WISPSTATION: A NEW AUTONOMOUS ABOVE WATER RADIOMETER SYSTEM

Steef Peters, Marnix Laanen, Philipp Groetsch, Semhar Ghezehegn, Kathrin Poser, Annelies Hommersom, Esther De Reus, Lazaros Spaias

Steef Peters, peters@waterinsight.nl, Marnix Laanen, laanen@waterinsight.nl, Philipp Groetsch, groetsch@waterinsight.nl Semhar Ghezehegn, ghebrehiwot@waterinsight.nl, Kathrin Poser, poser@waterinsight.nl, Annelies Hommersom, hommersom@waterinsight.nl, Esther de Reus, deReus@waterinsight.nl, Lazaros Spaias, Spaias@waterinsight.nl.

Abstract

A new autonomous above water radiometer system (WISPstation) was developed based on the experience with the handheld WISP-3 system. The instrument records radiance and irradiance with an extended wavelength range of 350 to 1100 nm in two viewing directions, which enables continuous and autonomous high-quality measurements for water quality monitoring and satellite validation. All channels are measured with a single spectrometer and an optical multiplexer. This design makes resulting remote sensing reflectances less sensitive to radiometric and spectral calibration errors and drifts. In various Copernicus projects (TAPAS, EOMORES and MONOCLE) the WISPstation is being tested in highly diverse water types and environmental conditions, ranging from case-1 in Mediterranean coastal waters to turbid waters with cyanobacteria proliferation in lakes and lagoons. In view of its initial scientific application, the system is designed to reliably produce high frequency observations to quantify variability in physical and biological water system parameters. The WISPstation results are stored in the online database WISPcloud allowing users to extract data for analysis. A web interface is being set up to visualise the measurements. We present spectral results and time series analysis for various locations.

Introduction.

Regular monitoring of water quality is an obligation in several directives of the European Union (Water Framework Directive, Bathing water directive, Marine Strategy, etc and important in many local, regional and national monitoring frameworks. With climate change and population increase, concerns are raised that clean water may become scarcer. Erratic precipitation and global warming may lead to serious water quantity and quality problems. Processes like eutrophication, turbidification and proliferation of cyanobacterial blooms can be witnessed more frequently and on a larger scale than ever before. Due to the dynamic nature of water movement and quality in the areas where the dependency on this natural resource is the highest (coastal areas, inland waters) frequent monitoring is a challenge. To understand these processes on a global scale, innovative monitoring techniques are proposed based on e.g. optical remote sensing (Dekker&Pinnel, 2018). Since satellite images have still infrequent temporal coverage (obstruction by clouds, overpass restrictions), additional monitoring strategies are required. Because the satellite derived reflectance- and water quality products need calibration, it is important to have match-up reflectance data collected at the surface. Based on the experience with the handheld WISP-3 system (Hommersom et al, 2012) it was clear that the optical measurement techniques imbedded in the WISP-3 system make it suitable for both satellite validation studies and direct -on the spot- measurements of water quality parameters. Many (potential) clients have additionally requested a fixed position instrument because that would allow to measure semi-continuously without going out in the field. Water Insight has developed such a fixed position autonomous optical measurement device, the “WISPstation”.

Characteristics of the WISPstation instrument

Several essentially different viewing geometry designs for above water optical systems have been proposed such as:

a) The sun-following design with one-radiometer (Seaprism, (Zibordi et al., 2009)), or with 3 radiometers, Dalec: (Brando et al., 2016))
b) The one viewing angle 2 radiometers system with the Lup sensor under water ((Lee, Ahn, Mobley, & Arnone, 2010))
c) The two (or more) fixed viewing angles system (Wernand, 2002, Tilstone et al., 2002)

Basis for designs a) and c) are the considerations by (Mobley, 1999), namely azimuth angle is optimal around 138 degrees from the sun, Lup angle is around 42 degrees from the nadir and Lsky angle is around 42 degrees from the zenith. With varying geometry, Mobley proposes a table of coefficients to account for surface reflections at various wind speeds and solar position.

The WISPstation is based on a modification of the Wernand design using two sets of sensors looking NNW and NNE instead of NW and NE. It should preferably be installed looking in a northward direction (on the Northern hemisphere) providing two optimal viewing geometry moments during the day and a large time window with acceptable viewing geometries that can be accounted for. The advantage of a fixed system with two viewing directions is that there are no moving parts, robots etc. which makes the system less costly, better to maintain and less prone to malfunctions.

In total the WISPstation features 8 channels:

- 2 Radiance channels collecting Lup and Lsky in the NNW direction
- 2 Radiance channels collecting Lup and Lsky in the NNE direction
- 2 Irradiance channels
- 1 unexposed dark radiance channel for evaluation of radiance channel degradation
- 1 unexposed dark irradiance channel for evaluation of the degradation of irradiance channels

All channels are connected to the central spectrometer by means of optical fibres and an optical multiplexer. The advantage of this design is, amongst others, that any variability or degradation of the sensitivity of the spectrometer is compensated in the calculation of remote sensing reflectance. A regular measurement cycle where each channel is measured 10 times at an optimal integration time takes usually less than 1 minute depending on ambient light conditions. The system is calibrated relative to a reference instrument. The reference instrument is calibrated in a certified laboratory using a lamp and integrating sphere with NIST traceable calibrations.

The WISPstation is water tight and built into a highly climate resistant case. Temperature of the sensor and humidity in the case is registered along with every measurement. Data are transmitted to the database (“WISPcloud”) autonomously through a cellular connection. The instrument can be remotely accessed and e.g. updated or configured to a specific time interval or measurement frequency. It is autonomously powered by a solar panel and internal large battery.

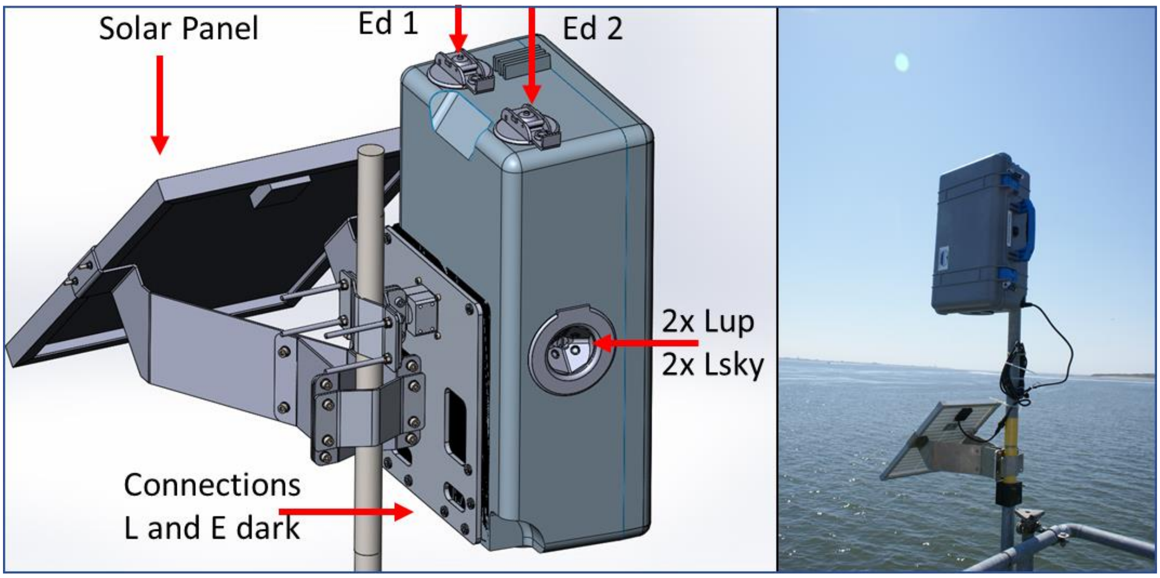

Figure 1: Layout and installation of a WISPstation

Currently the WISPstation is built around the Avantes Mini mk-1 spectrometer with a maximum wavelength range between 220 and 1100 nm. The grating has 300 lines per mm with a blaze of 300 nm. Together with a slit of 100 um this leads to a spectral resolution (FWHM) of 4.65 nm. Stray light is reported to be lower than 0.2%. The WISPstation spectral characteristics are to some extent configurable. The Avantes Mini is a rugged spectrometer designed for use outside of laboratories. Serial production by assembly robots warranty very small differences between instruments. While the standard measurement frequency is set to once per 15 minutes, it can be increased to once per two minutes if required, e.g. in intervals around satellite overpasses.

A scalable Postgres database (WISPcloud) is available to autonomously receive and store all measurements, to perform quality control, to apply water quality algorithms and to serve data requests directly to customers through an advanced API. Work is in progress to provide access to the data through e.g. a Jupyter notebook. Internal quality control procedures are increasingly being put into place to identify and flag sub-optimal measurements.

Currently glint correction is handled in a basic way (fixed $\rho sky = 0.028$), the results of research into advance options for glint correction (Groetsch et al.,2018) will be implemented soon.

For water quality monitoring purposes, the remote sensing reflectance observations are run through some standard water quality algorithms to make a first estimate of Chlorophyll-a (, TSM, CPC and kD

First Measurements results

The WISPstation has been placed in a number of locations in the framework of the European projects Tapas, EOMORS and Monocle. The sites feature extremely various water types:

WISPstation001: Lake Trasimeno Italy

WISPstation002: A Dutch North Sea station

WISPstation003: Lake Loch Leven, Scotland

WISPstation004: A bay near Chania on the island of Crete

WISPstation005: Lake Võrtsjärv in Estonia

WISPstation006: Halfway the Curonian lagoon in Lithuania

WISPstation007: At the inlet of the Curonian Lagoon near Klaipeda, Lithuania

This number of demonstration locations will be expanded to about 10 in 2018. The most recent Rrs spectrum of all instruments can be seen at the home page of our website (www.waterinsight.nl, scroll down). An example of how the Rrs spectra at the test locations look like is given in Figure 2.

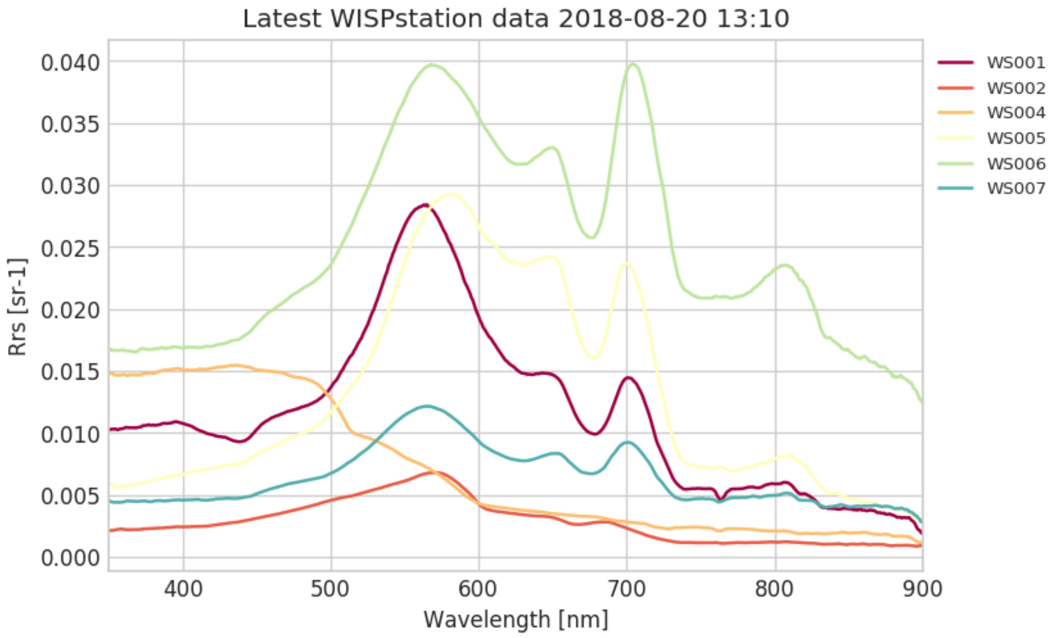

Figure 2: Example of WISPstation Rrs observations at test locations.

As can be seen from figure 2, the water types at the test locations vary from clear blue water (WS004) to turbid water with significant Chl-a and CPC concentrations (WS006). For comparison purposes the current implemented algorithms for Chl-a, TSM, CPC and kD are the same as implemented for the WISP-3 system (Hommersom et al., 2012). An example of how a time series of Chl-a looks like is given in Figure 3.

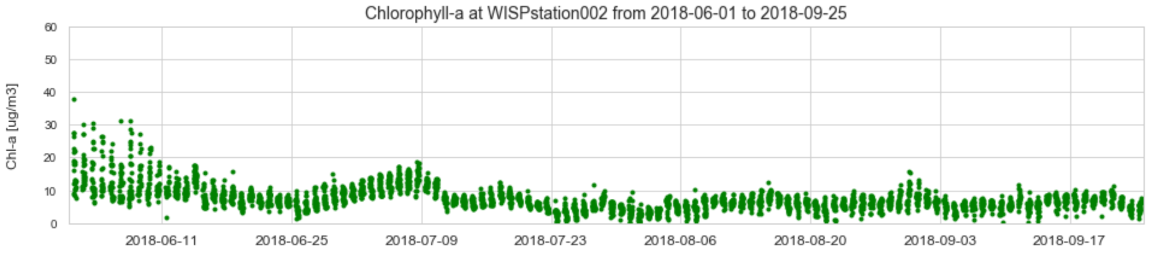

Figure 3: Chlorophyll-a measurements at a North Sea coastal station.

From concurrent studies it is known that the Chl-a algorithm produces reasonable results on this station. This particular station was also used to test sun glint effects on the remote sensing reflectance, so the instrument was purposely facing South. Even under those conditions (Using a fixed $\rho sky = 0.028$) the time series are convincing with a daily variability that could be attributed both to unaccounted variations in the ρsky and to real variations in the Chl-a concentration due to local horizontal and vertical variability. Another example is the time series of TSM in the Estonian Lake (Figure 4).

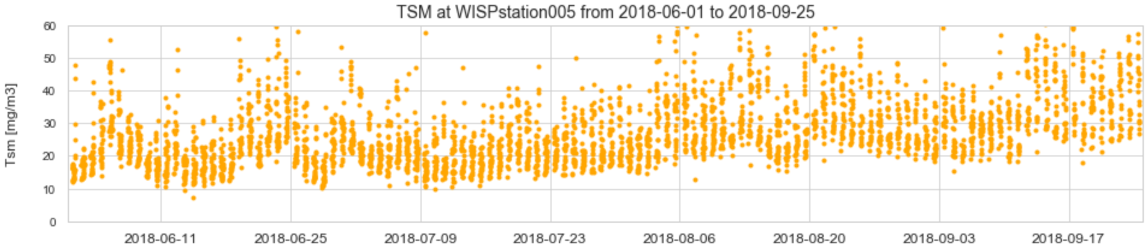

Figure 4: Development of the TSM concentration at WISPstation005.

Using a fixed ρsky probably leads to deviations in the amplitude of the spectrum at lower sun angles, hence the variability in the calculated TSM values. Still the small term variations and the trend wise incline of TSM during summer are already clearly visible.

Conclusions

The WISPstation is a new fixed position, autonomous water optics instrument, suitable for high frequency monitoring of a number of important water quality variables and indicators, and in principle also for satellite validation purposes. For water monitoring it is important to use algorithms that are designed for the specific water types. For satellite validation the requirements set for fiducial reference measurements should be assessed and addressed if necessary.

Acknowledgements:

This study has received funding from the European Union’s Horizon 2020 Research and Innovation programme (grants 730066: EOMORES, 678396: TAPAS, 77648: MONOCLE)

Literature

Brando, V., Lovell, J, King, E., Boadle, D., Scott, R., Schroeder, T. (2016) The Potential of Autonomous Ship-Borne Hyperspectral Radiometers for the Validation of Ocean Color Radiometry Data, Remote Sensing, 2016.

CEOS. 2017. A. G. Dekker and N. Pinnel, editors. Feasibility study for an aquatic ecosystem Earth observing system. Report v. 1.1. Committee on Earth Observation Satellites (CEOS) and Commonwealth Scientific and Industrial Research Organization (CSIRO). CSIRO, Canberra, ACT, Australia.

Groetsch, P.M.; Gege, P.; Simis, S.G.; Eleveld, M.A.; Peters, S.W. Validation of a spectral correction procedure for sun and sky reflections in above-water reflectance measurements. *Opt. Express* **2017**, *25*, A742–A761.

Hommersom, A., Kratzer, S., Laanen, M. L., Ansko, I., Ligi, M., Bresciani, M., ... Peters, S. W. M. (2012). Intercomparison in the field between the new WISP-3 and other radiometers (TriOS Ramses, ASD

FieldSpec, and TACCS). Journal of Applied Remote Sensing, 6, 06315-1-06315-21. DOI: 10.1117/1.JRS.6.063615

C. D. Mobley, “Estimation of the remote-sensing reflectance from above-surface measurements,” Appl. Opt. 38(36), 7442–7455 (1999), http://dx.doi.org/10.1364/AO.38.007442.APOPAI0003-6935

Tilstone, G. and G. Moore, eds. REVAMP Regional Validation of MERIS Chlorophyll products in North Sea coastal waters: Protocols document. 2002

Wernand M.R. Guidelines for (Ship-Borne) Auto-Monitoring of Coastal and Ocean Colour. In: Ackleson S.G., Trees C., editors. Proceedings of Ocean Optics XVI; Santa Fe, NM, USA. 18– 22 November 2002; http://melia.nioz.nl/phptoweb/colors/documentation/colours38.htm

ZhongPing Lee, Yu-Hwan Ahn, Curtis Mobley, and Robert Arnone. (2010). Removal of surface-reflected light for the measurement of remote-sensing reflectance from an above-surface platform. OPTICS EXPRESS. 6 December 2010 / Vol. 18, No. 25 / 26313-26324

Zibordi, G., Holben, B., Slutsker, I., Giles, D., D’Alimonte, D., Melin, F., Berthon, J.-F., Vandemark, D., Feng, H., Schuster, G., Fabbri, B. E., Kaitala, S., and Seppala , J.: AERONET-OC: a network for the validation of Ocean Color primary radiometric products, J. Atmos. Oc. Technol., 26, 1634–1651, 2009