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Report N°15

Report of the MAREL Carnot station, a high frequency monitoring station in an anthropogenically influenced coastal zone (Boulogne-sur-Mer) – Period 2020-2022.

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Summary

MAREL Carnot station is a high frequency monitoring station installed in the harbour of Boulogne sur Mer. It measures several parameters every 20 minutes, including: salinity, water and air temperature, fluorescence, turbidity, dissolved oxygen concentration, percentage of oxygen saturation, P.A.R., relative humidity, wind direction and speed, as Well as water height. On the other hand, nutrients such as phosphate, nitrate, and silicate are measured once every 12 hours.

The purpose of this report is to present the main elements that future users will need to know so that they can adjust their research according to the quality of the data and their objectives. The results of the measurements of various physiochemical parameters on the period 2020-2022 are shown in more detail to highlight the seasonal cycles characteristic of this ecosystem.

Keywords

Eastern English Channel, Boulogne-sur-Mer, high frequency time series, MAREL Carnot, hydrology, fluorescence IR ILICO, COAST-HF.

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1. Introduction

For centuries, the marine environment has been subjected to several sources of pollution. Increased public awareness of environmental issues, particularly those affecting coastal areas, resulted in the reinforcement of monitoring networks.

Traditionally, monitoring the marine environment has been done by collecting water in Niskin bottles during field campaigns, microscopic observations, and traditional cell counting techniques which are considered as low resolution approaches (sampling frequency > week). Indeed, advancements in physicochemical sensor technology allowed for the creation of networks of autonomous instrumented stations capable of performing high-frequency measurements and making them available online to users in near real time, through official websites and data portals.

Based on the expertise developed over many years in the operation of environmental monitoring networks, Ifremer has addressed the direct and indirect effects of human activities on the marine environment, highlighting the need for automated monitoring systems. Since 1992-1995, the concept of MAREL stations has been proposed in response to a variety of environmental constraints as well as users' requests. Then, within the framework of the ILICO Coastal Research Infrastructure (https://www.ir-ilico.fr/?PagePrincipale), the teams have been organized into a national multi-organism network (Système National d'Observation, SNO, in French): COAST-HF, which have led the implementation of various high frequency measuring stations all along the French coast. In the Eastern part of the English Channel, MAREL Carnot

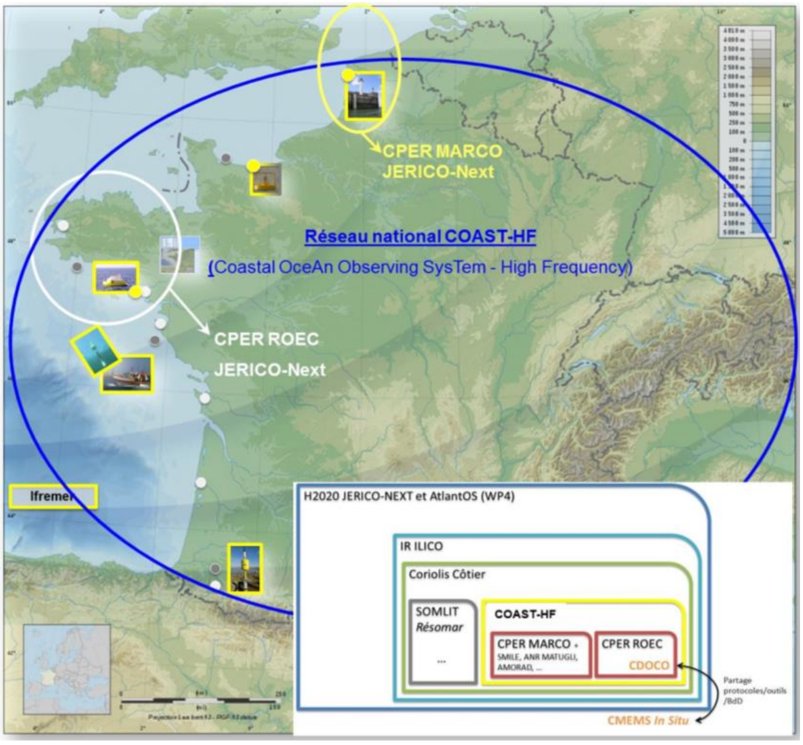

Figure 1 The location of the national COAST HF network's instrumented stations, as well as research infrastructures, scientific and technological projects

Station has been installed in 2004 to measure several physicochemical and biological parameters.

2. Operation of MAREL Carnot from 2004 to the present

An assessment report n°1, published in 2006, describes the various stages of the implementation of MAREL Carnot station, from the preliminary studies to the site's inauguration (Lefebvre & Répécaud, 2006).

The common objective of the MAREL measuring stations is the high frequency and automatic measurement of essential oceanic and atmospheric physicochemical parameters. Data is transmitted to a data processing center on land in real time. In other words, MAREL Carnot station measures physiochemical and biological parameters in a continuous and autonomous mode. With a sampling frequency of 20 minutes, it is capable of providing high resolution data for conductivity ($S.m^{-1}$), water and air temperature (°C), pH, fluorescence (FFU), turbidity (NTU), dissolved oxygen concentration ($mL.L^{-1}$), Photosynthetically Active Radiation or P.A.R (µmol of photons.$s^{-1}.m^{-2}$), wind direction (degree), and wind speed ($m.s^{-1}$), as well as sea level (m). On the other hand, nutrient concentration like nitrate, phosphate, and silicate are only measured once every 12 hours due to the dependency on the amount of chemical reagents.

Because technology is constantly evolving, and the sensors used in 2004 became outdated, significant changes were made to the MAREL system in 2014. As sensors are continuously updated, researchers using the data will have to tell the difference between the years 2004-2014 and 2014-2021. Below is a detailed description of MAREL Carnot station from 2004 till the present.

2.1 The MAREL Carnot system until 2014

The first MAREL Carnot station consisted of a measuring cell with multiple sensors. Water was pumped through a flow chamber into a zone for analysis and physiochemical parameter measurement. When there are no measurement cycles, seawater is chlorinated to prevent biofouling of the sensors. As a result of this chlorination, the sensors can remain in place without maintenance or cleaning for an average of three months.

Table 1 Sensor range and uncertainty of measured parameters

Physiochemical Parameters	Sensor Range	Measurement Uncertainty
Temperature	- 5 to + 35 °C	0.1 °C
Conductivity	0 to 7 mS/cm	0.3 mS/cm
Dissolved Oxygen	0 to 20 mg/L	0.2 mg/L
pH	1 to 14 UpH	0.2 UpH
Turbidity	0 to 500 NTU	10 %
Fluorescence	0 to 500 FFU	10 %
Nitrate	0.1 to 100 µmol/L	5 %
Phosphate	0.1 to 100 µmol/L	5 %
Silicate	0.1 to 100 µmol/L	5 %

The data was sent transmitted twice a day via GSM link to the Ifremer Manche Mer du Nord Center in Boulogne-sur-Mer, where it was validated and processed. During this transmission step, the data were subjected to various several quality control procedures. Then, the data was assigned a processing level and a quality code was given to each observation.

Part of this control was done automatically (control of the file format, the range of observed values according to reference values); the data were then assigned to a T0.5 processing level. A visual check was also performed to identify the quality level of the data (Figure 2).

Figure 2 Data processing Level and Quality Code during the Quality control procedure (Screenshot of the OCQ quality control tool)

After this step, the data were moved to processing level T1.0 and were accessible via the Internet at http://www.ifremer.fr/difMARELCarnot/ (Figure 3). Access was possible via three domains: public, scientific and technical depending on the user's profile. The information available was different depending on the user profile selected during the identification stage (red box in Figure 3). Thus, the public profile allowed to visualize the data and to have access to the metrology reports while the 'scientific' profile allowed to download the data and to have access to other information on the operation of the system. On the other hand, the ‘technical' profile was mainly reserved for people in charge of the maintenance of the system.

Figure 3 Home page of MAREL Carnot consultation site until 2014

The flow chamber was changed quarterly (4 times a year) and led to a quality assurance check of the sensor calibration (Table 2). A metrology report was then used to assign a final quality level to the data, which went to final processing level T2.0.

Table 2 Metrology: MAREL Carnot sensor compliance rules

Parameters	Dissolved Oxygen (mg/L)	Conductivity (mS/cm)	pH	Turbidity (N.T.U.)	Fluorescence (FFU) Without cleaning	Temperature (° C)
Conformity	+/- 0.20	+/- 0.30	+/- 0.20	+/- 10 %	+/- 10 %	+/- 0.1

2.2 The MAREL Carnot system from 2014 till the present

2.2.1 The database

In 2014, the data was uploaded on CORIOLIS database:

https://wwz.ifremer.fr/Recherche-Technologie/Infrastructures-de-recherche/Infrastructures-d-observation-des-oceans/CORIOLIS.

Data from high frequency measurement platforms such as MAREL Carnot are collected by CORIOLIS and disseminated by the Data Center for Operational Coastal Oceanography (CDOCO). They are accessible/downloadable via:

http://data.coriolis-cotier.org/

MAREL Carnot's CORIOLIS platform code was 62443 before October 2019. It has been changed to 6200443 to be consistent with the new international standards established by the World Meteorological Organization.

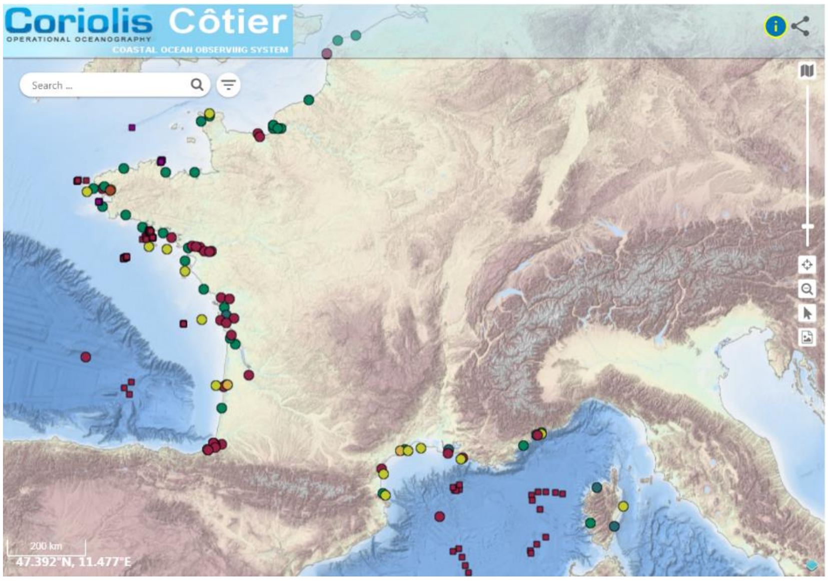

Figure 4 Location of the different sites of the CORIOLIS infrastructure, including MAREL Carnot

This website also allows direct access to the MAREL Carnot data visualization (Figures 6 to 14). The user of the data is required to cite the source using the following formula (change the words in square brackets):

Coriolis (2015). MAREL Carnot data and metadata from Coriolis Data Center. Data from [Start date] to [End date] http://www.ifremer.fr/coen/eulerianPlatform?contextId=395&ptfCode=62443&lang=en#+qcgoodonly).

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2.2.2 The measurement system

The MAREL Carnot automated station, which was built in December 2004, uses 1990s electronic, computer, and mechanical parts. The general aging process, especially in maritime systems, requires the replacement of several non-working parts. In other words, the damage of a significant number of electrical components necessitated the replacement of the measurement system with a new automated measuring probe. The system of circulation pump that was initially used to pump water to the probe was generated some issues with bubbles in the water circulation system, thus disrupting the measurements. Consequently, a new approach based on in situ measurements was implemented The core of the system is currently made up of the following components:

-A COSTOF2, COmmunication and STOrage Front-end second generation, developed by Ifremer which is a smart multisensor marine observation platform designed to suit a wide range of observation systems (Legrand et al., 2019),

-A small in situ circulation pump for pumping water to the probe,

- A chlorinator for the production of chlorine by electrolysis,

-A multi-parameter probe type MP6 NKE (Table 3 and figure 5),

-A Nutrient analyser (Systea WIZ) (nitrate, phosphate, silicate),

-Seabird PAR Satlantic to measure the Photosynthetic Active Radiation,

-A PONCPC-EH-10 probe for pH measurement.

Table 3 Principal characteristics of the NKE MP6 sensor

Parameters	Precision	Resolution	Sensor Range
Pressure	0.06 m	0.006 m	0 to 20 m
Temperature	0.0005 °C to 0°	0.05 °C	-5 to + 35 °C
Conductivity	0.05 mS/cm	0.0012 mS/cm	0 to 70 mS/cm
Dissolved Oxygen	5 %	0.01 %	0 to 120 %
Fluorescence	1 % range	0.08 µg/l	0 to 500 µg/l
Turbidity	2 % range	0.012 NTU	0 to 1500 NTU

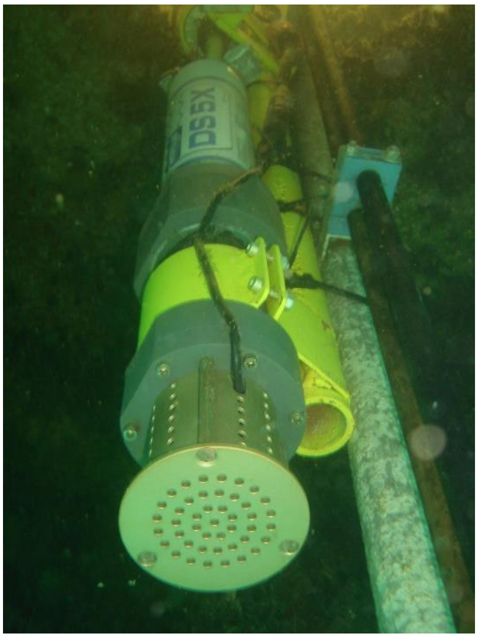

Figure 5 Measuring system immersed in position on its pole

Continuous updating of probes and sensors must be done in order to allow the acquisition of other physicochemical and biological parameters that are currently unavailable.

3. Results

Previous reports on MAREL Carnot contain information on the mode of action, data, and publication. They include Lefebvre and Répécaud (2006), Lefebvre (2007), Lefebvre (2008), Duval (2009), Lefebvre (2010), Lefebvre (2011), Lefebvre, Rousseeuw and Caillault (2012), Lefebvre and Rousseeuw (2013), Lefebvre and Rousseeuw (2014), Lefebvre and Devreker (2015), Lefebvre and Caillault (2016, 2017), Lefebvre and Grassi (2018), as well as Grassi, Poisson-Caillault et Lefebvre (2020). These reports can be downloaded from the website of the Environment & Resources Laboratory of the Ifremer Manche Mer du Nord center or from Archimer:

https://manchemerdunord.ifremer.fr/Environnement/LER-Boulogne-sur-Mer/Surveillance-et-Observation/MAREL-Carnot/Valorisations-Marel-Carnot

https://archimer.ifremer.fr/doc/00642/75445/76264.pdf

Up until now, nutrient measurements as well as certain other atmospheric parameters were not available. They are supposed to be available again in 2023. Certain other parameters, on the other hand, have only been available since 2020. The graphs corresponding to several parameters measured by the MAREL Carnot station are represented below. They are highlighting the complex signals obtained with such a high resolution frequency. Some important patterns such as interannuel variabilities, seasonal cycles, and extreme events are easily identified on these figures. However, new specific numerical methods are needed to make the most of these data sets (see section 4.3).

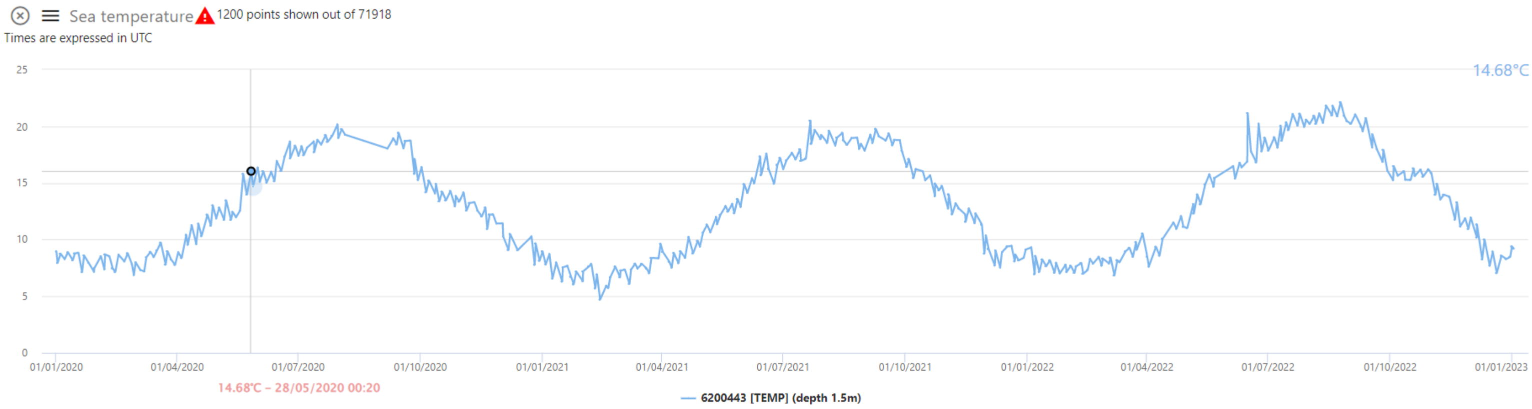

Figure 6 Sea temperature Signals from 01/01/2020 till 01/01/2023

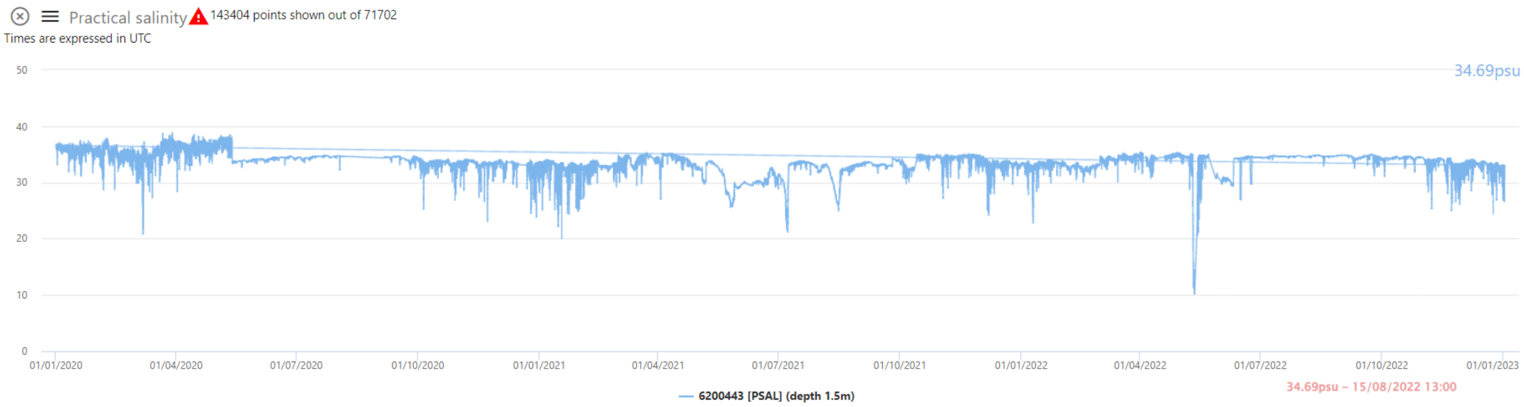

Figure 7 Practical Salinity Signals from 01/01/2020 till 01/01/2023

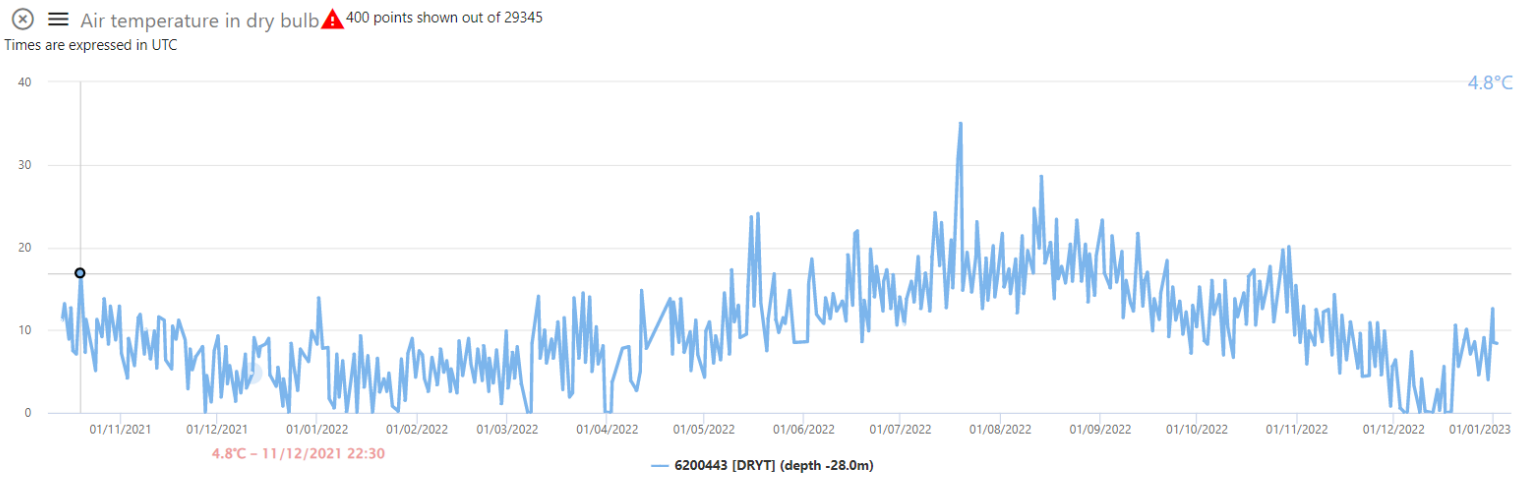

Figure 8 Air Temperature Signals from 01/01/2020 till 01/01/2023

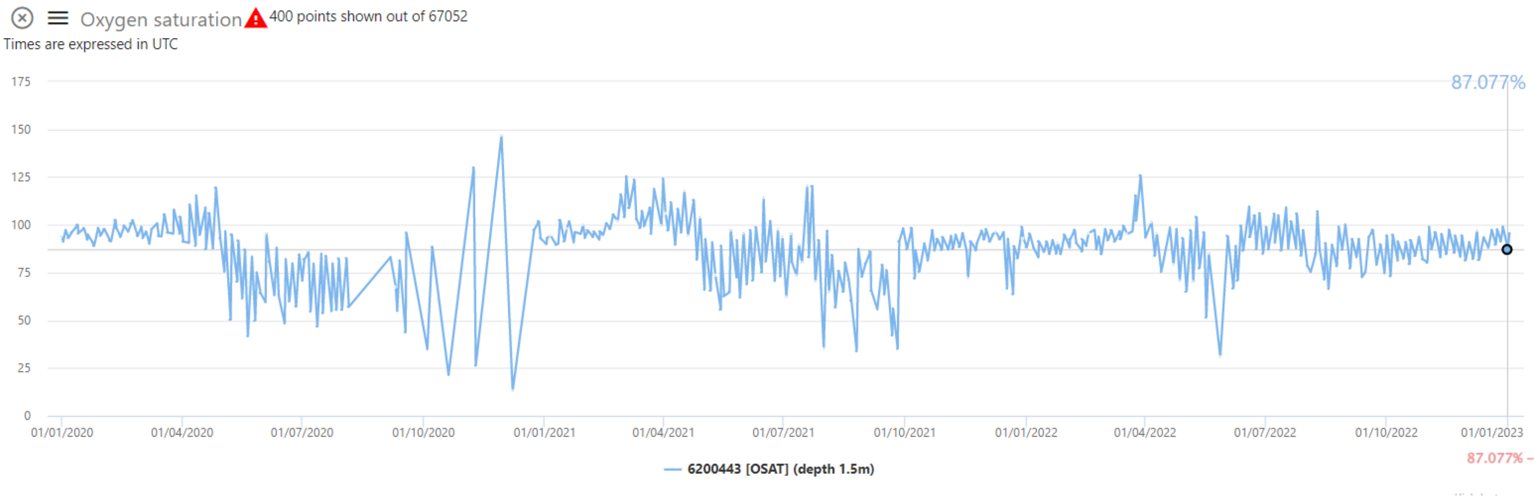

Figure 9 Oxygen Saturation Signals from 01/01/2020 till 01/01/2023

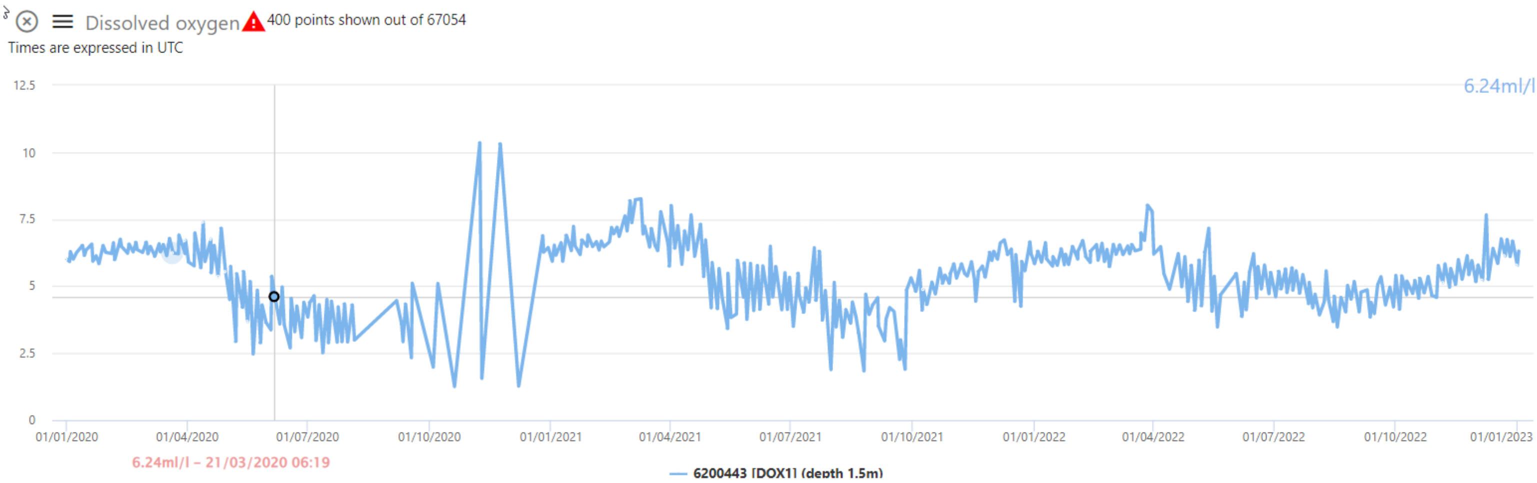

Figure 10 Dissolved Oxygen Signals from 01/01/2020 till 01/01/2023

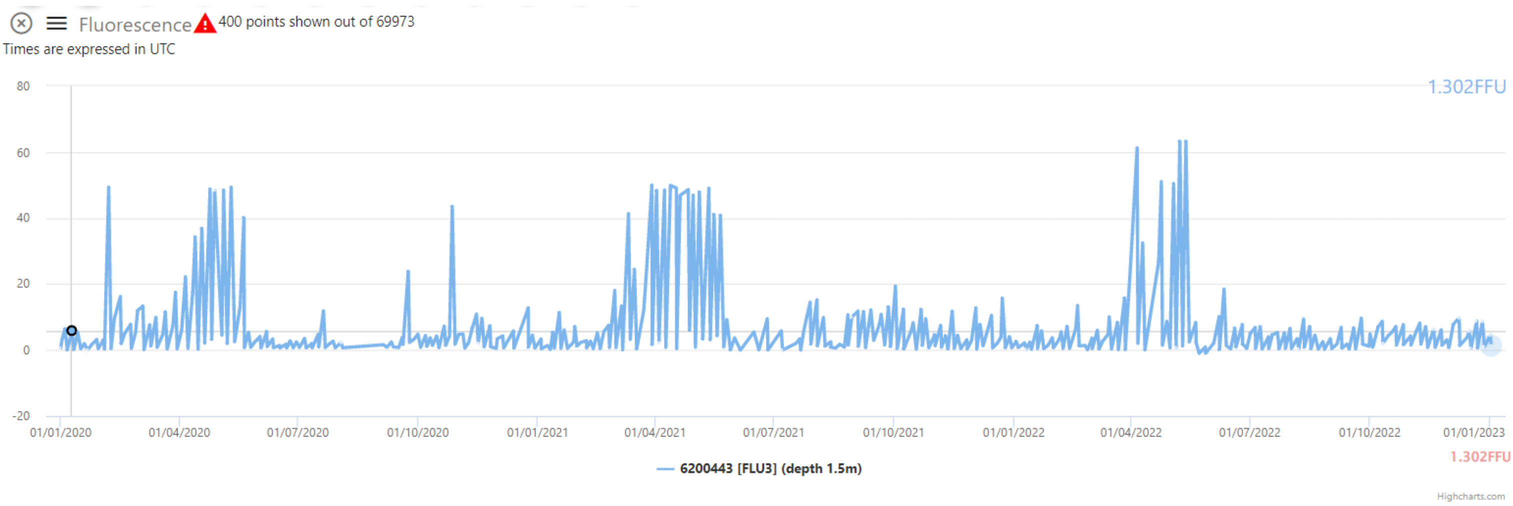

Figure 11 Fluorescence Signals from 01/01/2020 till 01/01/2023

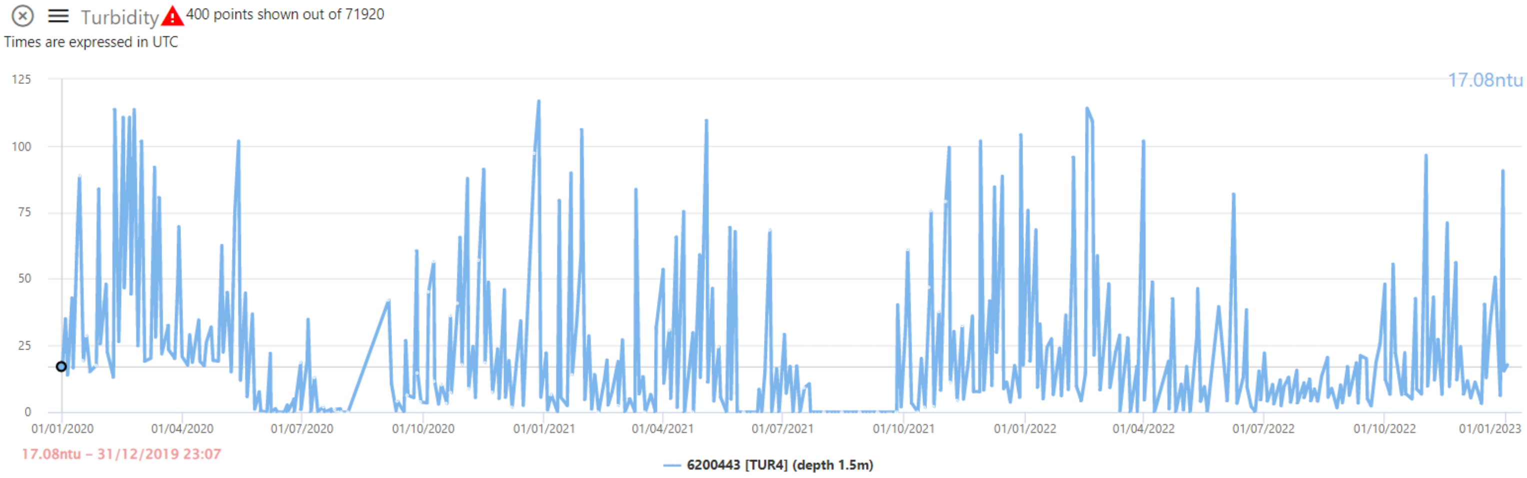

Figure 12 Turbidity Signals from 01/01/2020 till 01/01/2023

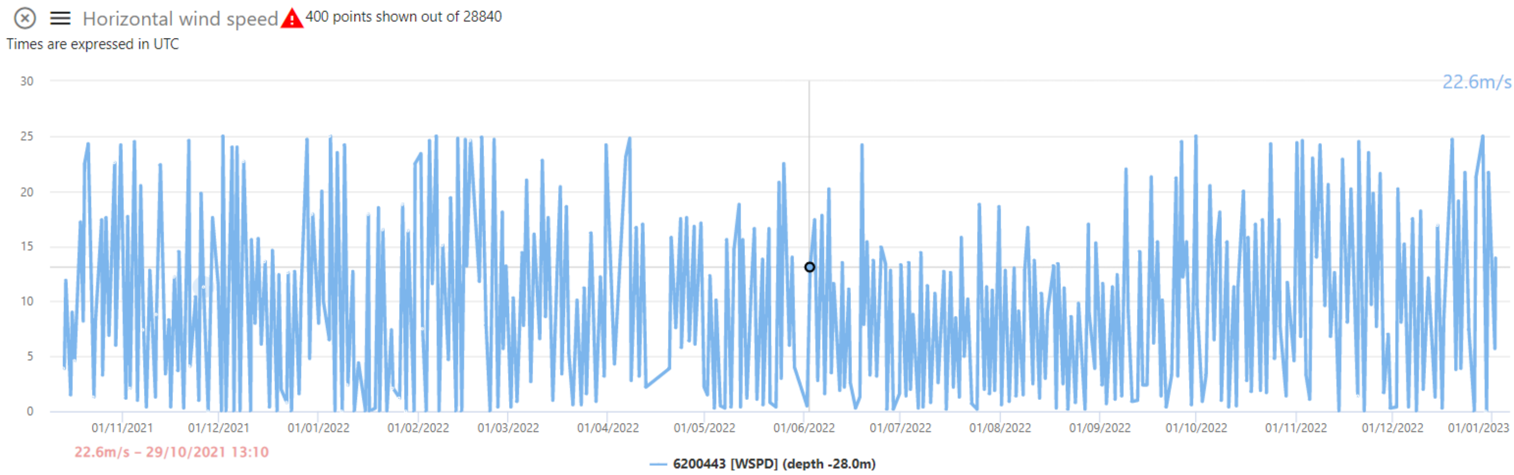

Figure 13 Horizontal Wind Speed Signals from 01/01/2020 till 01/01/2023

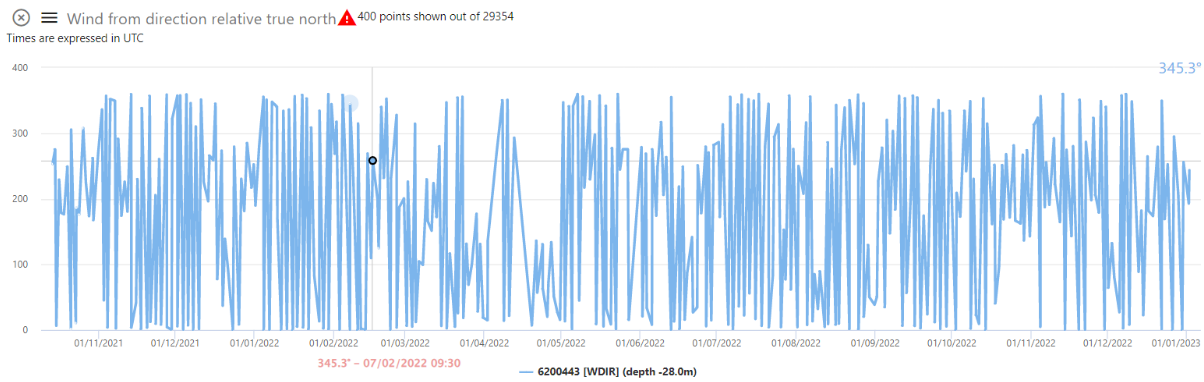

Figure 14 Wind Direction Signals from 01/01/2020 till 01/01/2023

The dissemination of MAREL Carnot data on the Seanoe website via its DOI allows for its use in both research and education (DOI: 10.17882/39754).

It is worth mentioning that, starting from the year 2020, certain parameters contain offsets due to sensor failure. For instance, the PAR parameter contains an offset that necessitates correction before direct usage.

4. Valorization of the results obtained

4.1 Communication Conference:

1- Lefebvre A., Halawi Ghosn R., Poisson-Caillault E., 2022. Machine Learning & Harmful Phytoplankton Blooms: Towards an expert Forecasting, Warning, and Decision-Support Numerical System. International Statistical Ecology Conference, Cape Town in South Africa. From 27 June until 1 July 2022 (Online).

2- Lefebvre A., Halawi Ghosn R., Poisson-Caillault E., 2022. Machine Learning & Harmful Phytoplankton Blooms : Towards an Towards an expert Forecasting, Warning, and Decision-Support Numerical System. Interational statistical ecology conference (ISEC), Cape Town, South Africa, 27 June – 1 July 2022.

3- Carrat M., Halawi Ghosn R., Hébert P.-A., Lefebvre A., Poisson-Caillault E., 2022. Incremental clustering of high frequency coastal and marine observations for the detection of changes in the environmental states and phytoplankton communities and, early warning of HABs. 11th Ferry Box Workshop, 28-29 September 2022, HEREON, Geesthacht, Allemagne.

4- Artigas L.F., Hubert Z., Gallot C., Louchart A., Epinoux A., Robache K., Verhaeghe F., Bonato S., Dédécker C., Lebourg E., Bruaut M., Didry M., Lizon F., Lefebvre A., 2022. English Channel and Southern North Sea phytoplankton monitoring applying automated approaches. JERICO S3 joint PSS/IRS workshop, 26-27 September 2022, HEREON, Geesthacht, Germany.

5- Halawi Ghosn R., Poisson-Caillault E., Lefebvre A., 2022. Machine Learning and Harmful Phytoplankton : Definition of Environmental States Favorable for Blooms, Bloom Dynamics, and Development of an Expert Forecasting, Warning and Decision Making System. Assemblée Générale du SNO COAST-HF de l'IR ILICO, 12-13 octobre 2022, Marseille.

6- Poisson-caillault E.Phan T.-T.-H., Lefebvre A. 2022. Missing data, DTW-based imputation. IA for water: a joint RAINSMORE/SWOT workshop on the use of Articificial Intelligence for time series and images processing for Hydrometeorological applications, 24-28 October 2022, Fortaleza, Brasil.

4.2 Publication

1- Data Paper: In progress – Data paper to be submitted to Earth System Science Data based on the updated data from Lefebvre Alain (2015). MAREL Carnot data and metadata from Coriolis Data Center

2- International Publication: In progress – Grassi K. Halawi Ghosn R., Poisson-Caillault E., Lefebvre A. Semi-supervised definition of the phytoplankton dynamics in the English Channel based on a multi-variable and multi-scale observation strategy.

4.3 Scientific Work Related to MAREL Carnot dataset:

Raed HALAWI GHOSN's PhD

This work is financially supported by Ifremer and the Office Français de la Biodiversité (OFB) under the grant agreement N° OFB.21.0578.

Coastal marine ecosystems are evolving significantly in response to changes in the pattern and intensity of anthropogenic pressures that have been exerted on them for decades. The paths of degradation and restoration no longer always follow the expected patterns, which makes it hard to figure out how to set management practices.

This research aims to characterize the dynamics of the coastal environment, and more particularly that of phytoplankton (including harmful or toxic blooms), in response to these forces at different time and space scales, from recurrent to extreme events, in order to understand the associated processes and to rank a set of control factors and define indicators and scenarios to assess this response.

Our approach entails integrating various machine learning methods in a meta-program that allows (i) to optimize multi-source and multi-scale observation data through the use of data completion methods, (ii) to define the environmental states as accurately as possible and to form a learning base via a deep approach (multi-level spectral classification), and (iii) to develop a model that will be the core of the Expert Digital System for forecasting harmful algal blooms.

The originality of this work lies in the implementation of optimized methods from machine learning coupled with a multi-source, multi-parameter, and multi-scale approach anticipating the needs of tomorrow's integrated observation systems. The proposed numerical approach has the advantage of optimizing the data pre-processing phase in order to exploit the maximum amount of available information and even allows for proposing expert series that are useless as they are. In addition to improving knowledge of the dynamics of phytoplankton blooms, particularly harmful or toxic algal blooms, and eutrophication, this research should be an important step in adapting to technological evolutions related to Monitoring and Assessment. The aim of this project is to provide a complete and innovative digital system for the observation of the marine environment. combining (i) classification of multi-criteria environmental states, (ii) warning, and (iii) prediction. This definition of environmental states and their dynamics should also allow for improved expertise during the evaluation phases of the ecological or environmental state as defined by the European directives.

To achieve the above objectives several datasets (from low resolution to high resolution) will be used including the MAREL Carnot dataset.

5. References

The list below corresponds to the documents quoted in this report, or to basic documents that can be used for the interpretation of the results, or to the documents related to high-frequency measurements. This list is not exhaustive but allows interested parties to have a minimum of documents to understand the subject of the high frequency measurement.

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