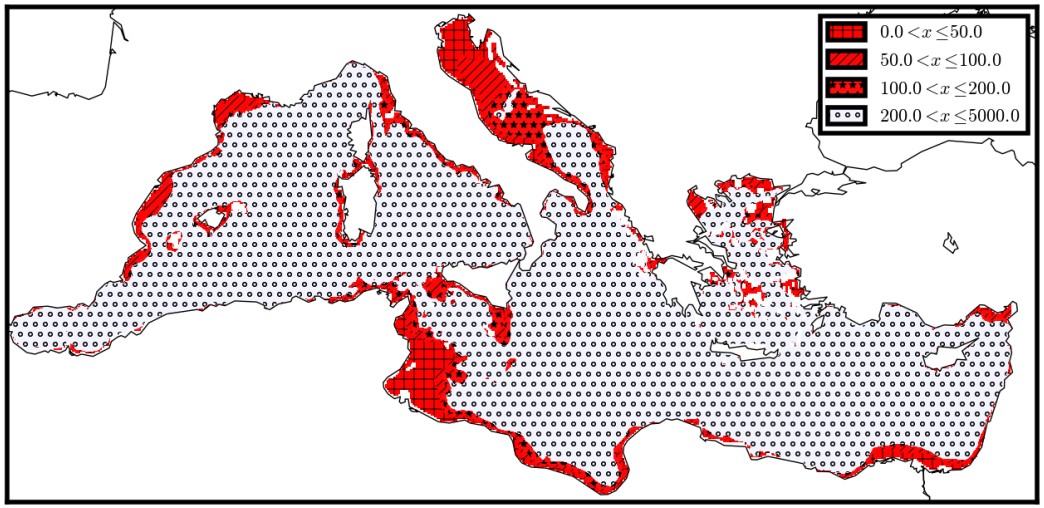
Kick-off workshop of the
Network of Experts for ReDeveloping Models of the European Marine Environment
Brussels, 20-21 January 2016

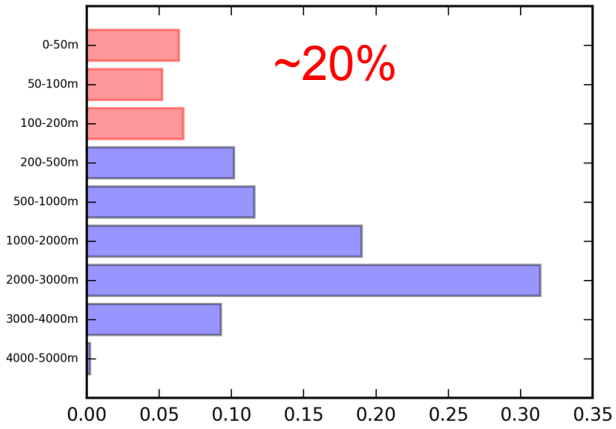
Modelling the primary productivity of the Mediterranean Sea

Lazzari P., Solidoro C., Salon S., Cossarini G., Teruzzi A., Crise A.

OUTLINE

- PRODUCTIVITY IN THE MEDITERRANEAN SEA
- OPEN OCEAN SCALE SPATIAL AND SEASONAL VARIABILITY
- LINK WITH NUTRIENT LIMITATION
- DATA TO CONSTRAIN THE SIMULATIONS
- SCENARIO SIMULATIONS



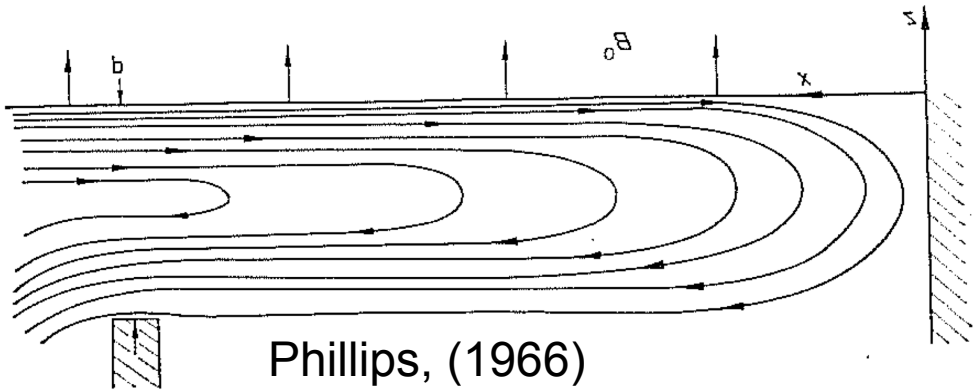


Box model of the Mediterranean Sea

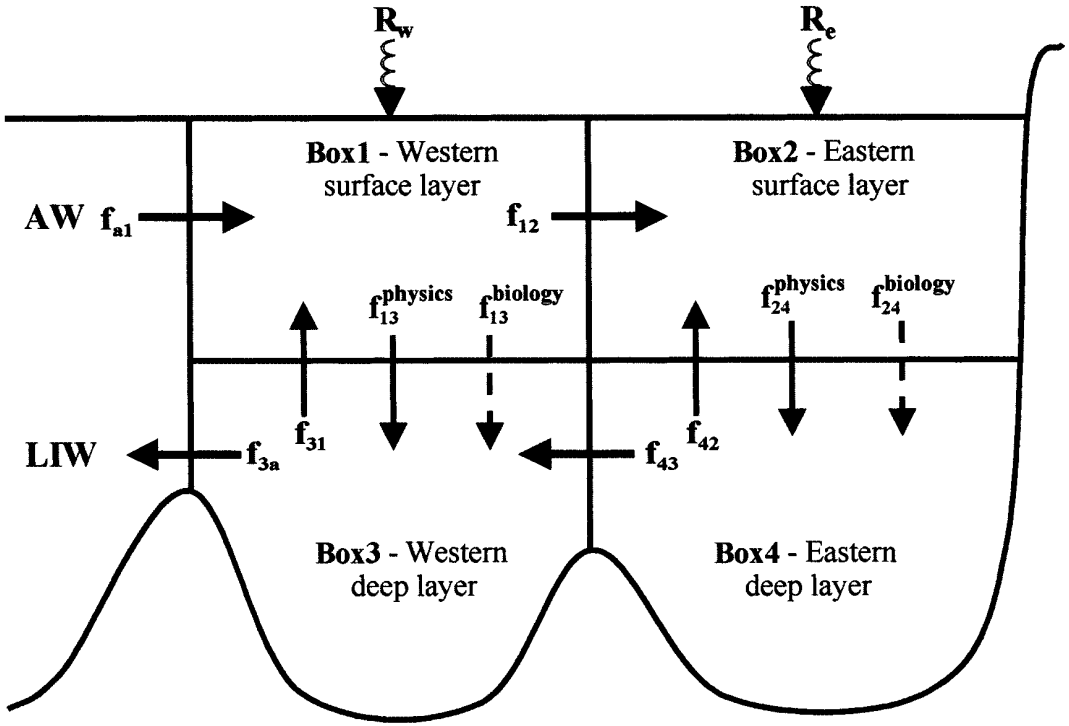
Anti-estuarine circulation, Mediterranean Sea → concentration basin

Water mass fluxes influencing biogeochemical tracers concentrations, upper layers → euphotic layer

Biological pump → vertical sinking of organic matter



Phillips, (1966)



Crispi et al. (2001)

Box model of the Mediterranean Sea

$$V \frac{\mathrm{d}}{\mathrm{d}t} \Sigma = F \Sigma + L,$$

ref mmol /m3	West	East
Surface	P: 0.22 N: 4.22	P: 0.10 N: 3.03
Deep	P: 0.29 N: 6.03	P: 0.16 N: 4.81

Inverse estuarine circulation and river inputs imbalance (W-E) explain the gradient in the deeper layers

biological pump creates surface layers gradient contrasting the concentration basin features

Model configuration: OGSTM-BFM scheme

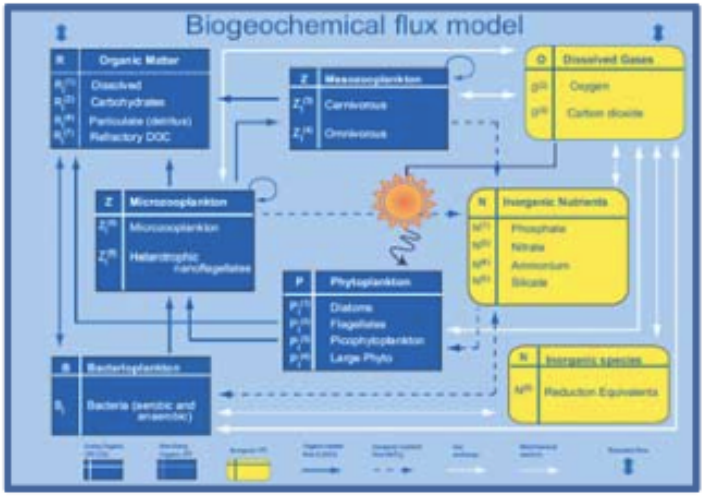
$$\frac{\partial c_i}{\partial t} = TRANSPORT + REACTION$$

OPA Tracer Model

$$-\mathbf{U}\cdot\nabla c_i + (-1)^{n+1} k_h \nabla_h^{2n} c_i + \frac{\partial}{\partial z}\left[k_v \frac{\partial c_i}{\partial z}\right]$$

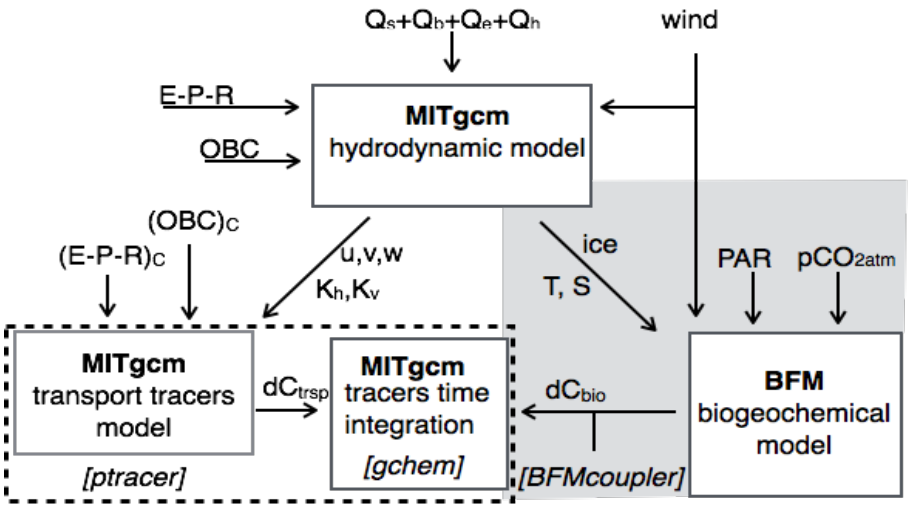
Physical forcings (**U**, *T*, *I*, *ecc*)

BFM $w_{si}\frac{\partial c_i}{\partial z} + R_{bio}(c_i, c_1 \ldots c_N, T, I \ldots)$



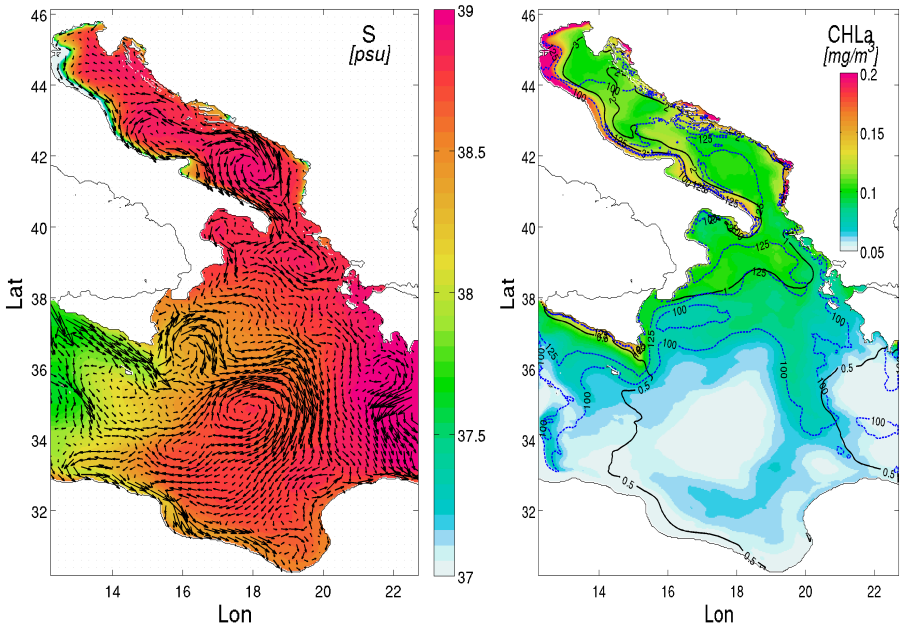
- ✓ **MESH= PHYS MODEL**
- ✓ **MPI+OPENMP**
- ✓ **OPEN SOURCE**

BFM in the Adriatic-Ionian System



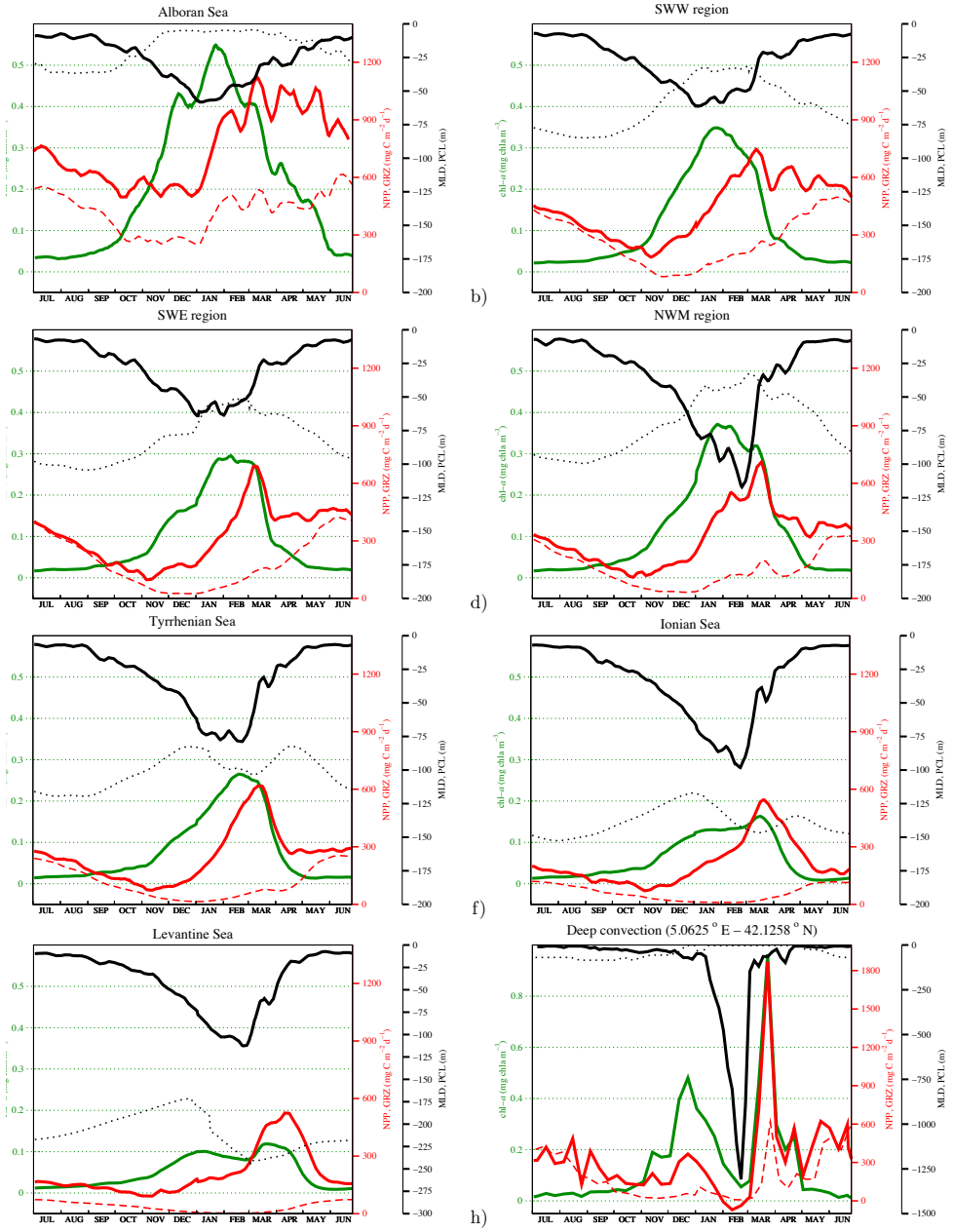
Online approach:

coupling with MITgcm,
Coupler release as MITgcm package



The horizontal resolution is 1/32° (equivalent approximately to 3 km) while vertical resolution is 72 z-levels such that the domain is easily nested into the Copernicus MED-MFC system

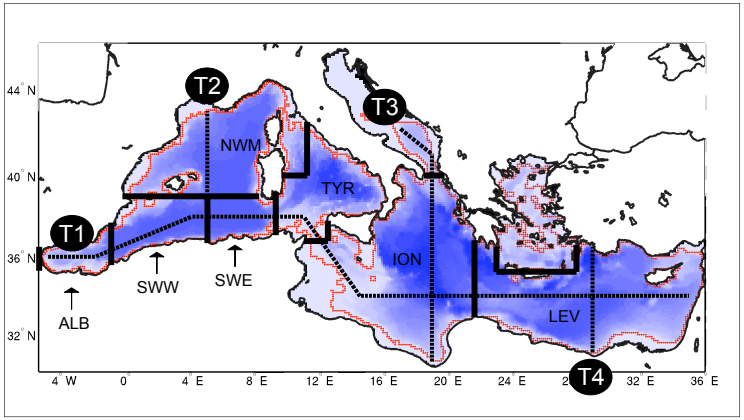
Longhurst schemes: MODEL RESULTS



Schemes based on MLD, chl-a and NPP, in the present case with phosphocline (PCL) temporal variability, and grazing (GRZ)

In the Longhusrt classification Med can be classified as *subtropical nutrient-limited winter-spring production period*

Deep mixing areas shows very different behaviour **Sverdrup** dynamics



NPP budgets: MODEL RESULTS

Table 1. Regional averages of net primary production presented as annual value and for shorter specific period selected on the basis of data availability. Data indicate typical mean and (for climatology only) related inter-annual variability, computed as mean and standard deviations of the six annual mean values, respectively. The average of the six standard deviations is reported in parentheses as the typical intra-period variability. References: **(a)** Crispi et al. (2002), **(b)** Allen et al. (2002), **(c)** Napolitano et al. (2000), **(d)** Colella (2006), **(e)** Sournia et al. (1973), **(f)** Marty and Chiaverini (2002), **(g)** Boldrin et al. (2002), **(h)** Moutin and Raimbault (2002), **(i)** Macías et al. (2009), **(j)** Lohrenz et al. (2003), **(k)** Moran and Estrada (2001), **(l)** Granata et al. (2004), **(m)** Bosc et al. (2004), **(n)** Conan et al. (1998).

	Climatology/All seasonal cycle ($gC\,m^{-2}\,yr^{-1}$)					Specific periods ($mgC\,m^{-2}\,d^{-1}$)	
	OPATM-BFM REF	Other models	Satellite model[(d)]	Other satellite models	In situ	OPATM-BFM REF	In situ
Mediterranean (MED)	98±5 (±82)	–	90±3 (±48)	135[(m)]	80–90[(e)]	–	–
Western basin (WES)	131±6 (±98)	120[(a)]	112±7 (±65)	163[(m)]	–	430 (±258)	> 350[(h)] (May–Jun)
Eastern basin (EAS)	76±5 (±60)	56[(a)]	76±2 (±20)	121[(m)]	–	200 (±107)	150–450[(h)] (May–Jun)
Alboran Sea (ALB)	274±11 (±155)	24–207[(b)]	179±13 (±116)	–	–	545 (±321)	6–644[(i)] (Nov)
South West Med (SWW)	160±8 (±89)	24–207[(b)]	113±6 (±43)	–	–	570 (±233)	299–1288[(j)] (May)
South West Med (SWE)	118±13 (±70)	–	102±4 (±38)	–	–	447 (±164)	> 450[(h)] (May–Jun)
North West Med (NWM)	116±6 (±79)	32–273[(b)]	115±8 (±67)	–	86–232[(f)] 140–150[(n)]	600 (±290)/ 142 (±96)	1000±11[(k)](Mar)/ 211–249[(l)](Oct)
Tyrrhenian (TYR)	92±5 (±63)	–	90±7 (±35)	–	–	279 (±118)	350–450[(h)] (May–Jun)
Ionian (ION)	77±4 (±58)	27–153[(b)]	79±2 (±23)	–	62[(g)]	189 (±99)/ 159 (±68)	150–450[(h)] (May–Jun)/ 186±65[(g)] (Aug)
Levantine (LEV)	76±5 (±61)	97[(c)]/ 36–158[(b)]	72±2 (±21)	–	–	208 (±110)	150–250[(h)] (May–Jun)

Lazzari et al., 2012

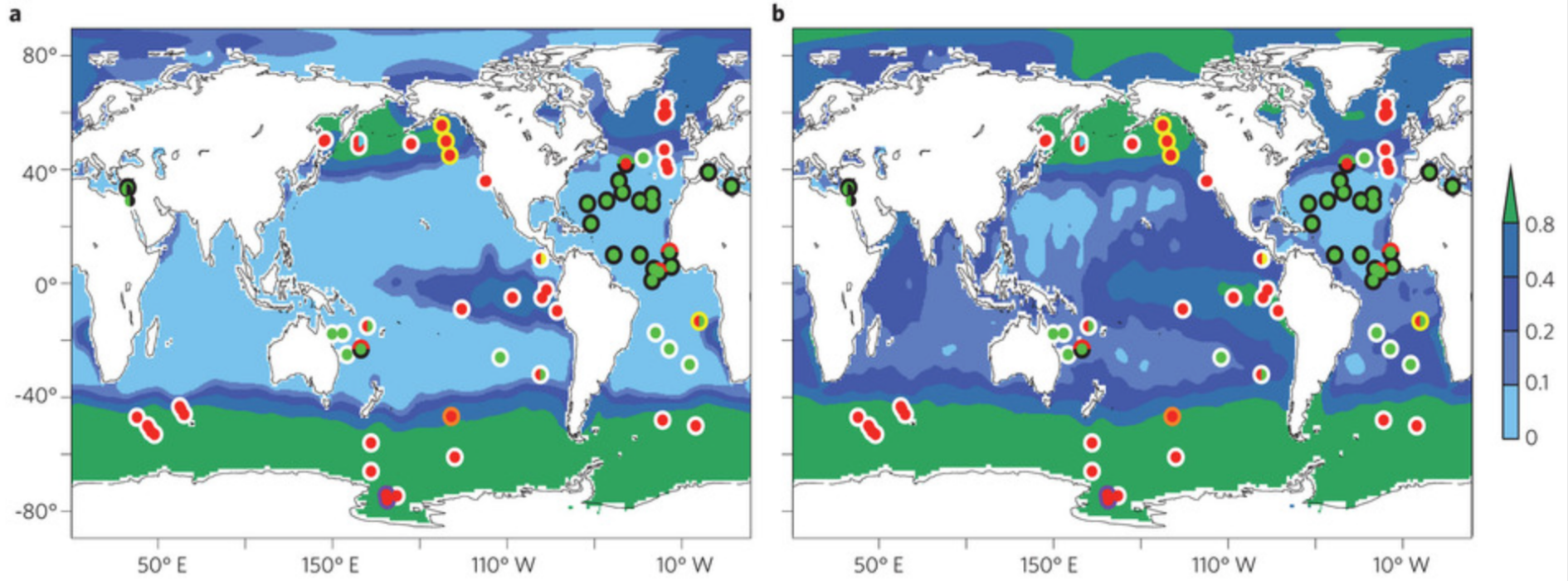
Sensitivity analysis: MODEL RESULTS

- ✓ The impact of atmospheric and terrestrial inputs on the annual budget of the integrated NPP (new production) is in the range of 3-5gCm^{-2}yr^{-1}.
- ✓ Impact of a 30% increase in the extinction factor *k* on the integrated NPP annual budget is approximately 10 gC m^{-2}yr^{-1}.

	OPATM-BFM REF	OPATM-BFM without ATI	OPATM-BFM REF (k+0.01)
Mediterranean (MED)	98±5 (±82)	95±4 (±85)	87±7 (±74)
Western basin (WES)	131±6 (±98)	127±5 (±103)	120±7 (±89)
Eastern basin (EAS)	76±5 (±60)	73±4 (±61)	64±8 (±53)
Alboran Sea (ALB)	274±11 (±155)	273±12 (±129)	243±7 (±137)
South West Med (SWW)	160±8 (±89)	156±7 (±91)	145±6 (±79)
South West Med (SWE)	118±13 (±70)	113±12 (±71)	109±12 (±66)
North West Med (NWM)	116±6 (±79)	111±6 (±84)	108±7 (±75)
Tyrrhenian (TYR)	92±5 (±63)	88±5 (±66)	88±6 (±62)
Ionian (ION)	77±4 (±58)	74±3 (±61)	68±6 (±54)
Levantine (LEV)	76±5 (±61)	73±6 (±61)	60±11 (±51)

On global scale …field experiments

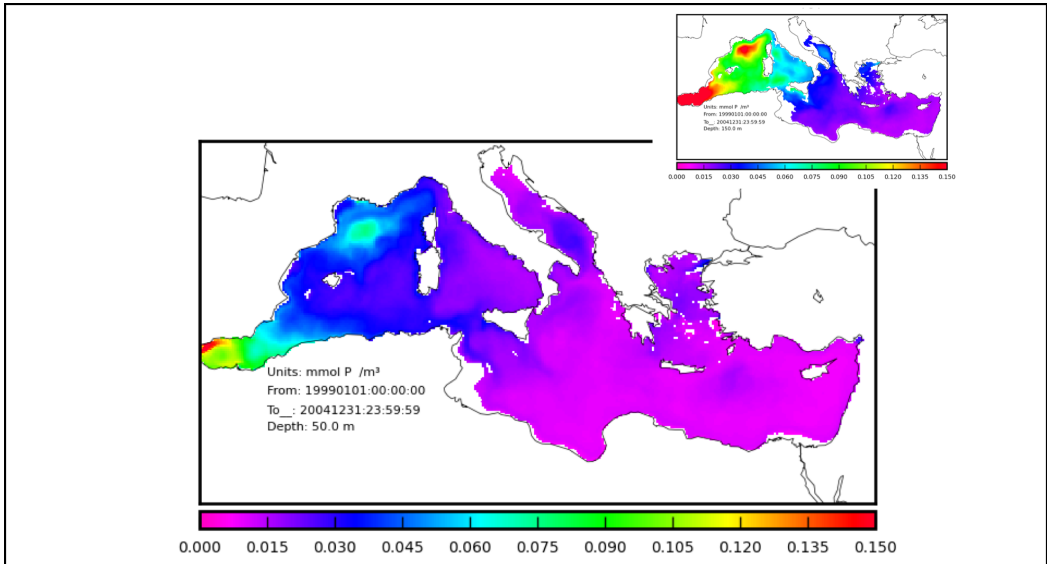
NUTRIENT LIMITATION



Backgrounds indicate annual average surface concentrations of nitrate (**a**) and phosphate (**b**) in μmol kg^{-1}. To assist comparison, nitrate is scaled by the mean N:P ratio of organic matter (that is, divided by 16; Fig. 1)[34]. Symbols indicate the primary (central circles) and secondary (outer circles) limiting nutrients as inferred from chlorophyll and/or primary productivity increases following artificial amendment of: N (green), P (black), Fe (red), Si (orange), Co (yellow), Zn (cyan) and vitamin B12 (purple). Divided circles indicate potentially co-limiting elements. White outer circles indicate that no secondary limiting nutrient was identified, which in many cases will be because of the lack of a test. See Supplementary Table S2 for references.

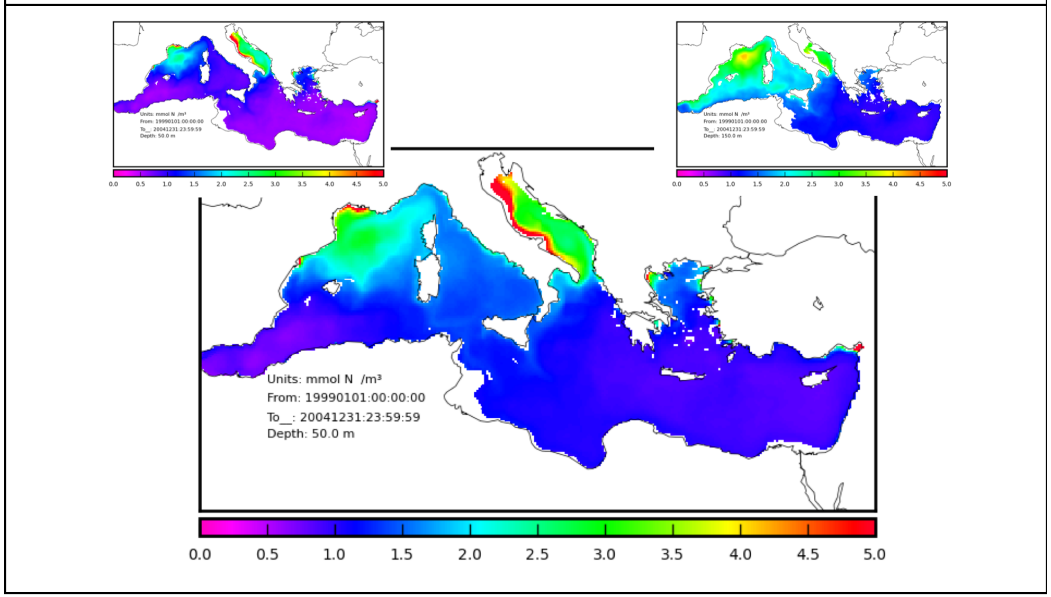
Moore et al. 2015

Nutrients distributions MODEL RESULTS



Upper layer average phosphate concentration, presents clear west east gradient

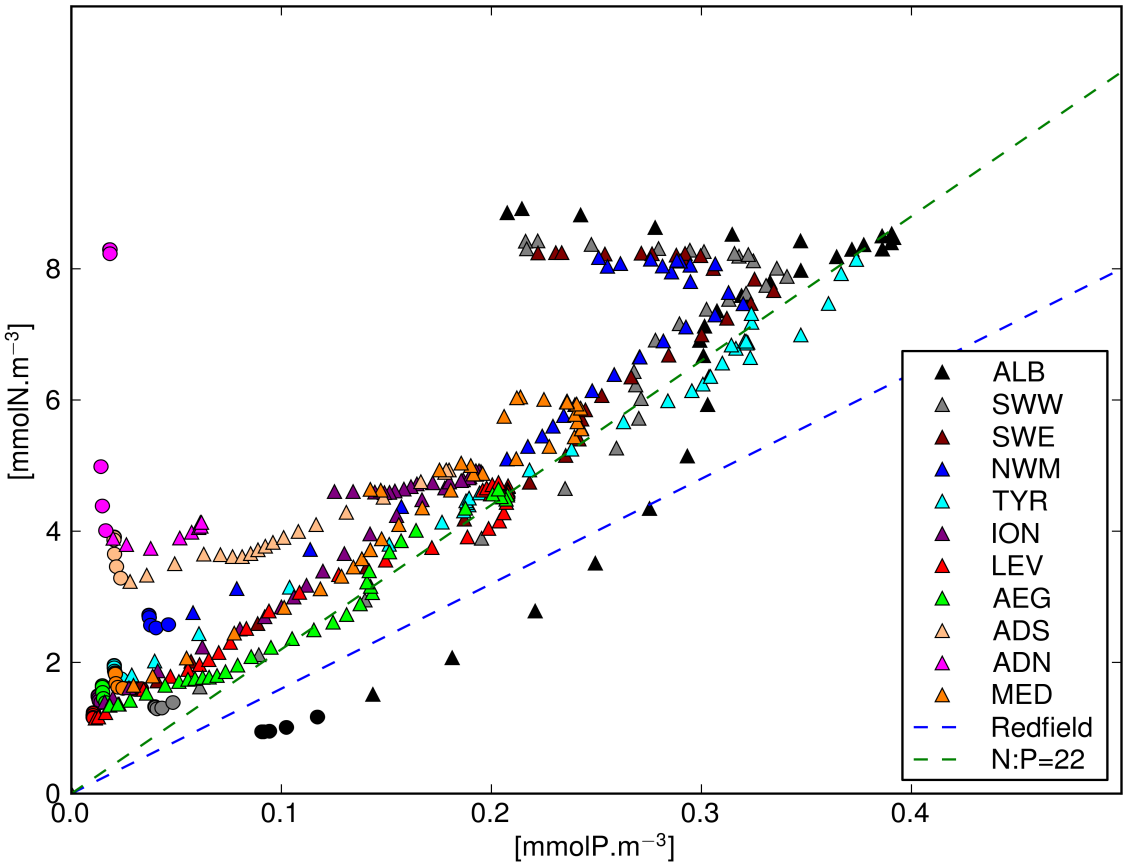
Alboran Sea and North Western Mediterranean richest areas in term of phosphates



Nitrates present strong south north gradient

Atmospherical deposition strongly affects open ocean nitrates budgets

N:P Ratio MODEL RESULTS

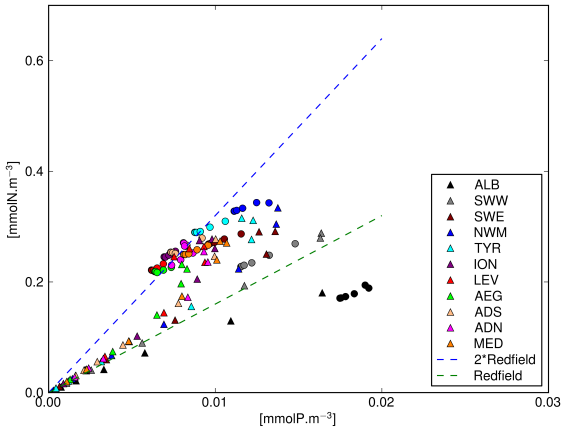


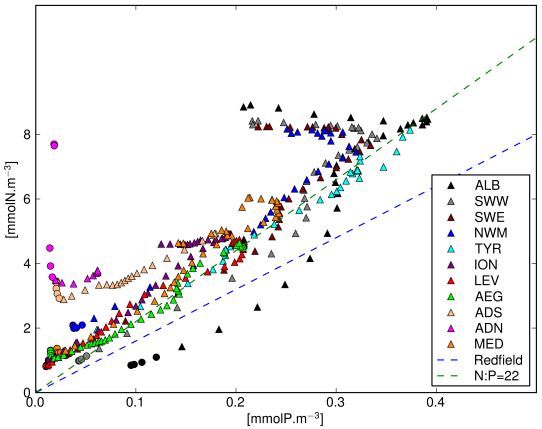
N:P ratio of inorganic nutrients in the large part of basin higher than Redfield, ALB below Redfield

ADN presents a very high N:P ratio, due to the strong influence of terrestrial inputs

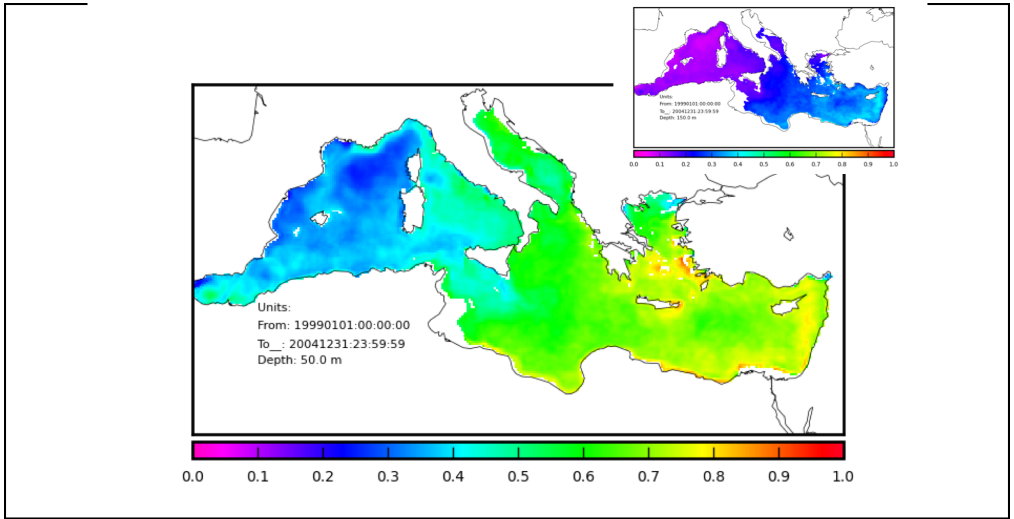
Internal quota mimics inorganic nutrient distribution

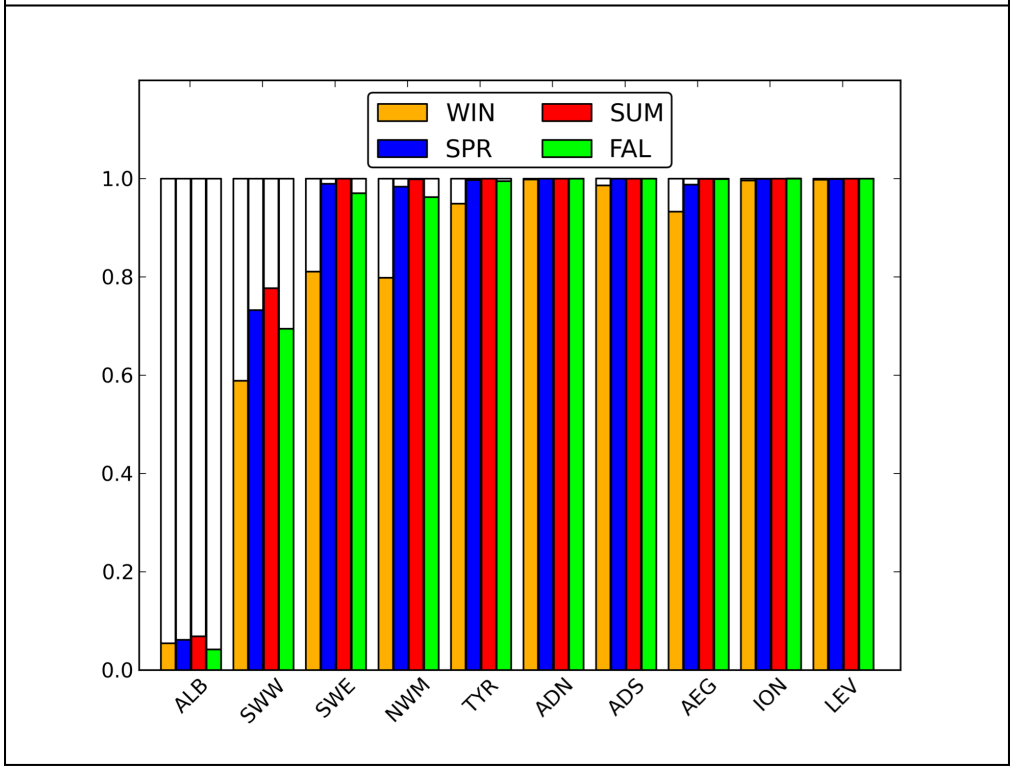
Atmospherical deposition perturbation affects principally surface layers





Nutrient limitation in the MODEL Results





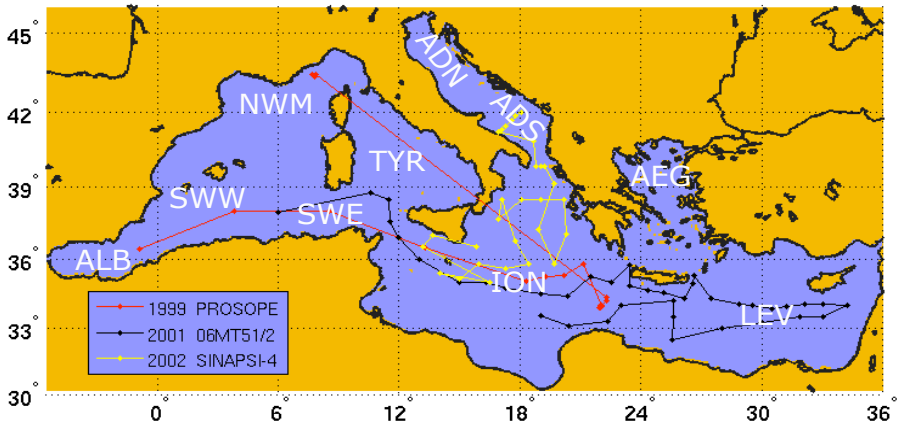
Release of DOC due to nutrient limitation, higher in the east, In the deeper layers light limitation is active

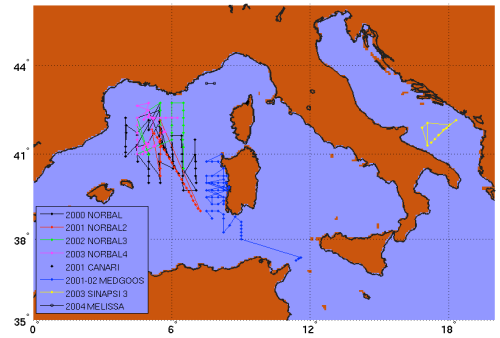
Nutrient limitation In term of internal phytoplankton quota

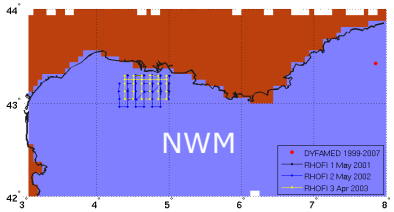
From nitrogen to phosphorus internal limitation moving eastward

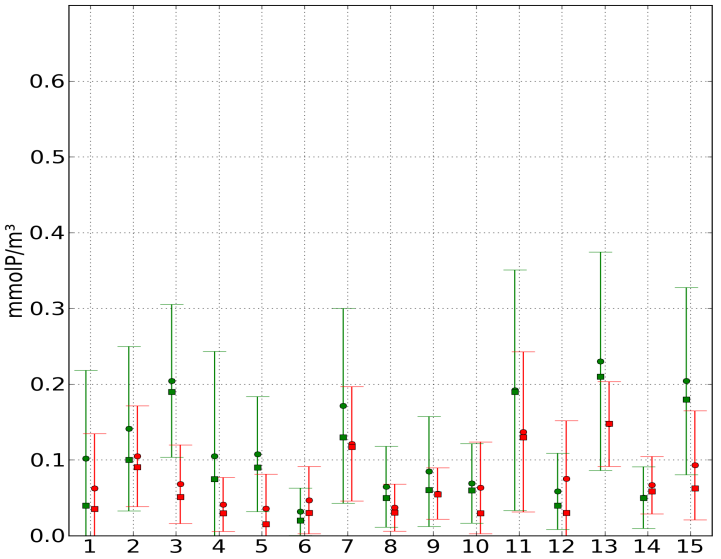
Lazzari et al., 2016

Data availability

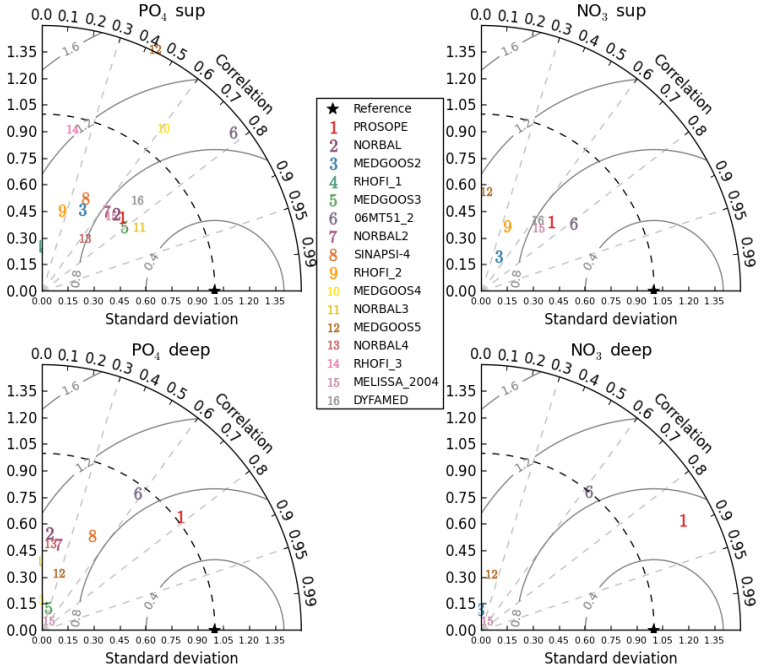








Dataset name	Period	Area	data PO_4 SUP	Data PO_4 DEEP	data NO_3 SUP	data NO_3 DEEP
		Research cruises				
1-PROSOPE	Sep-Oct 1999 (19)	SWW, SWE, TYR, ION, NWM	148	75	204	77
2-NORBAL	Mar-Apr 2000 (16)	NWM	528	655	-	-
3-MEDGOOS2	Mar 2001 (6)	NWM	112	12	112	12
4-RHOFI_1	May 2001 (2)	NWM	134	-	-	-
5-MEDGOOS3	Sep 2001 (4)	NWM	104	32	-	-
6-06MT51_2	Oct-Nov 2001 (18)	SWE, TYR, ION, LEV	97	553	127	555
7-NORBAL2	Dec 2001(6)	NWM	205	179	-	-
8-SINAPSI-4	Mar-Apr 2002 (13)	ION, ADS	222	313	-	-
9-RHOFI_2	May 2002 (6)	NWM	268	-	35	-
10-MEDGOOS4	May 2002(5)	NWM	125	25	-	-
11-NORBAL3	Sep-Oct 2002 (8)	NWM	193	322	-	-
12-MEDGOOS5	Nov 2002 (5)	SWE, TYR	76	15	203	38
13-NORBAL4	Mar 2003 (16)	NWM	288	205	-	-
14-RHOFI_3	Apr 2003 (6)	NWM	173	-	-	-
15-MELISSA-2004	Jan-Aug 2004 (8)	NWM	78	8	69	8
		Long-term Monitoring				
16-DYFAMED	1999-2004	NWM	523	433	552	502

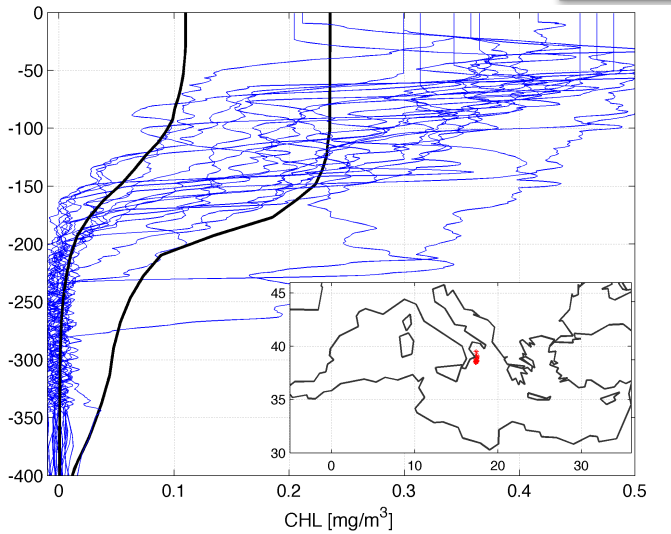


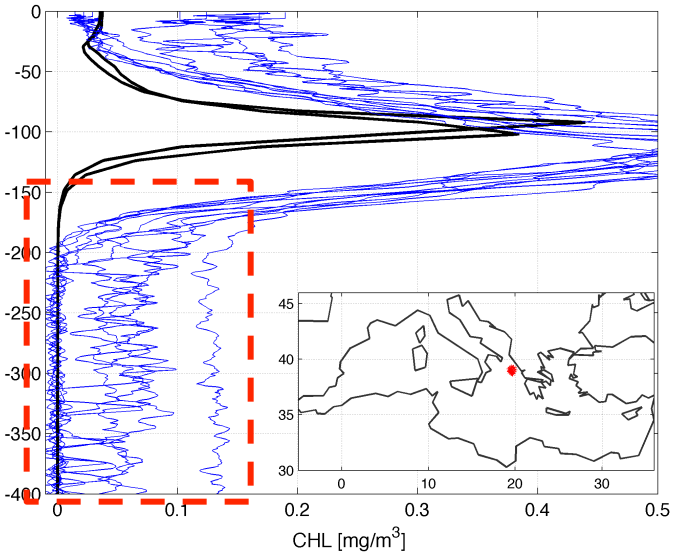
Ongoing development of new validation procedures for operational products

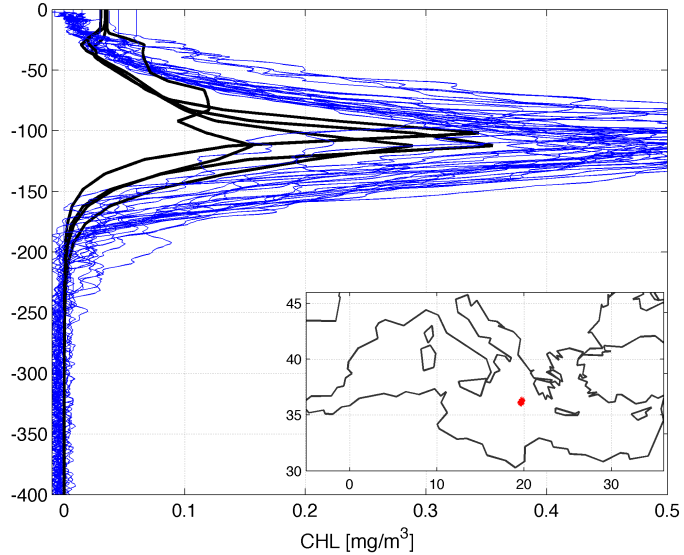
Weekly

- surface chlorophyll from OCTAC Copernicus (ISAC.CNR)
- **BioFloat data from Coriolis/IFREMER**

CHLA **model-float** match up works operationally, now working on statistics.







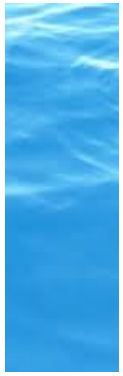
Not all adjusted data reliable

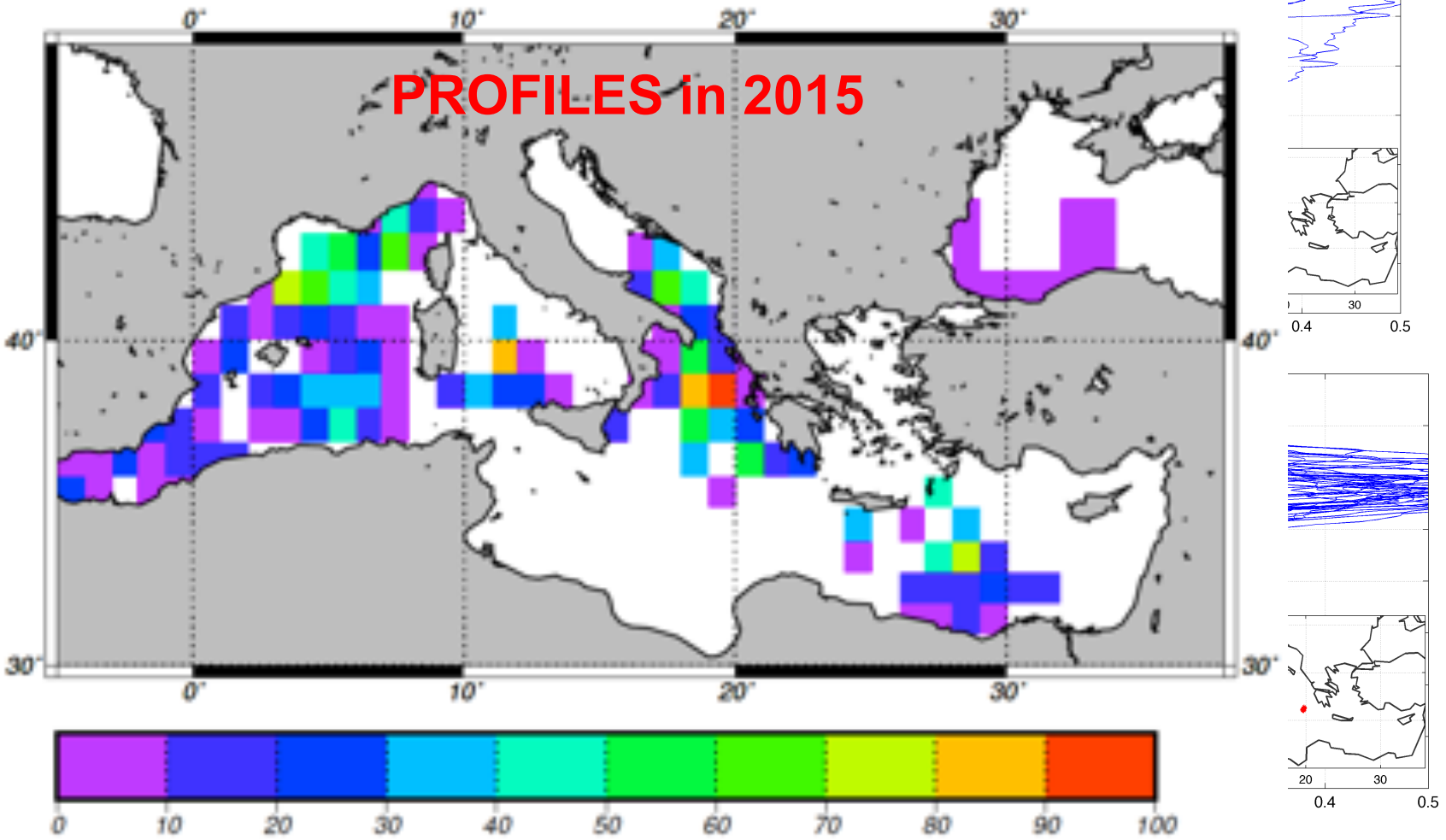
NO3 and OXY data not ready to be used (Coriolis, personal communication)

Ongoing development of new validation procedures for operational products

Weekly

- surf
  from
  Cop
  (ISA
- **Biol**
  Cori





Not all adjusted data reliable

NO3 and OXY data not ready to be used (Coriolis, personal communication)

BFM

European Commission

COPERNICUS
MARINE ENVIRONMENT MONITORING SERVICE

Providing PRODUCTS and SERVICES for all marine applications

Search terms OK

ABOUT US | BENEFITS | NEWS | SCIENCE & LEARNING | TRAINING | SERVICES PORTFOLIO | SHORT-CUT TO SERVICES

ONLINE CATALOGUE

CATALOGUE PDF | FIRST VISIT ? | MY CART 0

YOUR SEARCH

NEW SEARCH

AREA

- [ ] All areas
- [ ] Global Ocean (0)
- [ ] Arctic Ocean (0)
- [ ] Baltic Sea (0)
- [ ] European North-West Shelf Seas (1)
- [ ] Iberia-Biscay-Ireland Regional Seas (1)
- [x] Mediterranean Sea (8)
- [ ] Black Sea (1)

PARAMETER

- [ ] All parameters
- [ ] Ocean Temperature (1)
- [ ] Ocean Salinity (1)

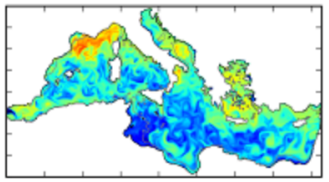
Found 8 products matching your criteria.

KEYWORD SEARCH SEARCH

MEDITERRANEAN SEA BIOGEOCHEMISTRY ANALYSIS AND FORECAST

MEDSEA_ANALYSIS_FORECAST_BIO_006_006

Numerical-Model, Ocean-Chemistry, Ocean-Chlorophyll, Ocean-Biology, Forecast, Near-Real-Time, Mediterranean-Sea



The biogeochemical analysis and forecasts for the Mediterranean Sea are produced by the OGS Production Unit by means of the OPATM-BFM model system (described below), using as physical forcing the output of the Med-MFC-currents products managed by the INGV Production Unit. The forecasting system is automatically run at the CINECA supercomputing centre (Bologna, Italy). Seven days of analysis/hindcast and ten days of forecast are produced twice per week on Wednesday and on Saturday, and data assimilation of surface chlorophyll satellite observations (provided by the OCTAC managed by GOS-ISAC-CNR) is performed once a week in the Wednesday run.

MORE INFO ADD TO CART

MEDITERRANEAN SEA BIOGECHEMISTRY REANALYSIS (1999-2012)

Numerical-Model, Ocean-Biology, Ocean-Chemistry

MEDSEA_REANALYSIS_BIO

Funded by the European Union Copernicus

ABOUT US | PARTNERS & STAKEHOLDERS | BENEFITS

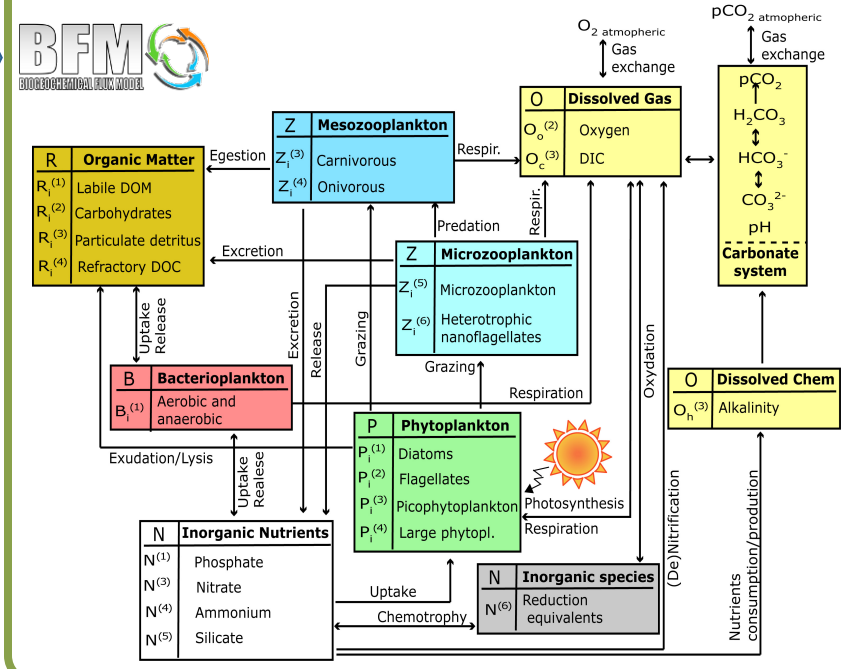
ANY QUESTION?
Get help from the Service Desk

CMEMS-Med-MFC Med-biogeochemistry component

PU=OGS + CINECA HPC-support

MED-CURRENT
Physical forcing

BIOGEOCHEMICAL MODEL
OGSTM-BFM (1/16, 72z)



SATELLITE OBSERVATIONS
Chlorophyll concentrations

ASSIMILATION
3D-VAR scheme

AN&FC + REAN
Products = 3D daily mean of:
chl, N, P, PrimProd, phytobiomass, Doxy

05/15
V
04/16

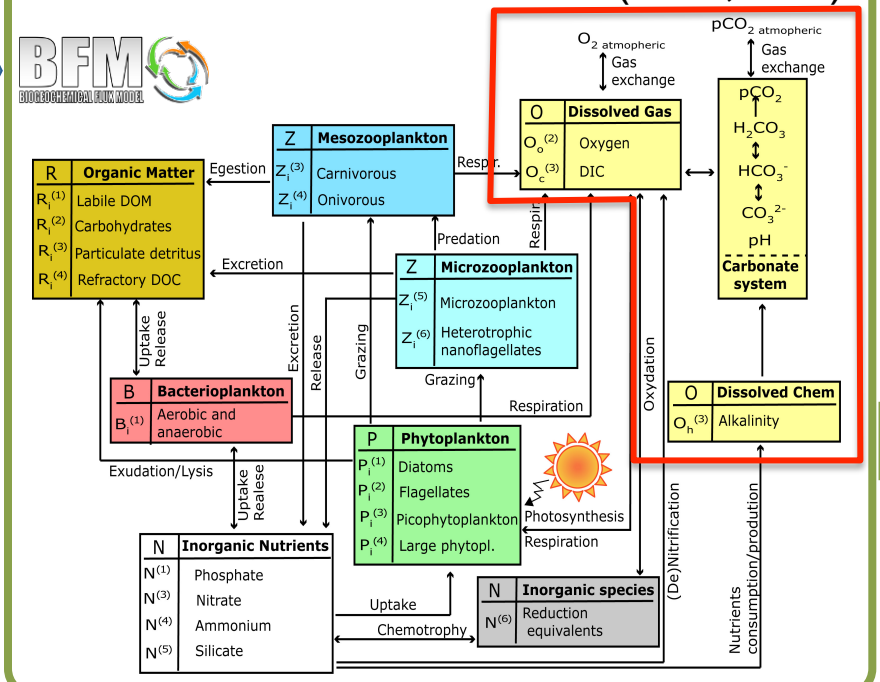
V1

CMEMS-Med-MFC Med-biogeochemistry component

PU=OGS + CINECA HPC-support

MED-CURRENT
Physical forcing

BIOGEOCHEMICAL MODEL
OGSTM-BFM (1/16, 72z)



SATELLITE OBSERVATIONS
Chlorophyll concentrations

ASSIMILATION
3D-VAR scheme

AN&FC + REAN Products =
3D daily mean of:
chl, N, P, PrimProd, phytobiomass, Doxy
+ pCO2, pH

04/16
V
03/17

V2

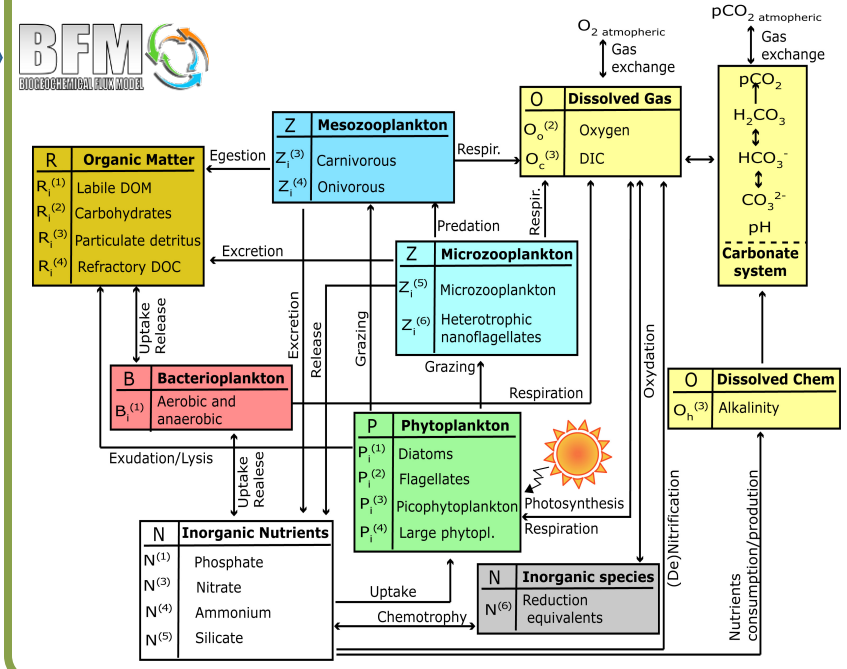
+ Back-up System
+ new Qual/Val
+ Carbonate system

CMEMS-Med-MFC Med-biogeochemistry component

PU=OGS + CINECA HPC-support

MED-CURRENT
Physical forcing

BIOGEOCHEMICAL MODEL
OGSTM-BFM (1/24, 120z)



SATELLITE OBSERVATIONS
Chlorophyll concentrations
+ coastal chlorophyll data

ASSIMILATION
3D-VAR scheme

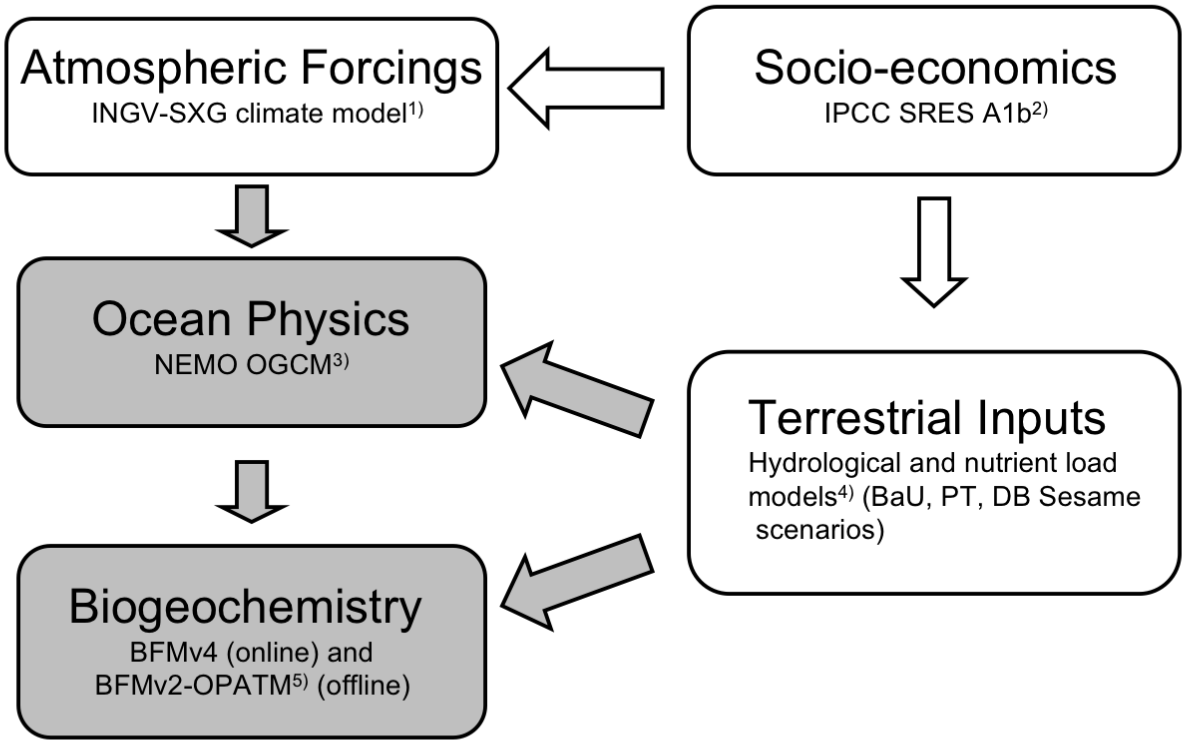
AN&FC + REAN Products =
3D daily mean of:
chl, N, P, PrimProd, phytobiomass, Doxy
+ pCO2, pH

+ Back-up System
+ new Cal/Val
+ rivers align with PHY

04/17
V
03/18

V3

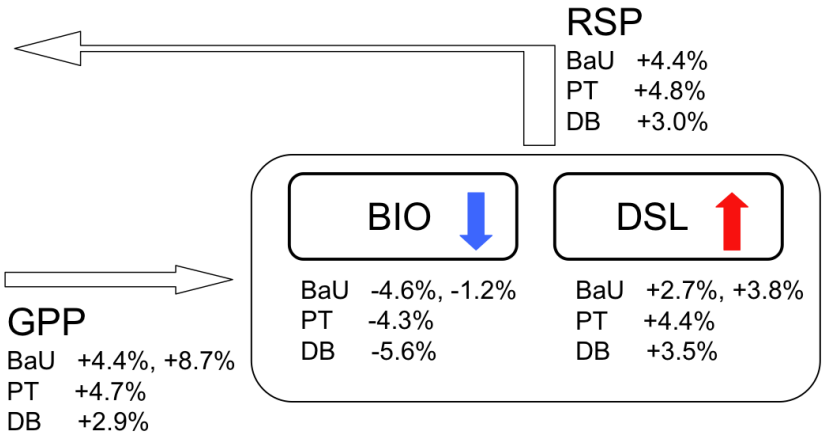
Climate simulations



1) Gualdi et al. (2008); 2) Nakicenovic and Swart (2000); 3) Oddo et al (2009); 4) Ludwig et al. (2010); 5) Lazzari et al. (2012)

Effect on carbon cycling

- ✓ **Increase of carbon rates both production (GPP) and community respiration (RSP)**
- ✓ **Increase of dissolved semi-labile carbon**
- ✓ **Reduction in biomass**



MEDITERRANEAN BASIN

	20C	A1B-BaU	A1B-PT	A1B-DB
GPP	0.66	0.044	0.047	0.029
RSP	0.65	0.044	0.048	0.030
NPP	0.36	0.032	0.036	0.015
NCP	0.01	-0.001	-0.033	-0.064
DSL	0.96	0.038	0.044	0.035
BIO	4.12	-0.046	-0.043	-0.056

WESTERN BASIN

	20C	A1B-BaU	A1B-PT	A1B-DB
GPP	0.81	0.023	0.017	0.011
RSP	0.80	0.023	0.016	0.013
NPP	0.46	0.009	0.001	-0.006
NCP	0.01	0.050	0.019	-0.002
DSL	1.02	0.030	0.027	0.025
BIO	4.97	-0.070	-0.074	-0.076

EASTERN BASIN

	20C	A1B-BaU	A1B-PT	A1B-DB
GPP	0.58	0.061	0.073	0.044
RSP	0.56	0.063	0.076	0.046
NPP	0.30	0.053	0.067	0.034
NCP	0.01	-0.035	-0.068	-0.104
DSL	0.93	0.045	0.056	0.042
BIO	3.63	-0.027	-0.018	-0.039

Impact of terrestrial inputs on coastal areas

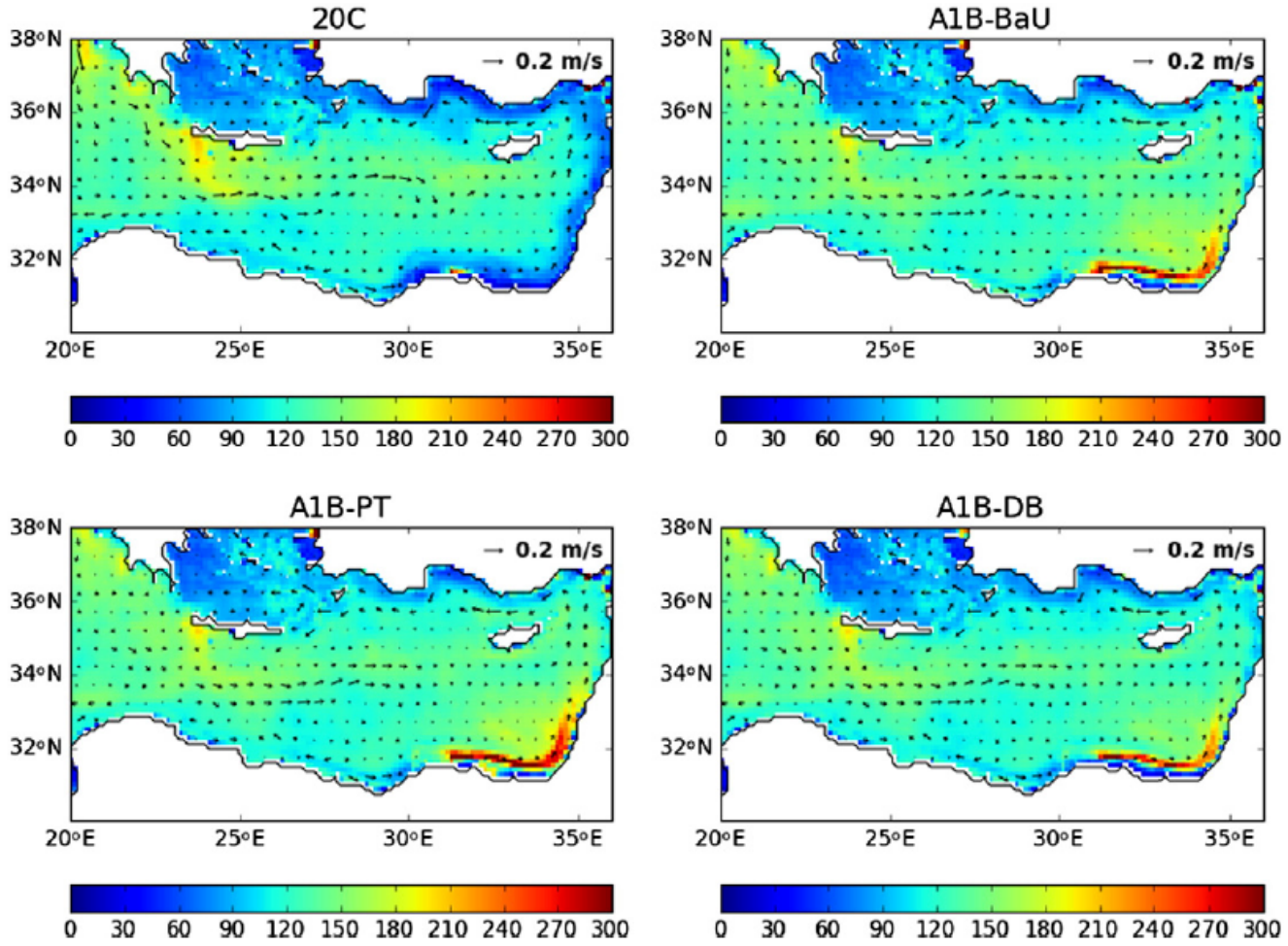
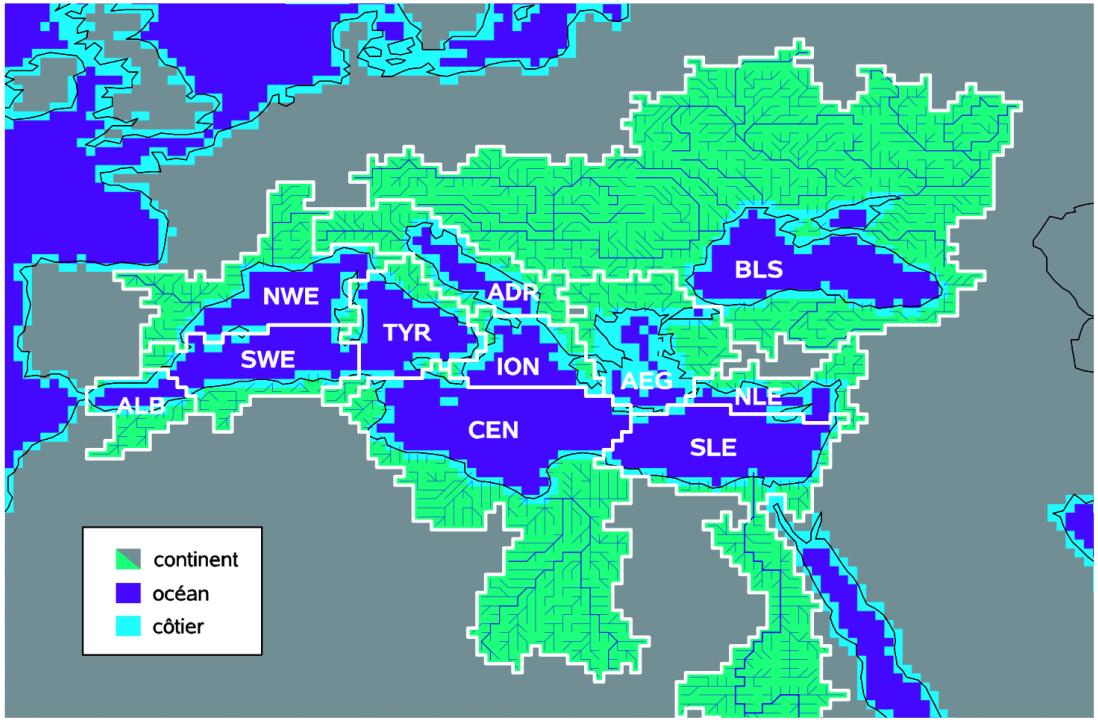
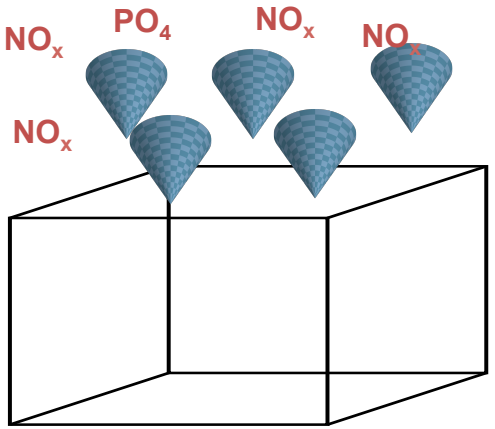


Fig. 8. The mean circulation field and NPP (gC m^{-2}/y) for the OPATM–BFM simulations: 20C (top left panel), A1B-BaU (top right panel), A1B-PT (bottom left panel), A1B-DB (bottom right panel).

Technical issue: description of Terr. Inputs

SESAME D4.3 DATASET from 1960 to 2000
HORIZONTAL RESOLUTION 0.25°
19 rivers with runoff > 50 m3/s





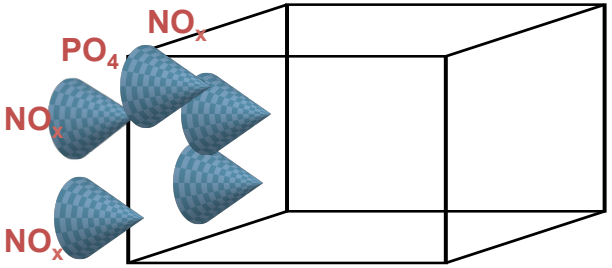
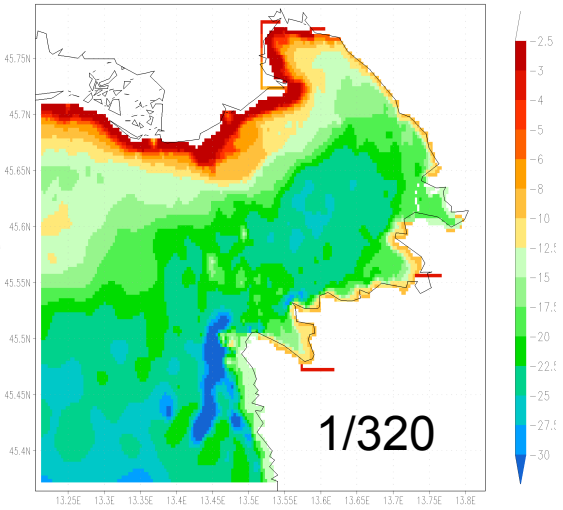


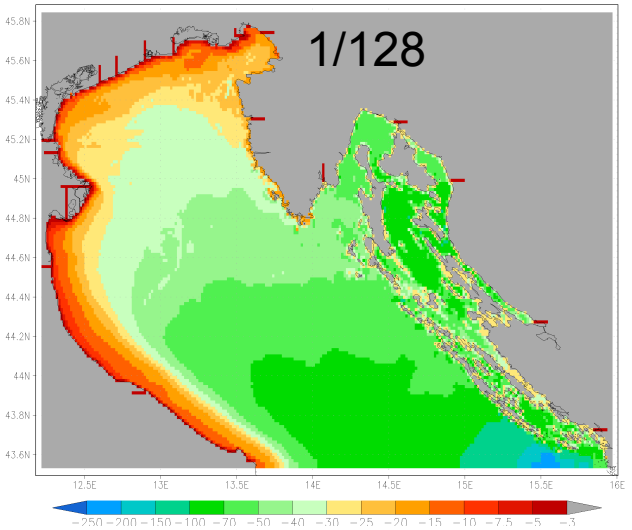
Figure 1 *– Distribution of the coastal grids (light blue colour) for which river fluxes of water and nutrients (N, P, Si) could be supplied for the period 1960-2000.*

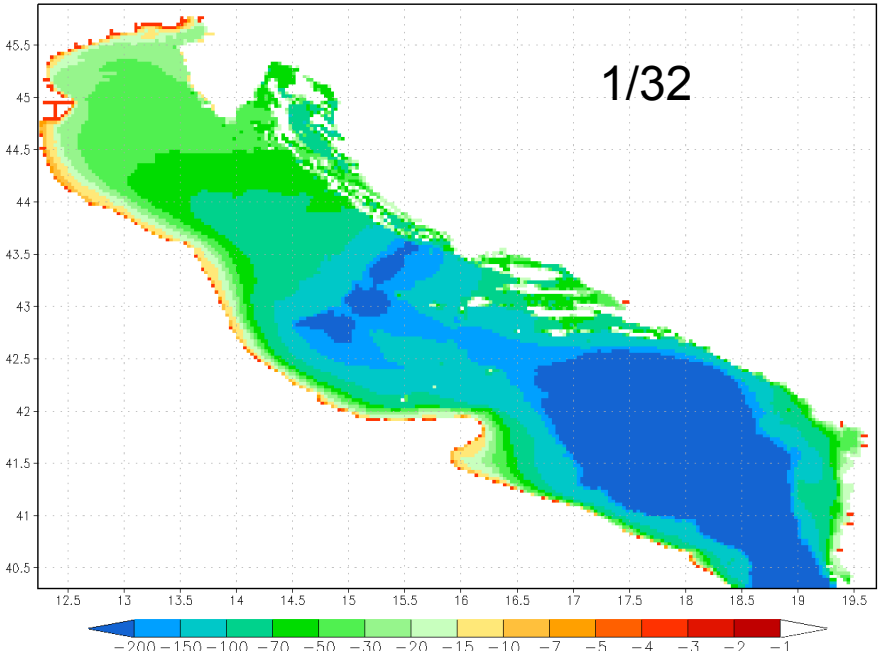
PERSEUS DATASET from 1980 to 2020 (monthly data);
HORIZONTAL RESOLUTION (1/12º)
39 rivers with runoff > 50 m3/s

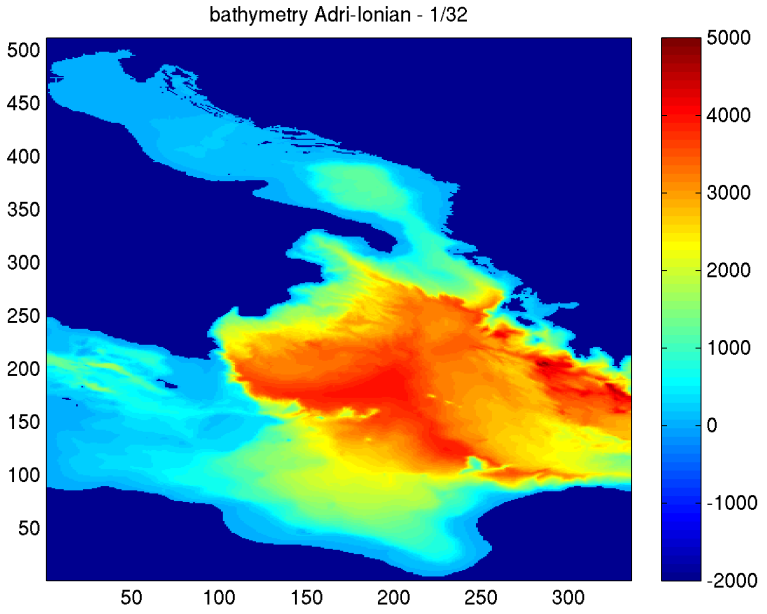
Technical issue: nesting approach

Nesting approach allows to scale from basin scale to coastal scale









Bathymetry courtesy Querin et al.,2006,2013

Conclusions

- Development of a model in the framework of open source code
- Past and ongoing effort in scientific (and technical) improvement of the tool, both in terms of operational and scenario simulations
- In order to develope a basin scale tool application to coastal areas will require further work to resolve all the physical and biogechemical processes involved

Thank you for the attention!

BFM BIOGEOCHEMICAL FLUX MODEL

Search Site

Home | The BFM Agreement | Model Description | Download | System Team | Publications

You are here: Home

What is the BFM

The Biogeochemical Flux Model (BFM) is a numerical model for the simulation of the dynamics of major biogeochemical properties in marine ecosystems.

The BFM is open source software freely available under the GNU Public License. The model description is available here.The code and the full documentation can be downloaded here.

Members of the BFM agreement

The development of the BFM is supported by a formal agreement. The agreement establishes a program for model development that is discussed and prepared every year by the participants. Model developments are inserted by the system team into the different releases of the model. The agreement is open to entrance of more contributors and more information can be requested to info(at)bfm-community.eu

Current members of the consortium are: CMCC, OGS, UNIBO, and UCT.

« January 2016 »

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	**19**	20	21	22	23
24	25	26	27	28	29	30
31						

Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

Dipartimento di Fisica e Astronomia, Alma Mater Studiorum Università di Bologna (UNIBO DIFA)

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)

Department of Oceanography, University of Cape Town (UCT)

The Plone® Open Source CMS/WCM is © 2000-2016 by the Plone Foundation and friends. Distributed under the GNU GPL license.

Modularity and flexibility

Equation Box 2.3 Bacteria equations

$$\left.\frac{dB_c}{dt}\right|_{bio} = \sum_{j=1,6}\left.\frac{dB_c}{dt}\right|^{upt}_{R_c^{(j)}} - \left.\frac{dB_c}{dt}\right|^{rsp}_{O^{(3)}} - \left.\frac{dB_c}{dt}\right|^{lys}_{R_c^{(1)}} - \sum_{k=5,6}\left.\frac{dB_c}{dt}\right|^{prd}_{Z_c^{(k)}} \quad (2.3.1a)$$

$$\left.\frac{dB_n}{dt}\right|_{bio} = \sum_{j=1,6}\frac{R_n^{(j)}}{R_c^{(j)}}\left.\frac{dB_c}{dt}\right|^{upt}_{R_c^{(j)}} + \sum_{i=3,4}\left.\frac{dB_n}{dt}\right|^{upt}_{N^{(i)}} - \left.\frac{dB_n}{dt}\right|^{rel}_{N^{(4)}} - \frac{B_n}{B_c}\left.\frac{dB_c}{dt}\right|^{lys}_{R_c^{(1)}} + \quad (2.3.1b)$$

$$\frac{B_n}{B_c}\sum_{k=5,6}\left.\frac{dB_c}{dt}\right|^{prd}_{Z_c^{(k)}} \quad (2.3.1c)$$

$$\left.\frac{dB_p}{dt}\right|_{bio} = \sum_{j=1,6}\frac{R_p^{(j)}}{R_c^{(j)}}\left.\frac{dB_c}{dt}\right|^{upt}_{R_c^{(j)}} + f_n^p\left.\frac{dB_p}{dt}\right|^{upt,rel}_{N^{(1)}} - \frac{B_p}{B_c}\left.\frac{dB_c}{dt}\right|^{lys}_{R_c^{(1)}} - \frac{B_p}{B_c}\sum_{k=5,6}\left.\frac{dB_c}{dt}\right|^{prd}_{Z_c^{(k)}} \quad (2.3.1d)$$

```
#-------------------------------------------------------------------------
#       PELAGIC STATE VARIABLES (volume)
#-------------------------------------------------------------------------
3d-state

#-------------------------------------------------------------------------
#       State Variable(s) for Nutrients
#-------------------------------------------------------------------------
 N1p   :         Phosphate  : mmol P/m3
 N3n   :         Nitrate    : mmol N/m3
 N4n   :         Ammonium   : mmol N/m3


#-------------------------------------------------------------------------
#       State Variable(s) for Phytoplankton
#-------------------------------------------------------------------------
 group PhytoPlankton[cnpls] (PPY) :  mg C/m3 : mmol N/m3 : mmol P/m3 :
                                     mg Chl/m3 : mmol Si/m3
         P1            : Diatoms
         P2[-s]        : Flagellates
         P3[-s]        : PicoPhytoplankton
         P4[-s]        : Large Phytoplankton
 end

#-------------------------------------------------------------------------
#       State Variable(s) for Mesozooplankton
#-------------------------------------------------------------------------
 group MesoZooPlankton[cnp]  (MEZ) : mg C/m3 : mmol N/m3 : mmol P/m3
              Z3       : Carnivorous Mesozooplankton
              Z4       : Omnivorous Mesozooplankton
 end
```