AUTOMATIC ASSESSMENT OF LAKE STATUS USING AN OPEN SOURCE APPROACH: LAKE LUGANO'S CASE STUDY

Daniele Strigaro[a,b]*, Massimiliano Cannata[b], Camilla Capelli[b], Fabio Lepori[b]

[a] Department of Earth and Environmental Sciences (DSTA), University of Pavia
Via Ferrata 9, 27100 Pavia, Italy - daniele.strigaro01@universitadipavia.it
[b] Institute of Earth Sciences, DACD, University of Applied Sciences of Southern Switzerland (SUPSI)
Via Flora Ruchat-Roncati 15, CH-6850 Mendrisio, Switzerland - (massimiliano.cannata, camilla.capelli, fabio.lepori)@supsi.ch

Commission IV, WG IV/4

KEY WORDS: istSOS, SIMILE, SOS, open source, lake, open standard

ABSTRACT:

Climate change and human activities are increasingly threatening water resources. In particular sub-alpine lakes are fundamental not only for tourism or other economical activities, but also as a source of water. In this context, there is a strong need to monitor such resources to understand, study and react to known and unknown impacts, so that appropriate mitigation actions can be taken. Unfortunately, although monitoring data already exist for many of these lakes, the information is archived in different formats and servers undermining the full exploitation of data and preventing a more efficient data management. The aim of this work is to improve this situation by implementing a system that integrates and standardizes data coming from different sources. In addition, the system integrates web based tools that estimate lake state indicators using open source software and standard. Thanks to this system, it will be possible to exploit the data potential more fully. This paper focuses on the achievements reached by the research carried out on Lake Lugano in the context of the project SIMILE after two years of work.

1. INTRODUCTION

Lakes are a fundamental resource that provide a number of environmental benefits and services to the local economy and the quality of life. For example, they can store water, protecting floodplains from floods and supplying water during droughts. In addition, they help recharge aquifers (Cannata et al., 2018) and support biodiversity. From an economic point of view, they attract tourism and provide recreational and professional opportunities to residential populations. Unfortunately, climate change and other human impacts are threatening the general health status of lakes and the services they provide (Fenocchi et al., 2018, Free et al., 2021, Lepori et al., 2018). In this context, monitoring can play a key role in the preservation of lakes, in particular by providing insights that could promote timely mitigation actions. Lakes Lugano and Maggiore are two large transboundary Swiss-Italian lakes. They are systematically monitored by both Italian and Swiss administrative agencies. Lake Lugano, the case study chosen for this work, has been monitored since the early 80s with limnological campaigns being performed every two weeks in three stations: Gandria, Melide and Figino. As a result, for some parameters, 40 year old time-series are now available. These series provide a precious set of data to investigate trends and changes over time. During last years, limnologists have been additional 'non-traditional' methods to measure lake parameters, often with the goal of increasing the spatial and temporal resolution. For example, remote sensing techniques permit to gather indirect information of many lake properties, i.e. water transparency, surface Chlorophyll-a concentrations, water temperatures, etc. (Dörnhöfer and Oppelt, 2016). However, remote sensing has intrinsic limits in temporal resolution (Sagan et al., 2020). The Internet of Things (IoT) revolution (Kumar et al., 2019) and the increasing availability of sensors and low powered Microcontroller allow to build custom, low-budget solutions to measure lake properties using in situ, fixed, high-frequency monitoring systems. Such systems can improve the temporal resolution of the data, which is necessary to quantify highly-dynamic phenomena such as algal blooms (Marcé et al., 2016). This scenario highlights how many data sources could potentially be available to better study lake ecosystems. Unfortunately, for Lake Lugano, a unique, integrated automated monitoring system is still missing. At present, monitoring data is stored in local databases and in different formats, which undermines the full exploitation of the data and prevents a more efficient data management. Therefore, we identified a need to improve data interoperability and standardization, as well as to create a unique digitalized archive for all the available information. This paper presents the main achievements of two years of research aimed a standardizing and homogenizing data from Lake Lugano. The work was carried out in the context of the SIMILE project (System for the Integrated Monitoring of Insubric Lakes and their Ecosystems). The specific objective is to improve data interoperability by developing a system that integrates and standardizes data coming from different sources. The system will facilitate the use of the data by implementing a web based tool to calculate and display a set of key lake indicators using open source software and standard. The INTERREG project SIMILE, born from a collaboration between Italy and Switzerland, aims at developing an information system using an open source approach and innovative technologies to help decision makers in the management and evaluation of the status of the transboundary and sub-alpines lakes such as lakes Maggiore, Lugano and Como. To this end, the SIMILE project intends to intensify the monitoring of these lakes by implementing an open real-time monitoring system. In addition, it will promote the use of data from satellite and citizen science in order to increase the monitored properties of the lakes. Ulti-

* Corresponding author

mately, SIMILE aims at helping decision makers by integrating data coming from different sources and offering a single access to the elaborated information.

2. MATERIALS AND METHODS

2.1 Study area

Lake Lugano is a transboundary lake divided into two main basins, North and South, with an area of 27.5 Km^2 and 21.4 Km^2 and a maximum depth of 288 and 95 m, respectively. Lake Lugano was severely affected by eutrophication, which reached a peak in the 60s-70s. Thanks to an ongoing restoration programme, the state of the lake has been improving, and the current trophic state ranges between meso- and eutrophic.

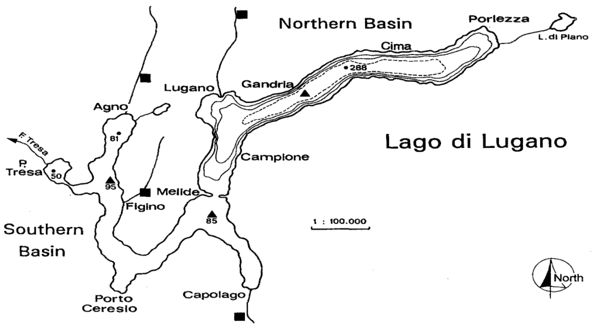

Figure 1. Lake Lugano map (Barbieri and Polli, 1992).

2.2 Data sources

The monitoring data available for Lake Lugano are collected in the South basin using three methods (see Figure 2). The first entails the use of multi-sensor CTD probes that are periodically (monthly or bi-monthly) lowered to the bottom of the lake. These sensors measure physical parameters such as water temperature, dissolved oxygen, conductivity, etc. (e.g. IDRONAUT 316 Plus or IDRONAUT 306) or derive biological information, as in the case of fluorimeter sensors, which use visible spectrum fluorescence to estimate algal biomass. The second method is based on the collection of water samples at discrete depths using Niskin bottles. The samples are then analysed in laboratory for an array of chemical and biological variables. The third method is based on a monitoring platform, i.e. an Automatic High Frequency Monitoring (AHFM) system mounted on a platform of 2.5 x 2.5 m deployed in the South basin corresponding to the maximum depth. The system was developed during last two years in the context of the project SIMILE. The AHFM system collects real-time data at different depths and with a frequency of 10 minutes (raw data have a frequency of 1 minute, but then they are aggregated every 10 minutes after performing a quality test on each observation). The AHFM system is composed by:

- six optical sensors (OPTOD by Ponsel) to measure water dissolved oxygen (mg/L and %) and temperature (°C) positioned at 0.4, 2.5, 5.0 , 8.0 ,12.5 and 20.0 meters depth;
- four fluorimeters (UNILUX by Chelsea Technologies) to measure Chlorophyll-a and Phycocyanin concentrations (µg/L). Two sensors are positioned near the surface at 0.4 meter depth and the other two at 10 meter depth;

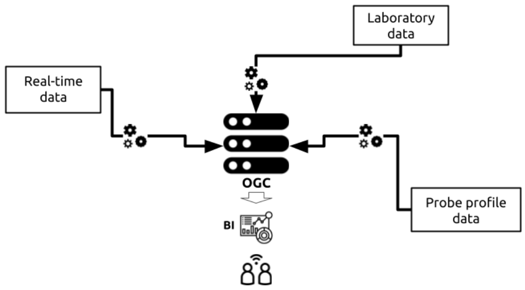

Figure 2. Graphical representation of main data sources available for Lake Lugano.

- a compact weather station (WS501 by Lufft) to measure air temperature (°C), relative humidity (%), pressure (hPa), wind velocity (m/s) and direction (°) and solar radiation (W/m^2).

Additional data are further elaborated to derive indexes of lake status (biovolume, LTECO and IPAM indexes).

Unfortunately all these data are currently archived in heterogeneous formats and databases (see Figure 3) and are archived in different servers, handled by respective administrative entities (SUPSI, ARPA, CIPAIS).

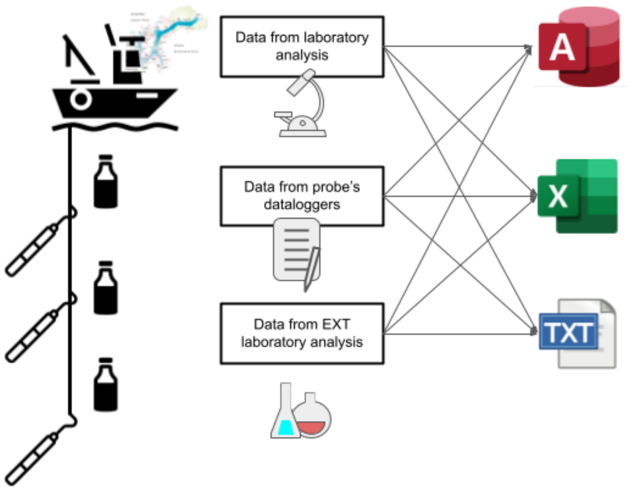

Figure 3. Data formats used to archive the historical data of Lake Lugano.

2.3 The information standardization

The missing in-data standardization is a critical issue because it highlights the current lack of data format uniformity, interoperability, ontology as well as an error-prone process, because data are accessible from different sources and a proper synchronization is missing. To fix these problems, international standards are available. They offer a solution to improve data homogenization and standardization (Giuliani et al., 2019, Liang et al., 2021). In environmental monitoring, the Sensor Thing API and the Sensor Observation Service of the Open Geospatial Consortium (OGC) are widely used. The first is strongly oriented to provide an open and unified framework for IoT devices interconnection (OGC SensorThings API Part 1: Sensing, Version 1.0., n.d.) using JSON format. The second is a standard structured and based on XML format. It encodes sensor metadata using the Sensor Model Language (SensorML), and measured values in the Observations and Measurements (O&M) encoding format (Bröring et al., 2012). The istSOS software has been selected to manage data according to the SOS standard since it is already used in production for the management of the data coming from the Hydro-Meteorological network of Canton Ticino Switzerland (Cannata et al., 2015). istSOS allows to standardize the ontology of the observed properties and of the unit of measures. In addition, the definitions of common data quality flags/codes improved the use of the software to indicate the quality of the observations inserted. In fact, when quality tests are performed on the data, the software allows to associate the observations to a flag that indicates which tests have been performed (Tiberti et al., 2021). In order to facilitate the import of historical data, a tool was implemented to extend the capabilities of istSOS (Figure 4). The importer tool, written in Rust, can decode a text file format and then permits to compile a web form to correctly individuate the data and columns. This tool takes advantage from the WebAssembly paradigm, that almost all browsers support. Hence, it is possible to run a script written with low level language directly on the client without using any server side process. Enabling the software user interface to interpret a WebAssembly script means to permit an easy expansion of the capabilities. It also increases the performance of running scripts written with low level language.

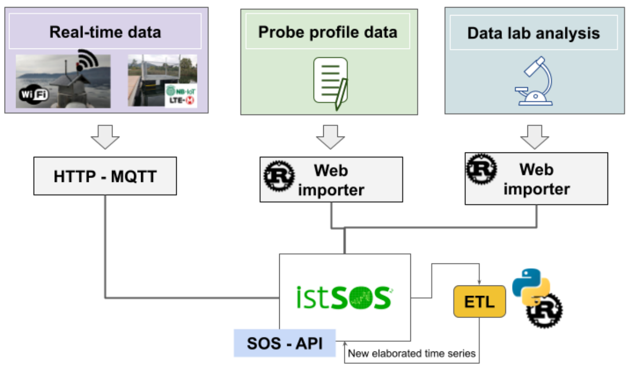

Figure 4. Data importing into istSOS.

2.4 Automatic Data elaboration

For monitoring the lake's health status, istSOS has been extended by enabling the possibility to write additional scripts, written using the Python programming language, that the software treats as plugins. Such scripts can retrieve observations using SOS standards or web API in order to extrapolate new time series by combining the already registered procedures with custom algorithms. To this end, a YAML configuration file must be structured to provide metadata explaining what the script does and describe the input data needed by the algorithm from which the web user interface can automatically generate a web form. Thanks to this new feature two main plugins were developed: Lake Analyzer and Data Analyzer plugins. The first is based on the LakeAnalyzer software (Read et al., 2011), which originally written in MatLab, a tool that allows to calculate common metrics for lake physical states. Hence, some of these functions were translated into Python in order to better integrate the plugin in istSOS, which uses Python, and to offer software based on an Open Source language. In table 1, the functions developed at the moment of writing the article are listed along with the requested data inputs.

Schmidt stability Schmidt stability is an indicator of the resistance, or the stability, of a lake in terms of amount of work required to mix the water column uniformly over depth. The algorithm was theorized by Schmidt (Schmidt, 1928) and was improved and modified by Hutchinson and Idso (Hutchinson, 1957, Idso, 1973). The result is a mixing energy required per unit area.

Name	Main data inputs
Schmidt stability	Water temperature profile; Bathymetry; Salinity
Epilimnion temperature	Water temperature profile; Bathymetry;
Thermocline depth	Water temperature profile; Minimum density gradient; Mixed cut-off
Buoyancy frequency	Water temperature profile
Water density	Water temperature profile; Water salinity profile; Salinity
Water density (cond)	Water temperature profile; Water conductivity
Metalimnion depth	Water temperature profile; Slope; Seasonal; Mixed cut-off
Mixed depth	Water temperature profile
Volume aggregation	Water parameter profile; Depths-Volumes values

Table 1. List of functions available on the Lake Analyzer plugin.

Epilimnion temperature In a stratified lake, the epilimnion is the top layer which has a nearly uniform temperature. The function developed within the LakeAnalyer plugin permits to calculate the average temperature from a profile of temperatures and the lake's bathymetry.

Thermocline depth The depth at which the downward change in temperature or density is greater than predefined thresholds (e.g. a rate of 0.5°C per meter) can be defined as the thermocline. Basically, it is the horizontal plane passing through the point of greatest change along a temperature or density vertical profile. The function adopted here uses the first derivative of the water density profile to estimate the thermocline depth.

Buoyancy frequency The buoyancy frequency, also called Brunt–Väisälä frequency, is a measure used to evaluate the stability of a fluid to vertical displacements such as those caused by convection. It can be calculated as in eq. 1 where g is gravity, i is depth, and ρ is water density.

$$N^2 = \frac{g}{\rho_i} \frac{(\rho_{i+1} - \rho_i)}{(d_{i+1} - d_i)} \tag{1}$$

Water density Temperature and substances dissolved in water influence the water density and so the capacity of a lake to be stratified or mixed. Therefore, water density is important to understand the physical dynamics of the lake. This function calculate the water density in Kg/m3 using Martin and McCutcheon's method (Martin and McCutcheon, 1999) or the one

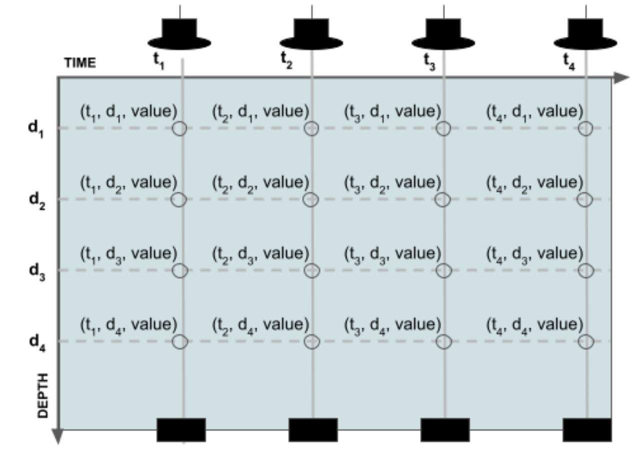

Figure 5. Schema of the profile type data composed by timestamp (t_n), depth (d_n) and value.

suggested by UNESCO (Millero and Poisson, 1981) which is mostly used for seawater.

Metalimnion depths In a stratified lake, the metalimnion is the transition layer between the epilimnion and the hypolimnion. It is characterized by the steepest thermal gradient (Wetzel, 2001). The function of this plugin permits to calculate the top and bottom depths of the metalimnion with correspond respectively to the bottom of the epilimmnion and the top of the hypolimnion.

Volume aggregation This function calculates a weighted average along a water profile based on the volume of a water layer thickness (eq. 2). It allows to assign different weights to data at various depths.

$$\frac{\sum_{d=i}^{N} a_i V_i}{V_{tot}} \tag{2}$$

The second plugin developed regards two main functions: a data aggregator and a data profile creator. The aggregator permits to select a *procedure* and one of its *observed properties* which will then aggregate on the basis of a time interval (ISO8601) and an aggregation function (e.g. AVG, SUM, COUNT, MAX, MIN). The data profile creator allows to integrate into a single *procedure* of type *profile* two or more *procedures* that share same observed properties. For example, the Automatic High Frequency Monitoring system positioned on Lake Lugano is composed by a chain of sensors. Each sensor is registered using a procedure of the type *insitu-fixed-point*, where at a timestamp corresponds to one or more observed properties. Thanks to this plugin, it is possible to create a single *profile procedure* in order to obtain per each timestamp the corresponding values of the *observed properties* at all depths (Figure 5).

Once a function is fired, all the information needed to run the algorithm are archived in the database. When an observation is inserted in istSOS, the PostgreSQL database lunches a notification which is listened by the Python server. Such notification carries information (e.g. the procedure name, the beginning and end time of the observations inserted, etc.) that are useful to recognize which procedures are updated and consequently triggers all the processes that have been created using those observations. Such processes will update the calculated procedure in order to update the values.

3. RESULTS

The open data management system developed in the context of the SIMILE project is composed by a single instance of istSOS where three istSOS services have been created. A *service* is a isolated space with a dedicated database which is potentially independent by other services also in terms of user permissions.

Name	**Description**
air-pressure	Atmospheric pressure (hPa)
air-relative-humidity	Absolute humidity relative to the maximum for that air (%)
air-temperature	Air temperature at 2 meters above terrain (C)
global-radiation	Solar radiation (W/m^2)
water-Chl-a	Chlorophyll-a concentration (μg/L)
water-Neph	Turbidity from Trilux Chelsea technologies (μg/L)
water-O2C	Oxygen concentration (mg/L)
water-O2D	Dissolved oxygen (ppm)
water-O2S	Oxygen saturation (%)
water-PAR	Photosynthetic active radiation (W/m^2)
water-PC	Phycocyanin concentration (μg/L)
water-SDT	Secchi Disk Transparency (m)
water-TSS	Total Suspended Solids
water-cond20	Conductivity at 20 C (μS/cm)
water-cond25	Conductivity at 25 °C (μS/cm)
water-depth	Depth from surface (m)
water-pH	Water pH at a specific depth
water-pressure	Pressure at a specific depth (hPa)
water-temperature	Temperature of water at a specific depth (°C)
wind-direction	Wind direction (°)
wind-speed	Wind speed (m/s)
wind-speed-max	Wind gust (m/s)

Table 2. List of observed properties registered and standardized on istSOS.

A dedicated service, called *ceresio*, has been created to manage all the available historical raw data. It is composed by 26 *procedures* for a total of 22 *observed properties* (Table 2) and more than 2 million *observations*. Part of these observations derive from the raw data of the AHFM system which has a rate of sampling of 1 minute. Such data are gathered during maintenance since data are remotely sent to the server after aggregation. In addition, historical time-series, which come from the campaigns performed on the lake since 1972 till today, have been also imported into *ceresio service*. The second *service*, named *ceresiohourly*, is composed by 12 *procedures* that corresponds to the sensors installed on the AHFM system. The AHFM system transmits to the server 10 minutes frequency data in real-time using a MQTT service every 15 minutes. Such data are, in primis, used to offer an instantaneous overview on the real-time parameters measure on the lake, which in future can be used to detect abrupt phenomena such has algal blooms, but also to check that the AHFM works correctly. In fact, in addition to the environmental parameter already described, observations about current voltage and power are archived in a dedicated *procedure* in order to check the state of the battery and voltages. Finally the last *service*, called *ceresiohourly*, has been created in order to offer data to external services. It comprises hourly aggregated data that thanks to the data aggregator was possible to automatically generate from the real-time data sampled by the AHFM and archived into the procedures registered on *ceresioremote service*. In addition, data from the CIPAIS (International Commission for the Protection of Italian-Swiss Water) annual reports and from ARPA monitoring campaign have been also added to this service in order to offer the public an interactive visualization of such data. A dedicated web user interface will be developed in the context of the project SIMILE. From the integration of the available data sources, it was possible to used the Lake Analyzer web tool in order to calculate indicators. Indicators such as Schimdt stability, Thermocline depth (Figure 7) and Mixed depth are useful to understand the physical status of the lake. For example, in Figure 6 the trend of the thermocline depth is shown. From 1988 until 2019 it is comprises between 0 and 20 m depth and only in 1991 the thermocline reached the 50 m depth. Of course when the lake is totally mixed the thermocline cannot be detected since it does not exist. The mixed depth is available in Figure 7. Since the South basin of Lake Lugano has a maximum depth of about 93 m, it can be highlighted that the water lake was mixed at least every year except for 1988, 2007, 2014, and 2016. In addition to that, the epilimnion depth (see Figure 8, ranged between 5 and 30 m. The seasonal behaviour can be appreciate from the graph. In the figures proposed, the dashboard for technical personnel has been showed. This interface permits to visualize data filtering on procedures, observed properties and time. Basically, two type of visualization are offered, *single stats* where there are available the plots for only one procedures and the mode *compare*, it allows to compare *procedures* with same observed properties.

4. CONCLUSIONS

The proposed paper wants to investigate a fully open web solution in order to calculate indicators that can help understand the health status of the lake and try to solve the limits that are currently affecting water monitoring. Such an open platform uses open standards as the Sensor Observation Service (SOS) of the Open Geospatial Consortium (OGC) to integrate different sources of data and to offer the possibility to gather the information in a standardized way. To this end, istSOS, a Python implementation of the SOS standard, was selected as main data management system since it is open source and demonstrated good performance and stability in a production environment. In fact, it is successfully used to manage the hydro-meteo network of Canton Ticino. Due to the open source nature of this software, it was possible to further extend its capabilities by implementing a system to manage custom scripts and treats them as plugins. In addition, thanks to the WebAssembly technology, it was possible to create an importer application, embedded into the User Interface (UI), to use clients system power to decode text file of profiles data and then trasmit such observations to the istSOS server instance. Thanks to these implemented tools, historical data were integrated into a single data source together with the data coming from the new AHFM system implemented during the project. The AHFM system collects information about temperature, dissolved oxygen, Chlorophyll and Phycocyanin concentrations and weather parameters (wind speed and direction, air temperature, air pressure, air humidity, global radiation). It transmits 10 minute frequency data in real-time every 15 minutes. The data standardization concerns also the ontology as for observed properties and unit of measure. This part was very important since the implemented solution will be adopted by other project partners for handling data of lakes Maggiore and Como. The database shaped by integrating almost all the data available on Lake Lugano support to the fully exploitation of the data for the scientists and researchers. The software is released under the GNU GPL v3 License (https://gitlab.com/ist-supsi/simile/istsos-suite). Due to sensibility of data, historical raw time series are available only upon specific requests. In order to facilitate and offer common methods to calculate basic lake indicators, a module based on the LakeAnalyzer functions was implemented using Python. The scope is to validate and standardize the calculations and providing a common validated tool. The indicators produced using these tools are automatically updated when new observations are inserted into the procedures which were selected in order to make the computations of each indicators. This feature was implemented extending the capabilities of istSOS by implementing a tool which can take advantage of the LISTEN/NOTIFY feature of the PostgreSQL, the database technology on which the platform is based. In conclusion, an overview of the results about the improvements in data interoperability and standardization reached during these years of project were presented. The proposed solution demonstrated how open software and standard can fill the gap in data interoperability and standardization which still is affecting the lake monitoring. Such open technologies helped in developing an automatic system that can calculate indicators to help decision makers in managing the water resource and scientists to better study the new unknown dynamic and facing the new challenges to which lakes are exposed.

ACKNOWLEDGEMENTS

The presented research has been carried out in the context of the SIMILE project (informative System for the Integrated Monitoring of Insubric Lakes and their Ecosystems, ID: 523544), which is funded by the European Commission in the frame of INTERREG Italy-Switzerland 2014-2021 program.

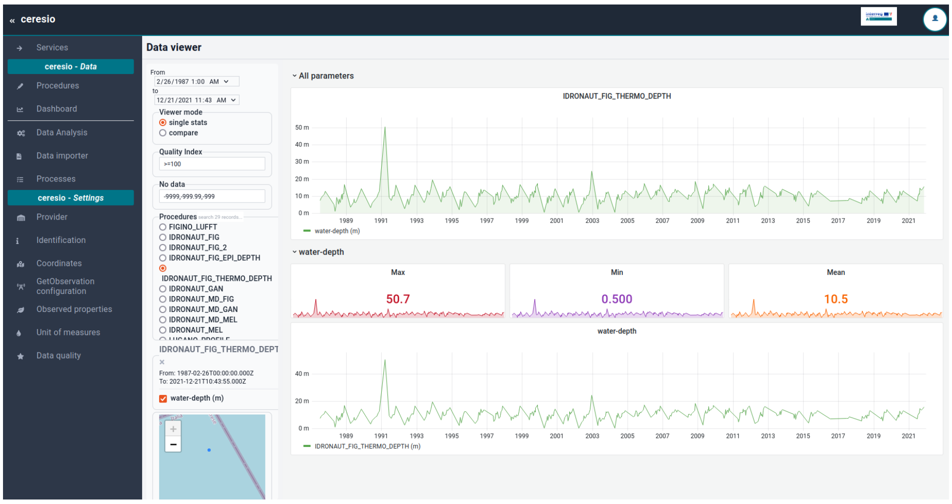

Figure 6. Thermocline depth calculated using the LakeAnalyer web plugin and the monthly data collected by the traditional campaigns, previously standardized and imported into istSOS.

Figure 7. Mixed depth calculated using the LakeAnalyer web plugin and the monthly data collected by the traditional campaigns, previously standardized and imported into istSOS.

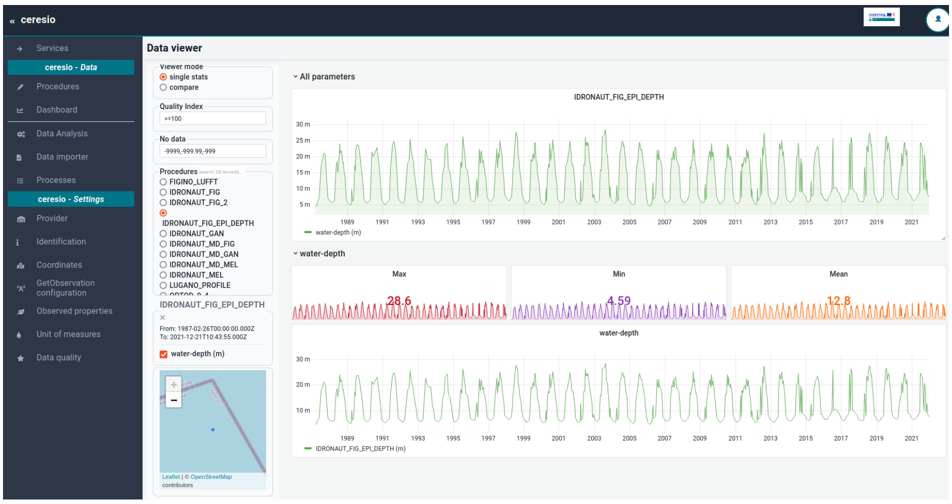

Figure 8. Epilimnion depth calculated using the LakeAnalyer web plugin and the monthly data collected by the traditional campaigns, previously standardized and imported into istSOS.

REFERENCES

Barbieri, A., Polli, B., 1992. Description of lake Lugano. *Aquatic Sciences*, 54(3-4), 181–183.

Bröring, A., Stasch, C., Echterhoff, J., 2012. OGC Sensor Observation Service Interface Standard, Version 2.0. Report, Open Geospatial Consortium.

Cannata, M., Antonovic, M., Molinari, M., Pozzoni, M., 2015. istSOS, a New Sensor Observation Management System: Software Architecture and a Real-Case Application for Flood Protection. *Geomatics, Natural Hazards and Risk*, 6(8), 635–650.

Cannata, M., Neumann, J., Rossetto, R., 2018. Open source GIS platform for water resource modelling: FREEWAT approach in the Lugano Lake. *Spatial Information Research*, 26(3), 241–251.

Dörnhöfer, K., Oppelt, N., 2016. Remote sensing for lake research and monitoring – Recent advances. *Ecological Indicators*, 64, 105-122. https://www.sciencedirect.com/science/article/pii/S1470160X15007141.

Fenocchi, A., Rogora, M., Sibilla, S., Ciampittiello, M., Dresti, C., 2018. Forecasting the Evolution in the Mixing Regime of a Deep Subalpine Lake under Climate Change Scenarios through Numerical Modelling (Lake Maggiore, Northern Italy/Southern Switzerland). *Climate Dynamics*, 51(9), 3521–3536.

Free, G., Bresciani, M., Pinardi, M., Ghirardi, N., Luciani, G., Caroni, R., Giardino, C., 2021. Detecting Climate Driven Changes in Chlorophyll-a in Deep Subalpine Lakes Using Long Term Satellite Data. *Water*, 13(6), 866.

Giuliani, G., Masó, J., Mazzetti, P., Nativi, S., Zabala, A., 2019. Paving the Way to Increased Interoperability of Earth Observations Data Cubes. *Data*, 4(3), 113.

Hutchinson, G. E., 1957. *A treatise on limnology. Vol 1: Geography, physics and chemistry*. John Wiley & Sons.

Idso, S. B., 1973. On the concept of lake stability 1. *Limnology and oceanography*, 18(4), 681–683.

Kumar, S., Tiwari, P., Zymbler, M., 2019. Internet of Things is a revolutionary approach for future technology enhancement: a review. *Journal of Big Data*, 6(1), 111. https://doi.org/10.1186/s40537-019-0268-2.

Lepori, F., Roberts, J. J., Schmidt, T. S., 2018. A Paradox of Warming in a Deep Peri-Alpine Lake (Lake Lugano, Switzerland and Italy). *Hydrobiologia*, 824(1), 215–228.

Liang, S. H. L., Saeedi, S., Ojagh, S., Honarparvar, S., Kiaei, S., Mohammadi Jahromi, M., Squires, J., 2021. An Interoperable Architecture for the Internet of COVID-19 Things (IoCT) Using Open Geospatial Standards—Case Study: Workplace Reopening. *Sensors*, 21(1), 50.

Marcé, R., George, G., Buscarinu, P., Deidda, M., Dunalska, J., de Eyto, E., Flaim, G., Grossart, H.-P., Istvanovics, V., Lenhardt, M. et al., 2016. Automatic high frequency monitoring for improved lake and reservoir management. *Environmental Science & Technology*, 50(20), 10780–10794.

Martin, J., McCutcheon, S., 1999. Hydrodynamics and transport for water quality modeling, Lewis Publishers. *New York*, 1–794.

Millero, F. J., Poisson, A., 1981. International one-atmosphere equation of state of seawater. *Deep Sea Research Part A. Oceanographic Research Papers*, 28(6), 625-629. https://www.sciencedirect.com/science/article/pii/0198014981901229.

OGC SensorThings API Part 1: Sensing, Version 1.0., n.d. https://repository.oceanbestpractices.org/handle/11329/914.

Read, J. S., Hamilton, D. P., Jones, I. D., Muraoka, K., Winslow, L. A., Kroiss, R., Wu, C. H., Gaiser, E., 2011. Derivation of Lake Mixing and Stratification Indices from High-Resolution Lake Buoy Data. *Environmental Modelling & Software*, 26(11), 1325–1336.

Sagan, V., Peterson, K. T., Maimaitijiang, M., Sidike, P., Sloan, J., Greeling, B. A., Maalouf, S., Adams, C., 2020. Monitoring inland water quality using remote sensing: potential and limitations of spectral indices, bio-optical simulations, machine learning, and cloud computing. *Earth-Science Reviews*, 205, 103187. https://www.sciencedirect.com/science/article/pii/S0012825220302336.

Schmidt, W., 1928. Über Die Temperatur- Und Stabili-Tätsverhältnisse Von Seen. *Geografiska Annaler*, 10(1-2), 145–177.

Tiberti, R., Caroni, R., Cannata, M., Lami, A., Manca, D., Strigaro, D., Rogora, M., 2021. Automated High Frequency Monitoring of Lake Maggiore through in Situ Sensors: System Design, Field Test and Data Quality Control. *Journal of Limnology*, 80(2).

Wetzel, R. G., 2001. *Limnology: lake and river ecosystems*. gulf professional publishing.