REPORT ON RECOMMENDATIONS FOR INLAND WATER QUALITY MONITORING FOR FUTURE SATELLITE MISSIONS

D8.9

Reference: ***INFORM_D8.9_v2.0***
Author(s): Dimitry VAN DER ZANDE (RBINS), Philip KLINGER (EOMAP), Mariano BRESCIANI (CNR), Claudia GIARDINO (CNR), Ils REUSEN (VITO), Els KNAEPS (VITO), Sindy STERCKX (VITO), Stefan SIMIS (PML), Peter HUNTER (U Stirling)
Version: 2.0
Date: 02/12/2017

DOCUMENT CONTROL

SIGNATURES

Author(s) : Dimitry VAN DER ZANDE (RBINS), Philip KLINGER (EOMAP), Mariano BRESCIANI (CNR), Claudia GIARDINO (CNR), Ils REUSEN (VITO), Els KNAEPS (VITO), Sindy STERCKX (VITO), Stefan SIMIS (PML), Peter HUNTER (U Stirling)

Reviewer(s) : Dimitry VAN DER ZANDE (RBINS), Ils REUSEN (VITO)

Approver(s) : Dimitry VAN DER ZANDE (RBINS), Ils REUSEN (VITO)

CHANGE RECORD

Release	Date	Pages	Description	Editor(s)/Reviewer(s)
1.0	15/11/2016	12	For submission to SPACE-TEC, DG GROW and REA	Dimitry VAN DER ZANDE, Ils REUSEN
2.0	02/12/2017	14	For submission as INFORM deliverable D8.9 to REA	Dimitry VAN DER ZANDE, Ils REUSEN

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EXECUTIVE SUMMARY

The European Commission's DG GROW has initiated an action to gather the user requirements for the next generation of the Copernicus Space Component. To this end, a consortium called NEXTSPACE (GMV, prime contractor, SpaceTec Partners, and FDC) has been entrusted to carry out this action and SpaceTec Partners took the lead the requirements gathering activity. To support the consultant's activity the INFORM partners provide a brief summary of the main requirement gaps and findings for inland water quality monitoring. These requirements are based on the interaction of the INFORM partners with their respective end users and can be seen as a translation of the end user needs to technical requirements to support the development of future sensors.

The following requirements/recommendations are discussed:

- Improved SNR characteristics of SWIR bands for atmospheric correction algorithms
- Inclusion of one or two bands in UV, around 360 and 368 nm for atmospheric correction in highly absorbing waters
- Inclusion of a NIR band at 760 nm for sun glint correction
- Adapted viewing geometry to avoid sun glint
- Inclusion of SWIR band around 1070 nm for the retrieval of total suspended matter concentrations in extremely turbid waters
- Inclusion of a band around 705 nm for the retrieval of chlorophyll-a concentrations
- Inclusion of an additional blue to improve the detection of the absorption features of yellow matter
- Inclusion of a band around 620 nm for the detection of cyanobacteria blooms
- Inclusion of multiple narrow bands in the blue-green spectral region for bathymetry determination
- Determination of end-user requirements base-line
- Hyperspectral global mapping satellite mission for measuring freshwater aquatic ecosystems
- Geostationary platforms for water colour radiometry sensor for observations over the European Continent.

1. Introduction

The EU's Earth Observation and monitoring programme, Copernicus, aims at the development and operation of a dedicated and sustained Space-based observation infrastructure consisting of six series of Sentinel satellites. The Sentinel satellites will be launched progressively ensuring continuity until 2026-2028 (First Generation). Copernicus is a user-driven programme and it is anticipated that there will be an evolution of the Space-based infrastructure in the form of a Next Generation of the Copernicus Space Component (post 2026). To achieve this evolution, a collection of observation requirements, resulting from user requirements, is needed to initiate the necessary feasibility studies and industrial development contract for the next generation Sentinels.

The European Commission's DG GROW has initiated an action to gather the user requirements for the next generation of the Copernicus Space Component. To this end, a consortium called NEXTSPACE (GMV, prime contractor, SpaceTec Partners, and FDC) has been entrusted to carry out this action, and SpaceTec Partners are leading the requirements gathering activity (Framework Contract "Requirements Framework for the next generation of the Copernicus Space Component Contract FWC - 386/PP/2014/FC). Once all requirements are collected and mapped to current and planned Copernicus services, a gap analysis will be conducted and data requirements for future spacecraft will be formalised. To support the consultant's activity, the INFORM partners provide a summary of the main requirement gaps and findings from a researcher or service provider perspective (section 2.1) and from an end-user perspective (section 2.2). The recommendations for future missions are provided in the following format:

- **Short description**
- **Application domain**
- **How updated are the requirements**
- **Main sources of requirements**
- **Which kind of future missions have been considered**

2. Requirements/recommendations for future missions

2.1. Requirements suggested by Research Partners and Service Providers

2.1.1. Requirement: requirements for atmospheric correction in water applications

Short description

- **Improved SNR characteristics of SWIR bands**. Monitoring of water quality by satellite ocean colour data requires high quality atmospheric correction and especially the accurate quantification of the aerosol contribution to the top of atmosphere radiance. Several methods have been proposed for atmospheric correction over turbid waters, including modelling the marine contributions to the NIR signal or switching to longer short-wave infrared (SWIR) wavelengths where the signal even in turbid waters can be assumed zero. The MultiSpectral Imager (MSI) on board of Sentinel-2 has a pair of 20 m SWIR bands at 1.6 and 2.2 µm, allowing for a robust image-based atmospheric correction, even over extremely turbid waters. The SWIR bands at 1.6 and 2.2 µm are used by default for the aerosol correction, as they should be black over all water types. Due to the low signal at these long wavelengths, the digitization in the L1C files (1/10000), and the relatively low signal-to-noise ratio of MSI, a spatial smoothing filtering for these bands is needed. When comparing the SNR characteristics of the SWIR bands of Sentinel-2 MSI with Landsat-8 OLI, it is observed that the SNR characteristics for Sentinel-2 MSI are 1/3 of those of Landsat-8 OLI. This results in more noisy water quality products (i.e. Rrs, TSM, CHL, etc.) which need to be avoided.
- The inclusion of one or two bands in UV, around **360 and 368 nm**, will help to improve the atmospheric correction in various turbid waters. In highly productive waters with high CDOM and detritus the water reflectance in the UV can be assumed to be quasi-black allowing detecting the presence of absorbing aerosols. Constraining the SWIR-based aerosol model retrieval using reflectance from a very short visible band (e.g. a **412 nm** band) or preferably an UV band is recommended.
- For sun glint correction: Kutser et al. (2009) developed a glint correction method applicable to a high spectral resolution sensor. The method uses the information available in the oxygen absorption feature at **760 nm** and two bands, at 739 and 860nm, outside the oxygen feature to estimate the amount of glint and to correct for it. Alternatively, an adapted viewing geometry (off-nadir) can be used to avoid sun glint issues which is a technique applied to the Sentinel-3 OLCI sensor but not to the Sentinel-2 MSI sensor.
- An elliptical geosynchronous mission to cover higher latitudes
- Provision of **L1B** data at medium and high resolution sensors, allowing for full radiometric image corrections on the original sensor-pixel grid. If reprojected data are provided instead

these should be based exclusively on nearest-neighbour resampling with full backward (un)projection support (pixel indices provided).

Application domain: Inland waters, Coastal waters
How up to date are the requirements: Nov-2017
Considered future missions: Sentinel-2

2.1.2. Requirement: requirements for the generation of improved water quality (WQ) products

Short description

- **Total Suspended Matter (TSM) products**: A SWIR based TSM algorithm for extremely turbid waters (Knaeps, 2012; Knaeps, 2015) uses a **1070 nm** spectral band. The relationship between TSM and SWIR reflectance did not show any saturation.
- **Detection of cyanobacteria:** Many optical detection methods of cyanobacteria blooms rely on algorithms targeting phycocyanin, a characteristic pigment associated with freshwater cyanobacteria. This pigment has a broad absorption feature at **620 nm**. To enable detection of phycocyanin it is necessary to acquire data with sufficiently fine enough spatial and spectral resolution.
- **Detection of cyanobacteria:** 650 nm channel to resolve diagnostistic algae/cyanobacteria separation (sensitivity to phycobilisomal fluorescence and chlorophyll-b)
- **Detection of Chlorophyll a (CHL):** For aquatic applications (indubitably also for terrestrial applications) the **705 nm band** provides a much needed reference point for retrieving chlorophyll-a absorption at 665 nm and thus can be used for estimating the chlorophyll-a concentration in turbid and productive waters. Several algorithms exist that exploit information in this spectral region, typically designed for MERIS or hyperspectral data (e.g. Gilerson et al., 2010; Gons et al., 2005). Alternatively, multiple narrow bands (3-4) between 600 nm and 700 nm enable a higher capability to determine chlorophyll concentrations.
- **Detection of phycoerythrin fluorescence: 590nm band,** with spatial, spectral, and radiometric resolution and sensitivity equivalent to 681 nm band on MERIS and OLCI for Chl-a fluorescence detection.
- **Dedicated mission for inland water monitoring:** mission design for inland/coastal water applications has been lacking a study of the spectral variability of absorption and fluorescence features observable by a remote sensor. These tend to be focussed on the ocean-colour needs and more recently, a combination of ocean-colour and land cover.
- **Determination of yellow substance absorption slopes:** An additional blue band is needed to improve the detection of the absorption features of yellow matter.
- **Bathymetry applications:** Multiple narrow bands in the blue-green spectral region are needed to determine the bathymetry, as these channels are most sensitive to the signal reflected by the bottom of lakes due to their low water absorption, i.e. highest penetration rate in water. Bathymetric maps with high spatial resolution based on sensors such as Sentinel-2 MSI are difficult to obtain due to the relative broad spectral bands of such sensors developed for land applications.

- **Multi-scale radiometric products:** A combination of high spatial resolution bands (can be broad) and high radiometric sensitivity but medium spatial resolution bands on the same sensor to resolve irregular coastlines and allow statistical extrapolation of water quality products to small bays (e.g. pan sharpening techniques)

Application domain: Inland waters, Coastal waters
How up to date are the requirements: Nov-2017
Considered future missions: Sentinel-2

2.2. Requirements suggested by End Users

2.2.1. Requirement: determination of end user requirements baseline

Short description

- In order to report on recommendations for inland water quality monitoring for future satellite missions we need to consolidate a clear, documented and validated **user requirements baseline for operational information data streams** not yet covered by current (or planned) in orbit satellite capacity. The activity of collecting and analysing user requirements has to be performed taking into account both the user needs (in terms for instance of the specific monitoring or reporting obligation for example associated to the Water Framework Directive) and the associated product requirements (that is the translation of the user need into geoinformation requirements).

Application domain: Inland water
How up to date are the requirements:

- The INFORM project has a dedicated Work Package (i.e. WP3) under the leadership of CNR which aims to gather users' needs for inland water products. The associated deliverables are providing a vision of currents requirements that have been gathered by both circulating two questionnaires to 24 European users' representatives of different categories (e.g. university, water authorities, and industry) and by dedicated interviews of the INFORM End User Board. The results of these end-user consultations are summarized in www.copernicus-inform.eu/sites/default/files/document/18.03_INFORM_RV02meeting_WP3_CNR_last.pdf as presented at the INFORM RV02 meeting in March 2016. At the end of 2017 a dedicated workshop for the results uptake end user workshop which will also provide a further updating (if any) of requirements. There are also prime examples of scientific papers which show updated requirements for satellite water quality monitoring missions: Hestir et al. (2015) reported the need for a hyperspectral global mapping satellite mission for measuring freshwater aquatic ecosystems; Tyler et al. (2016) discussed the recent developments in Earth Observation for monitoring of inland, transitional, coastal and shelf-sea waters; and Mouw et al. (2015) showed challenges and recommendations for future satellite missions for aquatic colour radiometry remote sensing of coastal and inland waters.

Considered future missions:

- So far we are not considering future missions for the end-user requirements as we are more oriented towards new opportunities, such as an archival global satellite hyperspectral satellite mission (Hestir et al. 2015) or a geostationary platform for water colour radiometry sensor. Huan et al. (2015) already provided the advantage of the Geostationary Ocean Colour Imager (GOCI) for characterising hourly dynamic of algae in Lake Taihu.

2.2.2. Requirement: specific requirements of UK end users

Short description

- The wider use of Earth Observation data by UK water regulators is likely to be dependent on the ability to monitor lakes and reservoirs (>0.5km²), mouths of large rivers and the near shore coastal zone (<20km) covered by the Water Framework Directive and other directives and at a temporal frequency that is at least comparable to the current in-situ effort after taking the loss of data due to clouds. In practice this comes down to the characteristics of the Sentinel-2 MSI resolution (< 30m spectral resolution in the visible spectrum) but with a global coverage better in less than 5 days (revisit time) and data provided at L1B processing stage rather than reprojected (which interferes with necessary image correction).
- A 620 nm band for cyanobacteria bloom detection
- Improved radiometric resolution (e.g. 16-bit) to improve our ability to retrieve of higher absorbing waters with low signal.

Application domain: Inland waters, coastal zone
How up to date are the requirements: Nov-2017
Considered future missions: Sentinel-2

3. Copernicus Next Generation Space Components: extract from Observation Requirement Report

This section presents an extract from the work performed to date under the "Requirements Framework for the next generation of the Copernicus Space Component" Framework Contract (FWC - 386/PP/2014/FC) relevant to marine and inland water applications of the Copernicus Space Component. The user requirements relevant to the INFORM partners and end users are presented below.

The end user requirements for the water domain can be summarized as follows:

- Monitor lakes and reservoirs, mouths of large rivers and the near shore coastal zone for good ambient water quality at a temporal frequency that is at least comparable to the current in-situ effort after taking the loss of data due to clouds.
- Support to aquaculture and fisheries.
- EO data to validate and improve mathematical models.
- Specifically, the product requirements include:
    - A European-wide Reference Datasets EU-HYDRO and Digital Elevation Model.
    - Water surface level of rivers and lakes.
    - Total suspended sediment, chlorophyll, dissolved organic matter, surface temperature and water level in lakes for sustainable fisheries.
    - Total Organic Absorption as proxy for the organic load
    - Detection of cyanobacteria by targeting phycocyanin
    - Ratio between green and blue-green algae
    - Land use and land cover, including lakes, at the catchment scale at regular intervals.

4. Conclusion

Current Earth Observation systems have been designed, built and launched with a focus on either terrestrial or ocean remote sensing applications. Within the INFORM project, land sensors such as Landsat-8/OLI and Sentinel-2/MSI were successfully used for inland water applications demonstrating the potential of high resolution sensors in an aquatic environment. However, such land sensors are not designed for these complex aquatic environments and are not likely to perform as well as a dedicated sensor would. Within the INFORM consortium, both project partners (public and private) and end-users were consulted on their requirements for future Earth Observations missions to fulfill their needs to monitor the water quality in lakes and reservoirs, mouths of large rivers, and the near-shore coastal zone. This resulted in a summary of the main requirements including the addition of spectral bands in key zones of the spectrum to improve the atmospheric correction in highly turbid or absorbing waters and improve sun glint corrections. Additional bands are needed for the determination of water quality parameters such as the concentration of chlorophyll-a, total suspended matter, yellow matter and cyanobacteria blooms.

These requirements support the findings provided by Dekker *et al*. (2017) who stated that a dedicated sensor of (non-oceanic) aquatic ecosystems could be a sensor with 26 bands in the 380-780 nm wavelength range for retrieving the aquatic ecosystems variables as well as another 15 spectral bands between 360-380nm and 780-1400nm for removing atmospheric and air-water interface effects. In that case the spectral bands would ideally have 5 nm spacing and Full Width at Half Max (FWHM), although it may be necessary to go to 8 nm wide spectral bands (between 380 to 780nm where the fine spectral features occur -mainly due to photosynthetic or accessory pigments) to obtain enough signal to noise. The spatial resolution should match the characteristics of the Sentinel-2 MSI resolution (< 30m spectral resolution in the visible spectrum) but with a global coverage better in less than 5 days (revisit time). Considering the needs of the end-users to monitor inland waters and coastal zones covered by international directives (e.g. Water Framework Directive) it is suggested for the spectral and spatial resolution to be as high as is technologically and financially possible. A high temporal resolution could be obtained by a constellation of Earth observing sensors in various low earth orbits augmented by high spatial resolution geostationary sensors (Dekker *et al.*, 2017).

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