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Monitoring the Environment in the Northwestern Mediterranean Sea

The Mediterranean Ocean Observing System for the Environment (MOOSE) network integrates a range of platforms to detect and identify long-term environmental anomalies.



The crew of the R/V *L'Atalante* is up and working at sunrise during an annual MOOSE-GE (Grande Echelle) oceanographic cruise. Since 2010, the Mediterranean Ocean Observing System for the Environment (MOOSE) network has integrated multiple ocean observing platforms to detect and identify long-term environmental anomalies and to define effective health indicators in the northwestern Mediterranean basin. Credit: Laurent Coppola, Pierre Testor, GENAVIR/IFREMER, CNRS/INSU

By [Laurent Coppola](#), [Patrick Raimbault](#), [Laurent Mortier](#), and [Pierre Testor](#) © 25 July

2019

The Mediterranean basin is considered a “hot spot” of climate change. A continuous trend toward drier conditions over the past several years is expected to continue and possibly increase in the coming decades. At the same time, extreme weather events continue to cause human and economic losses. These events also cause serious damage to marine ecosystems in intermediate and deep waters and in all marine habitats.

To meet this challenge, a Mediterranean Ocean Observing System for the Environment (MOOSE (<http://www.moose-network.fr/>)) network was put in place in the northwestern Mediterranean basin in 2010, and it has been in operation ever since. MOOSE integrates multiple platforms and collects data on multiple variables to detect and identify long-term environmental anomalies and to define effective health indicators.

A Dynamic Region

The northwestern Mediterranean basin is a very dynamic region: It concentrates many physical processes that are of great importance to the global-scale functioning of the oceans.

In this region, intense deep open-sea convection and shelf water cascading occur every winter. These processes renew and ventilate deep ocean water, and they are crucial to transporting heat, salt, oxygen, and carbon [*Testor et al.* (<https://doi.org/10.1002/2016JC012671>), 2018].

Cold, dry, intense mistral and tramontane winds drive these processes over a cyclonic gyre circulation. The intense vertical mixing that results is essential to replenishing nutrient stocks and for the development of phytoplankton, which forms the basis of the marine food chain and play a key role in the carbon biological pump.

The MOOSE Network Strategy

The MOOSE network aims to observe the variability over space and time of processes interacting between the land, coast, and open ocean and between the ocean and the atmosphere. It was built as an in situ observing system, capable of capturing variability at many scales. MOOSE was designed to monitor seasonal or interannual variabilities, as well as the impact of extreme events that control physical and biogeochemical fluxes and marine biodiversity.

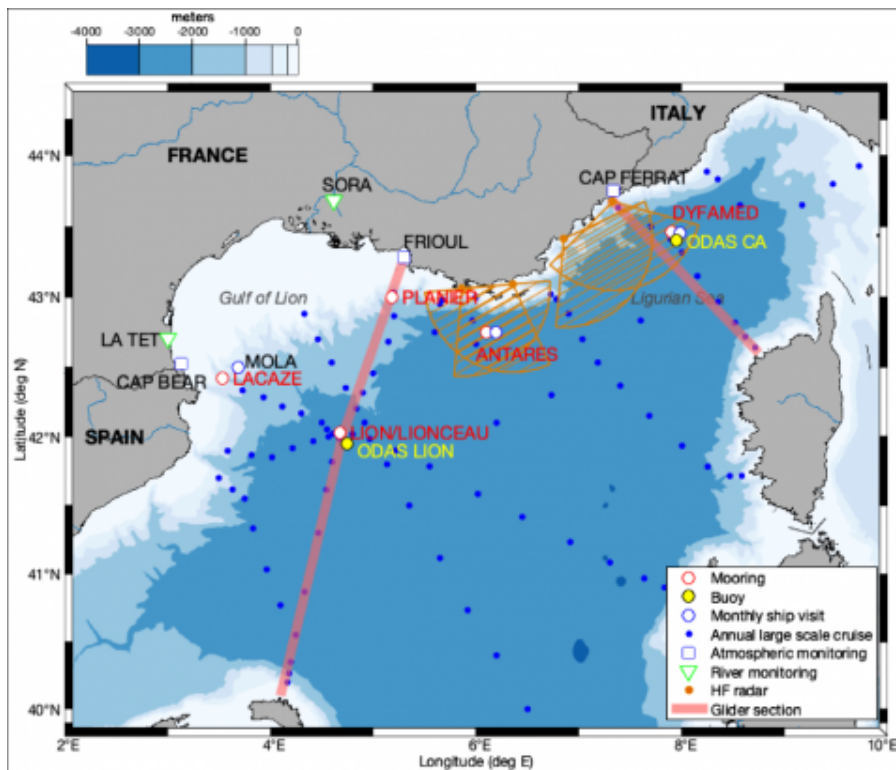


Fig. 1. Locations of the MOOSE observing system components in the northwestern Mediterranean basin. Station names are shown in red and yellow, red lines represent glider trajectories, and high-frequency radar coverage is shown in orange. Some of the observations from the MOOSE network are shown in the accompanying figures.

The network is based on multidisciplinary observing sites on land, coastal, and open oceanic regions (Figure 1). It combines fixed observatories, oceanographic cruises, and autonomous platforms to collect essential ocean variables (http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114). The monitoring sites include offshore moorings (including those from the European Multidisciplinary Seafloor and Water Column Observatory (<http://emso.eu/>) (EMSO)), meteorological buoys, glider endurance lines, annual basin-scale and monthly fixed-site ship surveys, high-frequency radars, river and atmospheric observatories, and Biogeochemical-Argo (<https://eos.org/project-updates/bringing-biogeochemistry-into-the-argo-age>) profiling floats that can make observations on seasonal to decadal scales.

An observing system simulation experiment (<https://cires.colorado.edu/research/research-groups/project/climate-observing-system-simulation-experiments>) approach was used to validate the MOOSE network strategy and its capacity to respond to key scientific issues. This

approach has confirmed the performance of the network to capture the newly dense water volume (<https://eos.org/editors-vox/observing-winter-mixing-and-spring-bloom-in-the-mediterranean>) and its dispersion into the northwestern basin [*Waldman et al.* (<https://doi.org/10.1002/2016JC011694>), 2016]. Thus, this approach suggests that the MOOSE network can be effective in observing and identifying biogeochemical properties and biological activities, mostly driven by physical processes in this dynamic region (Figure 2).

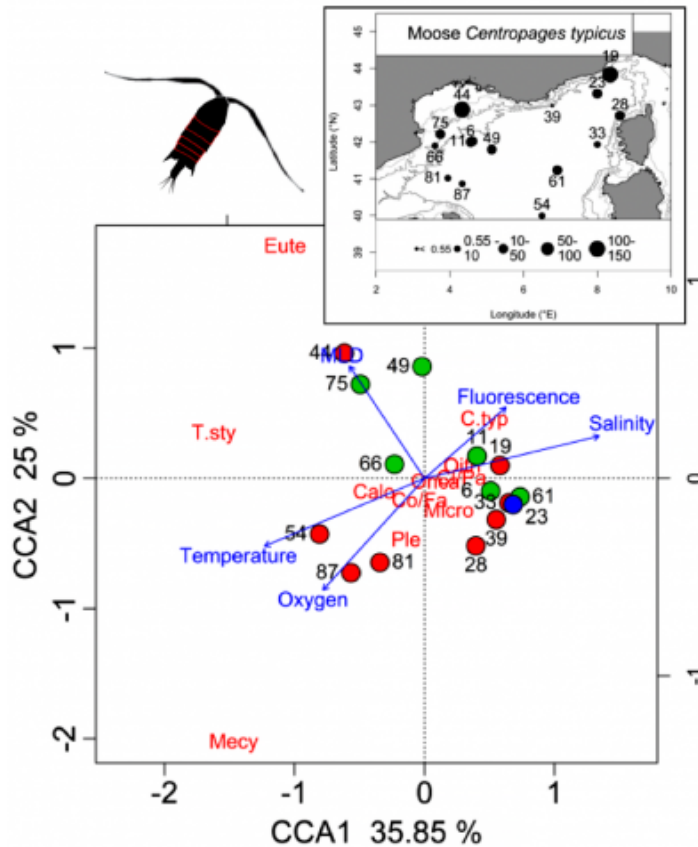


Fig. 2. Abundance distribution (top right; individuals per cubic meter) of the copepod plankton species *Centropages typicus* (top left) during MOOSE-GE 2014. (bottom) Canonical correspondence analysis (CCA) triplot of abundance based-copepod community structure during MOOSE-GE 2014. Taxa name abbreviations are in red: *Temora stylifera* (T.sty), *Centropages typicus* (C.typ), *Mecynocera* spp. (Mecy), *Pleuromamma* spp. (Ple), *Calocalanus* spp. (Calo),

Corycaeus/Farranula spp. (Co/Fa), *Oithona* spp. (Oith), *Oncaea* spp. (Onca), and *Microsetella* sp. (Micro). Environmental variables are in blue. Stations (circles) are color-coded by cluster location: green circles, Provençal region; blue circle, central Ligurian Sea; red circles, periphery of the MOOSE sampled area. From *Donoso et al.* (<https://doi.org/10.1002/2016JC012176>) [2017].

Scientific Issues and Advancements

The observation strategy of MOOSE is based on four topics that are relevant to the northwestern Mediterranean basin: water mass properties and regional circulation, climate and anthropogenic impacts from river inputs and atmospheric depositions, marine biogeochemical cycles and acidification, and biological communities and biodiversity. Since 2010, the MOOSE network has provided essential data to the scientific community, enabling progress on these key scientific issues.

Deepwater convection processes and their interaction with dense shelf water cascading events modify deepwater mass properties and deep sediment resuspension in the Gulf of Lion [*Durrieu de Madron et al.* (<https://doi.org/10.1002/2016JC012062>), 2017]. During the past decade, the MOOSE network has documented a slow increase in deepwater temperature, punctuated by very rapid warming, leading to even warmer and saltier deep waters (Figure 3).

Observations in the Ligurian Sea revealed that during severe winters, deepwater spreading and oxygen ventilation in this region modified the water column structure and the oxygen minimum that characterized the intermediate waters [*Coppola et al.* (<https://doi.org/10.1016/j.pocan.2018.03.001>), 2018]. Because vertical mixing is less intense in the Ligurian Sea than in the Gulf of Lion, the oxygen minimum would be more pronounced. With global warming, a slowdown in convection and ventilation phenomena could thus lead to a hypoxic state in the intermediate waters, with harmful consequences for carbon export and the marine ecosystem.

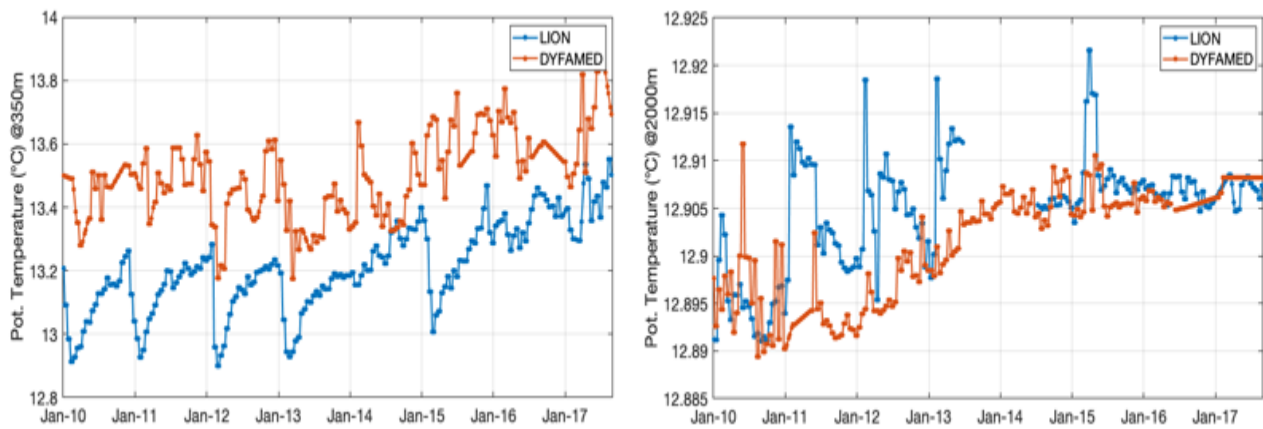


Fig. 3. Interpolated potential temperature data at depths of 350 meters (left) and 2,000 meters (right) from the LION and DYFAMED moorings (blue and red, respectively) from January 2010 to July 2017 (from EMSO).

Regular and long-term monitoring (<https://eos.org/features/monitoring-ocean-change-in-the-21st-century>) has provided significant results to interpret the temporal variability of nutrients and the zooplankton community, which are sensitive to deep vertical mixing events. Coastal observations showed that the long-term evolution of nutrient inputs here is driven by Rhône River water discharges, which respond differently depending on whether it is a climatic or an anthropogenic forcing (Figure 4).

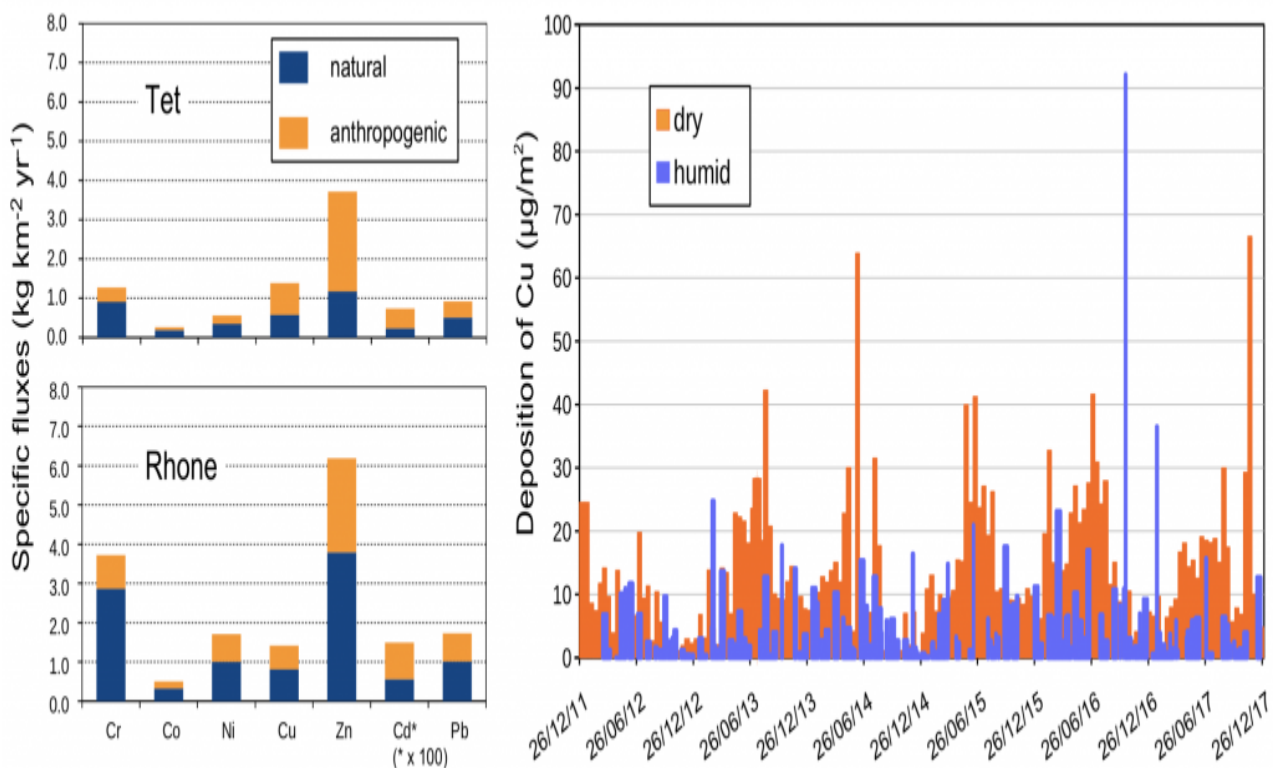


Fig. 4. Comparison of specific heavy metal fluxes from the Têt and Rhone River basins

(left) with atmospheric copper deposition rates at Cap Béar (right). River fluxes are based on regular monitoring during the years 2006–2011 [*Dumas et al.* (<https://doi.org/10.1016/j.apgeochem.2015.02.017>), 2015]. Note that the cadmium levels have been multiplied by 100 for visibility.

Data Management and European Integration

MOOSE oceanic data are validated using international protocols and best practices [*Pearlman et al.* (<https://doi.org/10.3389/fmars.2019.00277>), 2019]. This validation covers everything from sensor preparation to the systematic control of data at national data centers before these data are archived and released to the public.

The network was therefore designed to be based on proven techniques and procedures to ensure that these techniques and procedures are applied consistently across all measurements and by all partners with common collection and analysis protocols. The network is also designed to promote shared data to the end users. Once the data are qualified, they are archived on the Sea Scientific Open Data Edition (**SEANOE** (<https://www.seanoe.org/>)) repository, where a digital object identifier (DOI) is assigned.

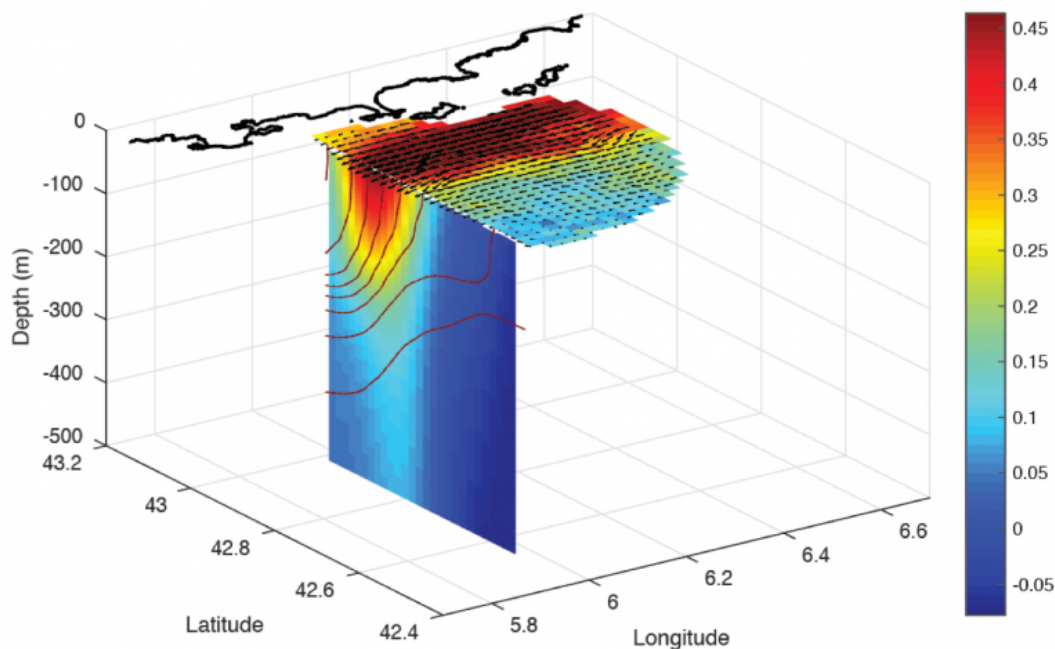


Fig. 5. Ocean surface current speeds and directions derived from high-frequency radar and glider measurements, with calculated geostrophic current velocities (from the balance between Earth's rotation and ocean pressure gradients), in meters per second, from 19 to 22 January 2013.

Real-time MOOSE data are transmitted to public databases for use with operational

oceanography and the Copernicus Marine Environment Monitoring Service (CMEMS (<http://marine.copernicus.eu/>)). Delayed-mode in situ data are stored in several national and European databases, including Coriolis (<http://www.coriolis.eu.org/>), Systèmes d'Informations Scientifiques pour la Mer (SISMER (<https://data.ifremer.fr/SISMER>)), the Observatoire Midi-Pyrénées Data Service (SEDOO (<https://en.aeris-data.fr/sedoo/>)), the European Marine Observation and Data Network (EMODnet (<http://www.emodnet.eu/>)), and SeaDataNet (<https://www.seadatanet.org/>). These delayed-mode data are essential for ocean circulation (Figure 5) and biogeochemical model calibration and validation and to fill gaps on a variety of scales and variables.

MOOSE is rooted in some relevant existing European Research Infrastructure Consortia to contribute to the emerging European Ocean Observing System (EOOS (<http://eurogoos.eu/eoos/>)). It also forms the long-term component of other studies conducted in the northwestern Mediterranean, such as those conducted in the framework of the Mediterranean Integrated Studies at Regional and Local Scales (MISTRALS (<http://www.mistrals-home.org/>)) program.



Crew members prepare to deploy plankton nets during a research cruise.

One goal of the MOOSE network is developing and adapting biological studies to long-term observation

strategies, enabling a holistic perspective of the diversity of planktonic ecosystems and ultimately helping to tackle societal challenges. Credit: Laurent Coppola, CNRS/INSU and GENAVIR/IFREMER

Future Challenges and Perspectives

The real challenges for MOOSE and other Mediterranean observing systems over the next decade are to sustain ocean observations within the research community, to monitor the variability at different space and time scales, and to develop and adapt biological studies to long-term observation strategies. For example, a new genomics approach should be developed to investigate plankton community (<https://eos.org/meeting-reports/sustainable-observations-of-plankton-the-seas-food-foundation>) structures across spatial gradients. This approach would provide a holistic perspective of both taxonomic and functional diversity of planktonic ecosystems and ultimately contribute to tackling societal challenges.

MOOSE offers a strategic network to deploy, maintain, and calibrate new autonomous platforms capable of measuring physical and biogeochemical variables. Thanks to this technology development, our capacity to provide higher data fluxes has begun to improve. We also have a greater ability to correct model biases and to produce some virtual variables (high-value biogeochemical variables based on temperature, salinity, and oxygen data sets) with the introduction of new deep learning techniques [*Sauzède et al.* (<https://doi.org/10.3389/fmars.2017.00128>), 2017]. The next challenge will be to adapt these deep learning techniques to regional basins through downscaling processes and specific training, which is largely based on the quality of in situ data provided by observing networks such as MOOSE.

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