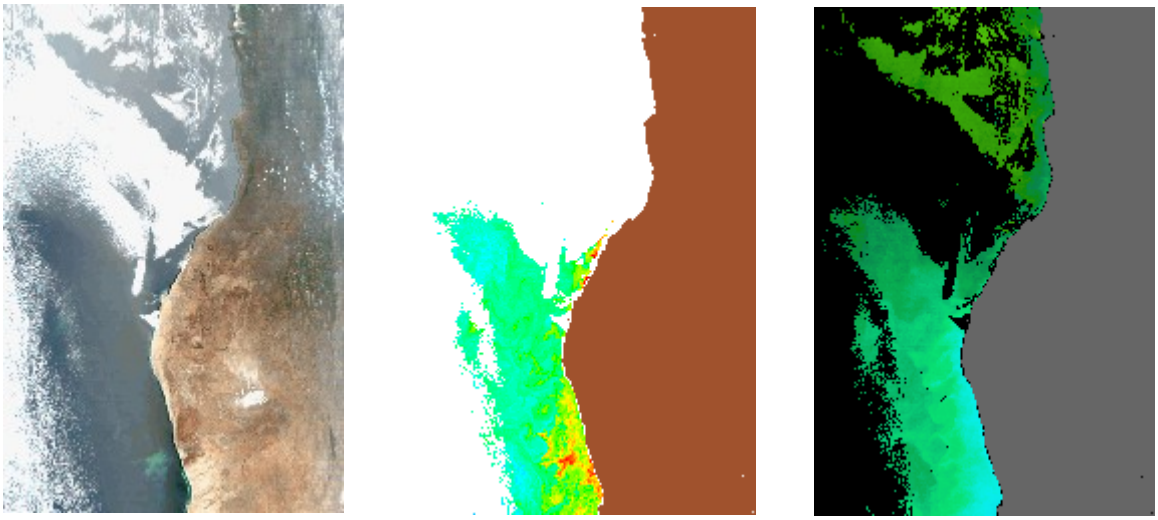
Assessing potential to produce final Ocean Colour maps of Namibia's marine environment

FINAL REPORT FOR BCLME/UNOPS

PCU/POLYTECH/05/01



MODIS Aqua products of 9 August 2005 for northern Namibia (Source : Ocean Color Web NASA)

Vera De Cauwer
Polytechnic of Namibia

Table of Contents

1. Introduction

Satellite products provide a useful management tool for Namibia, a country with a long and sparsely populated coastline and for which marine resources provide a major source of income. Their main use is to support the prior function of the relatively small research team at the Ministry of Marine Fisheries and Resources (MFMR) : providing information to estimate the Total Allowable Catch (TAC) for different commercial fish species every year. Limited time is available to actually validate the accuracy of the satellite products for Namibian waters and study interesting phenomena visible on the images in more detail. Academic institutions in Namibia that aim to increase their research potential, such as the Polytechnic of Namibia, could support and complement this research task of the Ministry.

It this with this in mind that a pilot project was set up at the Polytechnic of Namibia. Its main aim was to test the production of a set of ocean colour maps based on MODIS Aqua data and to perform a preliminary evaluation of the products. This step is necessary before actual marine remote sensing research and training can be started up. The project was spread over one year and performed with little time available (24 working days).

The project is an initiative of the Polytechnic of Namibia and supported by the Benguela Current Large Marine Ecosystem Programme (BCLME) Programme through UNOPS.

2. Background

The marine environment of Namibia is dominated by the Benguela Current system, a cold water system characterised by wind-driven coastal upwelling and one of the highest concentrations of marine life in the world. The high biological productivity (mean annual productivity of 1254 g C/m^2.y) is a direct consequence of the upwelling as it makes available an abundant supply of nutrients in the upper water layers which, together with sunlight, promotes extensive blooms of phytoplankton, rich resources of zooplankton and an abundance of pelagic fish (O'Toole, 1997).

The extent and intensity of coastal upwelling is primarily determined by wind and pressure fields which in combination with bathymetric features and the orientation of the coast results in the formation of a number of upwelling cells. Upwelling conditions vary through the year and characterise the dynamic Benguela system with continuously fluctuating temperature, chlorophyll *a* (chl *a*) and oxygen concentration, particularly in shelf waters (Fishwick *et al.*, 2003 ; Sakko, 1998).

Primary production is therefore variable with maxima measured at the Cape Frio upwelling cell of 4.1 g C/m^2.day and the southern Benguela of 2.0 g C/m2.day (Brown et al., 1991 ; Fishwick *et al.*, 2003 ; Wasmund *et al.*, 2005). Low phytoplankton abundance values are found around 27 – 28 °S at the base of the Lüderitz upwelling cell, one of the most intense upwelling cells in the world's oceans (Brown *et al.*, 1991).

Primary production can be derived by measuring chl *a* concentration, the most important pigment of phytoplankton allowing it to absorb light for photosynthesis. During active upwelling, the highest concentrations of chl *a* occur offshore off the Namibian coast (50 km), but during quiescent periods the phytoplankton is located close to the coast (Brown *et al.*, 1991). The highest chl *a* concentration in the upper 30 m water layer on the 23º S Walvis Bay monitoring line – which extends 70 km offshore - was 34 mg/m^3 during the period 2003 – 2004. There were several high chl events (> 10 mg/m^3) during that period (based on data of Louw, D., MFMR). Siegel, Gerth & Ohde (2004) measured values up to 42 mg/m^3 at a transect off Walvis Bay during the Meteor cruise in 2003.

The variability of the Benguela system significantly impact its biological resources (Fishwick *et al.*, 2003) and hereby one of the major resources of income for Namibia : fisheries. A better understanding of the variability of the system will contribute to the sustainable harvesting of marine resources. Currently, the idea that fisheries management should take a broader, more holistic view of the oceans' resources is rapidly gaining momentum in the region (Shannon *et al*., 2005).

In Namibia, the Ministry of Fisheries and Marine Resources (MFMR) has the responsibility to safeguard the marine resources and establish fishing quotas every year. This is a major task for a young, developing country with a population of about two million people and a coastline of 1470 km long (Mastailar, 1998) along which only five small towns are established. Collecting and processing the data required for a sustainable management approach to fisheries is limited by financial and human resources. Daily acquired satellite images which give a synoptic coverage of Namibian waters therefore provide a useful additional data source.

At the moment, the ministry uses the following marine remote sensing products : Sea Surface Temperature (SST) and chl *a* concentration products derived from NOAA, SeaWiFS (Sea-viewing Wide Field-of-view sensor), MODIS (Moderate Resolution Imaging Spectroradiometer) and Meteosat satellite data (Chris Bartolomae & Nande Nicanor, *pers. comm*.). Although most of these satellite products and the necessary software to process them can be obtained for free from the Internet, the ministry relies on the services of a company in Cape Town to download, process and send images against a fee of about N$ 36,000/year. The company – linked to the University of Cape Town – is the only institution with the necessary experience and infrastructure in the South-African region to provide this service. Since researchers do not receive the SeaWiFS images of the U.S. National Aeronautics and Space Administration (NASA) in real-time anymore, the company is starting to use MODIS images, as are many research institutions all over the world (Kevin Ruddick, Bouchra Nechad, Neville Sweijd, *pers. comm*.).

SeaWiFS, MODIS Terra and MODIS Aqua are ocean colour sensors of NASA launched in respectively August 1997, December 1999 and May 2002. The radiances they measure allow amongst others the estimation of chl *a* concentrations based on a blue/green ratio targeting to detect the chl *a* absorption peak at 440 ~ 443 nm.

As both MODIS satellite images and the software to process the images are for free, the Polytechnic of Namibia can easily test the possibility to process final ocean colour products in Namibia and initiate marine remote sensing training and research.

1. Hypothesis on the short term (pilot project - described in this proposal) : the Polytechnic of Namibia is able to produce and analyse final ocean colour products for Namibia (and if required for the South-African region) with the assistance of students ;

2. Research problems on the long term (follow-up projects, not included in this proposal and further discussed in the last chapter of this report) :

    - Provide satellite products as input and validation tools to early warning systems based on satellite chl *a* and SST products : e.g. for sulphide eruptions, harmful algal blooms such as red tides, Benguela El Niños and global weather effects ;
    - Study the cause and cycle of sulphur eruptions at the Namibian coast ;
    - Determine the feasibility of ocean colour products for studying the impact of marine mining on the turbidity of the water (through calculation of total suspended matter). Diamond mining may cause a seasonal increase in turbidity levels as bottom sediments are locally disturbed and resuspended into the water column during mining operations (O'Toole, 1997) ;
    - Study the seasonal, interannual and decadal variability of chl *a* concentration and its relation with commercial fish stocks and global weather effects (relevant to the development of ecosystem models) ;
    - Study the possibility to detection oil pollution with MODIS images ;
    - Assess the possibilities of ocean colour data for determining phytoplankton species composition ;
    - In-situ validation of the NASA algorithms for calculating earth-leaving radiances and chl *a* production for the Namibian marine environment with its exceptionally high chl *a* concentration ;

- Developing regional chl *a* algorithms based on earth-leaving radiances ;
- Test products of other ocean colour sensors such as MERIS (European Space Agency, ESA) for Namibian waters ;
- Determine the relation between chl *a* concentration in upper and lower water layers.

The direct deliveries of this pilot project are as follows :

- a computer installed at the Polytechnic of Namibia that is assigned to marine remote sensing (with SeaDAS image processing software) ;
- an archive of MODIS images stored on the computer ;
- a first evaluation performed on a set of images in SeaDAS ;
- the compilation of a draft manual for students to work with MODIS images in SeaDAS ;
- recommendations for further research at the Polytechnic of Namibia.

3. Methods

3.1 Hardware and software used

A computer was set-up at the Polytechnic assigned solely to ocean colour processing. Linux Fedora was installed, as well as the free **SeaDAS** (SeaWiFS Data Analysis System) software, version 4.9.4, of NASA. Linux support can be obtained from a few lecturers and IT staff of other departments at the Polytechnic, however this is not encouraged by management as the workload of these staff members is already overloaded.

At the start of the project, it was not possible to download the SeaDAS software of the NASA server, because of the Polytechnic firewall. After the Computer Services Bureau of the Polytechnic upgraded the Squid on the staff proxy to version 2.5.STABLE11 in July 2006, no download problems were encountered.

The image viewer **Seasat** was installed on a computer with a Windows operating system to look at satellite products downloaded from the South African Remote Sensing Server for Marine Sciences (for more information : see 3.2.2). Seasat is a free visulatisation tool that can be downloaded from the server, as well as the IDL virtual machine which is required to run Seasat. The Seasat software was developed by researchers of the French research institute *Institut de Recherche pour le Développement* (IRD).

3.2 Download of MODIS products

3.2.1 NASA ocean colour site

MODIS Aqua products covering Namibian waters were searched for a few periods between 2003 and 2005 by using the 'L1 and L2 browser' of NASA's ocean colour site (http://oceancolor.gsfc.nasa.gov). The ocean colour data archive can be visually searched based on quick looks displayed, after which the image can be downloaded. The process of looking for suitable images that are relatively cloud-free is time-consuming because of the slow response of the server.

There are two ways to download a selected image :

- ftp download : selecting and ordering a set of selected images which are placed on a temporary ftp site for you during 3 days (can be extended up to an additional 10 days) ;
- direct download : right clicking on the hyperlinks for the satellite products and saving them in a directory on your computer.

The first method did not work before July 2006 because of the same firewall problem encountered with the downloading of SeaDAS. Downloading with the second method was often interrupted because of a time-out of the server. Therefore, download managers such as GetRight or Internet Download Manager had to be used. Once downloaded, all images need to be decompressed from bzip2 (*.bz2) or gzip (*.gz) format.

3.2.2 South African Remote Sensing Server for Marine Sciences

The South African Remote Sensing Server for Marine Sciences (www.rsmarinesa.org.za) - further referred to as the Marine RS Server – provides daily and multi-temporal MODIS products for Namibia and other South African areas. This trial server is jointly funded by BCLME, the African Coelacanth Ecosystem Programme (ACEP) and the Bayworld Centre for Research and Education (BCRE), and is operated by the University of Cape Town, MFMR and the Benguela Environment Fisheries Interaction and Training Programme (BENEFIT).

The site currently provides archived and near-real time 1 km SST and chl *a* data from MODIS, using default NASA ocean colour processing. Next to the daily images, following products are provided as pictures and as binary files (Saulquin, 2006) :

- daily weighted averages : composite weighted averages of day – 1 (weight 1), day (weight 3), day + 1 (weight 1),
- daily anomalies : MODIS anomalies, calculated with 9 km resolution 5 day Pathfinder climatology for the SST product and with 9 km resolution monthly SeaWiFS climatology for the chl *a* product,
- pentads : composite averages of day 1 to day 5.
- new MODIS chl *a* calculation : since recently, chl *a* products are provided that were obtained with a new algorithm that is still being tested.

Several Chl *a* and SST products of the Marine RS Server were downloaded during this pilot project to compare the download process and the products with those obtained from the NASA site. The Marine RS server responded faster than the NASA server which makes it a good tool to find days with relatively cloud-free conditions.

There were some problems with downloading the archived products for Namibia, but this was solved in October 2006 after on-line assistance from Bertrand Saulquin was requested.

The display region for Namibia is not entirely correct on the Marine RS Server : it indicates the area [28º S, 4º E] to [14º S, 16º E] however Namibia extends further south-east with Oranjemund at -28.64º S, 16.48º E.

3.3 Image processing

All image processing was done in SeaDAS. This image processing software takes some time to learn, especially because the help and tutorial material is not that clear and straight forward. Another contributing factor is that there is no one else in Namibia using the software. Therefore, a draft manual was developed during this pilot project, which can be used and further developed by Polytechnic students.

Following procedures were most used for L2 products :

- projecting of images to Transverse Mercator, with central latitude -22° and central meridian 15°,
- creating subscenes of two study areas : Walvis Bay and Lüderitz (see figure 1),
- creating profiles of 23° south monitoring line situated south of Walvis Bay.

Tools used for both L1 and L2 products included amongst others :

- creation of scatter plots between 2 bands,
- creation of histograms of 1 band,
- display of flags.

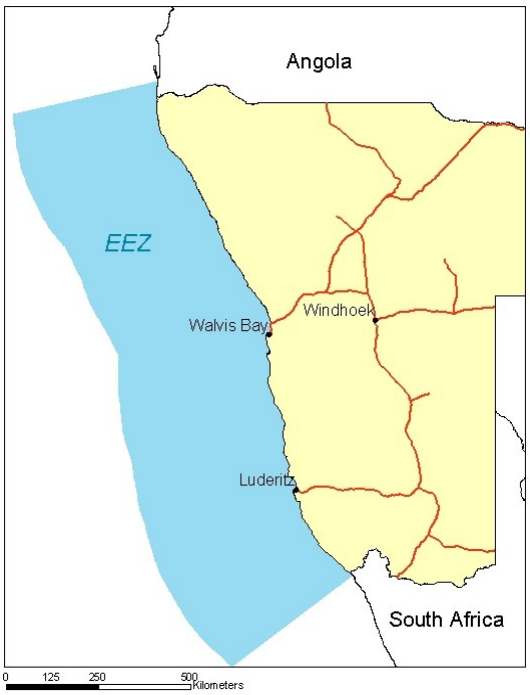
Processing from L1 to L2 data involved :

- geolocation : L1A to geo processing,
- modis_l1bgen : L1A to L1B processing,
- creation of true colour images.

Direct advantages of using an image processing software like SeaDAS compared to a viewer like Seasat are obvious and include :

- creation of custom sized colour schemes and legends,
- application of projection parameters adapted to the country,
- evaluation of the radiances of the different bands possible,
- choice of more data export formats,
- compilation of image composites,
- L2 flags can be studies and allow an evaluation of filter methods for L1 data,
- application of simple arithmetic functions can allow to test algorithms,
- ...

Figure 1 – Namibia with Exclusive Economical Zone (EEZ) indicated in blue



3.4 In-situ data

Some of the L2 chlorophyll products were compared with in-situ measurements. Chlorophyll a (chl *a*) measurements are made by MFMR along the 23° south latitude line of Walvis Bay since 2000. The Ministry performed monthly surveys until end 2004 while bi-monthly surveys were introduced in 2005. The measurement stations are spaced at 2 nm, 5 nm, 10 nm, and then every 10 nm up to 90 nm (168 km) offshore, but since 2003 only up to 70 nm (130 km). Chl *a* is measured between the surface and a depth of approximately 30 meters with a Turner fluorometer. Chl *a* extraction is done according to the Welschmeyer method. The measurements are illustrated in figures 2 and 3.

Figure 2 – Average chl a concentrations (µg/l) measured with a fluorometer between the surface and 30 m depth on the 23° south monitoring line by the Namibian Ministry of Fisheries and Marine Resources (MFMR) (Source : Louw, 2006)

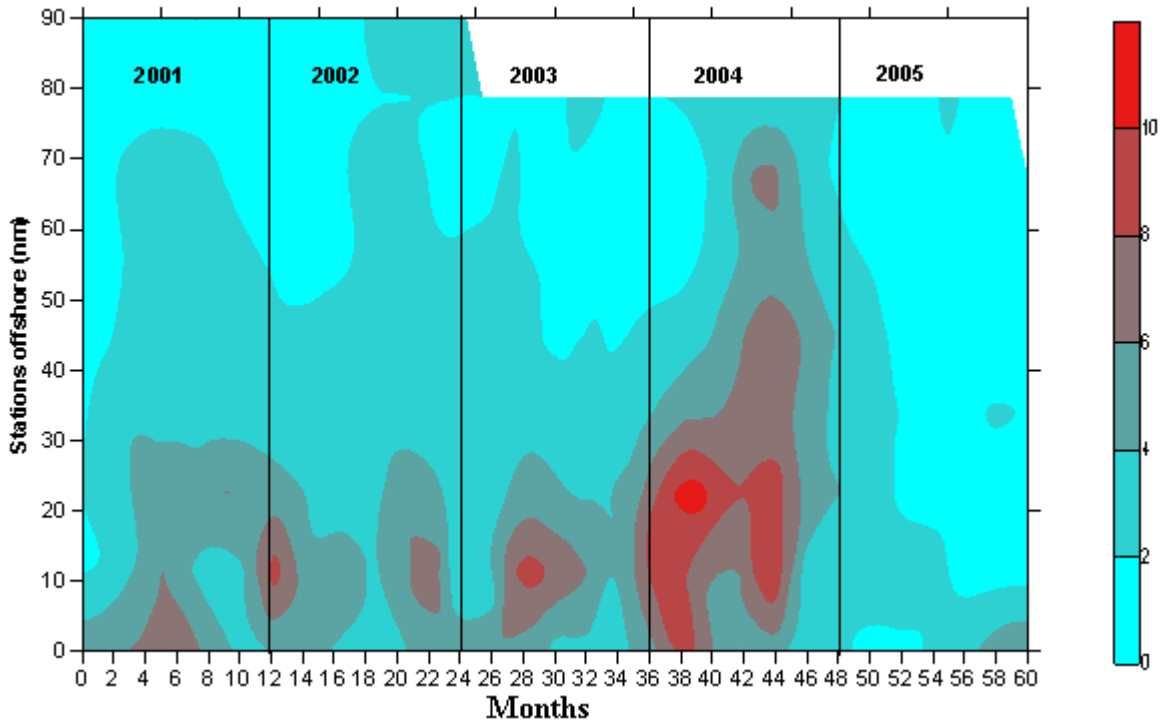
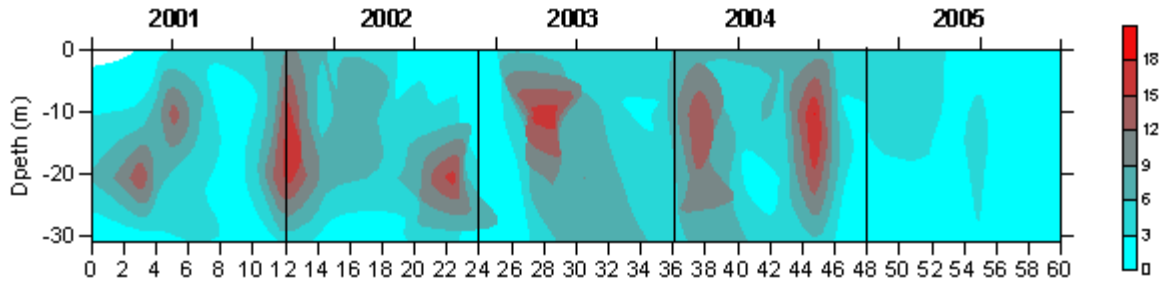


Figure 3 – In-situ chl a concentration measured on the 10 nm station off Walvis Bay on the 23° south line between the surface and 30 m depth (Source : Louw, 2006)



Mr Deon Louw provided the chlorophyll measurements of the period 2003 – 2004. He also mentioned that he had problems with the fluorometer, did not trust the measurements from 2005 onwards and that the instrument needs urgently to be calibrated. The highest chl a concentration in the upper 30 m water layer on the monitoring line during the period 2003 – 2004 was 34 mg/m^3. 24 % of the 147 station measurements recorded high chl events (> 10 mg/m^3) at the surface (depth of 1 to 3 meter) during that period. 77 % of the high chl events occurred at a distance of 2 nm to 20 nm offshore Walvis Bay.

At each station, measurements are made at the surface and at depths of about 10, 20 and 30 meter. For the period 2003 - 2004, most high chl *a* events were recorded at the surface (36 %) or at a depth of about 10 m (30 %). This is a good indication of the usefulness of satellite images to detect high chl events.

Ms Anja Kreiner of MFMR provided details about the exact dates of the following cruises, as well as the coordinates of the stations and the approximate times of the measurements :

- 4 March 2003,
- 15 April 2003,
- 27 January 2004,
- 30 November 2004,
- 11 February 2005,
- 12 May 2005,
- 29 June 2005.

It should be noted that the positions of the measuring stations as used in this study were determined by the absolute coordinates during the research cruise and not by the distance offshore.

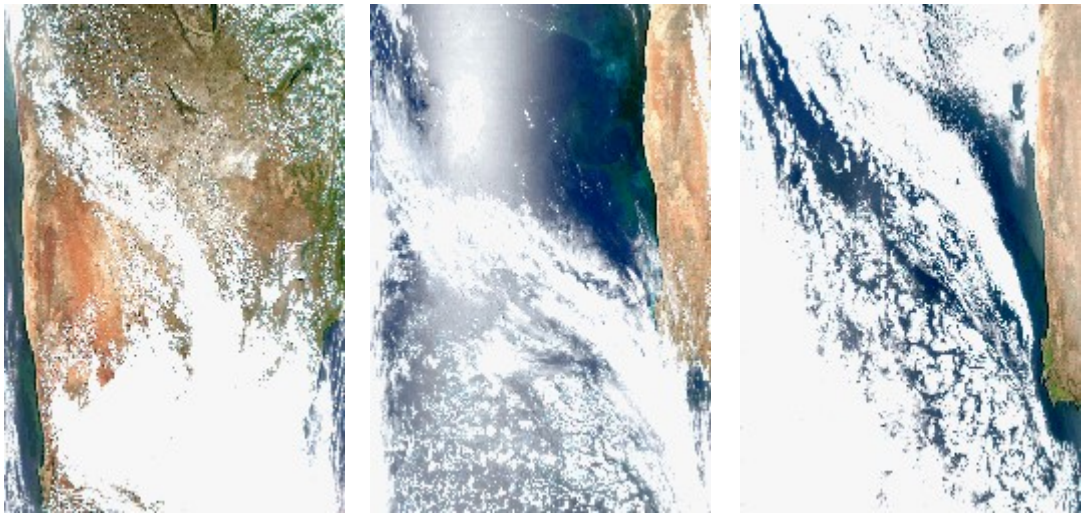
4. Archive of images downloaded

It is difficult to find cloud-free images for Namibian waters. Table 1 illustrates the frequency of MODIS Aqua image acquisitions under favourable cloud conditions. As MODIS Aqua has a daily overpass, the frequency is based on the amount of days considered. Figure 4 and the first page of this report illustrate some of the images that are considered to have favourable cloud conditions.

Table 1 – Availability of MODIS Aqua images with favourable cloud conditions for Walvis Bay or Lüderitz for several periods between 2003 and 2005 (assessment mainly based on quick looks)

Period	Days	Walvis Bay	Luderitz
16 Mar - 2 Apr 2003	18	9	10
27 Nov - 31 Dec 2004	35	11	11
9 - 28 Feb 2005	20	4	7
1 Aug – 19 Aug 2005	20	3	4
11 - 30 Sep 2005	20	3	5
Total	**113**	**30**	**37**
Total (%)		**27**	**33**

Figure 4 – Quasi true colour quick looks of MODIS Aqua images considered to have favourable cloud conditions for the areas offshore Walvis Bay or Lüderitz : (a) 19 March 2003, (b) 1 December 2004, (c) 5 August 2005



The list of downloaded satellite products is displayed in table 2. Downloading is a time consuming process because of the large size of the compressed files :

- Ocean **Level 1A (L1A)** data consists of uncalibrated raw radiances for 9 MODIS spectral bands. A dataset is about **57 MB** in compressed format (206 MB uncompressed). The format of the Ocean Level-1A file is near identical to that of the standard (full) Level-1A file, except that the 250-meter and 500-meter band Science Data Sets are removed, and certain 1-km bands are zeroed-out to enhance compressibility (Thomas & Franz, 2005) ;

Table 2 – Archive of MODIS products downloaded (file naming uses following convention : sensor (A for Aqua/MODIS, T for Terra/MODIS) and time of first scan in the file (yyyydddhhmmss)

	Date (Y-M-D)	Name	L1A	L2	Quality
1	03-03-30	A2003089133000	X		OK for central
2	03-03-31	A2003090123500	X	X	OK for south
3	03-04-14	A2003104125000	X	X	OK for Wbay
4	03-04-15	A2003105133000	X	X	Not so good, except for center
5	04-11-29	A2004334132000	X	X	Good for coastal area
6	04-12-01	A2004336130500	X	X	Very good
7	04-12-03	A2004338125500	X	X	Very good for north and south
8	04-12-10	A2004345130000	X	X	Good for south
9	04-12-19	A2004354125500	X	X	Good for north and extreme south
10	04-12-24	A2004359131500	X	X	Not so good for south and north
11	04-12-25	A2004360122000	X	X	OK for north
12	04-12-26	A2004361130000	X	X	Good for north
13	05-02-03	A2005034130500		X	Fairly OK
14	05-02-19	A2005050130500	X	X	Good for south and extreme north
15	05-02-25	A2005056123000	X	X	OK for south
16	05-02-26	A2005057131000	X	X	Very good for south
17	05-02-27	A2005058121500	X	X	Good for extreme south
18	05-06-03	A2005154121500	X	X	Ok for Luderitz area
19	05-06-29	A2005180125500	X	X	Good for south
20	05-08-02	A2005214124000	X	X	Good for center and south
21	05-08-09	A2005221124500	X	X	Good for south
22		A2005221125000	X	X	Good for north and center
23	05-08-11	A2005223123500	X	X	Good for coastline south
24	05-08-13	A2005225122000	X	X	Good coastline for extreme south
25	05-08-16	A2005228125000	X	X	Good for extreme south
26		A2005228125500	X	X	Ok for coastline south
27	05-08-18	A2005230124000	X	X	Good for center and south
28	05-09-01	A2005244125500		X	Good for south
29	05-09-15	A2005258130500	X	X	Very good for south, good for central (haze ?)
30	05-09-17	A2005244125500	X	X	Good for south
31	05-09-19	A2005262124000		X	Good for south
32	05-09-26	A2005269125000	X	X	Good for south
33	05-09-28	A2005271123500		X	Good

- **Level 2 (L2)** data consists of various derived products from the observed top-of-atmosphere radiances with amongst others chlorophyll a concentration, normalized water-leaving radiances for 6 MODIS bands and SST. An L2 product is about **10 to 20 MB** large in compressed format (about 50 to 80 MB uncompressed).

Table 3 gives an idea of the time required to download the images at the Polytechnic of Namibia. Early mornings (< 8:30) and late afternoons (> 16:00) were the best moments to start downloading images, while the smaller L2 files could also be downloaded quicker during lunch time. The bandwidth of the Polytechnic is relatively large for Namibia : about 1 MB connection to the Internet service provider – ISP. However it remains a long process to download satellite images of up to 57 MB on a regular basis because this bandwidth has to be shared by a large number of users (staff and students).

Table 3 – Time (hh:mm) needed to download part of the archived satellite products

	L1A	L2
	01:40	00:11
	01:48	00:15
	02:09	00:19
	03:04	00:21
	03:14	00:24
	03:46	00:26
	03:56	00:39
	04:51	00:41
	04:56	00:44
	05:03	00:54
	05:05	00:59
	05:46	01:29
	05:55	01:35
	05:59	01:38
	06:23	01:50
	07:28	01:55
	08:43	02:43
	08:47	03:12
	11:28	03:28
		04:02
COUNT	**19**	**20**
AVERAGE	**05:15**	**01:23**
STDEV	**02:33**	**01:09**
TOTAL	**100:01**	**23:43**

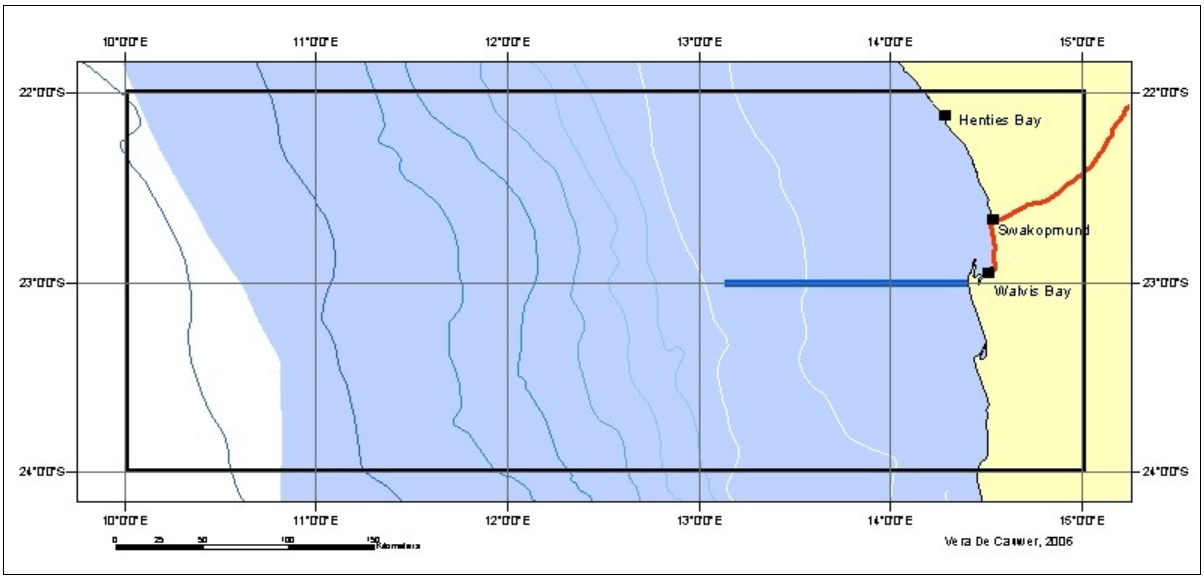
5. Evaluation of images

A preliminary evaluation was done for some of the downloaded satellite images concentrating on two study areas within the Namibian Exclusive Economical Zone (EEZ) : the area offshore Walvis Bay and the area offshore Lüderitz.

5.1 Walvis Bay area

The Walvis Bay study area is displayed in figure 5, as well as the 70 nm long monitoring line of the MFMR at -23º latitude. It is situated in the central part of the Benguela current system.

Figure 5 – Walvis Bay area with indication of 23º monitoring line (EEZ of 200 nm displayed in blue)



5.1.1 MODIS chlorophyll products

The standard chlorophyll products of MODIS (L2 level) were compared with the in-situ data of seven cruises of MFMR within the period 2003 - 2005. One cloud-free match-up was obtained for the considered cruises : 29 June 2005. A match-up condition is obtained when in-situ data is taken within half an hour of the moment of satellite acquisition. The archived MODIS Aqua images of Namibian waters are all taken between 12:15 and 13:30.

Relatively cloud-free images obtained within a day of chlorophyll measurements are those of 29 November 2004 and 1 December 2004 (in-situ data of 30 November 2004).

29 June 2005

The MODIS image of 29 June 2005 is taken at 12:55, its chlorophyll product is displayed in figure 6 for the study area. The black areas on the imags are caused by clouds. The chl *a* concentrations along the 23° south line are displayed in figure 7. Chl *a* concentrations are suspiciously high for 2 pixels close to the shoreline. They display values of 187.7 mg/m3 and 82.1 mg/m3.LU

Figure 6 - MODIS Chlorophyll a product of 29 June 2005 for Walvis Bay study area

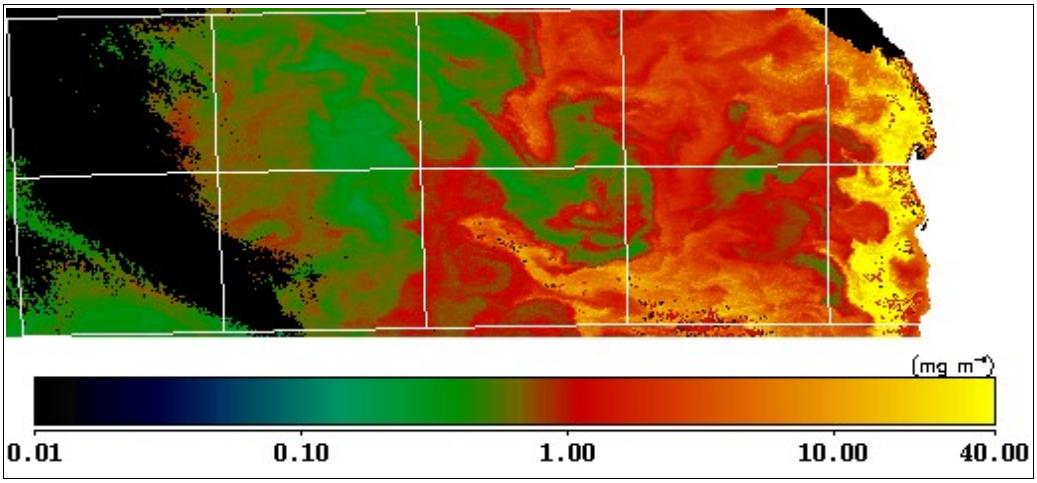
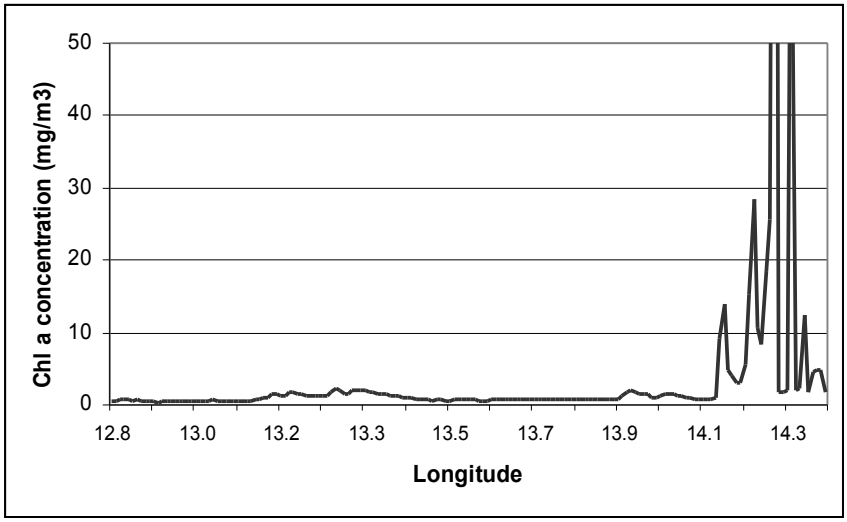


Figure 7 – Chl concentration along the 23° south monitoring line on 29 June 2005 as calculated by MODIS algorithm



The station at 40 nm offshore was sampled on the same day between 12:20 and 13:15, close to the time of the MODIS image acquisition. However the in-situ data could not be compared as Mr Louw did not consider this data trustworthy. This may be possible at a later stage when the instrument has been recalibrated.

30 November 2004

Relatively cloud-free images were obtained within a day of the chl *a* measurements of 30 November 2004. The chl *a* maps of 29 November and 1 December 2004 extracted for the study area are displayed in figures 8 and 9. Part of the study area is not covered by the image of 1 December, which is displayed as a black area in the northern part of the picture. Other black spots on the images are areas that have been masked, mainly because of clouds. More information on masked areas can be derived from the quality flags stored in the L2 dataset, or straight from the L1 bands. For example, band 16 (870 nm) gives an indication of atmospheric conditions (figure 10).

Figure 8 - MODIS Chlorophyll a product of 29 November 2004 for Walvis Bay study area

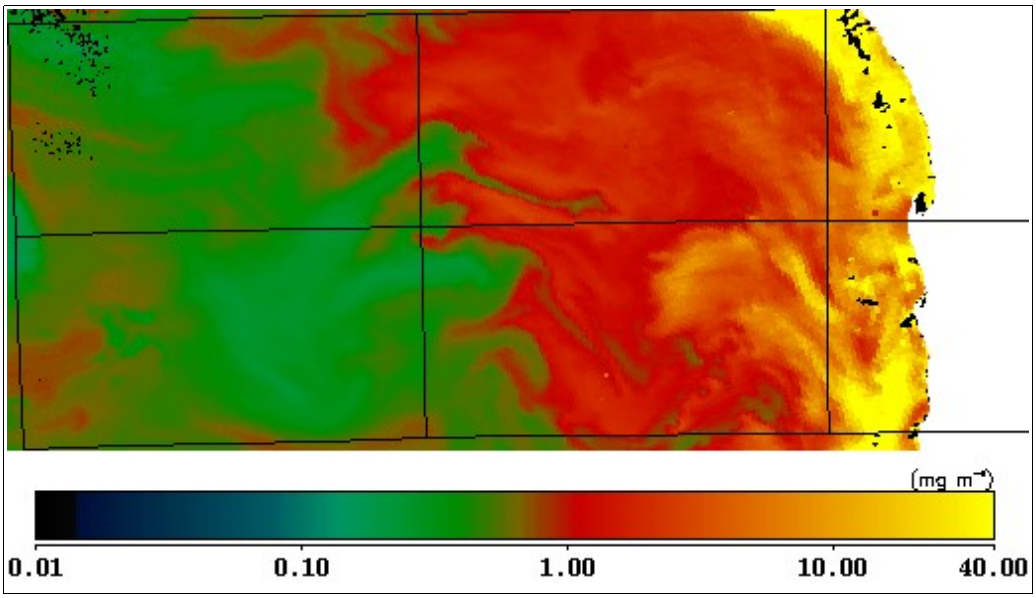


Figure 9 - MODIS Chlorophyll a product of 1 December 2004 for Walvis Bay study area

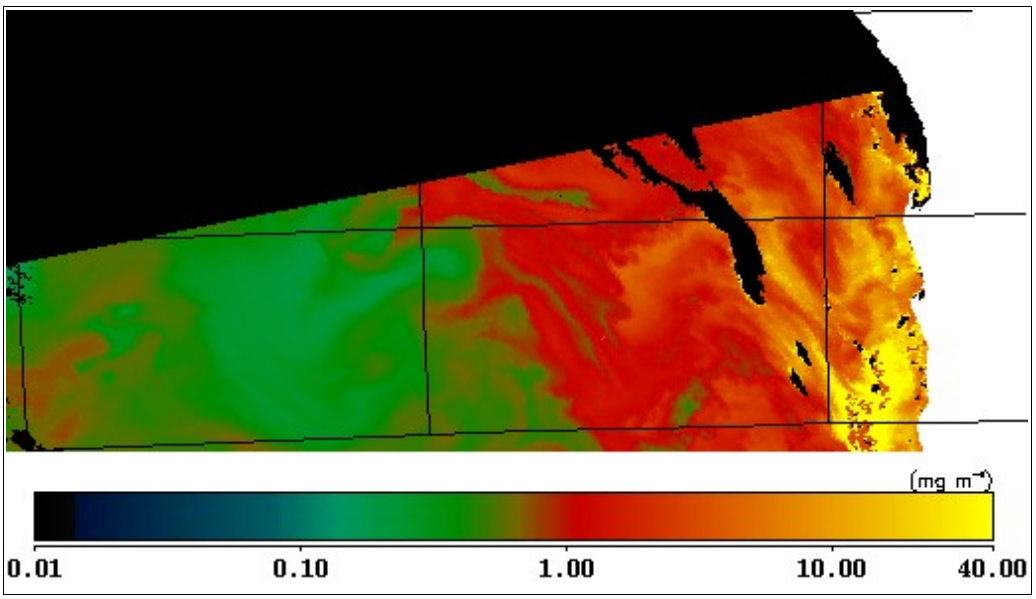
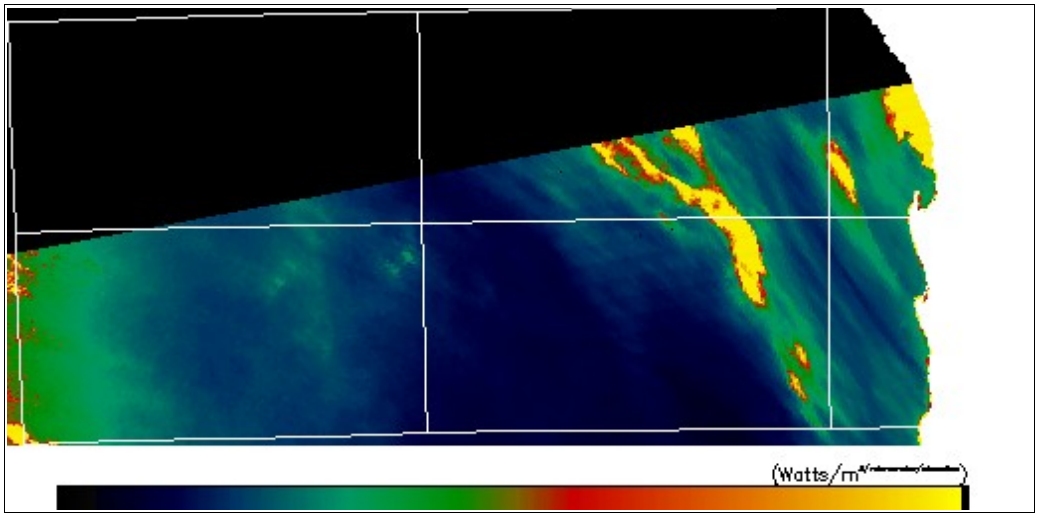
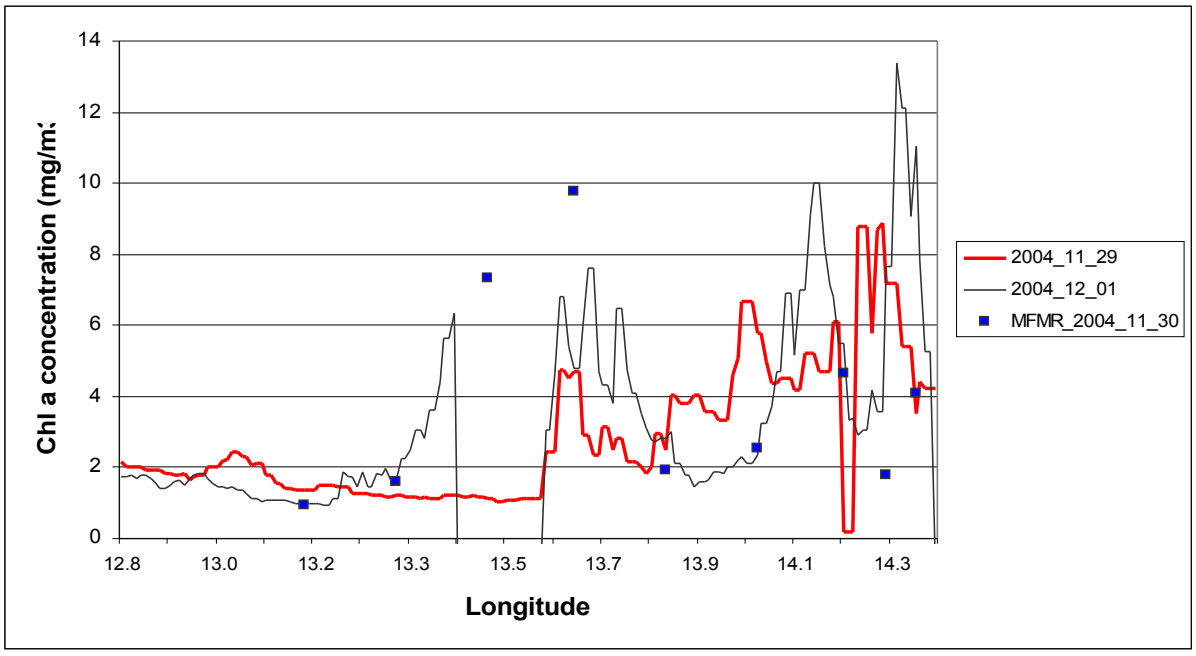


Figure 10 – Band 16 of MODIS (870 nm) on 1 December 2004 (based on L1B data)



A comparison of the data along the 23° south line for both MODIS products and the in-situ data is displayed in figure 11. There are no values displayed for the image of 1 December around the longitude of 13.5° as this coincides with the masked cloud. The in-situ values show a fairly good overlap with the MODIS data for most of the station measurements considering the time interval between measurements and image acquisition. The measurements of 30 November were taken between 10:00 am on 30 November and 1:00 am on 1 December, which might explain the slightly better overlap with the image of 1 December. The image of 1 December contains several extremely high chl *a* values (>100 mg/m3) close to the coast at other latitudes, which is suspicious.

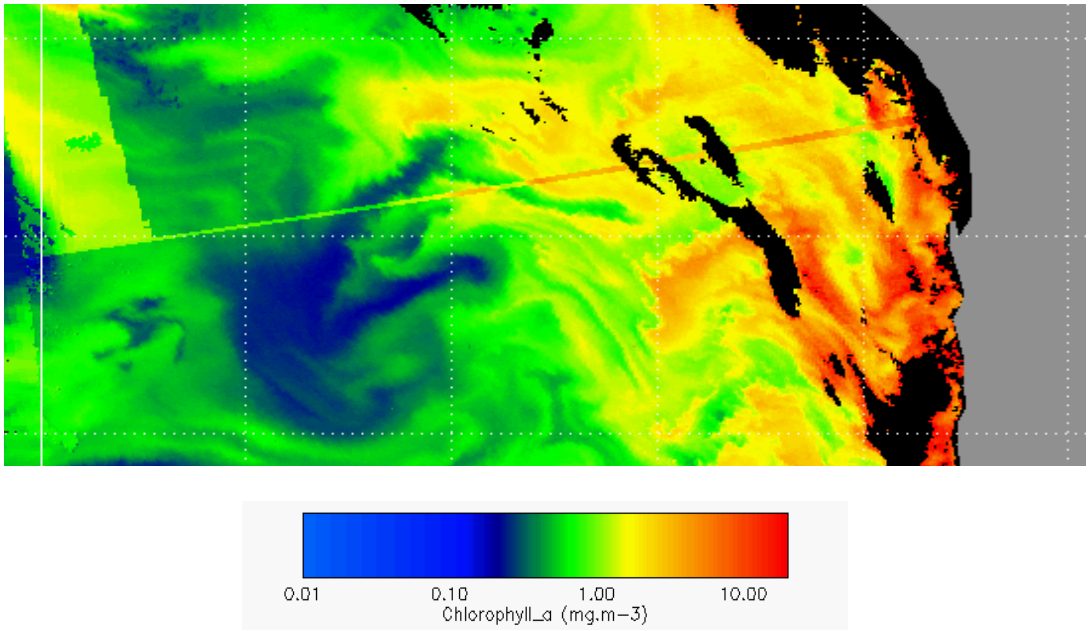
Figure 11 – Comparison of MODIS (lines) and in-situ data along the 23° south monitoring line



5.1.2 Chlorophyll products of Marine RS Server

The MODIS SST and chl *a* products can also be downloaded from the Marine RS Server in binary format. This format is compatible with the image viewer SeaSat that allows a quick and easy creation of pictures. An example of a picture created in Seasat is shown in figure 12. By comparing it with figure 9, it is clear that the chl *a* product is a composite of two MODIS images and that more areas have been masked in the image. The immediate and automatic creation of composites is an advantage for quick evaluations and certain operational uses. For certain research purposes, it is however necessary to get an image with exact date and time.

Figure 12 – Chl a product downloaded from the Marine RS Server for 1 December 2004 and displayed for the area offshore Walvis Bay



Seasat is easy and quick to use and has definitely a lot of advantages for certain users. However, as soon as the user prefers other settings for a map – for example a different projection, colour schemes or rescaling of the data – or to analyse the data it is necessary to import the data into another software such as SeaDAS or a GIS software.

The Marine RS server also provides new chl *a* products calculated with an algorithm that is currently being tested. It is indicated that this algorithm accounts for the sometimes poor MODIS correction. The product available for 1 December 2004 is shown in figure 13. The overlap between the two neighbouring images is not visible anymore.

The new chl *a* products for 29 November and 1 December 2004 are compared with the standard MODIS chl *a* product and the in-situ data in figures 14 and 15. The new algorithm reduces the chl *a* values for both images and it appears that this reduction is larger for the higher chl *a* values of the standard MODIS product. Match-up in-situ data would however be required to evaluate the new algorithm.

Figure 13 – New chl a product downloaded from the Marine RS Server for 1 December 2004 and displayed for the area offshore Walvis Bay

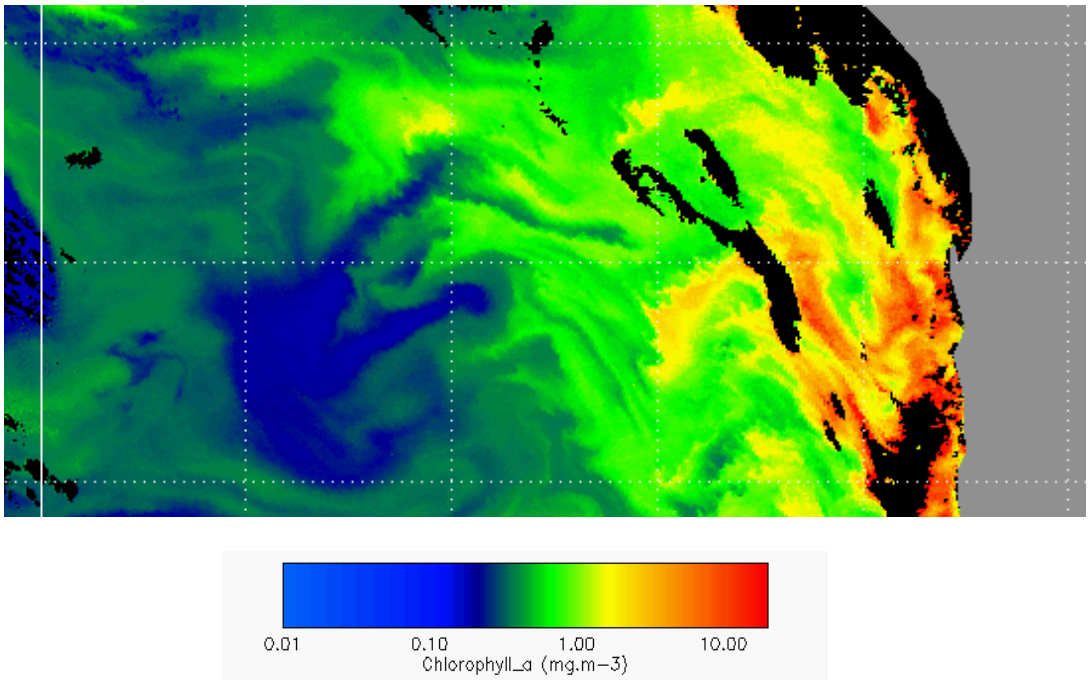


Figure 14 – Comparison of standard MODIS chl a product and new chl a product (Marine RS Server) of 1 December 2004 with in-situ data of 30 November 2004 for the 23º south monitoring line

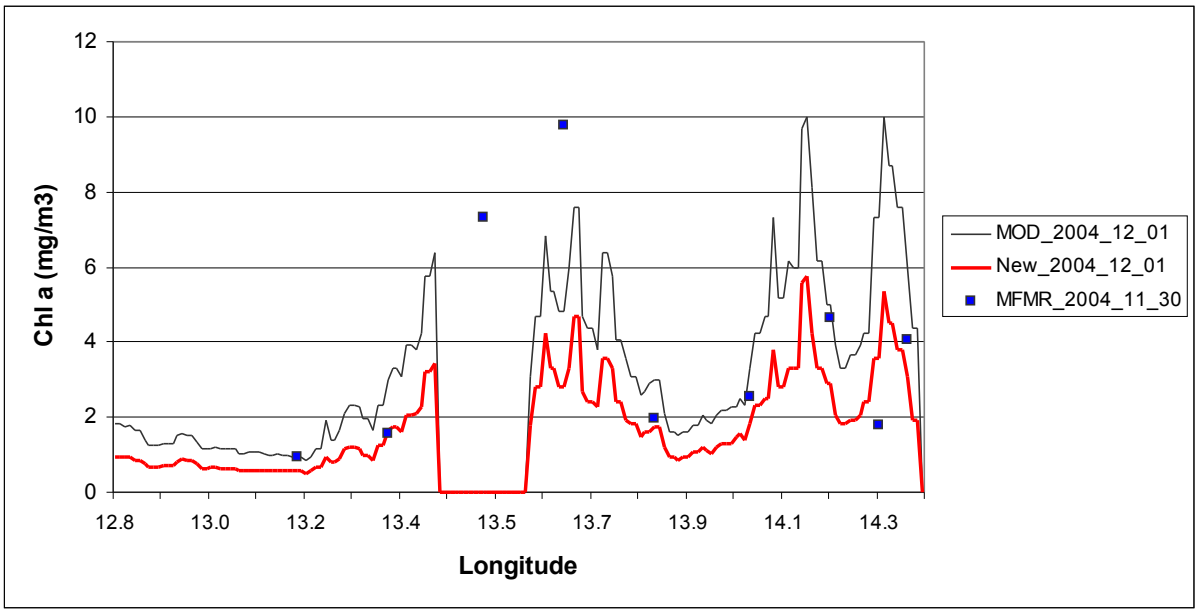
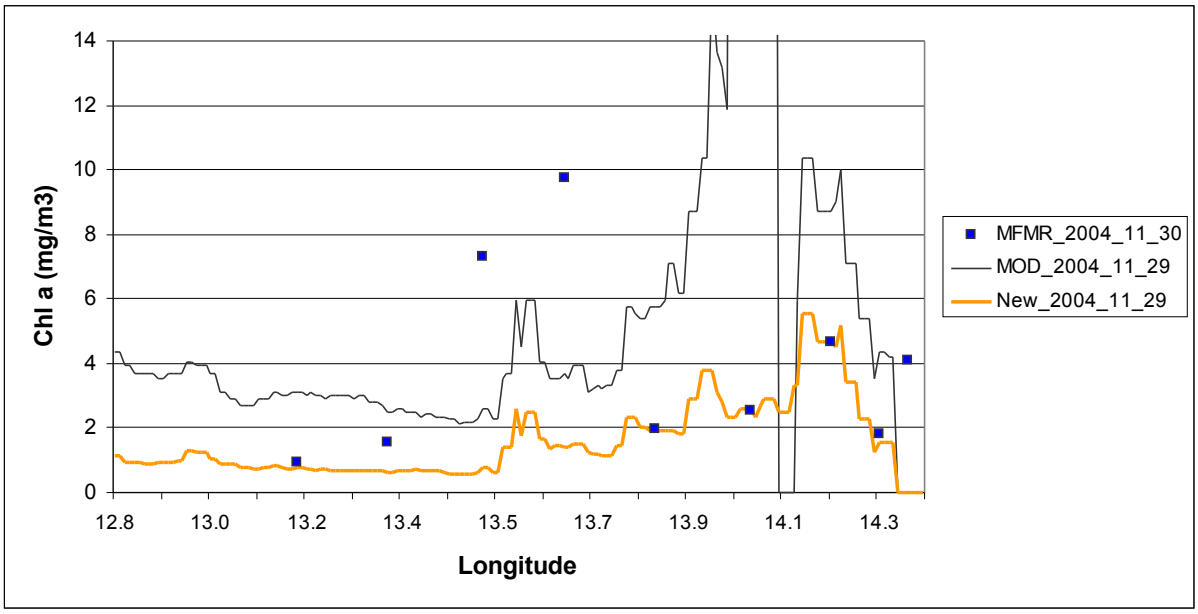


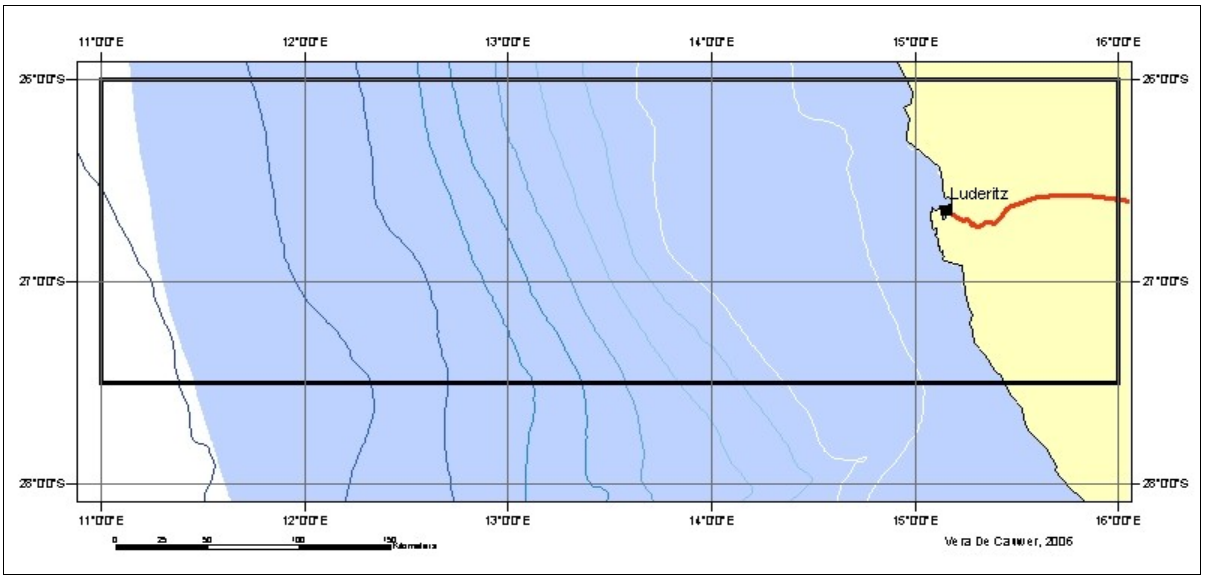
Figure 15 – Comparison of standard MODIS chl a product and new chl a product (Marine RS Server) of 1 December 2004 with in-situ data of 30 November 2004 for the 23º south monitoring line



5.2 Lüderitz

The study area offshore Lüderitz is displayed in figure 16. The upwelling cell found in this area is considered to be one of the most intense upwelling cells in the world's oceans (Brown *et al.*, 1991). It is also an area with a lot of coastal and marine mining activities and therefore it would be interesting to look into the amount of suspended matter in this area compared to other parts of the Namibian coast.

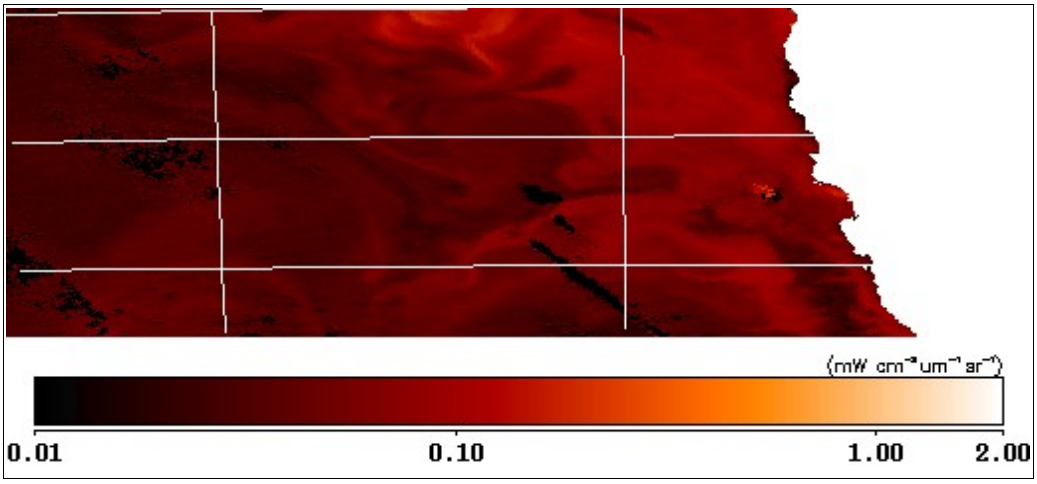
Figure 16 – Luderitz area (EEZ of 200 nm displayed in blue)



There was not enough time within this pilot project to perform such a study. It is proposed that this is done by a future research project. Following steps need to be taken :

- request the permission of MFMR and other institutes to use their in-situ data on suspended matter collected along the Namibian coastline, for example, the team of Siegel *et al.* (2004) measured suspended matter concentration ranges from 1.1 to 24 g/m^3 at a transect offshore Walvis Bay,
- find cloud-free MODIS images for the areas of the in-situ data with match-up conditions,
- perform a regression between the MODIS values of the different red and near-infrared bands (an example of red band is shown in figure 17) with the in situ values and establish a model relation (if there are not enough match-up images or in-situ data, existing models of other areas can be used, such as that of Nechad *et al.* (2003)),
- perform the model on the MODIS radiances for a set of images of the study area.

Figure 17 – Normalised water-leaving radiance for the red wavelength (667 nm) of MODIS in the study area on 29 November 2004



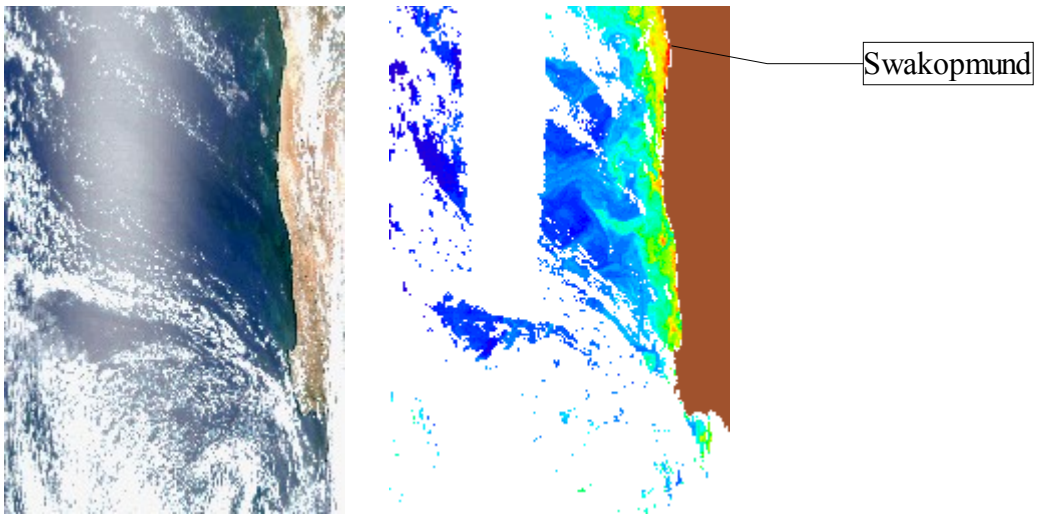
5.3 Detection of blooms

A lot of ocean colour images of the Namibian coast show turquoise plumes (figure 18 and first page), which had been identified as coccolithophorid blooms until Weeks *et al.* (2004) considered the features to be sulphur eruptions. Hydrogen sulphide eruptions do occur at the Namibian coast ; they are caused by the anaerobic degradation of organic material which rises to the surface and is accompanied by a rotten egg smell. Weeks *et al.* suggested that when the hydrogen sulphide reaches the surface and oxidises into molecular sulphur, it changes the water colour which allows detection by ocean colour sensors. However Siegel *et al.* (2004) made in situ measurements in a turquoise plume (detected on SeaWiFS quasi-true colour images) on 30 and 31 March 2003. They found a higher chl *a* concentration and a higher concentration of suspended matter (5.36 g/m3) compared to stations in the neighbourhood located outside the plume, but no sulphur or hydrogen sulphide. The authors propose that the upwelling of hydrogen sulphide enriched water occurs only closer to the coast.

However, water at the Namibian coast often turns turquoise without the 'rotten egg' smell. An example was clearly visible at the coast near Swakopmund on 3 February 2005 (own observations). This event is also visible as turquoise plumes on the MODIS quick-look images of that day (figure 18). It remains

debatable if the features are mainly caused by coccolithophorid blooms or by sulphur eruptions. The only way of providing an answer is collecting a few years of good quality in situ data. It is however difficult to organise the monthly cruises in such a way that measurements can be made in the turquoise plumes (Nande Nicanor, *pers. comm.*).

Figure 18 - Quasi true colour quick look and chl a product of MODIS Aqua image of 3 February 2006



After a discussion with Mr Nicanor of MFMR, it was therefore proposed that a student will study the quicklooks of satellite images of a few years and import the satellite images with blooms into a GIS to map the features. The advantage of the GIS maps will be that they are quicker to load and work with than working with a large image dataset. It is hoped that the mapping will give some more insight in the origin, process and timing of the 'blooms' and therefore facilitate the in situ data collection.

5.4 Oil spill detection

MODIS images have already been used for oil spill detection, however the 250 m resolution images are used in that case and not the 1 km images such as archived during this pilot study. Adamo *et al.* (2006) used the sun glint conditions on the high resolution images while Hu *et al.* (2003) did a visual examination of raw radiance data in the 645 nm and 859 nm bands.

It would be interesting to use MODIS or radar images of Namibian waters for oil spill detection in the shipping lanes or close to harbours. The main problem is that very few documented oil spills of the Namibian coast exist which would allow a comparative study (unless there is more information collected during the aerial surveys of MFMR – this still needs to be verified). The only information on an oil spill available for the period 2003 – 2005 is a very small incident on Friday 16 September 2005, 24:00 when two ships collided in the Walvis Bay port. About 100 tons of heavy fuel oil got into the water and this was contained within such a small area that it would not be detectable on 1 km resolution images. Moreover, Walvis Bay was fairly clouded on the days after the collision.

It may be of more interest to start such a study in South Africa (using the oil spill of 2000 near Cape Town) or Angola where a lot of marine oil exploitation is ongoing. As long as no more in situ data is available, this research topic is not considered as one that can yield relatively quick results for Namibian waters.

6. Student Manual

Draft 1 of a student manual for the image processing software SeaDAS is added in Annex 1. It is the aim that students will use and update this manual during research projects and in-service trainings from 2007 onwards. It is hoped that the projects will fit in the proposed cooperation with MFMR and UCT under the BCLME project EV/PROVARE/06/01 "Development of Satellite Remote Sensing Products for Operational Application".

7. Conclusions and way forward

This pilot project has proven that with a relatively small budget, it is possible to start marine remote sensing research at the Polytechnic. A computer with the image processing software SeaDAS was organised and is now assigned to marine remote sensing research projects. It contains an archive of MODIS Aqua images that currently consists of L1 and L2 products for 33 days within the period 2003 – 2005. A first draft of a manual for SeaDAS was compiled which can be used by students that work on marine remote sensing projects.

Different topics have been identified for research projects that can be performed by students or staff members of the Polytechnic in cooperation with researchers of the Ministry of Fisheries and Marine Resources (MFMR) and other marine remote sensing institutes :

1. *Validation of MODIS chl a products*

   In situ data of 7 cruises of MFMR was used to test the validation of standard MODIS chl *a* products and new chl a products (test version) from the South African Marine Remote Sensing Server. No match-up was available for those 7 cruises, however the data of one cruise could be compared with that of the MODIS images taken the day before and after. The new chl *a* product appeared to show lower values for the two images studied.

   Although the MFMR in situ data is not collected according to international accepted standards for ocean colour data validation, it will definitely be useful to compare all available MODIS images up till the end 2004 with the existing MFMR data. This would allow to get a fairly good idea of the accuracy of the standard MODIS or other chl *a* products for Namibian waters, in especially for the exceptional high chl *a* values recorded. The quality flags could be evaluated for those images and the reflectance spectra of high and low chl *a* pixels studied. The MFMR in situ chl *a* data of 2005 and later is currently not trustworthy as the instrument needs to be calibrated.

   If MFMR would agree with such a project, it would be necessary for the researcher working on it to visit the MFMR offices in Swakopmund to extract all relevant cruise data from their database, such as the exact dates of the cruises, the exact coordinates of the measuring stations and the exact times of the chl *a* measurements and possible also information on atmospheric and sea state conditions.

2. *Establishing a suspended matter algorithm*

   It is advised to establish a suspended matter algorithm algorithm for Namibian waters and test it on the areas where marine mining is taking place. A lot of in situ data is required and it is hoped that this can be contributed by MFMR or other research institutes. Such a model could assist the study of the 'bloom' events as higher suspended matter concentrations were recorded within blooms (Siegel *et al.*, 2004).

3. *Mapping of bloom events*

   The origin of turquoise plumes on ocean colour images of Namibian waters is still not explained in a satisfactory way. A major reason is a lack of in situ data collected in the plumes. It is proposed that all 'bloom' events that can be detected on historical MODIS images are mapped in a GIS to allow more understanding of the phenomenon and to facilitate future in situ data collection. The study of chl *a* anomalies during the blooms can accompany this mapping.

It is clear that topics 1 and 2 are in a high degree dependant on the in situ data available. These research projects will not be able to succeed without the cooperation of the MFMR. It is also advisable that the in situ data collection is not completely reliant on MFMR but that other funding sources are obtained that will allow the researchers to join cruises, hire measurement equipment and allow analysis by external laboratories. If this can be achieved, it would be worthwhile to investigate to what extent the methods used by MFMR would need to be adapted to allow validation of the ocean colour products according to international standards. Some examples of issues that might need to be addressed are :

- the chl *a* analysis method : MFMR uses the Welschmeyer method to extract chl *a*. However, it is strongly doubted if the internationally widely used high performance liquid chromatography (HPLC) method is an affordable option for Namibia, not only with regard to the purchase costs but also with regard to available staff capacity and required instrument maintenance and calibration. Alternative solutions could be the use of a South African laboratory.
- the sampling depth : the sampling depth at the surface seems to vary between 1 and 3 m. It is advised to fix the sampling depth according to international standards, for example the European Revamp protocol (Regional Validation of MERIS Chlorophyll products) uses 0.5 m sampling depth.

The performance of radiance measurements during cruises would also assist with the validation of chl *a* and other products as it would minimise the dependency on cloud conditions. Cheaper or research related instruments such as the French SIMBADA could be tested.

Other factors that will contribute to the success of the three research projects :

- the students with the School of Natural Resources and Tourism of the Polytechnic of Namibia are studying for a diploma or BTech degree, while the first two identified topics are more relevant for a Masters or PhD degree. The students could work on smaller projects that would contribute to the research. The last topic can be done by a last year diploma or BTech student within the framework of the BCLME project EV/PROVARE/06/01 “Development of Satellite Remote Sensing Products for Operational Application”. Negotiations are already going on between MFMR, the Polytechnic of Namibia and the University of Cape Town (UCT) to cooperate in this regard.
- The first two topics can easily be taken up by tutors or lecturers at the Polytechnic or University of Namibia that aim for a Masters or PhD degree. Lecturers at the Polytechnic have however not enough time available for research. For example, this pilot project had to be completed with about 5 hours per week available for research. A solution that can solve the time issue would be external bursaries to fund half-time PhD research. A cooperation with foreign Master and PhD students on the topics would assist to a certain extent.
- Namibia lacks a critical mass of researchers in the country. Only a very small fraction of the about 2 million habitants have a tertiary education. This makes that very few researchers are working in the same field and that there is little cooperation, division of work and 'cross-pollination' of ideas. It is for example a common fact that marine researchers not only perform their own measurements, but also perform the laboratory analysis, analysis and evaluation of the data on their own. It also makes that learning new software such as SeaDAS is a time absorbing issue as no one else is using it. This is however a problem without a solution on the short or even long term, but mentioning it can help foreign researchers understand the problems that Namibian researchers are facing. It makes it also more important to cooperate with institutes within and outside the region, such as UCT.

- The internet connections in Namibia are very slow as is illustrated in table 3. Downloading one L1 product is a time consuming process of several hours which makes it not interesting for the operational purposes of MFMR. This problem could be solved by cooperating with UCT and/or the South African Satellite Application Centre (SAC). If research institutes – who will always need to download some historical L1 images – focus on validation of products and fine tuning of algorithms, SAC could use the fine-tuned or new algorithms for the production of L2 images and put them on their server. Downloading of L2 images is much quicker. SAC has indicated that this can be done from February 2007 onwards as they currently produce images in hdf 5 format and not hdf eos which makes that not all SeaDAS functions work optimal (SAC, *pers. comm.*).

Acknowledgements

The author wishes to thank BCLME and UNOPS for funding this project, in especially Dr. M. O'Toole. Without the data and support provided by Mr Deon Louw, Ms Anja Kreiner, Mr Nande Nicanor and Mr Chris Bartholomae of MFMR, this pilot project would not have yielded much results. Finally, Dr Patrick Graz, Rudolf Rittman, Calvin Mouton and Peter Gallert of the Polytechnic of Namibia are thanked for their support to solve Linux and firewall related problems.

References

Adamo, M., De Carolis, G., De Pasquale, V. & Pasquariello, G., 2006. Exploitation of Modis and SAR imagery for oil spill detection. Geophysical Research Abstracts, Vol. 8, 08554, 2006.

Brown, P.C., Painting, S.J. and Cochrane, K.L., 1991. Estimates of phytoplankton and bacterial biomass and production in the northern and southern Benguela ecosystems. *S. Afr. J. Sci.*, 11, 537 – 564.

De Cauwer, V., K. Ruddick, Y. Park, B. Nechad and M. Kyramarios, 2004. Optical remote sensing in support of eutrophication monitoring in the southern North Sea. EARSEL eProceedings, 3 (2). http://las.physik.uni-oldenburg.de/eProceedings/

Fishwick, J.R., Barlow, R. and J. Aiken, 2003. Validation of MERIS surface reflection and chlorophyll 1 and 2 products during the BENCAL cruise (2002). Proc MAVT conference, Frascati, Italy.

Hu, C., Müller-Karger, F.E., Taylor, C.J., Myhre, D., Murch, B., Odriozola, A. L. & Godoy, G. (2003). Modis Detects Oil Spills in Lake Maracaibo, Venezuela. EOS, TRANSACTIONS AMERICAN GEOPHYSICAL UNION, VOL. 84, NO. 33, PAGE 313, 2003.

Louw, D., 2006. Phytoplankton monitoring off the Namibian coast. Internal report. MFMR.

Mastailar, M., 1998. Baseline study on the establishment of marine reserves in Namibia. Advisory Assistance to the Ministry of Fisheries and Marine Resources. Short term consultancy report. Cofad & DCPA-Consultants, Germany.

Nechad, B., De Cauwer, V., Park, Y. and Ruddick, K.G., 2003. Suspended Particulate Matter (SPM) mapping from MERIS imagery. Calibration of a regional algorithm for Belgian coastal waters in MERIS Users Workshop Proceedings 2003.

O'Toole, M.J., 1997. Marine environmental threats in Namibia. Research discussion paper 23. Directorate of Environmental Affairs, Ministry of Environment and Tourism, Namibia, 48 p.

Sakko, A.L.,1998. The influence of the Benguela upwelling system on Namibia's marine biodiversity. *Biodiversity and Conservation*, 7(4), 419 – 433. Springer Science+Business Media B.V.

Saulquin, B., 2006. Remote Sensing Server for Marine Sciences. URL : www.rsmarinesa.org.za.

Shannon, L.J., Cochrane, K.L. and Pillar, S.C. (*eds.*), 2004. Ecosystem approaches to fisheries in the southern Benguela. African Journal of Marine Science, 26. South African Department of Environmental Affairs and Tourism.

Siegel, Gerth & Ohde, 2004. Optical in situ measurements of a coccolithophorid bloom in the SE Atlantic ocean off Namibia identified and followed by satellite ocean colour data. Ocean Optics Freemantle.

Thomas, D. & Franz, B., 2005. Overview of MODIS Aqua Data Processing and Distribution. URL : http://oceancolor.gsfc.nasa.gov/DOCS/MODISA_processing.html

Wasmund, N., Lass, H.U. and Nausch, G., 2005. Distribution of nutrients, chlorophyll and phytoplankton primary production in relation to hydrographic structures bordering the Benguela-Angolan frontal region. *S. Afr. Mar. Sci.*, 27(1), 177 – 190(14).

Weeks, S.J., Currie, B., Bakun, K.R. & Peard, K.R., 2004. Hydrogen sulphide eruption in the Atlantic Ocean off southern Africa : implications of a new view based on SeaWiFS satellite imagery. Deep-sea research I 51, 153 – 172.

Annex 1 – Manual for working with MODIS images in SeaDAS 4.9.4 (Draft version 1)