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

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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, which is currently on-going and SpaceTec Partners are leading 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. 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 band 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 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, which is currently on-going and SpaceTec Partners are leading the requirements gathering activity. 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 brief summary in section 2 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:

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

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.

Application domain: Inland waters, Coastal waters
How up to date are the requirements: 2016
Considered future missions: Sentinel-2

References

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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 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.
- **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.

Application domain: Inland waters, Coastal waters
How up to date are the requirements: 2016
Considered future missions: Sentinel-2
References

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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.

References

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2.2.2. Requirement: 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 (>0.5km^2), 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).
- Additional 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: 2016
Considered future missions: Sentinel-2

3. Conclusion

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 also needed for the determination of water quality parameters such as the concentration of chlorophyll-a, total suspended matter, yellow matter and cyanobacteria blooms. Considering the needs of the end-users to monitor inland waters and coastal zones covered by international directives (e.g. Water Framework Directive) in terms of spectral, temporal and spatial resolution of Earth Observation data it was is suggested to use: 1) Hyperspectral global mapping for measuring freshwater aquatic ecosystems and 2) geostationary platforms for water color radiometry sensor for observations over the European Continent.