OCEAN COLOUR PRODUCTS FROM REMOTE SENSING RELATED TO *IN-SITU* DATA FOR SUPPORTING MANAGEMENT OF OFFSHORE AQUACULTURE

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ABSTRACT

The EU funded "AQUAculture USEr driven operational Remote Sensing information services project" (AQUA-USERS grant number 607325) is a user driven project for the aquaculture industry that aims at providing this industry with relevant and timely information based on the most recent satellite data and innovative optical *in-situ* measurements. The Water Insight Spectrometer (WISP-3) is a hand held instrument which can provide measurements of the optical parameters Chlorophyll-a (Chl-a), Total Suspended Matter (TSM), Coloured Dissolved Organic Matter (CDOM), and the Spectral Diffuse Attenuation Coefficient (Kd). Sampling campaigns were carried out between March 2014 and September 2015, to collect water samples at the same time as taking optical reading from the WISP-3 at an offshore aquaculture site off Sagres on the SW Portugal, operated by Finisterra Lda, one of the "users" in the project. The estimates from the WISP-3 for Chla and TSM have been compared with *in-situ* measurements from the water samples for these two variables, with the objective of calibrating the algorithms used by the WISP-3 for estimation of Chla and TSM. At a later stage in the project, it is expected that WISP-3 readings can be related to remote sensing products developed from the Ocean Land Coloured Instrument (OLCI) from the Sentinel-3 satellite. The key purpose of AQUA-Users is to develop, in collaboration with "users" from the aquaculture industry, a mobile phone application (app) that collates satellite information on optical water quality and temperature together with *in-situ* data of these variables to develop a decision support system for daily management of the aquaculture.

1. INTRODUCTION

1.1. AQUA-USERS Project

The increasing demand for the development of offshore aquaculture to supply seafood creates management challenges for the industry. Some examples of these challenges include: selection of suitable or more productive areas; the prediction of toxic blooms; the prediction of meteorological conditions; the monitoring of the *in-situ* environmental parameters for daily management, as well as conforming to the legal requirements for EU directives and national legislation. The EU-funded project AQUA-USERS aims to answer these aspects by providing the aquaculture industry with user-relevant and timely information based on the most up-to-date satellite data and innovative optical *in-situ* measurements (http://aqua-users.eu).

1.2. Ocean color measuments using the WISP-3

Within the AQUA-USERS project, the Water Insight Spectrometer (WISP-3) is an optical instrument that is being used as a daily management tool, enabling the measurement of relevant water quality parameters for aquaculture. This hand-held instrument can provide measurements of Chlorophyll-a (Chl-a), Total Suspended Matter (TSM), Coloured Dissolved Organic Matter (CDOM), and the Spectral Diffuse Attenuation Coefficient (Kd) based on the optical properties of the surface waters.

1.3. Offshore Mussel Aquaculture - Finisterra S.A.

One of the study sites for the AQUA-USERS project is located in the SW Portugal, Sagres. Finisterra S.A is an offshore mussel farm operating several longlines (***Figure 1. Boat in operation at the offshore mussel aquaculture, Finisterra SA.***Fig.1). This farm is included within the marine area of a natural park, and is therefore regulated under special environmental rules.

Figure 1. Boat in operation at the offshore mussel aquaculture, Finisterra SA.

1.4. Automisation of *in-situ* data (Buoy).

Remote sensing products have proven to be useful tools for aquaculture management, allowing the coverage of large spatial areas, although the frequency of satellite overpasses and images resolution are often limiting. Also, the collection of *in-situ* data can be expensive, time consuming, and limited by periods of bad weather conditions. For this purpose, an automatic buoy has been developed for the aquaculture site, recording data every hour and sending it by File Transfer Protocol to a web site. The buoy includes a multiprobe (pH, oxygen, temperature, conductivity), a backscatter sensor, two optics sensors placed at two depths, a transmissometer, a fluorometer and a wave height sensor (Fig.2). The sensors have been selected to fulfil three main objectives: 1) provide relevant information every hour to support aquaculture management; 2) enable environmental monitoring for national legislation and EU directives (e.g Marine Strategy Framework Directive); 3) obtain *in-situ* optical data to validate match-ups for Sentinel-2 and for Sentinel-3.

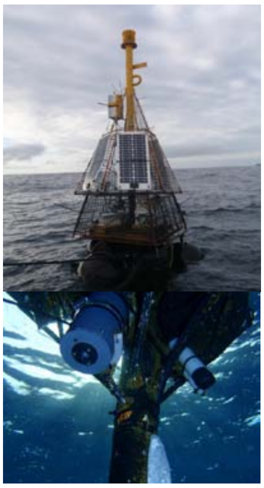

Figure 2. Buoy at the aquaculture site powered by solar panels. Underwater image shows optical and backscatter sensors attached below the buoy.

2. METHODS

2.1. *Deployment of the WISP-3*

At the aquaculture site, WISP-3 measuments were done according to the WISP user manual, ensuring an azimuth angle of ~ 135° relative to the sun to avoid direct reflectance effects (sun glint), and with a zenith angle over 30° above the horizon [1]. Fig.3 shows the correct way to perform a WISP-3 measurement. For each sampling campaign at the aquaculture site, a minimum of 3 good measurements were taken, although the measurements were more challenging to perform with rough sea conditions, or with totally overcast days. Sampling campaigns were carried out weekly between the March 2014 and September 2015. Water samples were collected for Chl-a and TSM and at the same time optical readings were done using the WISP-3 handheld instrument

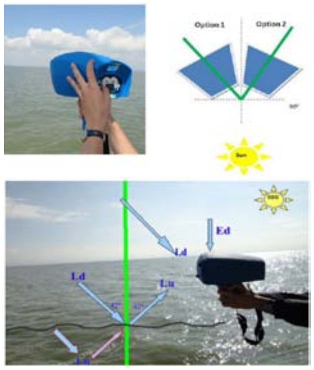

Figure 3. Performing a measurement using the WISP-3

2.2. In-situ data

Water samples collected at the aquaculture site were kept in the dark and taken to the laboratory. For Chl-a determination, 1.5l of water were filtered through a Whatman GF/F filter (3x replicates) and then wrapped in foil and frozen. The pigment extraction was done subsequently with acetone at 90%, and the Chl-a determined from spectrophotometric measurements [3]. For the determination of TSM by a gravimetric method, 2 litres of water were filtered through a pre-washed, ashed and weighed Whatman GF/F filter (2x replicates). After filtration, filters were rinsed 3x with 50ml of MiliQ water. The filters were left to dry at 60ºC in a drying oven for at least 48 hours. TSM is obtained by the difference of the final dry weight and the initial weight of the filter.

2.3. Validation of in-situ data

From the spectra obtained using the WISP-3 (Fig.4), some spectra were "flagged" where the outline of ***Ed*** (downwelling irradiance), ***Ld**_sky* (downwelling radiance), ***Lu**_sea* (upwelling radiance) differs by more than 25% at 550nm from either neighboring scan.

The OC4 algorithm, used for the MERIS sensor (Medium Resolution Imaging Spectrometer), was considered the most adequate for deriving the Chl-a concentrations from the WISP-3 measurements at Sagres.

The TSM concentrations were derived from the optical spectra, with a simple band ratio where the ratio R(0-,720)/R(0-,500) provided the best validation result for our dataset (see Eq. 1).

$$TSM_{drived} = 2.641 + (\ln R(0-,720)/(\ln R(0-,500)) + 8.291 \quad \textbf{(1)}$$

Where R(0-) is the irradiance reflectance at 720 and 500nm. Water samples were collected for the *in-situ* determination of TSM and Chlorophyll-a.

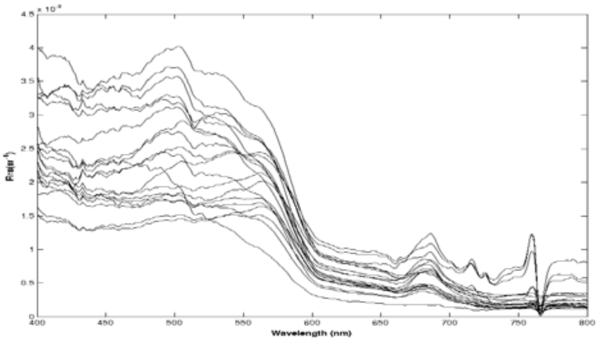

Figure 4. Reflectance's obtained using the WISP-3 at the aquaculture site (Sagres).

3. RESULTS

3.1. Chlorophyll-a (Chl-a)

The *in-situ* Chl-a concentration shows a large variability over the duration of the study period, with concentrations ranging from 0.1 to 5.9 mg.m^3, with a maximum concentration measured during August 2014 (Fig.5). Both the *in-situ* concentration of Chl-a and those derived from the WISP-3, show the same trend and variability. Although, the higher concentrations of *in-situ* are underestimated by the derived Chl-a, but at lower concentrations are slightly overestimated. The scatter plot between the *in-situ* and the derived Chl-a shows correlation factor of R^2=0.649 and a calculated RMSE =0.563 mg.m^3 (Fig.6).

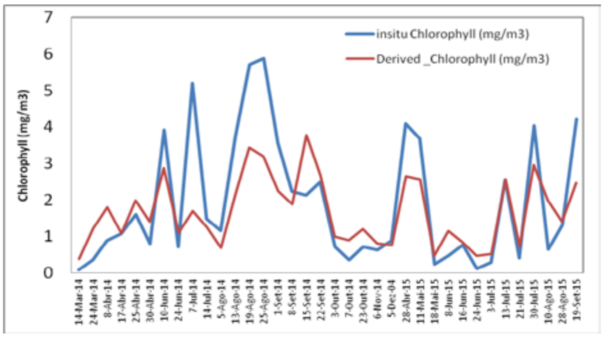

Figure 5. Chl-a concentrations derived from the algorithm and in-situ data (2014-2015).

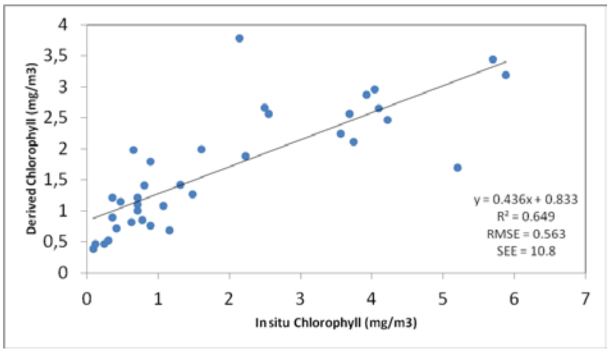

Figure 6. Scatterplot of derived vs in-situ Chl-a (2014-2015).

3.2. Total Suspended Matter (TSM)

The scatter plot between TSM derived the WISP-3 versus the *in-situ* TSM in Fig.7, shows a correlation coefficient of R^2= 0.6179 and the calculated RSME = 1.133 mg.m^3.

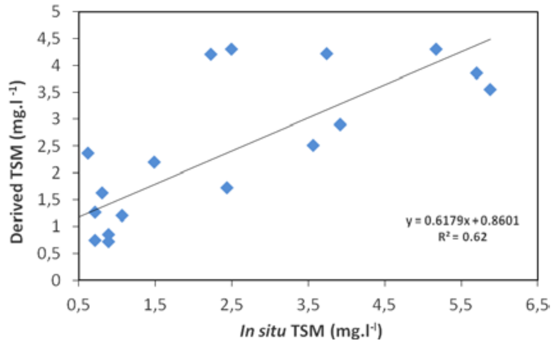

Figure 7. Scatterplot of derived versus in-situ TSM (2014).

The *in-situ* Chl-a concentration obtained with a fluorometer located in the buoy at the aquaculture site (Fig.8). There is a notable difference in the Chl-a concentrations between the diurnal and nocturnal periods, at night the measuments are more reliable because there is no influence from the sun light. During the week shown in Fig.8, there is a decreasing gradient in the concentration of chlorophyll, indicating the reduction of the availability of food for mussels; from information, a possible management decision could be taken by the farmer.

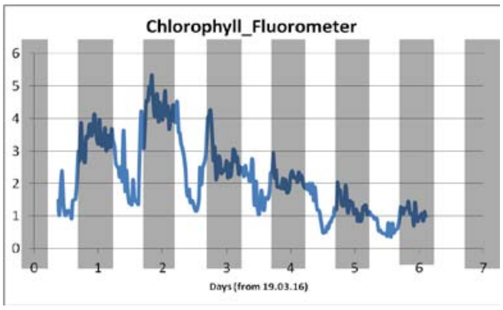

Figure 8. Chl-a concentration obtained by the fluorometer installed on the buoy; data is recorded every 30min. Shaded bands represents nocturnal periods

4. DISCUSSION

A contribution for the use of remote sensing products has been described by [2] as valuable tool to support aquaculture management.

The results in this study show interesting correlations, both for Chl-a and for TSM between the *in-situ* and the values derived from the WISP-3 spectra; these correlations should benefit from a higher number of measurements that are still being taken. Additionally, the use of a regional algorithm tuned for the Sagres area might provide better results [4]. The WISP-3 also provides instant Kd values that could be subsequently used to derive values for Secchi depth. As Secchi depth is often a routine measurement at aquaculture sites, it would be interesting to compare it with Kd measurements from the WISP-3.

The WISP-3 measurements show the same trend and variability for chlorophyll concentrations as the *in situ* data, showing its applicability for aquaculture management, although taking measuments during rough sea and totally overcast days has been challenging. The buoy still needs improvements, the occurrence of storms and problems with moorings resulted in some equipment failures, but the results obtained so far are promising and will be of high relevance for aquaculture management and for providing *in situ* optical measurements for validation of Sentinel-2 and Sentinel-3 products.

5. CONCLUSIONS

Correlations between the WISP-3 retrieved Chlorophyll and TSM versus the *in-situ* data show interesting correlations.

Simple band algorithms can be programmed into the WISP-3 to derive water colour parameters (Chl-a, SPM, CDOM). But as referred [1] these algorithms need regional tuning [4]. The 2014 and 2015 sampling campaigns at the offshore mussel aquaculture, both for optical and *in-situ* data, is an initial step to produce a robust database that will allow the evaluation of the most suitable algorithms for the aquaculture site. Developing specific WISP-3 algorithms for Sagres could particularly useful for local aquaculture managers; as the Algarve region has particularly favourable conditions for the development of offshore aquaculture.

The WISP-3 is to be implemented as a daily aquaculture management tool, which is one of the core objectives of the AQUA-USERS project.

6. REFERENCES

[1] A. Hommersom, S. Kratzer, M. Laanen, I. Ansko, M. Ligi, M. Bresciani, C. Giardino, J. M. Beltrán-Abaunza, G. Moore, M. Wernand, and S. Peters. Intercomparison in the field between the new WISP-3 and other radiometers (TriOS Ramses, ASD FieldSpec, and TACCS). *Journal of Applied Remote Sensing*, 6(1):063615–063615, 2012.

[2] J. Icely, G. Moore, S. Danchenko, P. Goela, S. Cristina, M. Zacarias, and A. Newton. Contribution of remote sensing products to the management of offshore aquaculture at sagres, sw portugal. *Ed. H. Ouwehand Proceedings of ESA Sentinel-3 OLCI/SLSTR and MERIS/(A)ATSR Workshop European Space Agency*, page 6, 2013.

[3] C. Lorezen. Determination of chlorophyll and phaeopigments: spectrophotometric equations. *Limnology and Oceanography*, 12:343–346, 1967.

[4] S Cristina, D.D’Alimonte, P.Goela, T.Kajiyama, J.Icely, G.Moore, B.Fragoso, A.Newton. Standard and regional bio-optical algorithms for chlorophyll a estimates in the Atlantic off the Southwestern Iberian peninsula. *IEEE Geoscience and Remote Sensing Letters*,13:1-5, 2016.

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