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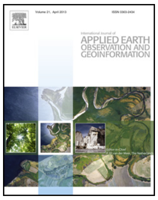

Citizens and satellites: Assessment of phytoplankton dynamics in a NW Mediterranean aquaculture zone

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ABSTRACT

Ocean colour measurements from space are well suited to assess phytoplankton dynamics over broad spatial scales. Closer to the coast however, the quality of these data degrades as a result of the loading of sediments and dissolved matter from terrestrial runoff, the influences of land reflection on atmospheric correction and sea-bottom reflection, which compromise their use in coastal management actions. Recently, the enabling of citizens to provide environmental observations has gained recognition as a way for enhancing the spatio-temporal coverage of satellite observations. In the FP7 funded EU project "Citclops" (Citizens' observatory for coast and ocean optical monitoring), a smart phone app for the classification of water colour, simplified to 21 hues of the Forel Ule (FU) scale, is developed.

In this study we examine two bays in the Ebro Delta (NW Mediterranean) where satellite data, hyperspectral measurements, and observations with the citizen tool for colour comparison were available. FU values and their corresponding novel colorimetric parameter, the hue colour angle, were derived in the bay at 12 stations with the traditional FU scale and one automated in-situ radiometric system at the Alfacs Bay aquaculture site. Both methods complied well during the study course of May–June 2011. These measurements were further compared to data from Full Resolution MERIS (Medium Resolution Imaging Spectrometer) satellite images. The quality of the retrieved hue angle varies over the image. For high-quality sites, MERIS hue colour angles and FU values gave a good estimate of seasonal algal dynamics in the bays over the year 2011, while ground measurements revealed colour changes over short space- and time frames, which are indicative of the fast dynamics of phytoplankton in the area that could not be fully resolved with MERIS data.

The use of FU values and hue colour angle of water will allow a simple integration of data from hyperspectral measurements, MERIS multispectral observations and citizens observations with the (Citclops/EyeOnWater) water colour app. Such observational data can be included to local monitoring efforts, and can also foster an increased interest of the general public to local environmental management and governance issues.

1. Introduction

The colour of natural waters, as apparent to the human eye, is a direct result of substances in it, in particular of phytoplankton (Dekker et al., 2000; IOCCG, 2000). Phytoplankton is usually associated to a greening of water, due to the presence of the ubiquitous pigment chlorophyll a (Chl*a*). Hence, changes in colour that are observed over time and space can be directly linked to processes of societal concern, such as eutrophication or algal blooms. Since the establishment of water colour measurements from optical sensors in space, satellite data have been used to assess algal dynamics and high biomass bloom situations over broad spatial scales (Busch et al., 2013a; Zielinski et al., 2009). While this advantage has brought space-borne information to large algal monitoring programs (e.g., Stumpf et al., 2003), there remain remarkable disadvantages: data quality of coastal observations can be disturbed by the high complexity of water components of terrestrial origin (i.e. those other than phytoplankton); and also pixels may be corrupted by portions of land or corruption of the atmospheric correction by

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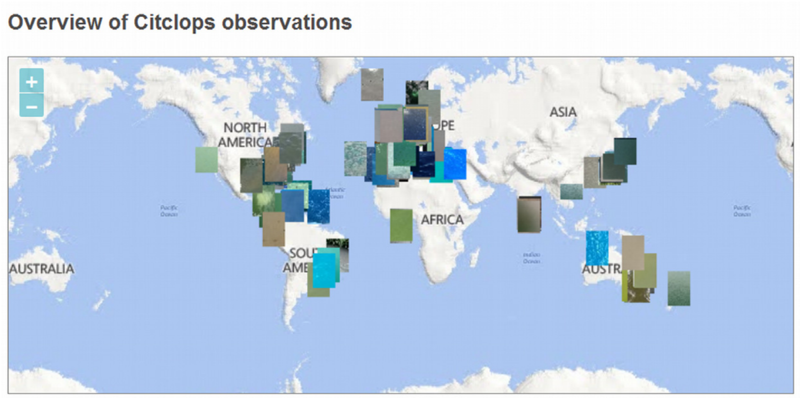

Fig. 1. More than 600 water colour images worldwide have been sent by use of a water colour App to the citizen science project server (www.citclops.eu, accessed 14.09.15.).

vegetation on nearby land (see www.coastcolour.org). In addition, the temporal resolution can suffer from a flyover rhythm which is often exceeding that of algal dynamics (Van der Woerd et al., 2011). Therefore, new observations to validate and complement satellite data are needed.

Recently, the involvement of the general public in management programs has gained increased recognition under the phrase 'citizen science' (Tulloch et al., 2013). Citizens can help to collect data to increase the volume of data, and therefore provide a better coverage of processes. In addition, direct involvement is also a means to foster environmental stewardship of the general public (Dickinson et al., 2012). In addition to a large number of terrestrial initiatives (Casanovas et al., 2014; Sullivan et al., 2014; Wilson et al., 2013), ocean related projects are involving citizens on different levels of participation (Marshall et al., 2012, http://www.secchidisk.org/, http://www.secchidipin.org or http://www.microb3.eu/myosd). Advantageous for such studies is the integration of simple measurement tools that allow comparison to existing historical datasets, such as the Secchi disk for water transparency measurements (Wernand, 2010) or the Forel Ule (FU) water colour comparator scale (Wernand et al., 2013b). In particular, the rise of consumer-grade mobile devices that are in every-day use is of considerable interest for citizen science (Johnson and Johnston, 2013). Devices such as smart phones can provide measurement location and time, as well as information about the collecting device itself, crucial for geo-referencing single measurement points and understanding their results. In addition, aspects concerning quality control during and after measurements can be included in smart phone applications.

With the incentive to improve the coastal-water science capacity of the general public, the EU FP7 funded project Citclops (www.citclops.eu) aims to develop new instruments and smartphone applications to assess the colour, transparency and fluorescence of coastal waters. As a first step, a smartphone app for the measurement of water colour has been released. These measurements are based on a discretization of water colour to 21 hues (blue–brown) of the FU scale (Novoa et al., 2014). Citizens can measure water colour with a plastic scale, or a digitalised version which is incorporated to a smart phone app. Retrieved data undergo a quality control and are visualised on a map on the project website (www.citclops.eu/www.eyeonwater.org) (Fig. 1).

In this study, ground observations of colour are directly compared to MERIS full resolution ocean colour satellite data for the Ebro delta coastal zone in Spain, which are available from the ESA-DUE coastcolour project (www.coastcolour.org). In particular, this study focusses on the satellite and citizen phytoplankton surveillance efforts in near-coastal areas and even shallow bays such as Alfacs and Fangar Bays that are important economic areas (recreation and aquaculture). Standard MERIS remote sensing reflectance data are converted to FU number and hue angle by the FUME algorithm (Wernand et al., 2013a). The hue angle of water (α_w) is an independent measure of intrinsic water colour and a universal optical property that can be calculated from radiometric spectra, from digital RGB (red–green–blue) images (Novoa et al., in press) and MERIS data (Wernand et al., 2013a). This angle provides the means to access the intrinsic water colour, also in combination with citizen science: each of the 21 FU colours is assigned to a certain range of α_w, lowest FU colours – indicating a higher blue fraction of water – correspond to highest hue angles.

The objectives of this study are to gain insight into how citizen science and earth observation data complement each other, can be included in natural resource management and foster environmental stewardship of the general public. A detailed inter-comparison of in-situ data (FU scale and hyperspectral data) and satellite data is presented and their compatibility, strengths and weaknesses in monitoring the seasonal and short term phytoplankton dynamics are analysed.

2. Material and methods

2.1. Location and description of the study area

The quality and usability of acquired space-borne and ground data were tested in the Ebro Delta which borders the Mediterranean Sea. As major spot for the aquaculture of mussels in two semi-enclosed embayments Alfacs and Fangar (Ramón et al., 2007) (Fig. 2), the region is subject to harvesting closures due to harmful algal blooms (HABs) (Delgado et al., 1990; Delgado et al., 1995; Diogène et al., 2008). Some of these are due to high biomass formations of toxic algal species, and such blooms could be visualised by synoptic optical ocean colour data techniques (Busch, 2013). Typically, algal biomass patterns (by proxy of the algal pigment Chl*a*) are linked to hydrodynamics of the bays and to seasonal influences of rice agriculture and related inflow of irrigation freshwater (Llebot et al., 2011). Toxic outbreaks have, however, often been observed in areas with long residence time of water, such as in the local harbour of Sant Carles de la Rapita at Alfacs Bay (Delgado et al., 1990), or in the NE part of Alfacs Bay (Artigas et al., 2014).

2.2. Water based observations

Measurements of water colour were obtained by traditional use of a liquid colour scale (LaMotte COMPANY, Maryland, USA), based on the principle of the well documented FU scale (Novoa et al., 2013, 2014; Wernand, 2011), which resembles data taken by citizens. The traditional liquid scale was used from a small boat, along a transect