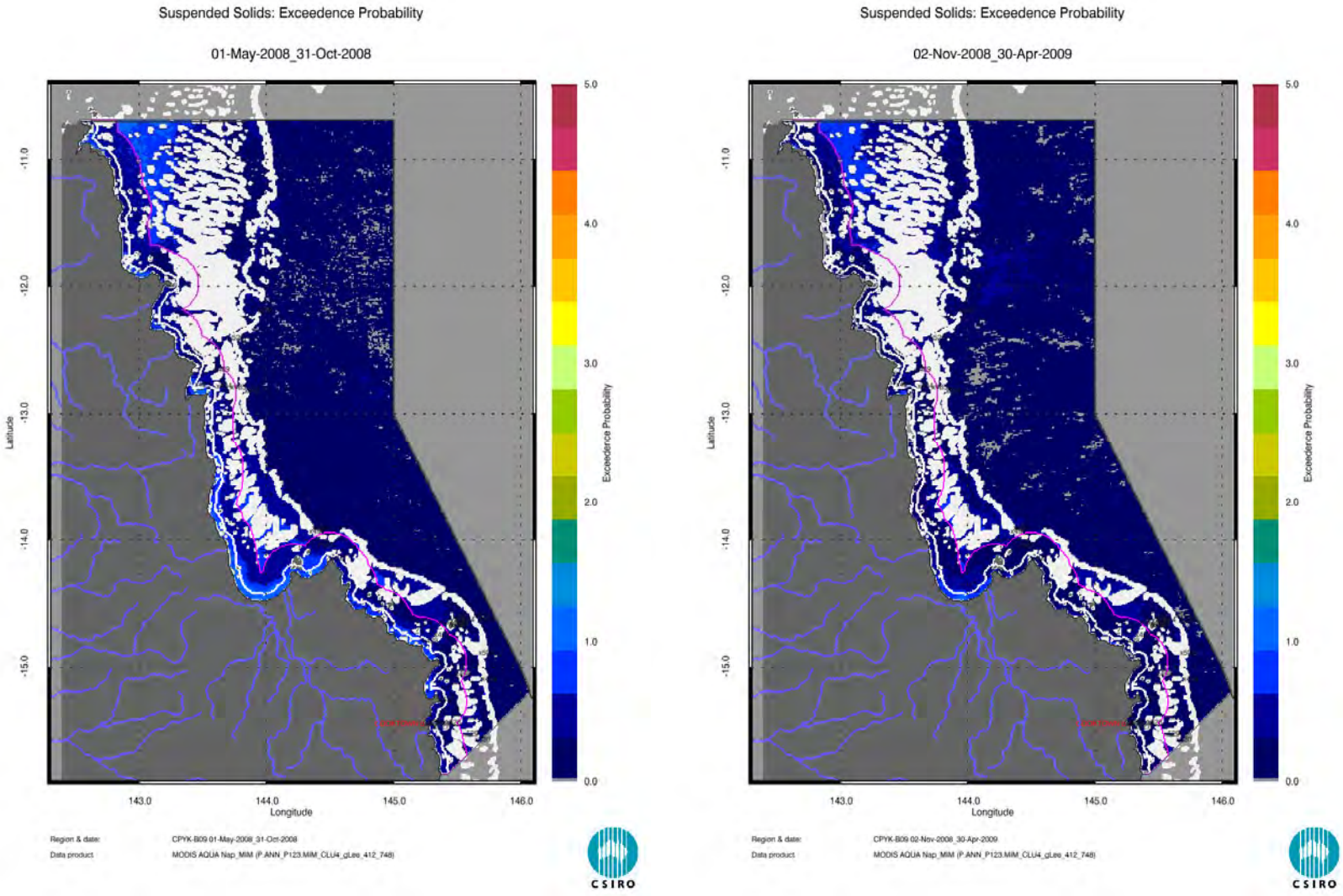


Figure 26. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance probability maps for the dry and wet season for the Cape York region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

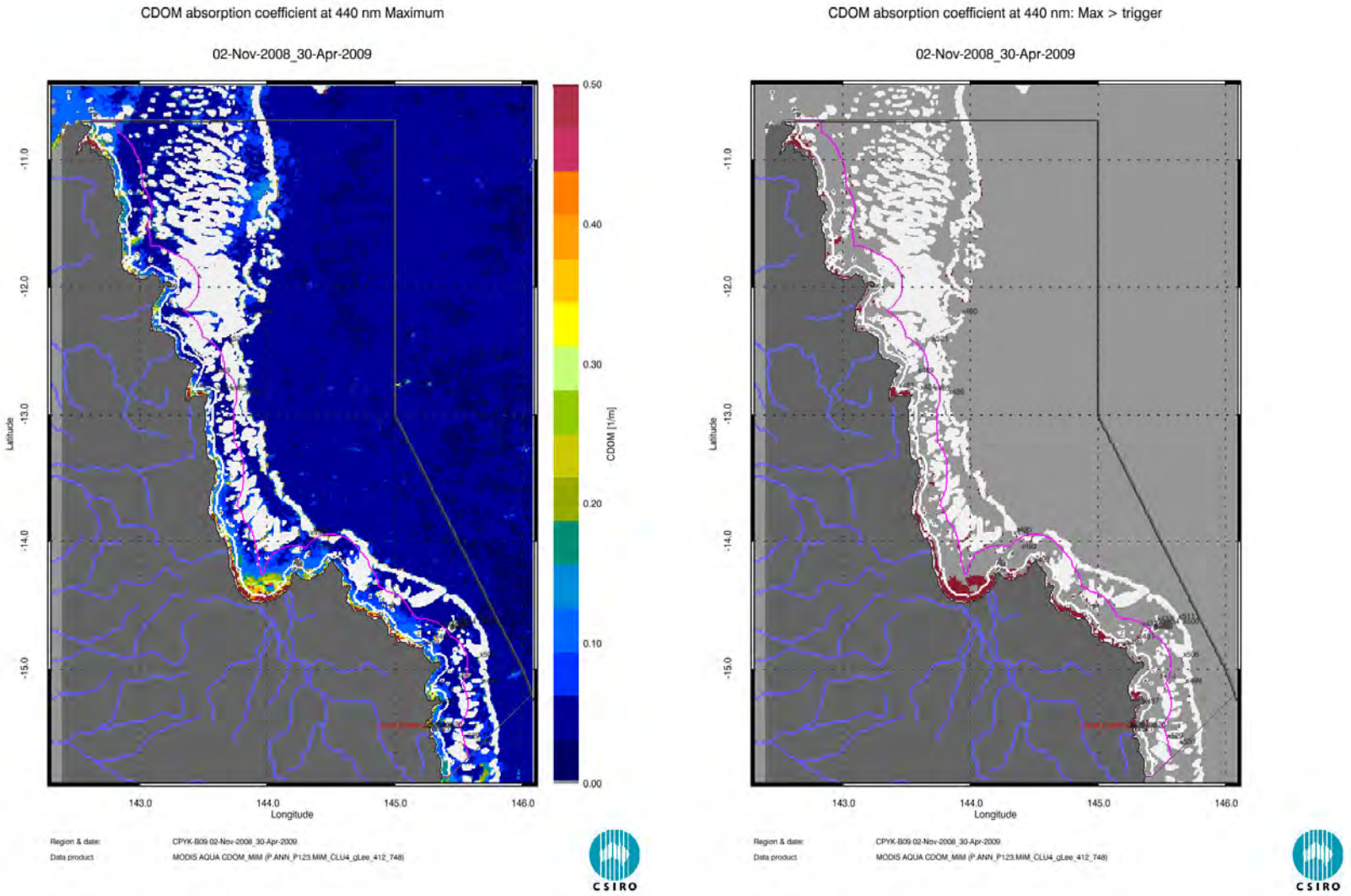


Figure 27. Map of flood extent for the wet season for the Cape York region. The first map presents the maximum value of CDOM for the Wet Season 2008/2009 (November 2008- April 2009), while the second map presents flood extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m-1. See text for annotation explanation.

Regional reports: Wet Tropics region

Land use practices within the wet tropics catchment include primary production such as 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, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of chlorophyll (Figure 28) for the Wet Tropics region show high chlorophyll 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 reef matrix ranged ~0.15-0.25 μgL^{-1}. The lobe of rwelatively high chlorophyll 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 29) for the Wet Tropics region show values higher than 0.20 m^{-1} in for a costal band ~5-10 km wide.

The wet and dry season median maps of non-algal particulate matter (as a measure of total suspended matter) (Figure 30) for the Wet Tropics region show similar gross patterns as for the CDOM distribution..

The wet and dry season median maps of vertical attenuation of light (Figure 31) for the Wet Tropics region show similar gross patterns as for the chlorophyll, 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 32) for the Wet Tropics region show similar gross patterns to the maps of vertical attenuation of light (Figure 31).

The maps in Figure 33 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.

Assessment of the exceedance of water quality guidelines

The exceedance of water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA using CSIRO's algorithm.

Figure 34 presents the maps of Chlorophyll exceedance as defined by the guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 35 presents the map of the Exceedence Probability for Chlorophyll. This map reports in a continuous colour scale the Number of day 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 Suspended solids (using Non-algal particulate matter as a measure of Suspended Solids, Figure 36 and Figure 37).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 28, Figure 30) and by the steep changes in trigger values

between the Midshelf and Offshore areas. The mean values of Chlorophyll exceeded the guidelines in the wet season only in correspondence to the river mouths: Mossman –Daintree, Barron, Russell-Mulgrave, Johnstone, Tully, Murray and Herbert rivers and Hinchinbrook Channel.

For the Wet Tropics region the mean values of Chlorophyll exceeded the guidelines values for 74% of the Open Coastal area in the dry season and 56 % in the wet season. In the dry season Chlorophyll also exceeded the guidelines for 53 % of the Midshelf and 18% of the Offshore areas (Figure 34, Table 9, Table 10). Similar exceedance values were retrieved if the median was used for the assessment (Figure 35, Table 9, Table 10).

The mean values of Suspended solids exceeded the guidelines values for 61% of the Open Coastal Area in the dry season and 19 % in the wet season, In the dry season the mean values of Suspended solids also exceeded the guidelines for 28 % of the Midshelf and 14% of the Offshore area. 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 values for the Open Coastal area where significantly lower that those for the mean values (25% for the dry season and 3% for the wet season, Figure 37, and Table 11).

Table 12 and Table 13report 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 Exceedence Probability for that period. These metrics are based on a high number of observations (ranging from 50 Thousands valid observations for Open Coastal area in the wet season to over 1 Million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll exceeded the guidelines values for the Open Coastal area in both seasons, while the mean values of Suspended solids exceeded the guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the Suspended solids concentration differed substantially (for all regions and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of flood extent during the wet season

Figure 38 reports the flood extent for wet Season 2008/2009 (November 2008- April 2009) for the Wet Tropics region. The flood extent was estimated applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Wet Tropics region the flood extent for the Wet Season 2008/2009 (November 2008- April 2009) was 4906 km^2 while in the Wet Season 2007/2008 (November 2007 - April 2008) was 2680 km^2 (Figure 15). The higher flood extent was due to the freshwater discharge from the Herbert River that was more than three times the annual median flow, and to the flow conditions in the Barron, Russell, Johnstone and Tully Rivers were slightly above median levels (1.08 – 1.29 times median levels, Figure 14).

Table 9 Summary of the annual exceedance maps for Chlorophyll 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-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2723	153380	673908	57%	58%
MS	6920	518460	1939329	9%	10%
OS	24295	1320487	6588886	0%	0%

Table 10 Summary of the exceedance maps for Chlorophyll for the dry and wet season for the Wet Tropics region (Figure 34, Figure 35). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2723	107657	355940	74%	74%	45679	313997	26%	21%
MS	6920	350777	1025325	53%	67%	167683	914004	4%	0%
OS	24295	812061	3483550	18%	17%	508426	3105336	0%	0%

Table 11 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Suspended solids) for the dry and wet season for the Wet Tropics region (Figure 36, Figure 37). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	2723	107657	355940	61%	25%	45679	313997	19%	3%
MS	6920	350777	1025325	28%	4%	167683	914004	5%	0%
OS	24295	812061	3483550	14%	0%	508426	3105336	12%	1%

Table 12. Summary of Chlorophyll exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	119229	476525	**0.73**	**0.54**	72%	50285	424788	**0.71**	**0.53**	65%
MS	382891	1211000	0.37	0.36	24%	183099	1079520	0.40	0.36	35%
OS	1008402	4251625	0.26	0.21	11%	625486	3790020	0.26	0.21	15%

Table 13 Summary of Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	119229	476525	**2.83**	1.35	32%	50285	424788	**2.05**	0.89	21%
MS	382891	1211000	1.74	0.61	22%	183099	1079520	1.59	0.65	21%
OS	1008402	4251625	**0.87**	0.15	22%	625486	3790020	**1.04**	0.27	29%

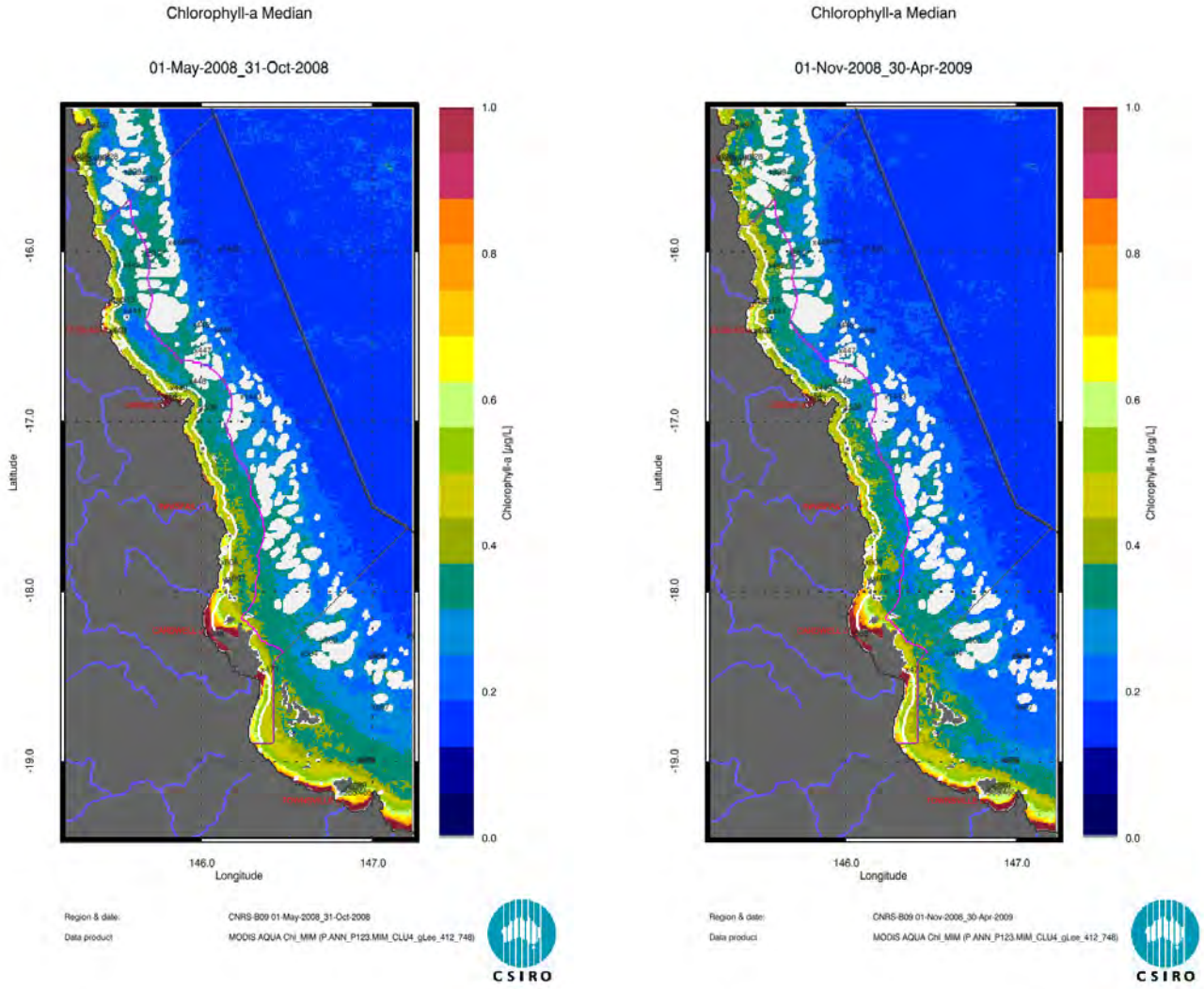


Figure 28. Chlorophyll Median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

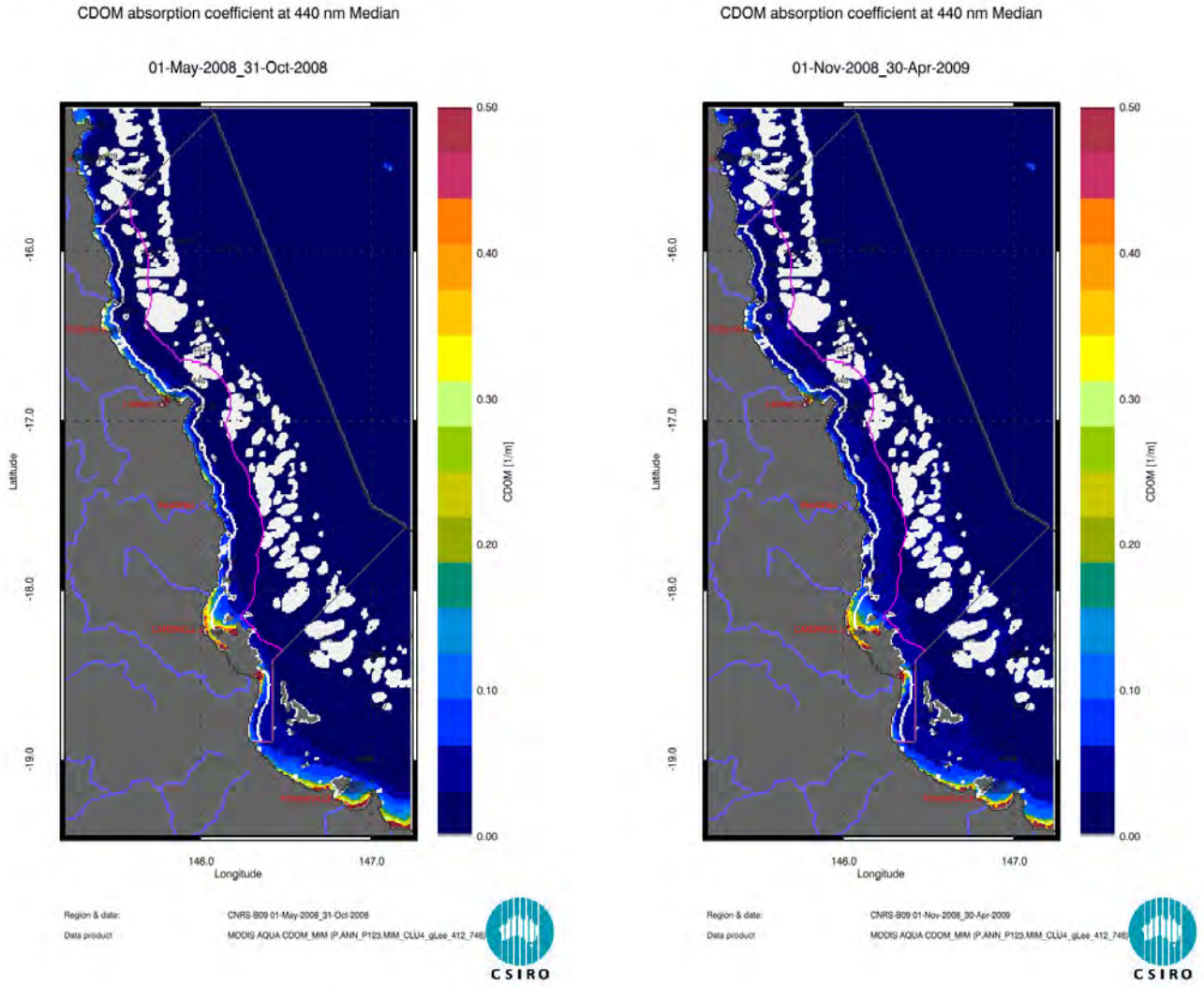


Figure 29. CDOM Median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

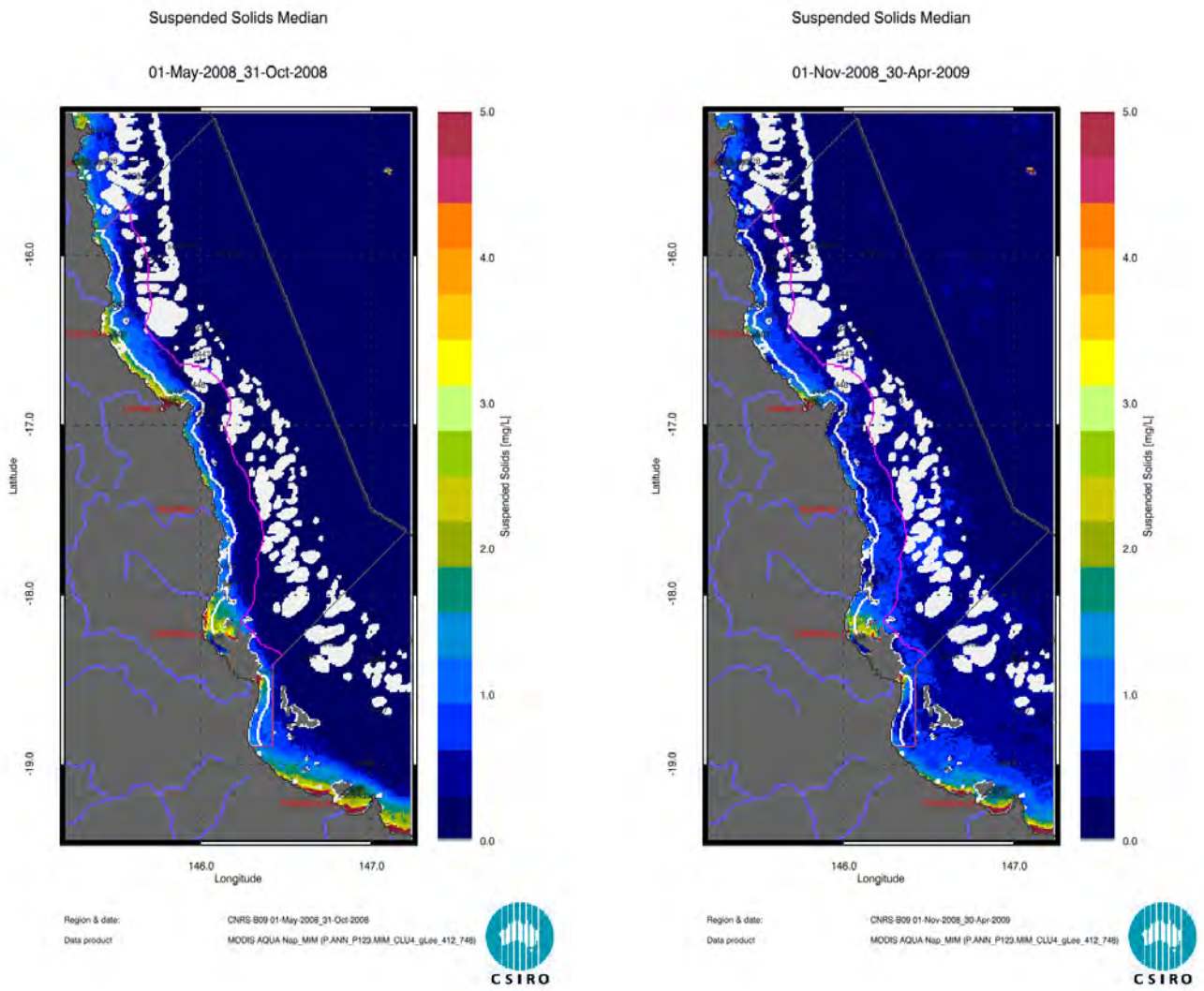


Figure 30. Non-algal particulate matter (Nap as a measure of Suspended solids) Median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

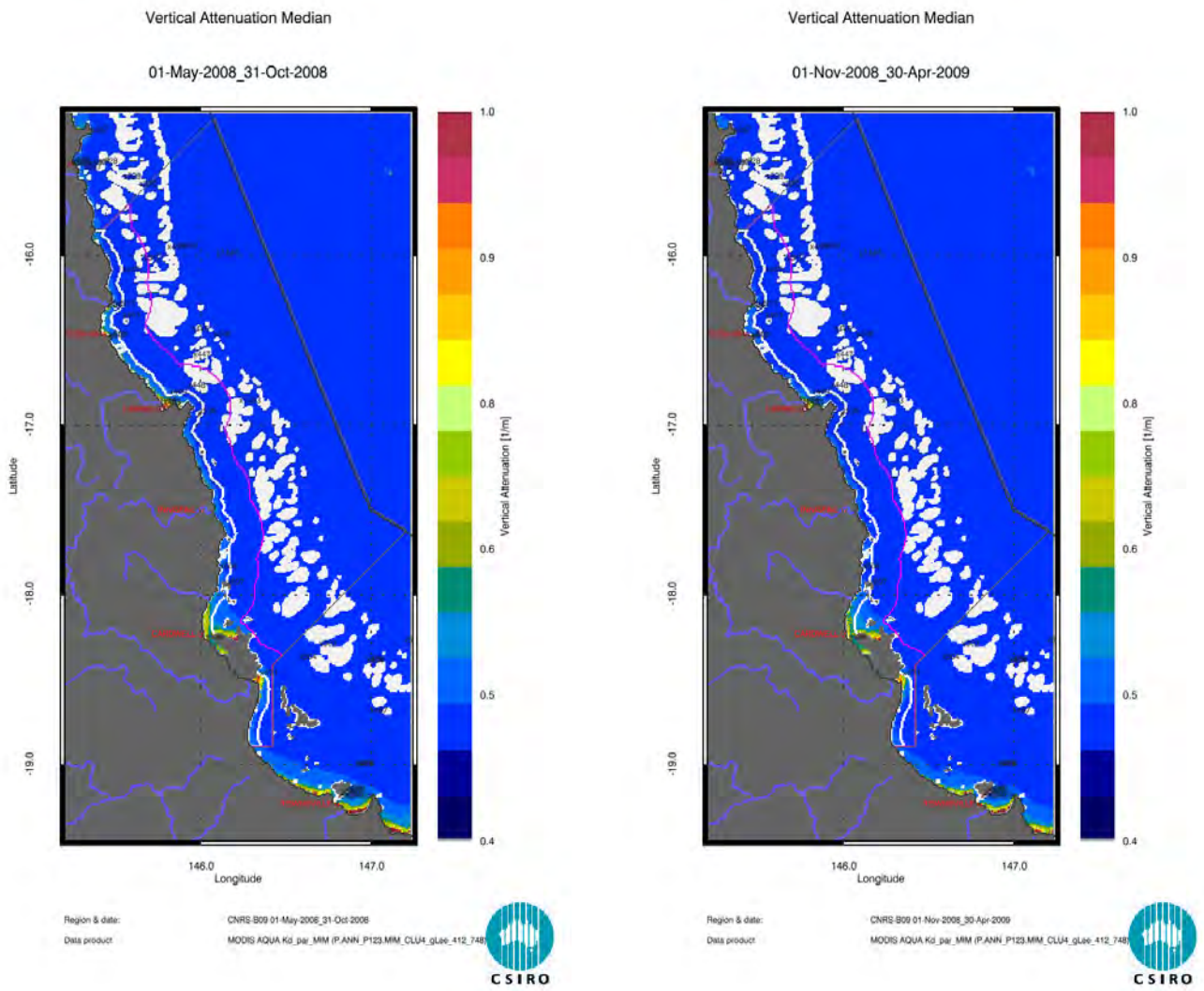


Figure 31. Vertical attenuation of light (Kd ,as estimate of water clarity) Median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

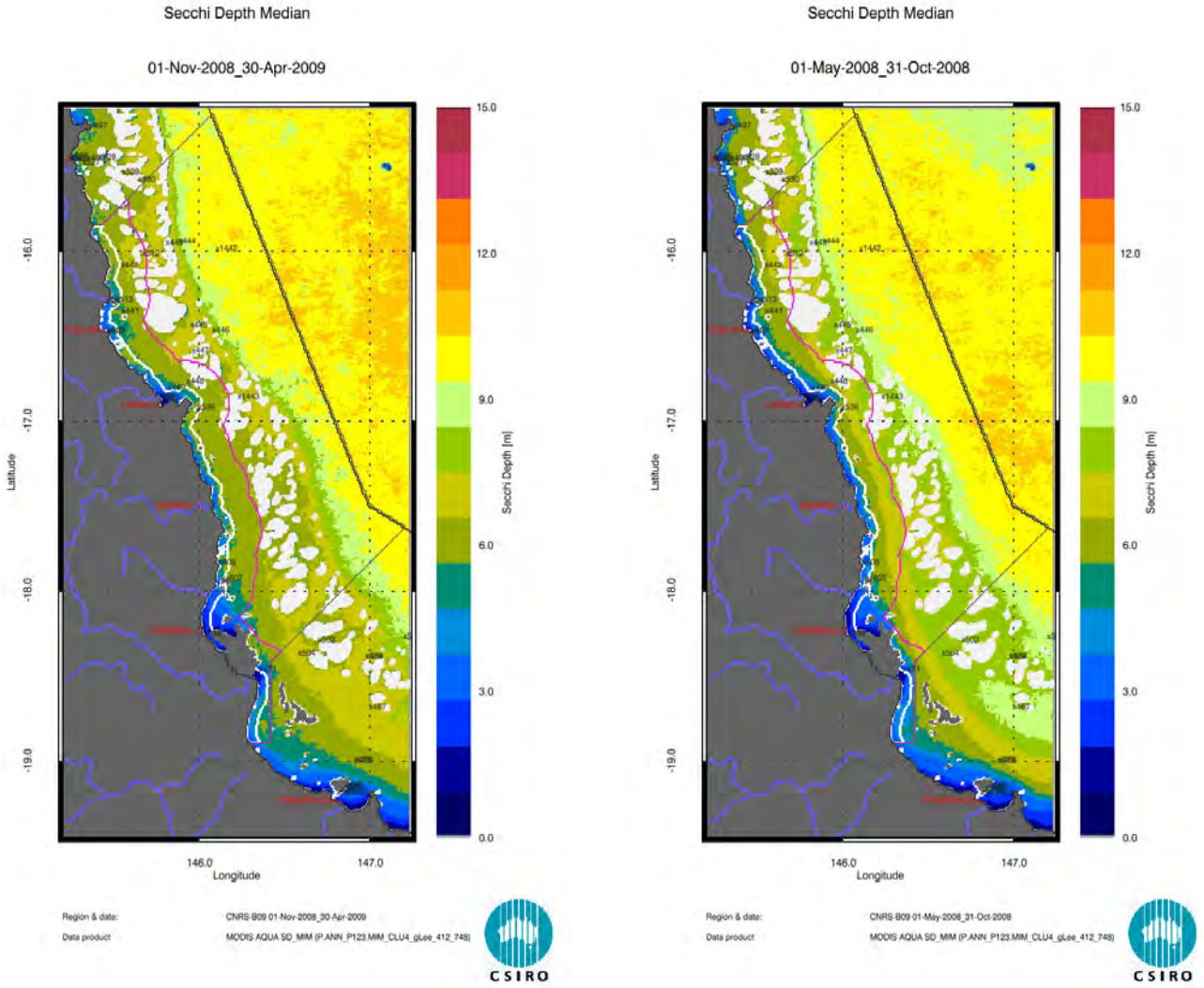


Figure 32. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

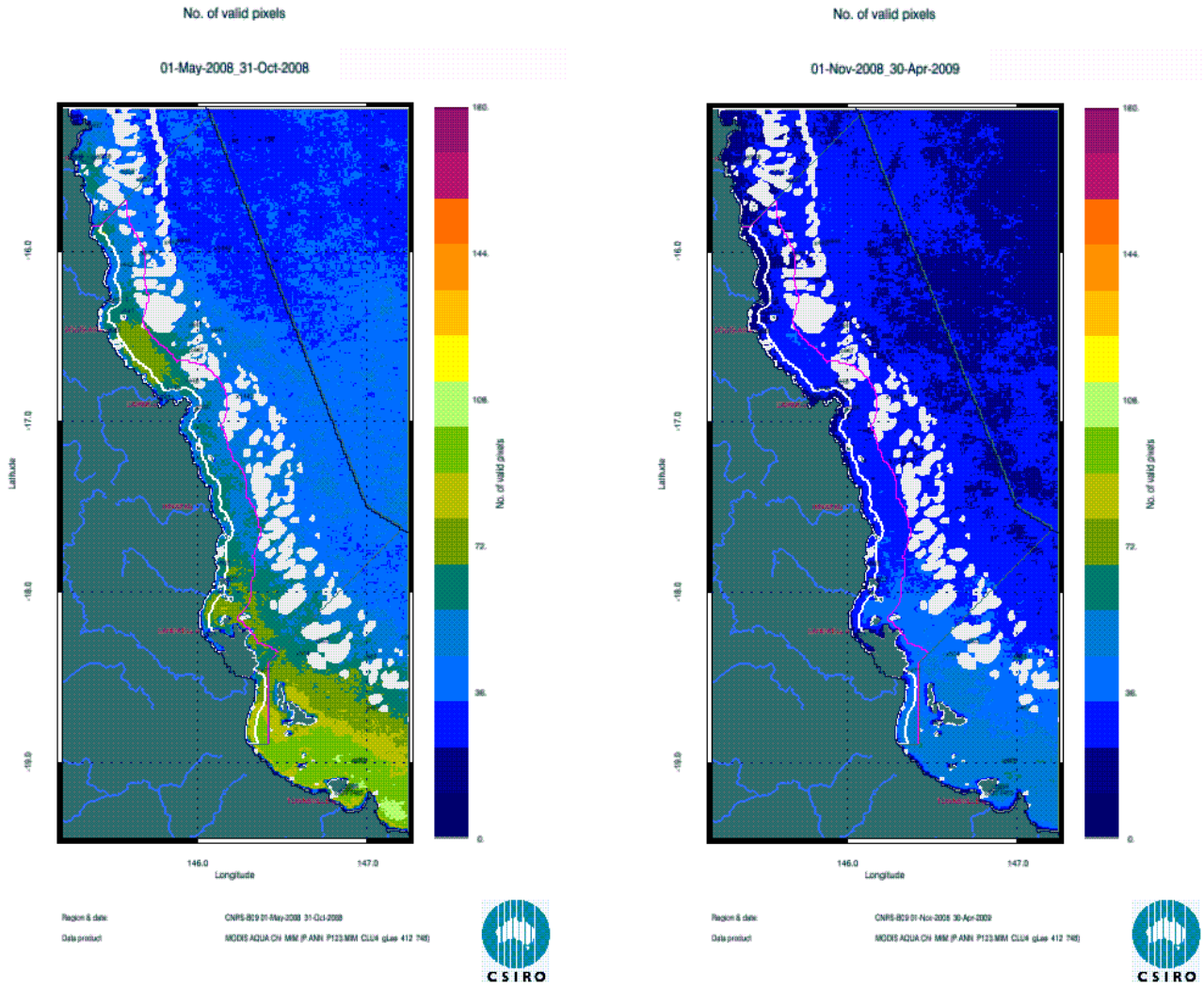


Figure 33. Number of pixels used to calculate the Median maps (Figure 28- Figure 32) for the dry and wet season for the Wet Tropics region. The first map presents the number of pixels available for analysis in the Dry Season 2008 (May - October), while the second map presents the number of pixels available for analysis in the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

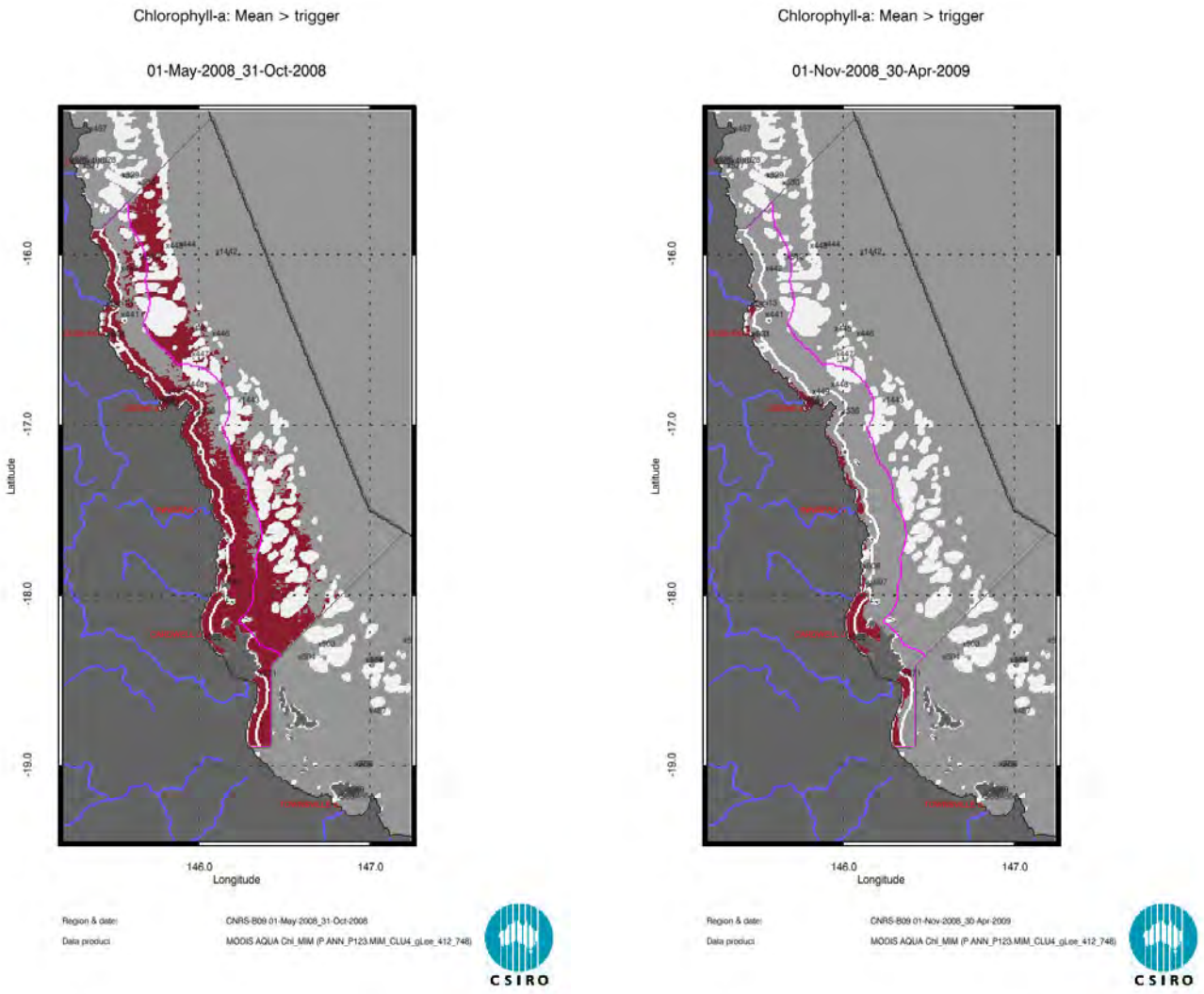


Figure 34. Chlorophyll exceedance maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

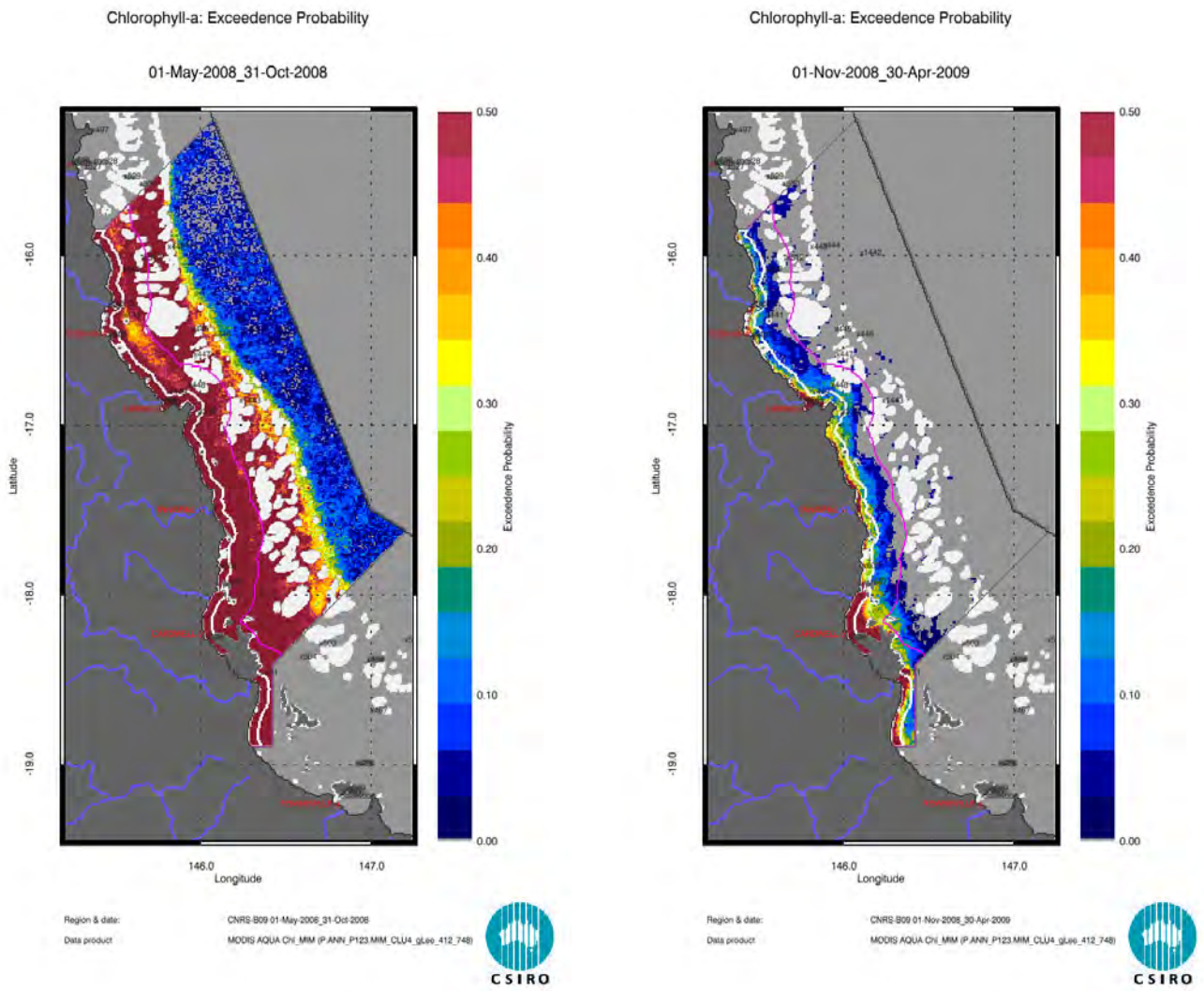


Figure 35. Chlorophyll exceedance probability maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

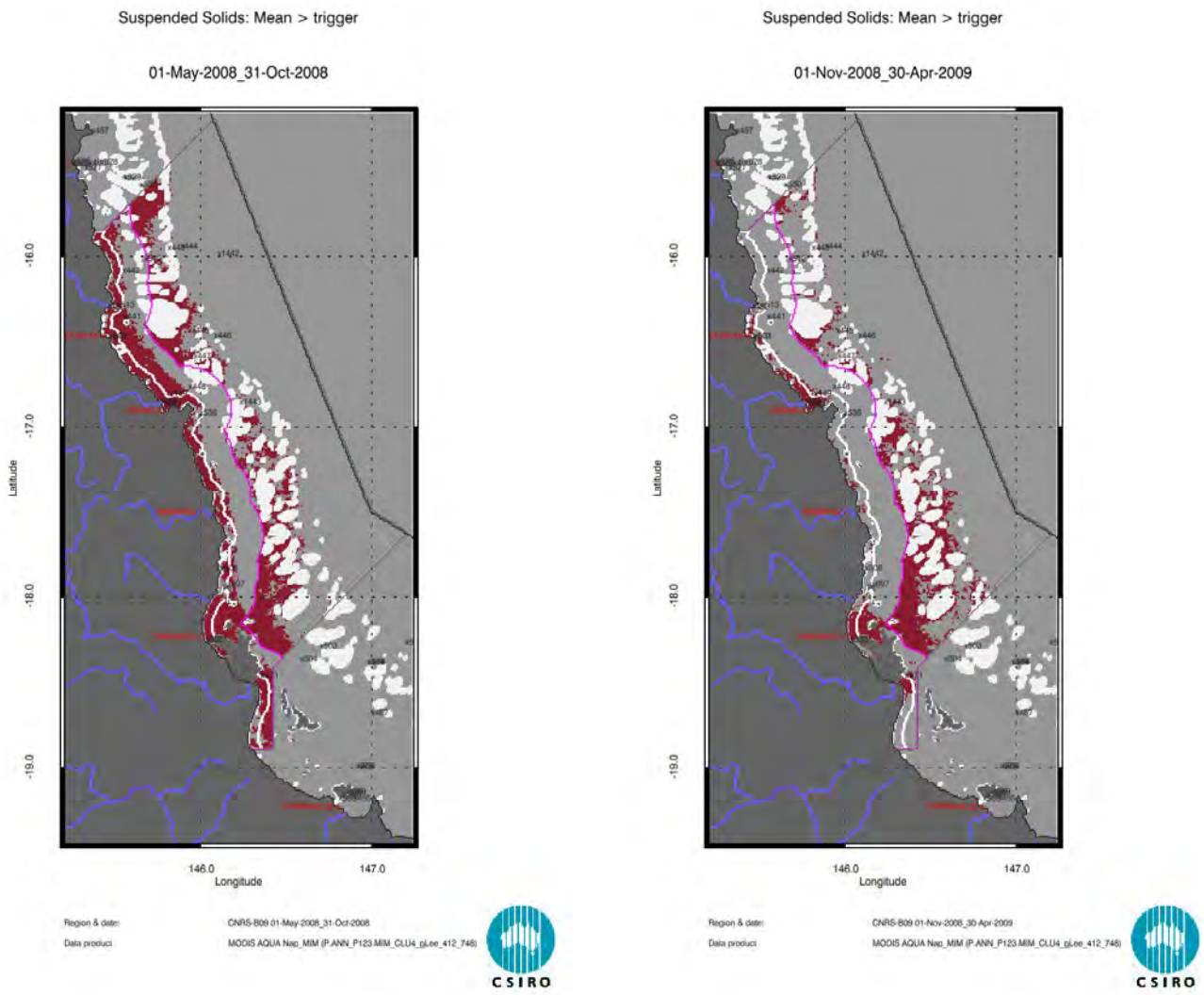


Figure 36. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

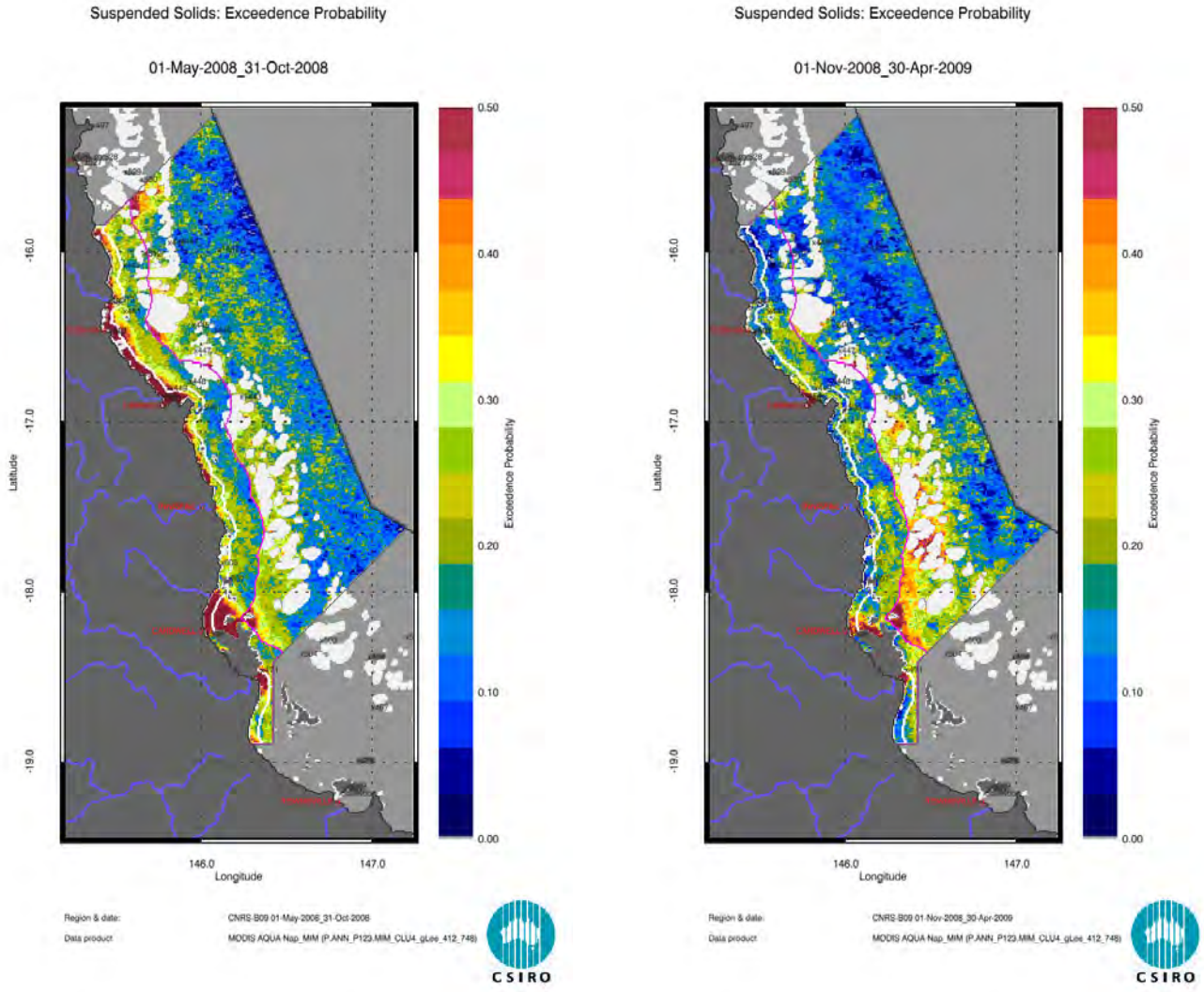


Figure 37. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance probability maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

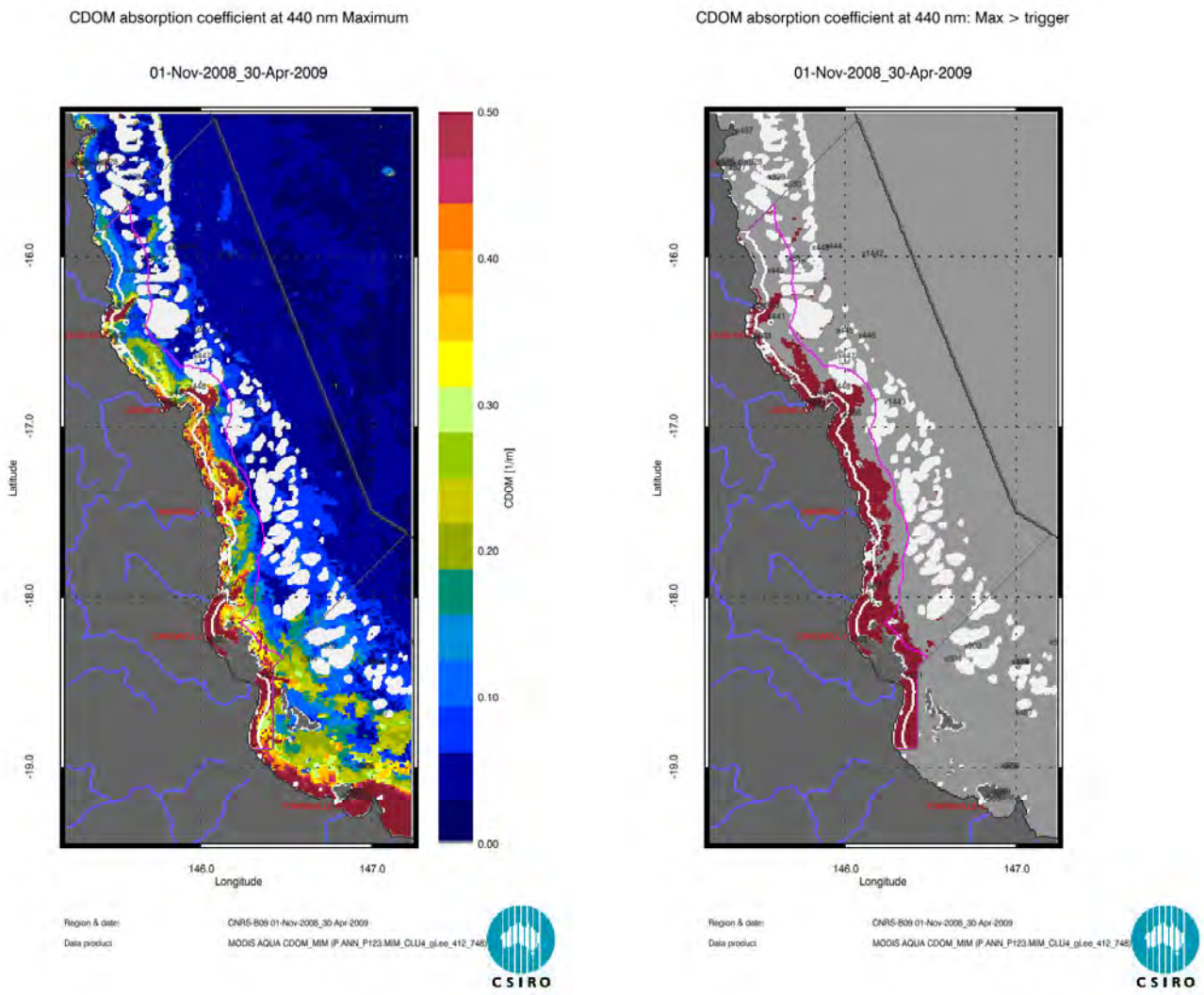


Figure 38. Map of flood extent for the wet season for the Wet Tropics region.. The first map presents the maximum value of CDOM for the Wet Season 2008/2009 (November 2008- April 2009), while the second map presents flood extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m-1. See 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, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of chlorophyll (Figure 39) for the Burdekin region show high chlorophyll 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 reef matrix ranged ~0.15-0.25 μgL^{-1}. The lobe of rwelatively high chlorophyll 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 40) for the Burdekin region show values higher than 0.20 m^{-1} in for a costal 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 matter) (Figure 41) for the Burdekin region show similar gross patterns as for the CDOM distribution..

The wet and dry season median maps of vertical attenuation of light (Figure 42) for the Burdekin region show similar gross patterns as for the chlorophyll, 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 43) for the Burdekin region show similar gross patterns to the maps of vertical attenuation of light (Figure 42).

The maps in Figure 44 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.

Assessment of the exceedance of water quality guidelines

The exceedance of water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA using CSIRO's algorithm.

Figure 45 presents the maps of Chlorophyll exceedance as defined by the guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 46 presents the map of the Exceedence Probability for Chlorophyll. This map reports in a continuous colour scale the Number of day 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 Suspended solids (using Non-algal particulate matter as a measure of Suspended Solids, Figure 47 and Figure 48).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 39, Figure 41) and by the steep changes in trigger values between the Midshelf and Offshore areas.

For the Burdekin region the mean values of Chlorophyll 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 of Chlorophyll also exceeded the guidelines for 36 % of the Midshelf and 11% of the Offshore areas (Figure 45, Table 15). Similar exceedance values were retrieved if the median was used for the assessment (Figure 46, Table 15).

The mean values of Suspended solids 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 47 and Table 16). No exceedance was recorded for the Midshelf and Offshore areas in both seasons if the median was used for the assessment , While the exceedance values for the Open Coastal Area where significantly lower (37% for the dry season and 10% for the wet season, Figure 48, and Table 16).

Table 17 and Table 18 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 Exceedence Probability for that period. These metrics are based on a high number of observations (ranging from 180 Thousands valid observations for Open Coastal in the wet season to over 1.7 Million for the Offshore are in the dry season). According to these metrics both the mean and the median values of Chlorophyll exceeded the guidelines values for the Open Coastal area in both seasons. The mean and median values for the Suspended solids concentration differed substantially (for all regions and seasons. The mean values were ~ 2 times higher than medians.

Assessment of flood extent during the wet season

Figure 49 reports the flood extent for wet Season 2008/2009 (November 2008- April 2009) for the Burdekin region. The flood extent was estimated applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum.

For the Burdekin region the flood extent for the Wet Season 2008/2009 (November 2008- April 2009) was 10195 km^2 while in the Wet Season 2007/2008 (November 2007 - April 2008) was 8027 km^2 (Figure 15).This reflects the high freshwater discharge from the Burdekin River that was more than five times the annual median flow(Figure 14).

Table 14 Summary of the annual exceedance maps for Chlorophyll 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-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4463	532814	1343109	54%	53%
MS	11524	1509959	3751035	1%	2%
OS	32239	2156319	9003840	0%	0%

Table 15 Summary of the exceedance maps for Chlorophyll for the dry and wet season for the Burdekin region (Figure 45, Figure 46). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4463	357625	716021	76%	80%	175145	623920	36%	21%
MS	11524	993498	2002765	34%	52%	516458	1747952	0%	0%
OS	32239	1358097	4807360	11%	10%	798222	4196480	0%	0%

Table 16 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Suspended solids) for the dry and wet season for the Burdekin region (Figure 47, Figure 48). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	4463	357625	716021	75%	37%	175145	623920	50%	10%
MS	11524	993498	2002765	10%	0%	516458	1747952	2%	0%
OS	32239	1358097	4807360	4%	0%	798222	4196480	6%	0%

Table 17. Summary of Chlorophyll exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	366623	807803	**0.648**	**0.480**	57%	179353	705154	**0.679**	**0.483**	56%
MS	1012902	2085844	0.306	0.317	10%	526671	1820792	0.327	0.255	14%
OS	1702506	5835259	0.241	0.203	9%	1004763	5093762	0.242	0.204	10%

Table 18 Summary of Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	366623	807803	0.132	0.061	19%	179353	705154	0.140	0.059	18%
MS	1012902	2085844	0.025	0.021	0%	526671	1820792	0.041	0.025	2%
OS	1702506	5835259	0.025	0.021	0%	1004763	5093762	0.029	0.022	0%

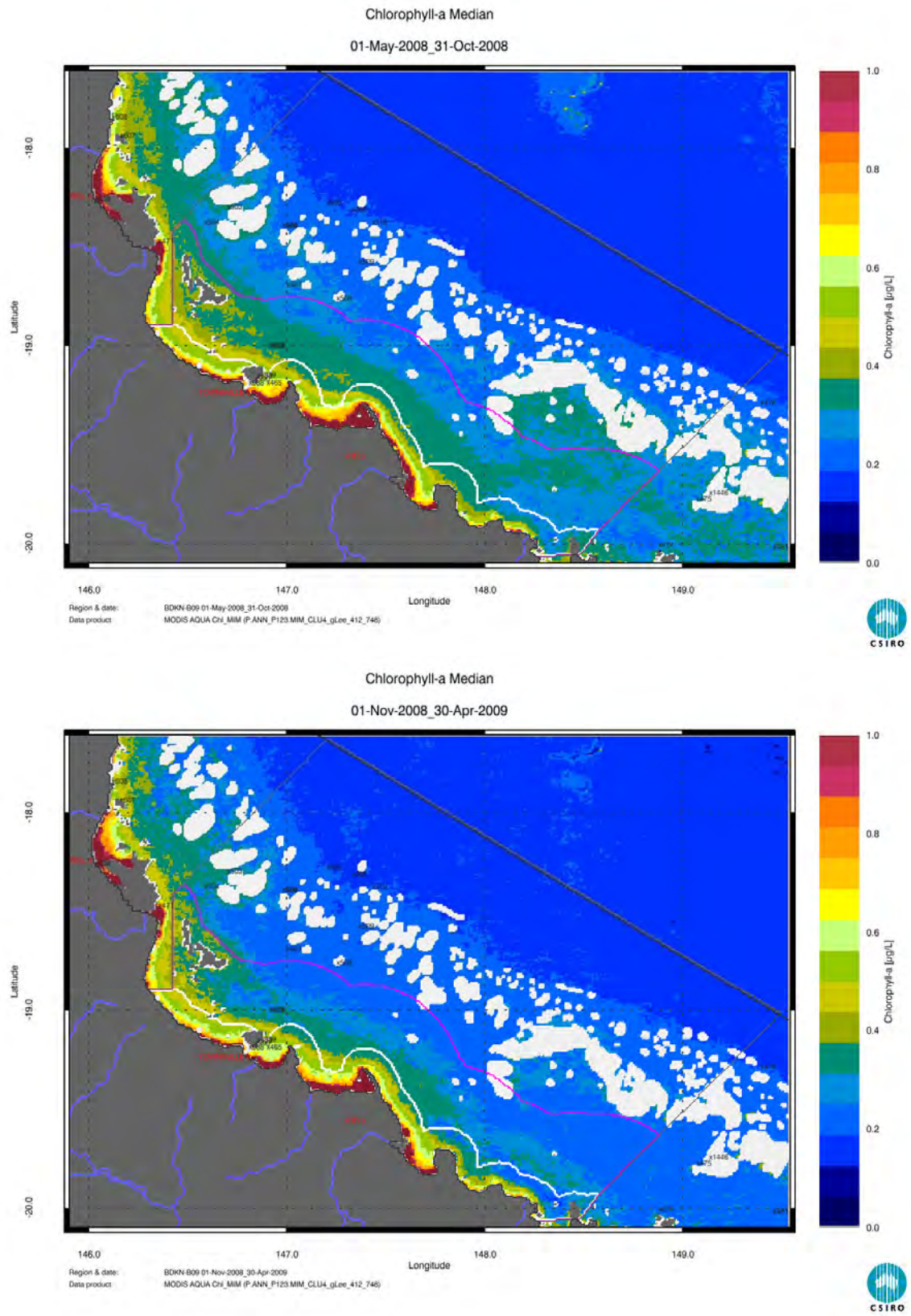


Figure 39. Chlorophyll Median maps for the dry and wet season for the Burdekin region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

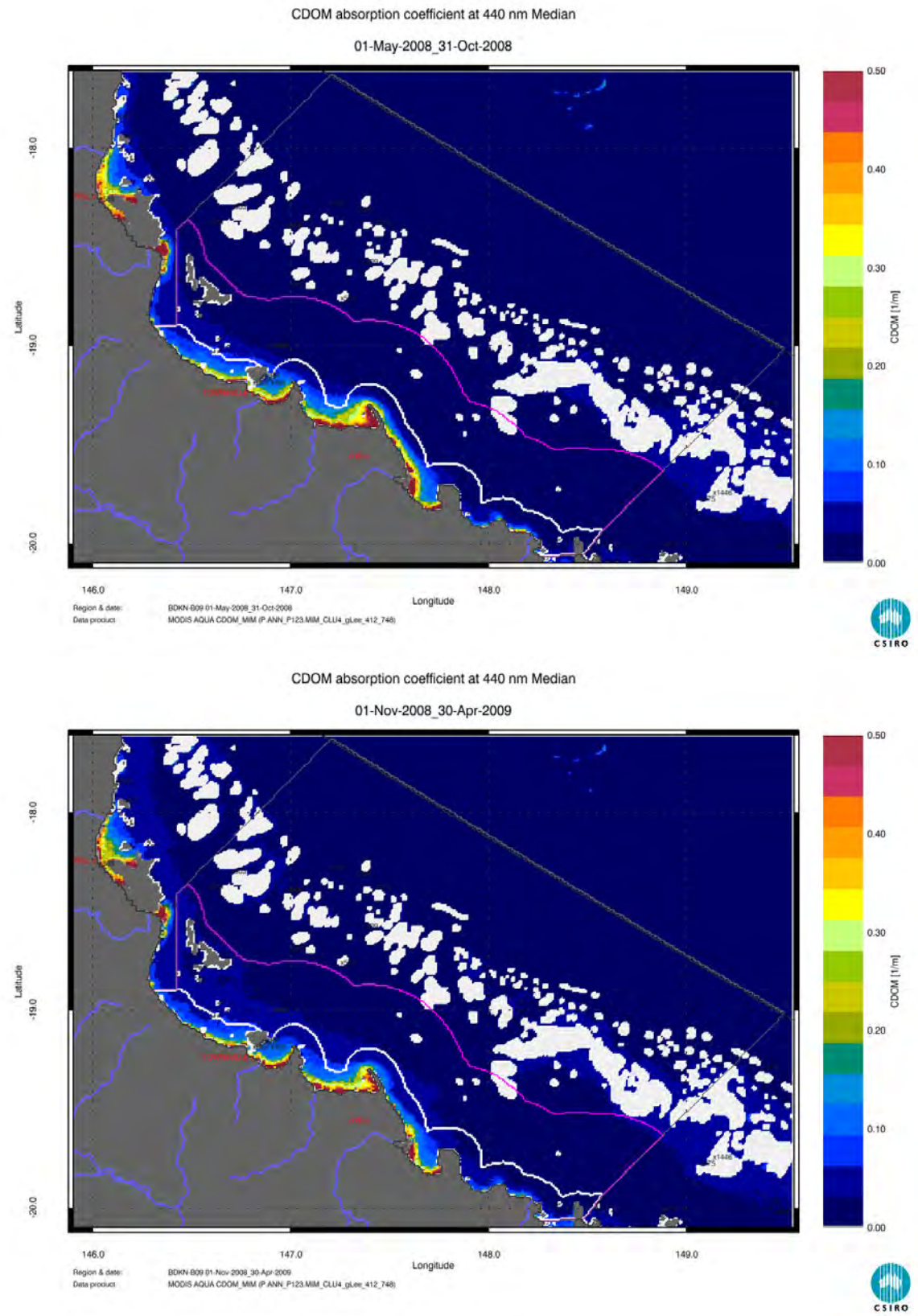


Figure 40. CDOM Median maps for the dry and wet season for the Burdekin region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

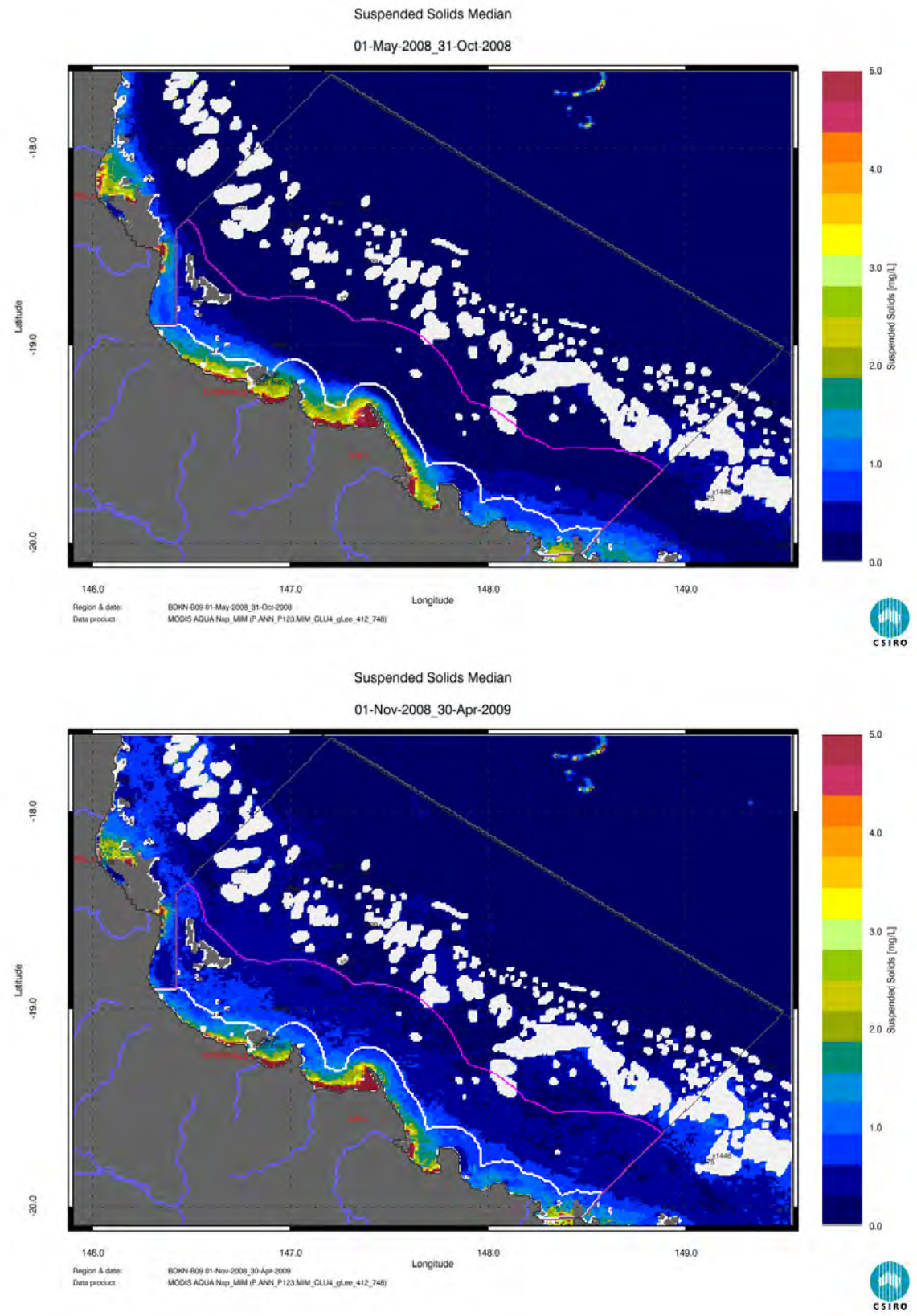


Figure 41. Non-algal particulate matter (Nap as a measure of Suspended solids) Median maps for the dry and wet season for the Burdekin region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

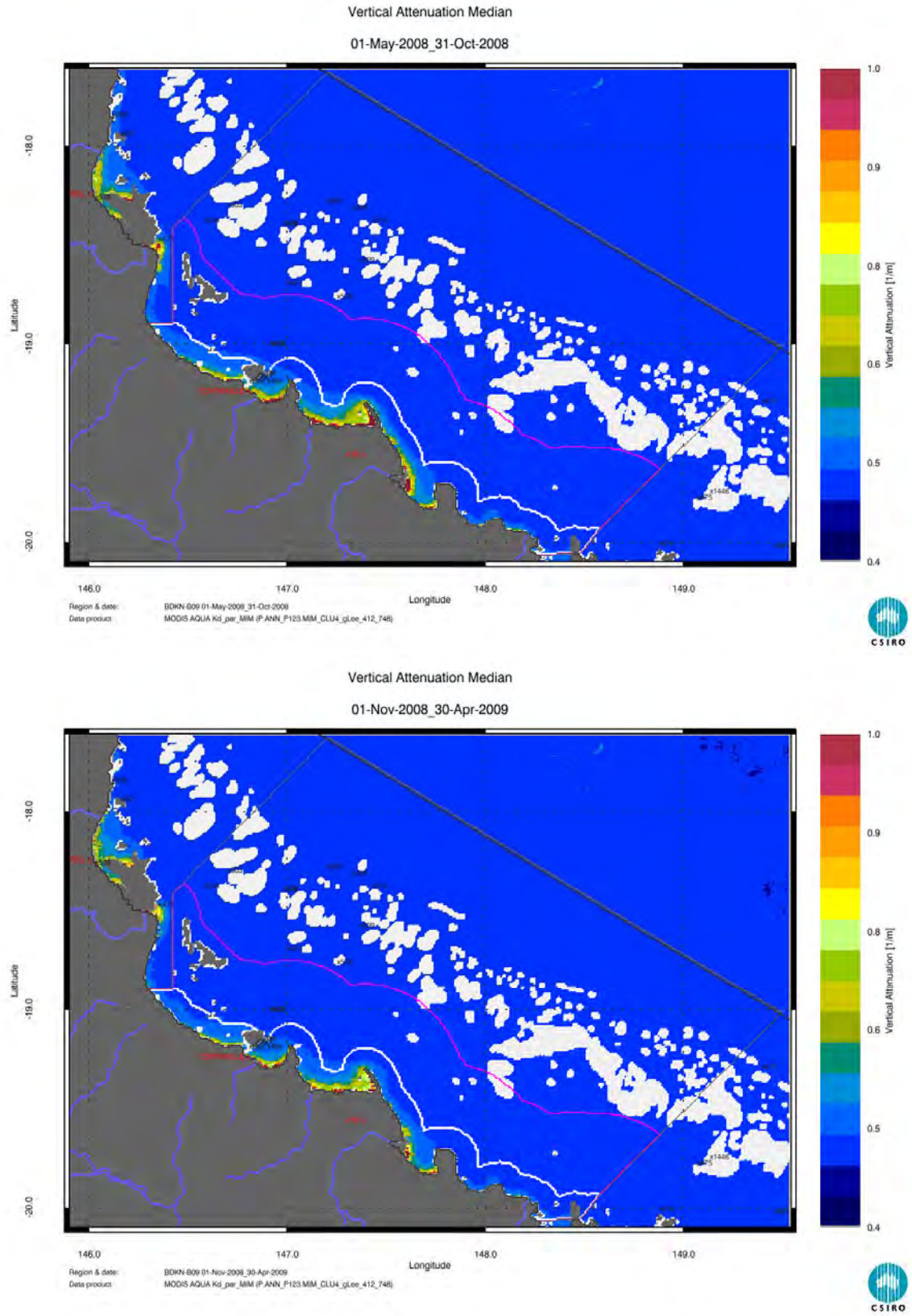


Figure 42. Vertical attenuation of light (Kd ,as estimate of water clarity) Median maps for the dry and wet season for the Burdekin region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

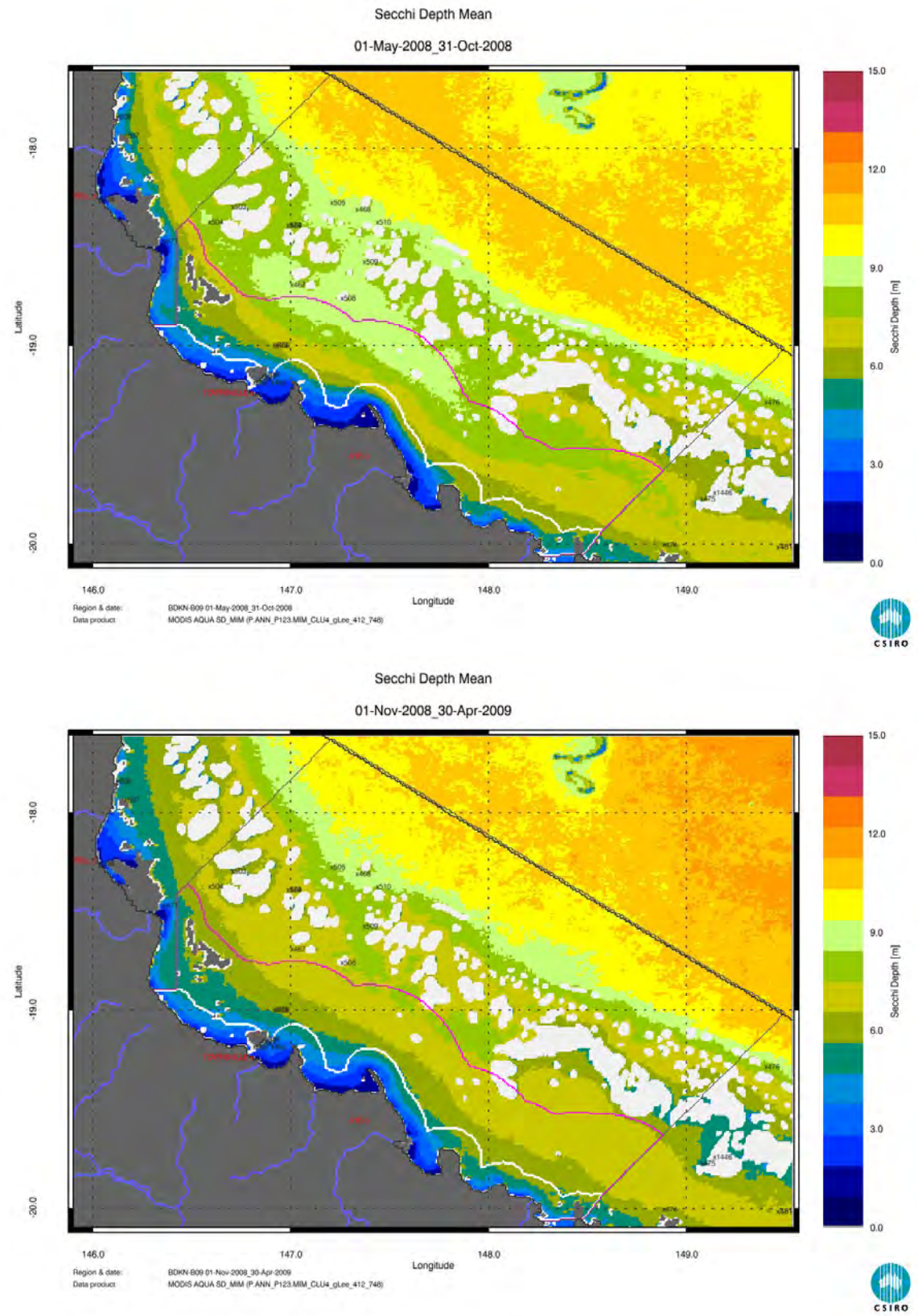


Figure 43. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Burdekin region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

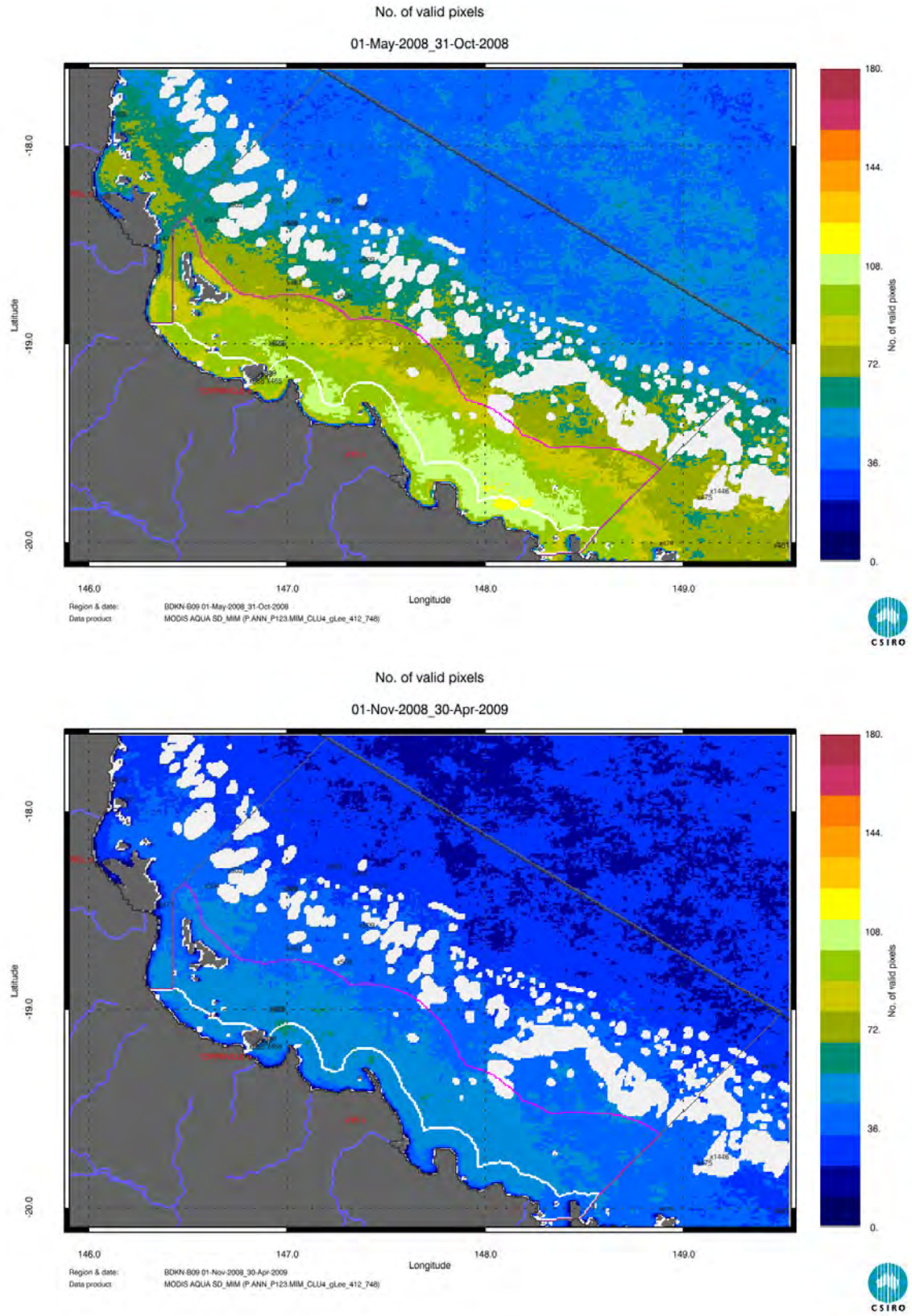


Figure 44. Number of pixels used to calculate the Median maps (Figure 39 - Figure 43) for the dry and wet season for the Burdekin region. The first map presents the number of pixels available for analysis in the Dry Season 2008 (May - October), while the second map presents the number of pixels available for analysis in the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

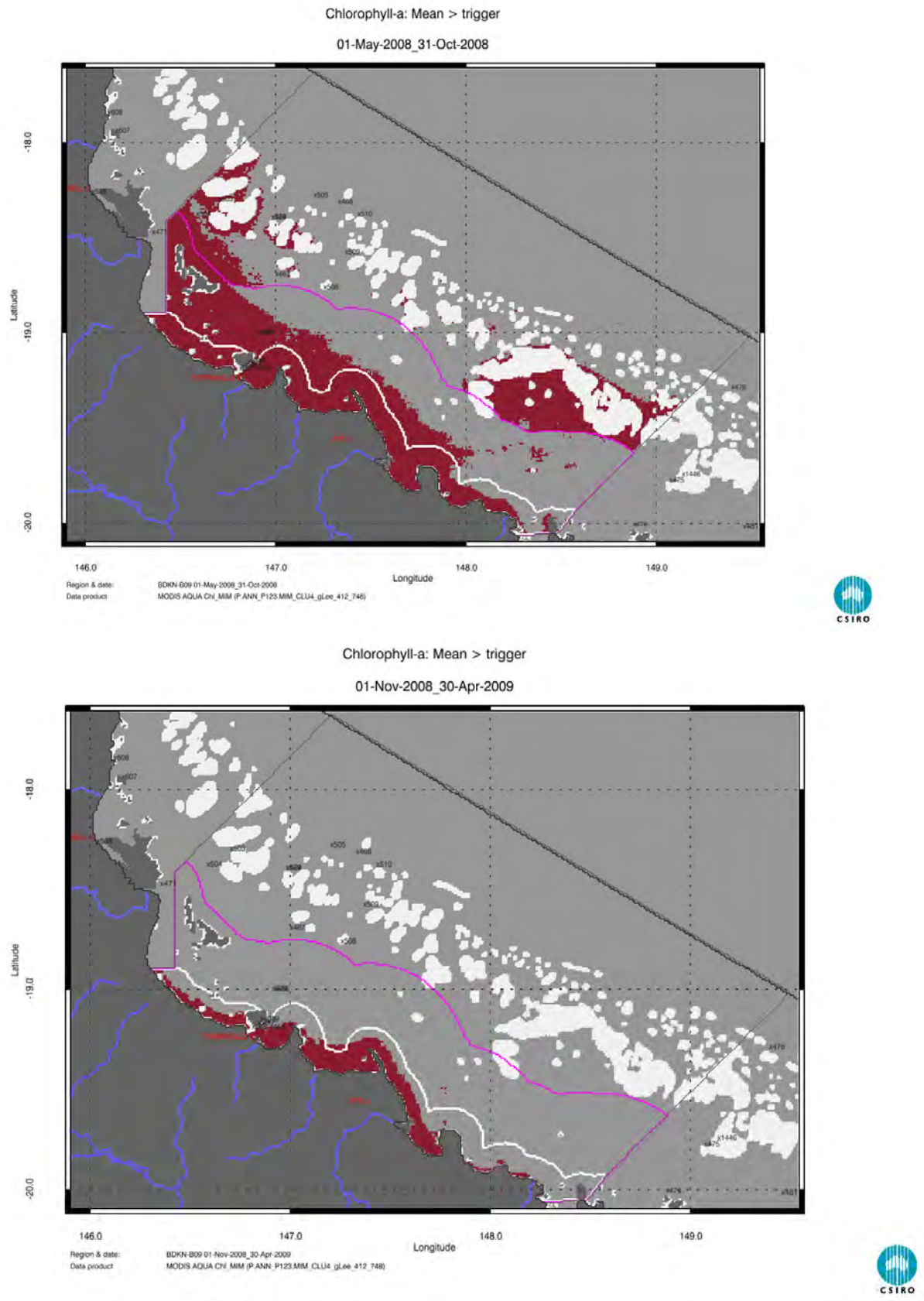


Figure 45. Chlorophyll exceedance maps for the dry and wet season for the Burdekin region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

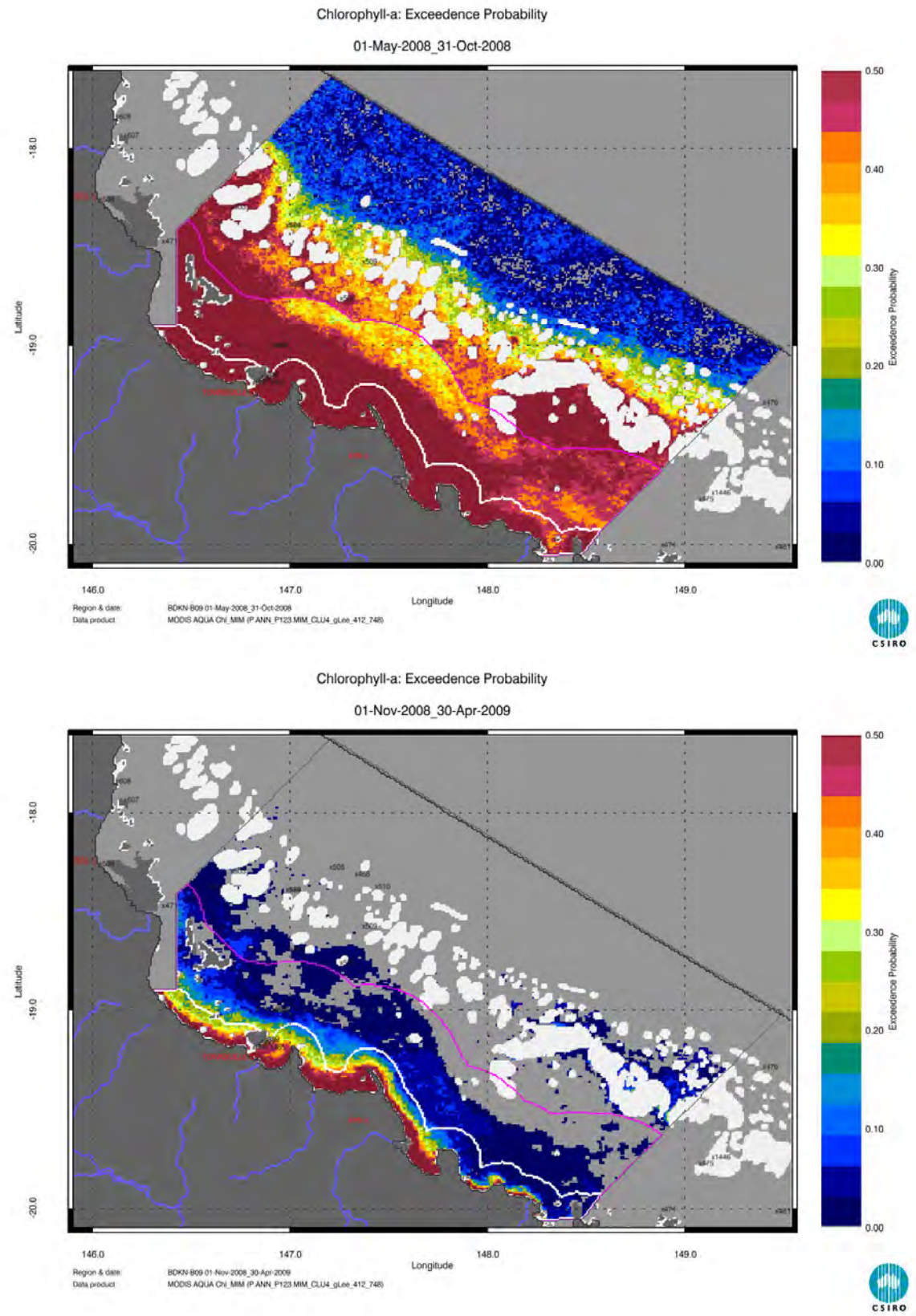


Figure 46. Chlorophyll exceedance probability maps for the dry and wet season for the Burdekin region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

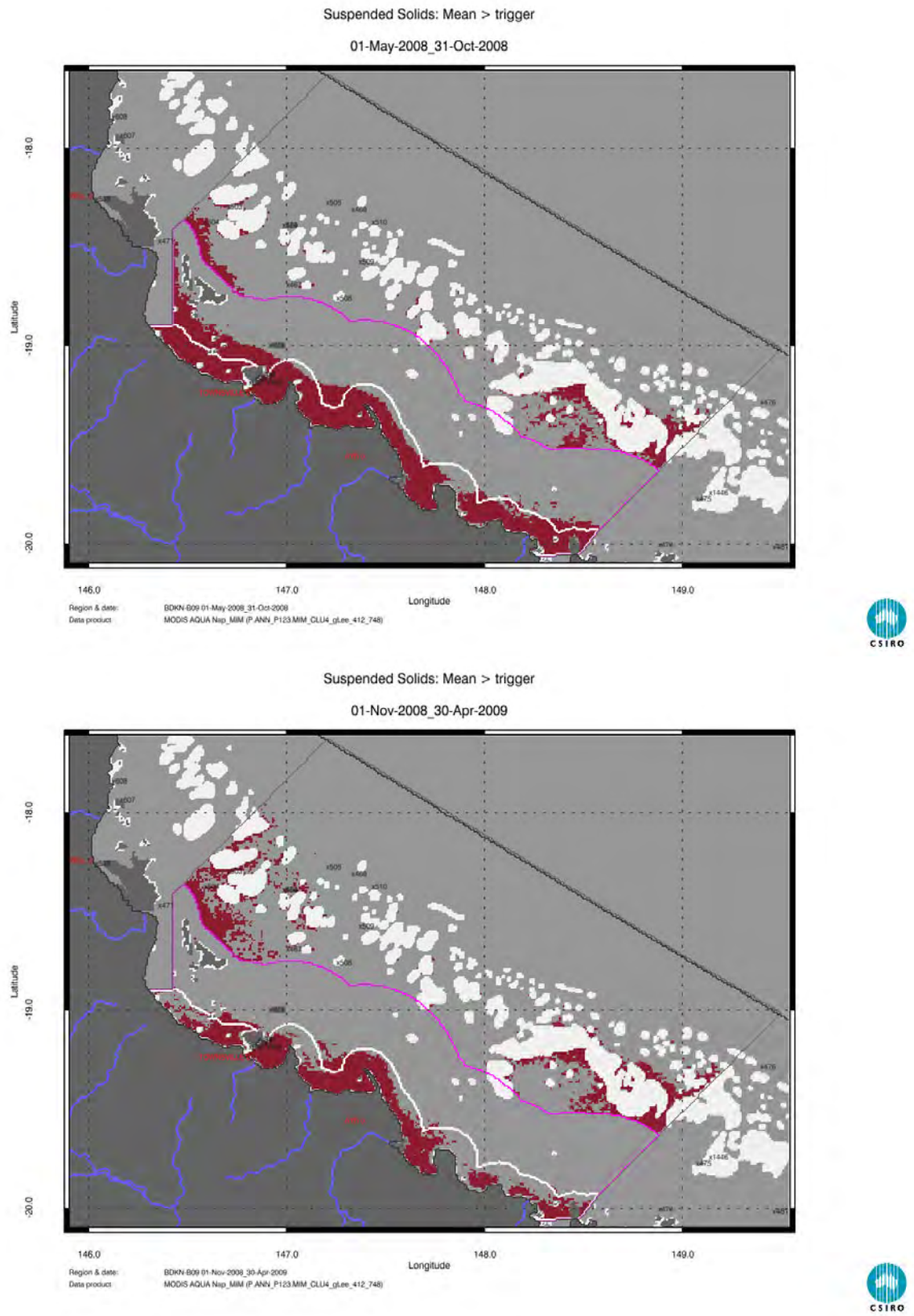


Figure 47. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance maps for the dry and wet season for the Burdekin region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

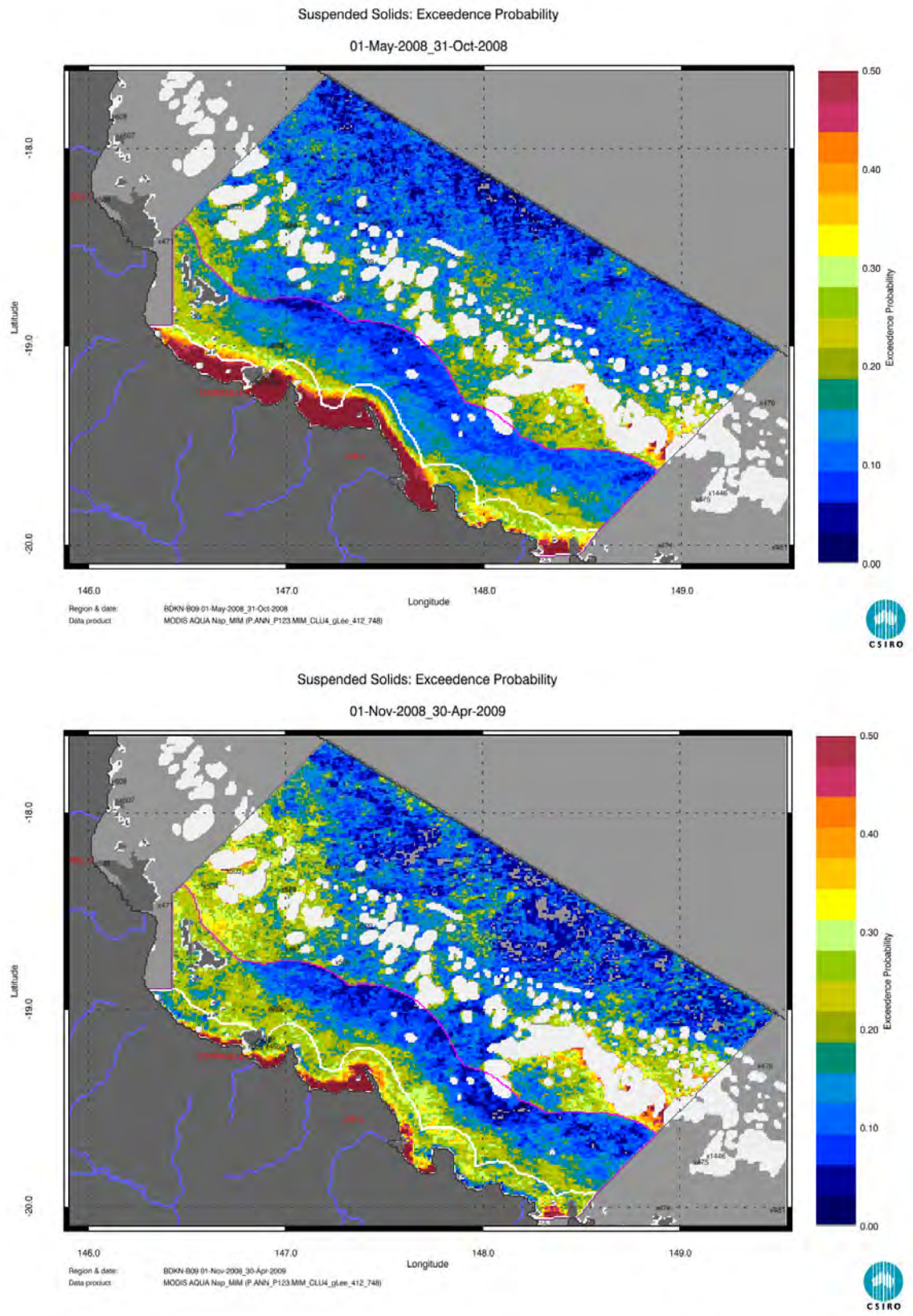


Figure 48. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance probability maps for the dry and wet season for the Burdekin region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

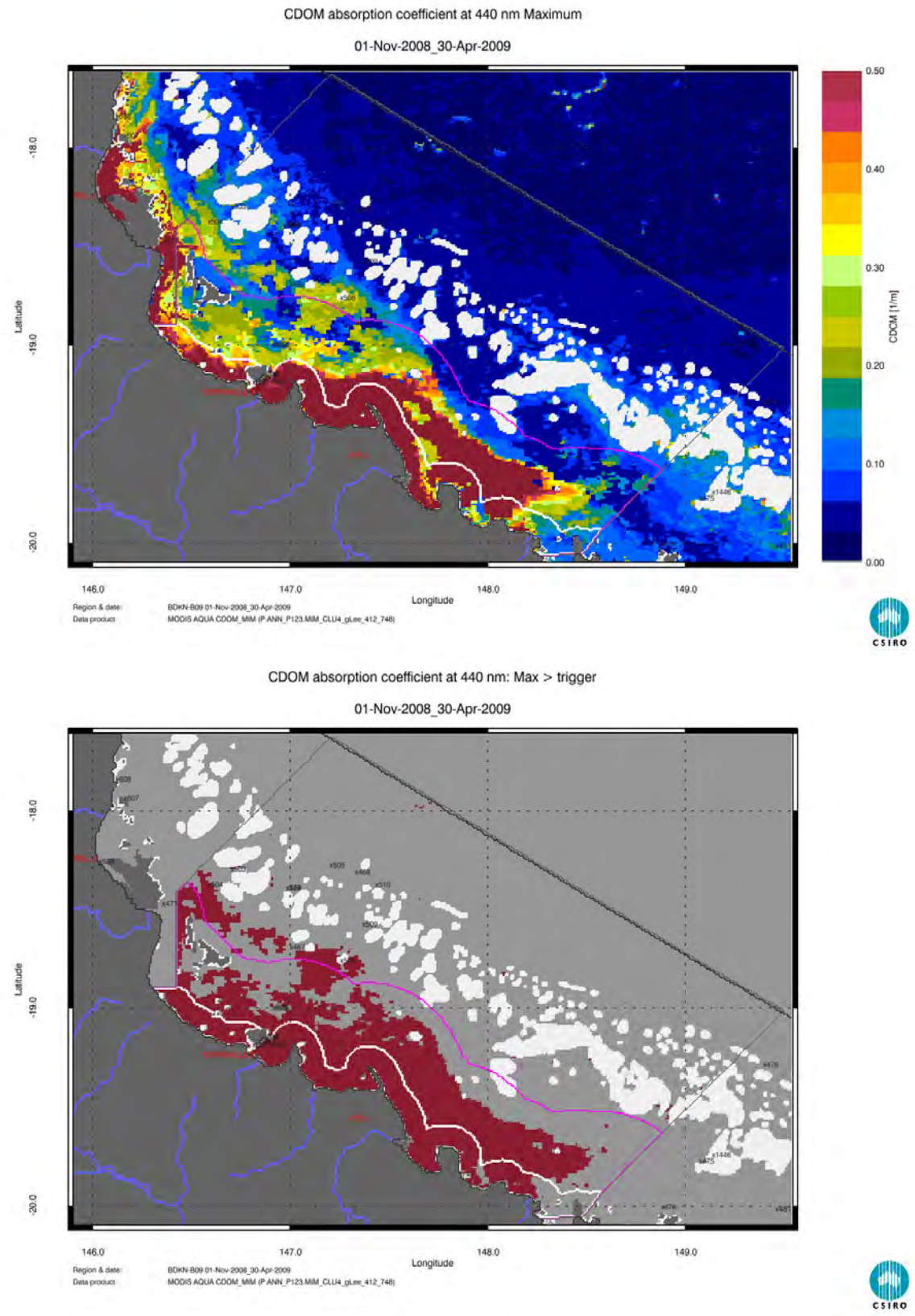


Figure 49. Map of flood extent for the wet season for the Burdekin region. The first map presents the maximum value of CDOM for the Wet Season 2008/2009 (November 2008- April 2009), while the second map presents flood extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m-1. See text 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, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of chlorophyll (Figure 50) for the Mackay Whitsunday region show high chlorophyll 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 reef matrix ranged ~0.15-0.25 μgL^{-1}. The lobe of relatively high chlorophyll 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 51) for the Mackay Whitsunday region show values higher than 0.20 m^{-1} in for a costal band ~5-10 km wide.

The wet and dry season median maps of non-algal particulate matter (as a measure of total suspended matter) (Figure 52) for the Mackay Whitsunday region show similar gross patterns as for the CDOM distribution..

The wet and dry season median maps of vertical attenuation of light (Figure 53) for the Mackay Whitsunday region show similar gross patterns as for the chlorophyll, 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 54) for the Mackay Whitsunday region show similar gross patterns to the maps of vertical attenuation of light (Figure 53).

The maps in Figure 55 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.

Assessment of the exceedance of water quality guidelines

The exceedance of water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA using CSIRO's algorithm.

Figure 56 presents the maps of Chlorophyll exceedance as defined by the guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 57presents the map of the Exceedence Probability for Chlorophyll. This map reports in a continuous colour scale the Number of day 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 Suspended solids (using Non-algal particulate matter as a measure of Suspended Solids, Figure 58 and Figure 59).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 50, Figure 52) and by the steep changes in trigger values between the Midshelf and Offshore areas. The mean values of Chlorophyll exceeded the guidelines in the wet season only in correspondence to the river mouths: Proserpine and O'Connell, Pioneer and Plane Rivers

For the Mackay Whitsunday region the mean values of Chlorophyll exceeded the guidelines values for 67% of the Open Coastal area in the dry season and 12 % in the wet season. In the dry season Chlorophyll also exceeded the guidelines for 15 % of the Midshelf and 40% of the Offshore areas (Figure 56, Table 19, Table 20). Similar exceedance values were retrieved if the median was used for the assessment (Figure 57, Table 19, Table 20).

The mean values of Suspended solids 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 59, and Table 21).

Table 22 and Table 23 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 Exceedence Probability for that period. These metrics are based on a high number of observations (ranging from 210 Thousands valid observations for Open Coastal area in the wet season to over 2.1 Million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll exceeded the guidelines values for the Open Coastal area in both seasons, while the mean values of Suspended solids exceeded the guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the Suspended solids concentration differed substantially (for all regions and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of flood extent during the wet season

Figure 60 reports the flood extent for wet Season 2008/2009 (November 2008- April 2009) for the Mackay-Whitsunday region. The flood extent was estimated applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Mackay-Whitsunday region the flood extent for the Wet Season 2008/2009 (November 2008- April 2009) was 5626 km^2 while in the Wet Season 2007/2008 (November 2007 - April 2008) was 3779 km^2 (Figure 15). The larger flood extent in 2008/09 correlates with a freshwater discharge for the Proserpine, O'Connell, Pioneer and Plane Rivers above median flows (Figure 14).

Table 19 Summary of the annual exceedance maps for Chlorophyll 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-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5761	575561	1536704	24%	20%
MS	12869	1429099	3838093	3%	0%
OS	32396	2526710	8620460	0%	0%

Table 20. Summary of the exceedance maps for Chlorophyll for the dry and wet season for the Mackay Whitsunday region (Figure 56, Figure 57). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5761	385822	811485	67%	73%	189683	721024	12%	7%
MS	12869	955971	2027242	15%	30%	473124	1810531	1%	0%
OS	32396	1692871	4553240	40%	24%	833839	4067220	0%	0%

Table 21. Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Suspended solids) for the dry and wet season for the Mackay Whitsunday region (Figure 58, Figure 59). 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.

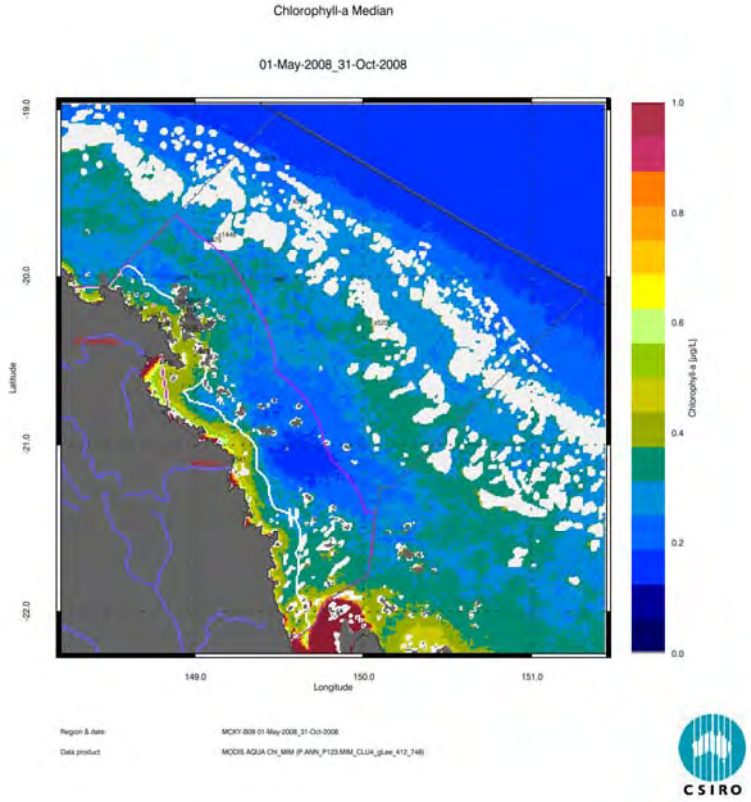
		01-May-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	5761	385822	811485	73%	44%	189683	721024	73%	24%
MS	12869	955971	2027242	59%	14%	473124	1810531	38%	0%
OS	32396	1692871	4553240	50%	7%	833839	4067220	53%	8%

Table 22. Summary of Chlorophyll exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	432216	1025458	0.45	0.40	35%	211557	915999	**0.45**	0.38	38%
MS	1026343	2290682	0.30	0.30	10%	507084	2046171	0.28	0.21	11%
OS	2149025	5766488	0.30	0.25	21%	1073927	5150964	0.28	0.22	19%

Table 23. Summary of Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	432216	1025458	**3.73**	1.73	42%	211557	915999	**5.95**	2.09	52%
MS	1026343	2290682	**2.68**	1.03	33%	507084	2046171	**3.47**	1.16	33%
OS	2149025	5766488	**1.17**	0.34	33%	1073927	5150964	**1.74**	0.60	45%



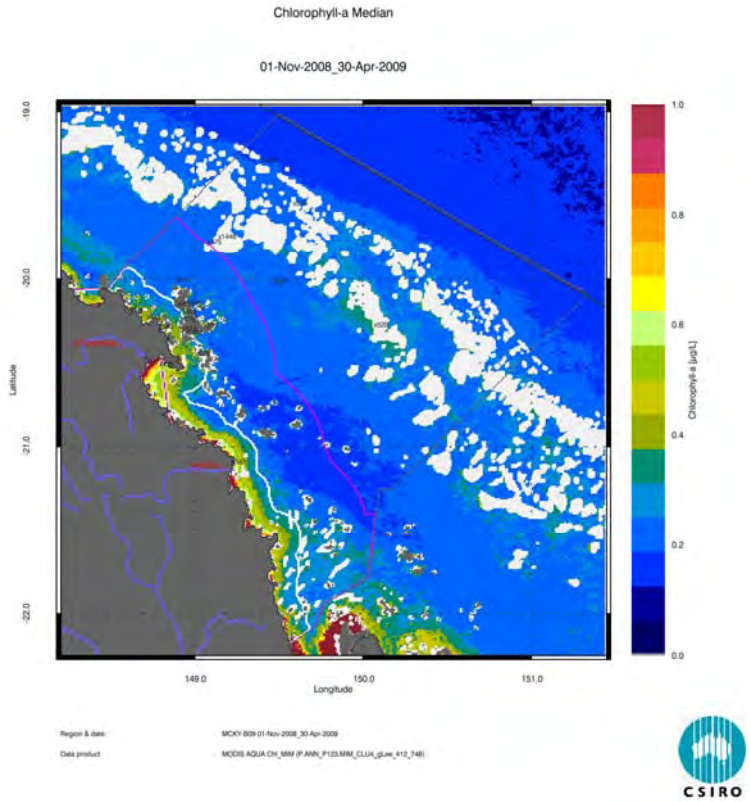
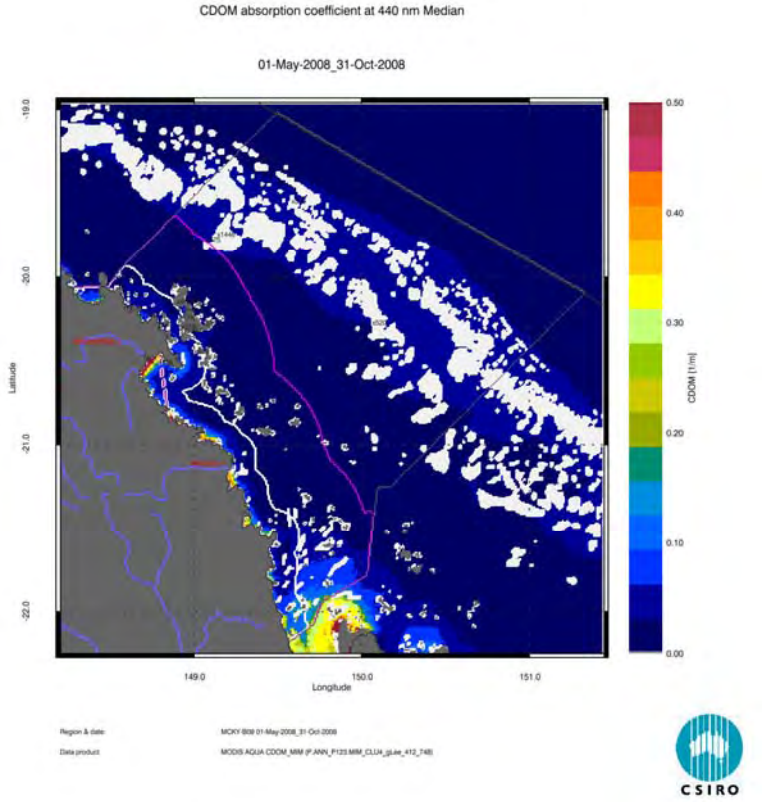


Figure 50. Chlorophyll Median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.



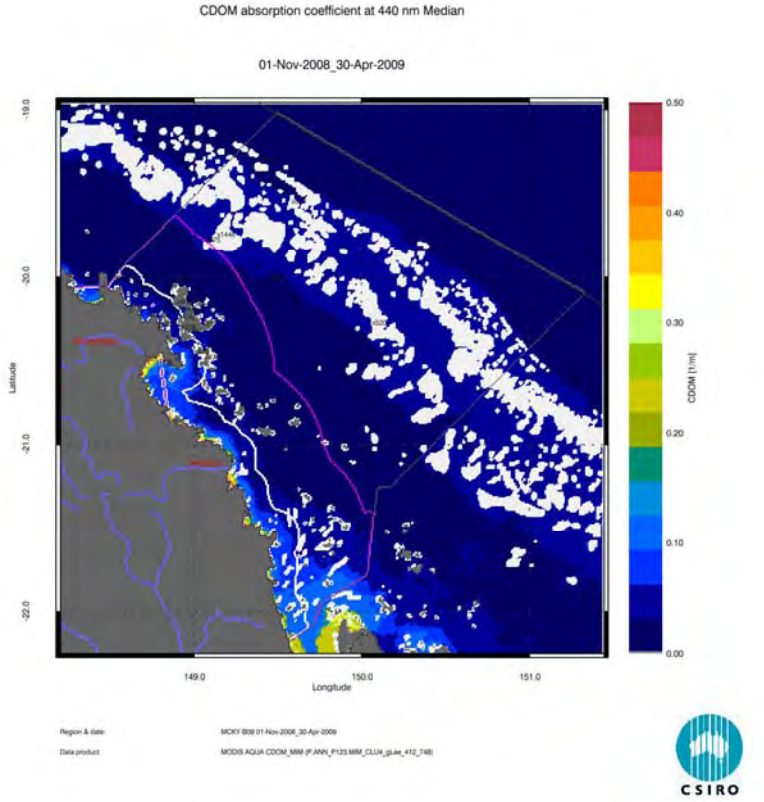


Figure 51. CDOM Median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

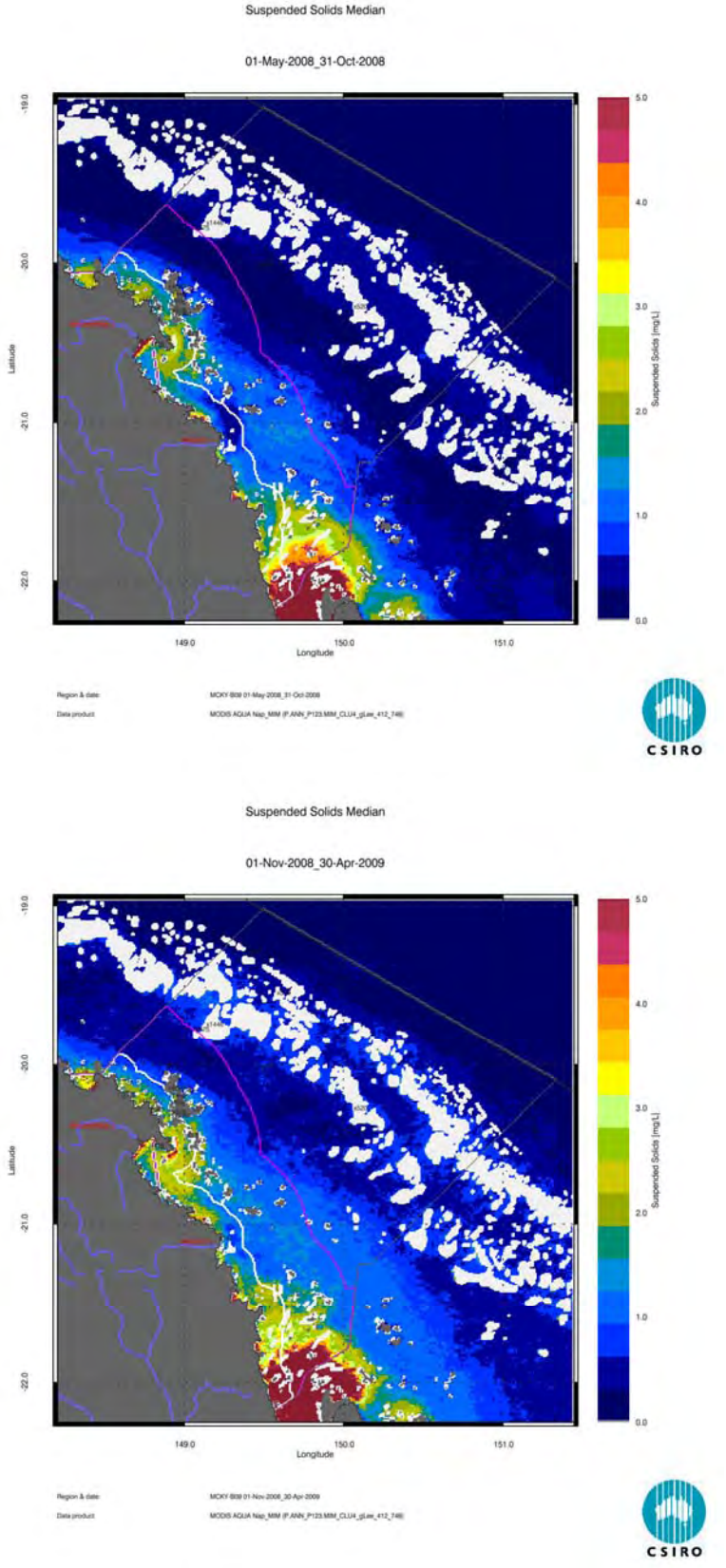


Figure 52. Non-algal particulate matter (Nap as a measure of Suspended solids) Median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

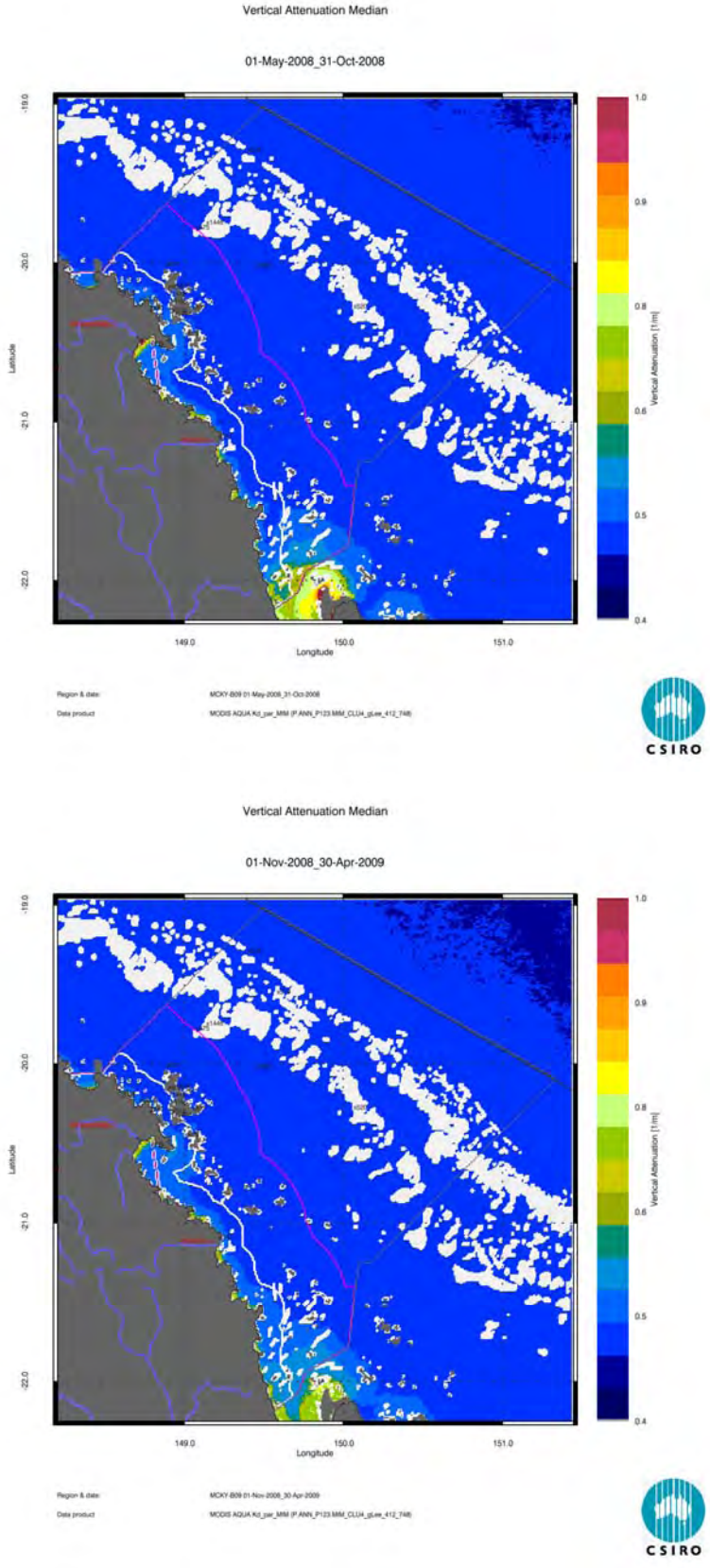


Figure 53. Vertical attenuation of light (Kd ,as estimate of water clarity) Median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

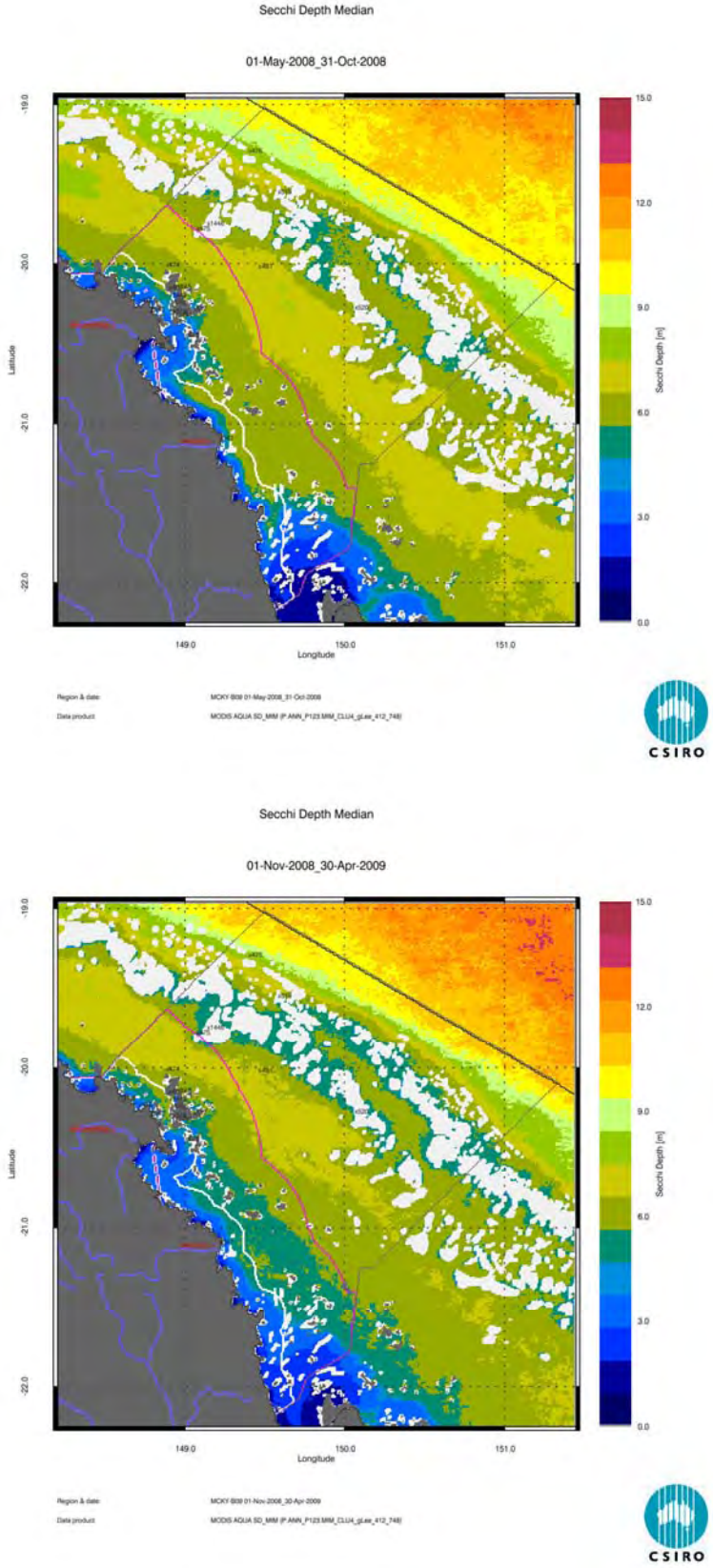
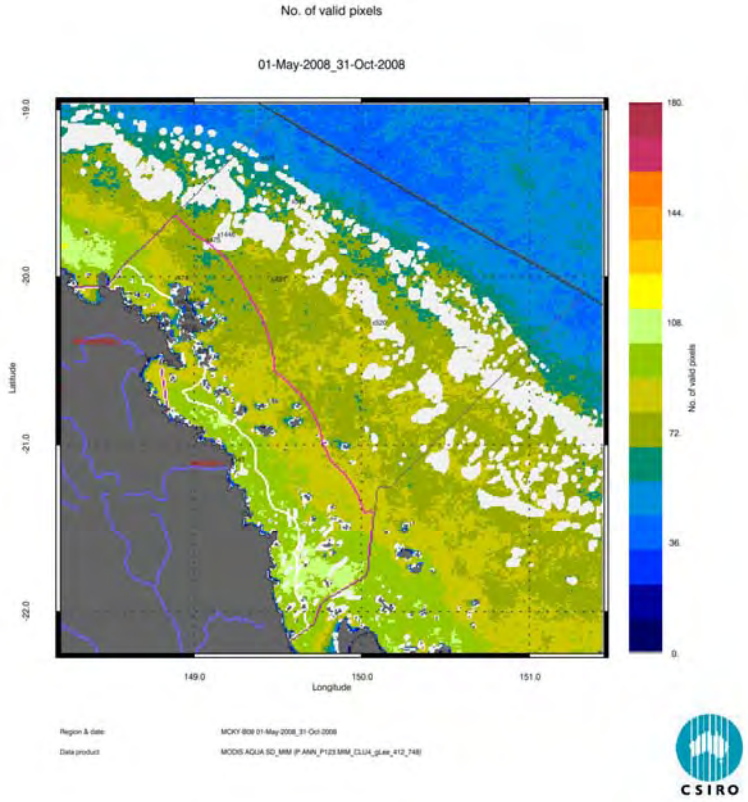


Figure 54. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.



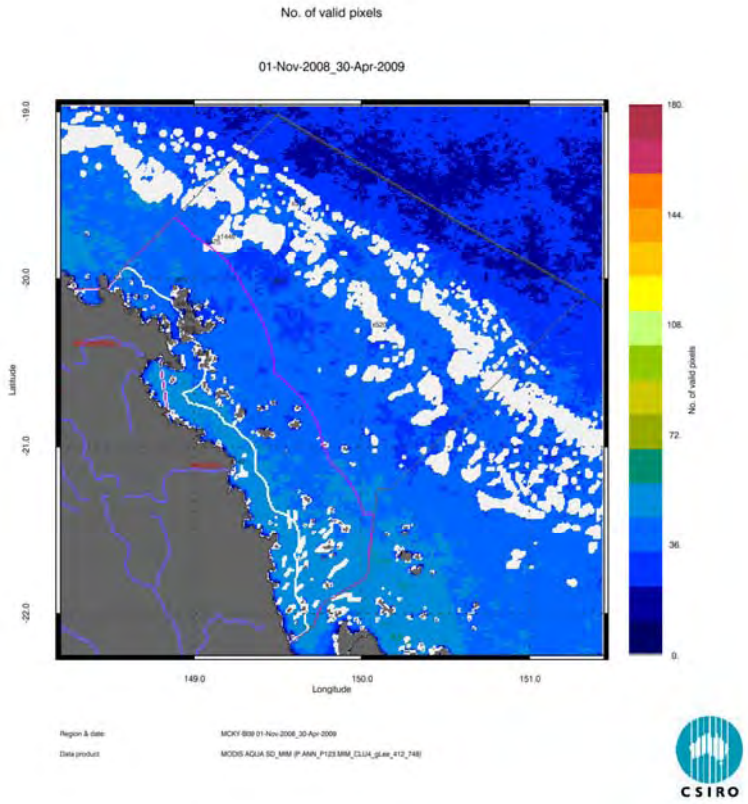
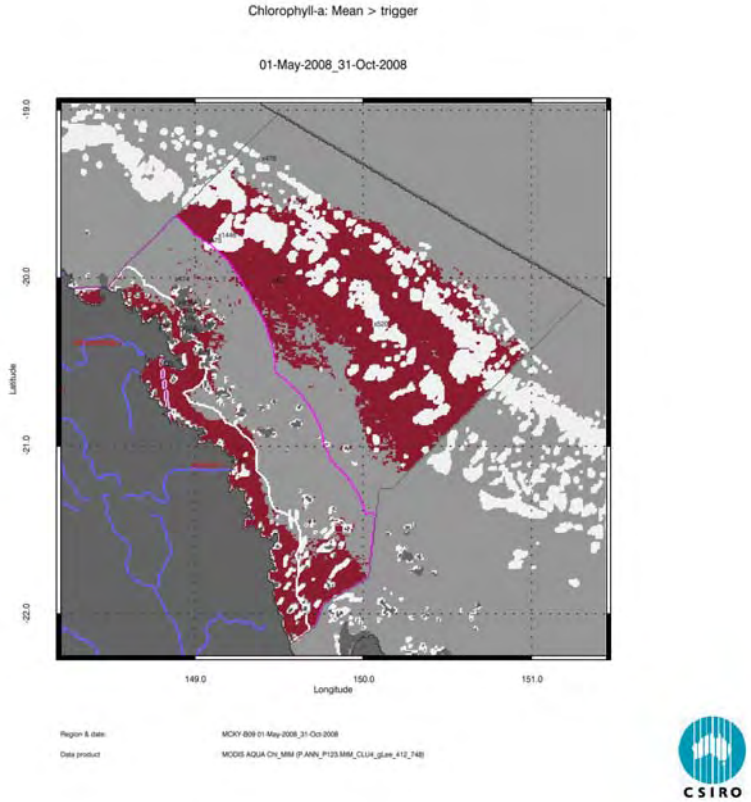


Figure 55. Number of pixels used to calculate the Median maps (Figure 50 -Figure 54) for the dry and wet season for the Mackay Whitsunday region. The first map presents the number of pixels available for analysis in the Dry Season 2008 (May - October), while the second map presents the number of pixels available for analysis in the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.



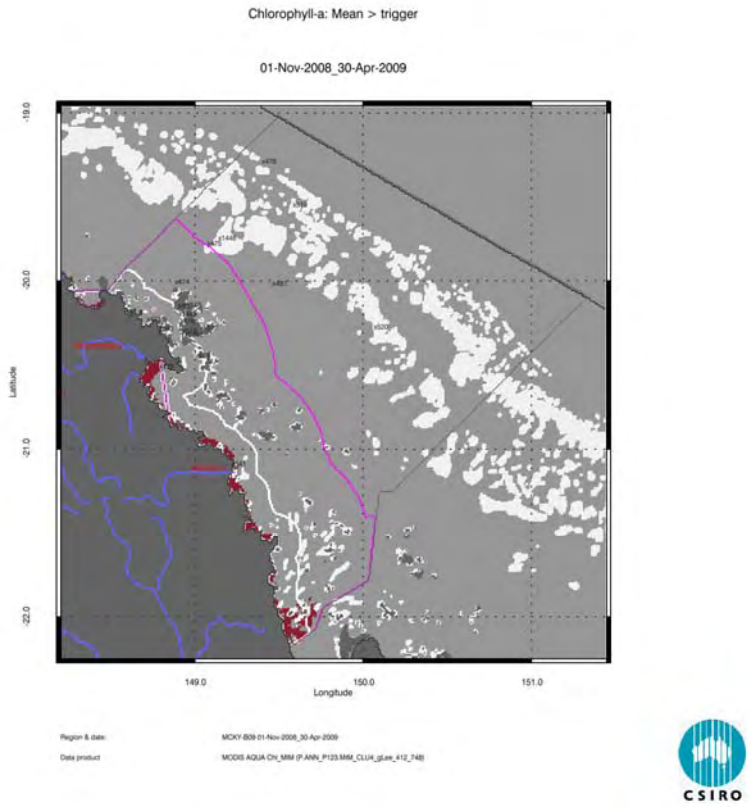


Figure 56. Chlorophyll exceedance maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

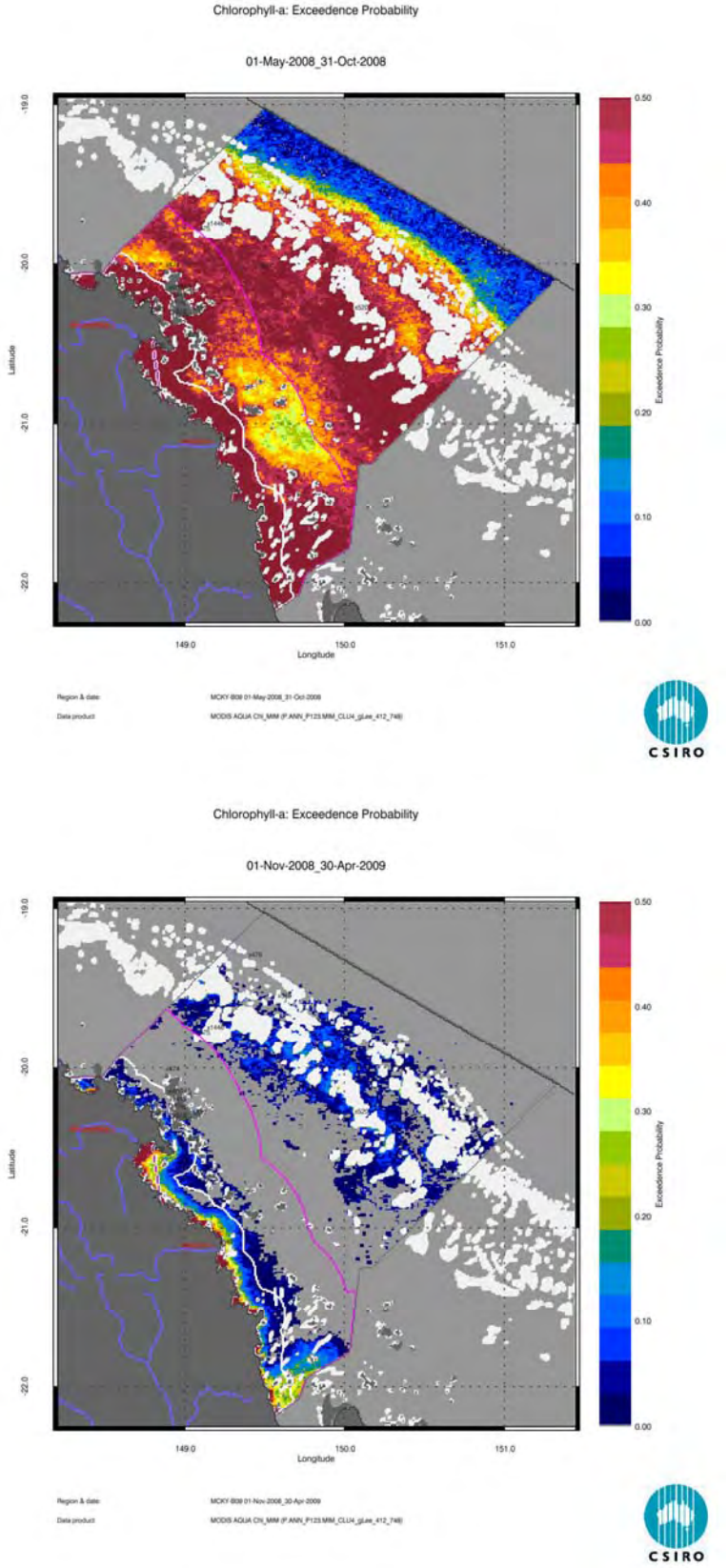
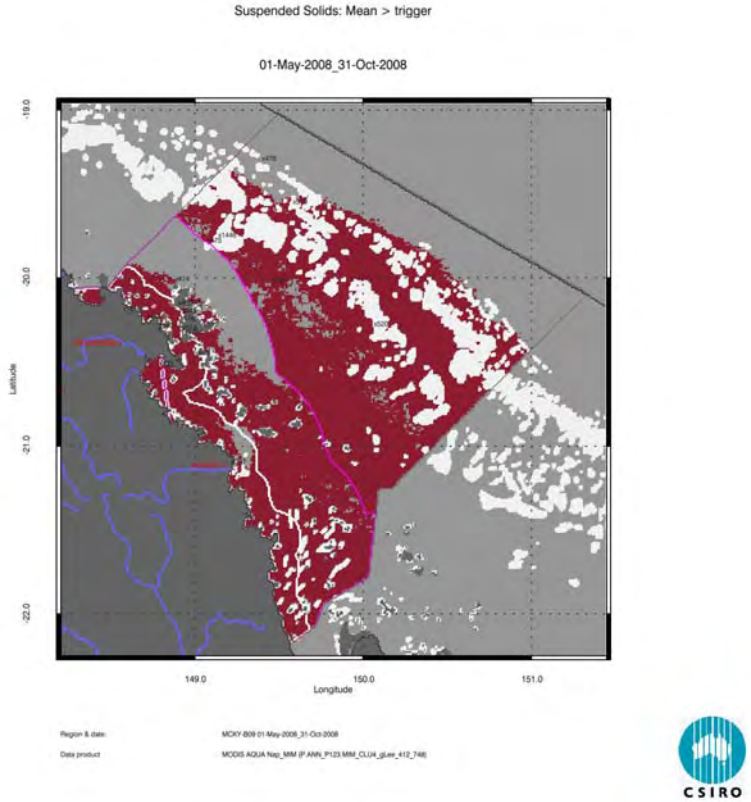


Figure 57. Chlorophyll exceedance probability maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.



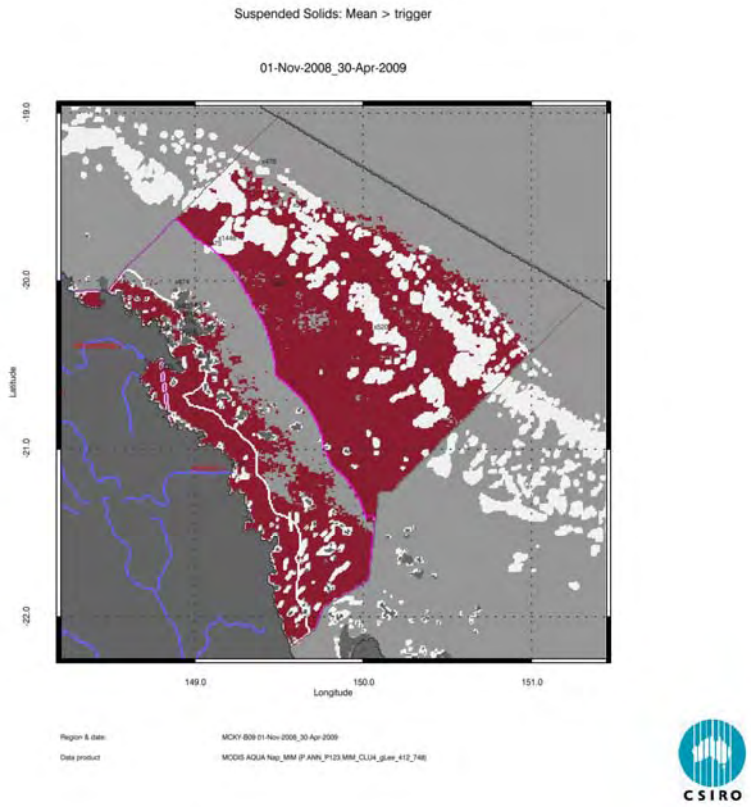


Figure 58. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

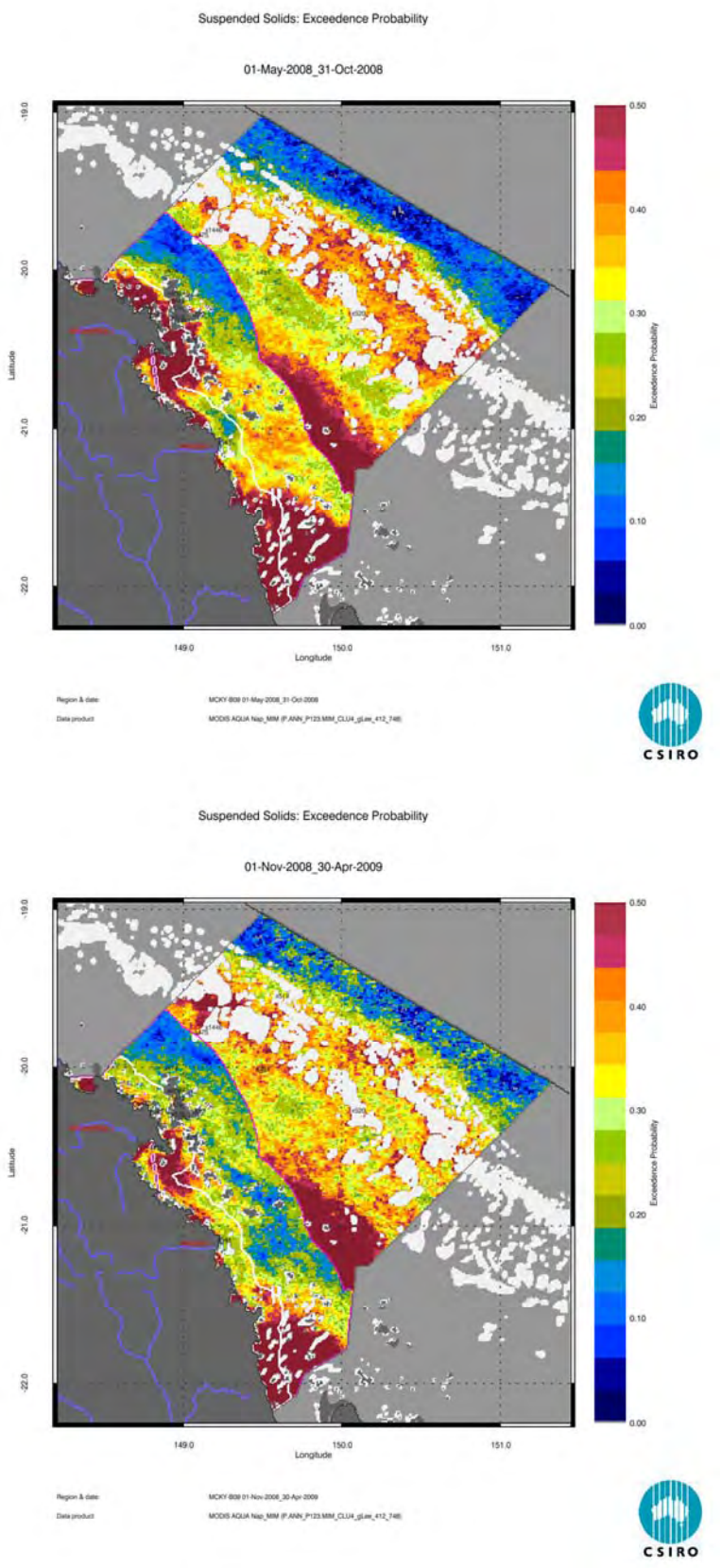
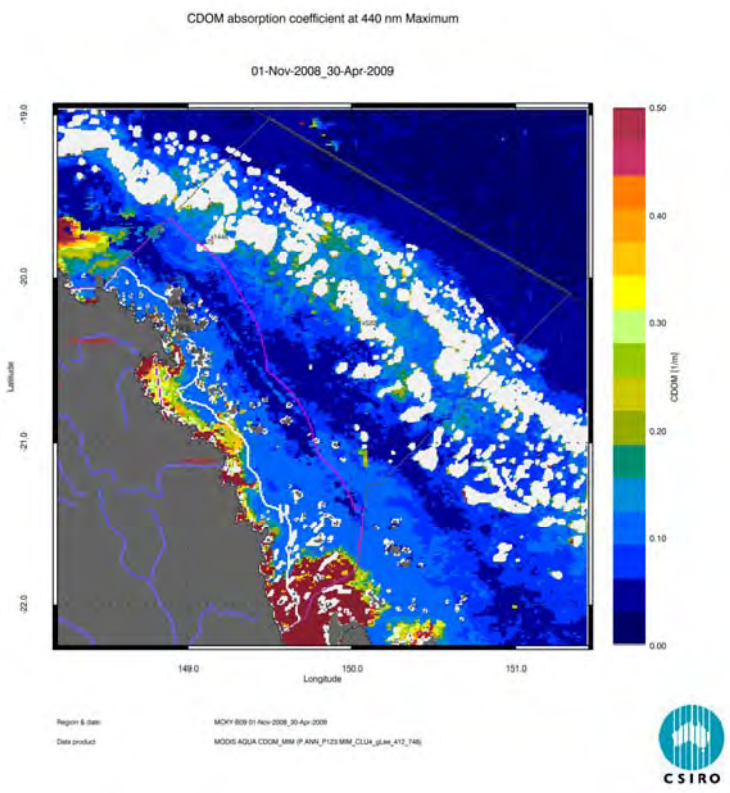


Figure 59. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance probability maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.



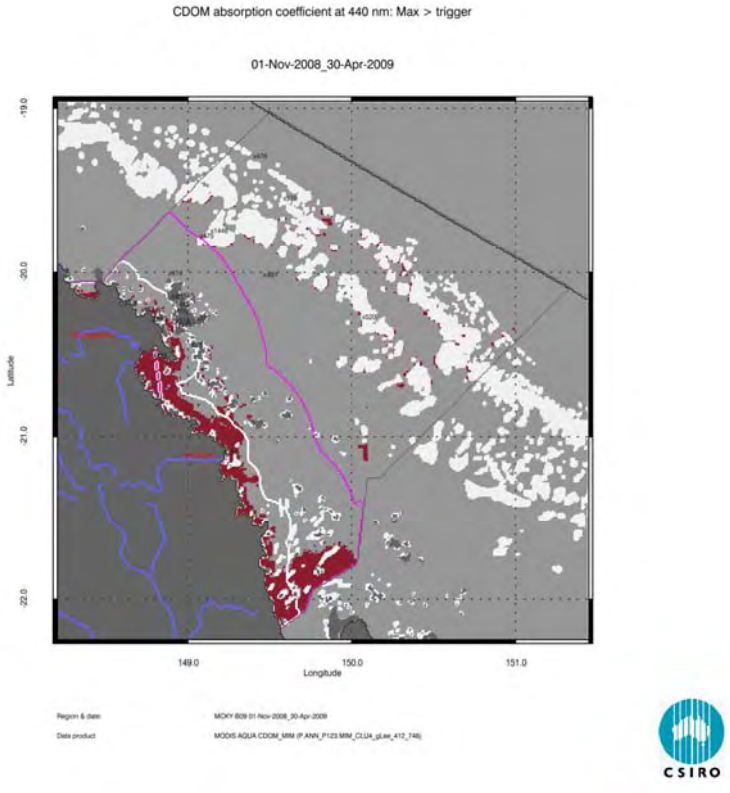


Figure 60. Map of flood extent for the wet season for the Mackay Whitsunday region. The first map presents the maximum value of CDOM for the Wet Season 2008/2009 (November 2008- April 2009), while the second map presents flood extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m-1. 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, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of chlorophyll (Figure 61) for the Fitzroy Estuary –Keppel Bay region show high chlorophyll 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 62) for the Fitzroy region show values higher than 0.20 m^{-1} in for a costal 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 matter) (Figure 63) 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.

The wet and dry season median maps of vertical attenuation of light (Figure 64) for the Fitzroy region show similar gross patterns as for the chlorophyll, 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. Care must be taken in interpreting the Shoalwater Bay results as we did not parameterise these waters for the bio-optical model (and they are presumably very different from our previously sampled waters) and there may be a bottom visibility issue too.

The wet and dry season median maps of water clarity expressed as Secchi depth (Figure 65) for the Fitzroy region show similar gross patterns to the maps of vertical attenuation of light (Figure 64). This 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, 2008).

The maps in Figure 66depict 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 about 90 for each season for each pixel location.

Assessment of the exceedance of water quality guidelines

Figure 67 presents the maps of Chlorophyll exceedance for the Fitzroy region as defined by the guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 68 presents the map of the Exceedence Probability for Chlorophyll. This map reports in a continuous colour scale the Number of day 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 Suspended solids (using Non-algal particulate matter as a measure of Suspended Solids, Figure 69 and Figure 70).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 61, Figure 63) and by the steep changes in trigger values between the Midshelf and Offshore areas.

For the Fitzroy region the mean values of Chlorophyll 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 of Chlorophyll also exceeded the guidelines for 54 % of the Midshelf and 40% of the Offshore areas (Figure 67, Table 24, Table 25). Similar exceedance values were retrieved if the median was used for the assessment (Figure 68, Table 24, Table 25).

The mean values of Suspended solids 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 69 and Table 26). Low exceedance was recorded for the Midshelf and Offshore areas in both seasons if the median was used for the assessment, while the exceedance values for the Open Coastal Area where significantly lower t (34% for the dry season and 25% for the wet season, Figure 70, and Table 26) when compared to exceedance of the mean.

Table 27 and Table 28 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 Exceedence Probability for that period. These metrics are based on a high number of observations (ranging from 270 Thousands valid observations for Open Coastal in the wet season to over 4.2 Million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll 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 Suspended solids concentration differed substantially (Table 28) for all regions and seasons. The mean values were ~ 2.5 times higher than medians. Only the mean values of Suspended solids exceeded the guidelines values for the Open Coastal and Offshore areas for both seasons.

Assessment of flood extent during the wet season

Figure 71 reports the flood extent for wet Season 2008/2009 (November 2008- April 2009) for the Fitzroy region. The flood extent was estimated applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum.

For the Fitzroy region the flood extent for the Wet Season 2008/2009 (November 2008- April 2009) was 4943 km^2 while in the Wet Season 2007/2008 (November 2007 - April 2008) was 8744 km^2 (Figure 15). Freshwater discharge was less than the long term median flow for the Fitzroy River, while in the previous wet season the largest flood since 1991 had occurred.

Table 24 Summary of the annual exceedance maps for Chlorophyll 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-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	7942	742478	2189625	35%	36%
MS	19477	2529946	6834191	2%	2%
OS	61048	5118440	18057784	0%	0%

Table 25 Summary of the exceedance maps for Chlorophyll for the dry and wet season for the Fitzroy region (Figure 67, Figure 68). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	7942	496673	1161885	74%	74%	245709	1019406	25%	16%
MS	19477	1663667	3628937	54%	78%	866277	3205079	1%	0%
OS	61048	3418244	9586808	40%	29%	1700196	8467536	0%	0%

Table 26 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Suspended solids) for the dry and wet season for the Fitzroy region (, Figure 69, Figure 70). 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.

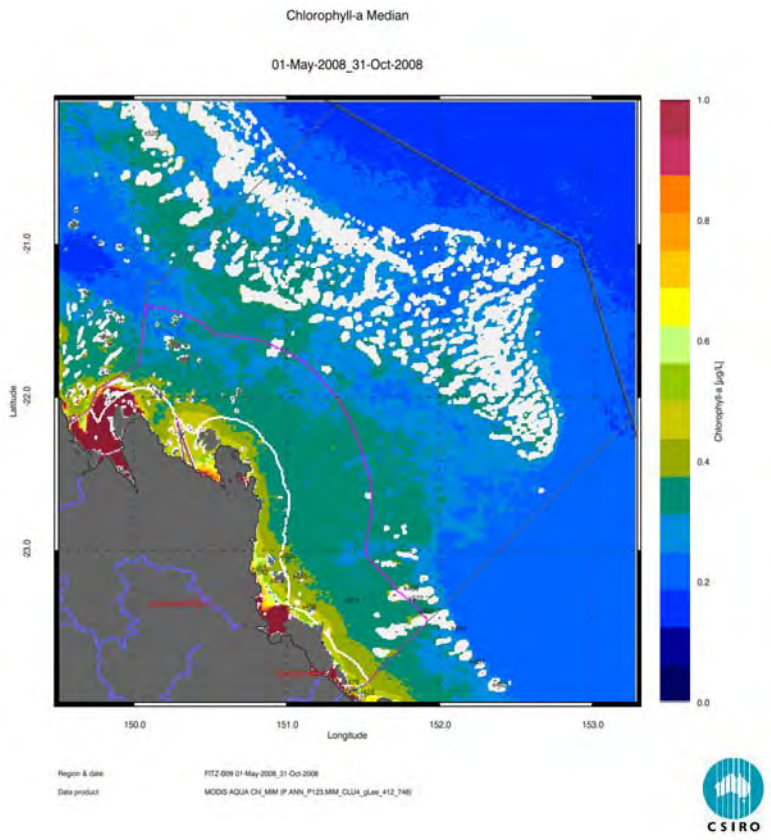
		01-May-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	7942	496673	1161885	46%	34%	245709	1019406	45%	25%
MS	19477	1663667	3628937	14%	5%	866277	3205079	14%	0%
OS	61048	3418244	9586808	42%	1%	1700196	8467536	31%	2%

Table 27. Summary of Chlorophyll exceedance for the dry and wet season 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" and “Median” report the mean and median concentrations computed on all the valid observations, “EP” provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	537551	1564574	**0.76**	0.44	48%	265149	1381908	**0.63**	**0.46**	52%
MS	1740352	3836969	0.34	0.34	14%	906265	3388998	0.31	0.25	17%
OS	4244350	12026456	0.29	0.25	19%	2110793	10622352	0.27	0.22	15%

Table 28 Summary of Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance for the dry and wet season 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	537551	1564574	**3.80**	1.47	41%	265149	1381908	**5.00**	1.79	47%
MS	1740352	3836969	1.30	0.31	17%	906265	3388998	1.97	0.71	26%
OS	4244350	12026456	**0.94**	0.27	27%	2110793	10622352	**1.35**	0.44	35%



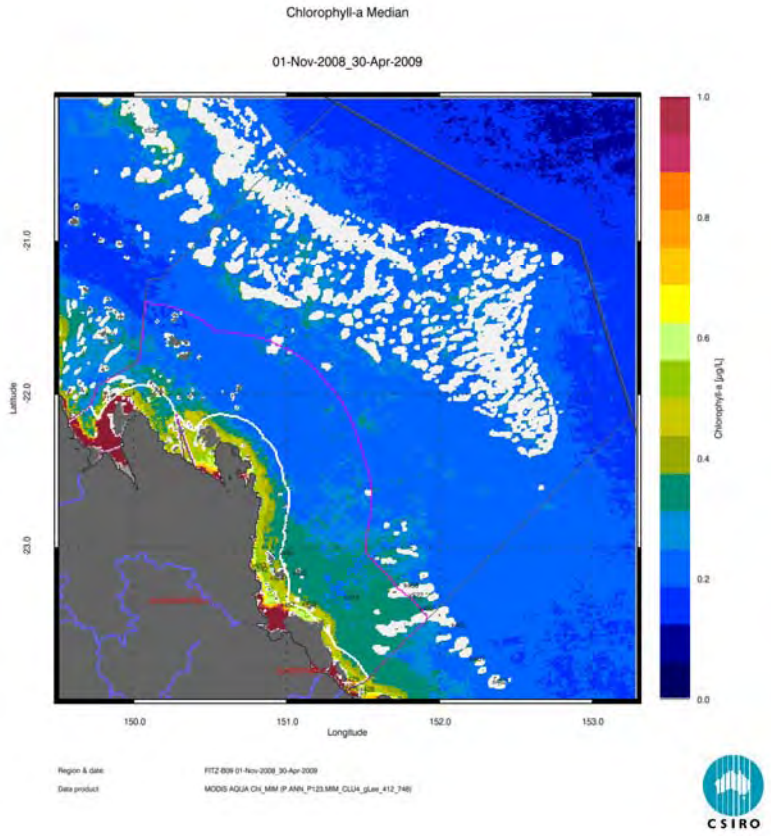


Figure 61. Chlorophyll Median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

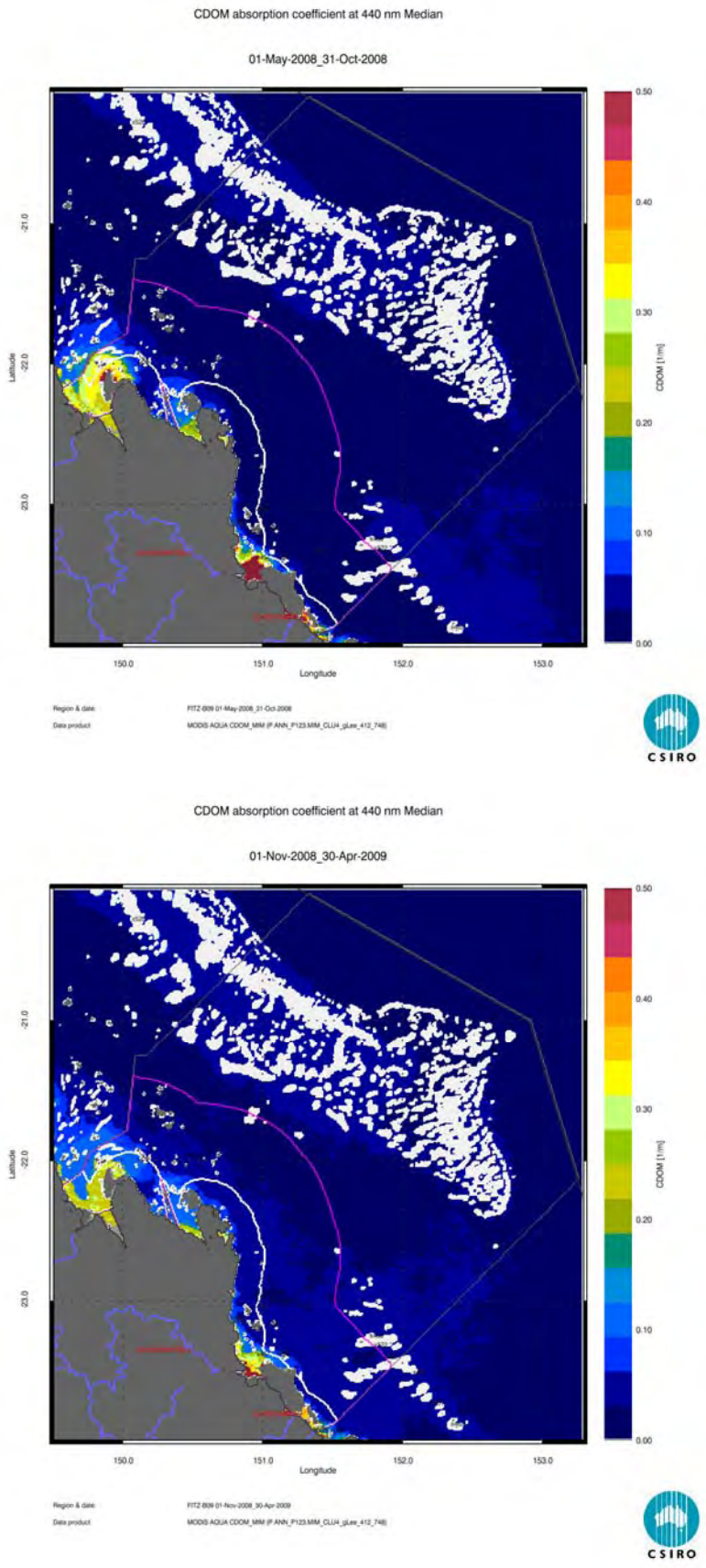


Figure 62. CDOM Median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

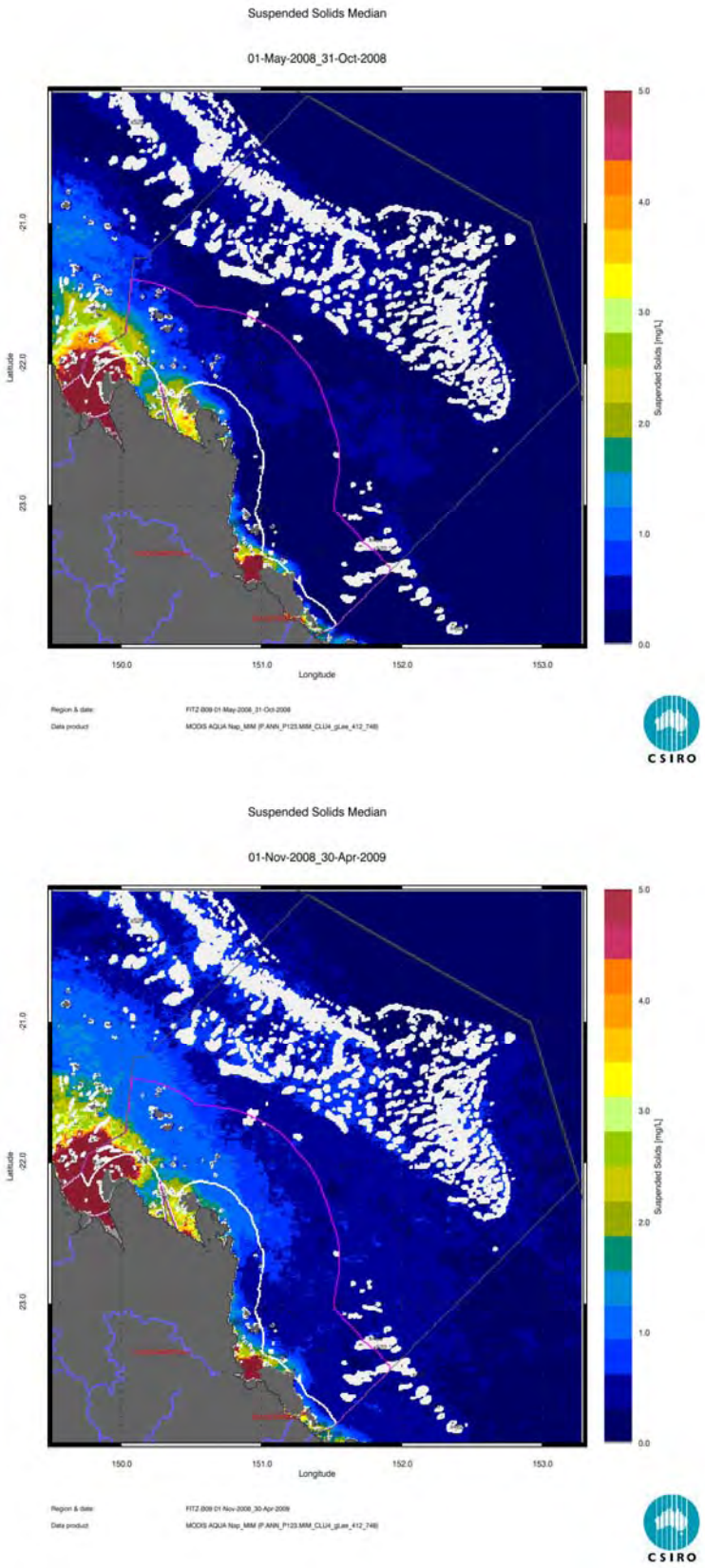


Figure 63. Non-algal particulate matter (Nap as a measure of Suspended solids) Median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

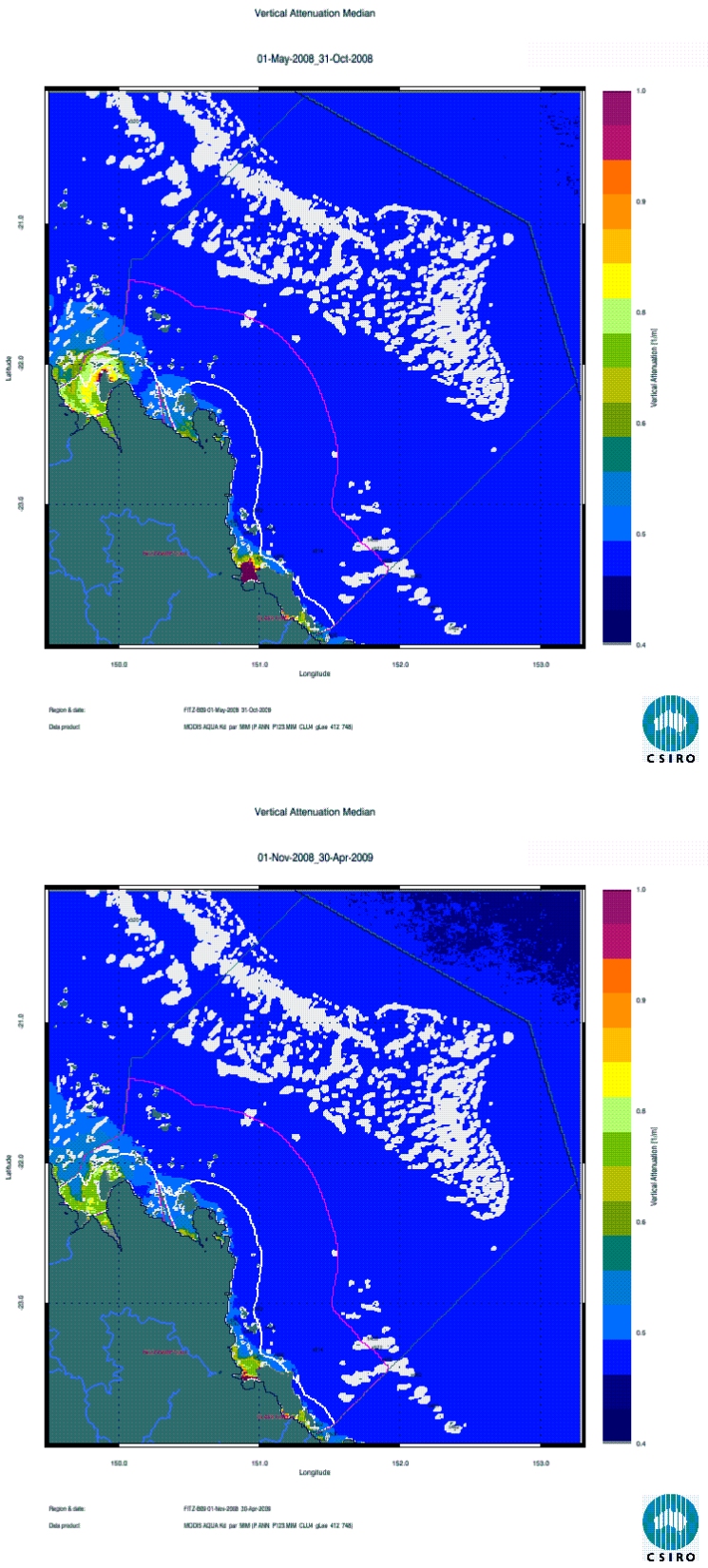


Figure 64. Vertical attenuation of light (Kd ,as estimate of water clarity) Median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

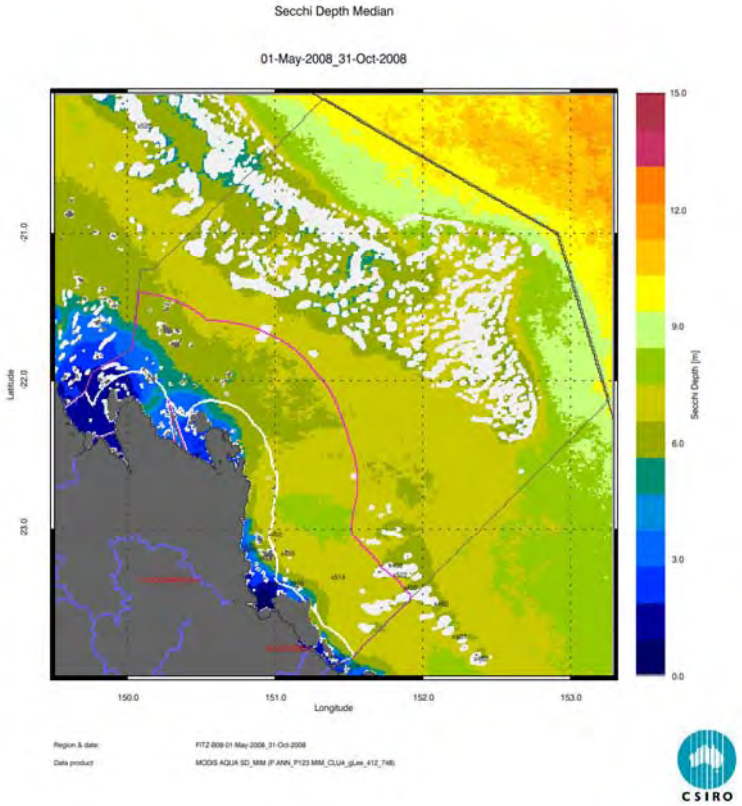


Figure 65. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

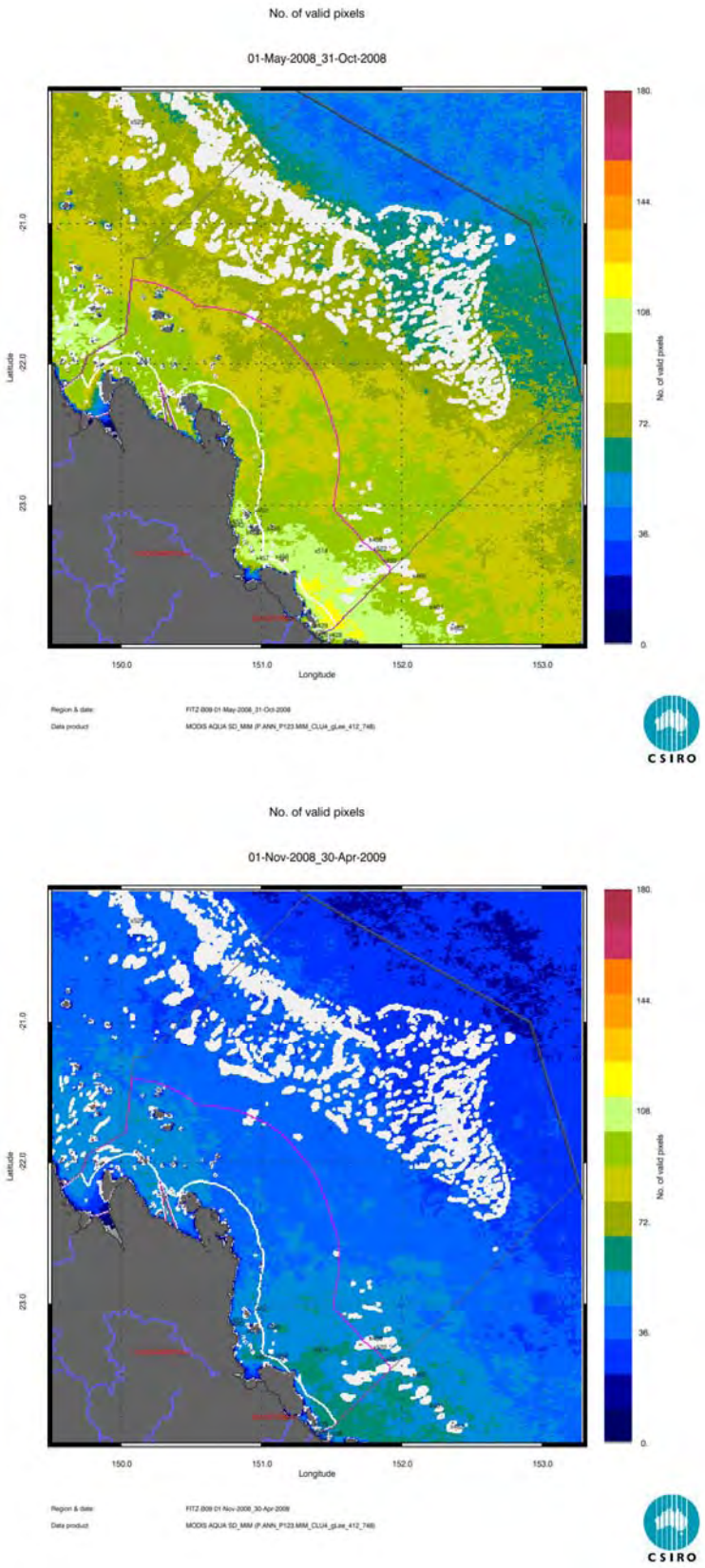


Figure 66. Number of pixels used to calculate the Median maps (Figure 61 - Figure 65) for the dry and wet season for the Fitzroy region. The first map presents the number of pixels available for analysis in the Dry Season 2008 (May - October), while the second map presents the number of pixels available for analysis in the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

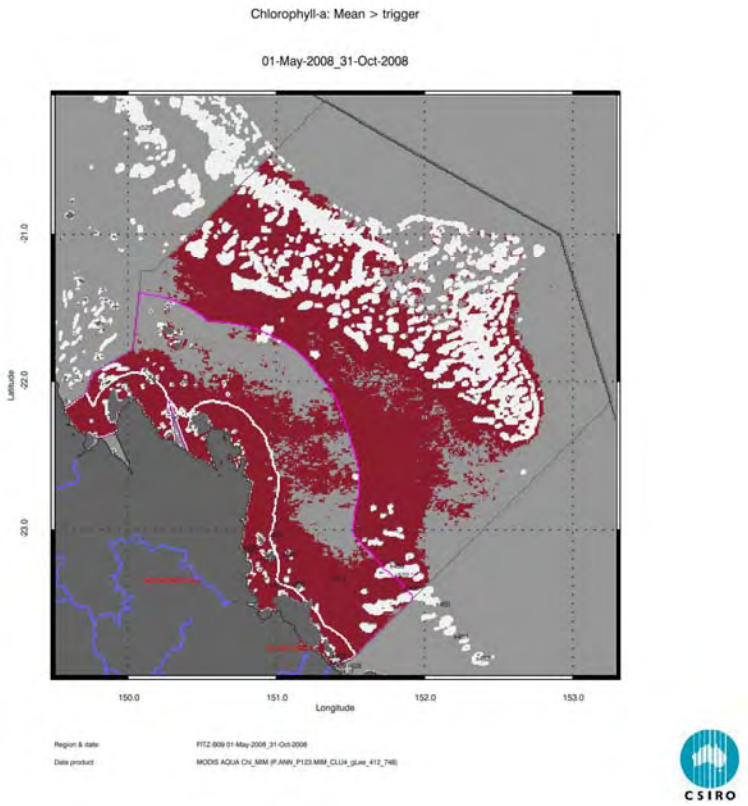


Figure 67. Chlorophyll exceedance maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

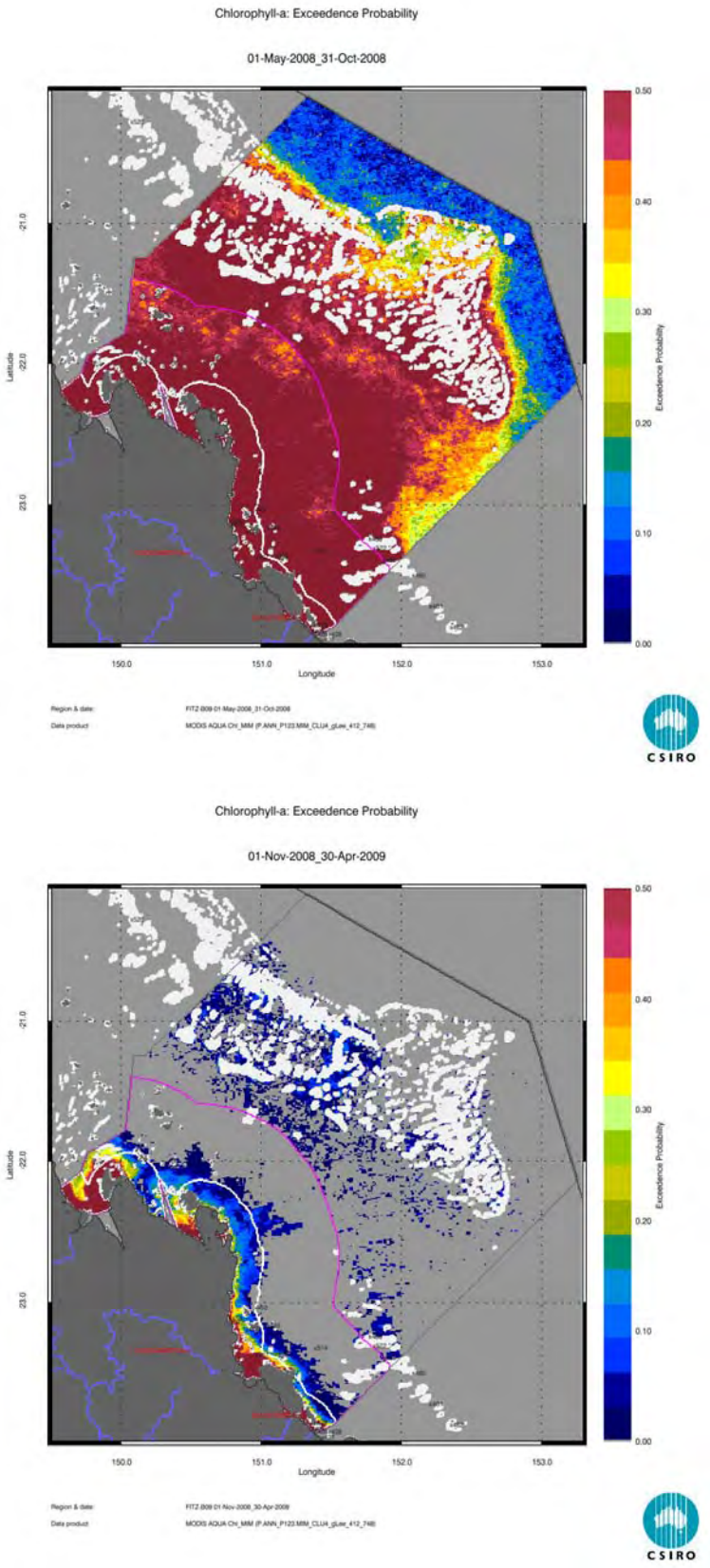
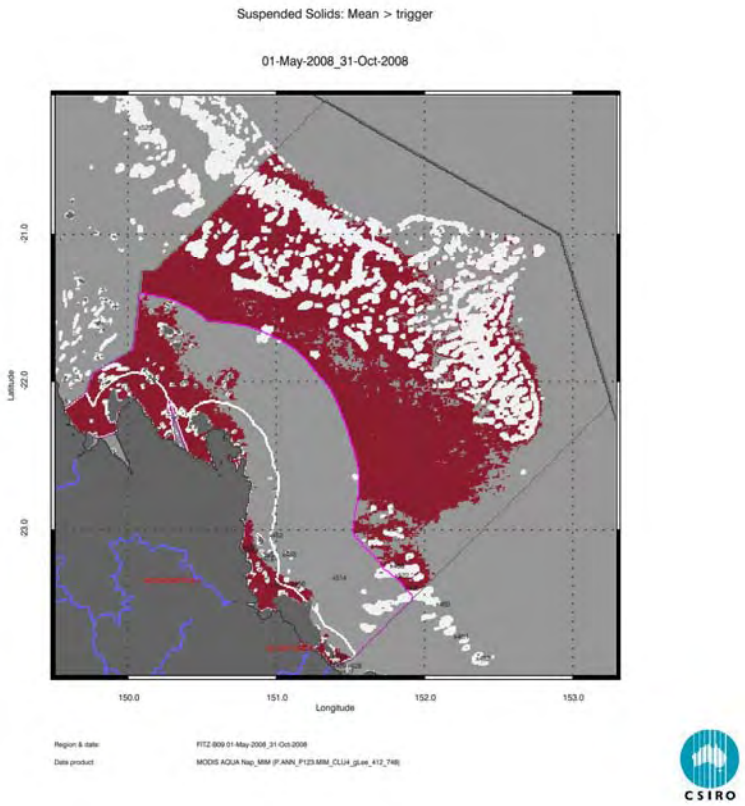


Figure 68. Chlorophyll exceedance probability maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.



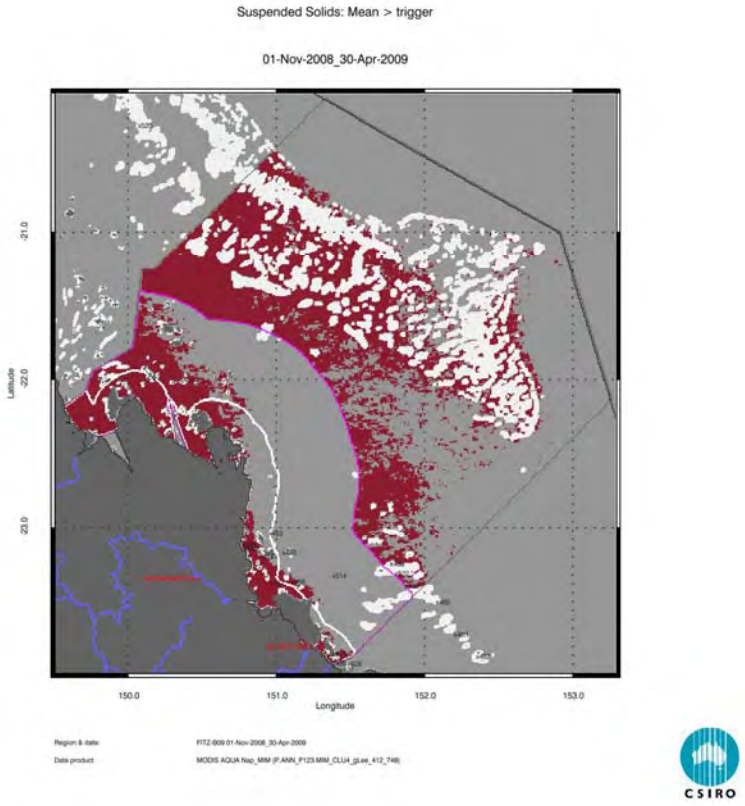


Figure 69. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

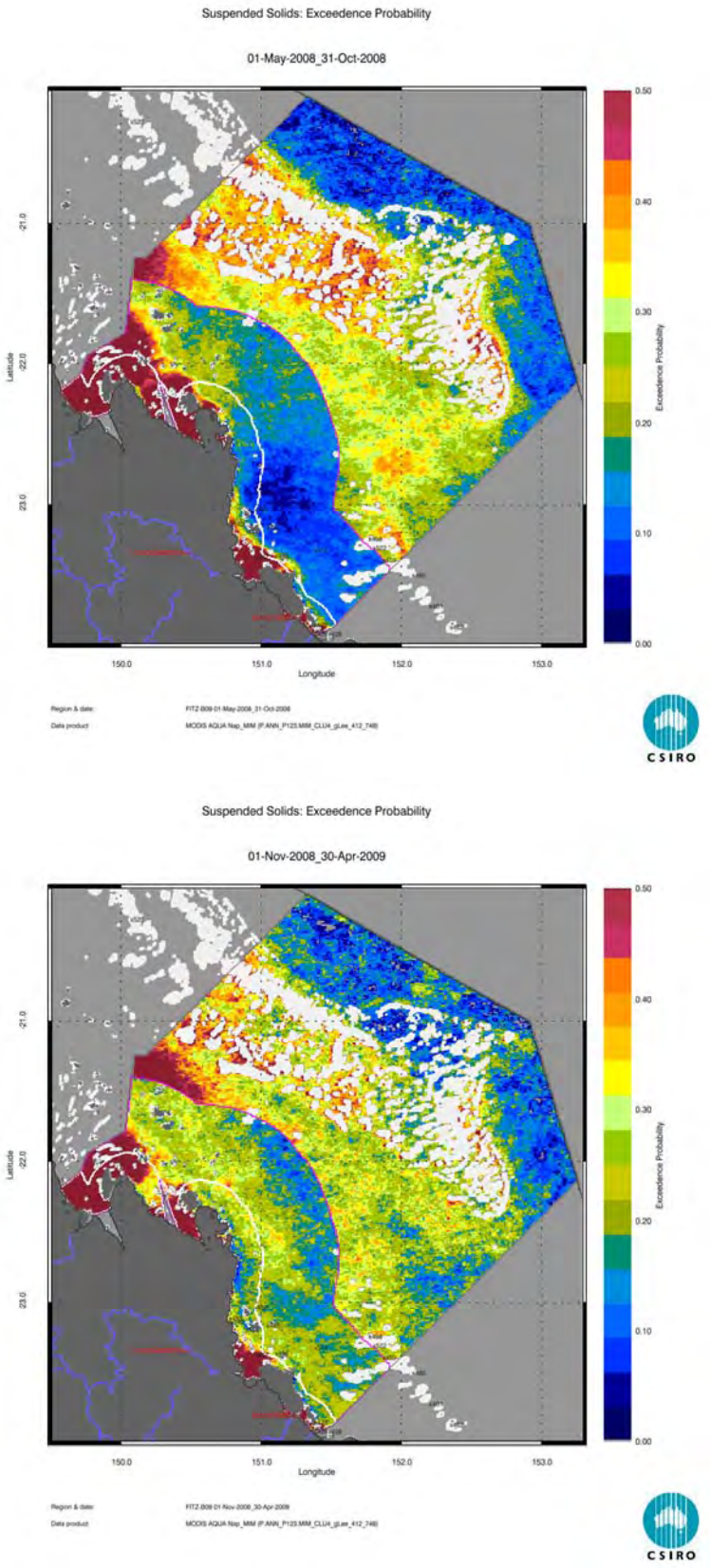


Figure 70. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance probability maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

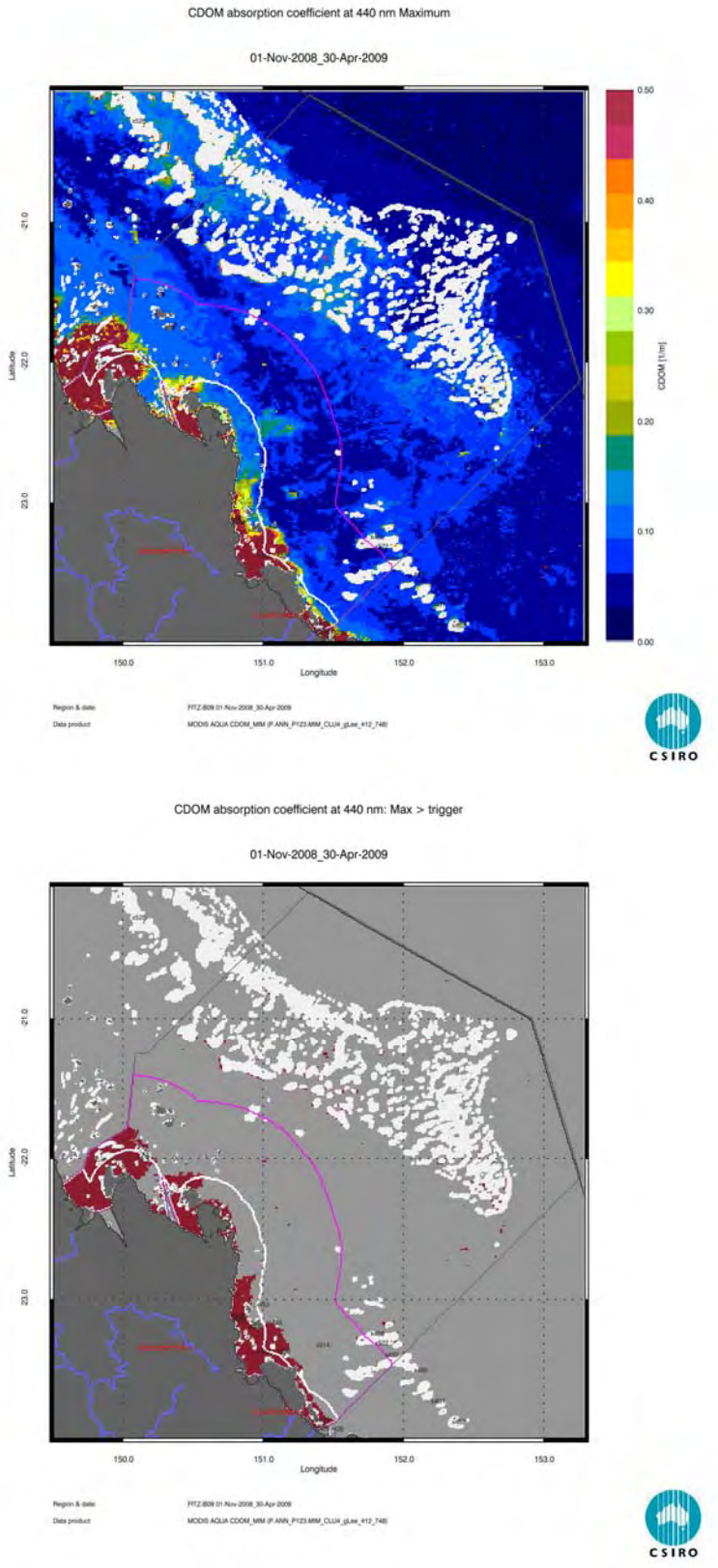


Figure 71. Map of flood extent for the wet season for the Fitzroy region. The first map presents the maximum value of CDOM for the Wet Season 2008/2009 (November 2008- April 2009), while the second map presents flood extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m-1. See text 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, suspended matter and vertical attenuation coefficient of light.

The wet and dry season median maps of chlorophyll (Figure 72) for the Burnett Mary region show high chlorophyll 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 reef matrix ranged ~0.15-0.25 μgL^{-1}. The lobe of relatively high chlorophyll 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 73) for the Burnett Mary region show values higher than 0.20 m^{-1} in for a costal band ~5-10 km wide.

The wet and dry season median maps of non-algal particulate matter (as a measure of total suspended matter) (Figure 74) for the Burnett Mary region show similar gross patterns as for the CDOM distribution..

The wet and dry season median maps of vertical attenuation of light (Figure 75) for the Burnett Mary region show similar gross patterns as for the chlorophyll, 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 76) for the Burnett Mary region show similar gross patterns to the maps of vertical attenuation of light (Figure 75).

The maps in Figure 77 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 water quality guidelines was assessed for the two of the water quality the variables that can be retrieved from remote sensing: the Chlorophyll and Non-algal particulate matter (as measure for Suspended solids) retrieved form MODIS AQUA using CSIRO's algorithm.

Figure 78 presents the maps of Chlorophyll exceedance as defined by the guidelines. Pixels are mapped in dark red when mean values for the year (and seasons) exceed the thresholds. Figure 79 presents the map of the Exceedence Probability for Chlorophyll. This map reports in a continuous colour scale the Number of day 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 Suspended solids (using Non-algal particulate matter as a measure of Suspended Solids, Figure 80 and Figure 81).

The spatial patterns in exceedance are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 72, Figure 74) and by the steep changes in trigger values between the Midshelf and Offshore areas.

For the Burnett Mary region the mean values of Chlorophyll 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

also exceeded the guidelines for 76 % of the Midshelf and 13% of the Offshore areas (Figure 78,Table 29, Table 30). Similar exceedance values were retrieved if the median was used for the assessment (Figure 79, Table 29, Table 30).

The mean values of Suspended solids 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 81 , and Table 31). The estimated exceedance for the all areas was significantly lower for the median values that those for the mean values (Figure 81 and Table 31).

Table 32 and Table 33 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 Exceedence Probability for that period. These metrics are based on a high number of observations (ranging from 210 Thousands valid observations for Open Coastal area in the wet season to over 2.1 Million for the Offshore area in the dry season). According to these metrics both the mean and the median values of Chlorophyll exceeded the guidelines values for the Open Coastal area in both seasons, while the mean values of Suspended solids exceeded the guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the Suspended solids concentration differed substantially (for all regions and seasons). The mean values were ~ 2-3 times higher than medians.

Assessment of flood extent during the wet season

Figure 82 reports the flood extent for wet Season 2008/2009 (November 2008- April 2009) for the Burnett Mary region. The flood extent was estimated applying a threshold of 0.2 m^{-1} for the CDOM seasonal maximum. For the Burnett Mary region the flood extent for the Wet Season 2008/2009 (November 2008- April 2009) was 624 km^2 while in the Wet Season 2007/2008 (November 2007 - April 2008) was 1633 km^2 (Figure 15). Freshwater discharge was well below the long term annual median flow in the region (Figure 14).

Table 29 Summary of the annual exceedance maps for Chlorophyll 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-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	950	103684	265101	27%	33%
MS	3426	552733	1200553	2%	3%
OS	34557	4282628	11975876	0%	0%

Table 30 Summary of the exceedance maps for Chlorophyll for the dry and wet season for the Burnett Mary region (Figure 78, Figure 79). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	950	68069	140997	77%	77%	35605	123415	17%	15%
MS	3426	355081	639388	76%	83%	197652	561165	1%	0%
OS	34557	2824256	6378086	13%	13%	1458370	5597788	0%	0%

Table 31 Summary of the exceedance maps for Non-algal particulate matter (Nap as a measure of Suspended solids) for the dry and wet season for the Burnett Mary region (Figure 80, Figure 81). 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-2008_01-Nov-2008				01-Nov-2008_01-May-2009			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
OC	950	68069	140997	14%	3%	35605	123415	13%	1%
MS	3426	355081	639388	2%	0%	197652	561165	2%	0%
OS	34557	2824256	6378086	2%	0%	1458370	5597788	8%	0%

Table 32. Summary of Chlorophyll exceedance for the dry and wet season for the Burnett Mary 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	71305	178600	**0.49**	0.45	49%	37051	156750	0.50	0.45	49%
MS	357489	644088	0.34	0.35	17%	198946	565290	0.33	0.33	19%
OS	2874128	6496716	0.24	0.22	5%	1489176	5701905	0.23	0.20	6%

Table 33 Summary of Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance for the dry and wet season for the Burnett Mary 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" and "Median" report the mean and median concentrations computed on all the valid observations, "EP" provides the Exceedence Probability, i.e. number of observation where the concentration exceeded the threshold divided by number of observation with (error-free) data for that period. Mean and median are presented in **red and bold** if they exceed the trigger value in the guidelines.

	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	71305	178600	1.03	0.40	13%	37051	156750	1.74	0.66	21%
MS	357489	644088	0.61	0.18	10%	198946	565290	1.15	0.40	20%
OS	2874128	6496716	0.31	0.11	11%	1489176	5701905	0.60	0.24	21%

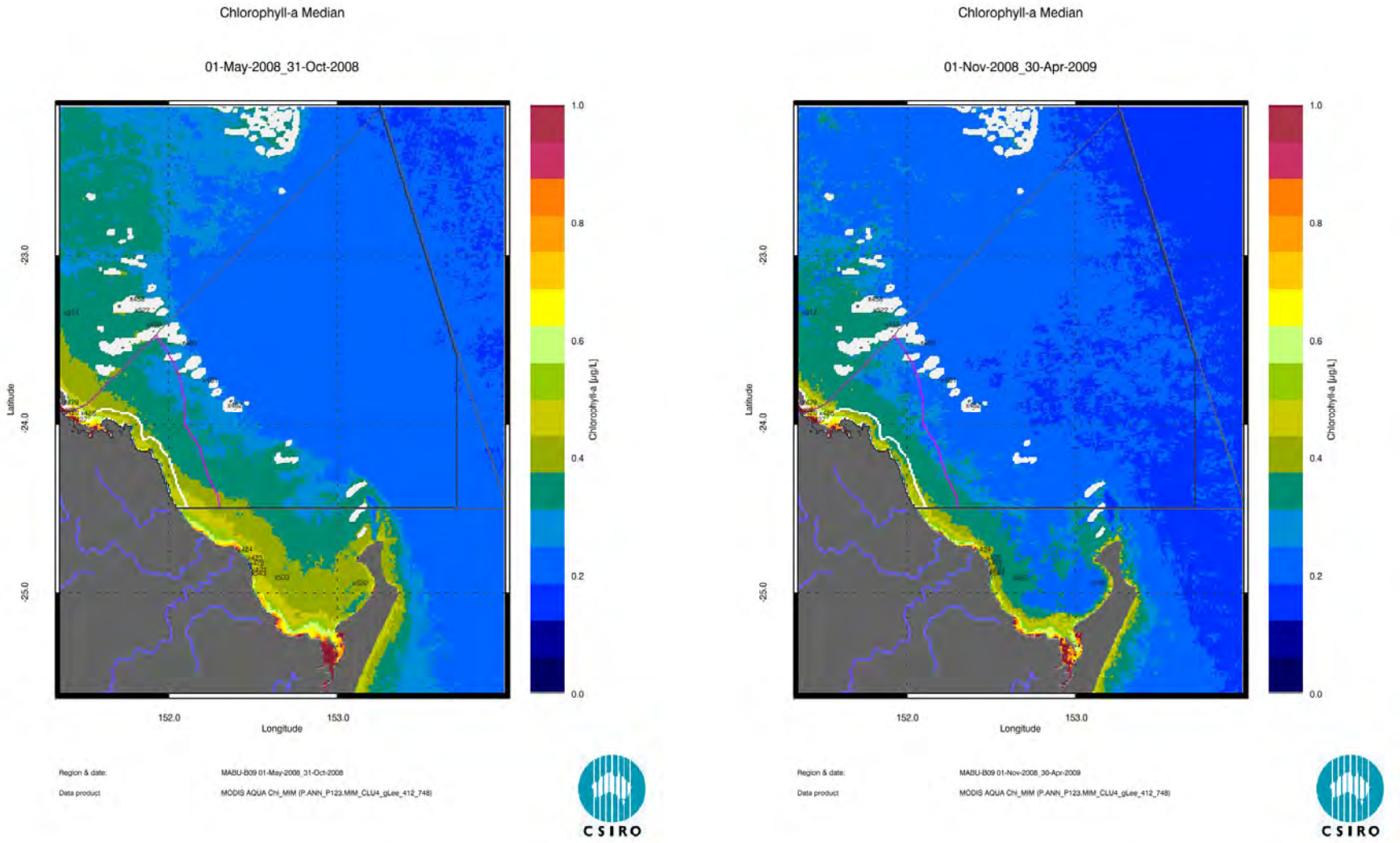


Figure 72. Chlorophyll Median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

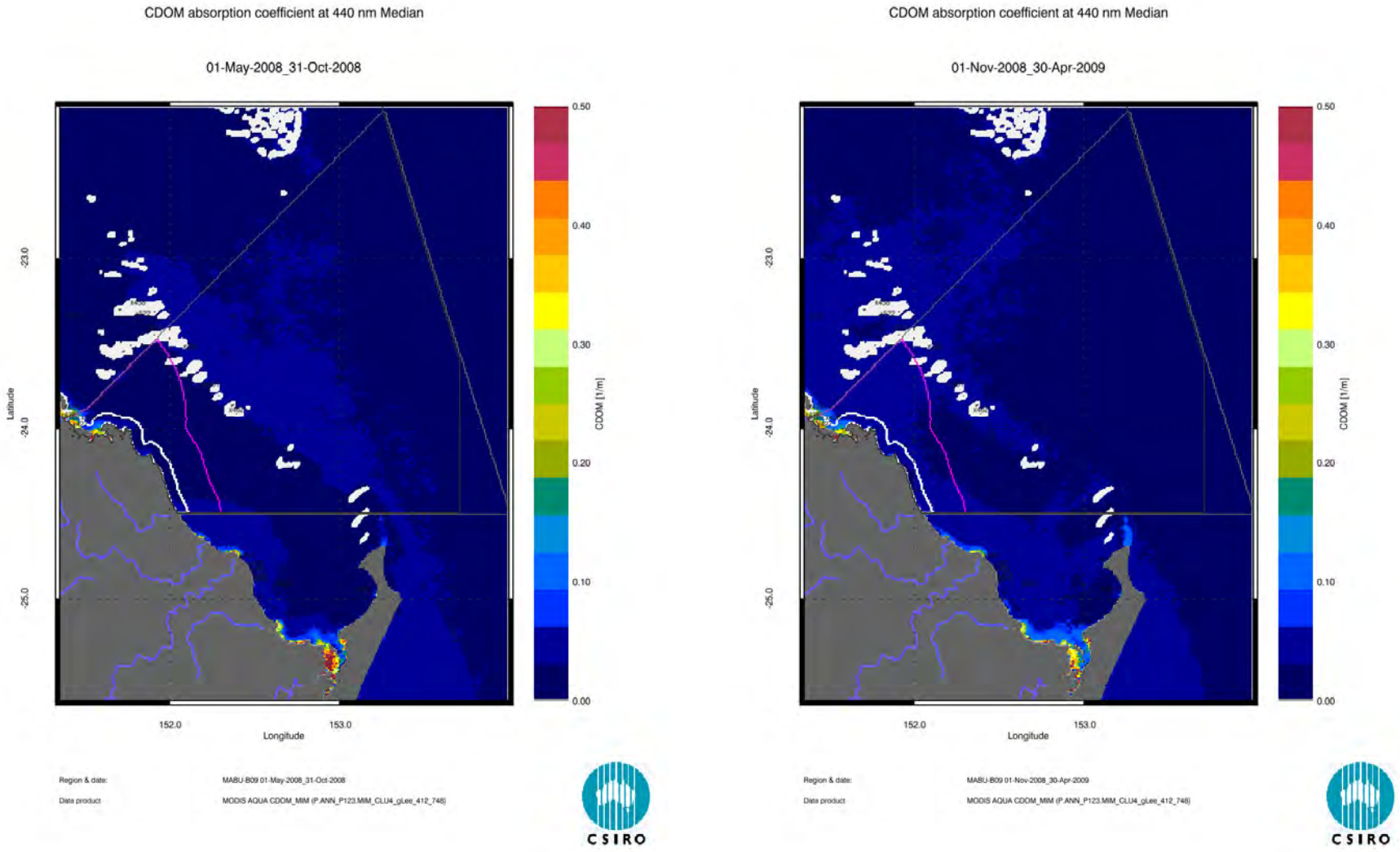


Figure 73. CDOM Median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

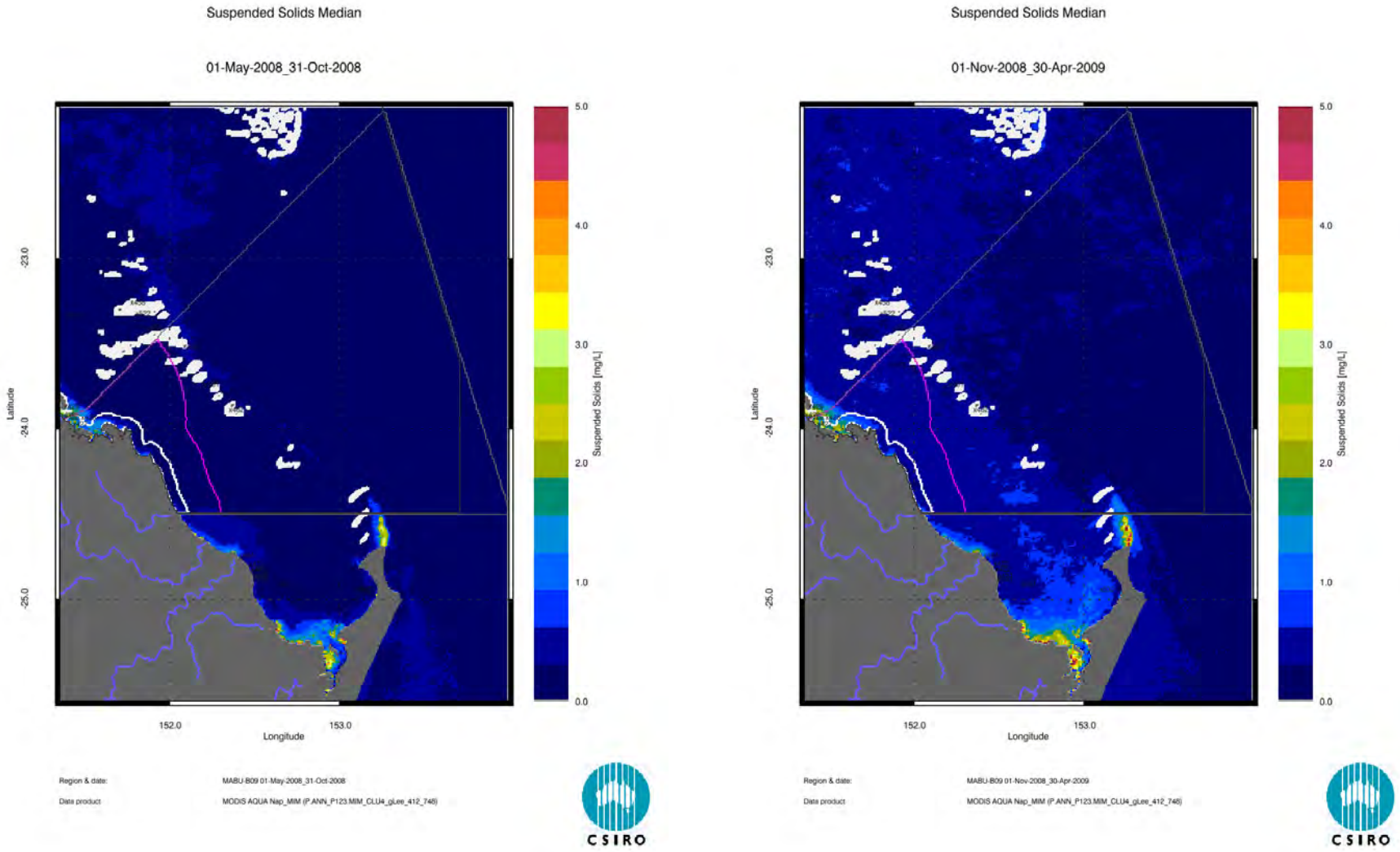


Figure 74. Non-algal particulate matter (Nap as a measure of Suspended solids) Median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

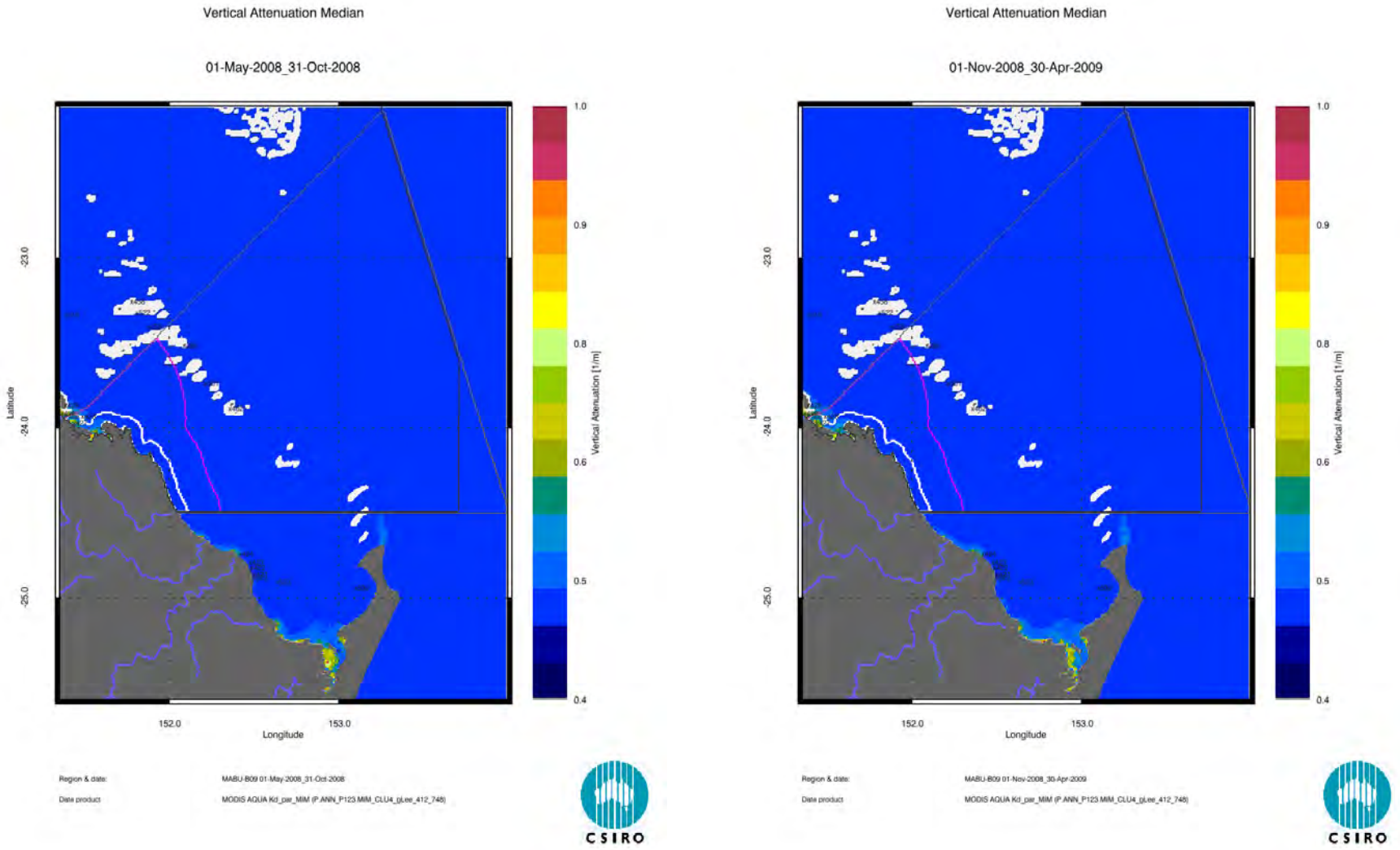


Figure 75. Vertical attenuation of light (Kd ,as estimate of water clarity) Median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

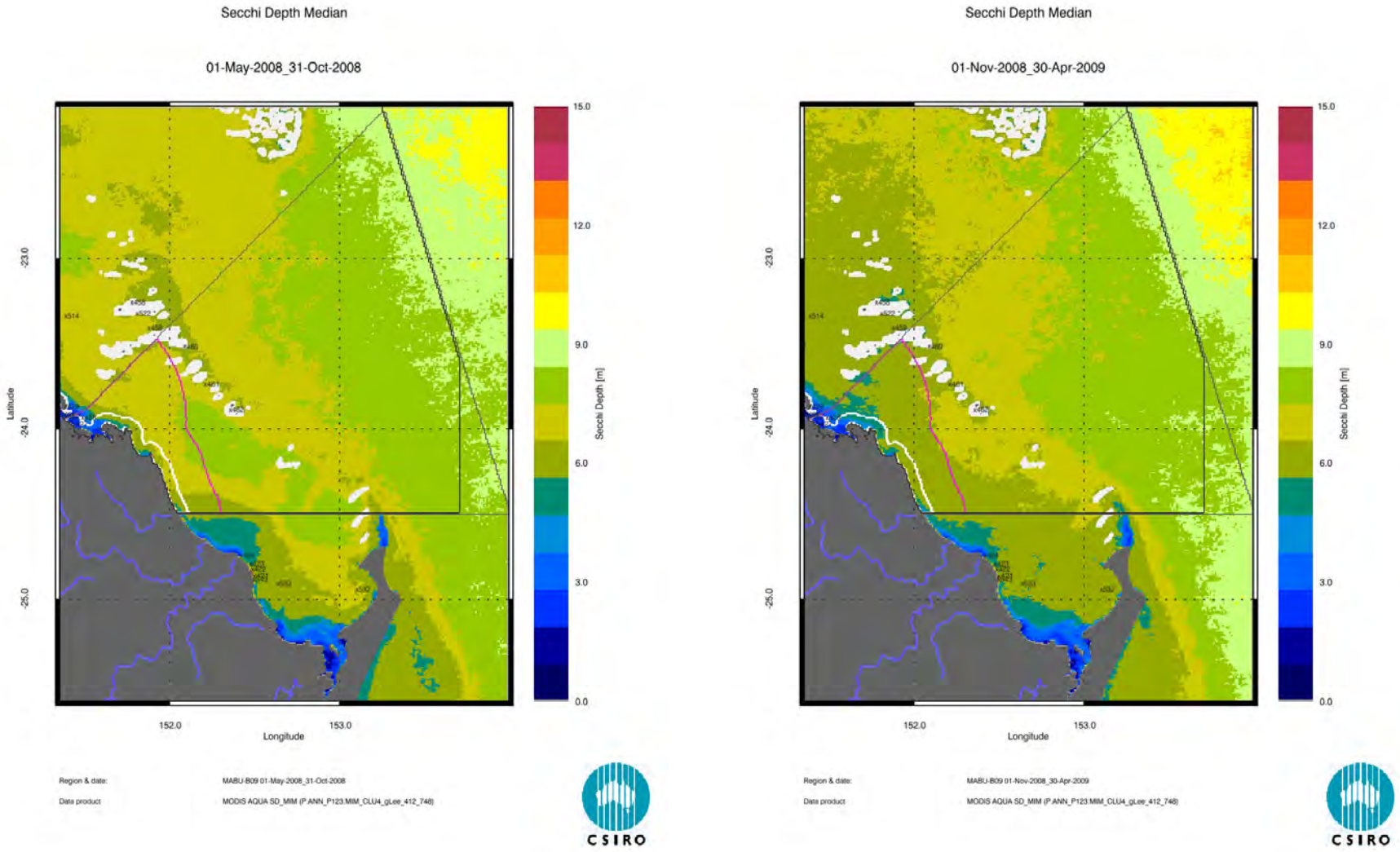


Figure 76. Secchi Depth (as estimate of water clarity) median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the Dry Season 2008 (May - October), while the second map presents the median for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

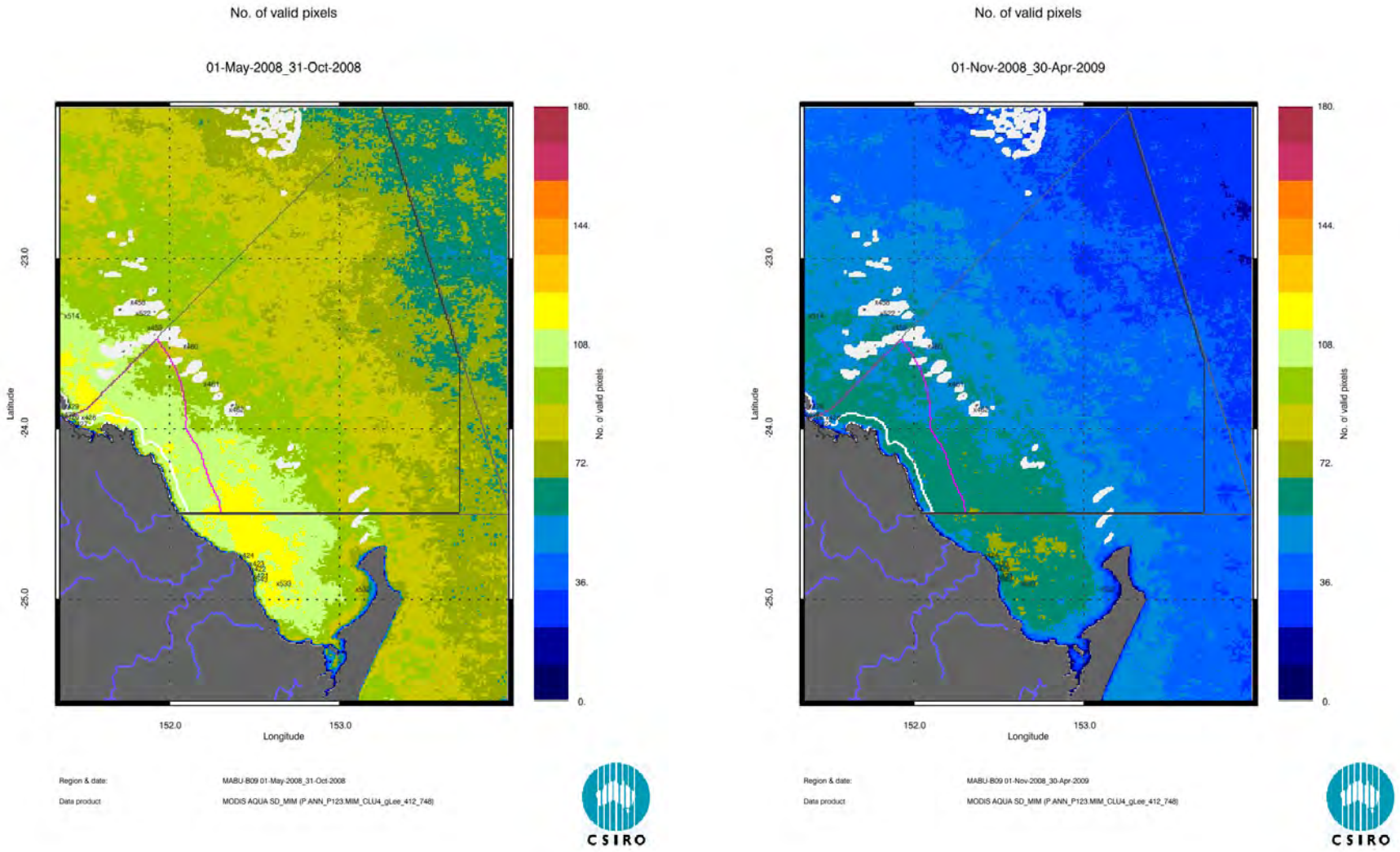


Figure 77. Number of pixels used to calculate the Median maps (Figure 72 - Figure 76) for the dry and wet season for the Burnett Mary region. The first map presents the number of pixels available for analysis in the Dry Season 2008 (May - October), while the second map presents the number of pixels available for analysis in the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

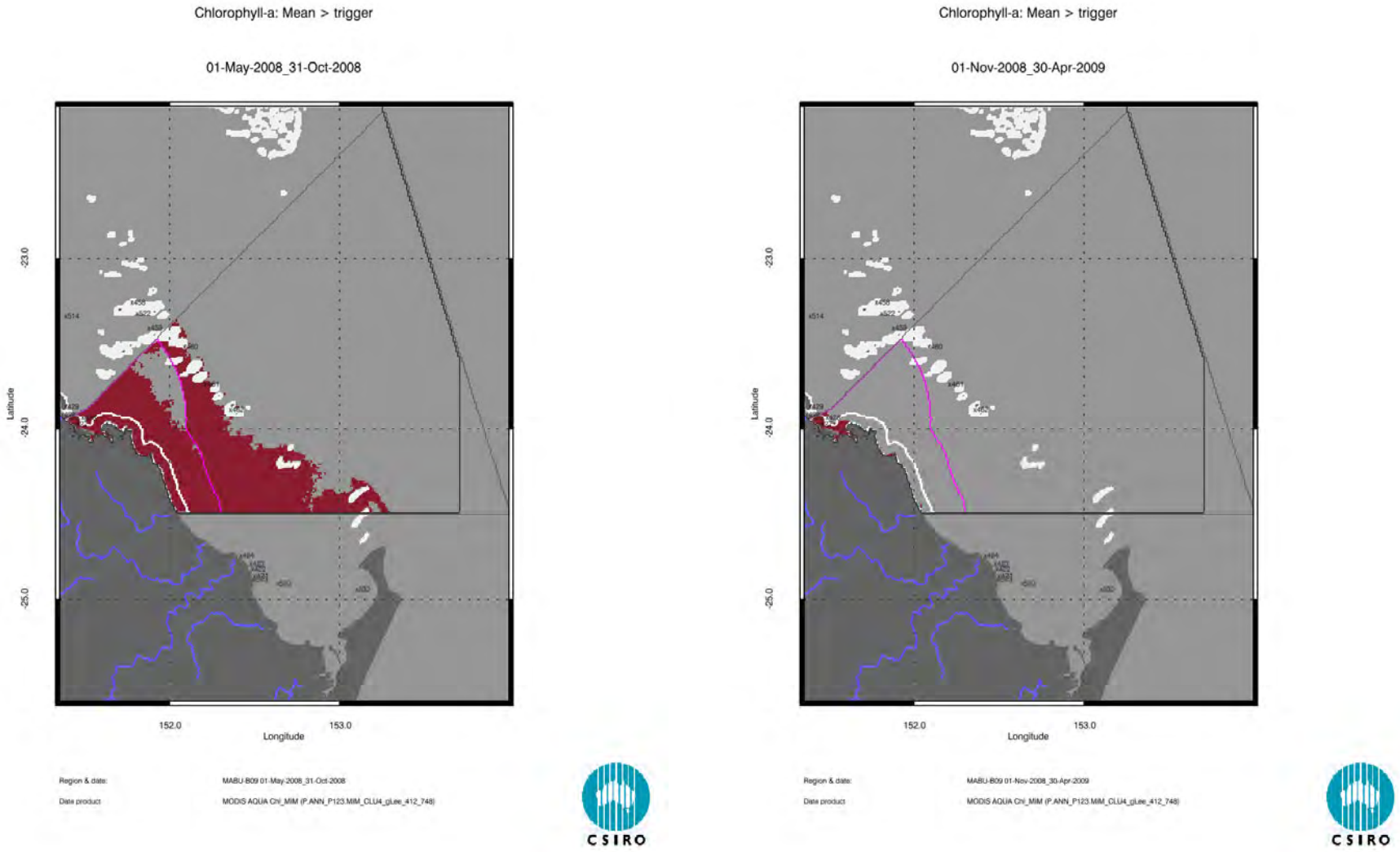


Figure 78. Chlorophyll exceedance maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

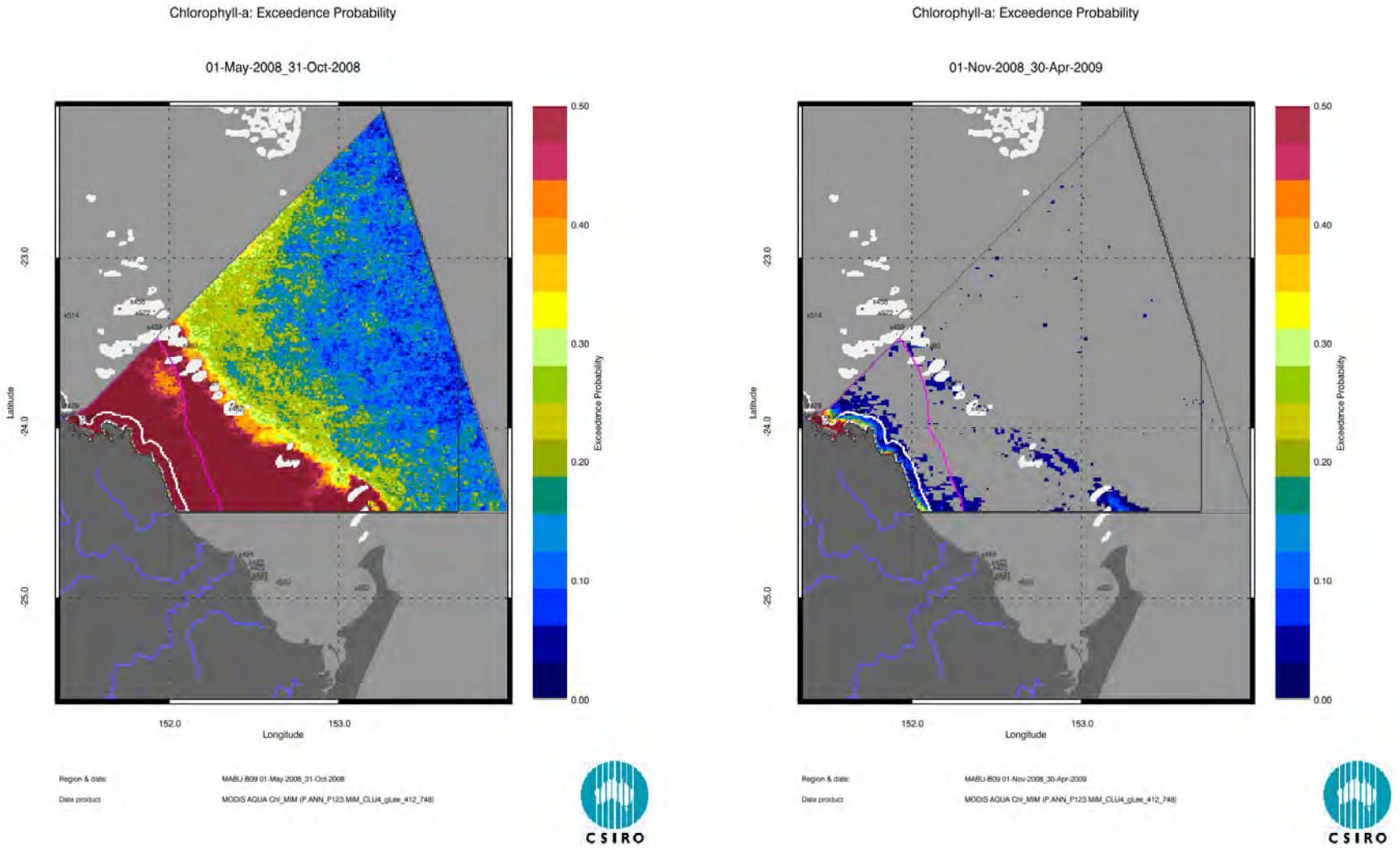


Figure 79. Chlorophyll exceedance probability maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

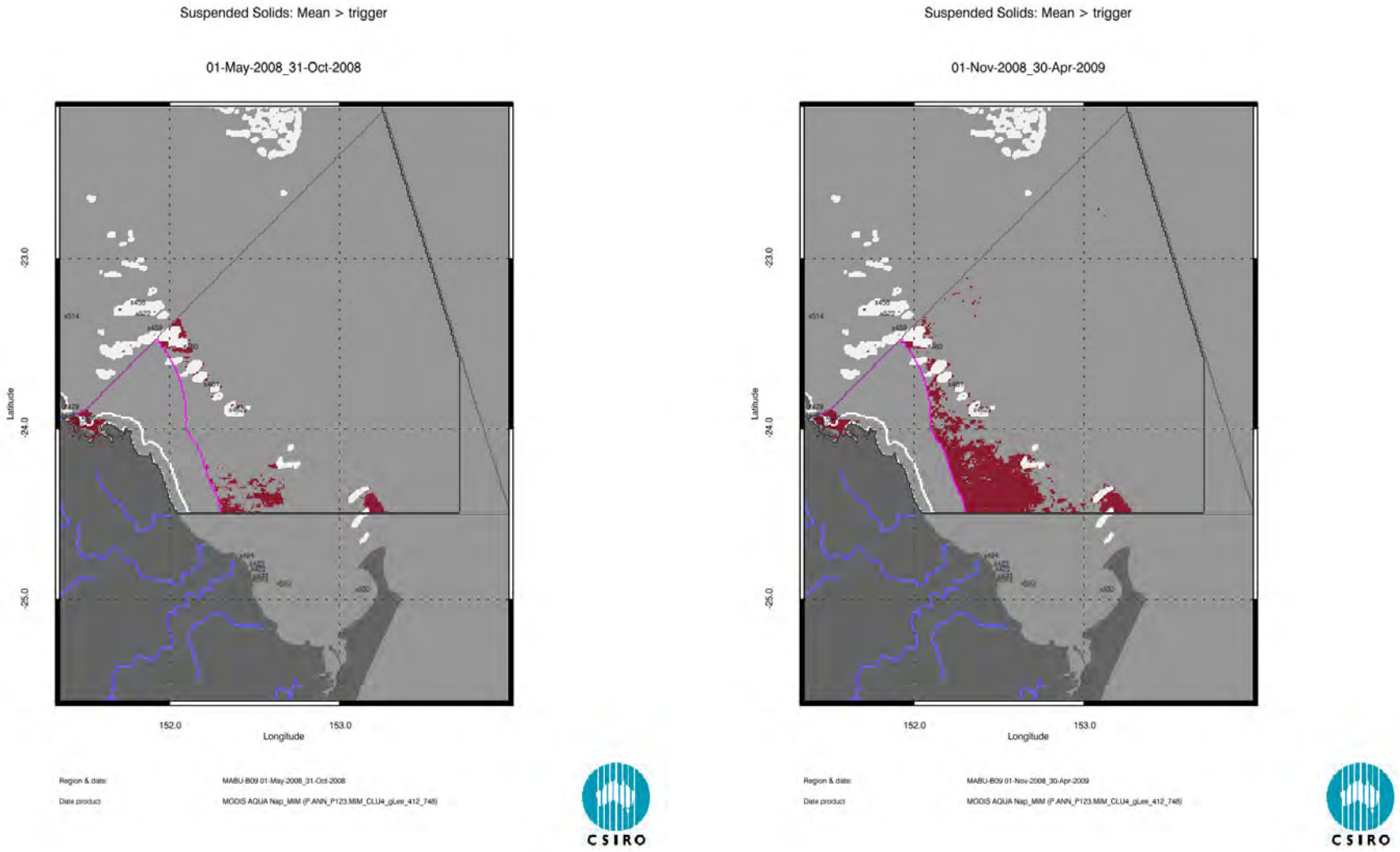


Figure 80. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance for the Dry Season 2008 (May - October), while the second map presents the exceedance for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

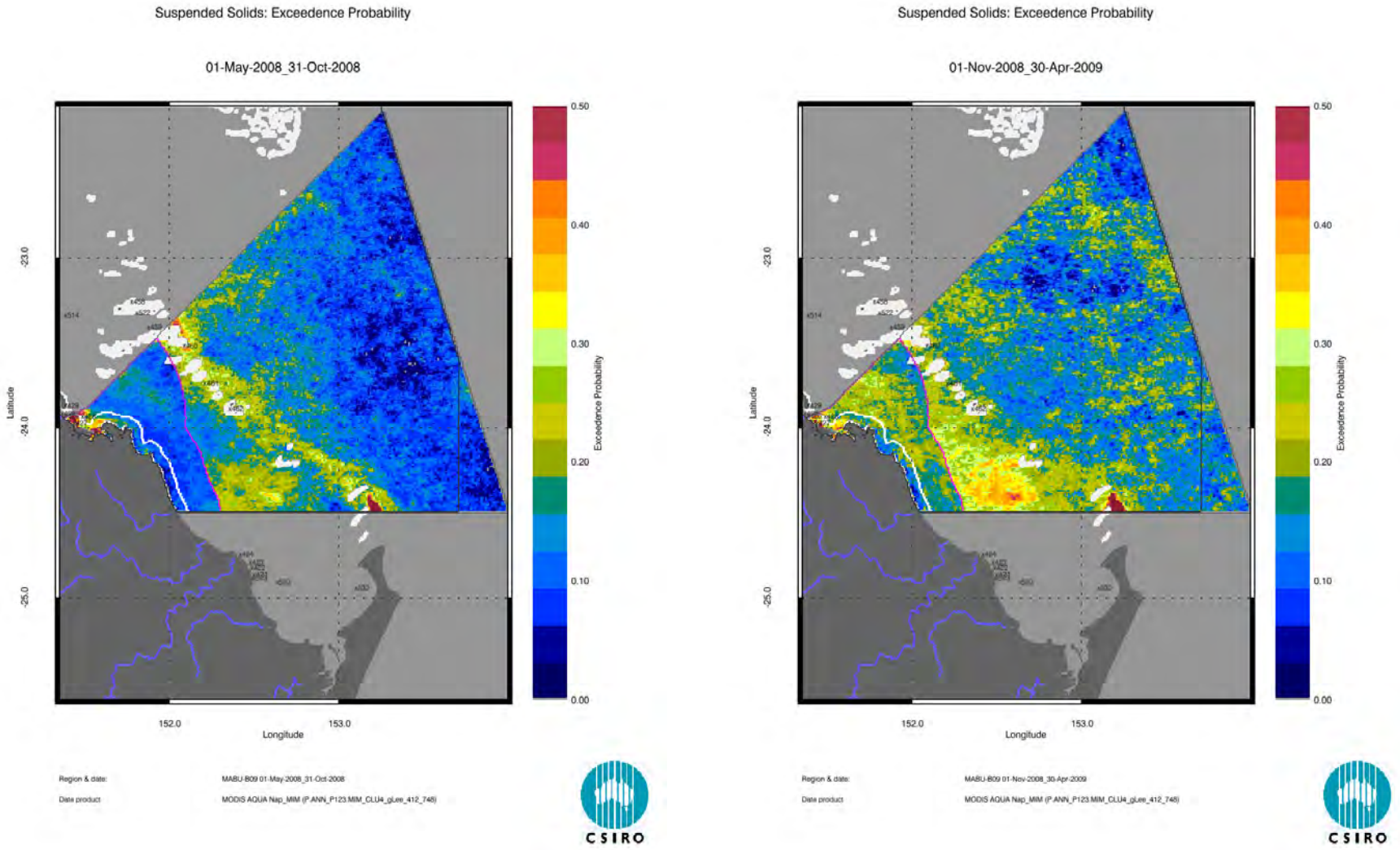


Figure 81. Non-algal particulate matter (Nap as a measure of Suspended solids) exceedance probability maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance probability for the Dry Season 2008 (May - October), while the second map presents the exceedance probability for the Wet Season 2008/2009 (November 2008- April 2009). See text for annotation explanation.

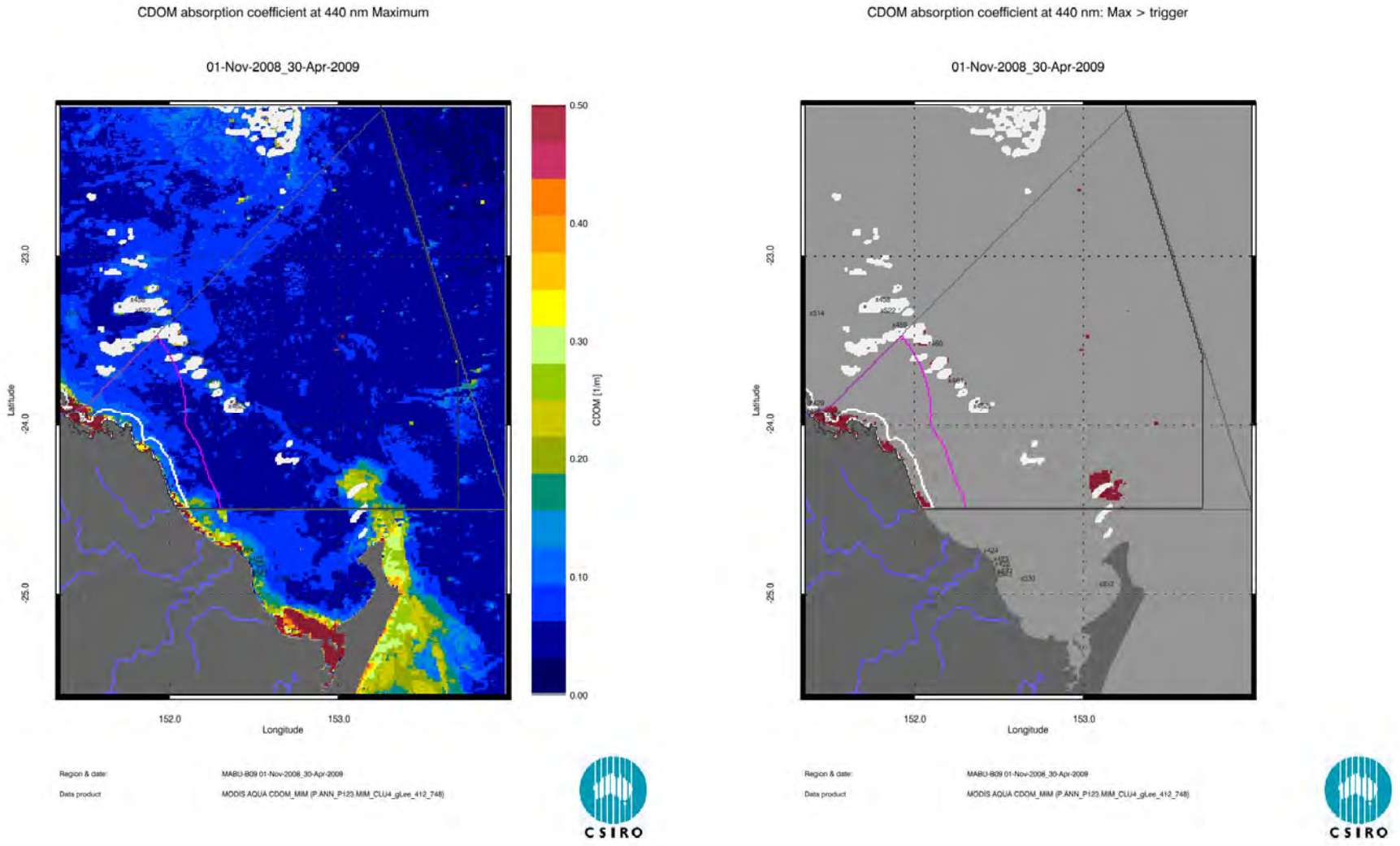


Figure 82. Map of flood extent for the wet season for Burnett Mary region. The first map presents the maximum value of CDOM for the Wet Season 2008/2009 (November 2008- April 2009), while the second map presents flood extent estimated with a threshold for the CDOM seasonal maximum of 0.2 m-1. See text for annotation explanation.

CONCLUSION AND RECCOMENDATIONS

A cornerstone of the Great Barrier Reef Water Quality Protection Plan and the Water Quality Improvement Plans 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 Great Barrier Reef (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 total suspended sediment (TSS), water clarity and the 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 to decades. 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.

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. 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 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. 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 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 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 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.

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 regionally appropriate algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon (Brando et al 2009, Brando et al 2010). This 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 (Brando et al 2009, Brando et al 2010).

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 there results would include:

1. An optical characterization of dissolved and particulate matter in the GBR lagoon, the reef matrix and the outer waters with a focus on the wet seasons. The optical characterization would follow the methods of Blondeau-Patissier et al. (2009). The measurements of reflectance and vertical attenuation of light will be used for parameterization, calibration and validation of the inversion algorithms and for validation of satellite retrievals.
2. 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 the optical characterizations of the wet seasons and the data collected at the Integrated Marine Observing System (IMOS) facilities: the Lucinda Jetty Coastal Observatory and the National Reference Station moored at the Yongala wreck.
3. 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.
4. Develop methods to estimate on a pixel by pixel basis the uncertainty associated with the retrieval of each water quality variables (chlorophyll-a, TSS, CDOM and water clarity) for all the available remote sensing imagery
5. Perform a spatial and temporal analysis to identify trends and anomalies in the water quality for the whole-of-GBR.
6. Separate the effects of short-term inter-annual ENSO-induced variability from the long-term effects of land management practices in relation to sediment laden river plumes and algal blooms. This will be carried out by relating the EDR of the water quality variables (chlorophyll-a, TSS, CDOM and water clarity) to driver variables such as rainfall, river flow and sea surface temperature records in a statistical analysis.

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 the flood waters of the Fitzroy River in Keppel Bay (February 2008) and the wet season sampling of the wet tropics (April 2008).

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, 2008). The Secchi depth (m) database would allow a direct validation the Secchi Depth estimates done from remote sensing data.

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.

In the 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 chlorophyll *a* data from GBROOS/IMOS underway sampling and moorings should be investigated as a priority over the next 24 months.

CSIRO's Environmental Earth Observation Group is currently exploring avenues for assimilation of satellite observational data with biogeochemical and sediment transport models in Keppel Bay, within a collaborative project funded by CSIRO's "Water for an Healthy Country" Flagship. An improved model for light attenuation based on the specific optical characteristics of dissolved and particulate substances in Keppel Bay was developed based on the local optical measurements and remotely sensed light attenuation estimate. Currently the group is evaluating the use of satellite observations to supplement in situ data to improve calibration and parameterisation of the model for the estimate of fluxes to the GBR. Assimilation of satellite observations with biogeochemical and sediment transport models is likely to become increasingly important in the near future, as it combines the merits of both tools.

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.

ACKNOWLEDGMENTS

Lesley Clementson, for discussion on phytoplankton absorption spectra

References

Furnas, M. (1992), Pelagic Trichodesmium (=Oscillatoria) in the Great Barrier Reef region, in *Marine Pelagic Cyanobacteria: Trichodesmium and other Diazotrophs.*, edited by E. J. Carpenter, et al., pp. 265-272, Kluwer Academic Publishers, Netherlands.

Revelante, N., and M. Gilmartin (1982), Dynamics of Phytoplankton in the Great Barrier Reef Lagoon, *Journal of Plankton Research*, *4*(1), 47-76.

Sarangi, R. K., P. Chauhan, S. R. Nayak, and U. Shreedhar (2005), Remote sensing of *Trichodesmium* blooms in the coastal waters off Gujarat, India using IRS-P4 OCM, *International Journal of Remote Sensing*, *26*(9), 1777-1780, doi:10.1080/01431160310001642340.

Subramaniam, A., and E. J. Carpenter (1994), An empirically derived protocol for the detection of blooms of the marine cyanobacteria *Trichodesmium* using CZCS imagery., *International Journal of Remote Sensing*, *15*(8), 1559–1569, doi:10.1080/01431169408954191.

Subramaniam, A., C. W. Brown, R. R. Hood, E. J. Carpenter, and D. G. Caponea (2002), Detecting Trichodesmium blooms in SeaWiFS imagery, *Deep-Sea Research II*, *49*, 107-121, doi:10.1016/S0967-0645(01)00096-0.

Brando, V.E., & Dekker, A.G. (2003). Satellite hyperspectral remote sensing for estimating estuarine and coastal water quality. *IEEE Trans.Geosci.Remote Sens., 41*, 1378-1387

Brando, V.E., Blondeau-Patissier, D., Dekker, A.G., Daniel, P.J., Wettle, M., Oubelkheir, K., & Clementson, L. (2006a). Bio-optical variability of Queensland coastal waters for parameterisation of coastal-reef algorithms. . In, *Ocean Optics XVIII* (p. CD rom). Montreal (Canada): ONR-NASA

Brando, V.E., Dekker, A.G., Marks, A., Qin, Y., & Oubelkheir, K. (2006b). Chlorophyll and Suspended Sediment Assessment in a Macro-Tidal Tropical Estuary Adjacent to the Great Barrier Reef: Spatial and Temporal Assessment Using Remote Sensing. (p. 114) Indooroopilly, Qld, Australia: CRC for Coastal Zone, Estuary and Waterway Management

Brando, V.E., Robson, B.J., Cherukuru, N.R.C., Dekker, A.G., & Webster, I.T. (2007). Toward assimilation of ocean colour satellite observation into coastal ocean biogeochemical models: the tropical Fitzroy River Estuary case study. In Proceedings of *Assimilation of Remote Sensing and In Situ Data in Modern Numerical Weather and Environmental Prediction Models*. (pp. 66850D-66858). San Diego, CA, USA: SPIE

Brando, V.E., Dekker, A.G., Schroeder, T., Park, Y.J., Clementson, L.A., Steven, A., & Blondeau-Patissier, D. (2008). Satellite retrieval of chlorophyll CDOM and NAP in optically complex waters using a semi-analytical inversion based on specific inherent optical properties. A case study for Great Barrier Reef coastal waters. In Proceedings of *Ocean Optics XIX*. (p. 0445). Barga, Italy

Carder, K.L., Chen, F.R., Lee, Z., Hawes, S.K., & Cannizzaro, J.P. (2003). *MODIS Algorithm Theoretical Basis Document ATBD 19*. (p. 67pp)

Giardino, C., Brando, V.E., Dekker, A.G., Strombeck, N., & Candiani, G. (2007). Assessment of water quality in Lake Garda (Italy) using Hyperion. *Remote Sensing of Environment, 109*, 183-195

Gordon, H.R., Brown, O.B., Evans, R., Brown, J., Smith, R.C., Baker, K.S., & Clark, D.C. (1988). A semianalytical model of ocean colour. *J.Geophys.Res., 93(D9)*, 10909

Hoge, F.E., & Lyon, P.E. (1996). Satellite retrieval of inherent optical properties by linear matrix inversion of oceanic radiance models - an analysis of model and radiance measurement errors. *Journal of Geophysical Research-Oceans, 101*, 16631-16648

Hoogenboom, H.J., Dekker, A.G., & De Haan, J.F. (1998). Retrieval of chlorophyll and suspended matter in inland waters from CASI data by matrix inversion. *Canadian Journal of Remote Sensing, 24*, 144-152

Lyon, P., & Hoge, F. (2006). The Linear Matrix Inversion Algorithm. In Z. Lee (Ed.), *IOCCG Report Number 5. Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms, and Applications* (pp. 49-56). Dartmouth, Canada: IOCCG

Maritorena, S., Siegel, D.A., & Peterson, A.R. (2002). Optimization of a semianalytical ocean color model for global-scale applications. *Appl.Opt., 41*, 2705-2714

Qin, Y., Dekker, A.G., Brando, V.E., & Blondeau-Patissier, D. (2007). Validity of SeaDAS water constituents retrieval algorithms in Australian tropical coastal waters. *Geophys. Res. Letters, 34*

Schaffelke, B., Carleton, J., Zagorskis, I., Furnas, M.J., Skuza, M., Wright, M., Dekker, A.G., Blondeau-Patissier, D., & Brando, V.E. (2006). *Nearshore marine water quality monitoring. In: CRC Reef Consortium. Water Quality and Ecosystem Monitoring Programs–Reef Water Quality Protection Plan. Final Report August 2006 (revision November 2006).* (pp. 105-170) Townsville: CRC Reef Research

Schroeder, T., Brando, V.E., Cherukuru, N.R.C., Clementson, L.A., Blondeau-Patissier, D., Dekker, A.G., Schaale, M., & Fischer, J. (2008). Remote sensing of apparent and inherent optical properties of Tasmanian coastal waters: application to MODIS data. In Proceedings of *Ocean Optics XIX*. (p. 0445)

Wang, P., Boss, E.S., & Roesler, C. (2005). Uncertainties of inherent optical properties obtained from semianalytical inversions of ocean color. *Applied Optics, 44*, 4074-4085