EGU General Assembly 2020
GI4.4: Sensors networks, instrumentation and measurements for water and climate
Co-organized by HS1.1

In-Situ Validation of Water Quality Algorithms and Monitoring of Irish Lakes using Sentinel 2 Imagery

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1. Abstract

Through the Remote Sensing of Irish Surface Water (INFER) project, we validated the algorithms to infer lake water quality using Sentinel 2 imagery, which comprises two European Space Agency (ESA) terrestrial satellites with a combined temporal resolution of 5 days. The project is focused on selection of optimal algorithms that will be applicable in regional context in relation to the high cloud cover and relatively small sizes of the water bodies involved. C2RCC and ACOLITE processors were used to compute the chlorophyll and turbidity from identified lakes. Field radiometry tasks were carried out using a TRIOS RAMSES radiometer. Standard field procedures were employed for acquiring glint free reflectance from the water bodies. Based on the validation with field data, a coupled technique was developed to atmospherically correct and compute water quality parameters.

2. Introduction

The Remote Sensing of Irish Surface Water (INFER) project focuses on the application of earth observation data for fresh and transitional waters in Ireland. The main objective of the study is to develop a processing chain that will help to establish remote sensing as a complimentary tool for environmental monitoring.

The study employed historical field samples to determine the best practices for sampling in order to optimize the temporal and spatial matchups. Historical data collected from the 11 lakes, which had field bathymetry survey data, were analysed to determine the influence of environmental conditions on the quality of samples. Based on the analysis, recommendations to collect field samples from areas deeper than 10 m and 30 m away from the shoreline were provided in order to avoid the reflectance from the bottom and the surrounding topography. A site selection process was undertaken during the spring of 2019 to shortlist appropriate sites for field validation of satellite-derived products. A total of 6 lakes were sampled for field validation based on several criteria such as size, depth, trophic status and EC Water Framework Directive (WFD) status. In addition, a timetable for proposed sampling was established by drawing up a schedule of satellite overpasses starting from summer of 2019.

Altogether 75 samples with chlorophyll (Chl-a) concentration and field transparency measurements were recorded as shown in Figure 1. The Sentinel 2 (S2) archive was scanned for cloud-free views of the sampled location. Considering the fast-changing weather conditions of Ireland, it was difficult to obtain the exact overlap between the S2 overpass and the field sampling. The target was to get the scene with a minimum number of days, but only 59 data points were used and the rest were discarded as no corresponding clear scenes were found. Figure 2 shows that almost half of the data had the same day acquisition whereas 75% of the data points had corresponding acquisition within two weeks.

Field radiometry was conducted using a TRIOS RAMSES radiometer from late 2019 to early 2020. The current procedure entails collection of reflectance data from the lakes during S2 overpass to minimize the potential error in the atmospheric correction. Altogether 6 data points from 4 different lakes were collected. Glint free measurements were collected using the techniques described by Kutser et al. (2013). Table 1 shows the detailed information regarding location and dates. The days of field radiometry were carefully planned based on S2 overpass and local weather conditions.

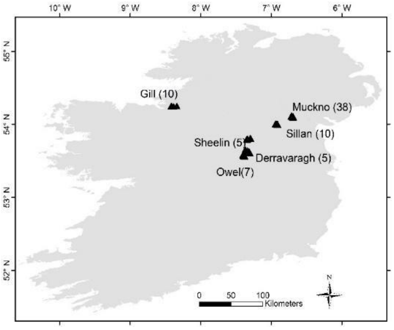

Figure 1: *Sampled lakes with total number of samples for each lake.*

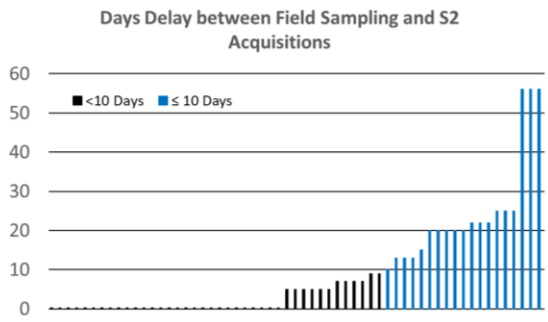

Figure 2*: Days delay between the field sampling and S2 acquisitions for 59 field samples. Almost half of the data points had acquisition within the same day.*

Table 1*: Field radiometry locations and dates.*

SN	Name	Lat	Long	Date
1	Owel	53.5657	-7.3850	18/09/2019
2	Sillan	54.0068	-6.9273	20/09/2019
3	Gill	54.2529	-8.3725	19/01/2020
4	Muckno	54.1032	-6.6956	09/12/2019
5	Muckno	54.1032	-6.6956	26/08/2019
6	Muckno	54.1032	-6.6956	14/11/2019

3. Methods

Acolite and C2RCC processors were used to perform atmospheric correction and the computation of water quality parameters. The data collected from field sampling and radiometry were analysed and compared with the results obtained using a water quality processor on the satellite data. Figure 3 shows the detailed breakdown of the steps followed to identify the best workflow for the project. For atmospheric correction, a dark spectrum fitting technique (Vanhellemont and Ruddick, 2018; Vanhellemont, 2019) was applied in Acolite whereas neural network based technique (Brockmann et al., 2014) was used in C2RCC processor. Within the Acolite processor, different algorithms were analysed and finally the red edge algorithm by Gons et al. (2002) was selected for processing Chl-a (mg/m^3). Similarly, the algorithm developed by Nechad et al. (2009; 2010) was used for turbidity (FNU) computation using Acolite.

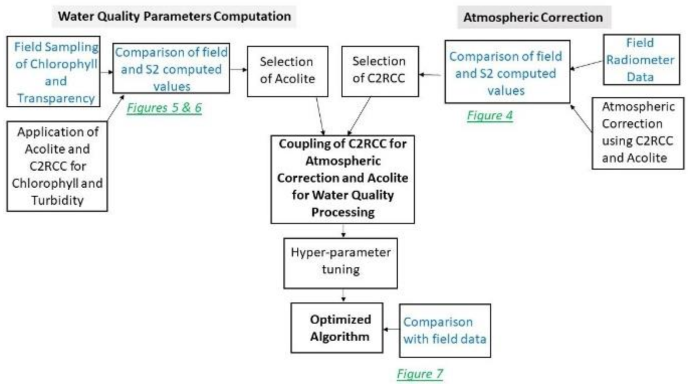

Figure 3: *Steps adopted to develop the optimized algorithm.*

4. Results and Discussions

The comparison of the field and satellite derived results showed the C2RCC algorithm providing better estimates after the atmospheric correction. Figure 4 shows that the atmospheric correction results from C2RCC were closer to the glint free measurements from the field.

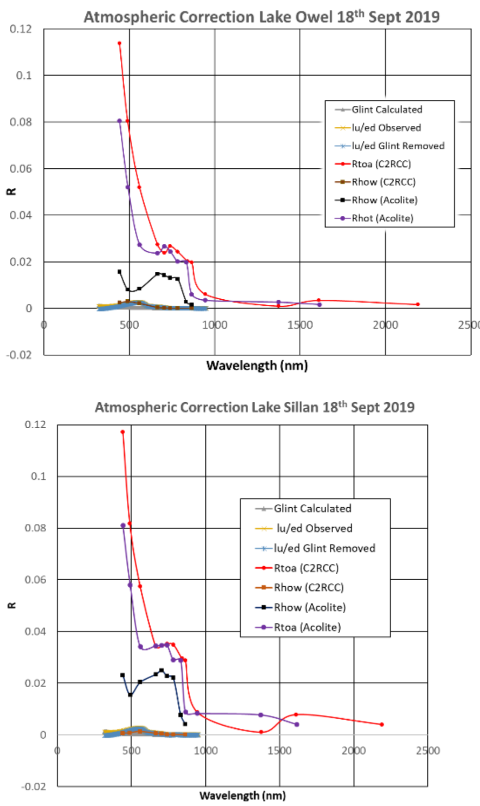

Figure 4: *Comparison of atmospheric correction results and field radiometer data for Lake Owel and Lake Sillan.*

Similarly, the S2 derived water quality results were compared with those measured from the field where the results from the Acolite processor showed better approximation than those from C2RCC. The sets of trained neural network used in the model for case 2 water may explain the better performance of C2RCC regarding atmospheric correction but not for the water quality parameters. Figures 5 and 6 show the comparison of results from both processors for turbidity and Chl-a. Based on the overall results, the coupled approach was developed where the atmospheric correction was done using the C2RCC and the water quality parameters were computed using the techniques adopted in Acolite processor (Chl-a: Gons et al., 2002; turbidity: Nechad et al., 2009 and 2010). The parameters were tuned in the coupled algorithm to better reflect the field measured samples. The results from the final algorithm are presented in Figure 7.

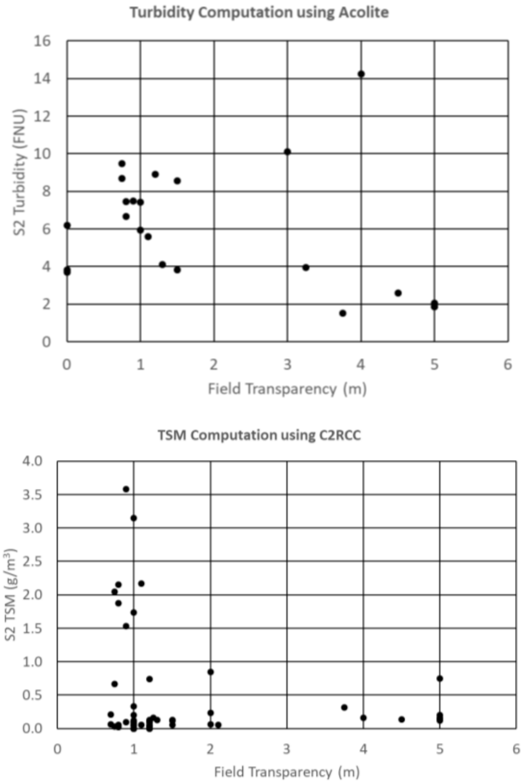

***Figure 5**: Turbidity (FNU) and TSM (g/m^3) computation results from Acolite and C2RCC respectively. C2RCC shows the overall underestimation of values.*

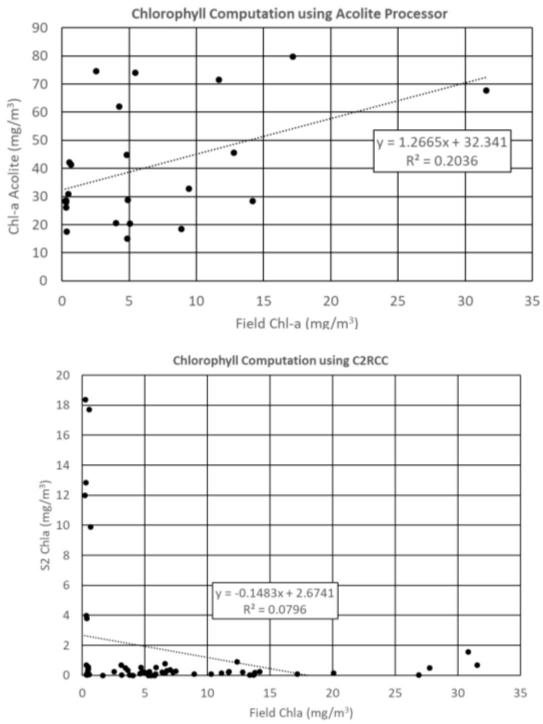

***Figure 6**: Chla (mg/m^3) computation results from Acolite and C2RCC respectively. C2RCC shows the overall underestimation of values.*

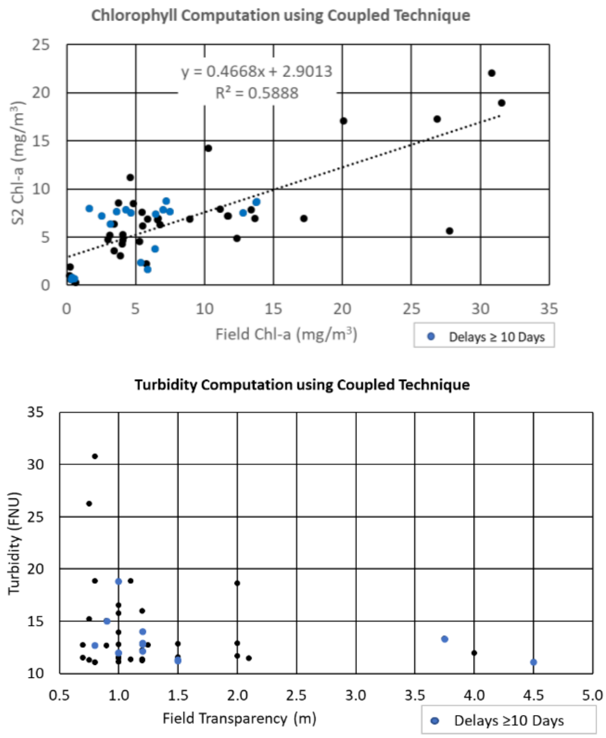

***Figure 7**: Chl-a (mg/m^3) and Turbidity (FNU) computation results from coupled technique. Delays higher than 10 days are shown in blue.*

5. Conclusions and Future Works

We optimised and validated the atmospheric correction and water quality processor for fresh and inland fresh waters in Ireland with the help of field collected data. The coupled algorithm can be applied to compute turbidity and chlorophyll using S2 images. Currently the work is underway to collect and validate the data from coastal waters. After the validation and application of the algorithms for coastal water bodies, the algorithm will be adapted further to incorporate estuaries and bays. The final product of this project is the web platform with the access to S2 derived water quality products for Ireland. This will promote the use of earth observation data for inland water quality monitoring and would enable sustainable utilization of the water resources.

Competing interests: The authors declare that they have no conflict of interest.

Acknowledgements: This project (Remote Sensing of Irish Surface Waters (*2017-W-MS-30*) is funded under the EPA Research Programme 2014-2020. The EPA Research Programme is a Government of Ireland initiative funded by the Department of Communications, Climate Action and Environment. It is administered by the Environmental Protection Agency, which has the statutory function of coordinating and promoting environmental research.

Author contributions: SK, JH, CD and MA completed the remote sensing part of the research. KF, VM, EJ and VV completed the sampling, field work and analysis. AG and AM managed and supervised the project. CD and VM secured the funding for the project.

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