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Citclops

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Crowdsourcing technologies for the monitoring of the colour, transparency and fluorescence of the sea

D2.4: Key scientific aspects of Quality Control

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Abstract (for dissemination)	This deliverable provides documentation on the quality control (QC) that will be deployed during the Citclops project at various stages of development of crowdsourcing technologies. The QC will consist of a protocol with knowledge rules that analyse the status of an observation of the colour, fluorescence and transparency. The key elements of perfect observations and the potential disturbances are summarized. Good practices to detect and correct these errors are described.
Keywords	crowdsourcing, Smartphone, Citclops, data quality control, Protocols, colour, transparency, fluorescence

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1 Introduction

Citclops measurements will be collected by innovative Smartphone applications (with/without extensions) and data collected by new low-cost sensors. The successful implementation of these new measurements and their acceptance by the public and policy makers is highly dependent on the quality of the data.

This document describes the scientific background of the procedures to assess the quality of the measurements made in the Citclops project. A large part of the Data Quality Control (QC) is directed at the processing of the database of collected observations and integration with other spatial information and satellite information. In Citclops large volumes of data will be collected of the colour, fluorescence and transparency from natural waters. In order to handle these large volumes in a transparent and objective way the procedures for QC are laid out in a protocol: a set of rules that is followed in the processing of data. But also at the data collection itself quality control procedures are performed when the citizens upload their measurements to the server. Within the Citclops App a stream of information is foreseen to provide the mobile observer with directions to improve the measurements.

The QC procedures for observations by standard marine instruments are already well developed and documented (SeaDataNet, 2010). These instruments are already deployed and tested for a longer period and that experience has helped to draft the protocols. However, within the Citclops project the instruments are under constant development. Also, due to the very nature of the project (participatory science) the instruments should be low cost and easy to use by the public. This is a very different objective from the development of scientific instrumentation where everything is optimized to get a good observation and cost is no major issue. Therefore this report will describe both the instrumentation and conditions that might have an impact on the quality of the observations. For each instrument the following information is provided:

- Science of the measured parameter
- Description of the implementation of the measurement
- Instrumental characteristics that can influence the measurement
- Effects that might have an effect on the measurements (field aspects)
- Simple protocols and knowledge rules to get the highest quality

The report is structured as follows: Section 2 gives a general introduction to optical properties of natural waters, including the inherent optical properties like absorption, scattering and fluorescence and their relation to the composition of the water. Field observations of natural waters are influenced by the environmental conditions at the time and place of observations, particularly the illumination conditions. The most influential aspects are reviewed: the solar zenith angle, sun glitter at the air-water interface, waves and lens effects and rapid changes in cloud cover.

In the next four sections the following parameters are treated; The colour of the water as measured above water (Section 3), The vertical and horizontal light attenuation under water (Sections 4 and 5) and the ex-situ fluorescence of phytoplankton (Section 6). These sections contain the status and knowledge of the instruments at the time of the first test campaign in The Netherlands (August 25 – 31 2013).The available QC flagging of satellite information is described in Section 7.

Section 8 combines the information on QC protocol for the multiple instruments. It contains the list of parameters that will be used to check the observational conditions and detection of errors.

Heritage:

This report contains information derived from work that is already reported in the Citclops deliverables:

D2.1 Review of the state-of-the-art in low-cost smart sensors
D2.2 Review of state of the art in affordable fluorescence sensors
D2.3 Algorithms for FU index and water light extinction coefficient retrieval from images coming from smart phones and wearable underwater cameras.
D5.1 Formats for metadata description and storage and procedure for validation of Citclops data sets
D8.1 Transformation of MERIS multispectral remote-sensing images to GIS layers

2 Background

2.1 Optical properties of natural waters

The colour of the water is a complex optical feature, influenced by the composition of the water and the illumination conditions. Basically, all Citclops measurements are made to retrieve the optical properties that are inherent to the water composition or water quality parameters. Influence by other parameters like the presence of water plants (floating or submerged) or bottom reflection (Figure 2.1 left panel) should be minimized.

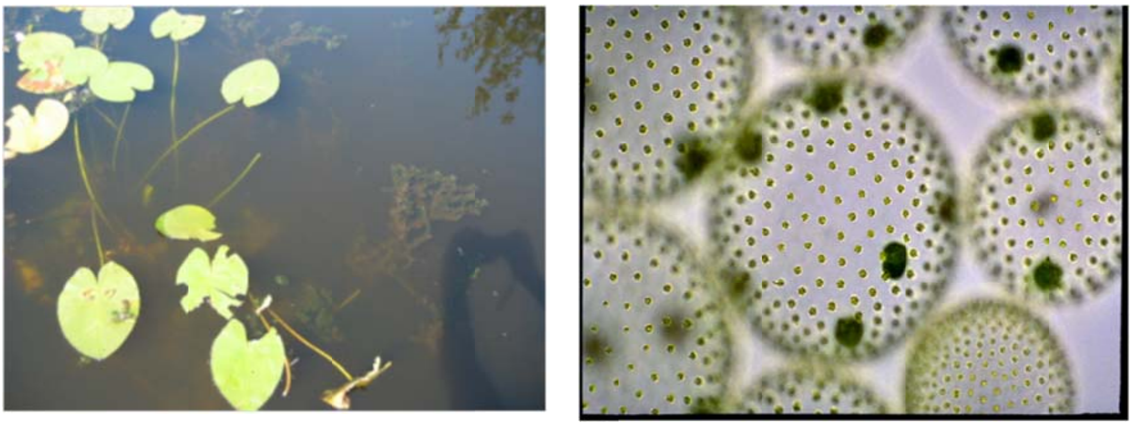

Figure 2.1. The presence of chlorophyll-a pigments in natural waters. Left on the macro scale (leaves of macrophytes) and right on the micro scale (globules of Phaeocystis).

In natural waters the following water quality parameters have the largest impact on the optical properties in the visual domain (wavelengths between 400 and 750 nm).

- Chlorophyll-a Pigments (mg/m3) CHL
- Suspended Particulate Matter (g/m3) SPM or TSM
- Colored Dissolved Organic Matter (m-1) CDOM

These parameters are essentially bulk parameters, each representing a large collection of biological, chemical and geophysical properties: The multitude of phytoplankton species in the water are characterized by the main light-harvesting pigment Chlorophyll-a. However, more accessory photosynthetic pigments can play a role, like phycocyanin (PC). All the particulate matter is integrated in TSM, characterized by the mass concentration; it includes inorganic particles in different size classes (from sand to fine sediment), but also the carbon weight of phytoplankton cells can be important, for example at intense algal blooms. The CDOM (gilvin or yellow substance) contains the breakdown products of organic material, both from terrestrial and aquatic origin.

All these optically active components can be discriminated by the way they absorb (a) and scatter (b) the light. In the scattering process radiation is redirected, while in absorption the radiation is removed from the light field and converted to heat or a chemical reaction, like carbon fixation in a cell. In phytoplankton and CDOM a very small fraction (1 to 2 %) of the absorbed energy is emitted again (fluorescence).

The total absorption and scattering of the water (expressed in m^{-1}) are summations of the contributions of various optical active constituents.

$$a_{\text{total}} = a_{\text{water}} + a_{\text{chl-a}} + a_{\text{TSM}} + a_{\text{CDOM}}$$
$$b_{\text{total}} = b_{\text{water}} + b_{\text{TSM}}$$
$$[b_{chla} \equiv 0; b_{CDOM} \equiv 0] \quad \text{(eq. 2.1)}$$

In coastal and inland waters the scattering by CDOM is zero by definition and the scattering by phytoplankton is very small compared to sediment. The attenuation of radiation c (m^{-1}) is simply the sum of absorption and scattering.

$$c \equiv a + b \quad \text{(eq. 2.2)}$$

All these parameters are called Inherent Optical Properties (IOPs) of the water. IOPs vary as function of wavelength; the photosynthetic pigments, for example, mainly absorb blue and red light and only marginally absorb green light; that is the reason why leaves and phytoplankton rich waters are green. CDOM mainly absorbs the extreme blue light and sediment absorbs and scatters a bit more efficiently in the blue light. In the laboratory, when a water sample is contained in a small cuvette and a well defined parallel beam of light the IOPs of the water and its separate components can be determined.

2.2 Environmental disturbances of optical measurements

In the field the optical conditions are much more complex, see Figure 2.2. Various processes contribute to the signal as measured by a digital camera or sensor close to or in the water or in a satellite above the atmosphere.

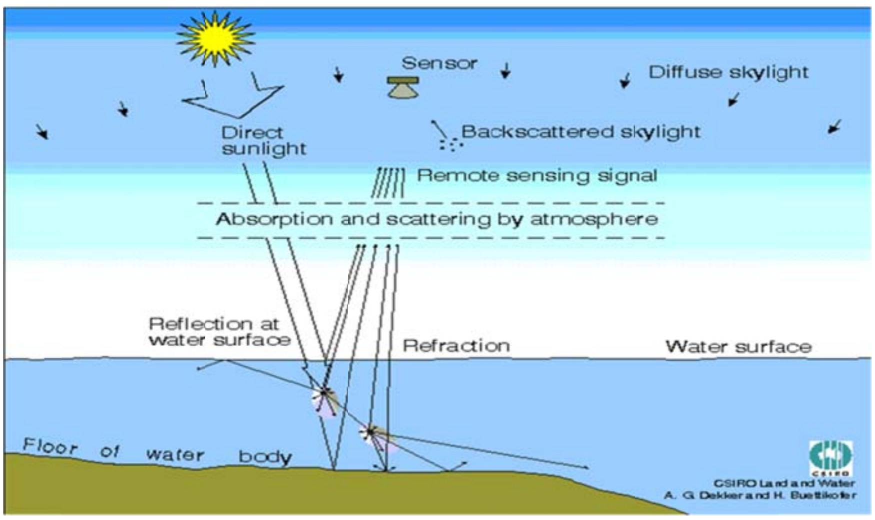

Figure 2.2 Pictogram of the multiple components that have an effect on the visual radiation. Copied with permission from Dekker et al. (2001).

In the field we measure the so-called Apparent Optical Properties (AOPs); these are parameters that depend on the substances in water AND the ambient light field. Examples are the above-water reflectance as measured with a camera and the diffuse attenuation of light in the water.

Quality control (QC) is needed to minimize the impact of ambient light conditions on the interpretation of the measurements. Active QC (that gives directions at the time of the measurement) and passive QC (that applies rules in the processing of data) help to convert AOPs to IOPs in the best possible way. QC is based on studies in the scientific literature that describe the influence of environmental conditions on the AOPs. Here we shortly introduce the most important aspects.

Radiation from sun and sky illuminate the water from all incident angles between 0° (zenith) and 90° (horizon). Part of the light (See Figure 2.3 for non-polarized light) is reflected at the surface and scattered back into the air. For angles below ~ 40° this part is small (around 2.6 % with some dependence on salinity, expressed in the breaking index n_w). The largest part is refracted at the water surface and goes downward into the water. However, for lager incident angles the reflectance rapidly increases to a value of one, a perfect mirror.

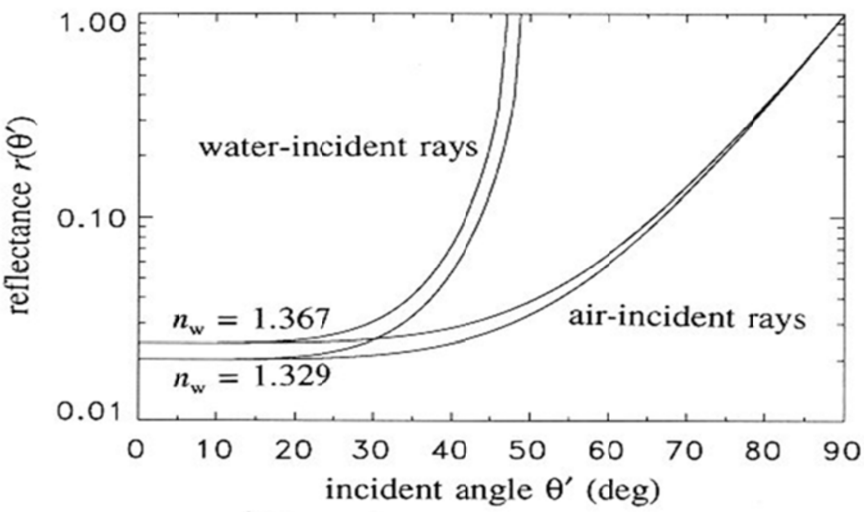

Figure 2.3. Dependence of the reflected light fraction (r) on the incident angle for light that illuminates the water surface from above (air-incident rays) and from below (water-incident rays). From Kirk (2011).

Therefore, always a fraction of the incoming light is reflected at the surface and contributes to the signal when an observation of the water colour is made. Under perfect conditions this reflectance should be no problem, because the measured signal can be corrected for these effects. Perfect conditions are:

1. Strong signal from the water, relative to the incoming light (high contrast).
2. Exact knowledge of the observation angle.
3. Flat water surface (no waves and ripples).
4. Stable, uncoloured illumination (like at full white cloud cover)

Point 1 is almost never true. Without bottom reflection, the only way to get incoming radiation again out of the water (towards the observer) is to scatter radiation backwards by water and particles (eq. 1). However, the SPM in natural waters has a very weak backscattering fraction and the reflection (the ratio of upward directed energy (Eu) over downward directed energy (Ed)) is typically in the order of a few percent. This is of the same order as the surface reflectance, making a correction for incoming light very important. The brightest light source is the sun itself, therefore measurements should avoid under all circumstances reflection of sunlight at the water surface into the camera.

This is also illustrated in Figure 2.4, where four curves are plotted, based on measurements with professional Ramses sensors, developed by one of the Citclops partners (TriOS): The downward irradiance divided by π (Ed/pi, red), The sky radiance (Lsky, blue), the radiance from the surface (Lsrfc, green). The lowest curve is the radiance emerging out of the water (Rrs, purple), calculated as

$$Lw = (Lsfce - 0.026\ Lsky) \qquad \text{(eq. 2.3)}$$

In this calculation we have assumed a perfect flat surface of the water and an observation angle below 40˚.

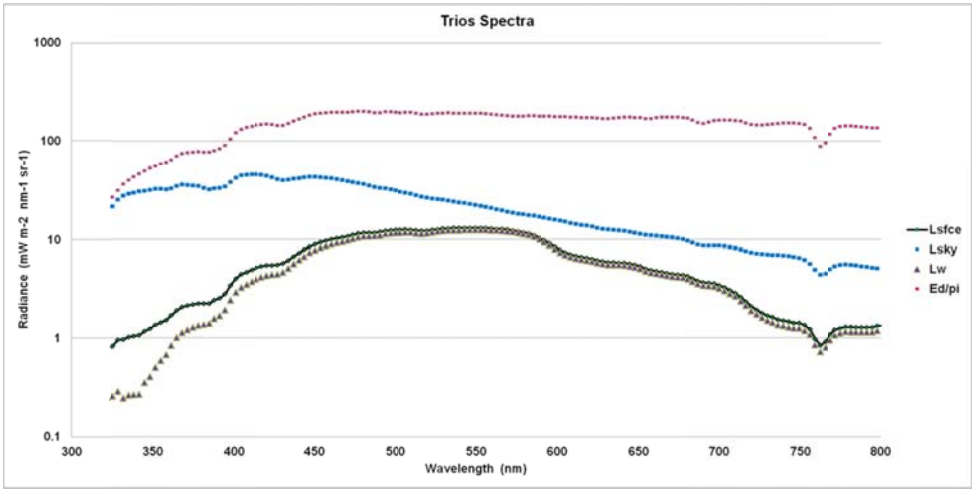

Figure 2.4. Example of spectra collected by S. Novoa (NIOZ) at the North Sea on March 12th 2013, 9.05 UTC. Bright sky and early morning sun.

Point 2 is somewhat easier to handle. From Fig. 2.3 it can be seen that the reflectance is more or less constant for incident angles below 40°. Therefore we do not have to fix the exact angle, but must check that observation angle stays below this limit. This is also illustrated by Fig. 2.5 left panel where the sky contribution increases toward the left at higher angles.

Figure 2.5. Left: Image of calm water near Amsterdam taken with a Samsung S4. Right: Image of the North Sea taken with a Samsung S3.

Point 3 is almost never true, but relatively flat water surface can be found at sheltered inland waters. Other waters, like coastal waters can show significant wave action. The image at the right of Fig 2.5 (courtesy S. Novoa, NIOZ) was taken from the deck of the RV Pelagia, some 5 meters above the water surface. Besides the dominant green colour, the wave action provides not only foam and air bubbles in the water, but also a highly variable air-incident angle over the image.

Point 4 is also not very often fulfilled. The effect of a changing illumination can be inferred from the red (Ed) and blue (Lsky) spectra shown in Fig. 2.4. The (yellow) sun in a blue sky provides a relatively constant irradiation between 450 and 700 nm. When clouds obscure part of the sky, the relative contributions change. A small cloud only before the sun gives a blue illumination. Therefore, care must be taken in the case of rapidly changing illumination conditions.

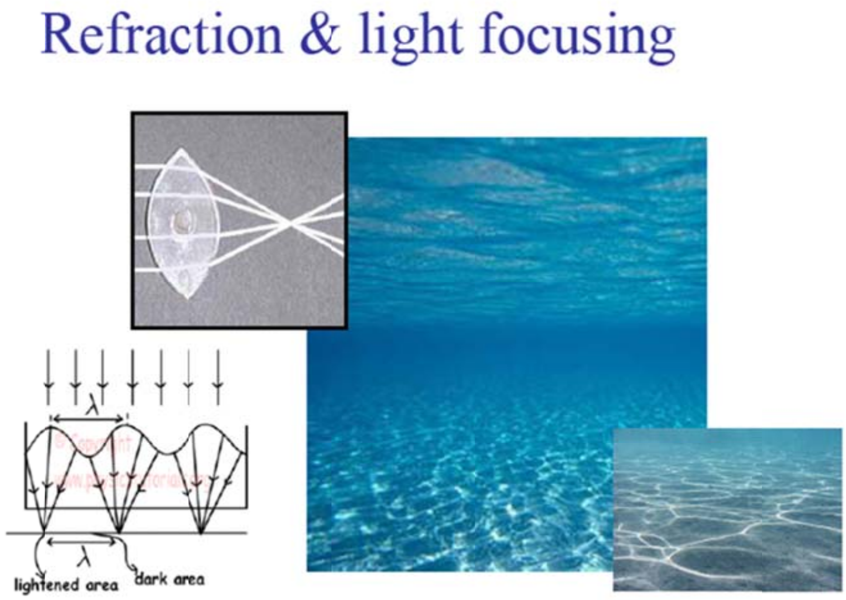

Figure 2.6. Demonstration of light refraction at the surface and its effects on the vertical light attenuation.

The effect of illumination conditions and shape of the air-water surface has also effects on the light conditions in the water itself. In figure 2.6 this is nicely illustrated for very clear and shallow water. Light from the sun and sky are refracted at the surface and rapidly changing patterns of high intensity emerge. This is mainly true for very clear waters in the upper part (meters) of the sea (Hieronymi, 2013). When light goes downward it will be more and more scattered by water molecules and particles in the water, thereby losing a preferred direction. In very turbid water this occurs very rapidly in the upper meters. An important water quality parameter is the amount of solar energy that is available for growth at every depth in the water. This parameter is expressed by Kd(z), the value of which describes the attenuation of downward flux of solar radiation energy. This property can be dependent on the depth (z). Kd is expressed in (m^{-1}) and defined as:

$$K_d = \frac{-\ln \frac{E}{E_0}}{z} \qquad \text{(eq.2.4)}$$

where

E Irradiance at a given depth (W m^{-2} nm^{-1})

E_0 Irradiance at the surface (W m^{-2} nm^{-1})

z Depth, taken positive downward from the sea surface (m)

Note that Kd is dependent on the wavelength. For example, water is a strong absorber of radiation with wavelengths larger than 700 nm and no near-infrared light penetrates below a few cm of water. The Kd(PAR) describes the attenuation of downward irradiance averaged over the PAR-wavelength range (400-700 nm).

The value of Kd over a range of 20 m deep is illustrated by Fig. 2.7 where the radiation transfer code HydroLight was used to calculate the diffuse attenuation coefficient Kd(z) for water with IOPs a= 0.2, b=0.8 and c=1.0 m^{-1} at a wavelength of 560 nm . Optical radiation transfer modelling explains how the radiometric properties change in the water column due to the optical properties (IOPs) of the medium. (Kirk 2011; Mobley 1994). In Fig. 2.7 is can be seen that Kd reaches a constant value near z=20 m. At lower depths the Kd can vary as function of the illumination above water. When the sun is at zenith (SZA= 0˚) the radiation undergoes less attenuation than radiation coming from larger angles (sun at higher SZA and cloudy skies). Therefore Kd is cannot be considered formally as an IOP.

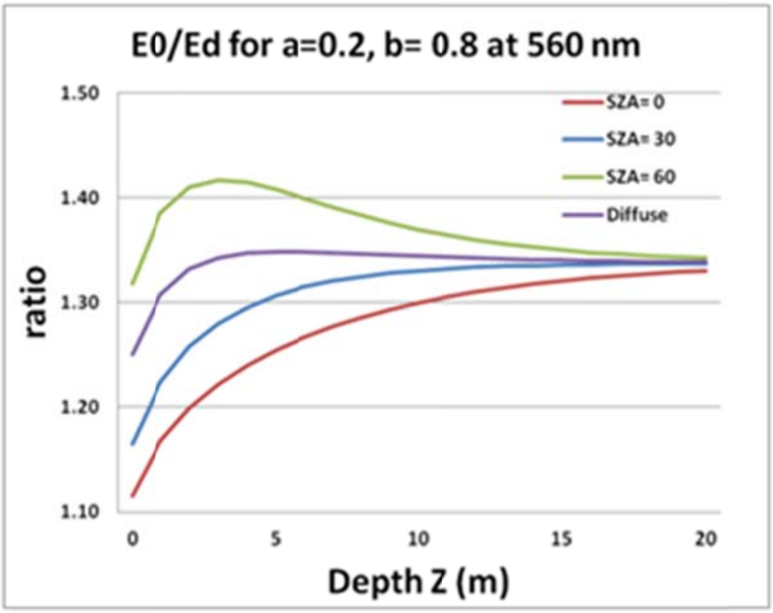

Figure 2.7. The Kd as function of depth for four scenarios. The sun is positioned at zenith and at 30 and 60 degrees from zenith. The purple describes the case of perfect diffuse illumination (for example fully overcast or mist conditions).

2.3 Fluorescence

The emission of light shortly after absorption of light is called fluorescence. Fluorescence is an IOP of the dead and living material in the water. The wavelength of fluorescence excitation, as well as the time and wavelength of emission of light is specific to the molecule, which makes fluorescence a powerful and specific tool for measurements. The energy which is released via fluorescence is the quantum yield (relation of photons absorbed by excitation and emitted by fluorescence), and this is dependent on outer conditions, such as temperature, pH and nutrient availability. Presupposed that all environmental conditions are similar, the magnitude of the fluorescence signal is expected to be proportional to the concentration of the target fluorescing parameter.

The fluorescence quantum efficiency (φ) of phytoplankton is defined as the ratio of mol photons emitted as fluorescence divided by the moles photons absorbed by the pigments (Huot et al. 2005). Measured values of φ for CHL are in the order of 1% (Behrenfeld et al. 2009; Huot et al. 2005). The pure fluorescence signal is emitted over a range of wavelength and the signal can be described by a Gaussian curve with a full width halve maximum of 25 nm with a maximum height at 682 nm (Mobley 1994).

At least at low concentrations, a linear proportionality can be expected, however, a number of factors alter the signal and negatively influence linearity. The most important aspect is that fluorescence only involves about 1% of the absorbed energy. Therefore, a slight change in the cell physiology, ranging from heat transfer, nutrient availability, accessory pigments, energy transfer to the PS II centre for Carbon fixation and so on, will already change the strength of fluorescence signal. The know effects are

- Chl *a* amount is dependent on the growth stage, availability of nutrients and on the algal species.
- Acclimatization to light conditions leads to a changing use of photons in the cell and thereby the size of the fluorescence efficiency. One option to prevent changes due to light acclimatisation and achieve a better comparable dataset is to do measurements of dark adapted cells during night/dawn.
- Disturbing influences of other pigments than Chl *a* (e.g., Chl *b*, Chl *c,* pheophytin *a* *etc.*) may alter the fluorescence signal.

2.4 Existing QC protocols for Citclops parameters

In the second half of the last century the science of marine optics has become mature. Next to dedicated instrumentation also the equations of radiation transfer in natural waters were solved numerically, leading to a wealth of measurements and new insights. The coupling between IOP and AOP was better understood and knowledge rules on 'how to make the best measurement of parameter "y" with instrument "x"' were developed. With the development of the ocean colour instruments on satellite platforms (CZCS, SeaWiFS, MODIS and MERIS) also more was invested in the drafting of very detailed measurement protocols and the collection of measurements that were carried out exactly following these protocols.

Optical and bio-optical protocols can be found in the protocols that were developed for the NASA instruments SeaWiFS and MODIS (Mueller et al., 2003) and the ESA instrument MERIS (Tilstone et al., 2004).

Information from scientific literature on how the physiological parameters and prior illumination influence the Chl *a* concentration can be found in the description of the continuous fluorescence measurements in FerryBox measurements (EU-Project: FerryBox, Contract number : EVK2-2002-00144).

The data QC of Citclops is linked to the data QC of SeaDataNet. This is a European Infrastructure (DG-Research – FP6) project which is developing and operating a Pan-European infrastructure for managing, indexing and providing access to ocean and marine environmental data sets and data products (e.g. physical, chemical, geological, and biological properties) and for safeguarding the long term archival and stewardship of these data sets.

Data are derived from many different sensors installed on research vessels, satellites and in-situ platforms that are part of various ocean and marine observing systems. The "DATA QUALITY CONTROL PROCEDURES" manual from SeaDataNet (2010) is based on existing documents produced by international organisations (e.g. IOC's International Oceanographic Data and Information Exchange (IODE) programme, JCOMM Data Management Programme Area (DMPA) and the International Council for the Exploration of the Sea's Working Group on Data and Information Management (ICES WGDIM)), international projects and programmes (e.g. WOCE, JGOFS, GTSPP, GOSUD, Argo, GLOSS, etc.), other European projects (in particular MyOcean for real time quality control) national programmes and expertise from national oceanographic data centres.

The report summarizes a set of recommended standards for quality control of a variety of marine data. Although Citclops will rely on data collection and transfer by means of a dedicated App, it is good practice that a number of basic automatic checks should be carried out on all data. These include date and time and position:

- Date and time of an observation has to be valid and always conversable to UTC
- Latitude and longitude have to be valid and must not be on land. This is relatively easy to check for oceanographic data, but already more difficult for inland waters, coastal waters etc. Maybe a more relaxed test can be carried out, e.g. the position must be closer than 100 m from water.

The SeaDataNet QC procedures also perform range tests:

- Global range test: Tests that observed parameter values are within the expected extremes encountered.

- Regional range test: Tests that observed parameter values are within the expected extremes encountered in particular regions

For the FU-scale and Kd measurements these range tests can be based on the satellite information from MERIS (D8.1 Bernard et al., 2013). However, for in-situ data only a limited historical data set is available for the two test areas (North Sea/Wadden Sea and Mediterranean/ Alfacs Bay).

Further scientific quality control is carried out on the data sets, and may be dependent on the data type. There is often a subjective element in this process, mainly because the QC rules are based on a long experience with these observations. The SeaDataNet (2010) contains multiple examples of simple QC tests. We will not repeat all these tests and procedures because they are instrument specific. Also we will not repeat the standard statistical tests that are available to look for outliers, correspondence of measurements etc. These can all be found in standard text books.

In contrast to the instrumentation described in the SeaDataNet (2010) manual, the Citclops new "low-cost" sensors have just been developed and the experience must be build. This can only be done if more and more data are collected in the next phase of Citclops. Therefore the Data QC will be updated regularly as the data base of measurements expands.

3 Forel-Ule colour

3.1 Science of the FU colour comparator scale

The Forel-Ule (FU) colour comparator scale is a device where the colour of the water is compared to the colour of a well-defined set of chemical solution in glass-tubes. The development, calibration and interpretation of these measurements is extensively described in Wernand (2011). Traditionally, the human eye is used to compare colours. In Citclops use is made of the colour images by Smart Phones that requires additional calibration and processing (D2.3). Also satellite images taken by the MERIS instrument, that employs 9 small colour bands, are converted to FU values (D8.1).

The FU scale has been applied globally and intensively by oceanographers and limnologists since the end of the 19th century, providing one of the oldest oceanographic data sets. Present and future FU classifications of global oceanic, coastal and continental waters can facilitate the interpretation of these long-term ocean colour data series and provide a connection between the present and the past that will be valuable for climate-related studies. It can also be an important resource for water quality assessment, as changes in water colour can indicate changes in the environment. The FU scale is composed of 21 colours, going from ‘indigo blue’ to ‘cola brown’, and represents the range of colours that can be found in the open sea, coastal and continental waters.

Figure 3.1. The Forel-Ule colour comparator scale.

Wernand et al. (2013) showed a good relationship between chlorophyll-a concentration (a proxy for phytoplankton biomass) and the FU index (FU1-FU10), evidencing the potential usefulness of the FU number as an index of phytoplankton biomass in the clearest waters.

3.2 Description of the FU crowdsourcing measurements

Within the EC-funded project Citclops we reproduced the Forel-Ule scale with the original recipes from the XIX century, digitalized its colours (see Novoa et al., 2013 for details) by means of spectral measurements, converted them to RGB values and included them in a Smartphone application ‘App’ that will be used to retrieve the colours of the water by citizens. The App will also allow the user to take a picture of the water, which will be used to calculate the FU using the algorithm explained in D2.3.

A plastic FU colour comparator scale was developed as well, as an additional crowdsourcing tool. This scale is validated with the liquid FU and can be used by citizen who do not own a Smartphone, or as an additional measurement, offering an additional way of quality control by increasing the number of independent observations.

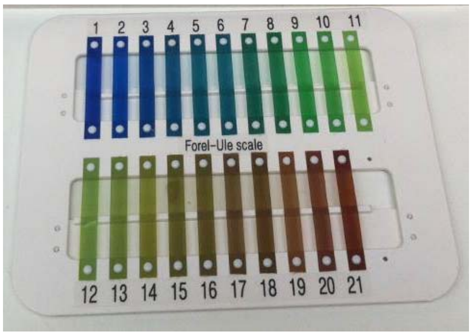

Figure 3.2. Forel-Ule plastic colour comparator scale developed for Citclops.

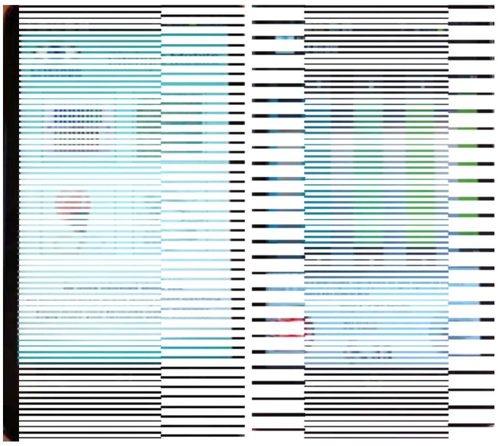

Figure 3.3. Beta- versions of the Citclops colour comparator 'App'.

<u>There will be four types of measurements that citizens can conduct:</u>

1. Visual comparison between the colour of the liquid/plastic FU scale (Coastwatch questionnaire) and the colour of natural waters;

Figure 3.4. Visual comparison of liquid and plastic scales.

2. Visual comparison between liquid/plastic scales and the colour of the water.
3. Visual comparison between the colour of the smart phone screen FU scale and the colour of natural waters;
4. Acquisition of digital image of the water surface, where the visual comparison of the FU scale on the Smartphone screen was conducted.

There will be two types of data that Citclops will determine:

1. Image conversion from RGB to FU scale number (post-processing), see deliverable 2.3 for details.
2. Comparison of historic FU with newly collected data (area/site specific), using historic *in situ* data, GIS layers and remote sensing images.

3.3 Instrumental characteristics that influence the measurements

Different scale materials. The liquid, plastic and digital (Smartphone) scales are composed of different materials that react differently to daylight. Even if an extensive validation of the three methods is being conducted on the field, some users can still provide different FU index estimated visually in the same location.

Different Smartphone or digital camera characteristics, which can cause pictures of a same location to differ as well, hence it is important to know the brand of the Smartphone/camera. Tests will be performed during Citclops to determine differences between cameras.

Satellite sensors use radiometers that measure the reflectance of the water surface at several wavelengths or bands, up to 30 depending on the device on the visible and infra-red. The data they provide is therefore different to digital cameras which only use three bands (RGB: Red, Green and Blue). This can also cause differences in the estimation of the FU index.

3.4 Field conditions that influence the measurements

Secchi disc. The three scales are initially designed to determine the colour of the water over a Secchi disc at half the disc's depth (Secchi-depth (SD); where the disc disappears from sight). If the user does not use a Secchi disc to establish FU or the observational SD-depth differs from ½ SD, can affect the determination of the colour.

The meteorological conditions can also have an effect on the image acquisition. If it is cloudy the colour reflected by the sky is whitish, while if it is a sunny day, the reflection is dominated by blue sky light (see example spectra in Fig. 2.4). For that reason it is important to take the picture in the shade, however, the sky will still have an influence that should be taken into account.

Image acquisition. The image used to calculate the FU index from the RGB digital image is affected by the manner in which the image is acquired. If the Smartphone has an angle above 30 degrees with respect to nadir, there will be a high influence of the sky light on the picture, causing an incorrect estimation of the FU index. It is also important to consider the azimuth angle with the sun to avoid sunglint, since it can affect the colour of the image. Furthermore it has great advantage to take a picture of the water alone, avoiding (white-) surfaces that are highly reflective and can influence the white balancing of the camera. See also section 5.

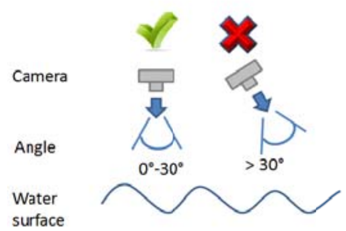

Figure 3.5. Preferred geometry of the camera inclination angle.

Selection of region of interest on image. The images acquired by digital cameras cover a wide area (e.g. 4608 x 2592 pixels with the Samsung galaxy Camera). Because of this, some parts of the images could influenced by sky reflectance, hence, an automated way of selecting the correct part of the image is important, selecting for example, the darkest pixels of the image.

Figure 3.6. Image showing the reflection of the sky on the left side.

The selection of the darkest pixels in coastal waters can be even more challenging because of the highly variable angles at the surface. If we take a small section out of the lower left corner in the image in Fig. 2.5 b (North Sea water) and process it according to the algorithms described in D2.3 we can attributed to every pixel the angle in the chromaticity diagram (Figure 3.7). The co-located FU measurement with the liquid scale and Secchi Disk was FU=8, which corresponds to an angle of around 102 degrees (Novoa et al, 2013). Clearly many pixels are showing larger angles (more blue in colour) due to blue sky reflection at the surface.

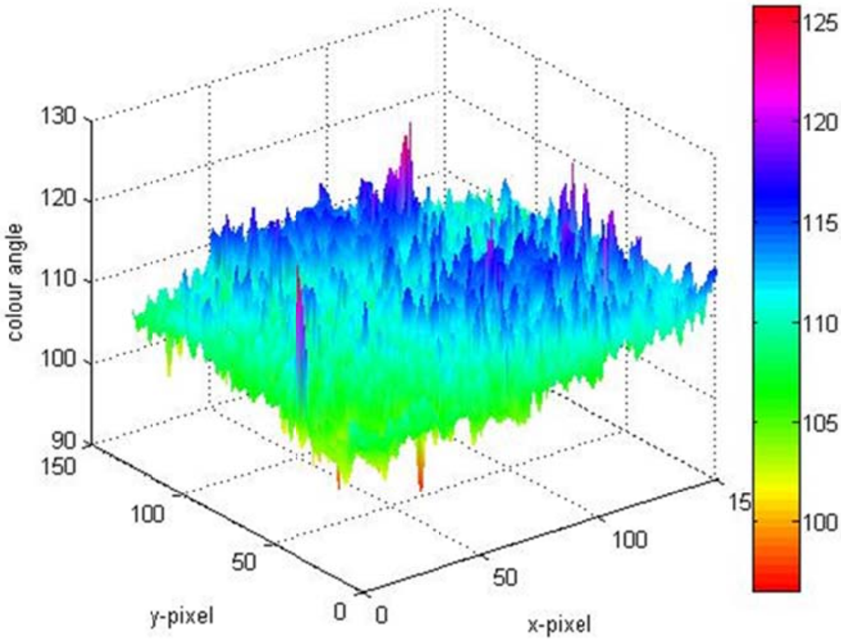

Figure 3.7. Illustration of the conversion of a sub-image to the colour angle on pixel level.

Because this effect is so profound we propose to include active selection of most reliable section in the image itself in the App and check it before any information is transferred to the database. This is done by performing the following steps:

First the most important geometries and observation conditions are checked (see next section). An image is taken and displayed on the screen.

If the observer makes use of a Secchi Disk, the camera is already pointed in the downward direction. A raster with grid size 100 by 100 pixels is displayed on top of the image. The observer is asked to select the cells that contain the Secchi Disk.

If the observer does not make use of a Secchi Disk first two calculations must be carried out: the Nadir Viewing Angle of every pixel and a measure of the light intensity. The NVA of each pixel can be calculated from the instrument NVA and the Field of View characteristics of the camera. Although the information of three colour channel can be combined, we propose to use the digital number (0 to 255) of the Green channel as an indication of the brightness. A raster with grid size 100 by 100 pixels is displayed on top of the image. All pixels with angle larger than 40 degrees are removed from the image. Only the green band is displayed and converted to a scale where it is intuitively clear where the darkest regions are. The observer is asked to select the cells that contain the darkest regions.

The selected cells are blown up to have a better comparison to the FU scale bars that are now displayed next the sub-image. The observer may select a scale. The sub-image coordinates and selected FU number are stored and transferred with the image.

A more in depth analysis of the image can be made with procedures described in D2.3 that will first focus on the indicated sub-regions of the image.

3.5 **Protocols to determine the quality of a measurement:**

Based on the NASA and ESA protocols, information given in the Secchi Dip-in Entry Form (2013) and analysis of test data collected at the North Sea (March 2013 by S. Novoa NIOZ) it is recommended to carry out the following set of tests. For each test it is indicated if it must be calculated in the App (Active QC).

Check the use of a Secchi Disk (SD). FU measurements with the liquid or plastic scales are always made with a Secchi Disk. This quantity is derived by the App. Boolean. Active QC: yes.

Check if the water surface is in the shadow (SHA). Ask if you measure in the shadow of your ship or platform, like encouraged in the standard FU protocols). This quantity is derived by the App. Boolean. Active QC: yes.

Check if you have a view on water plants or the bottom (BOV). Ask if you see the bottom or plants (like duckweed) drifting in the water. This quantity is derived by the App. Boolean. Active QC: yes.

Check if Rains (RAI). This quantity is derived by the App. Boolean. Active QC: yes.

Collect information on the clouds in the sky (CLO). This quantity is derived by the App. This can be derived from a slider that can be set between 0.0 and 1.0.. Active QC: yes.

Collect information on the Wind conditions (BFT). This quantity is derived by the App. This can be derived from a slider that can be set between 1 and 8. Active QC: yes.

Know the brand of the Smartphone/camera. This quantity is derived by the App Field: device_type). The different cameras are calibrated at NIOZ and these calibration tables are used to exchange FU values between cameras, human observations and satellite observations. Active QC: No; no feedback to the user is given.

Calculate the Solar Zenith Angle (SZA). From time (Field: Date_time) and position (Field: Location_lat_long) we can calculate the SZA. Flag the observation when the SZA is too large (SZA > 70˚) and therefore too close to the horizon. Active QC: nice to have.

Derive the Azimuth Angle (AA), the angle between observation and the position of the sun in a plane parallel to the water surface. This quantity is derived by the App Field: azimuth_angle). Flag the observation when the following conditions apply 0˚< AA< 90˚, 270˚< AA < 360˚, 160˚< AA < 200˚. In that case the observations are most sensitive to wave action and sunglint. Active QC: yes.

Derive the Nadir Viewing Angle (NVA), the angle between the camera viewing direction and the vertical (up down). This quantity is derived by the App Field: viewing_angle). Flag the observation when the following conditions apply 0˚< NVA < 40˚. Active QC: yes.

Calculate the Nadir Viewing Angle for every pixel (NVAi), based on NVA, the position vectors of the camera and the FOV characteristics of the camera that basically convert the distance from the centre in pixels to an angle that has to be added to the NVA for each pixel. Active QC: yes, this information is later offered in the selection of the most reliable section of the image for FU determination.

Select the best region for analysis. The image is overlaid with a fine raster. In the App the observed is asked to select those cells that should be used in further analysis. For a SD this will include the SD section. For other images, the selection is based on the NVAi and the darkest section of the image. Active QC: yes. The coordinates are stored.

Calculate the colour angle for each pixel in the selected cells. Use the algorithm proposed and described in D2.3. If the algorithm takes too much computer time, large sections of the sub-image (e.g. 5 by 5 pixels) can taken and calculated. Take the mean and standard deviation of the angles and convert those to FU numbers. Develop tools to interpret these numbers in the overall QC. Active QC: Yes. If the Standard deviation is more than 2 FU numbers the observer must be asked to restart the loop with image collection and sub-image selection.

Compare the FU index acquired with the Smartphone colour comparator scale and the FU extracted from the RGB image acquired simultaneously. Active QC: no

If the user reports an additional measurement conducted with either the liquid or the plastic scale at the same time, it can be used to assess the accuracy of the digital measurement. If the FU indexes differ (e.g. more than 2 FU numbers) then the measurement is flagged. Active QC: no

The data provided by the user can be compared to previous measurements conducted in the same area by other users, or to GIS layers and satellite FU index estimated for the area. A great difference in number can show that the measurement is incorrect, and can therefore be flagged. Active QC: no

The white balance is a characteristic of the camera that might influence the recording of the actual water colours. This is an issue that is not resolved at this moment of writing. It is very good to have the mode of white balancing registered by the App. In the Samsung Galaxy S4 the options are (AWB=automatic, daylight, clouds, and artificial light sources). When the characteristics of the modes are better known from laboratory and field experiments a change in the actual processing can be implemented. Active AC: no, just recording of the mode.

4 Light attenuation with the KdUINO

4.1 Science of the measured parameter

The composition of natural waters has a strong influence on the solar radiation and causes attenuation of the radiation with depth. Water itself is a medium with weak scattering and absorption properties over the largest part of the visual spectral domain, thus allowing light to reach depths of a few hundred meters in the clearest oceanic waters. Algae in the water contain pigments absorbing radiation energy that is partly used for carbon fixation. The remainder of the energy is converted to heat or emitted as fluorescence. Blue light is absorbed by dissolved material from the large group of humic acids. Mineral particles in the water scatter light and thus change the overall geometry of the light field. After a number of scattering events the radiation field will become more diffuse. In practice the attenuation of light with depth is expressed as the change in energy flux through a horizontal plane and defined by the diffuse attenuation coefficient for downwelling irradiance, Kd (Mobley, 1994; Kirk, 2011):

$$K_d = \frac{-\ln \frac{E}{E_0}}{z} \qquad \text{(eq. 4.1)}$$

where

E Irradiance at a given depth (W m^{-2} nm^{-1})

E_0 Irradiance at the surface (W m^{-2} nm^{-1})

z Depth positive downward from the sea surface (m)

Kd Diffuse attenuation coefficient in the downward direction (m^{-1}).

Approximately 90% of the diffuse reflected light from a water body comes from a surface layer of water of depth $1/K_d$. Thus K_d is also an important parameter for remote sensing of ocean color (Zheng er al., 2002).

4.2 Description of the implementation of the measurement

The proposed technology is based on Arduino, an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software which can be considered to be a very good alternative for the development of citizen science oriented sensors (Barjadi et al., 2013). The KdUINO is a moored system for low-cost sensing that will obtain light (irradiance) measurements at multiple depths. From these measurements the diffuse attenuation coefficient can be derived. The module structure of the KdUINO is composed of 4 elemental parts (see Figure 4.1):

- Array of light sensors
- Microprocessor
- Transmission module
- Antenna

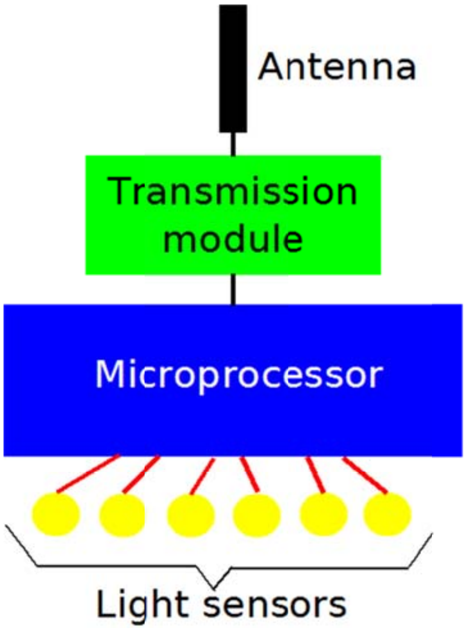

Figure 4.1. Basic Hardware structure of the moored system, the KdUINO

The light sensors are quasi digital-optical sensors that convert light irradiance into frequency. With this simple conversion it is possible to obtain long time-integrated measurement of irradiance values near the water surface, reducing the measurement variability by large light fluctuations, caused by focusing of sunlight by surface waves (Darecki et al., 2011).

Figure 4.2, KdUINO prototype, based on the Arduino platform

The sensors are assembled in a glass capsule filled with semitransparent silicone. The silicone acts as a waterproof isolator and also as a low cost light diffuser.

The light-to-frequency converter used is the TSL230RP-LF sensor (AMS, 2013). According to the sensor specifications, the output frequency has a linear dependence with the light intensity. The sensor's datasheet contains little information about the variation of the outcome as function of the wavelength of incoming radiation or of the output relation to multiple wavelengths. The datasheet just contains information on the output frequency (kHz) versus the irradiance (μW/cm^2) at 640 nm. A calibrated source with a known spectral power distribution along with the spectral outcome for this particular sensor is needed to calibrate it in the future.

These sensors have 3 configurable sensitive levels. The sensitivity can be set to 1×, 10×, or 100×, thus allowing the optimization of the output of the device at a given light level while preserving the full-scale output-frequency range. The sensitive levels should be properly configured depending on the expected maximum irradiance of the sensors at different depths.

The instantaneous output frequency of the light sensors may change according to the light fluctuations caused by the surface waves. However, the number of pulses generated by the light sensors during the integration interval should be proportional to the averaged irradiance. According to formula (4.1), there should be a linear relationship between the measurement depth and the natural logarithm of the pulses.

The following figure shows some results obtained by plotting the linear regression of the logarithm of the number of pulses stored at each depth during an integration time of one minute. For this Eq. 1 was rewritten to Eq. 2 that shows that K_d is the value of the slope of the line and the offset is irradiance just below the water surface.

$$\ln(Ed(z)) = -K_D(\lambda) \times z + \ln(Ed(0)) \qquad \text{(eq. 4.2)}$$

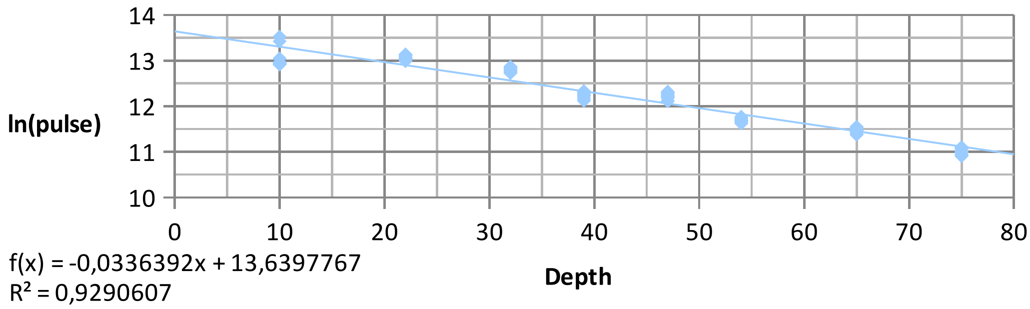

Figure 4.3. Example plot of some KdUINO measurements as function of depth (cm).

It's important to note that this is a test result and there was no correction procedure carried out to reduce the sensor measurement variability. Clearly, the linear relationship between the ln(pulses) and sensor depth is very good. This result indicates that the design is very robust.

4.3 Instrumental characteristics that influence the measurements

The sensitivity of the sensors may change due to several factors: capsule orientation in the water, internal sensor position within the glass capsulate. Also some factors might be influenced potential construction or assembling errors that might occur when the system is built by non-expert participants. We highlight three important factors that are still under investigation:

The response of the sensors depending on the form and material of the capsule

Tests have been done comparing the KdUINO estimations (with different types of capsules) and those obtained with a commercial optical profiler PRR-800 (Biospherical, 2013). The preliminary results show a linear dependence between the light extinction coefficient estimated with KdUINO and the PRR-800. These first results suggest that the proposed measuring system KdUINO is a very robust system to estimate light extinction.

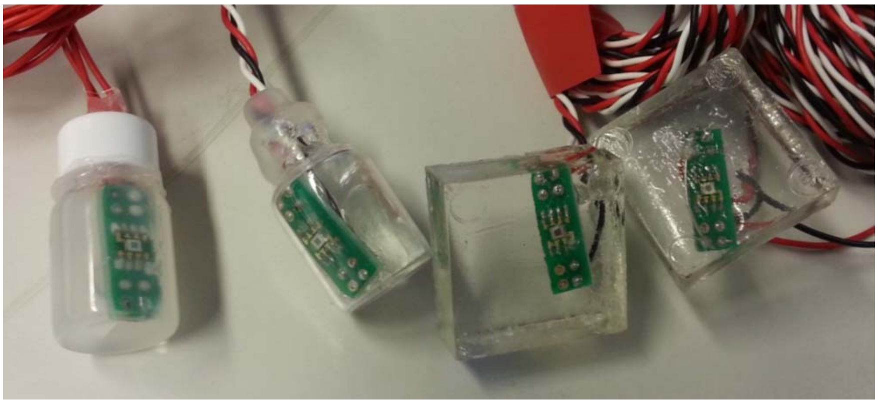

Figure 4.4. Sensors' capsules

Position of the sensor in terms of pitch and roll

The output value of the sensor can change depending on the position. For example, the sensor will receive different radiance energy if it is looking up or down.

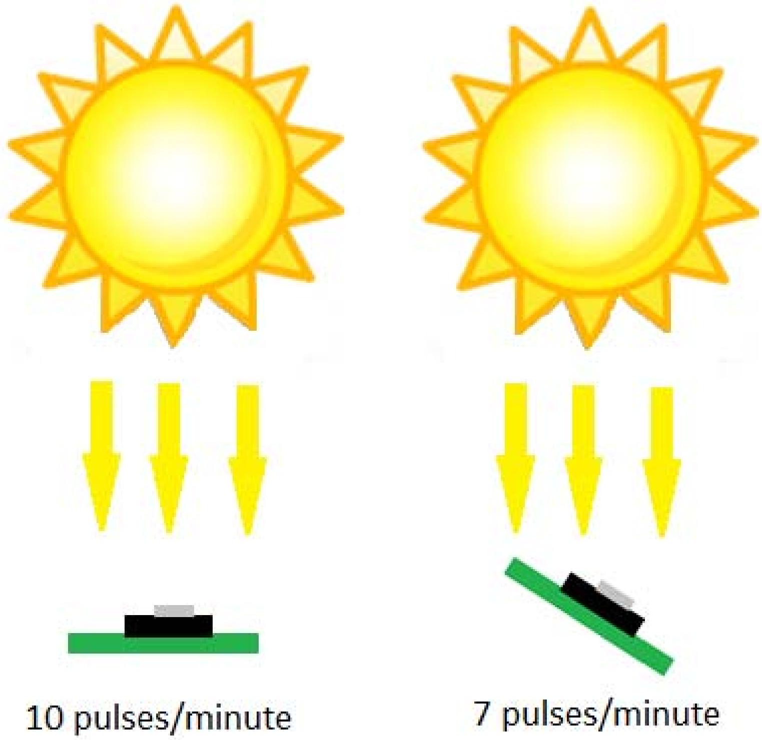

Figure 4.5. Differences of the sensor's output value depending on the pitch and roll

The result of the first tests with the KdUINO and the PRR-800 shows that it is perhaps not a major factor: in case of systematic orientation differences between the sensors, more scatter is expected around the results of eq. 4.2 (see also Fig 4.3).

Position of sensors in terms of depth

To obtain the coefficient of attenuation with the KdUINO, a linear regression is computed from the plot of the natural logarithm of the pulses at different depths. The exact depth of each sensor is crucial to get a correct linear regression.

As an example, the following figure shows two buoys: the first buoy has several sensors at a known depth. All sensor data can be used for the linear regression. The second buoy has several sensors too, but the depth of the second sensor is not known. The data of the second sensor should not be used for the linear regression.

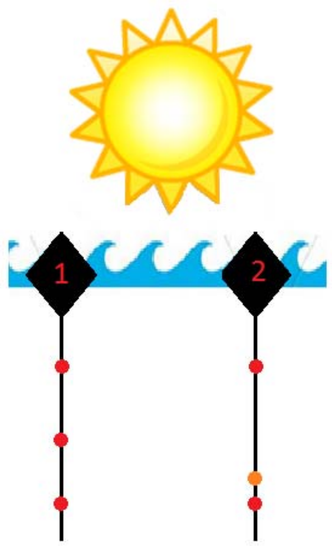

Figure 4.5. Example of a bad position of one (orange) sensor

It is important to known exactly the value of the depths of the sensors. However, before the sensors are attached to their definite position, their position and gain-factor must be adjusted to the water composition. In very clear waters the Kd is small (0.1-0.3 m^{-1}), while the very turbid waters from the Wadden Sea can have Kd= 1.0-2.0 m^{-1}

4.4 Field conditions that influence the measurements

If it's a sunny day the sensors that are closer to the surface may be saturated. It is very important to detect which sensors are saturated and delete their data in the final regression.

The absolute values are an indication of impact of clouds on the measurements. When all sensors experience the same effects of clouds, the Kd is still calculated correctly (see eq. 4.2). However, when during the integration time the irradiance (translated to frequency) varies by more than a factor X (to be determined) it should be flagged for later quality control.

The lens effect is strongest in the upper layers of the water, but due to the nature of the sensors (allowing long integration time) these effects are minimized.

In the deployment of the KdUINO at a buoy care must be taken to reduce the systematic shading of the sensors nearest to the buoy. The first (top) sensor should be at least 30 cm below the water surface to avoid temporary (fraction of integration time) saturation. Also this minimizes the chance of surfacing in times of heavy currents and waves.

The distance between the sensors should be adapted to the IOPs of the water. The overall reduction in Ed as function of depth is exponential, as is shown by eq. 4.2. In order to have the largest range in Ed values and thereby the best knowledge of Kd in the euphotic zone (z= 4.6/Kd), it is useful to optimize gain setting and depth setting for best coverage of the exponential Ed profile.

4.5 Protocols to determine the quality of a measurement:

Check that the distance from the surface from which each measurement is acquired is properly known and recorded by mentioning the distance on the rope. Active QC: yes.

Ensure that the sensors are indeed deployed properly and that the distance is translated 1:1 to the depth. Disturbing aspects like wire angles changes due to currents rapidly changing wave heights during measurements. Active QC: yes

If some sensors are known to be saturated, data can be deleted if the pulses/min of the sensor are higher than MAX_PULSE (the maximum value of the pulse/min for each sensor sensitivity). Active QC: yes

Check the performance of each sensor by make a linear regression to the data, like shown in Fig.4.3. If the r^2 of the linear regression is less than a fixed threshold MIN_R2, it means that the buoy may have some problems with the position of the sensors and data should be discarded. A more precise analysis might be performed in the App and in the QC procedures in the data base (like bootstrap methods to identify the bad sensor). Active QC: yes, this certainly needed to support the gain setting and depth setting of the sensors in a new position and new water type.

Check the instrument ID, so QC can use a calibration file for each instrument. This might correct for the instrument type, wavelength dependence and integration over PAR (400-700 nm) and material of the capsule. Active QC: yes.

5 Water transparency based on underwater pictures

5.1 Science of the measured parameter

Visibility is a concept that predicts the ability of some observer (human or instrumental) to detect some object in a given environment, like in the atmosphere or in natural waters. The visibility problem in water is determined by a range of parameters, like characteristics of the target (size, shape, spectral reflectivity, markings, etc.); 2) the optics of the detector (like Signal to Noise 3) the IOPs of the water and 4) the external lighting conditions by solar irradiation of the water (Zaneveld and Pegau, 2003).

It was the experimental and theoretical work of Preissendorfer (1986) and Davies-Colley (1988) that clarified the visibility of black and white disks in the water and the role of the observer. Basically they used the fact that the human eye has a reasonable constant and very low contrast limit that could be used to accurately determine when a white or black disk blended in the background. Subsequently this distance was proven to relate to 1/(Kd+C) for vertical measurements and 1/C for horizontal measurements (Zaneveld and Pegau, 2003).

With digital cameras this use of the contrast limit is also possible. However, as long as the digital camera behaves as a reasonably accurate radiometer an alternative way to establish the light attenuation as function of distance can be followed.

In Citclops underwater pictures will be taken of a high-contrast target by scuba-divers or snorkelers with waterproof cameras. From these images an index for water transparency (Kp) will be computed using the following formula (Rao and Lee, 2006):

$$K(\lambda) \approx -\frac{1}{z_1 - z_2} \ln \frac{L(\lambda, z_1)}{L(\lambda, z_2)} \qquad \text{(eq. 5.1)}$$

Where Z_1 and Z_2 are two different distances from a digital camera and $L(\lambda, z_2)$ is the measured radiance for each particular band (red, green or blue). Formally, this equation is different from the definition of Kd (eq. 4.1) that is based on the irradiance attenuation. This equation was 3 tested well in comparable studies (Koponen et al., 2011). More details on the whole measurement set up and procedures can be found in deliverable D2.3.

5.2 Description of the implementation of the measurement

A first step is to estimate accurately the distances between the picture and the photographer (Z_1 and Z_2) by processing it using the scheme illustrated in Fig. 5.1. Once the back and white pattern are extracted, the distance is derived, based on the fact that Z it is inversely proportional to the size of the radius of the circle pattern, see Fig. 5.2. More stability tests and the optimization of the pattern to be photographed can be found in deliverable D2.3.

The Kp is derived by applying the procedure to estimate the camera-target distance twice, extract the DN from the images and apply equation 5.1.

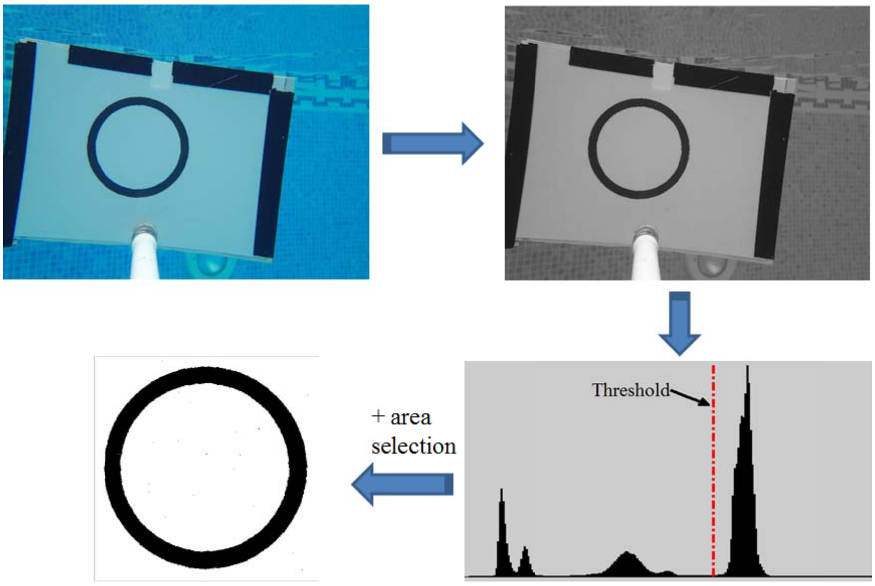

Figure 5.1, Processing of an underwater image before distance estimation. The picture is first converted to grayscale then to black and white using thresholding and finally the region of interest is selected.

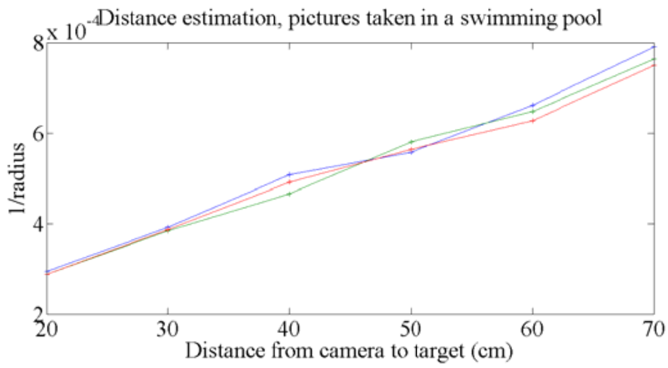

Figure 5.2, The inverse of the maximum distance between two points of the target is computed and plotted versus the distance between the target and the camera. It can be seen that there is a linear dependence.

5.3 Field conditions that influence the measurements

In the whole measurement procedure some errors might introduce errors in the Kp value:

The distance is subject to deformation of the target due to misplacement of the camera and object and internal breaking of light rays in the water. Our method has proven (see D2.3) to be robust enough and the error remains relatively low.

The depth variation of the photograph between two pictures is also very important, mainly because the interpretation is less obvious. For perfect horizontal changes in distance, the derived parameter should be proportional to the total attenuation c=a+b. For other geometries also the change of illumination of the object with depth (Kd) comes into the equation.

The choice of the ROI is not obvious due to the so-called undesired near surface light fluctuations, as can be seen in Fig. 5.3 for example. This is of crucial importance as it can give erroneous brightness. It is expected that when the measurements are taking place at a larger depths, these effects will disappear or average out due to a longer integration time of the camera.

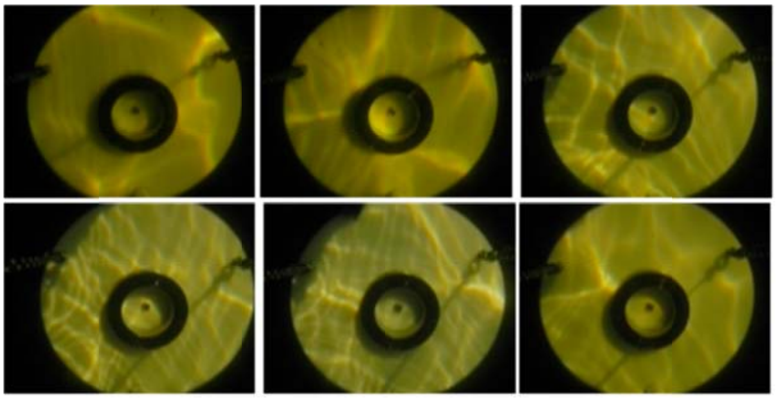

Fig. 5.3. Near-surface light fluctuations. At the same place, the grey level can vary a lot

5.4 Protocols to determine the quality of a measurement:

This application is still in very much under development and thus protocols cannot easily be produced at this moment. Once the distance calibration is fully solved, most QC procedures should focus on reducing the impact of variability in the illumination conditions.

One approach that can be tested in the field is to increase the number of pictures taken significantly, such that the radiance as function of distance can be estimated from a linear regression (see section 4) and outliers are more easily detected.

6 Fluorescence

6.1 Science of the measured parameter

The relationship between fluorescence and the concentration of a parameter is

$$F(\lambda_1) = E(\lambda_2) \times C \times \varphi_f\,(\lambda_1, \lambda_2) \qquad \text{(eq. 6.1)}$$

with F being fluorescence, E is excitation light intensity (natural solar light in nature and in the case of Smartphone the internal flashlight LED) at wavelength, C is the concentration of the target component, and φ_f is the quantum yield of fluorescence (number of photons emitted/photons absorbed). Note that the wavelength of emission (λ_1) is always different (larger) than the absorbed wavelength (λ_2).

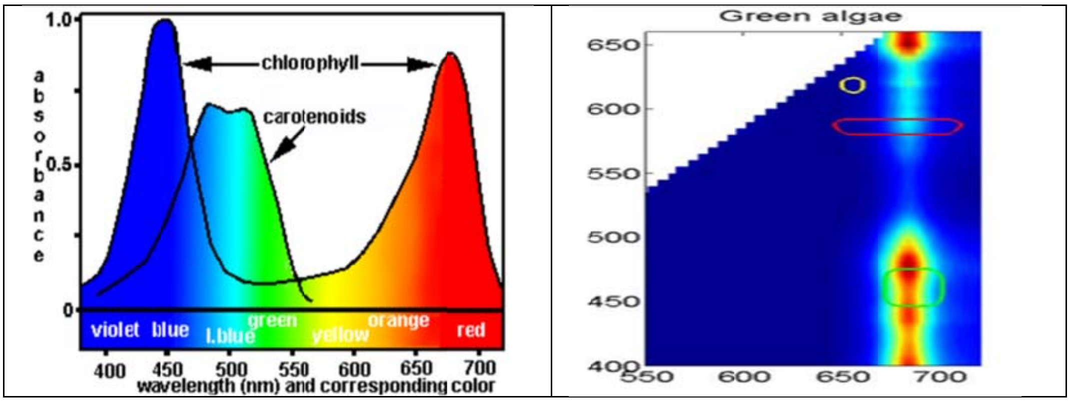

Figure 6.1. Left Panel: Algae can produce a range of different pigments that absorb light predominantly in the blue and red part of the visual light. Right Panel.: Example of the φ_f (λ_1, λ_2) excitation-emission matrix for Green Algae. The fluorescence emission is predominantly near 682 nm, but the strength depends on the excitation wavelength. (Jukka Seppälä private communication).

For the two parameters that are primarily targeted for fluorescence measurements, CHL, as well as for CDOM, the following general points are to be considered under the scientific interpretation and quality control:

<u>General aspects for Chl *a*:</u>

- Chl *a* amount is dependent on the growth stage of an algal culture, and therefore also likely in their natural environment. It increases up to a fixed date and then decreases with increasing age. Also, the CHL to biomass ratio changes within the growth process (Llewellyn and Gibb, 2000).
- Acclimatization to light conditions leads to a changing amount of Chl *a* due to physiological processes (Falkowski and Owens, 1980). This implies a lack of stability (variable fluorescence) and no possibility for an “always valid” calibration. One option to prevent changes due to light acclimatisation and achieve a better comparable dataset are measurements of dark adapted cells during night/dawn.
- Disturbing influences of other pigments than CHL (e.g., Chl *b*, Chl *c,* pheophytin *a*) may alter the fluorescence signal (EPA methods).

These physiological parameters and prior illumination influence the CHL concentration as also described for continuous fluorescence measurements in FerryBox measurements (EU-Project: FerryBox, Contract number : EVK2-2002-00144).

<u>General aspects for CDOM:</u>

- Photochemical degradation under light conditions. This includes photo-bleaching of natural surface waters (Vodacek et al., 1997; Coble, 2007), as well as for samples which are not stored under dark conditions.
- Usually, CDOM refers to dissolved organic material and therefore to the material which passed a 0.2 µm filter (Twardowski, 2002). A prior filtration or sedimentation of scattering material for CDOM measurements would therefore be desirable (Coble, 2007).
- CDOM is a proxy for dissolved material, but does not necessarily equal total dissolved organics, but only refers to the fluorescing part. The proportions of CDOM and “non coloured” DOM may vary seasonally (Vodacek et al., 1997).

Good practice to circumvent such variability in fluorescence is to conduct reference measurements on a regional/seasonal basis. Yet, this option is not applicable for the general public and general practise in Citclops.

6.2 Description of the implementation of the measurement

Within Citclops, two general approaches for fluorescence measurements are followed. One is the application of affordable in-situ sensors, in which the Smartphone merely serves as “steering & storage device”, the second is the use of internal Smartphone elements for fluorescence measurements. In this second case, the “flashlight” LED is used for the excitation of fluorescence, and the CCD chip of the integrated camera for its detection and record. Major target parameter is the ubiquitous algal biomass proxy CHL, but also coloured dissolved organic material (CDOM) will be approached.

6.2.1 Affordable in-situ sensors

In the microFlu fluorescence instruments, ultra bright LEDs in pulsed mode are used for excitation of the fluorescing molecules (Figure 6.2). Within the instrument, fluorescence raw readings are directly converted. The reading on this output is linear over its full range and gives directly a value for the concentration of the substance.

For the conversion of raw readings to concentrations, calibration coefficients are stored internally in the sensor. The calibration is conducted by following equation:

$$F_{conc} = C \times (F_{rawcounts} - Offset) \qquad \text{(eq. 6.2)}$$

Where F_{conc} is the substance concentration in physical units, $F_{rawcounts}$ is the raw fluorescence reading, C is a linear calibration factor in physical units per count (scaling factor) and *Offset* is the offset value. Both measuring ranges (amplification LOW and HIGH) have offset and scaling factors, which are determined in the factory calibration.

Figure 6.2: Left: TriOS microFlu-chl for Chl a fluorescence measurements. Right, principle optical configuration of the microFlu with the excitation beam (in green) which is focused approx.. 15 mm in front of the optical window (grey plate) by a small lens. The fluoresced light is collected by the same lens, reflected by a dichroitic beam-splitter and detected by a large area photodiode. In front of the photodiode, an interference filter excludes stray light (Source images and description: TriOS microFlu manual).

- The offset values for CHL and CDOM sensors are derived by using pure water (free of humic and fulvic acids; e.g. millipore water)
- For both sensor types, all solutions are filled in a glass beaker (no plastic beakers – plastic fluoresces and will interfere with the sample fluorescence), which offers at least 8-10 cm free view between the sensor head and the bottom of the beaker (e.g. 250 ml beaker, high form). Below the beaker a dark/black non-reflective surface is required to minimize errors due to reflections. Any artificial light is switched off during the calibration process.
- For CHL, the scaling factors are determined by using standard solutions of chlorophyll a (Sigma C-6144; free of chlorophyll b) in 90% Acetone. Multiple point calibration is chosen with at least two standard solutions for each amplification. Typical concentrations for the standard solutions are 10 and 20 µg/l for the HIGH-Channel and 10, 20, 100 and 200 µg/l for the LOW-Channel. Fluorescence response of in vivo CHL varies with the species of phytoplankton, the ambient conditions, like ambient light level, nutrients, etc. Due to this, the scaling factor between chlorophyll a in acetone (which is used for instrument calibration) and in vivo CHL also varies. For this reason the user is recommended to carry out a post-calibration using the species of phytoplankton most likely to be encountered in deployment.
- For CDOM, the scaling factors are determined by using standard solutions of Quinine sulfate Dihydrate (Fluka 22640) in 0.05 M Sulfuric acid. Multiple point calibration is chosen with at least two standard solutions for each amplification. Typical concentrations for the standard solutions are 10 and 20 µg/l for the HIGH-Channel and 10, 20, 100 and 200 µg/l for the LOW-Channel.

All microFlu units have a RS232 and an analogue (0..5VDC) data output. For operation with a Smartphone as control device, the fluorometers are connected to a rechargeable battery pack with Bluetooth connection via a cable. The fluorescence signal is then transmitted via Bluetooth from the sensor to the Smartphone. Measurements are conducted *in situ* and triggered via the Smartphone application.

6.2.2 Smartphone ex-situ adapter

The aim of fluorescence measurements with internal Smartphone elements, which are the flashlight for light excitation and the camera for record of fluorescence within Task 2.5, is set up as a proof-of-principle with subsequent demonstration and validation. Therefore, the measurement procedure is still under development and not all aspects of QC can be fully tackled at this early stage. As for CDOM fluorescence, external excitation sources in the UV would be crucial, efforts are here predominantly concentrated on Chl fluorescence measurements. The measurements will be done in a Smartphone adaptor which holds a cuvette. At the current state, a water sample is filled in a cuvette, and so the water sample is analyzed outside the water (ex situ). Then the cuvette is placed in a cuvette holder, excited by a Smartphone LED and recorded by the internal Smartphone camera. The whole setup is taken in dark conditions. For the recording of fluorescence, a short video is taken by means of the Citclops fluorescence App (AppLED) including dark measurements before and after excitation with the flashlight. The prominent frames are then extracted from the video. In the case of Chl *a* retrieval, a red-pixel-algorithm will be developed and applied.

6.3 Instrumental characteristics that influence the measurements

- For the exclusion of stray light of excitation, an interference filter is used in front of the photodiode, which restricts the passing light to a defined small range of the wavelengths that are required for excitation.
- To cope with variations of the excitation energy, a small percentage of the excitation light is reflected by a dichroic beam-splitter (Short Wave Pass SWP) and is used as a reference signal in the in situ device. For ex situ measurements such a reference signal is under consideration.
- Influences of ambient light (e.g., at surface waters) are eliminated by a special developed circuitry in the in situ device. Such are not necessary for the ex situ setup.
- Determination of instrument offset: For the use of Smartphone as control system, an additional correction due to the possible offset during signal transfer might be required. Blank readings should be conducted in pure water (readings should be zero) as described above.
- Clean optical window: To prevent contamination of the optical window, this should be cleaned regularly. In situ device: When submerging the sensor, the optical window needs to be checked for bubbles. These can be removed by gently moving the instrument from side to side. Furthermore, the optical window may be blocked by large material, such as floating macro-algae. This needs to be removed.
- Heterogeneous distribution of substances: Especially phytoplankton can be heterogeneously distributed in the water column. Therefore, measurements at different depths provide insights on the vertical distribution of phytoplankton. Likewise, the horizontal distribution may be targeted. For both, duplicate or triplicate measurements are recommended. For ex situ measurements, samples need to be thoroughly mixed before measurements.
- Variations in temperature are corrected by the interplay of reference and measurement diode in the in situ device.

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6.4 Field conditions that influence the measurements

With respect to inherent optical properties –in particular backscattering of light on intact algal cells or sediment which are suspended in natural water- the fluorescence signal is weak. This means, that the fluorescence signal may be superimposed by scattered light.

6.5 Protocols to determine the quality of a measurement:

For the *in situ* measurements, input data to- and output data from the Citclops server is the value of estimated parameter concentration as numerical digit. Corrections for temperature and variations in the excitation intensity are conducted internally in the fluorometer. The input values from the Smartphone measurements to the server are as image or video (*.jpg or *.mp4). The output value will be the estimated parameter concentration. In addition, information for quality control, such as the intensity of the LED for excitation of fluorescence, will be taken into account and may include additional input of image or text to the Citclops server. This procedure is currently under development and will be defined in the on-going construction process. For both approaches, duplicate/triplicate measurements are recommended. Of these multiple measurements, a mean will be displayed as output value. Specification on quality rules for such duplicate measurements will be considered.

For fluorescence measurements with Smartphone internal elements, following general and particular key rules for measurements apply:

Check if a significant time difference between measurement and sampling occurs, this needs to be checked by the App.

Check the sampling light conditions (e.g., sunny, cloudy, night), and temperature if possible (questionnaire by APP).

Check dark measurements of the cuvette before and after excitation with the LED (given by APP)

Check the availability of a blank measurement for calibration. The same measurement should be conducted with a blank which can be de-ionized water or the same sample water which was filtered through an at least 0.45µm filter.

Check the disturbing influences of scattering by particles in the water.

Determine internal camera/ settings like the white balance.

7 Satellite based information

7.1 Science of the measured parameter

The application of optical satellite remote sensing techniques to monitor the radiation scattered back from the water column became a major breakthrough in the seventies for monitoring ocean, sea and coastal areas. Dedicated ocean colour instruments, like SeaWiFS, MERIS and MODIS-AQUA, have provided fundamental new insight in the dynamics and role of oceanic plankton. Observations are now starting to span multiple decades, allowing a first glimpse at long-term variations in the plankton composition of the oceans and coastal waters.

With the launch, in 2002, of the MERIS instrument (Rast et al., 1999) that measures water-leaving reflectance in fifteen spectral bands with high signal-to-noise, it became possible to collect water-leaving radiance with high confidence in regional seas and coastal waters. This has led to development of many new algorithms that can retrieve not only the phytoplankton pigments, but also the mass concentration of suspended material and the absorption by dissolved material (e.g. Van der Woerd and Pasterkamp, 2008). The derived water-quality parameters are the major products of ocean-colour instruments, while the colour itself can be considered as a primary product. In Citclops the MERIS observations are used to provide climatology of the two test areas, including the colour expressed in FU numbers (Bernard et al., D8.1).

The water-leaving radiance (Lw), with a spatial resolution of 300 m at nadir, is derived after applying a number of processing steps on the raw instrument data. The main steps include the instrument calibration and the atmospheric correction that subtracts the signal originating from scattering in the atmosphere. The most important science that is included in this processing is described in the MERIS Algorithm Theoretical Basis Documents (MERIS, 2013). Next to the standard products provided by ESA, there are now a number of alternative processing lines available to the scientific community, like that from the Coastcolour project.

7.2 Description of the implementation of the measurement

In the frame of the Citclops project and the WP8, some Coastcolour products will be provided to the community and will be linked to the crowdsourcing data. The ESA funded CoastColour project has put together specialist of colour water issues and expert of water optical parameters, biology expert and specialist of in-situ measurements in order to have better MERIS products in the coastal zones around the world.

The purpose is to have information on the spatial and temporal behaviour of ocean colour parameters (colour, concentration, optical parameters) thanks to a climatology based on a long-term satellite observation since 2005. The basic products are the level L2W products from the sensor MERIS/ENVISAT measurements and processing. They include inherent water optical properties (IOPs), concentration variables, and transparency/turbidity information.

CoastColour process the MERIS level 1B data to obtain level 2 products and make available these products to the community on 27 coastal zones all over the world. Within the Citclops project we will focus on two pilot regions: the Alfacs Bay (Spain coast) and the Wadden Sea (Germany & Netherlands coasts) (see figure 7.1), through a web GIS layers system.

In the frame of the WP8, the L2W products have been selected and are described in the D8.1.

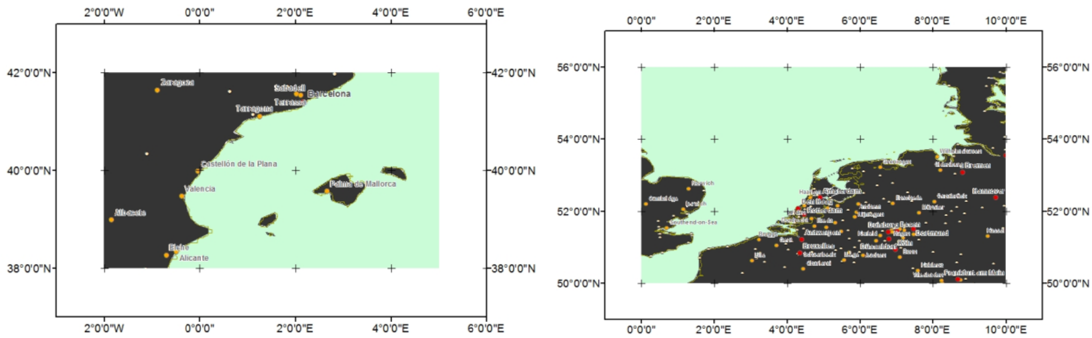

Figure 7.1: The two web GIS pilot zones, Alfacs Bay (left) and the Wadden Sea (right), on which the CoastColour product will be disseminated.

7.3 Observational condition that influence the measurements

The MERIS instrument has observed the Earth for more than a decade and an extensive knowledge base has been build on the potential errors that may occur in the whole processing chain. This knowledge is expressed in a large set of so-called “flags”, binomial (0 or 1) indicators if a step in the processing has resulted in “out-of-bounds” parameters. In Citclops these flags are determined for each pixel and give in total a data quality assessment.

Noveltis is in charge of providing these L2W products. They will be provided at full resolution (FR – 300 x 300m). First, CoastColour processes an atmospheric correction from the L1B MERIS product. This L1B product comes with a first quality control (see below). The level 2R obtained (after atmospheric correction) provides the directional water leaving reflectance. Then, the level 2W provides the water constituents products (IOP, concentration, and transparency/turbidity). For each image a quality mask (flag setting for each pixel in the image) is provided for four steps in the processing.

- The level 1b instrumental flags;
- The flag set by pre-processing: land/water, cloud screening, classification,…;
- The flag specific to the atmospheric correction;
- The flag specific to retrieval of water IOPs.

A detailed account of the processing and flag setting can be found in the reference documents MERIS (2011) and CoastColour (2013). The most important flags used in Citclops are:

<u>The flag L1b</u>

The flag of L1b includes:

- pixel classification: land/cloud/water
- coastline, cosmetic, suspect

<u>The flag of the pre-processing</u>

- land/water mask:
    - A land flag: if true, the pixel is 100% land
    - A coastline flag: if true, the pixel has 0% < water fraction < 100%

- cloud screening mask includes :
    - Cloud risk (includes sun glint risk but do not the distinction)
- Sea ice / snow screening includes:
    - Risk of snow/ice on pixel where an ice climatology has a minimum ice coverage > 0%

The flag for the atmospheric correction

The flags of the atmospheric correction are specific to this processing (failure of the atmospheric correction, negative water-leaving reflectance, presence of absorbing aerosol and so on).

The flag of the IOP retrieval

For the algorithm in Case 1 waters (includes atmospheric correction + IOP retrieval in case 1 and case 2) :

- anomalous scattering water flag : presence of case 2 water
- yellow substance loaded water flag : presence of case 2 water
- Flag indicating whether input to the Chl_1 algorithm is invalid : it summarises all out of range input conditions for the Case 1 processing algorithm
- Flag indicating whether output from the Chl_1 algorithm is invalid : it summarises all out of range output conditions for the Case 1 processing algorithm

For the Case2R algorithm (independent for the first one, optimized for case 2 water and applied everywhere):

- Flag indicating whether input to the neural network is invalid
- Confidence flag from neural network

7.4 Protocols to determine the quality of the climatology database

The goal of climatology products is to process temporal averages (monthly, yearly and seasonal) based on the best flag quality for the selection of the pixels included.

The statistics information like minimum, maximum, standard deviation, 98th percentile will be given as complementary GIS layers.

The database will be used as a reference data set for QC and additional information for the users (observers or policy makers) with typical values for the geographical zone and the period of interest.

To process the climatology the most severe quality flag will be applied to ensure the most confident retrieval ocean colour parameters.

The selection will be based on the L2W flag which is a combination of the previous levels (L1b and L2R) flags and flags resulting from the L2W processing.

The L1b flags give information on the identification of each pixel: clouds, shadow, land/water, case 1 & 2 waters, coastline, glint risk, snow or ice (see figure 7.2).

The L2R flags will give information about the quality of the atmospheric correction to obtain the water-leaving radiances. The ranges of the Top of Atmosphere (TOA) and Top of Standard Atmosphere (TOSA) pixels are evaluated and classified. The largest solar zenith angles are also flagged (see figure 7.3).

The L2W flags include the result of the out of training range evaluation for the water leaving reflectances and the water constituents. A risk for the white caps is also flagged. Some flags concern the retrieval algorithms (negative values, imaginary number) (see figure 7.3).

Based on a combination of such flags, an automatic system will be applied on the L2R and L2W selected products (see D8.1) to make the climatology as confident as possible. Adapted to each product, the most stringent choices will be done on the flags to discard the discrepancy pixels and the out of range values.

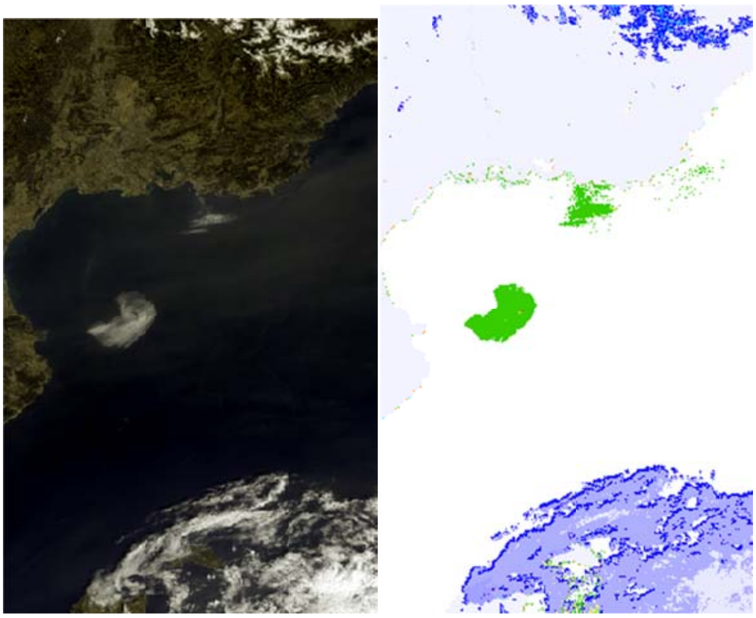

Figure 7.2: (left) RGB image from CoastColour L1P product for the 29 March 2012 near the Spanish coast. (right) The quality flag: white=water; gray=land; light blue=cloud; dark blue=cloud shadow; green=glint risk.

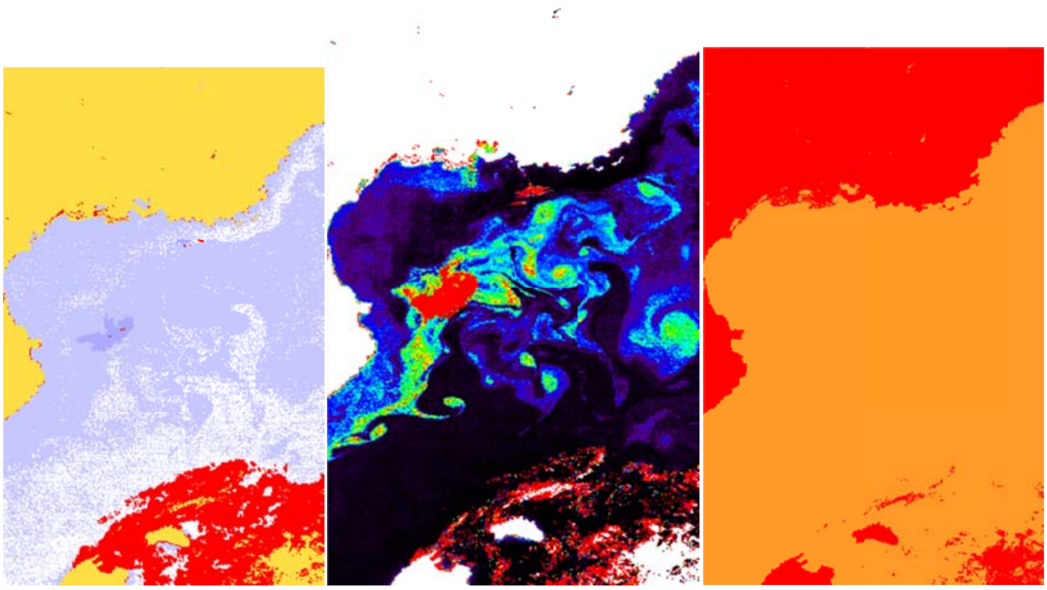

Figure 7.3: (left) The L2R quality flags: yellow=land; light gray=TOSA reflectance out of scope; dark gray=TOA out of range; red=L2R invalid & suspect pixels. (centre) Chl-a concentration from the CoastColour L2W product: colour scale is from 0 to 4 mg.m-3. (right) The L2W quality flag: orange=valid pixels, red=invalid pixels.

7.5 Comparing in situ and remote sensing data

The Citclops system will combine information coming from different sources, and citizen measurements will be compared with maps from satellite data (Bernard et al., 2013, D8.1).

Many of the AOPs and IOPs are already available in the in the CoastColour (CC) products. For Citclops, the FU product is added to this parameter set. Hence direct comparison of various remotely sensed parameters with in situ parameters is possible.

Regarding the comparison of AOPs (FU in situ with FU from remote sensing, or (ir)radiance, reflectance products), or comparison of IOPs, again the very strict ocean colour validation protocols (Mélin et al., 2007) will have to be relaxed for Citclops. Instead of comparing measurements 1-to-1 (as matchups), it might be better to see how a measurement fits in a climatology map and distribution, or to have a look at time series (Eleveld et al., 2008). Finally, remote sensing should be used to set the scene: this should be perceived as verification rather than as formal validation.

8 Summary of Citclops data quality control parameters

In this document the state-of-the-art of data QC in Citclops is described. The development of the instrumentation and smart-phone application for colour, attenuation and fluorescence is ongoing. In each section the most important scientific aspects have been shortly addressed and where possible test on parameters are proposed to check the observation and flag suspects results. In the table below we summarized these tests:

Table 8.1 Overview of the QC parameter tests.

Specification	FU	KdUINO	Under Water pictures	Fluo-1 in-situ	Fluo-2 ex-situ
Lat Lon of measurement	X	X	X	X	X
Time of measurement	X	X	X	X	X
Depth of measurement		X	X	X	X
Use of a Secchi Disk	X				
Water surface is in the shadow	X				
Water plants or the bottom view	X				
Rain	X				
Cloud fraction in the sky	X	X		X	X
Wind conditions	X	X			
Brand of the instrument	X	X	X	X	X
Excitation intensity				X	X
white balance of the camera	X		X		X
Solar Zenith Angle	X	X	X	X	X
Azimuth Angle	X				
Nadir/Zenith Viewing Angle	X	X	X		
Region of Interest in image	X		X		X
Saturation of sensor signal		X			
Calculation of statistics	X	X	X	X	X

List of abbreviations and acronyms

AOPs	Apparent Optical Properties
CC	CoastColour
CDOM	Coloured Dissolved Organic Matter
CHL	Chlorophyll-a pigment concentration
Citclops	Citizens' observatory for coast and ocean optical monitoring
DN	Digital number
ESA	European Space Agency
Ex	Irradiance flux from direction x (W m^{-2} nm^{-1})
FU	Forel-Ule (a colour comparator scale for natural waters)
IOPs	Inherent Optical Properties
Ky	Attenuation coefficient (m^{-1})
Lx	Radiance flux from direction x (W m^{-2} nm^{-1} sr^{-1})
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
PAR	Potential Active Radiation
PC	Phycocyanin pigment in Cyanobacteria
QA	Quality Assessment
QC	Quality Control
RGB	Red Green Blue information bands in the eye or instruments
SD	Secchi Disk
sIOPs	Specific Inherent Optical Properties
SPM	Suspended Particular Matter
TSM	Total Suspended Matter

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