New insights into nutrient dynamics and the carbonate system using a neural network approach in the Mediterranean Sea

Marine Fourrier*, Laurent Coppola, and Fabrizio D'Ortenzio
Sorbonne Université, CNRS, Laboratoire d'Océanographie de Villefranche, LOV, F-06230 Villefranche-sur-Mer, France

Introduction

The Mediterranean Sea is characterized by a short residence time[1], an elevated salinity and is one of the largest oceanic nutrient-depleted areas[2] exhibiting an eastward-increasing oligotrophy gradient[3]. In the context of a critically undersampled ocean, the development and intensive use of instrumented *in situ* autonomous platforms, such as BGC-Argo floats, gliders and moorings, allows to densify the measurements of some biogeochemical variables (remaining however far from exhaustive).

CANYON-MED method

A homogeneous quality controlled dataset of *in situ* measurements from 1981 to 2018 was compiled, including samples of core variables such as dissolved oxygen (O_2), temperature, salinity as well as macronutrients (nitrates: NO_3^-, phosphates: PO_4^{3-}, silicates: $Si(OH)_4$) and carbonate system variables (total alkalinity: A_T, total carbon: C_T, and *in situ* pH on the total scale: pH_T).

A neural network-based method, CANYON-MED (for Carbonate system and Nutrients concentration from hYdrological properties and Oxygen using a Neural-network in the MEDiterranean Sea; Fourrier et al, submitted) was trained and validated on this dataset.

The method (*Figure 1*) provides estimations of nutrients and carbonate system variables from systematically measured oceanographic variables (T, S, O_2, geolocation, sampling date). These "input" variables are measured by autonomous platforms such as Argo floats and moorings.

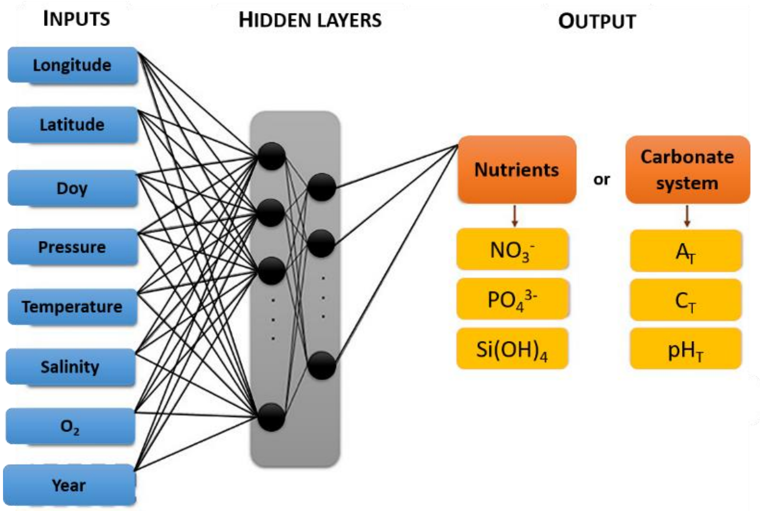

Figure 1: Schematic representation of the architecture of the neural networks, adapted from [4].

The regional CANYON-MED neural networks produce satisfactory results: accuracies of **0.73**, **0.045**, and **0.70 µmol.kg⁻¹** for $\mathbf{NO_3^-}$, $\mathbf{PO_4^{3-}}$ and $\mathbf{Si(OH)_4}$ respectively, and of **0.016**, **11 µmol.kg⁻¹** and **10 µmol.kg⁻¹** for $\mathbf{pH_T}$, $\mathbf{A_T}$ and $\mathbf{C_T}$ respectively. These accuracies are comparable to the ones obtained by the NO_3^- (±1 µmol.kg^{-1}) and pH_T (±0.005) sensors mounted on BGC-Argo floats.

CASE STUDY

The Gulf of Lion, located in the northwestern part of the Mediterranean Sea is a well known site for deep convection[5]. This intermittent phenomenon occurs with variations in intensity and volume of newly formed waters from year to year.

This region is well sampled thanks to the Argo floats deployed in the area (*Figure 2*, 15 floats profiled there from 2012 to the end of 2018).

In 2012 occurred an exceptional deep convection event[5], homogenizing the water column and enriching the surface layers with nutrients from deeper waters.

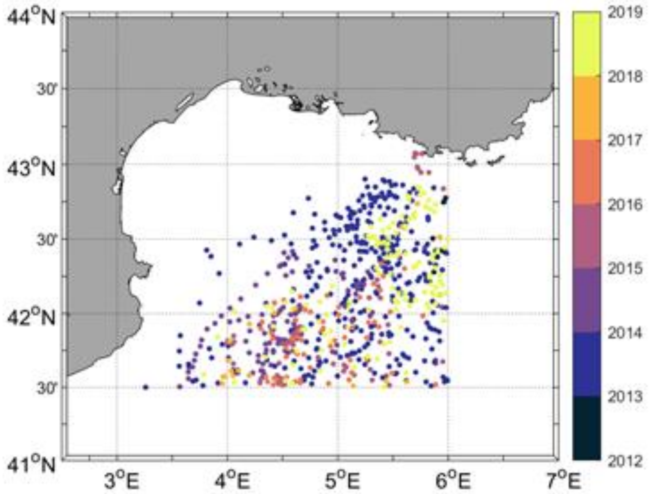

Figure 2: Location of the Argo float profiles in the Gulf of Lion according to year.

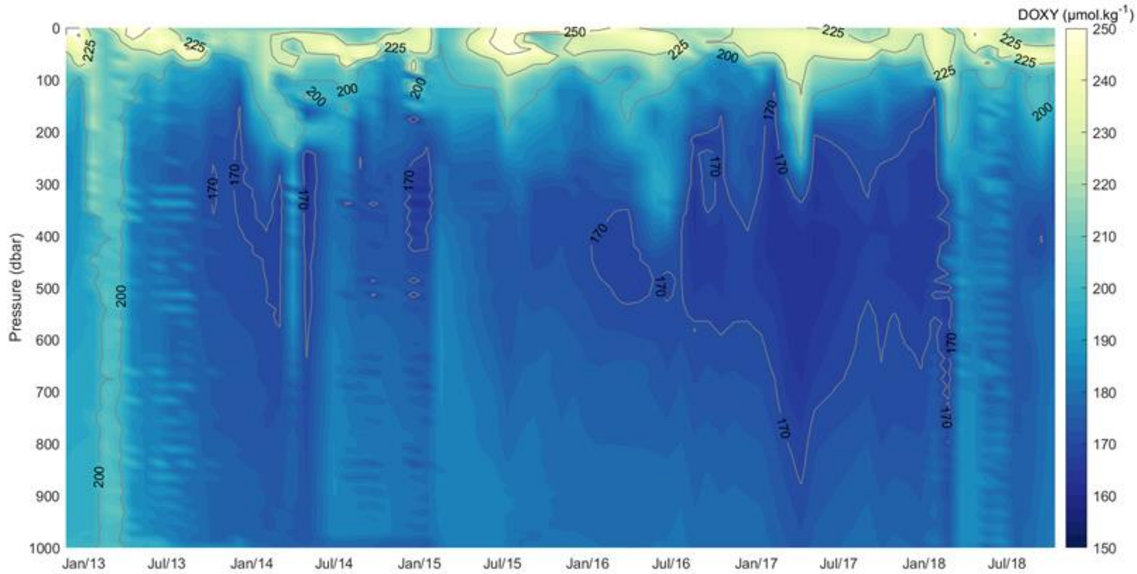

Figure 3: Timeseries of dissolved O_2 according to pressure in the Gulf of Lion area. Grey lines represent oxyclines.

The O_2 timeseries in the Gulf of Lion (*Figure 3*, average of Argo float data) exhibits the mixing event of 2012-2013. Thereafter, the O_2 minimum in the intermediate layers (delineated by the 170 µmol.kg^{-1} isoline) returns and reinforces with time along with an increase of its vertical extent. In the winter of 2018, another convection event occurs, once again homogenizing the water column and erasing the oxygen minimum. The Argo floats used in this area only went down to 1000 m, therefore limiting our view of the maximum depth reached by convection to 1000m, in the present study.

Marine Fourrier – PhD candidate – LOV, SU **fourrier@obs-vlfr.fr**

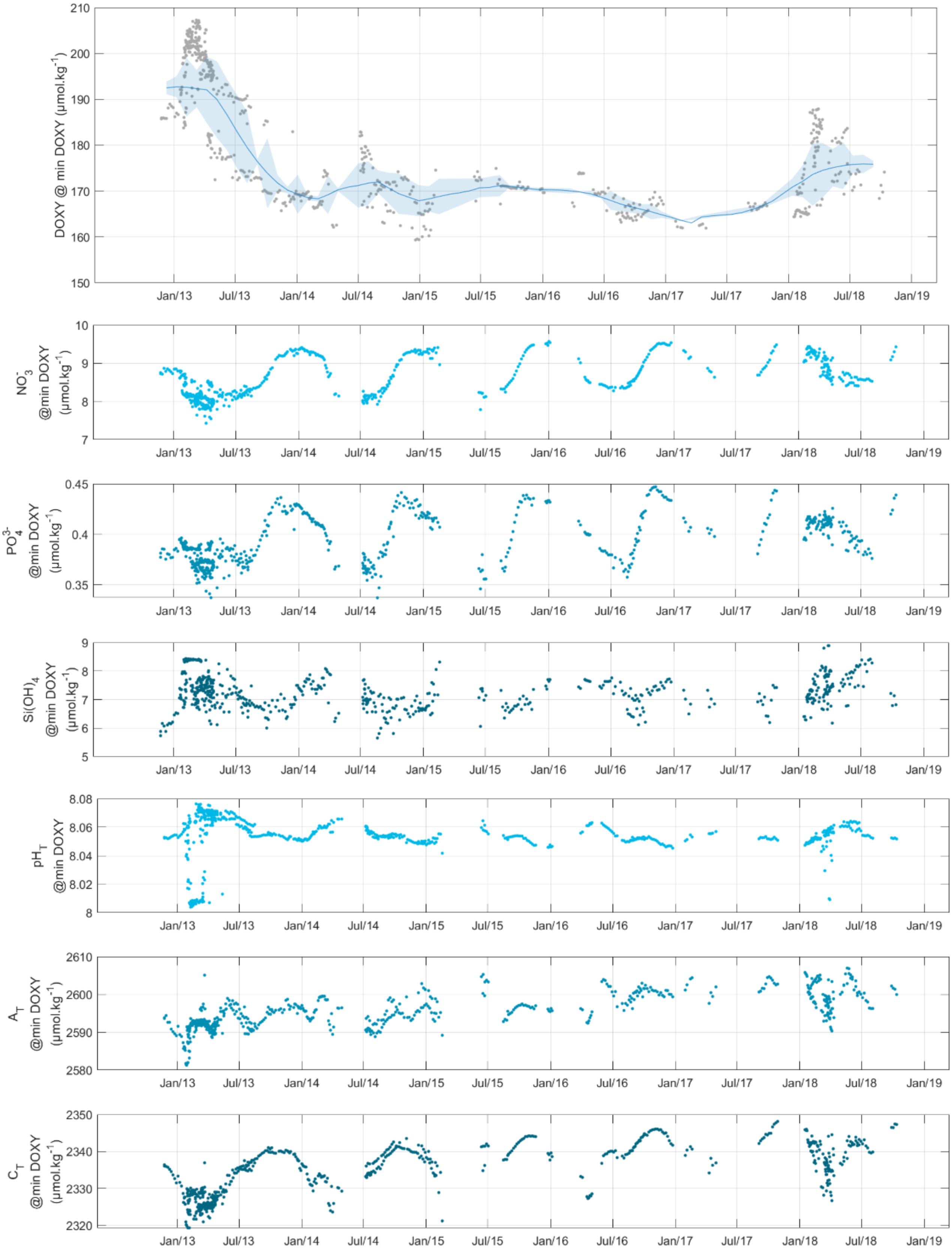

Figure 4: Timeseries of CANYON-MED derived NO_3^-, PO_4^{3-}, $Si(OH)_4$ and pH_T, A_T, C_T at the depth of the minimum of oxygen (intermediate waters), in the Gulf of Lion area.

Marine Fourrier – PhD candidate – LOV, SU **fourrier@obs-vlfr.fr**

The depth of the core of the minimum of O_2 varies between 300 and 500 meters, slightly below the core of the Levantine Intermediate Waters (as verified with the salinity maximum). O_2 at the depth of the minimum of oxygen (*Figure 4, top panel*) decreases with time (-2.3 µmol.kg^{-1}.an^{-1} between 2013 and the end of 2017) as evidenced in *Figure 3*, with a sharp increase during the winter 2018.

Using the CANYON-MED neural network-based method, virtual data of NO_3^-, PO_4^{3-} and $Si(OH)_4$ were obtained, from Argo float data, at the depth of core of the minimum of oxygen (in intermediate waters). During the winter of 2013, the values are scattered, corresponding to the mixing event. A seasonal cycle is exhibited by NO_3^- and PO_4^{3-} and a small upward trend is visible during the studied period for these variables (+0.12 µmol.kg^{-1}.an^{-1} for NO_3^- and + 0.004 µmol.kg^{-1}.an^{-1} for PO_4^{3-}). Seasonnality is less marked for $Si(OH)_4$. During the 2018 convection event, nutrients at the depth of the minimum of O_2 exhibit a higher variability, probably due to mixing.

Virtual data of carbonate system variables, namely pH_T, A_T and C_T were also derived using CANYON-MED. pH_T is highly sensitive to the two mixing events (2013 and 2018), with a decrease during mixing up to 0.05 pH units. Between the two mixing events, pH_T slowly decreases (-0.0015 unit.year^{-1}). Conversely, A_T and C_T are less sensitive to the convection events, but exhibit an upward trend between 2013 and 2018 (+2 and +1.79 µmol.kg^{-1} for A_T and C_T respectively).

Perspectives

The regional CANYON-MED neural networks are a promising method to derive nutrients and carbonate system variables in the Mediterranean Sea with a given accuracy. By applying it to the large and growing network of autonomous platforms in the Mediterranean Sea (Argo floats, moorings, gliders), this method allows us to gain new insights into nutrients and carbonate system dynamics in targeted areas. In particular, in the Gulf of Lion, the impact of deep convection and its variability over time on biogeochemistry (e.g., nutrient replenishment and pH_T variability) is poorly covered by observing networks. By applying it on Argo floats measuring O_2, the biogeochemistry at the minimum of O_2 (in intermediate waters) is investigated, and increasing trends of NO_3^-, PO_4^{3-}, A_T and C_T are evidenced, together with a small decreasing trend of pH_T. Furthermore, the high impact of mixing on O_2 and pH_T dynamics is highlighted.

References

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Marine Fourrier – PhD candidate – LOV, SU **fourrier@obs-vlfr.fr**