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PROCESSING AND EXPLOITATION OF MULTISENSOR OPTICAL DATA FOR COASTAL WATER APPLICATIONS – THE HIGHROC PROJECT

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ABSTRACT

The FP7/HIGHROC ("HIGH spatial and temporal Resolution Ocean Colour") Project is developing the next generation of optical products for coastal water services. These products are based on both mainstream ocean colour sensors (Sentinel-3/OLCI, VIIRS) and other satellite missions such as the meteorological MSG/SEVIRI sensors and the land-oriented Landsat-8 (L8) and Sentinel-2 (S2) missions. The geostationary SEVIRI gives data every 15 minutes, offering much better temporal coverage in partially cloudy periods and the possibility to follow diurnal and tidal processes in cloud-free periods. S2 and L8 offer much better spatial resolution, down to 10m (S2), allowing detection of many human impacts invisible at 300m resolution.

HIGHROC R&D includes the development of algorithms, acquisition of in situ measurements and programming of image processing chains. The new products and services will be tested during User Service Trials covering a range of applications including coastal water quality monitoring, Environmental Impact Assessment and sediment transport.

1 INTRODUCTION

1.1 Objective

The HIGHROC ("HIGH spatial and temporal Resolution Ocean Colour") project is carrying out the R&D necessary for the next generation coastal water products and services from ocean colour space-borne data, giving an order of magnitude improvement in both spatial and temporal resolution and thereby opening up new applications and strengthening existing ones.

1.2 Opportunities of new missions

Coastal water end-users of satellite data, e.g. for Water Framework Directive (WFD) reporting, routinely use data from ocean colour remote sensors such as MODIS, MERIS and VIIRS. The Sentinel-3/OLCI mission has been designed as a follow-on mission to ENVISAT/MERIS and ensures data continuity for these users over the next decades. Despite their improved coverage with respect to in situ monitoring, these sensors have critical limitations of spatial and temporal resolution (typically 300m, 1/day) with respect to user requirements.

Precursor research studies have shown that other satellite missions, although not designed for coastal water applications, can help better meet user requirements by providing improvements in sampling frequency and spatial resolution. References [1,2] showed that it is possible to map parameters such as Suspended Particulate Matter concentration, turbidity and diffuse attenuation of Photosynthetically Available Radiation (KdPAR) in turbid waters from the geostationary SEVIRI at 15 minute temporal resolution (and about 5km spatial resolution for the Southern North Sea). Reference [3] showed that fine scale sediment transport can be resolved by Landsat-8 (L8) at 15-30m resolution (with a 16-day or 8-day revisit for the Southern North Sea). Similar performance is expected from Sentinel-2/MSI (S2: 10-20m spatial resolution, 5-10 day revisit in Southern North Sea for one satellite depending on swath overlaps) with additional possibilities for mapping of chlorophyll in turbid waters because of the additional red edge bands [4]. Taking advantage of the opportunities offered by these new ideas/missions, HIGHROC is preparing coastal water quality parameters from a) Sentinel-2 (S2) and Landsat-8 (L8) at 10-20m resolution and b) SEVIRI at 15 min resolution, thus complementing OLCI data with a more than 10-fold improvement in spatial and temporal resolutions.

These developments will both improve the services that are provided to existing users of ocean colour data and will open up entirely new applications, particularly for the high spatial resolution data. In coastal waters many human impacts that were not detectable at 300m resolution, e.g. related to ports, offshore constructions and dredging activities, become visible with 10-20m spatial resolution [5]. The positioning of HIGHROC services with respect to pre-existing Copernicus (then called "GMES") and downstream services such as the MARCOAST project is illustrated in Fig 1.

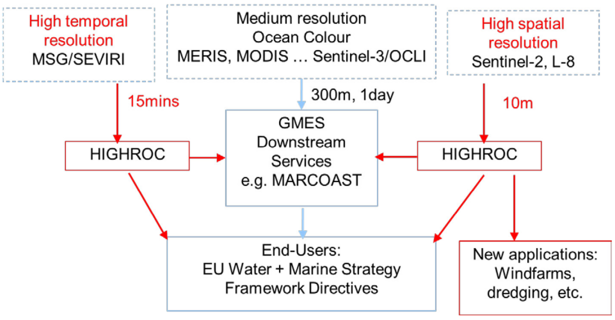

Figure 1. Positioning of the new HIGHROC products and services with respect to the existing medium resolution ocean colour data stream and services.

1.3 Users and applications

Application Type	User
Water Quality Monitoring and Reporting for the EU Water Framework and Marine Strategy Framework Directives (WFD/MSFD)	National governments
Dredging optimisation and monitoring	Dredging consultancies, Government
Coastal Aquaculture	Aquaculture operators, Government
Environmental Impact Assessment for coastal and offshore construction	Consultancies, Government
Initialisation/validation data for sediment transport and ecosystem models	Sediment transport and ecosystem modelling scientists

Table 1. Key applications and end-user communities for HIGHROC products and services.

Key applications and end-user communities for HIGHROC products and services are summarised in Tab 1. In many cases the satellite data can provide information both to private companies carrying out commercial activities (dredging, aquaculture, etc) and to national/local governments responsible for authorising/controlling such activities as well as to various scientists from universities or other research centres providing advice and adding value to the basic HIGHROC products.

1.4 Project structure

The HIGHROC project is funded by the European Union under the 7th Framework Programme (FP7) for the period Jan 2014-Dec 2017 and is carried out by 7 partners (see author affiliations for abbreviations):

- RBINS (coordinator)
- UPMC/LOV
- NIVA
- BC
- VITO
- CEFAS
- UHULL (added Sept 2015)

Research activities are focussed on algorithm development, in situ measurements, image processing and product validation. The new products and services will be tested by a Core User group during User Service Trials which will take place from October 2016 to September 2017. These User Service Trials will provide feedback for future refinement/operationalisation of the services in a sustainable long term framework.

2 METHODS

2.1 Test Regions

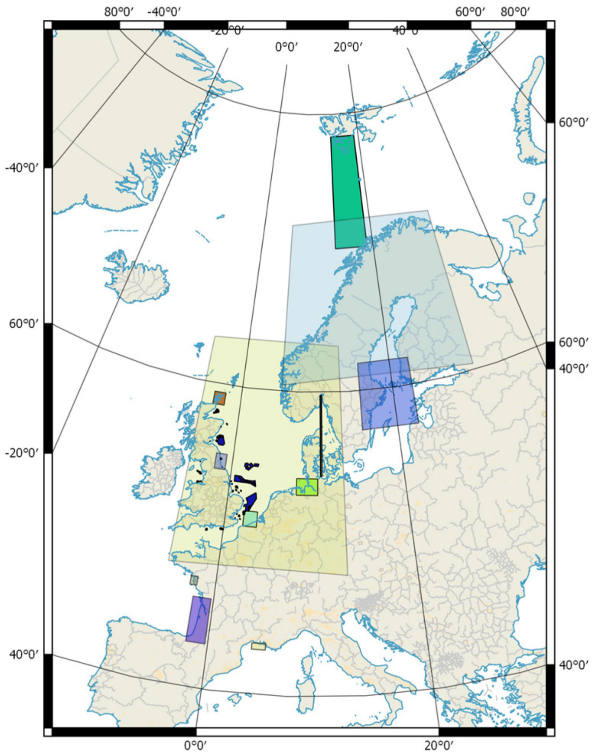

Figure 2. HIGHROC test regions.

The User Service Trials will be carried out in various European test regions as shown in Fig 2. In addition to these pre-defined test regions the project is set up for generic test regions, in preparation for future expansion of the user base.

2.2 Parameters

After consultation of the Core Users and confrontation of their requirements with the capabilities of optical remote sensing the list of core parameters shown in Tab. 2 was decided.

Parameter (units)	Symbol
Remote sensing reflectance (sr^{-1})	Rrs
Aerosol reflectance spectrum	*RHOa*
Aerosol Angstrom exponent	*ANG*
Aerosol optical thickness	*AOT*
Suspended Particulate Matter ($g\ m^{-3}$)	SPM
Turbidity (FNU)	TUR
Particulate backscatter 555nm (m^{-1})	*bbp555*
Chlorophyll a ($mg\ m^{-3}$)	CHL
Algal pigment absorption 443nm (m^{-1})	*apig443*
Diffuse attenuation spectrum (m^{-1})	Kd
Diffuse attenuation of PAR (m^{-1})	KdPAR
Euphotic depth (m)	Ze
CDOM absorption 443nm (m^{-1})	aCDOM443
Secchi Depth (m)	SD
RGB Image (Rayleigh corrected)	RGB

Table 2. Core HIGHROC parameters divided into 5 groups from top to bottom: L2R (radiometric), L2W/S (suspended matter-related), L2W/C (chlorophyll-related), L2W/K (attenuation-related) and L1RGB. Parameters in italics are not required by users but are considered necessary for product evaluation.

2.3 Algorithm development

HIGHROC algorithm development covers various aspects of data processing, including:

- Pixel identification from level 1 (L1) data to provide flagging of clouds, cloud shadow, land and other non-water pixels for which water products will not be calculated.
- Atmospheric correction to yield Rrs from L1 data
- L2 water (L2W) product algorithms to generate the main products listed in Tab. 2.

Not all L2 water parameters can be defined for all satellite missions because of signal:noise and spectral limitations. E.g. Only Rrs, SPM and TUR are defined for SEVIRI because of spectral limitations. CHL can also not generally be estimated from L8 because of inadequate spectral resolution.

2.4 In situ Measurements

In situ measurements are acquired by the project for validation of algorithms and products. Three partners (RBINS, NIVA, UPMC/LOV) participated together in a cruise of the Research Vessel Belgica in 2014 to consolidate and compare methods. All in situ measurement partners (NIVA, RBINS, UPMC/LOV, CEFAS) then participated in a protocol intercomparison workshop in Oslo (February 2015), to compare radiometer calibration in laboratory and outdoor (sky-pointing) conditions (Fig. 3) and to compare various in-water scattering instruments in indoor tanks with well-controlled water composition (Fig. 4): fjord water, ultrapure filtered water, river water, and water with varying concentrations of Formazine, Kaolin and algal cultures.

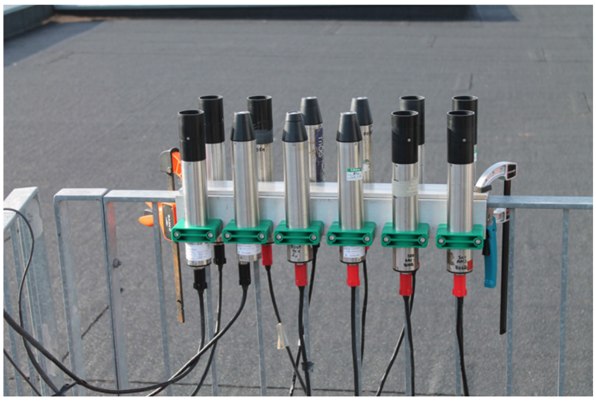

Figure 3. Outdoor (sky-pointing) intercomparison of radiometer calibration at HIGHROC protocol intercomparison workshop.

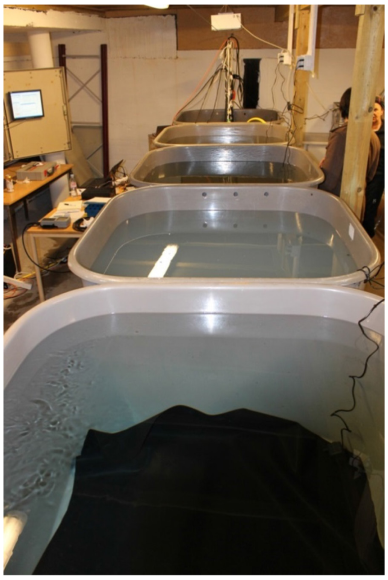

Figure 4. Tanks used for comparison of in-water scattering instruments during HIGHROC protocol intercomparison workshop. Tanks were filled variously with fjord water, ultrapure water, river water, and water mixed with Formazine, Kaolin and algal cultures.

Measurements are made throughout the project duration in various test regions both from ships (Ferryboxes, Research Vessel Belgica) and fixed structures, including Smartbuoys [6], AERONET-OC platforms (Zeebrugge, Thornton and Blyth) [7] and a TRIOS radiometer system deployment with underwater backscatter at the MESURHO location in the Rhône plume [8].

2.5 Image Processing

Image processing has been divided into three satellite data streams: GEO (geostationary: SEVIRI), S3PLUS (medium resolution ocean colour: MODIS, OLCI, etc.), S2 (Sentinel-2 and Landsat-8). Products from all 3 streams will also be combined in a multimission processor generating synergy products. The core HIGHROC parameters are generated by the processing centres for the test regions and supplied to HIGHROC partners for tailoring and value-adding before being supplied to the end-users as depicted in Fig 5. Each HIGHROC partner serves at least one end-user, typically from their own geographic region.

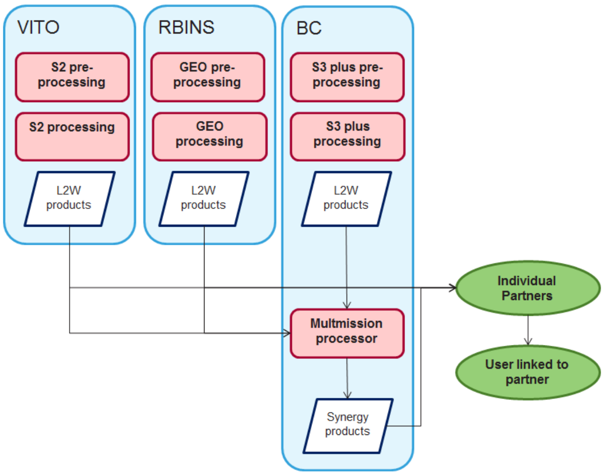

Figure 5. HIGHROC processing centres and data streams.

3 RESULTS

A few early results of the project are summarised here. More results will be published as the project progresses.

3.1 Pixel identification algorithm

Algorithms have been developed to identify pixels containing non-water features such as clouds (possibly divided into subtypes such as cirrus, semi-transparent, ambiguous), cloud shadows, snow/ice and land. Further details of a cloud shadow detection algorithm are provided in [9] and a HIGHROC intercomparison of various algorithms, including those of HIGHROC partners (ACCAm, AFAR, IDEPIX) and a standard FMASK algorithm [10] can be found in [11].

3.2 Atmospheric correction algorithm

Atmospheric correction (AC) algorithm development in HIGHROC has focussed primarily on the new L8 and S2 data with some minor refinements of the GEO AC already published [2]. The "ACOLITE" NIR/red L8 AC [3] has been further developed to a SWIR-based algorithm [12], more appropriate for turbid waters, and has been adapted also for S2 bands [4]. The "OPERA" algorithm has been refined for AC over both land and water [13]. An AC for L8 has also been tested for the SeaDAS software [14]. C2RCC Neural Nets for AC and in-water retrieval have been trained for S2 and the C2RCC processor is available for the project in the SNAP environment.
Use of the panchromatic Landsat-8 band has been demonstrated for achieving higher spatial resolution (15m) for SPM mapping applications [15].

3.3 L2W algorithms

Most HIGHROC Level 2 water (L2W) algorithms are based on prior work from HIGHROC partners or other scientists and various algorithms may be offered to partners and hence users for a single parameter, e.g. for SPM. In some cases original algorithms have been developed within HIGHROC, e.g. the regional SPM algorithm of [8]. A CHL algorithm has also been implemented for S2 [4].

3.4 Other algorithms – black sediment flag

Analysis of L8 data revealed that new processes can be observed such as the disposal of black dredged sediments. To facilitate automatic detection, a "black sediment" flag was developed in [12].

3.5 Measurement intercomparison

A sample of results from the HIGHROC protocol intercomparison are shown in Fig 6.

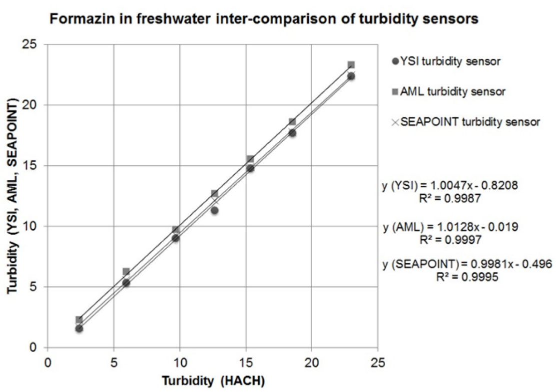

Figure 6. Sample results from the HIGHROC protocol intercomparison workshop showing measurements of 3

in-water turbidimeters compared to a Hach handheld turbidimeter for a tank of water with Formazine.

3.6 Processing of backscatter data

The processing of data from backscatter meters has been studied in detail using Monte Carlo simulations and an improved method has been developed to correct for path length attenuation [16].

3.7 Sub-pixel scale effects of measurement platforms

Landsat-8 data has been used to study small scale effects around an AERONET-OC site including platform-induced wakes and the effect of platform reflectivity itself at the scale on an OLCI pixel [17]. For use of AERONET-OC data from the Thornton site, a large platform, it is recommended to use a satellite pixel displaced from the location of the site because of platform contamination.

3.8 Multisensor mapping of SPM

Pre-HIGHROC research [18] demonstrated the potential for synergistic combination of data from geostationary (SEVIRI) and polar-orbiting (MODIS) sensors, In an early HIGHROC study, precursor to the full suite of data that will be available during the User Service Trials, [8] show the potential of combining high frequency data from SEVIRI with daily data from MODIS-AQUA/TERRA and high spatial resolution data from Landsat-8 to show dynamics of the Rhône river plume.

4 CONCLUSIONS AND FUTURE PERSPECTIVES

The HIGHROC project is developing a new generation of coastal water products and services with an order of magnitude improvement in both temporal and spatial resolution over the existing medium resolution data: 15 minutes instead of daily, 10-20m instead of 300m. New algorithms have been designed, including cloud and cloud shadow detection algorithms and atmospheric correction algorithms for Landsat-8 and Sentinel-2. One entirely new product, a “black sediment” flag has been developed. Measurement protocols have been intercompared and improved to best practice. An early study for the Rhône plume shows the advantage of combining the high temporal resolution (SEVIRI) data with medium resolution (MODIS) and high spatial resolution (L8) data. Image processing chains are being developed for systematic generation and distribution of products from all three data types. Services based on these products will be delivered to Core Users during User Service Trials in the period October 2016-September 2017 to evaluate and where necessary refine these products according to user requirements.

Further results will be published as the project progresses and made available via the project website (www.highroc.eu).

5 ACKNOWLEDGEMENTS

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