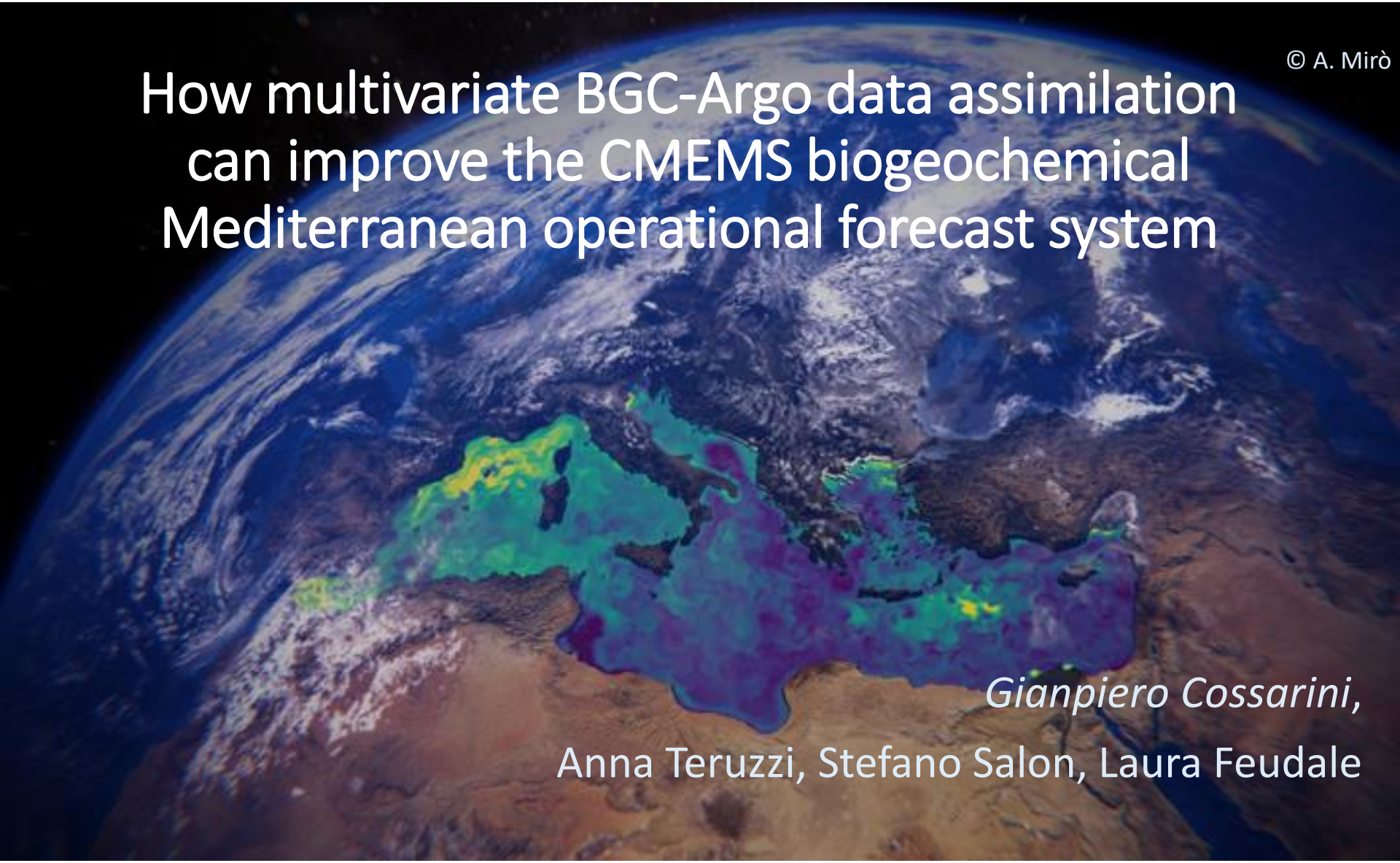

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How multivariate BGC-Argo data assimilation can improve the CMEMS biogeochemical Mediterranean operational forecast system

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Context

- ***This work is part of the R&D (2015-2018 MASSIMILI project OGS LOV) of COPERNICUS MARINE ENVIRONMENT MONITORING SERVICES (CMEMS), the EU system for the operational oceanography***

CMEMS Mediterranean Forecast and Monitoring Centre: a system of models for PHY – BIO – WAV

[Mediterranean model domain: 17W-36E, 30N-46N, 4.5km hor. res., 141 z*levels]

Atmospheric forcing
ECMWF-IFS: 3h/6h at 1/8° momentum, water and heat fluxes analysis & forecast

Land interface: runoff and nut loads
39 rivers (GRDC, UNEP-MAP, Perseus dataset)

Boundary Conditions for PHY, BIO & WAV:
Atlantic (from GLO-MFC 1/12° and climatology) & Dardanelles (from climatology)

Observations: T, S, SSH, CHL, WAVE

MED-PHY

MFS @ CMCC

NEMO 3.6 – ocean dynamics
non-linear free surface

WaveWatch-III (WW3)
coupling to wave dynamic

3DVAR – data assimilation
variational scheme with assimilation of T and S vertical profiles and along-track satellite SLA observations

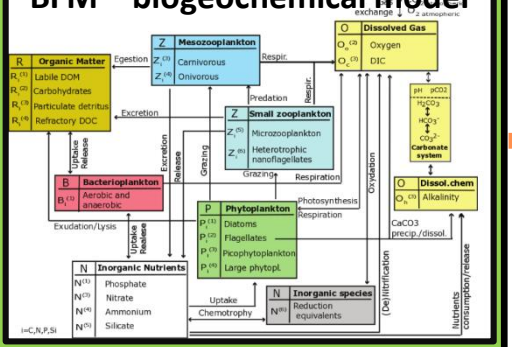
MED-BIO

MedBFM @ OGS

OGSTM – transport model
non linear free surface

$$\left.\frac{\partial \boldsymbol{C}}{\partial t}\right|_{tra} = -\boldsymbol{v}\cdot\nabla\boldsymbol{C} + \nabla(K\nabla\boldsymbol{C})$$

BFM – biogeochemical model



3DVarBio – data assimilation
variational scheme with assimilation of CHL from satellite OC

MED-WAV

WAM @ HCMR

WAM Cycle 4.6.2 – wave model
wave spectrum discretized with 32 freqs in 24 directions

Double grid set-up
North Atlantic at 1/6
Mediterranean Sea at 1/24

OI – data assimilation
DA scheme of WAM with optimal interpolation of SWH

FORECAST & REANALYSIS PRODUCTS

CMEMS catalogue at marine.copernicus.eu

3DVarBio: variational assimilation scheme

- Minimization of the cost function J with background error covariance matrix B decomposition

Minimization of the cost function J

$$J = \frac{1}{2}\delta \boldsymbol{x}^T \mathbf{B}^{-1} \delta \boldsymbol{x} + \frac{1}{2}(\boldsymbol{d} - \mathbf{H}\delta \boldsymbol{x})^T \mathbf{R}^{-1} (\boldsymbol{d} - \mathbf{H}\delta \boldsymbol{x})$$

d innovation vector, B and R error covariances of background and observation

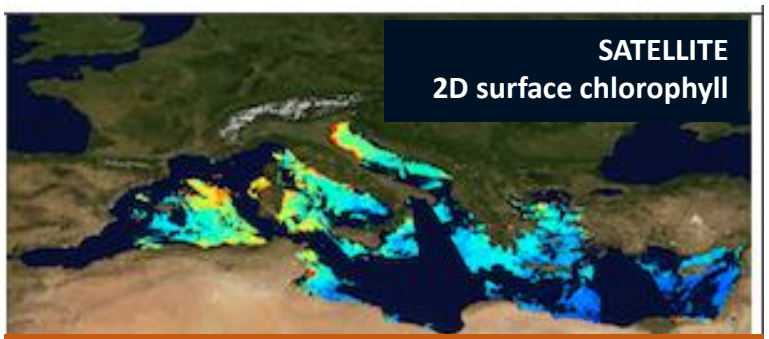
With B background error covariance matrix decomposition

$$\mathbf{B} = \mathbf{V_b}\ \mathbf{V_h}\ \mathbf{V_v}$$

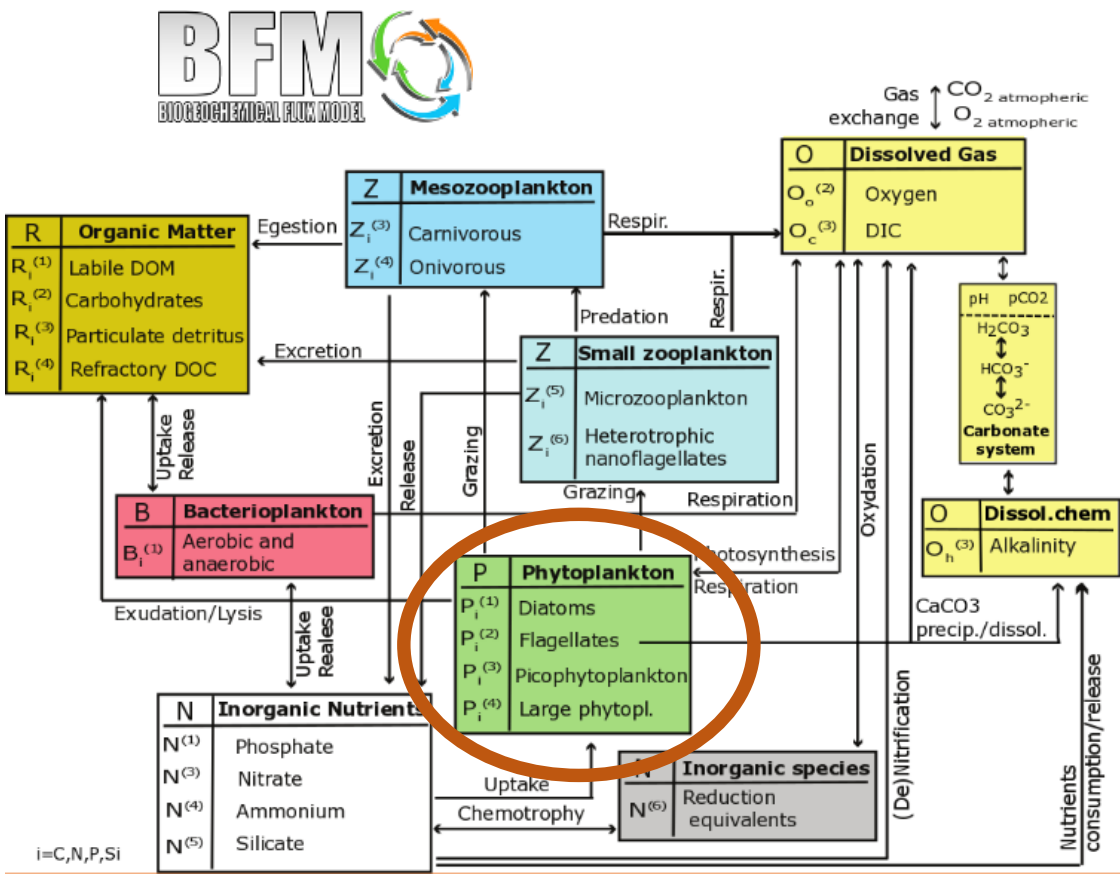
V_v vertical error covariance
V_h horizontal error covariance
V_b accounts for covariance among biogeochemical variables

(Teruzzi et al., 2014 and 2018)

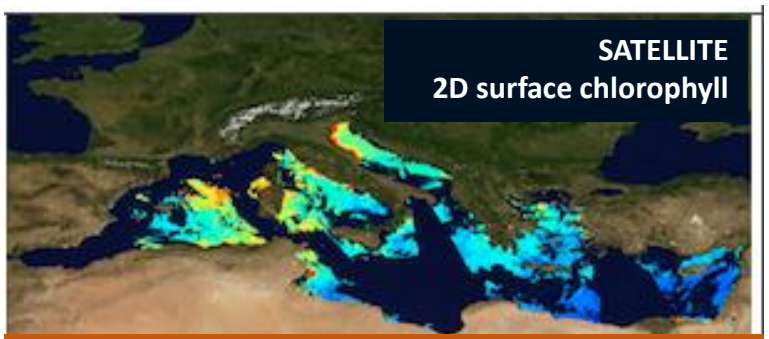
3DVarBio assimilation scheme: operational assimilation of satellite chlorophyll



Assimilation of open sea and coastal concentration (Teruzzi et al., 2018, Teruzzi et al. 2019)



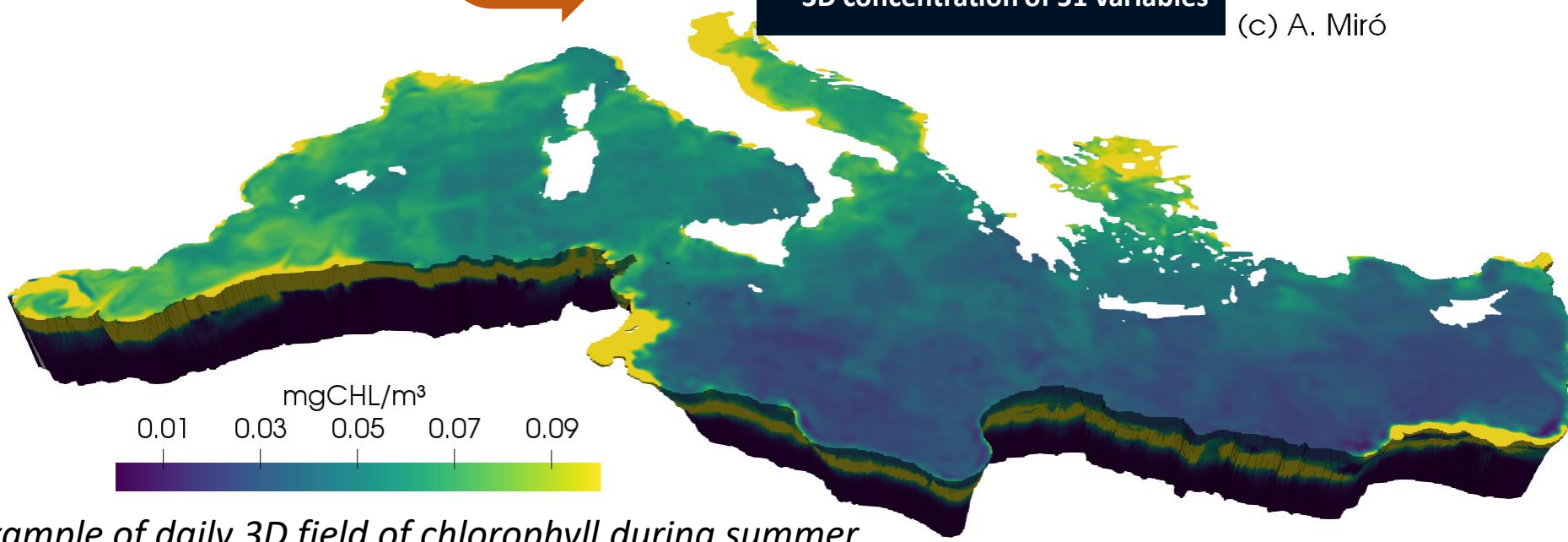
3DVarBio assimilation scheme: operational assimilation of satellite chlorophyll



Assimilation of open sea and coastal concentration (Teruzzi et al., 2018, Teruzzi et al. 2019)

BIOGEOCHEMICAL MODEL
3D concentration of 51 variables

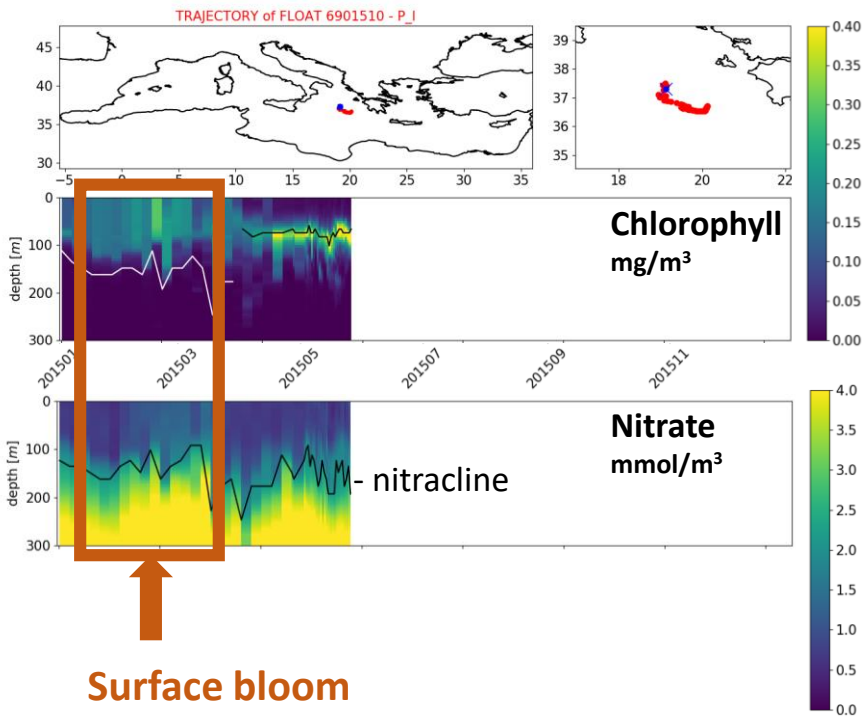
(c) A. Miró

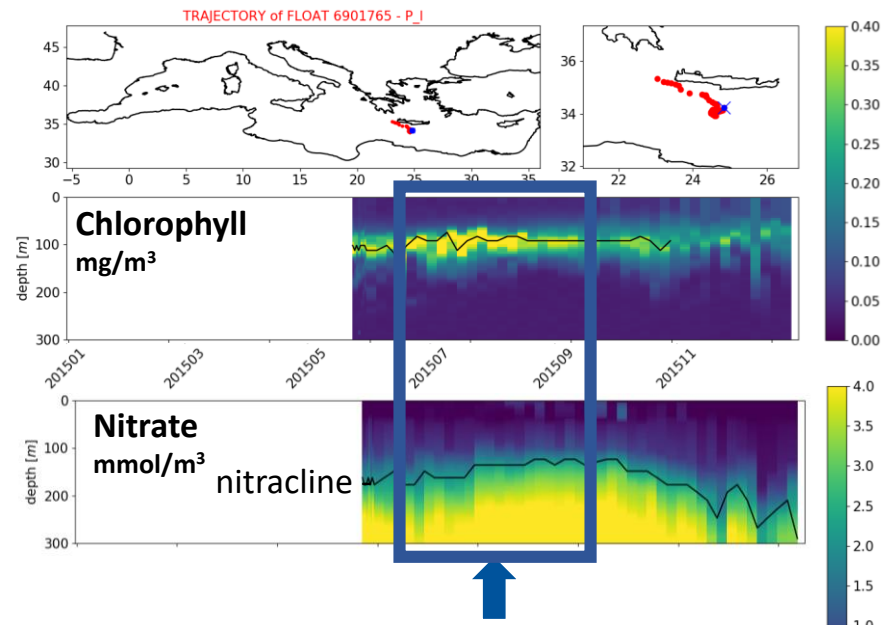


Example of daily 3D field of chlorophyll during summer

BGC-Argo measurements

- Chlorophyll and nitrate profiles along float tracjectory





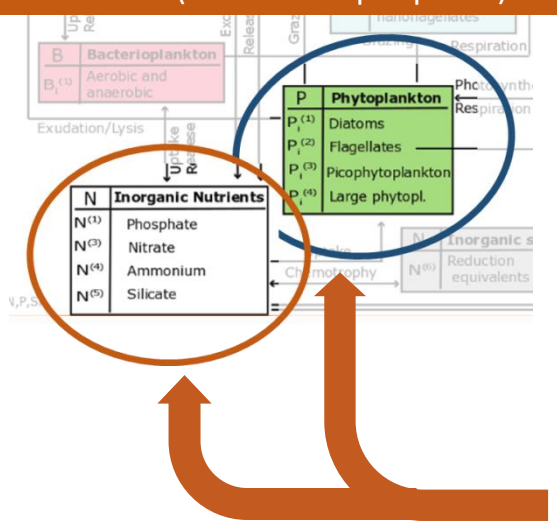
Deep Chlorophyll Maximum condition and evolution of nitracline (max vert gradient)

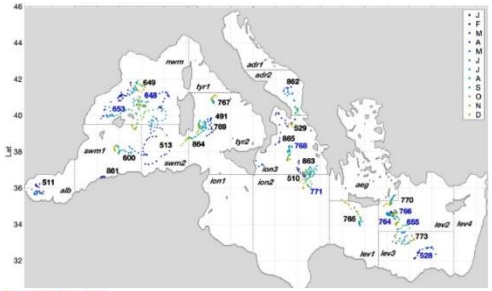
Assimilation of BGC-Argo chlorophyll and nitrate

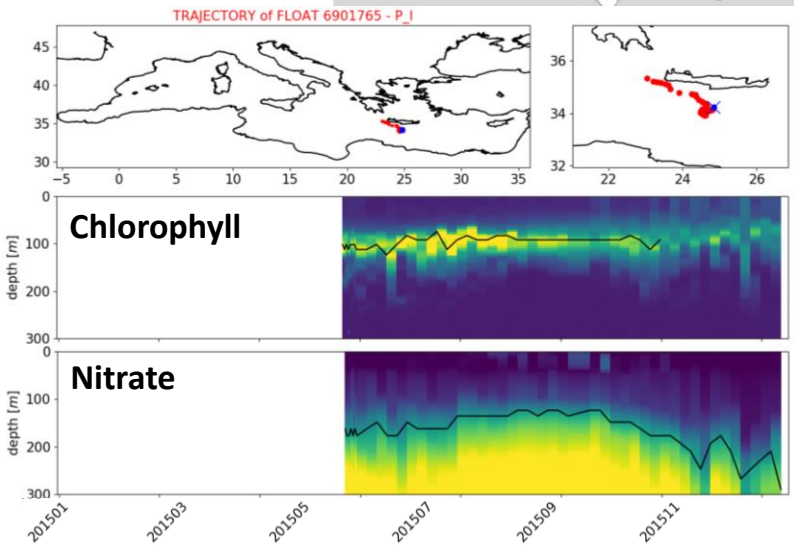
Vb applies increments on the 17 phytoplankton variables

and on nutrients

DA chl & nitrate → phytoplanton & nutrients (nitrate and phophate)



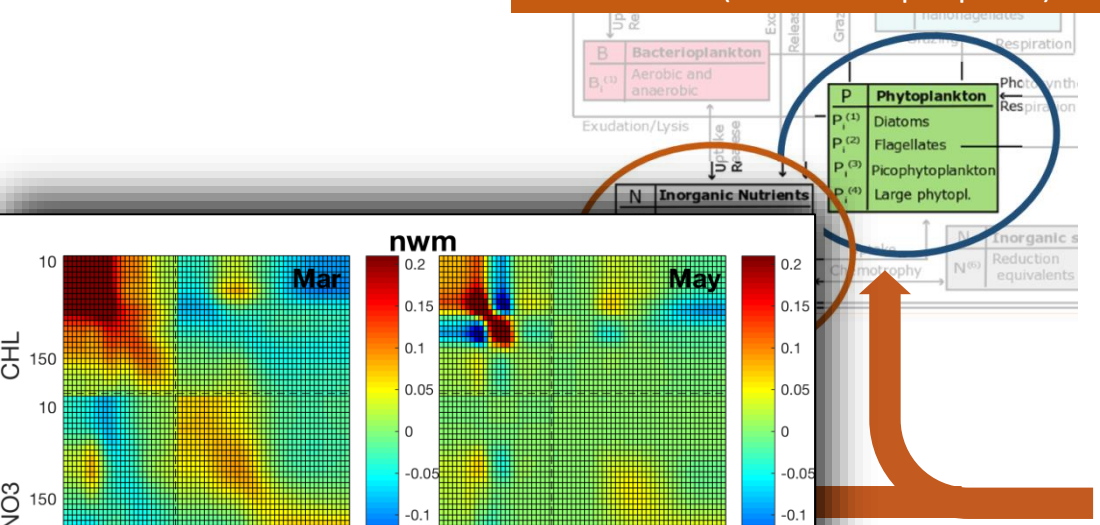


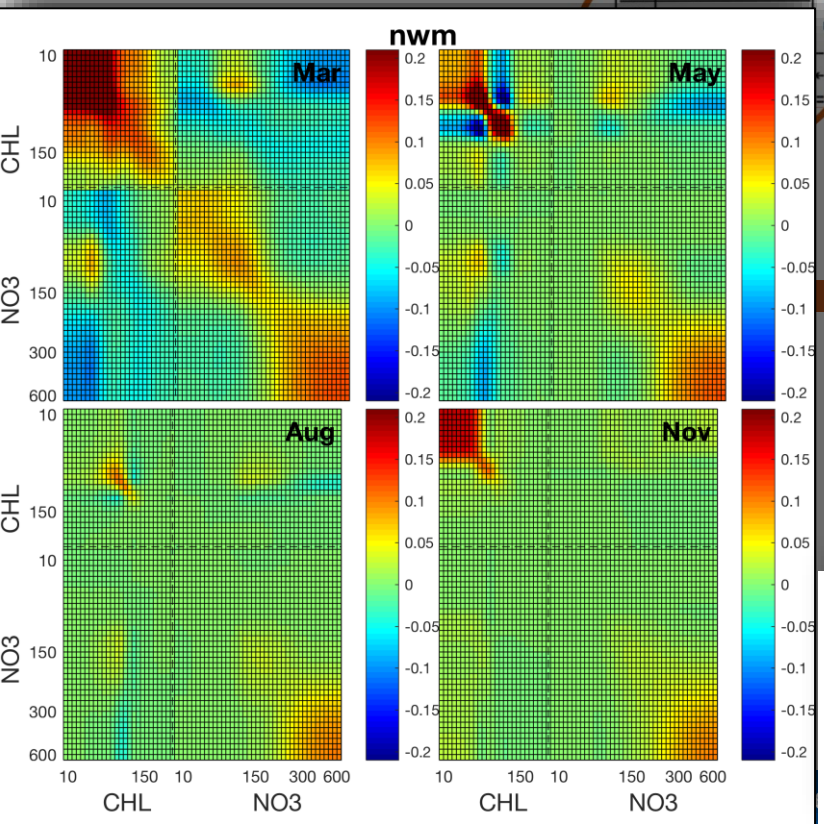


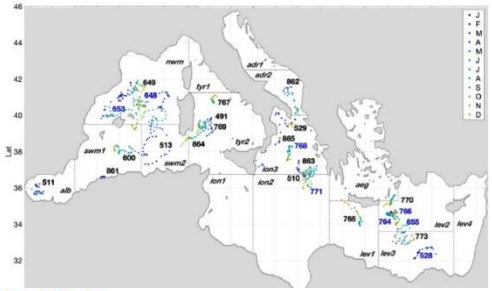
BGC-Argo FLOATS CHLOROPHYLL and NITRATE

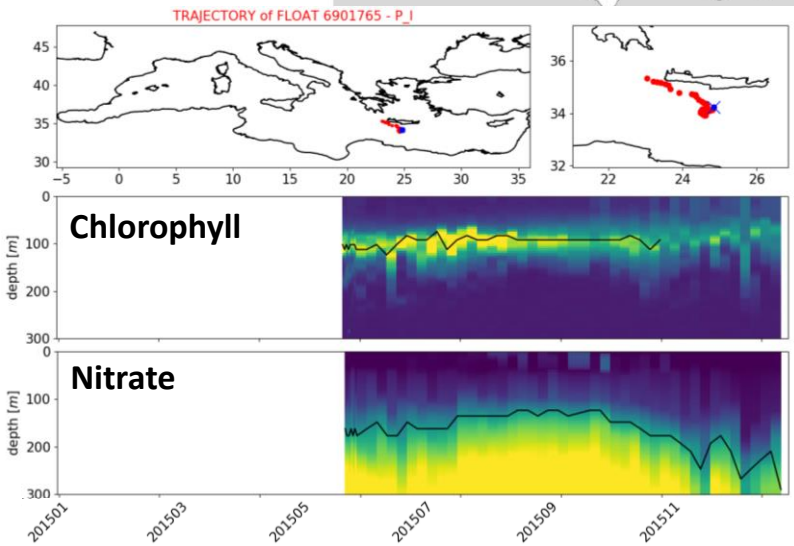
Assimilation of BGC-Argo chlorophyll and nitrate: critical aspects

DA chl & nitrate → phytoplanton & nutrients (nitrate and phophate)







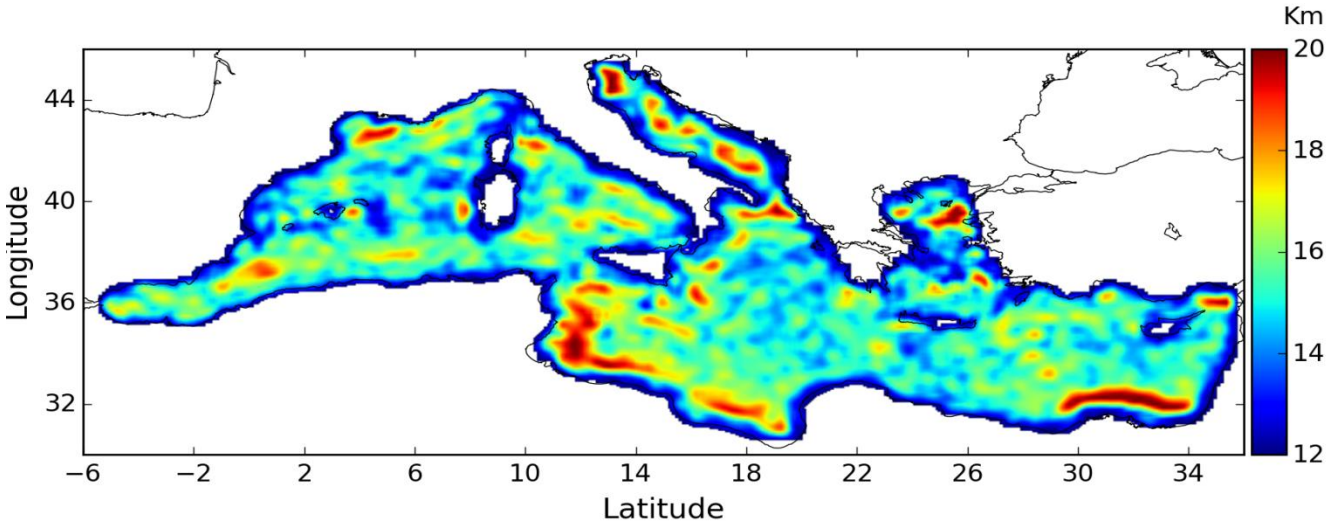


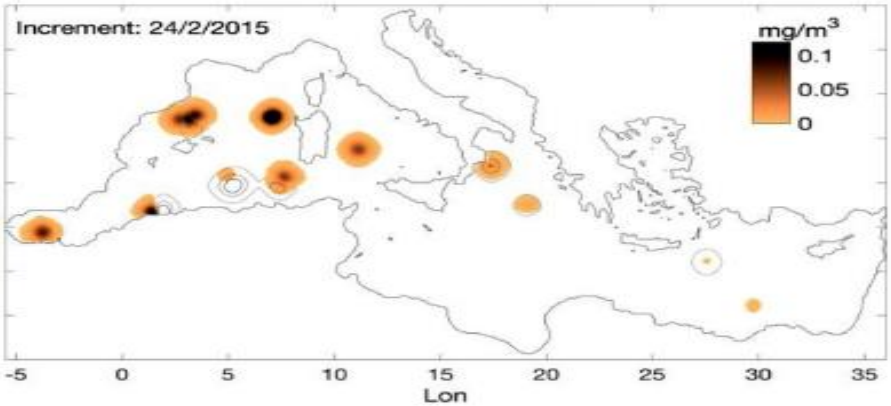
BGC-Argo FLOATS CHLOROPHYLL and NITRATE

Monthly and sub-areas **multivariate (chlorophyll and nitrate) and vertical component of the background error covariance matrix**: EOFs decomposition based on high frequency model output (2016-2018)

3DVarBio: critical aspects for the BGC-Argo assimilation

horizontal component of the background error: first order Gaussian filter forced by non uniform correlation radius length scale to enhance impacts of local

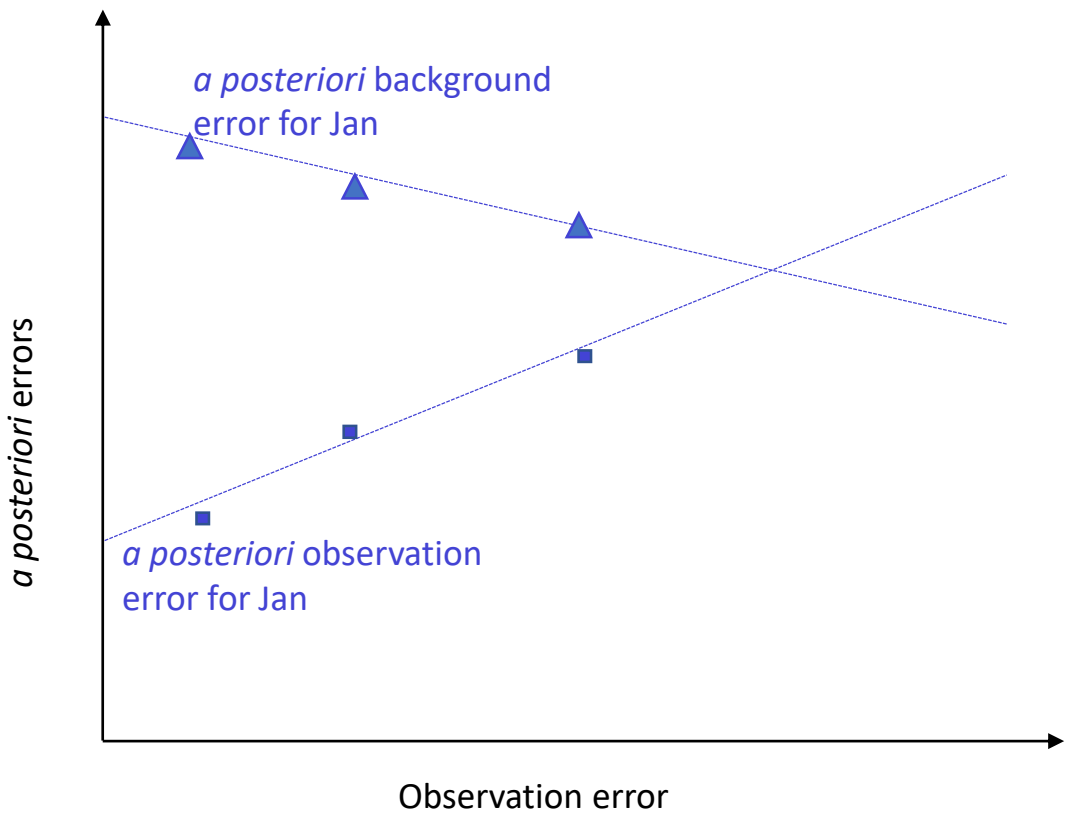




Example of map of increments for one DA day
(~10% of Med surface impacted with 10 floats in one day)

3DVarBio: critical aspects for the BGC-Argo assimilation

Observation error for chlorophyll estimated from monthly *a posteriori* observation and background errors (according to Desroziers et al., 2005) to include representation error



3DVarBio: critical aspects for the BGC-Argo assimilation

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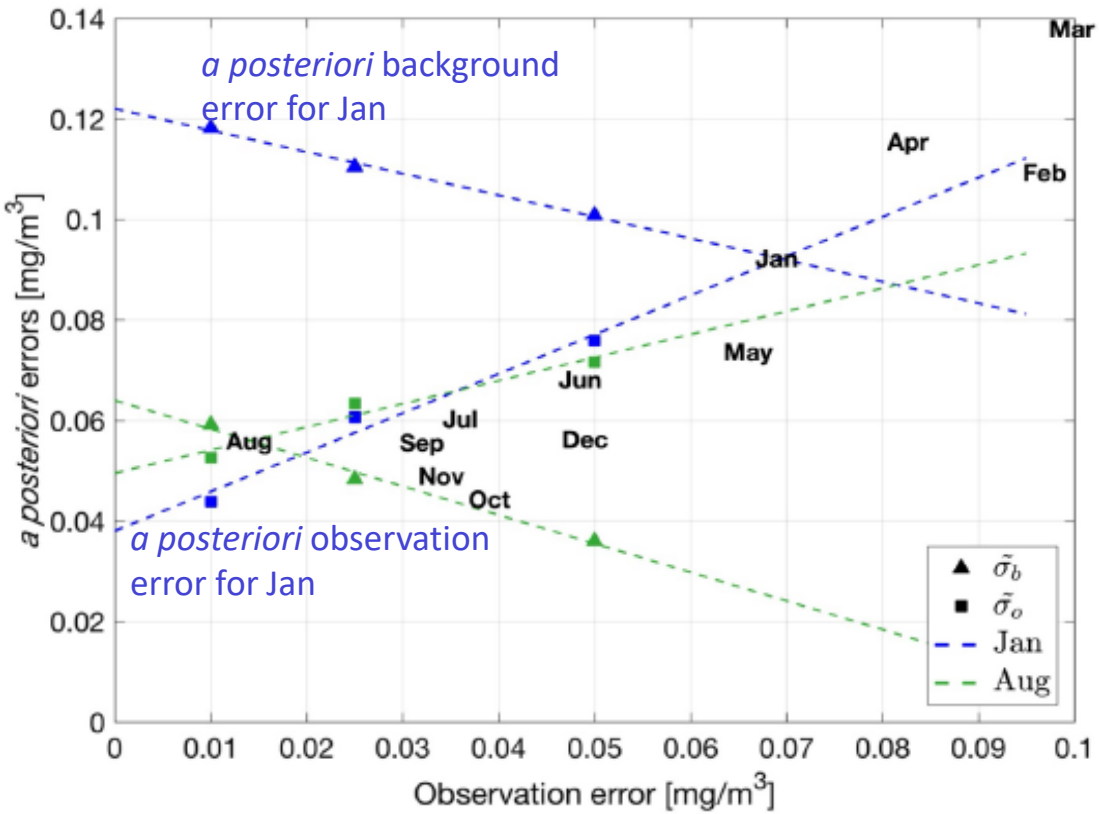
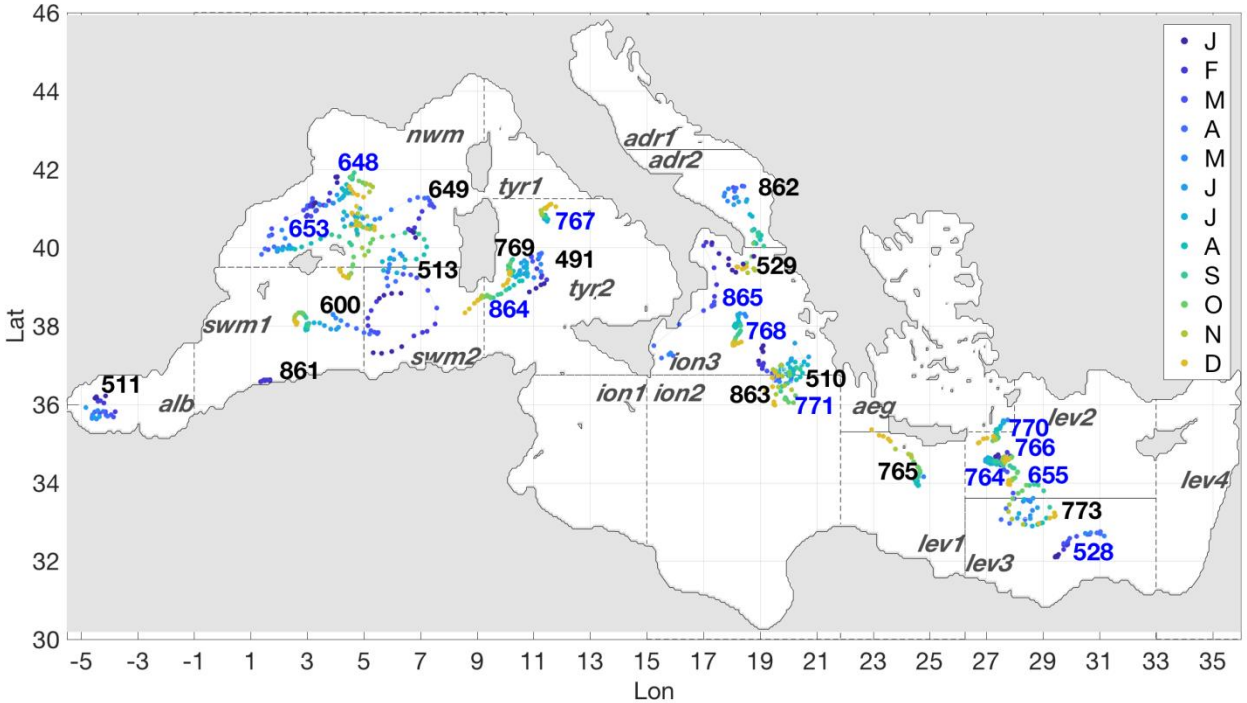


Cossarini et al., 2019

Observation error for nitrate: 0.25mmol/m^3 estimated using triple collocation method (Mignot et al., 2019)

BGC-Argo measurements

BGC-Argo profiles availability and QC @ OGS for year 2015:



25 chlorophyll floats: 1357 profiles (3-7 per day)

12 nitrate floats: 668 profiles (1-3 per day)

CHLA_ADJUSTED from dac.coriolis and QC@OGS :

1. Correction for nonphotochemical quenching (as proposed by LOV)
2. Shift to avoid dark values CHLA(400m-600m)=0
3. Filtering CHLA<0.005 mg/m^3
4. Gaussian smoothing and resampling at surface layer
5. Rejection if misfit>0.5mg/m^3

NITRATE_ADJUSTED from dac.coriolis and QC@OGS:

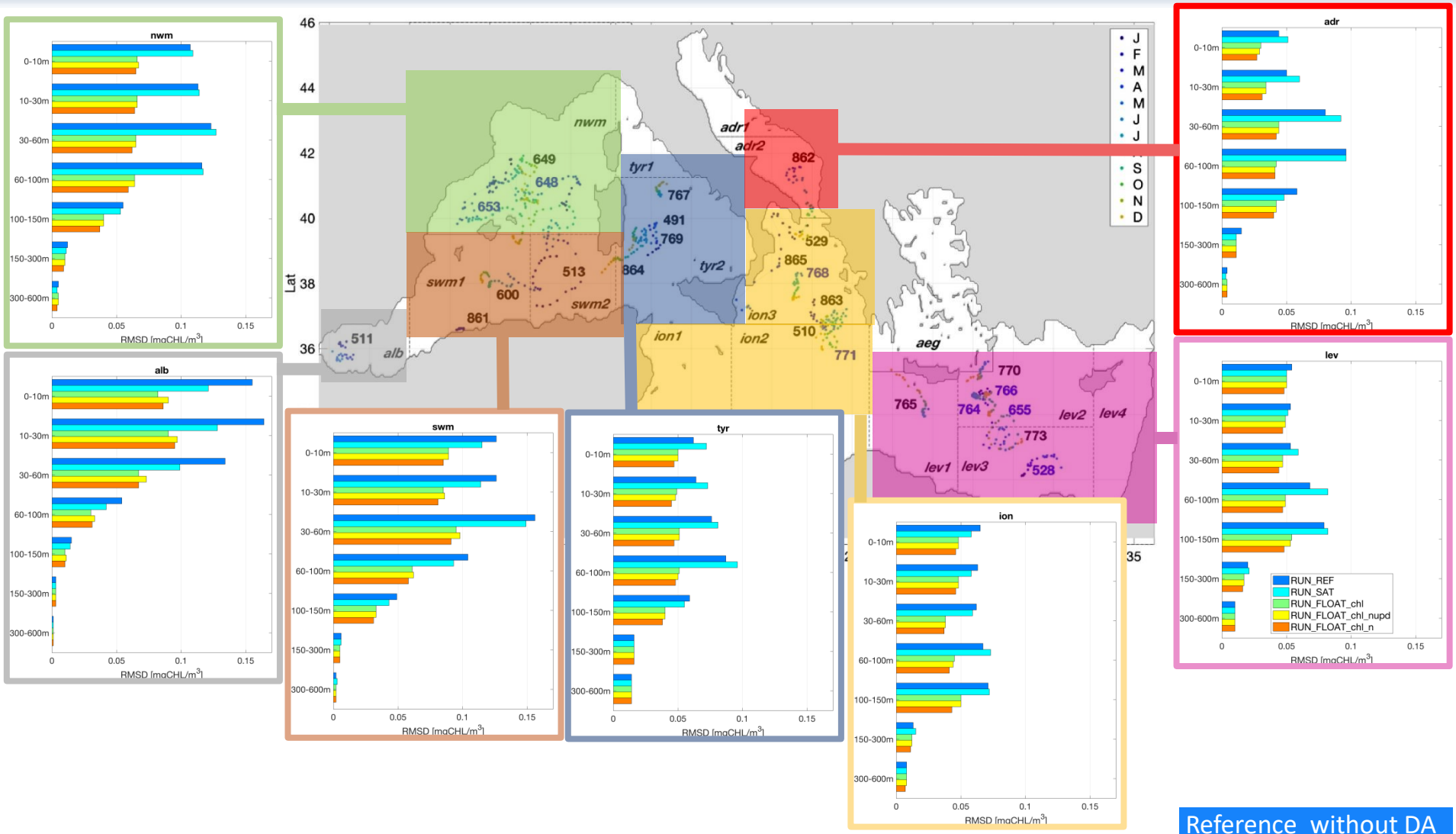
1. Adjusting at depth with WOA climatology (SR_NO3_ADJUSTED by LOV)
2. Fine tuning according TCM (Mignot et al., 2019)
3. Filtering NO3<0.01 mmol/m3
4. Gaussian smoothing and resampling at surface layer
5. Rejection if misfit> 1 mmol/m^3

3DVarBio: critical aspects for the BGC-Argo assimilation

Strategy for multivariate assimilation -> testing different combinations of assimilated and updated variables

		Updated variables	
	Assimilated variables	**Chlorophyll & phytoplankton biomass**	**nitrate & phosphate**
RUN_SAT	CHLa from Satellite	√	
RUN_FLOAT_chl	CHLa from Floats	√	
RUN_FLOAT_chl_nupd	CHLa from Floats	√	√
RUN_FLOAT_chl_n	CHLa and NO3 from Floats	√	√

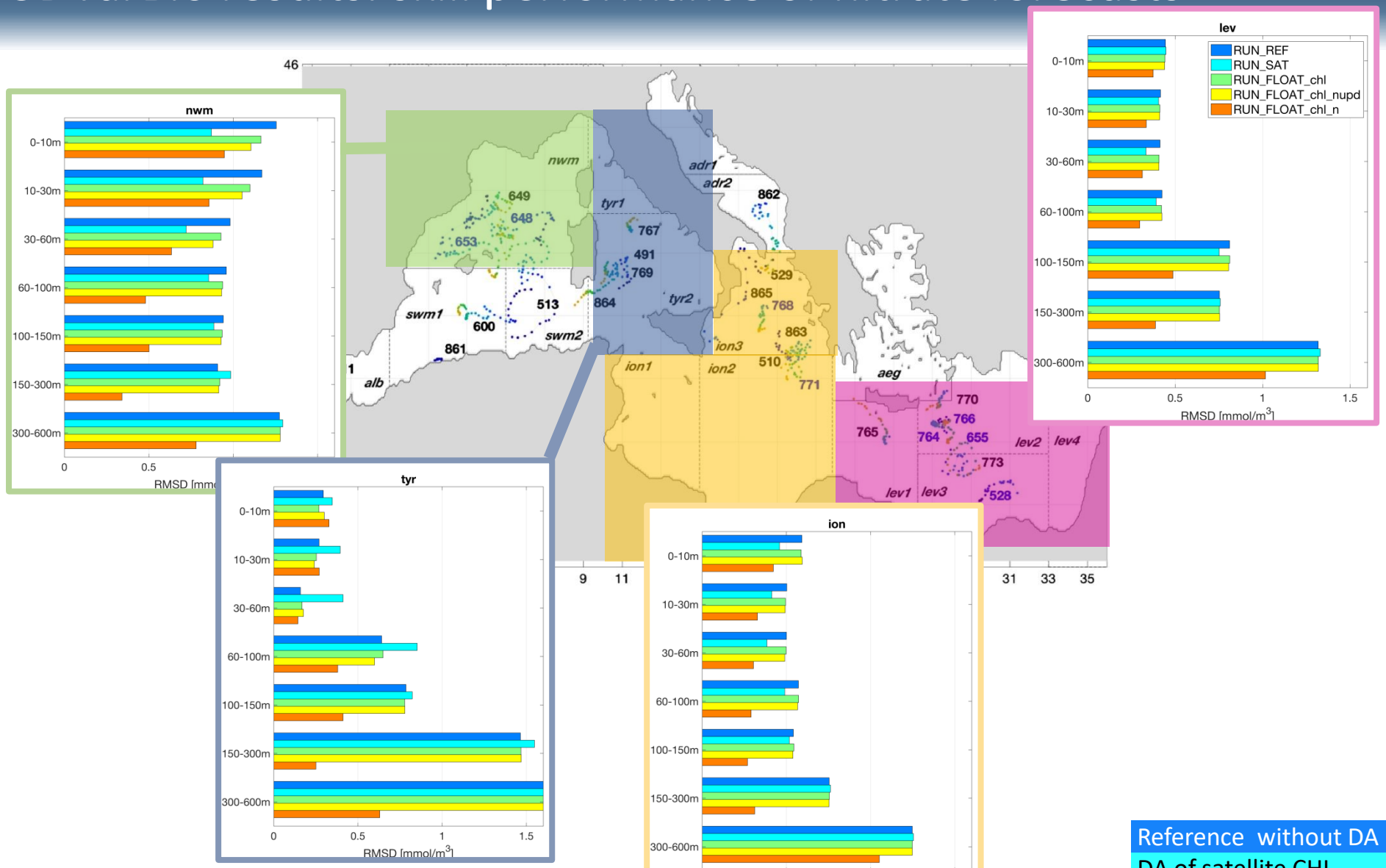
3DVarBio results: skill performance of chlorophyll forecasts



RMS of the differences between model forecast and BGC-Argo data for chlorophyll

Reference without DA
DA of satellite CHL
DA of float CHL
DA of float CHL (N upd)
DA of float CHL and N

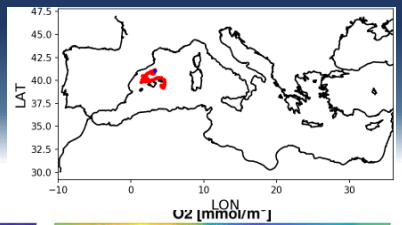
3DVarBio results: skill performance of nitrate forecasts

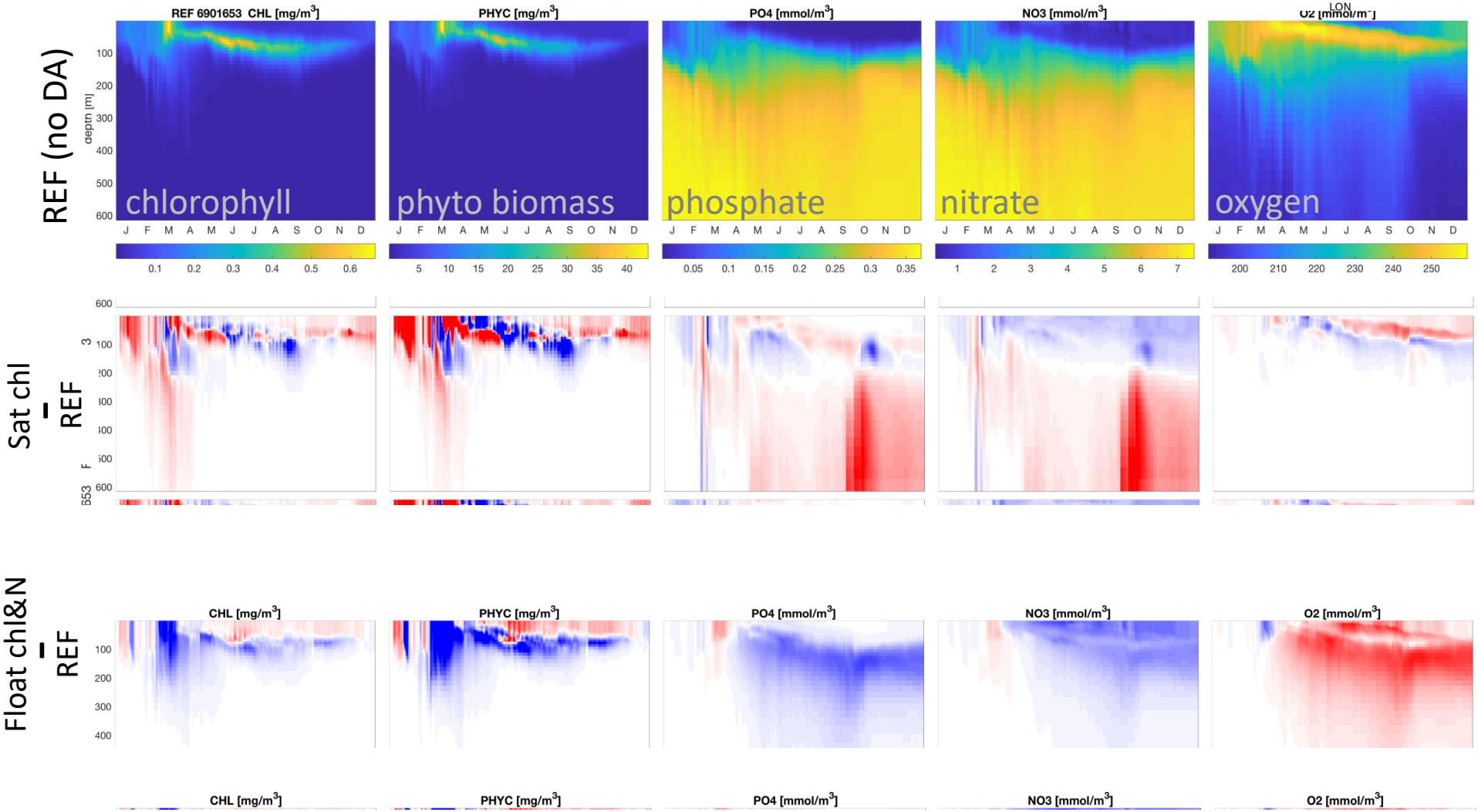


RMS of the differences between model background and BGC-Argo data for nitrate

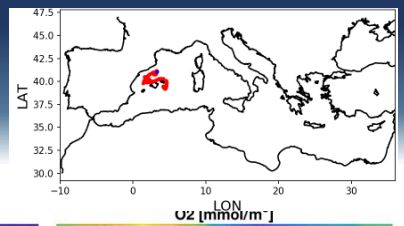
Reference without DA
DA of satellite CHL
DA of float CHL
DA of float CHL (N upd)
DA of float CHL and N

3DVarBio results: impact on model dynamics in the surrounding of a float trajectory

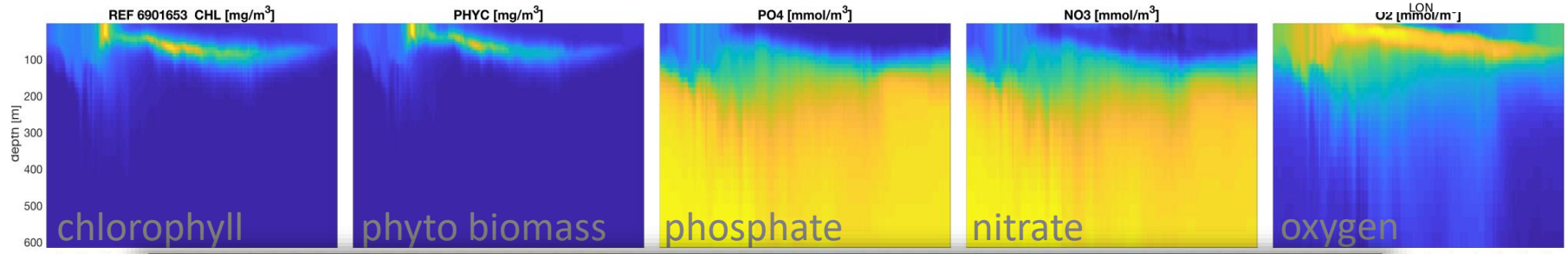




3DVarBio results: impact on dynamics in the surrounding of a float trajectory

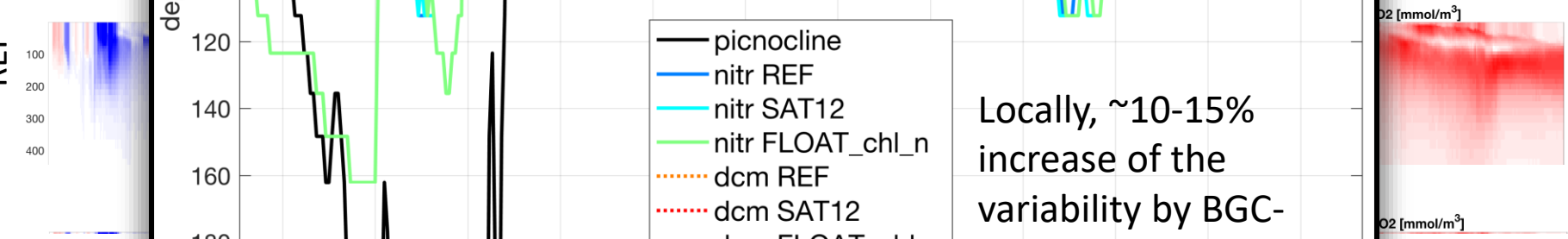


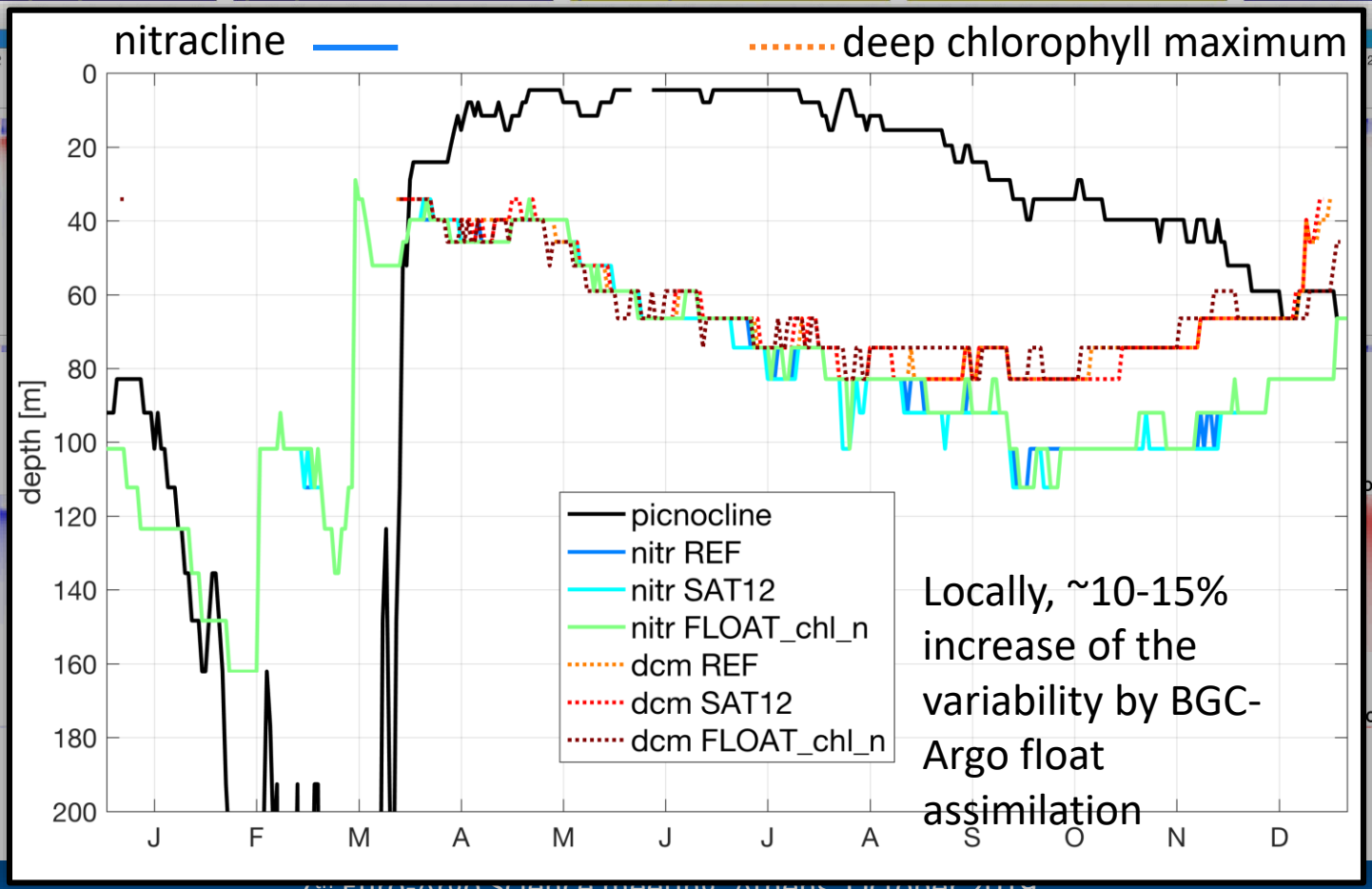
REF (no DA)



Sat chl - REF

Float chl&N - REF





Locally, ~10-15% increase of the variability by BGC-Argo float assimilation

conclusions

- Assimilation of BGC-Argo nitrate and chlorophyll is feasible and increases the forecast accuracy
- Assimilation of BGC-Argo can effectively improve the simulation of vertical biogeochemical dynamics
- Corrections are mostly local but persistency is of the same order (chlorophyll) and longer (nitrate) than float cycle length (5 days)
- Use of different assimilation frequency for satellite and BGC-Argo to avoid inconsistency issue

- Next steps:
  - CMEMS Mediterranean forecast system will operationally assimilate BGC-Argo floats starting from March 2020 (available and checked floats up to T-2)
  - Assimilation of physical Argo floats on BGC to increase the impact of the low number of BGC-Argo floats

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Thank you
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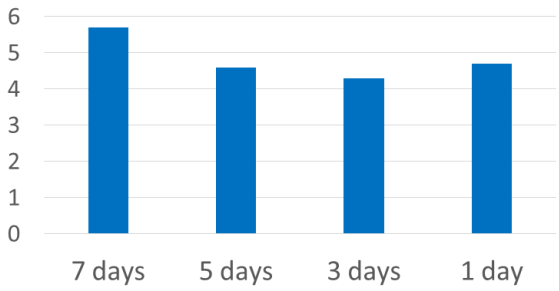
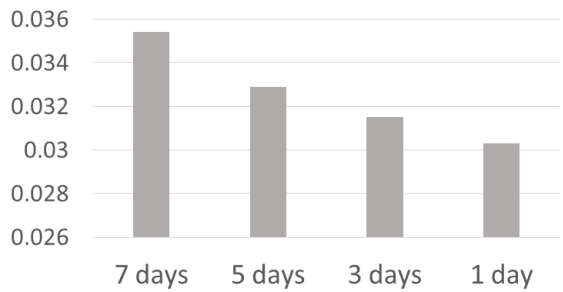
3DVarBio: critical aspects for the BGC-Argo assimilation

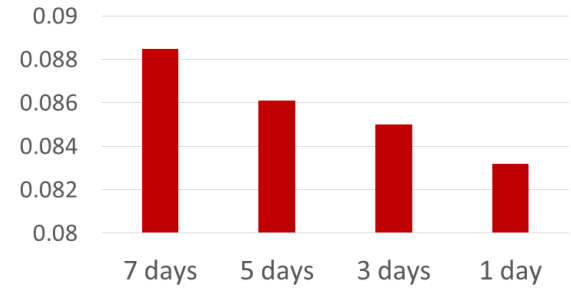
Frequency of assimilation: trade off between spatial impact, persistency and forecast skill



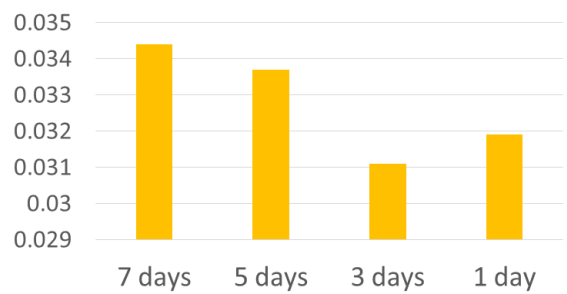
Index of temporal persistency
(ITP [day], the higher the better)



Integral of the increases
(INT [mg/m^3], the higher the better)



RMSD of the forecasts
(σ_b mg/m^3, the lower the better)



Index of overfitting
(IO [mg/m^3], the lower the better)

	Assimilation cycles			ITP [days]	INT [mg/m^3]	e_b [mg/m^3]	*IO* [mg/m^3]
	frequency	n. of cycles	n. of profiles				
OEtun	7 days	52	20	5.7	0.0354	0.0885	0.0344
OEtun5d	5 days	73	15	4.6	0.0329	0.0861	0.0337
OEtun3d	3 days	121	10	4.3	0.0315	0.0850	0.0311
OEtun1d	1 day	291	4	4.7	0.0303	0.0832	0.0319

Cossarini et al., 2019

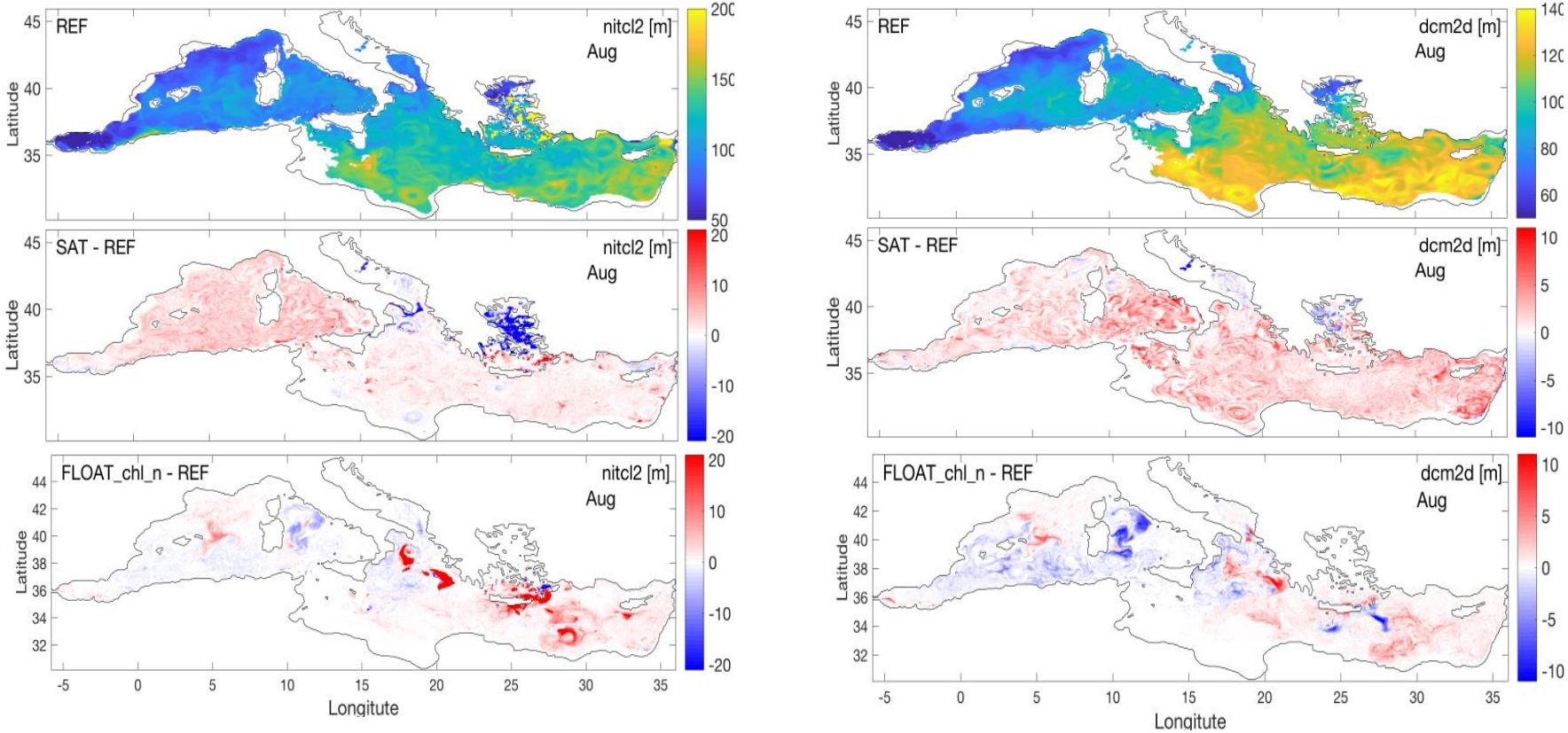
3DVarBio results: Impact on nitracline and deep chlorophyll maximum dynamics

nitracline[m]

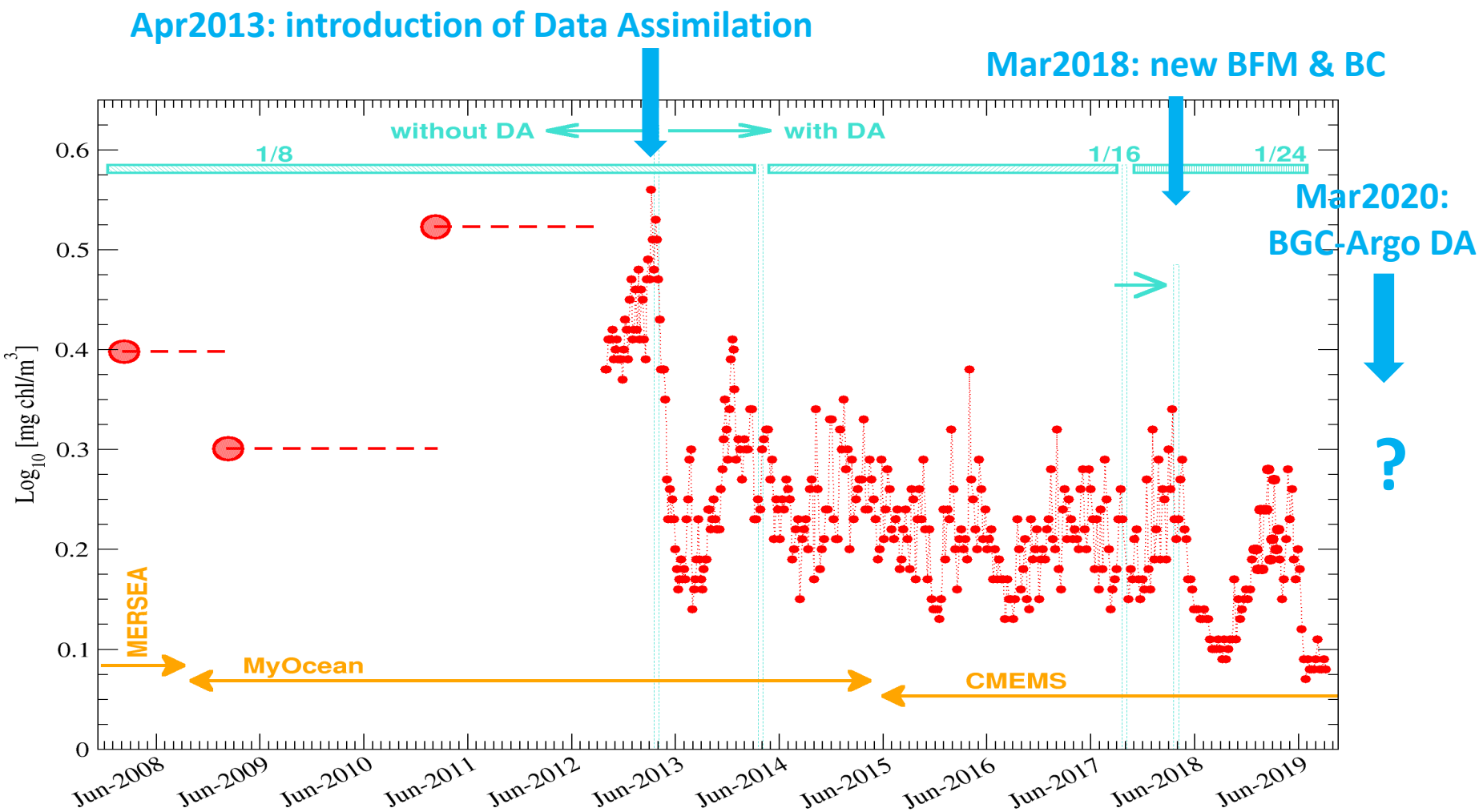
Deep chlorophyll maximum [m]

Sat chl - REF

Float chl&N - REF

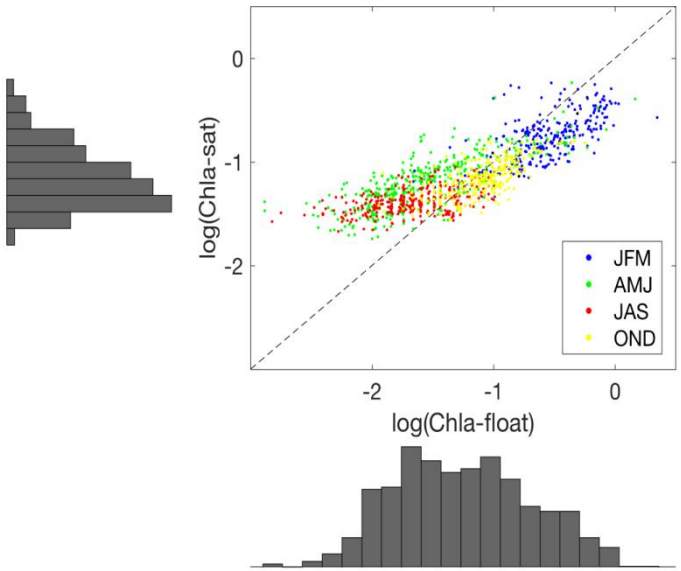


Skill of the forecast of the CMEMS biogeochemical Mediterranean system



RMS of the differences between model forecast (before assimilation) and chlorophyll satellite computed every week and published on http://marine.copernicus.eu/services-portfolio/scientific-quality/

Satellite - Floats



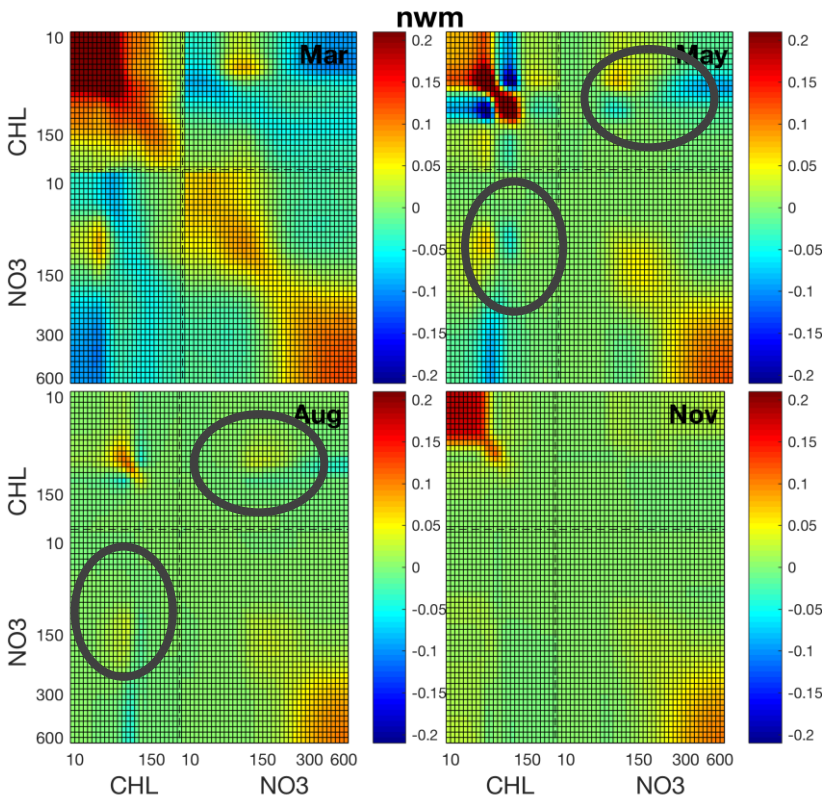
Seasonal distribution of surface CHL from satellite and float observations

Significant differences in summer (AMJ-JAS)

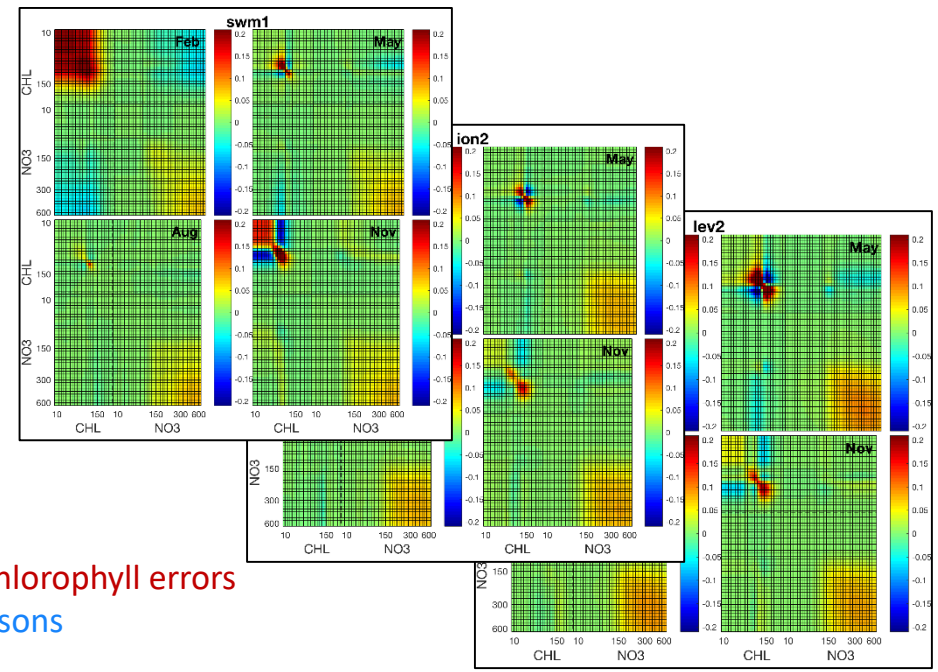
Inconsistency between observation subsets (different platforms)

3DVarBio: critical aspects for the BGC-Argo assimilation

multivariate (chlorophyll and nitrate) and vertical component of the covariance error matric: EOFs decomposition based on high frequency model output (2016-2018) for sub-basin



Covariance change from month to month and from sub-basin to sub-basin



High error covariance at surface during winter for nitrate and chlorophyll errors

High error covariance for nitrate below nutricline during all seasons

Chlorophyll-nitrate covariance at the nitracline/DCM depth