Long term vision of the Ligurian Sea changes using gliders endurance lines

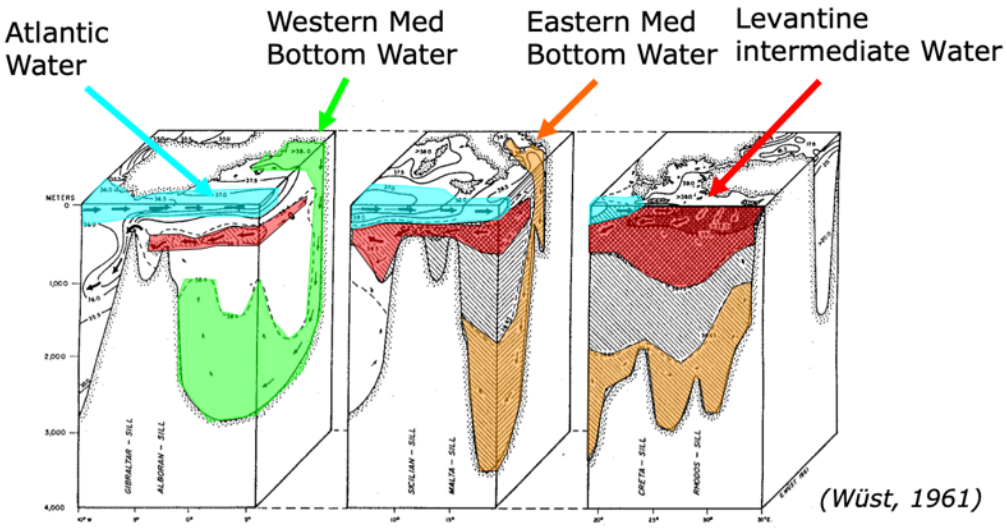
L.Coppola, P.Testor, L.Mortier, P.Raimbault, A.Bosse,

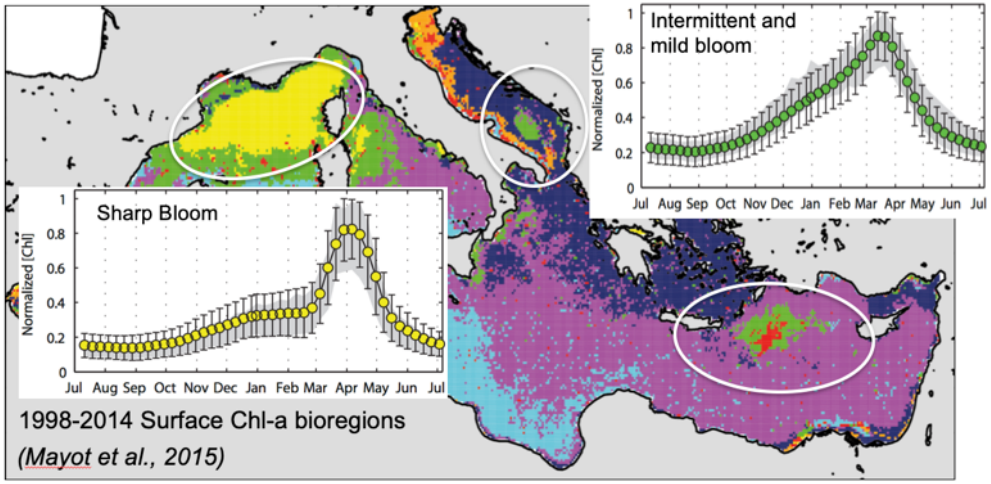
F.Margirier, L.Houpert, DT-INSU gliders group,

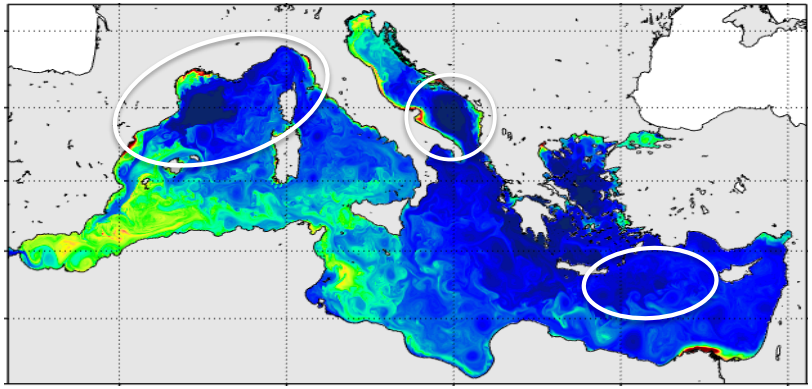
E.Diamond, G.de Liège

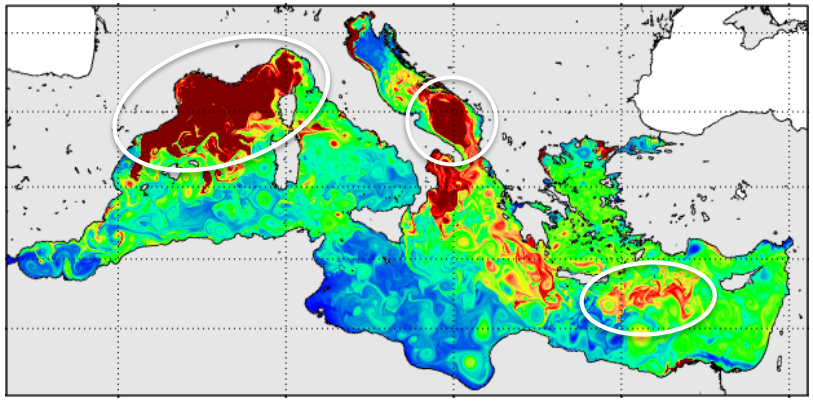
The Mediterranean Sea system

- Deep water formation and rapid THC (100 years)
- Winter: nutrients supply + plankton dilution + ventilation/spreading
- Spring: high bloom + grazing + OM export and respiration









Convection and ventilation processes

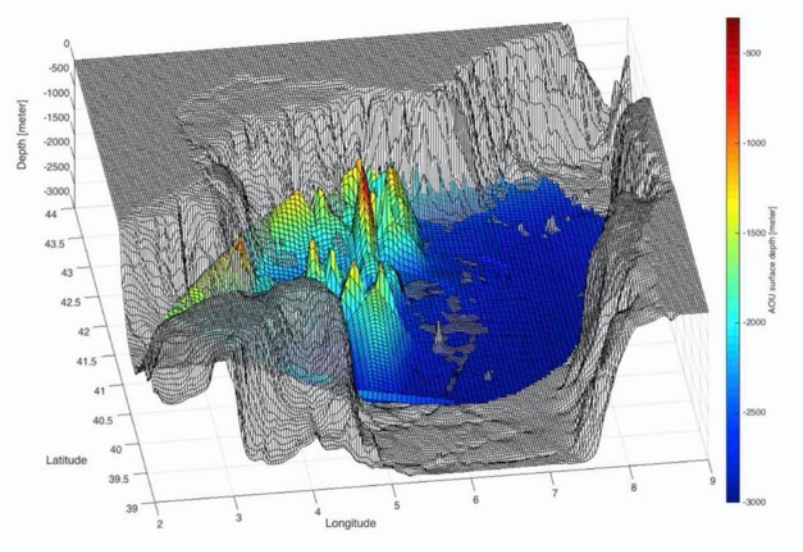
AGU PUBLICATIONS
JGR
Journal of Geophysical Research: Oceans

RESEARCH ARTICLE
10.1002/2016JC012594

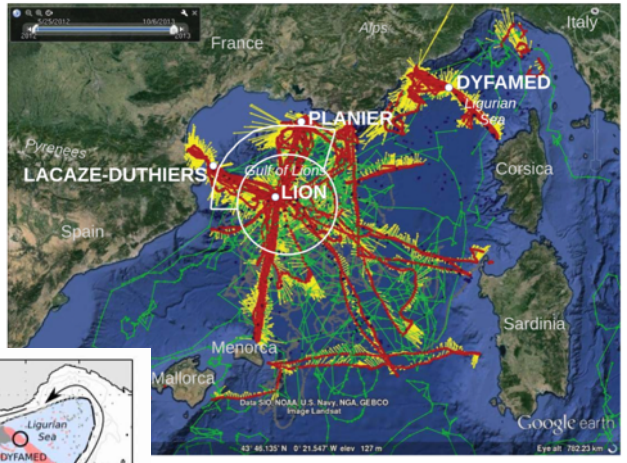
Special Section:
Dense Water Formations in the North Western Mediterranean: From the

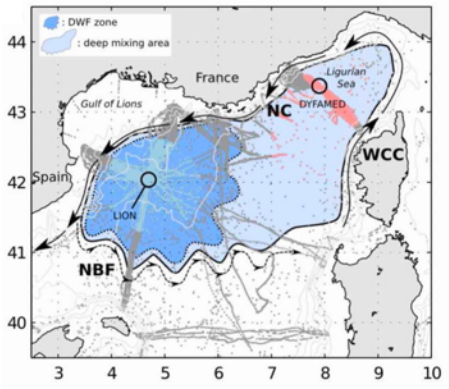
Observation of oxygen ventilation into deep waters through targeted deployment of multiple Argo-O_2 floats in the north-western Mediterranean Sea in 2013

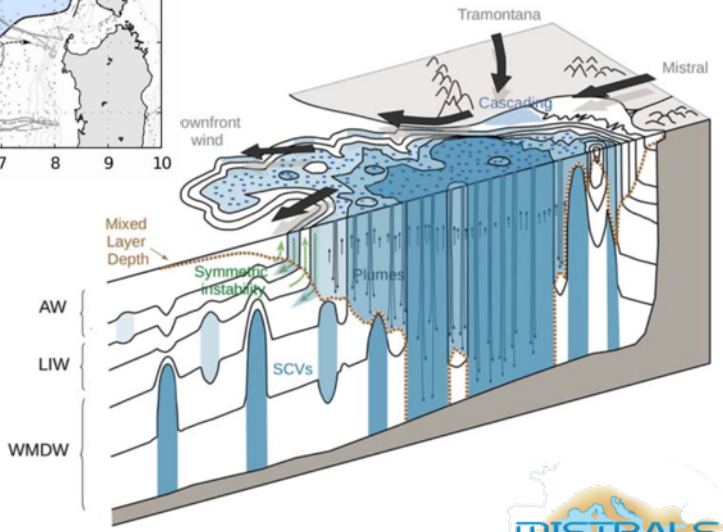
L. Coppola[1], L. Prieur[1], I. Taupier-Letage[2], C. Estournel[3], P. Testor[4], D. Lefevre[2], S. Belamari[5], S. LeReste[6], and V. Taillandier[1]



Coppola et al., 2017







Testor et al., 2018

NW Mediterranean Sea dynamic system:

Cyclonic water circulation: isolated open sea water

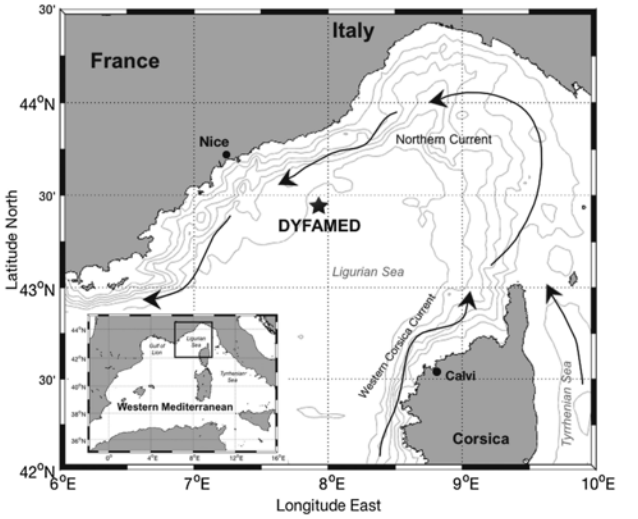
Strong and cold winds in winter (Tramontane, Mistrals)

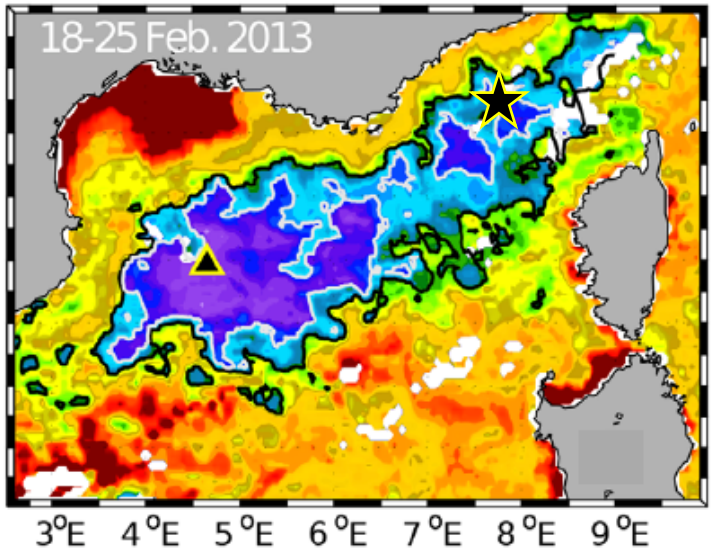
Strong air-sea fluxes in patches during short periods

Bottom reach convection in some years

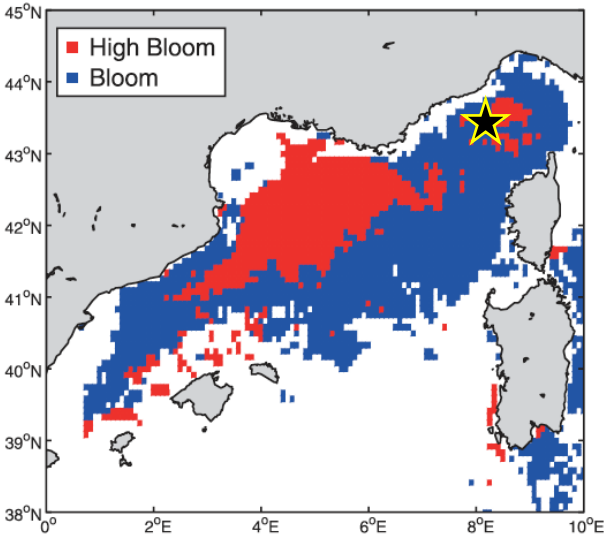
The Ligurian Sea system

- Open sea site with dense water formation zone
- Passage of LIW (oxygen minimum)
- Strong atmospheric inputs
- Seasonal phytoplankton bloom scenario
- Strong bloom which impact carbon export

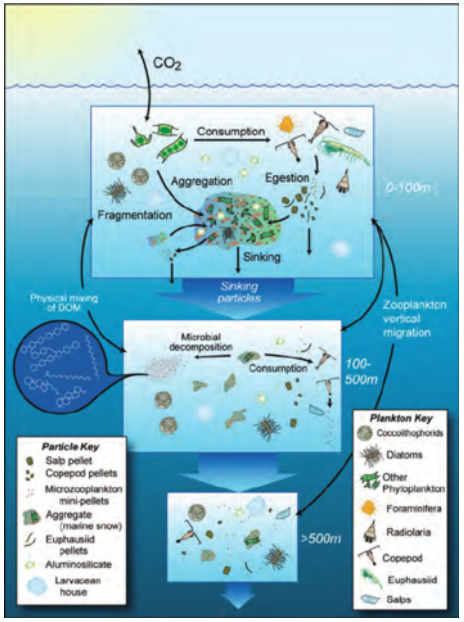




Surface Chla (MODIS) during winter open sea convection (Houpert et al., 2016)

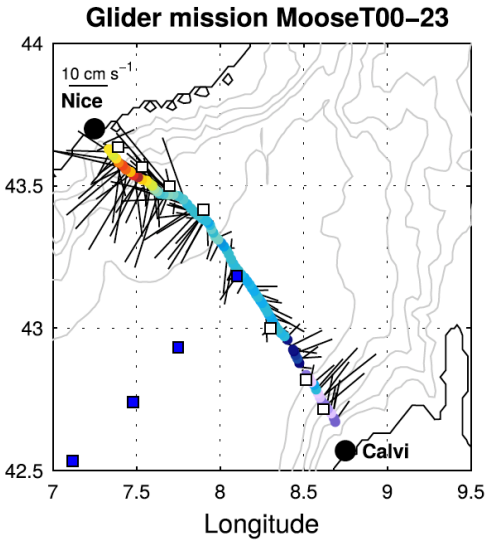


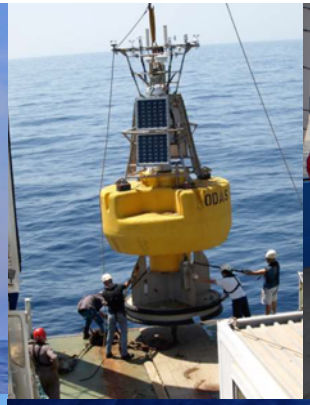
Spatial distribution of Chla (Mayot et al., 2017)

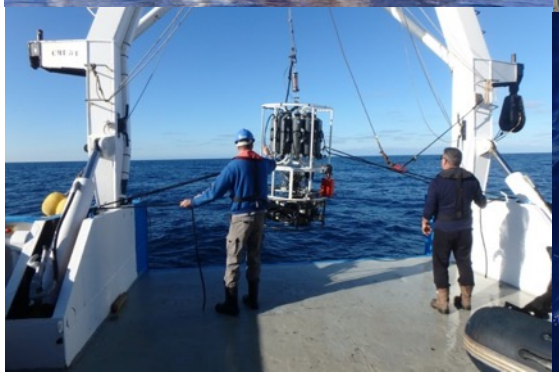


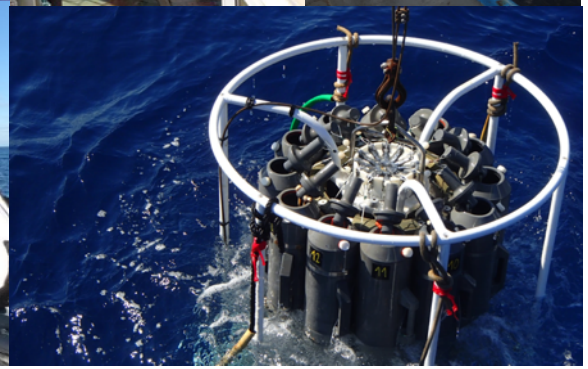
A multi-platform observatory in the Ligurian Sea:

- One standalone **deep mooring** (150-2350m) with two sediment traps (200 & 1000m) – infrastructure ERIC EMSO
- **One surface buoy** (Meteo France): upper layer (0-250m) and weather conditions – MOOSE
- **Monthly ship visits**: deep CTDO2 profiles, BGC sampling, Underwater Vision Profiler, zooplankton net – MOOSE
- **Glider endurance line**: monthly section Nice-Calvi (MOOSE T00) – MOOSE





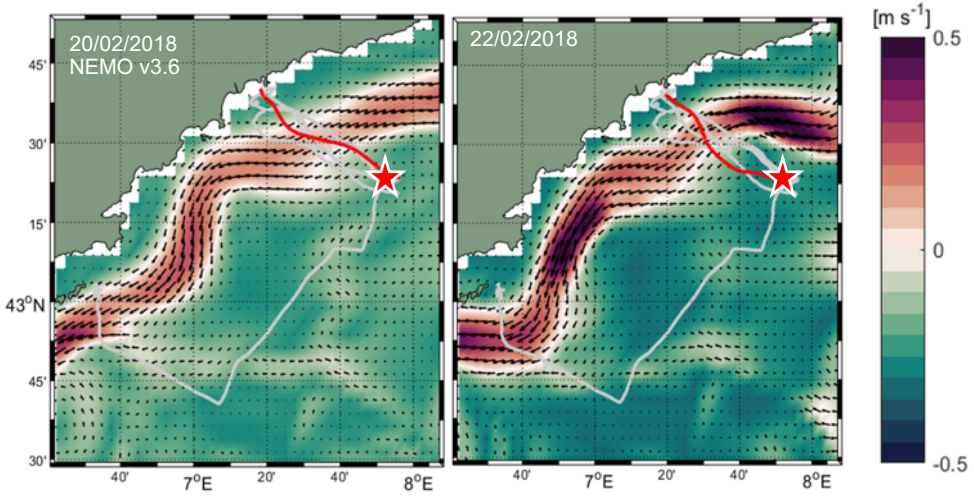


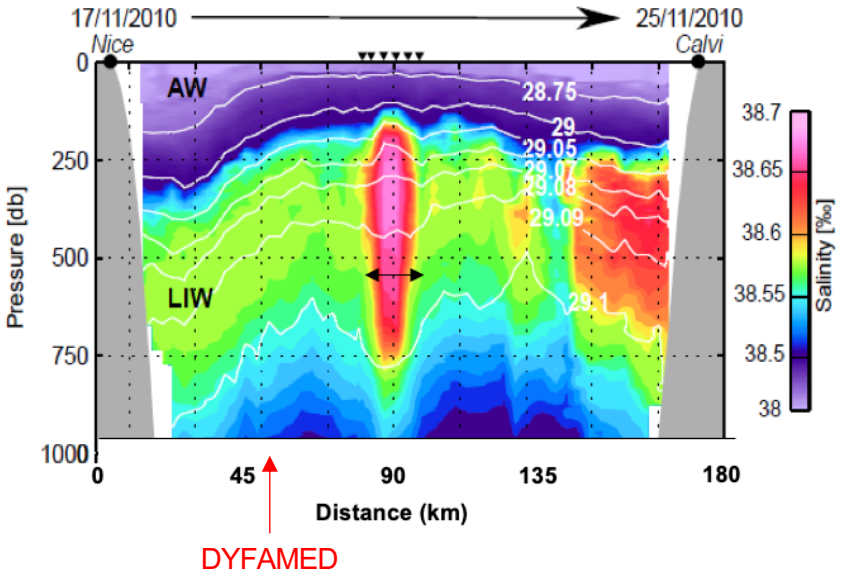


The limits of a fixed observing system

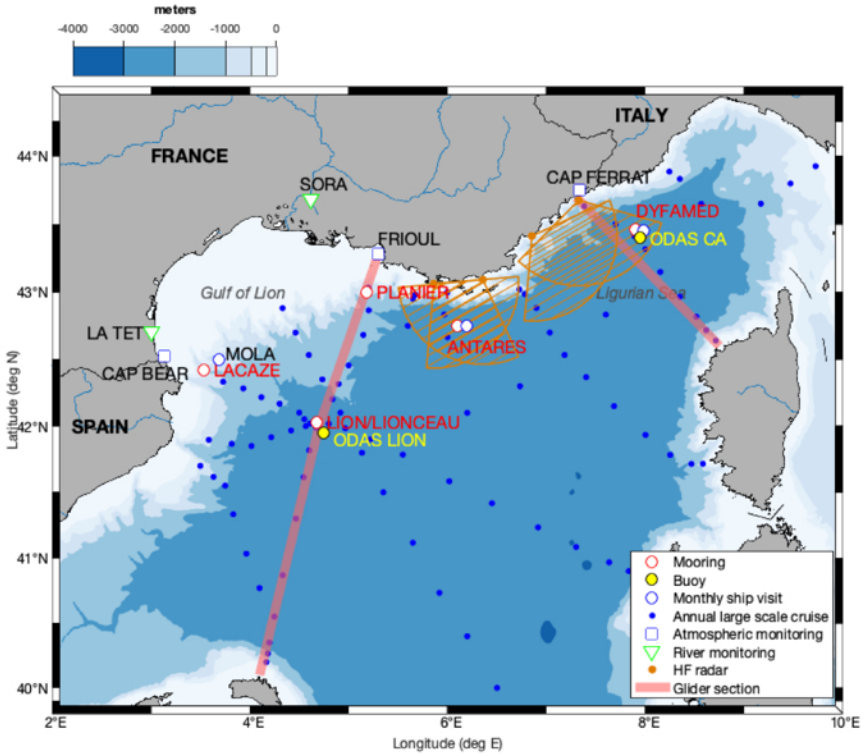
- Cyclonic circulation creates a doming of LIW in the central zone (thermocline lift)
- The Northern Current moves according to the seasons, the years
- Winter mixing is sometimes more intense beyond the site (70-100 km): some winters are not well observed ; the mixed patch is present in the center with biogeochemical implications
- Frontal movement and presence of sub-mesoscale eddies are not sampled but they have an essential role in the BGC dynamics and biology activity

Gliders can provide synoptic views of the newly-formed water masses on repeated sections and are able to observe fronts, plumes, small eddies with BGC impacts





MOOSE observing system strategy with gliders (since 2010)



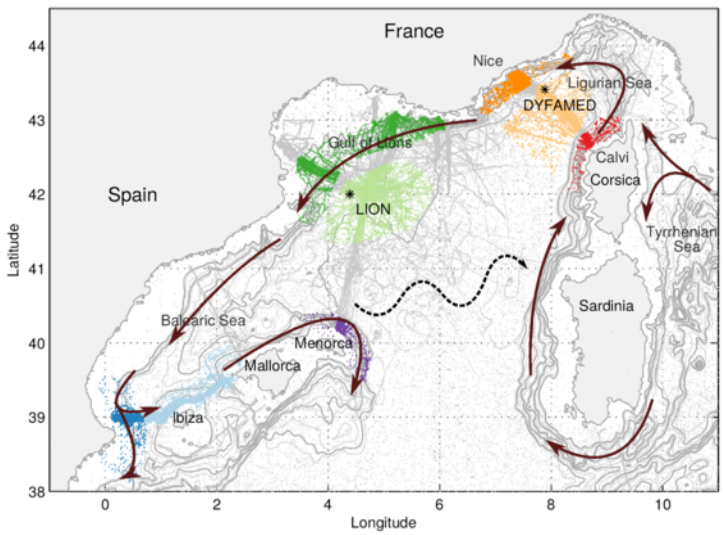
Coppola L., Raimbault P., Mortier L., Testor P. An integrated multidisciplinary observing system in the north-western Mediterranean Sea (MOOSE). 2019, EOS journal (Earth and Space Science News)

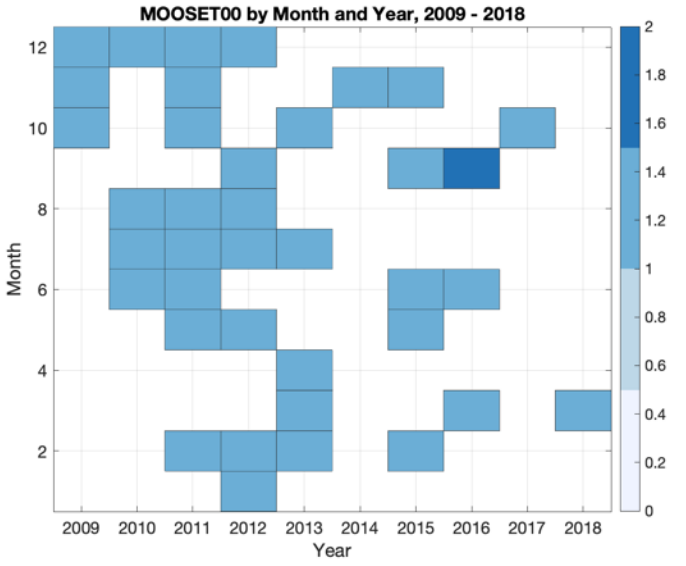
MOOSE T00 Nice-Calvi: LIW invasion, OML, bloom scenario, small eddies, impacts of fronts (NC, WCC)

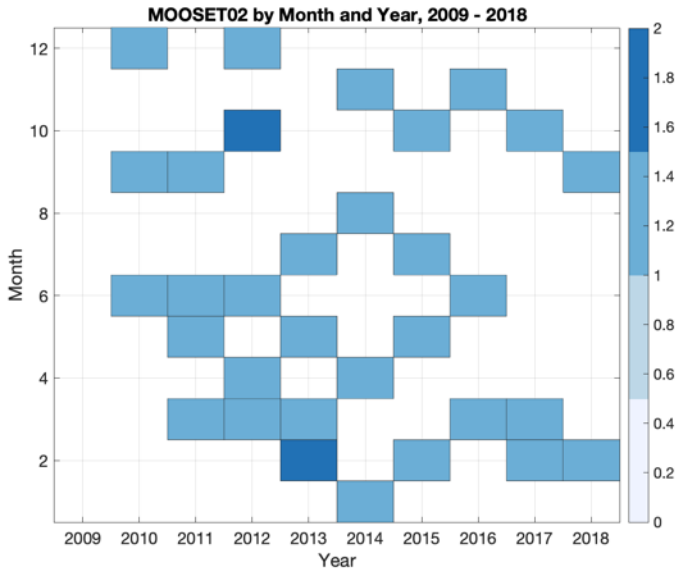
MOOSE T02 Marseille-Minorca: convection, spreading, ventilation, LIW invasion

Objectives = Jan-May + Oct-Dec

Gliders sections in the NW Med Sea



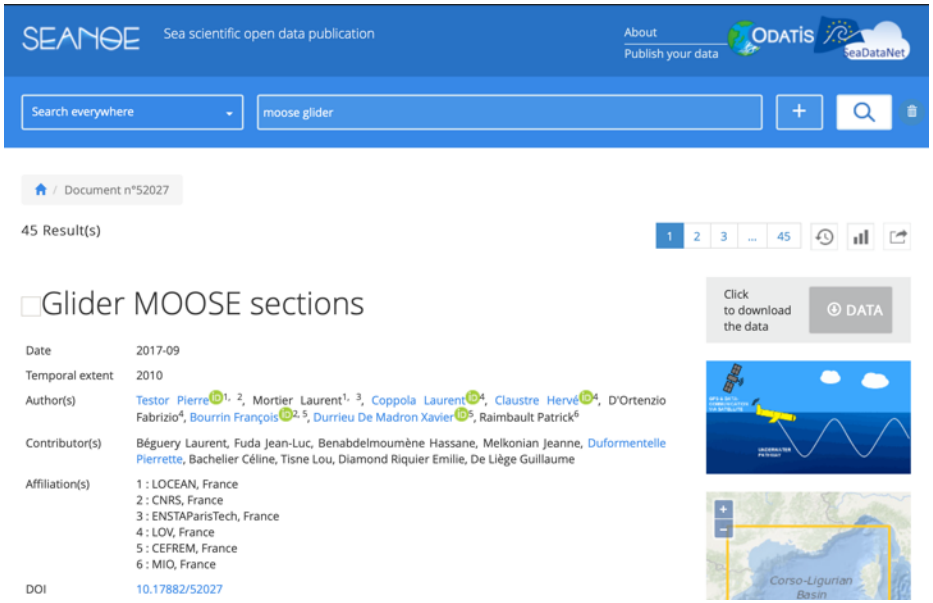




MOOSE T00 = 42 sections
MOOSE T02 = 22 sections (+ 12 from PERSEUS/MISTRALS)

MOOSE T00		MOOSET02	
Year	Days	Year2	Days2
2009	72		
2010	145	2010	184
2011	214	2011	118
2012	158	2012	253
2013	172	2013	156
2014	28	2014	197
2015	181	2015	299
2016	128	2016	198
2017	59	2017	133
2018	69	2018	140
Total	**1226**	**Total**	**1678**

MOOSE gliders data production



Period 2010-2018:

15 papers using MOOSE gliders data
7 phD thesis using MOOSE gliders data

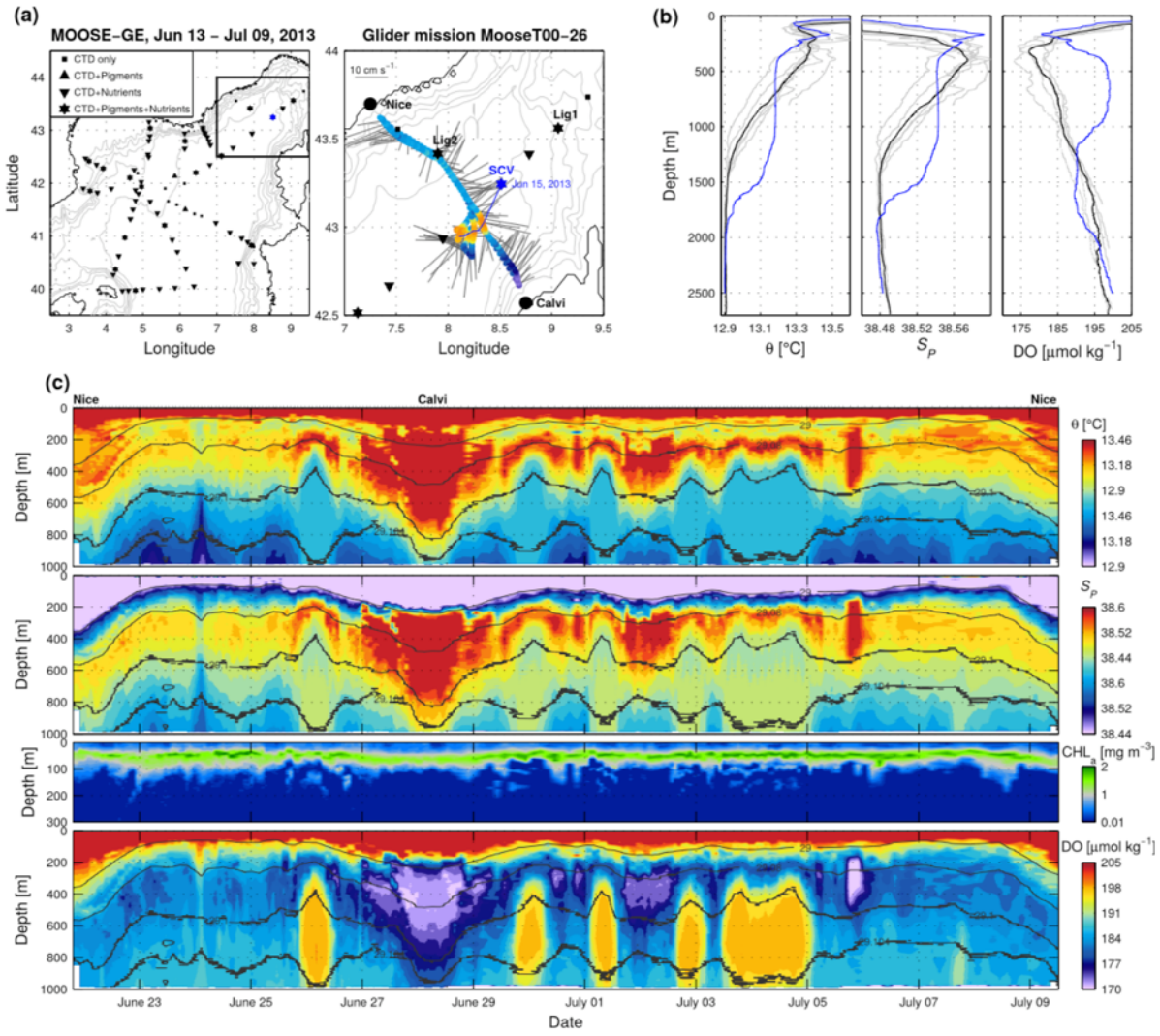
Characterization of the variability of deep water formation processes: (Testor et al, 2018; Somot et al, 2018) (Houpert et al, 2015; Margirier et al, submitted).

Characterization of (sub)mesoscale processes (Bosse et al., 2015a, 2015b; Damien et al., 2015) (Thesis A. Bosse, testor et al., 2018) (Margirier et al., 2017).

Quantification of coastal - open sea exchanges (Margirier et al., submitted)

DOI: Testor Pierre, Mortier Laurent, Coppola Laurent, Claustre Hervé, D'Ortenzio Fabrizio, Bourrin François, Durrieu De Madron Xavier, Raimbault Patrick (2017). **Glider MOOSE sections**. SEANOE. https://doi.org/10.17882/52027

Observation of Submesoscale Coherent Vortices (SCV)



Submesoscale anticyclones at intermediate depth characterized by a small radius (around 5km)

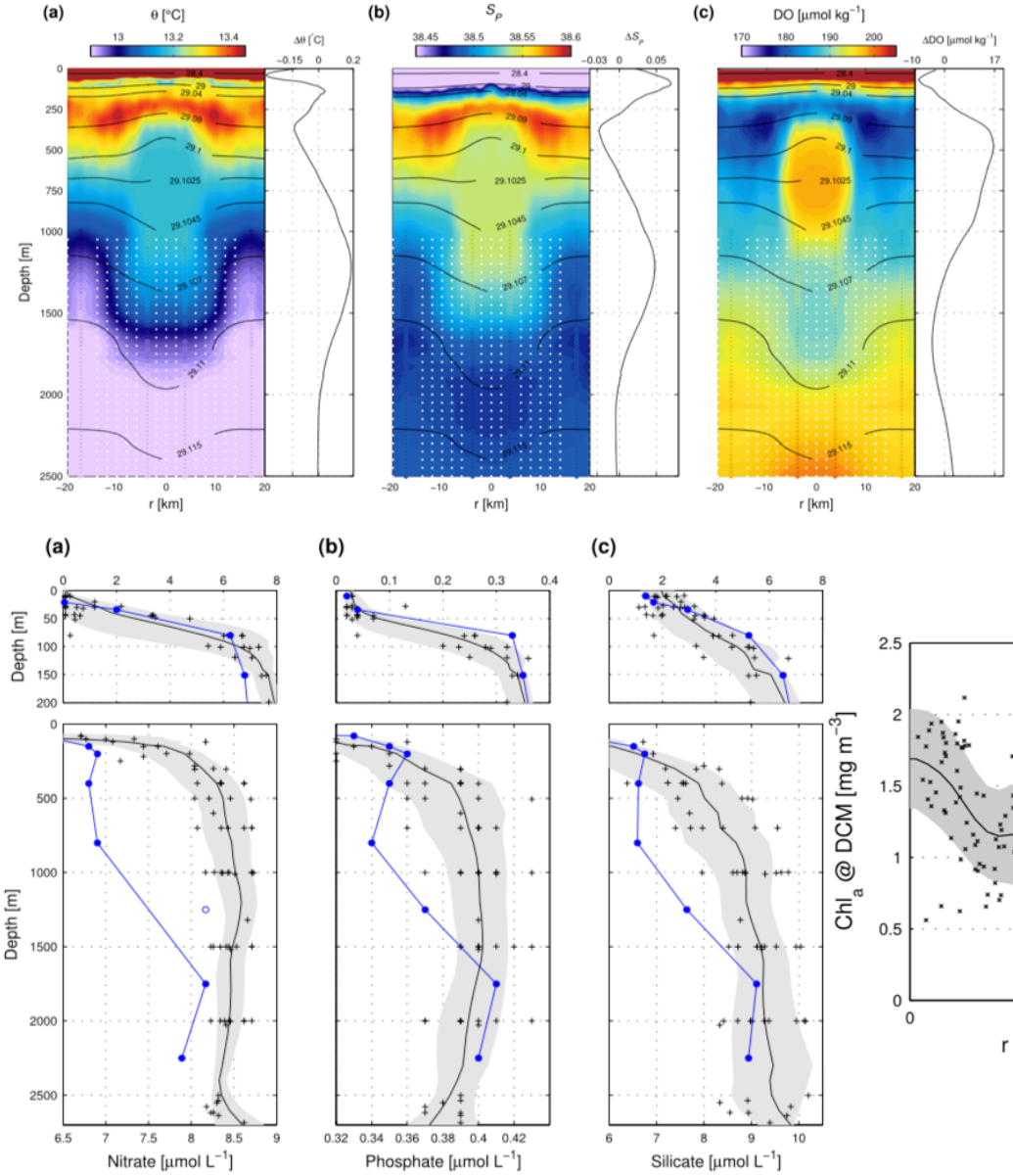
Formed by WCC circulation with LIW signal (O2 min)

Formed during DWF (higher O2, lower nutrients)

Bosse et al. 2016, 2017

Impacts on oxygen, nutrients and Chl-a

summer 2013



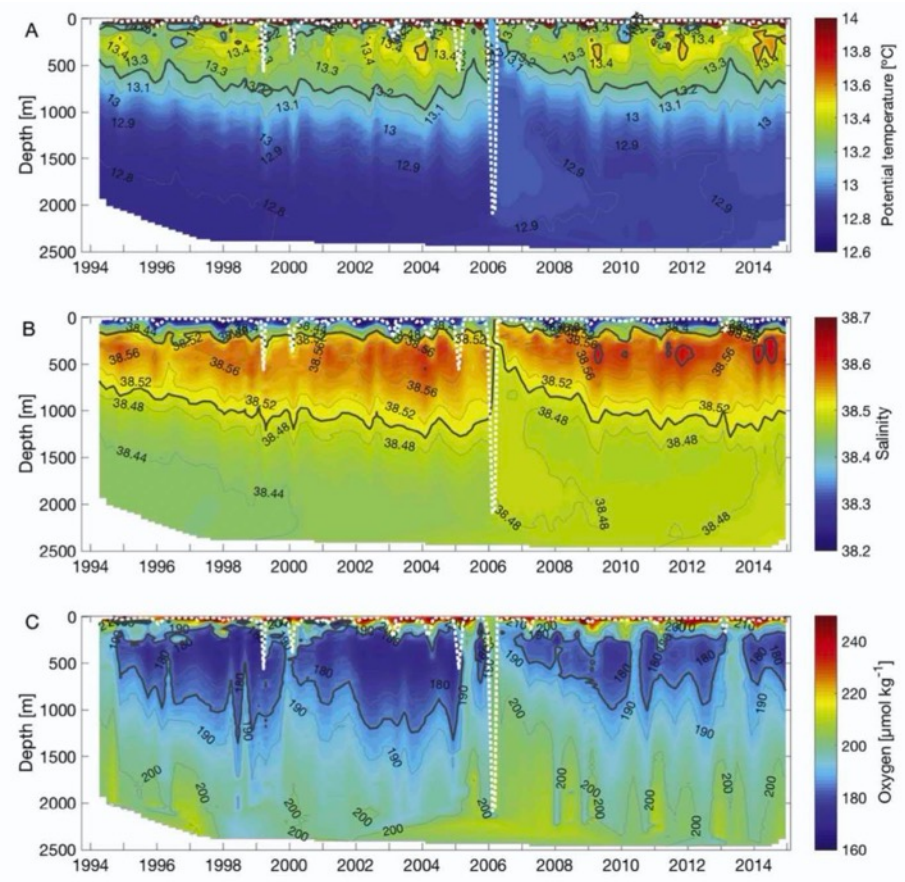
Help to spread the LIW or the newly formed deep water in western basin

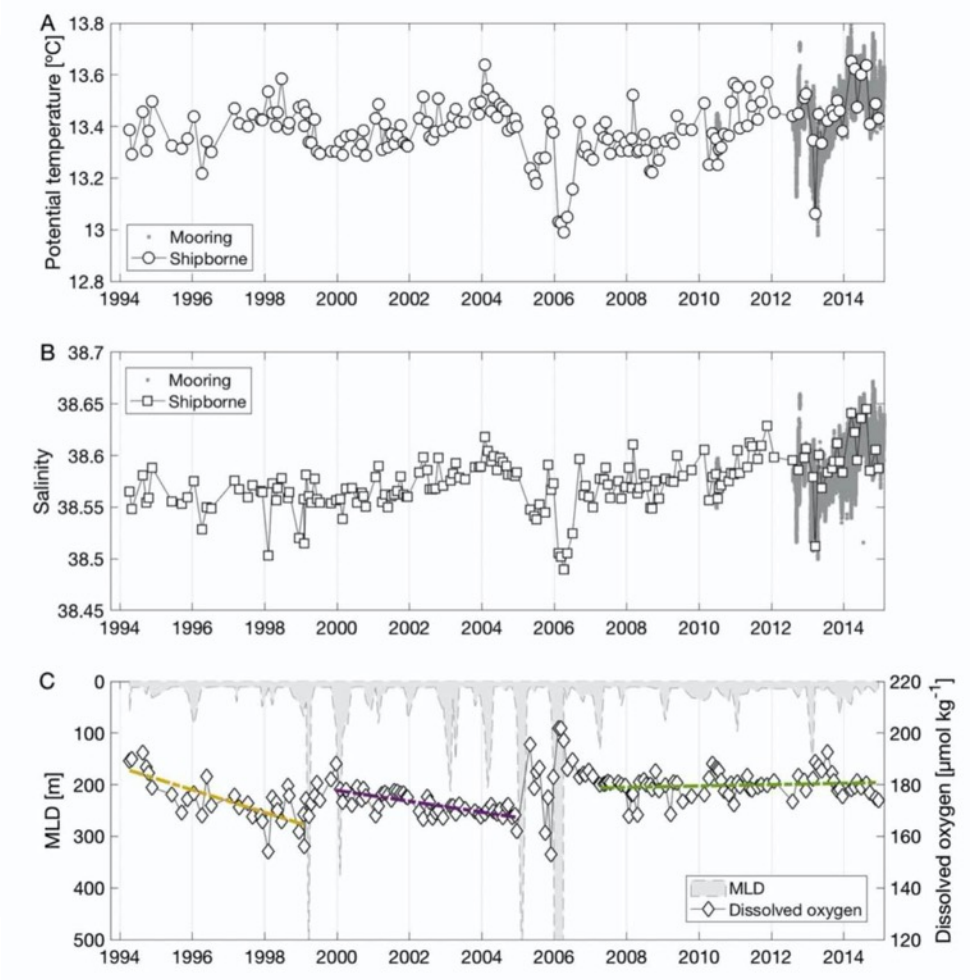
The core is depleted in nutrients and nutriclines are shifted to surface helping the nutrients availability for phytoplankton

Chlorophyll-a in DCM are twice bigger in the eddy

Bosse et al. 2017

Oxygen minimum trend in the Ligurian Sea



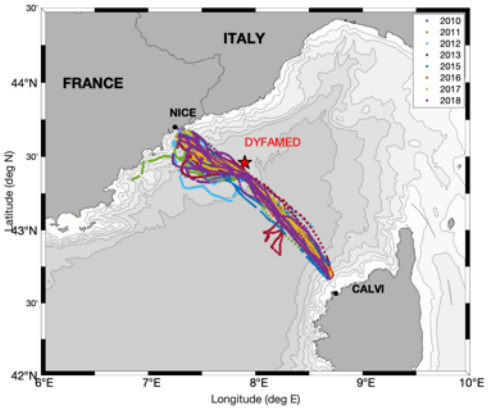


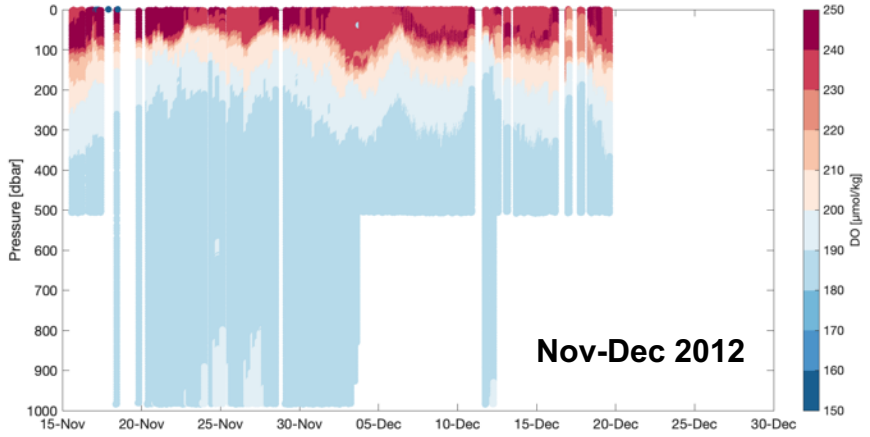
Coppola et al., 2018

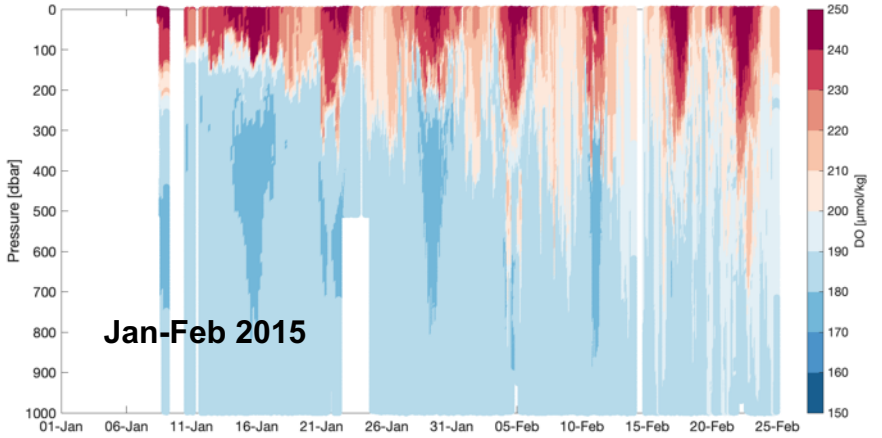
Estimated decrease of 5-7 µmol/kg based on 20 years of observation on fixed site (ship + mooring)

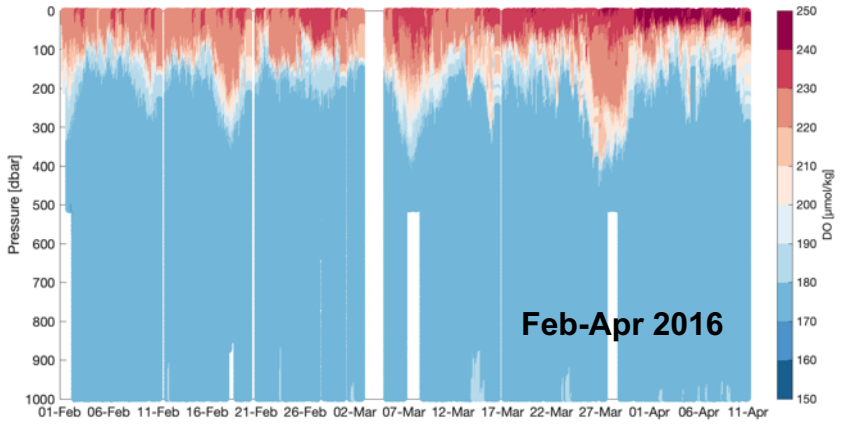
Oxygen adjustment for gliders (optode)

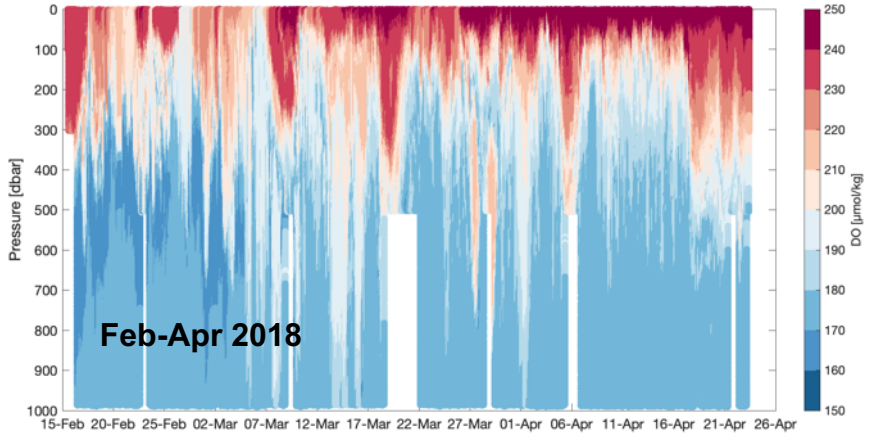
- Multi-points calibration and optode storage are now used
- Follows Argo recommendations: temperature correction and time lag correction to minimize the differences between up- and down-casts
- Adjustment through pO2 (slope, offset) using reference casts (time series)











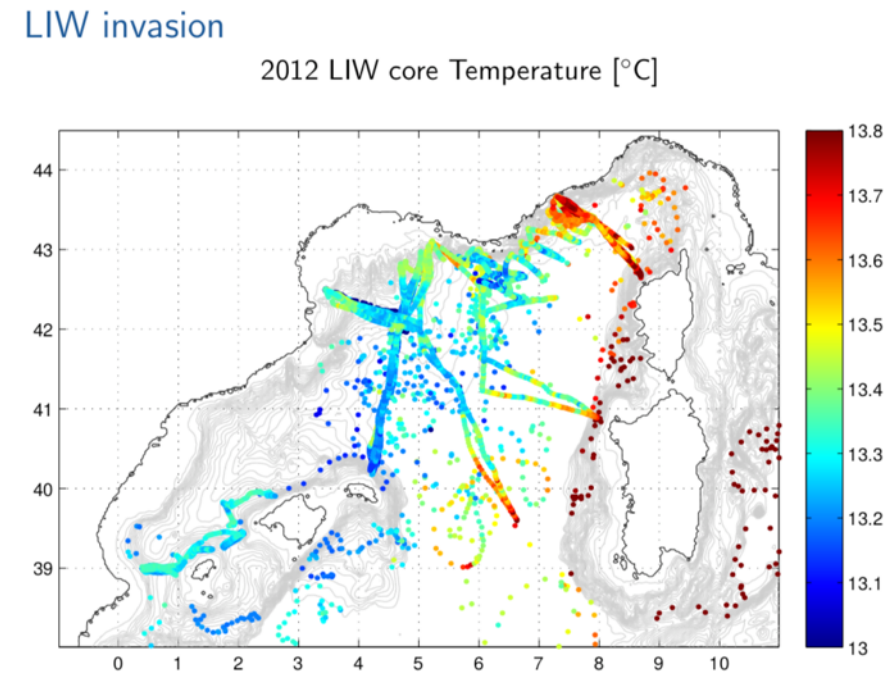
Levantine Intermediate Water (LIW) invasion

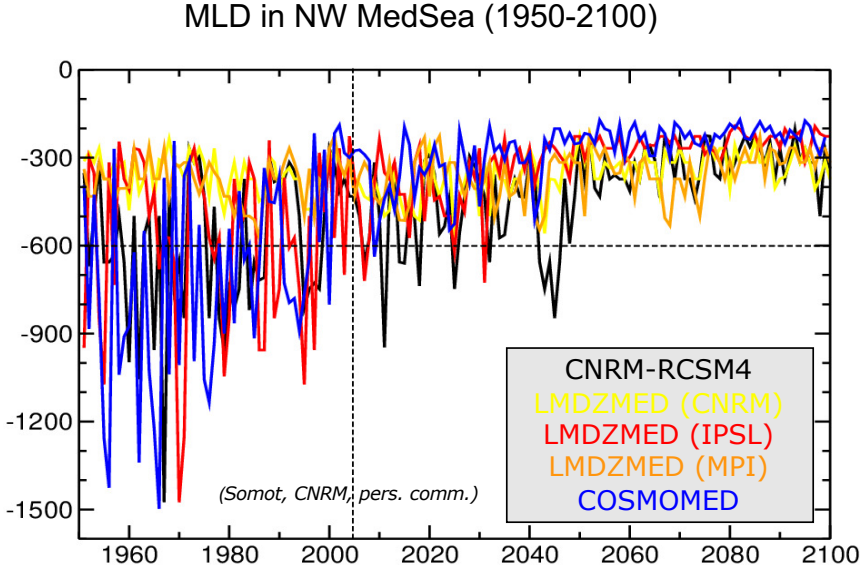
Quantification of basin scale and interannual deep convection (heat and salt invasion at intermediate layer)

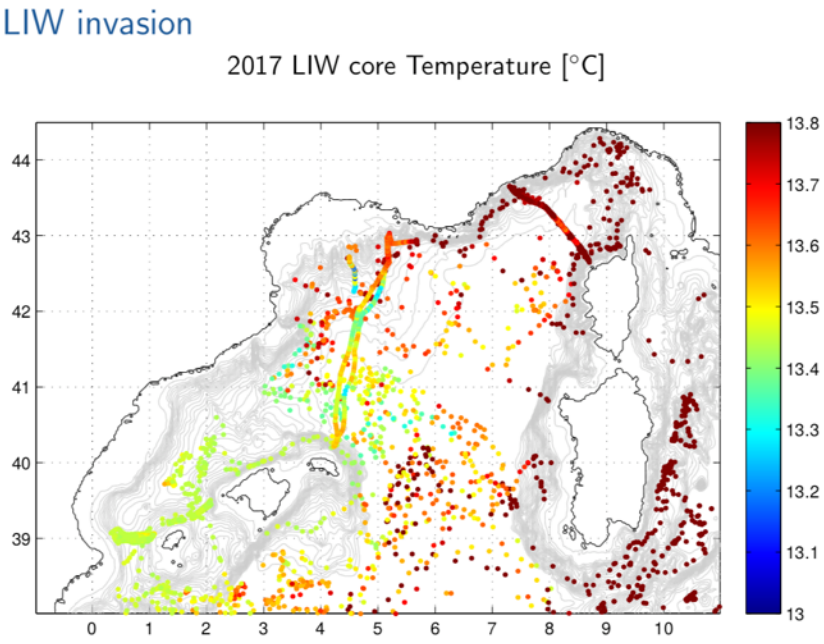
Properties of LIW are important for the preconditioning phase

Deep convection intensity depends on the previous year (being convective or not)

Impact on the O2 minimum layer ?

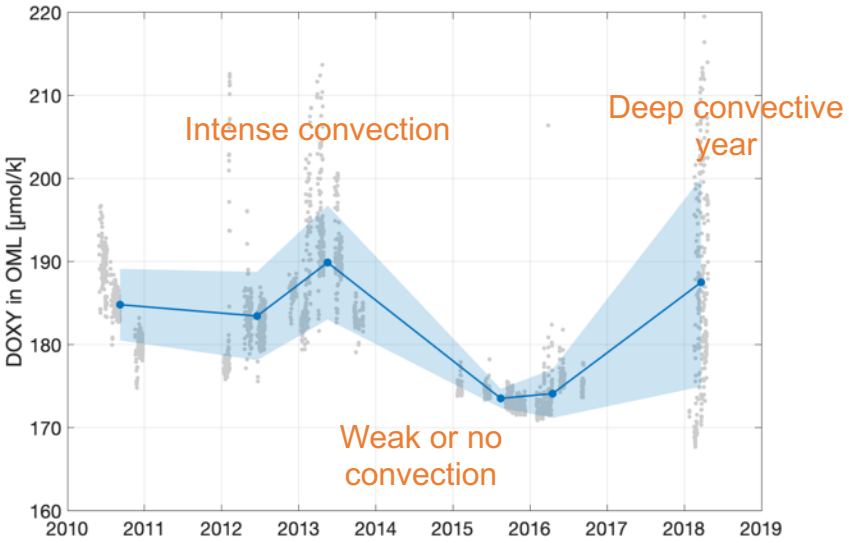


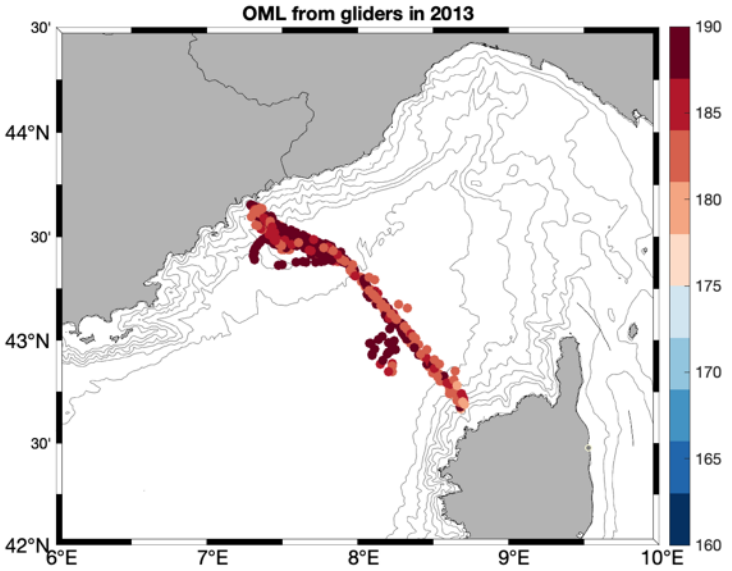


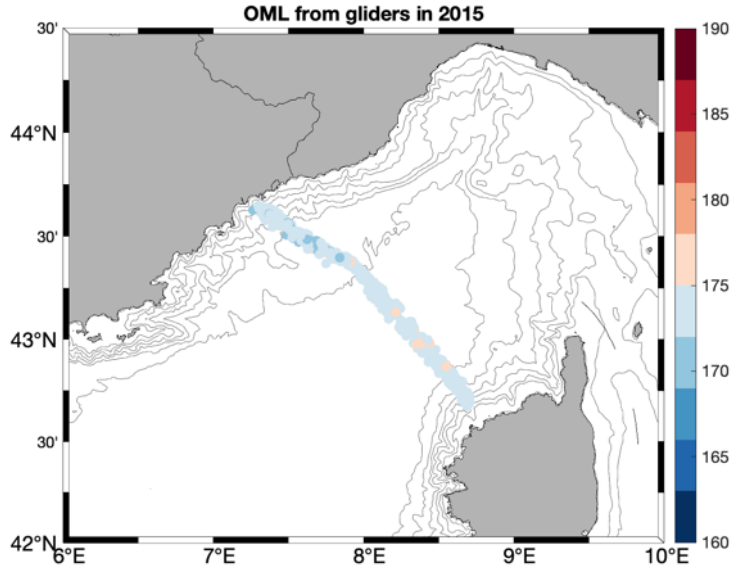


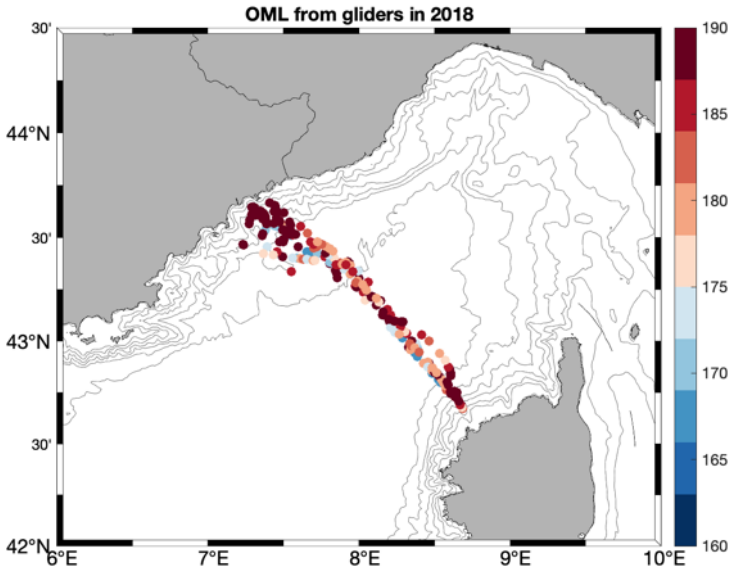
F. Margirier et al. (2017; phD thesis)

Oxygen Minimum Layer evolution in the Ligurian Sea



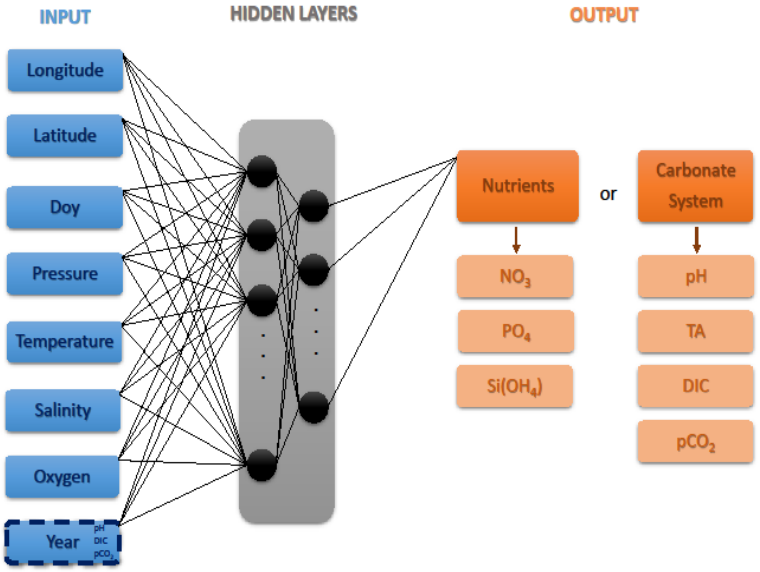






Deep-learning applications

- Deep learning techniques are used to capture intrinsic and complex (non-linear) relationships between variables in a dataset and those to be predicted (training + validation)
- Use of GLODAP v.2 at the global level to find the "best" estimates of nutrients (NO3) and carbonates (pH)



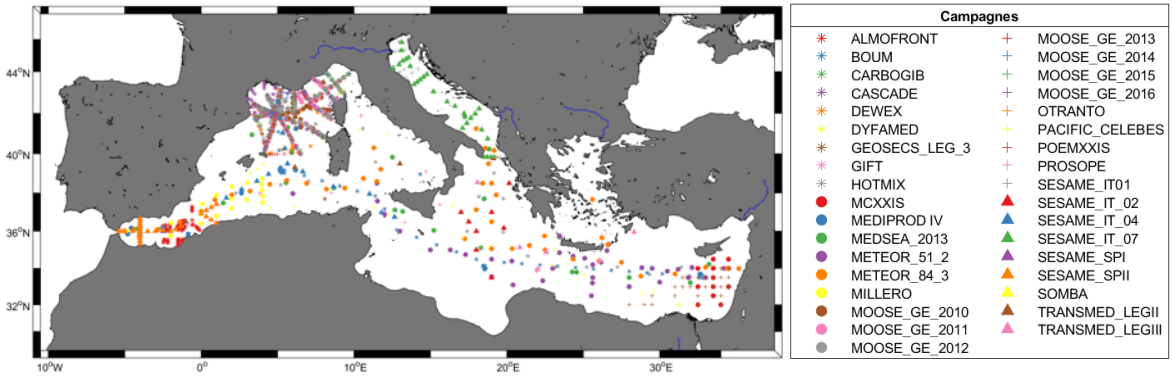
Estimates of Water-Column Nutrient Concentrations and Carbonate System Parameters in the Global Ocean: A Novel Approach Based on Neural Networks

Raphaëlle Sauzède[1,2], Henry C. Bittig[1], Hervé Claustre[1], Orens Pasqueron de Fommervault[1,3], Jean-Pierre Gattuso[1,4], Louis Legendre[1] and Kenneth S. Johnson[5]*

Set of the 10 best topologies for each variable to reduce output uncertainties

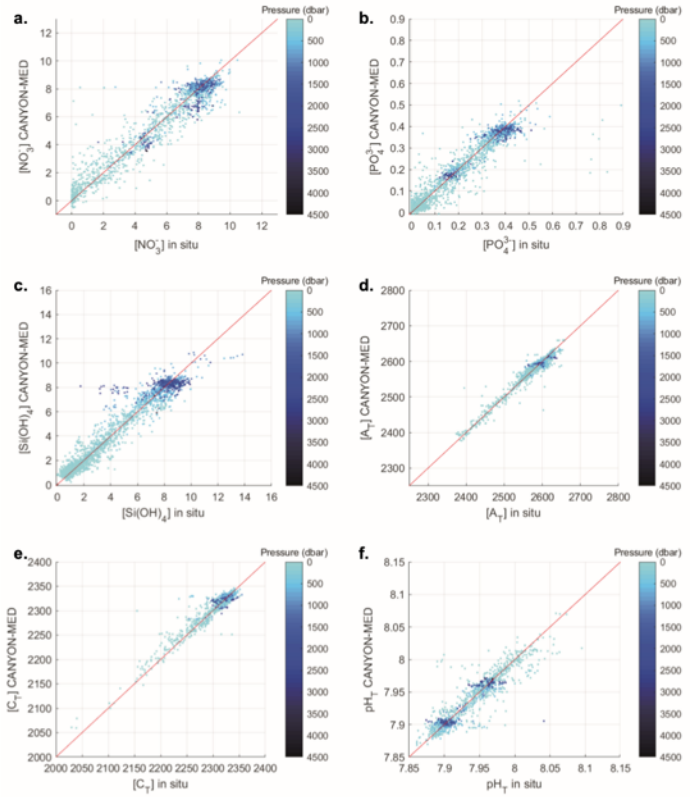
CANYON = « CArbonate system and Nutrients concentration from hYdrological properties and Oxygen using a Neural-network » (Sauzede et al. 2016 & 2017)

Downscaling to the MedSea « CANYON-MED »



Training: 35 cruises 1976-2018 (adjusted and validated level 2) including DYFAMED time series

Validation: ANTARES time series



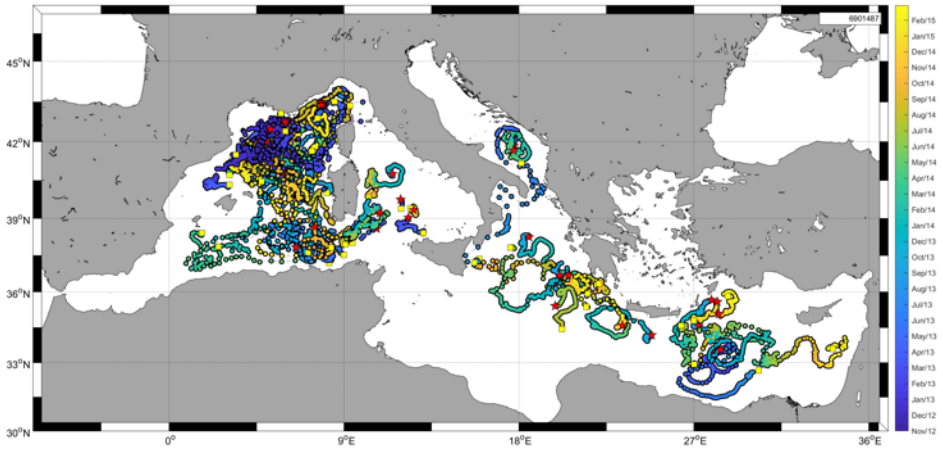
	CANYON-MED			
	R^2	Slope	MAE	RMSE
NO_3^- (µmol.kg^{-1})	0.95	0.96	0.47	0.77
PO_4^{3-} (µmol.kg^{-1})	0.91	0.95	0.028	0.047
$Si(OH)_4$ (µmol.kg^{-1})	0.96	0.95	0.40	0.70
A_T (µmol.kg^{-1})	0.95	0.98	7	11
C_T (µmol.kg^{-1})	0.89	0.91	9	14
pH_T	0.87	0.91	0.010	0.015

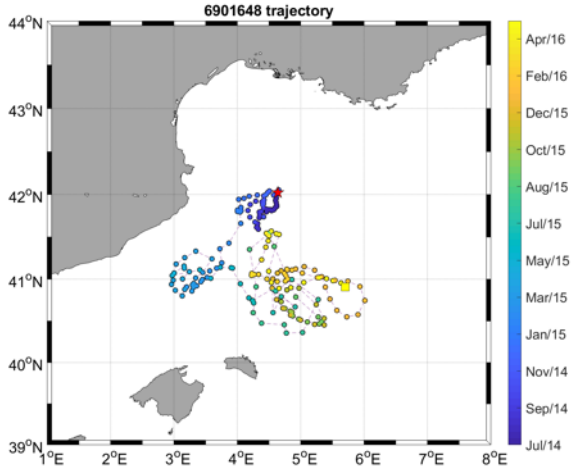
Performances of CANYON-MED

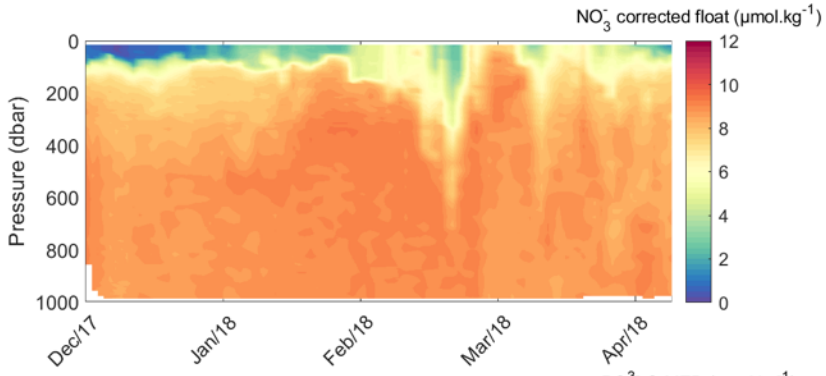
Improve the spatial and seasonal variability of nutrients and carbonates (role of nitracline in primary production)
Penetration of anthropogenic CO2
pH evolution

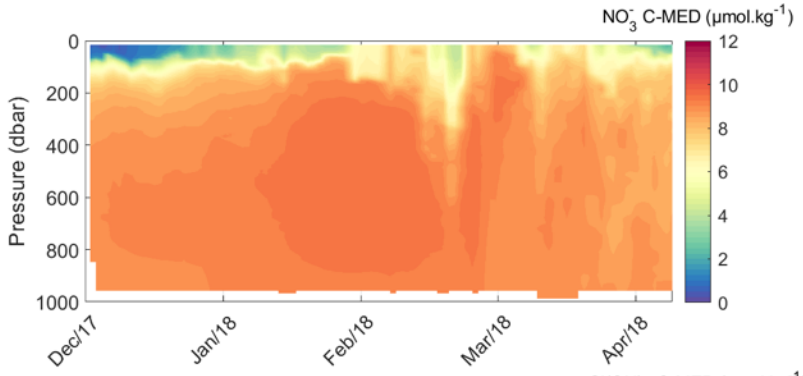
phD thesis M. Fourrier (2018-2021)

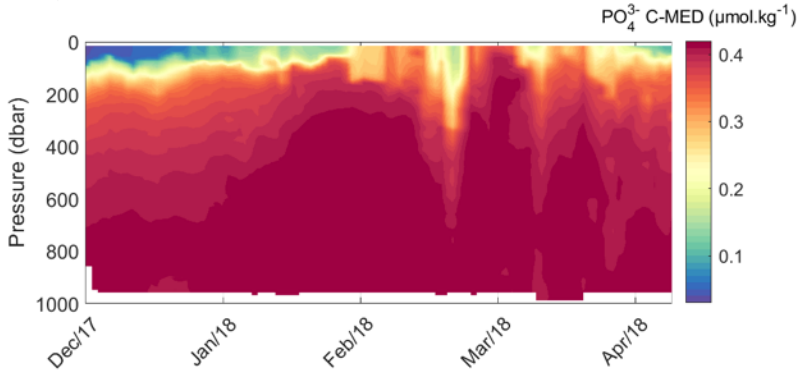
Future applications using gliders adjusted data (TSO2)

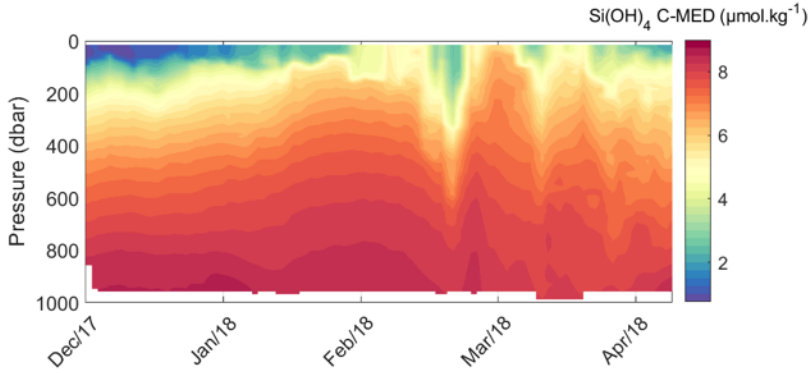












MOOSE gliders review

- Gliders are vital component for the MOOSE network (repeated sections): coastal-open sea processes, small and larger structures, combined physical and BGC approaches, useful for operationnal oceanography, education and society

- Great potential to observe and understand processes as deep convection and spreading, identify small eddies, LIW invasion, oxygen minimum evolution

- Gliders data would be complementary to Argo to produce higher level BGC dataset through CANYON-MED

- Inbalance between MOOSET00 and MOOSET02: should focus on winter-spring period (at least) to do some science

- Need to adopt Argo data correction protocols (in process)