Monitoring Chlorophyll and Optical Properties of the Southwest Tropical Pacific

C.Dupouy[a,*], T. Savranski[a], J.Lefevre[a,b], M. Despinoy[c], M. Mangeas[c], R. Fuchs[a], S. Ouillon[b], M. Petit[c]

[a]LOPB-IRD UMR 213, Centre IRD of Noumea, 98848 NEW CALEDONIA – (Cecile.dupouy, Rosalie.fuchs)@ird.fr)
[b]LEGOS-IRD 31400 Toulouse, FANCE -- (Jerome.lefevre@,sylvain.ouillon)@ird.fr
[c]ESPACE-IRD 140, Centre IRD of Noumea, 98848 New Caledonia/31400 Montpellier, FRANCE -- (michel.petit, marc.despinoy, morgan.mangeas)@ird.fr

Abstract -- We present data collected as part of VALidation HYperspectral of a BIOgeochemical model (ValHyBio), a PNTS-sponsored program dedicated to chlorophyll satellite imaging and validation as affected by bathymetry in the South Western Tropical Lagoon of New Caledonia. MODIS Aqua match-ups collected over the period 1997-2010 (ValHySat database) are examined for two algorithms OC3 and OC5.

Keywords: chlorophyll, New Caledonia, lagoon waters, MODIS matchups, algorithm

1. INTRODUCTION

Sea surface chlorophyll is a proxy of phytoplankton biomass and is a direct integrator for the nutrient status of water masses and chlorophyll monitoring by satellite will greatly expand our knowledge of the functioning of coral reef lagoons. Measuring chlorophyll a from space would allow the validation of simulations of chlorophyll by recently developed coupled biogeochemical models (Fuchs et al., 2010).

The New Caledonia lagoon (22 177 km2, 25 m as a mean depth) lies in the South Western Tropical Pacific from 20°S to 22°S, and 166° to 167°E, with a heterogeneous bathymetry due to a complex geomorphology and a variety of different bottom colors. It is very sensitive to anthropogenic (nutrients, mining) perturbations as well as to inter-annual changes linked to the balance between dry El Nino and wet La Nina episodes (Ouillon et al., 2010). The lagoon belongs to optically complex waters (classified as Case 2 waters) where mineral particles and colored dissolved organic matter mix with phytoplankton (Dupouy et al., 2010). It is largely connected to the open ocean in the south part of the lagoon, but only by narrow passes in the south west part of the lagoon and has low input by rivers. The central lagoon is characterized by oligotrophic to mesotrophic waters (yearly average chlorophyll-a concentration of 0.25 ± 0.01 mg m-3) (Neveux et al., 2009). Indeed current algorithms such as OC4v4 for SeaWiFS and OC3 for MODIS developed for optically deep data where chlorophyll drives variability of bio-optical properties (absorption and backscattering) are not adapted to those waters (Dupouy et al., 2010).

The ValHyBio project objective was to examine the performance of the MODIS chlorophyll algorithms to retrieve *Chla*. The ValHySat project aimed at archiving and calculating chlorophyll from the MODIS imagery with a dedicated algorithm.

In this paper, we present the first MODIS validation in the New Caledonia lagoon for chlorophyll data. Regressions for MODIS match-ups in chlorophyll are established in the New Caledonia lagoon and adjacent waters as a function of bathymetry.

2. MATERIAL AND METHODS

2.1. Cruise data

Cruises in the South Western Tropical Pacific Ocean and in the lagoon of New Caledonia were performed from 1997 to 2010 in the frame of French PROOF (DIAPAZON program) and PNEC-EC2CO programs (CAMELIA project, IRD Noumea) and also in the frame of CNRS-INSU programs (BISSECOTE, ECHOLAG, PNTS-VALHYBIO cruises). MODIS matchups obtained in open waters off the lagoon of New Caledonia and inside the barrier reefs, are shown according to their depth at Figure 1.

Water sample was collected with Niskin bottles (3 meters). Chlorophyll measurements were made by filtering 250 ml of seawater on a Whatmann (GF/F) and frozen at -80°C and analyzed by spectrofluorometry with a Hitachi F4500 spectrofluorometer operating in a ratio mode as in Neveux et al., 2009. We define Tchl *a* as the sum of chlorophyll a + divinyl-chl a. Total chlorophyll concentrations (sum of chlorophyll a + phaeophytin a) were also measured by fluorometry and are comparable to spectrofluorometry.
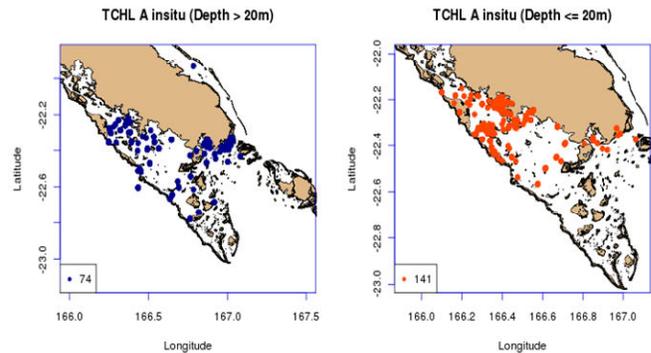

Figure 1ABC. Location of stations inside of the barrier reef of the New Caledonia lagoon in dark blue Depths > 20 meters, orange < 20 meters.

2.2. MODIS satellite data and match-ups extraction

As a result of the Valhysat project, MODIS L2 products were calculated with Ocean Color IDL Seadas (OceanColor) routines for atmospheric correction (MSL12 (Multi Sensor L1 to L2) and for two algorithms of chlorophyll retrieval, OC3 (adapted from O'Reilly et al., 2000) and OC5. OC5 is an algorithm dedicated to the chlorophyll retrieval in coastal areas for SeaWiFS (Gohin et al., 2002) and adapted for MODIS (Lefevre, 2010). For the calculation of chlorophyll, the two different algorithms OC3 and OC5 were compared. Satellite reflectance and L2 products were

processed at the nominal 1 km x 1 km resolution and also at 500 m x 500 m resolution with the sharpening procedure. Experimental products are maps of OC3 and OC5 Chlorophyll, and also other derived products including turbidity concentration and MODIS marine reflectance, Rrs. Each netcdf file product contains geolocation and bathymetry information (in situ and from MODIS) which allows the research of the mean value of the pixels around the in situ station. A specific mask for New Caledonia lagoon was a composition of seven SeaDAS masks. Match-ups were selected according to a statistical analysis of standard deviation for pixels over a distance of 1.5 km around the in situ station (Bailey and Werdell, 2004). For all the valid match-ups, the intervals between satellite overpass and in situ measurements were one day.

Extract products of the pixels centered on the in situ location based on 1.5 km×1.5 km pixel box (Figure 2), - 2) For each box, eliminate invalid satellite pixels that have negative or overflow values of Rrs, - 3) Calculate the median and standard deviation (SD) of Rrs. Delete the outlier pixels from every pixel box to prevent abnormal values from influencing statistical results. Outliers are identified as pixels whose values are larger than 1.5 times SD. The process is implemented identically for different bands, - 4) Check the percentage of good pixels in the box. If the number of good pixels is more than 30, the pixel box is adopted for the following match-up analysis, and - 5) The mean of the remaining pixels is compared with the corresponding in situ measurement ("mean"). The closest pixel ("closer") was also selected for comparison with the "mean".
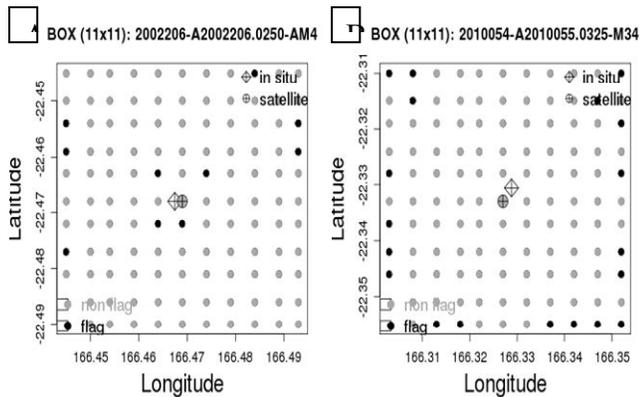

Figure 2AB. Box plot of accuracy statistics for the MODIS 500 m map for 2 MODIS scenes. The two crosses represent the in situ and the closest pixel. The selection was made for a circle of 1.5 km of diameter, approximately .

For the purpose of evaluating OC3 or OC5 algorithm performances for chlorophyll, linear regression analyses were carried out between the observed in situ parameters (in situ CHl a) and those estimated by the algorithms (OC3 or OC5 Chl a) The evaluation of the algorithms by the mean normalized bias (MNB) and the normalized root mean squared error (RMSE), in percent, are calculated as in Dupouy et al. (2010).

3. RESULTS

The performance of the OC3 and OC5 algorithms are shown at Table A and at Figure 3AB. The results are expressed by separating open ocean, deep and shallow stations.

Table A. Statistical results for OC3 and OC5 chlorophyll retrieval from MODIS in the New Caledonia lagoon and adjacent waters. N: data number; CV: variation coefficient; NMB: normalized mean bias; R^2: regression coefficient; RMSE: root mean square error.

| OC3	N	S	I	R2	Min	Max	Med	STD	CV	NMB(%)	RMSE(%)
OO	175	0.66	-0.29	0.34	0.03	1.09	0.19	0.28	78.58	-5.49	58
bathy>20m	392	0.58	-0.01	0.24	0.07	19.55	0.54	0.26	151.82	73.62	104.16
bathy<20m	419	0.7	0.26	0.26	0.17	46.18	0.86	0.4	185.49	217.09	358.37
OC5	N	S	I	R2	Min	Max	Med	STD	CV	NMB(%)	RMSE(%)
OO	134	0.48	-0.53	0.28	0.1	0.71	0.14	0.21	61.71	-36.27	30.86
bathy>20m	388	0.49	-0.31	0.27	0.1	3.73	0.29	0.21	71.94	-9.88	43.92
bathy<20m	409	0.65	-0.12	0.32	0.12	7.59	0.4	0.33	123.89	-23.96	120.07
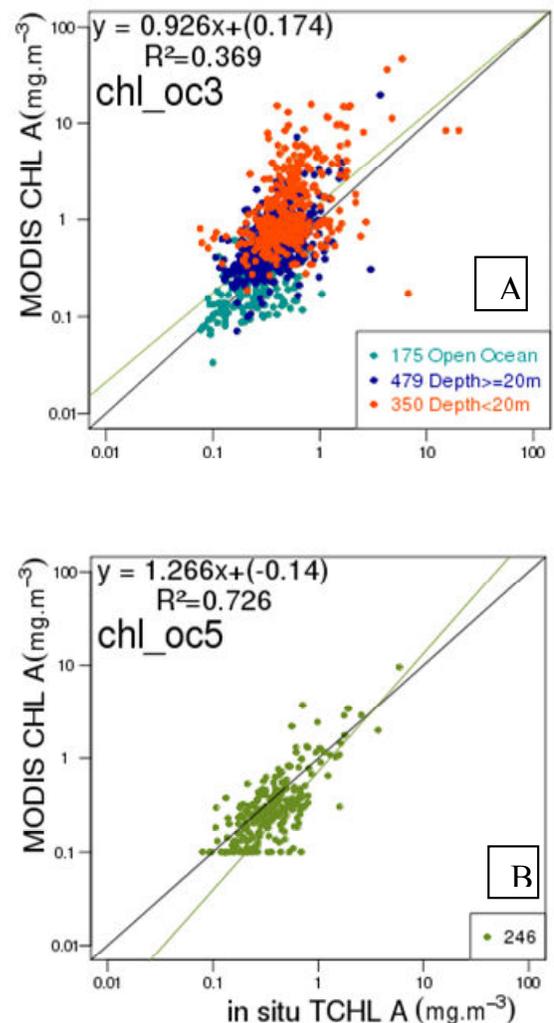
Figure 3AB. Matchups within 1 day. Regression between in situ chlorophyll and OC3 and OC5 MODIS chlorophyll for open ocean (light blue), deep (> 20m), and shallow stations (< 20 m). B. Regression for OC5 chlorophyll for the closer pixel.

The correlation between in situ *Chla* and *Chla* retrieved from MODIS using OC3 or OC5 is poor when evaluated for the global data set, which correspond to a mixture of case 1 and case 2 water types (Fig. 1A, Table A).

The good regression Fig 3B was obtained for OC5 chlorophyll and excluding bays and white sand reflectant bottoms.

For the open ocean stations, MODIS underestimates *Chla* with a mean bias of -23% for OC3 and - 47% for OC5.

The OC3 or OC5 algorithms are inadequate for shallow stations (in orange, Figure 3AB). This result was also found for the OC4v4 algorithm (overestimation by a factor of about 3 on average and almost no correlation with *Chla*), because the bio-optical properties driving remote sensing reflectance, viz. the absorption and Hydroscat-6 backscattering coefficients are poorly related to *Chla* (Dupouy et al., 2010).

The best result is obtained for OC5 when using the closer pixel method (Fig. 3B).

4. CONCLUSION

By gathering all chlorophyll collected over the lagoon of New Caledonia, we obtained about 1000 matchups when considering a large interval between in situ measurements and MODIS imagery (5 days) and about 400 matchups when considering only matchups of the same day.

Low regressions between extracted chlorophyll and in situ chlorophyll include - coastal effects include the masking of stations near the coast or near the barrier reef, - coastal atmospheric correction problems, - bathymetry effect and bottom effect in bays. The OC3 algorithm adequately performs for deep lagoon waters but saturates in shallow waters. OC5 performs correctly in lagoonal waters, with chl a better retrieved. Better algorithms are in development in the frame of the Valhybio project (Minghelli-Roman et al., 2010).

The monitoring of bio-optical properties (hyperspectral reflectance, absorption) and backscattering coefficients is ongoing and will allow the comparison with MODIS remote sensing reflectance. Satellite retrievals are examined as a function of bathymetry and for the special case of *Trichodesmium* red tides. The feasibility of a long-term monitoring program of water optical properties with satellite remote sensing techniques validated by in situ data is examined in the frame of the GOPS (South Pacific Integrated Observatory) project.

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