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Impacts of climate change on the biogeochemistry of the Mediterranean Sea

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Outline

Mediterranean Sea biogeochemistry

- ✓ Med sea features
- ✓ Primary productivity
- ✓ Carbonate system

Scenarios simulations

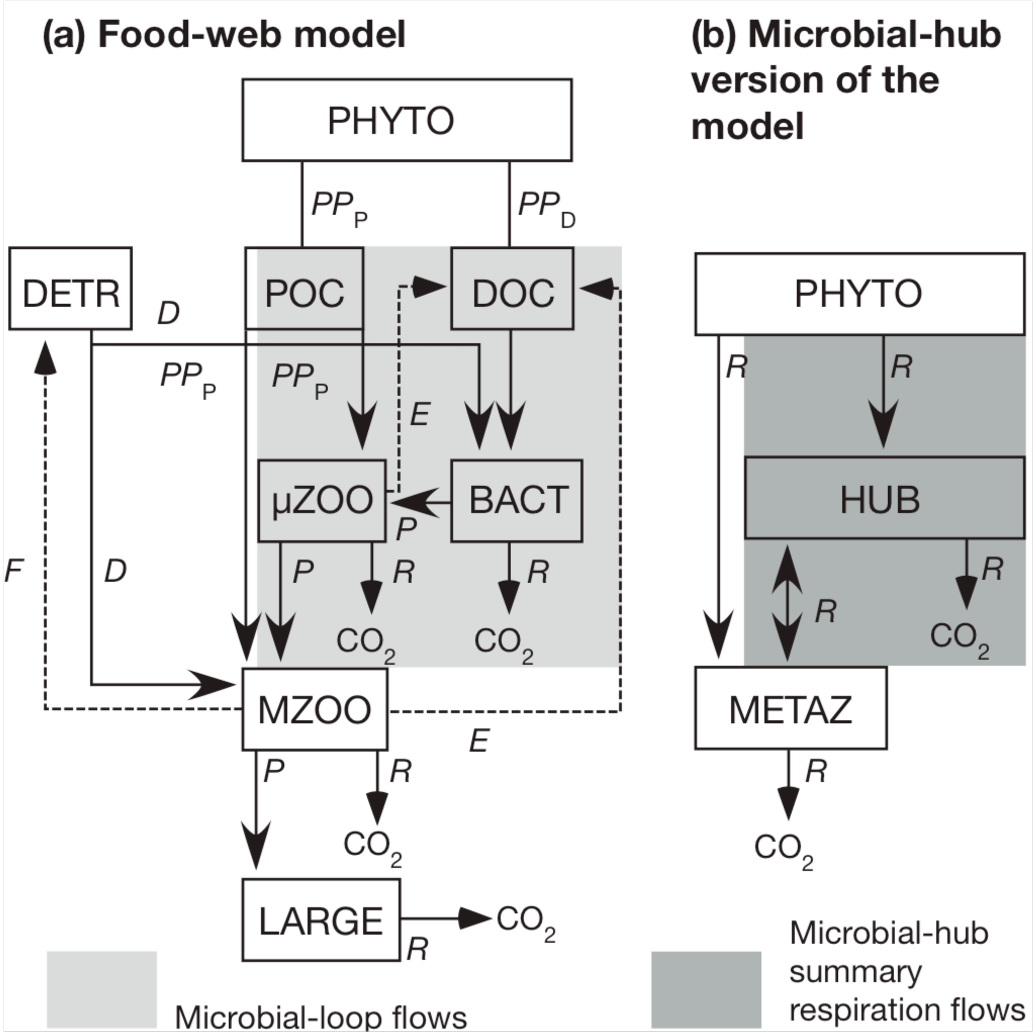
- ✓ Physical forcings
- ✓ Impact on biogeochemical variables
- ✓ Sesame simulations

- ✓ Tools employed: numerical models

Brief description of Med. Sea Features

- ✓ Semi-enclosed Sea
- ✓ Relevance of thermohaline circulation
- ✓ Low average nutrient concentrations (in particular phosphates)
- ✓ In general oligotrophic regime (west – east trophic gradient)
- ✓ Presence of Deep Chlorophyll Maximum, with the exception of winter period
- ✓ High diversity and variability in spatial and temporal scales in plankton, Siokou Frangou et al. (2010)

Classical and microbial food web



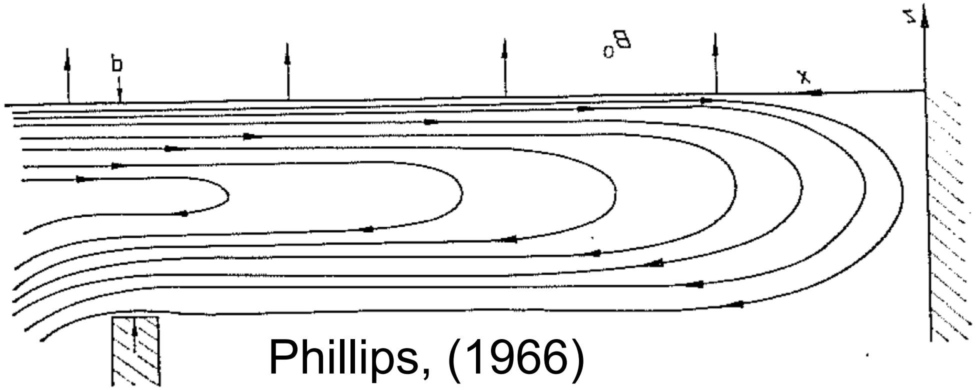
Legendre and Rivkin, 2008

Box model of the Mediterranean Sea

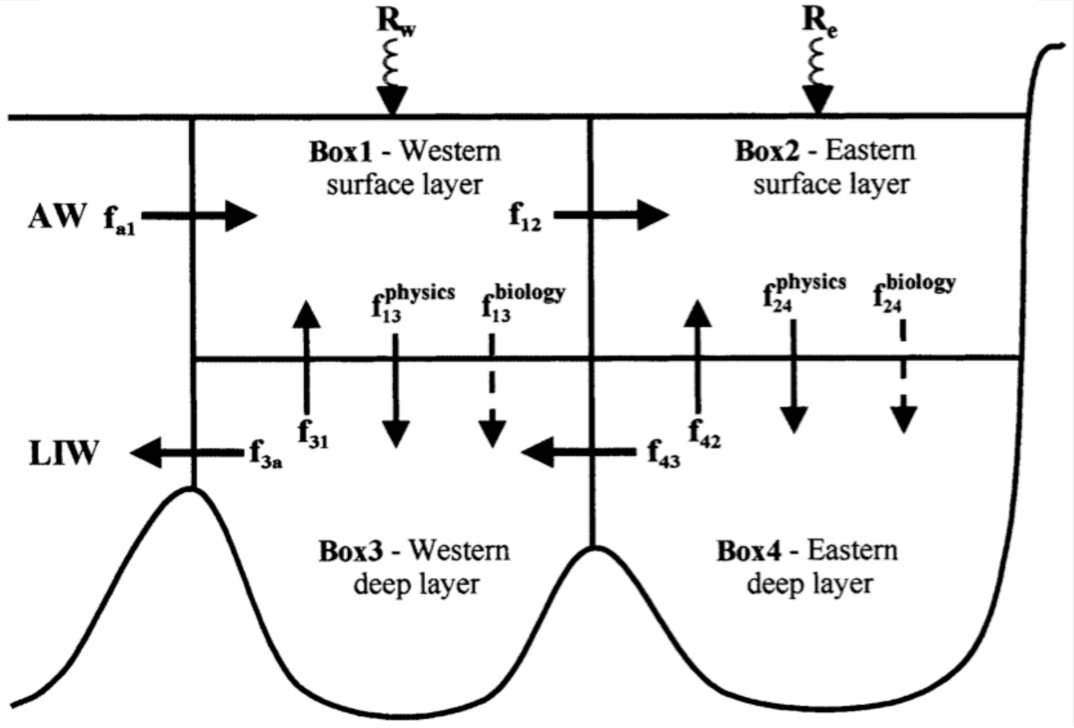
Anti-estuarine circulation, Mediterranean Sea → concentration basin

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

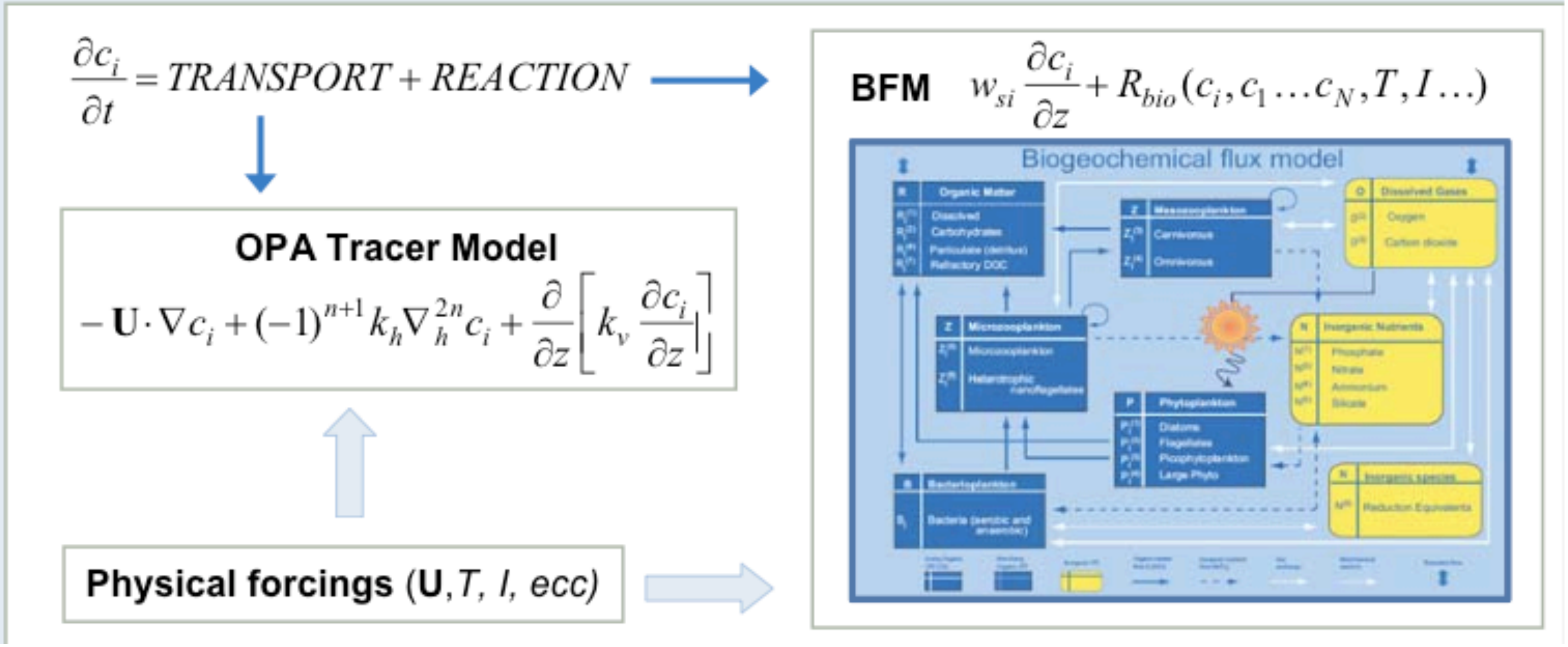
$$V \frac{d}{dt} \Sigma = F \, \Sigma + L,$$

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

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

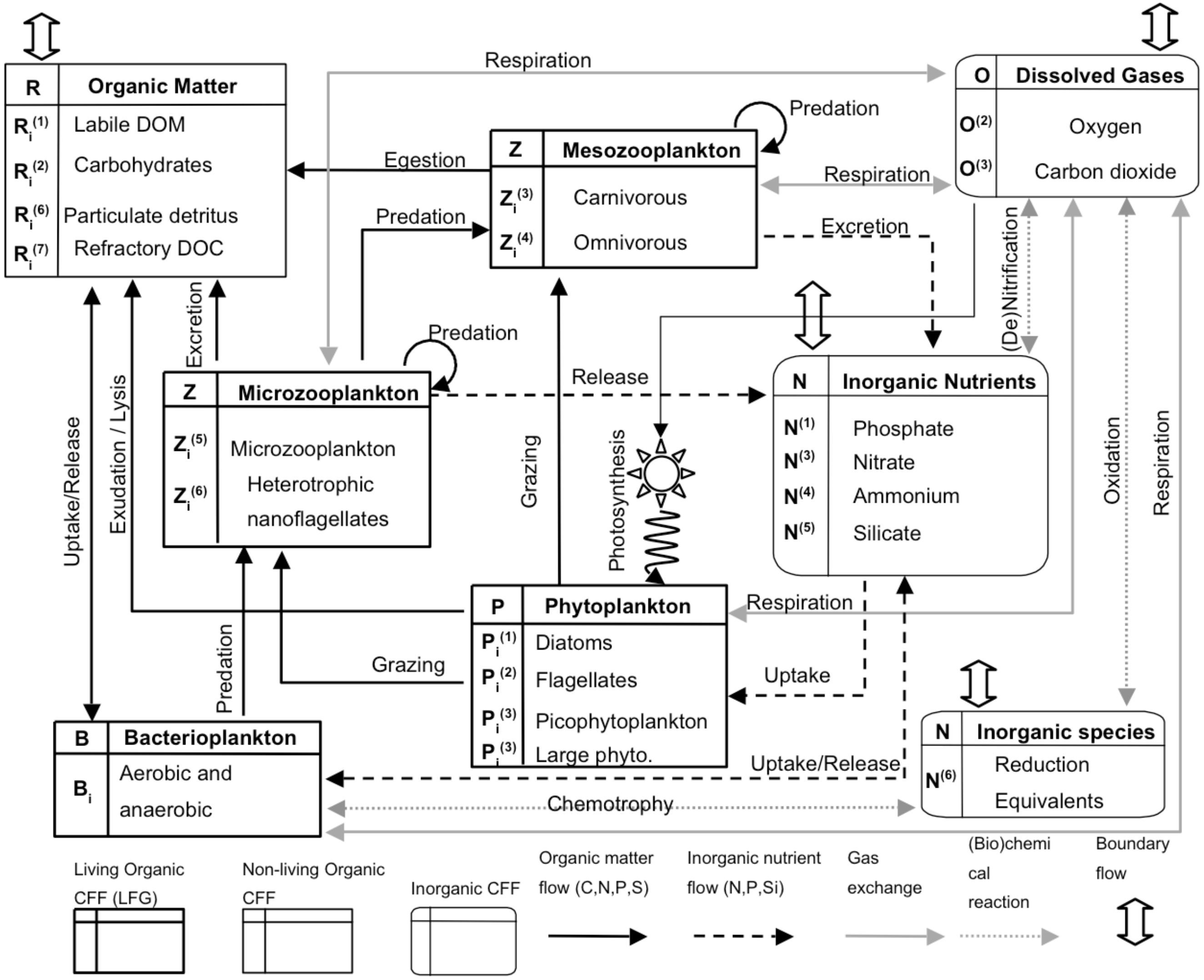
Physical forcings (**U**,*T*, *I*, *ecc*)

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

- ✓ Horiz. Res. = 1/8°
- ✓ Vert. Res. = 43/72 levels
- ✓ Time Res. = 1800 s
- ✓ 1 year simulated in 2 hours

Model configuration: BFM scheme

- ✓ **Multi element description (C, P, N, Si, Chl*a*)**
- ✓ **Classical and Microbial loop food-web**
- ✓ **4 phytoplankton functional types**
- ✓ **4 zooplankton functional types**



✓ **Vichi et al. (2007), Lazzari et al. (2012)**

PFT parameterization

- ✓ **Diatoms ESD[20,200] μ unicellular eukariotes enclosed by a silica frustule grazed by micro and mesozooplankton**
- ✓ **Autotrophic nanoflagellates ESD[2,20] μ motile unicellular eukariotes grazed by heterotrophic nanoflagellates, micro and mesozooplankton**
- ✓ **Picophytoplankton ESD[0.2,2] μ small autotrophic organisms grazed by heterotrophic nanoflagellates preference in ammonium**
- ✓ **Large partial inedible phytoplankton ESD [100,+∞[μ**

Key feature: Initial and Boundary conditions

✓ **Initial Conditions** MEDAR-MEDATLAS dataset with (corrections for phosphates from literature data)

✓ **Atlantic inputs from Gibraltar strait** – MEDAR/MEDATLAS

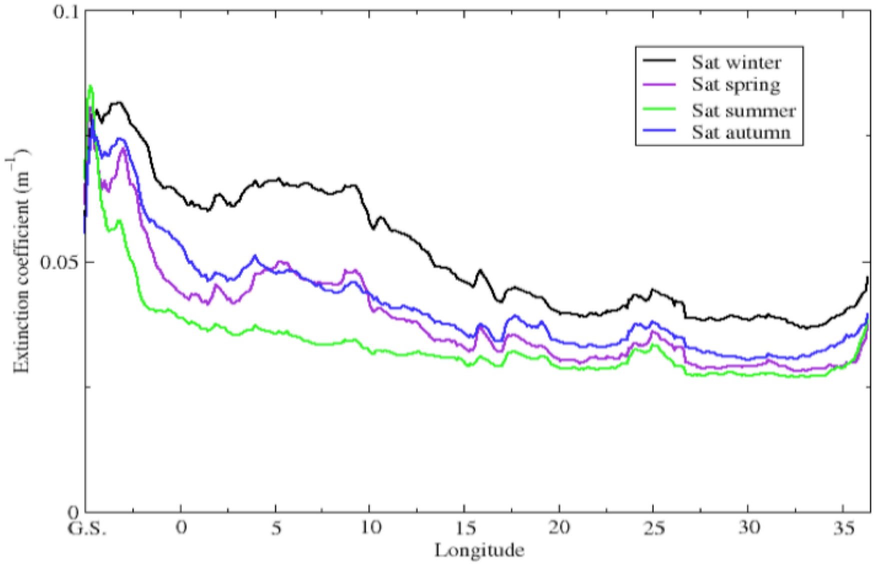
✓ **River inputs** – Data from WP1, task 1.7 by Wolfgang Ludwig, CNRS - CEFREM)

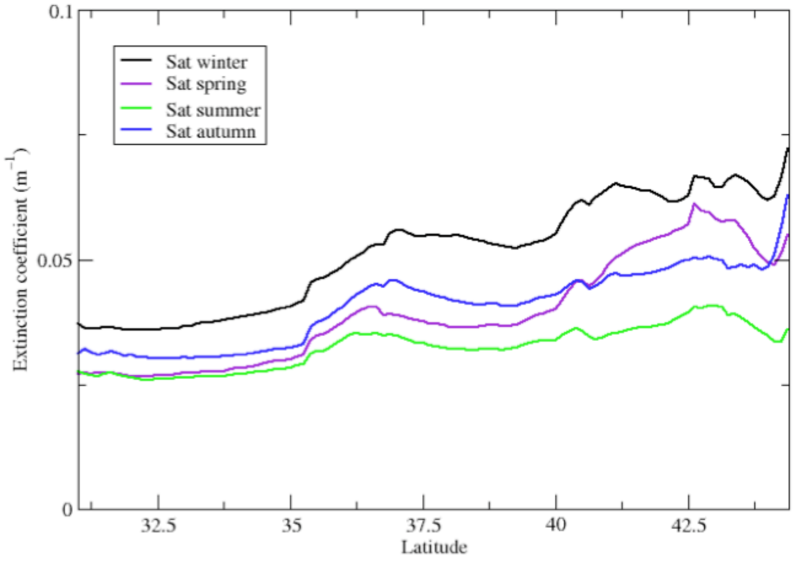
✓ **Atmospheric inputs** – data from Guerzoni et al. (1999)

Key feature: Extinction coefficient

- ✓ Extinction coefficient (*k*) regulates light penetration along the water column

- ✓ Difficulties to determine k (Morel et al., 2009), assimilated from K490 satellite product

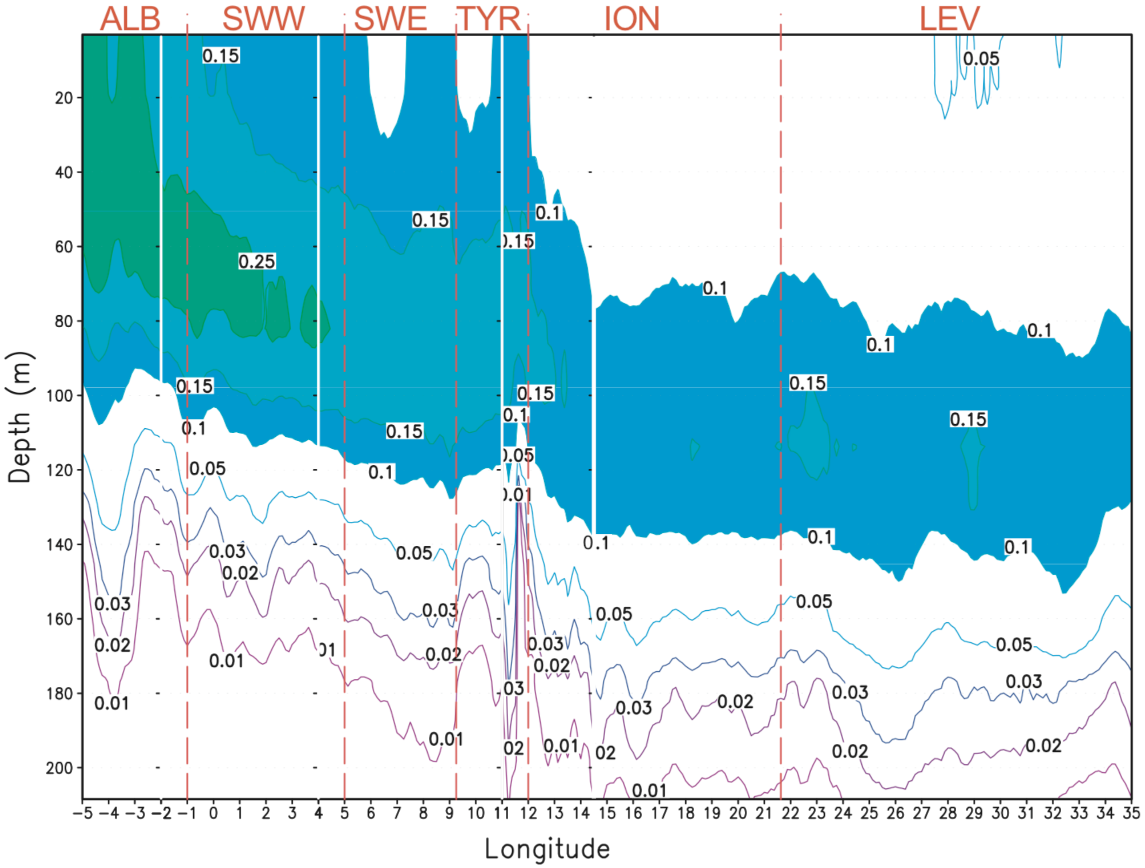


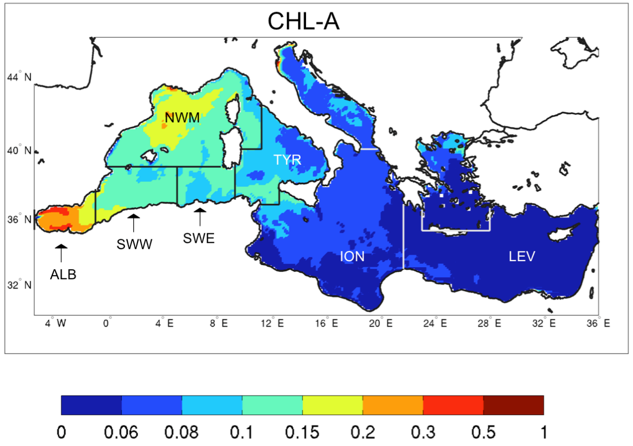


Model Validation: Spatial variability of chla

Controlling mechanism extinction factor coefficient (*k*)

Declining DCM moving eastward

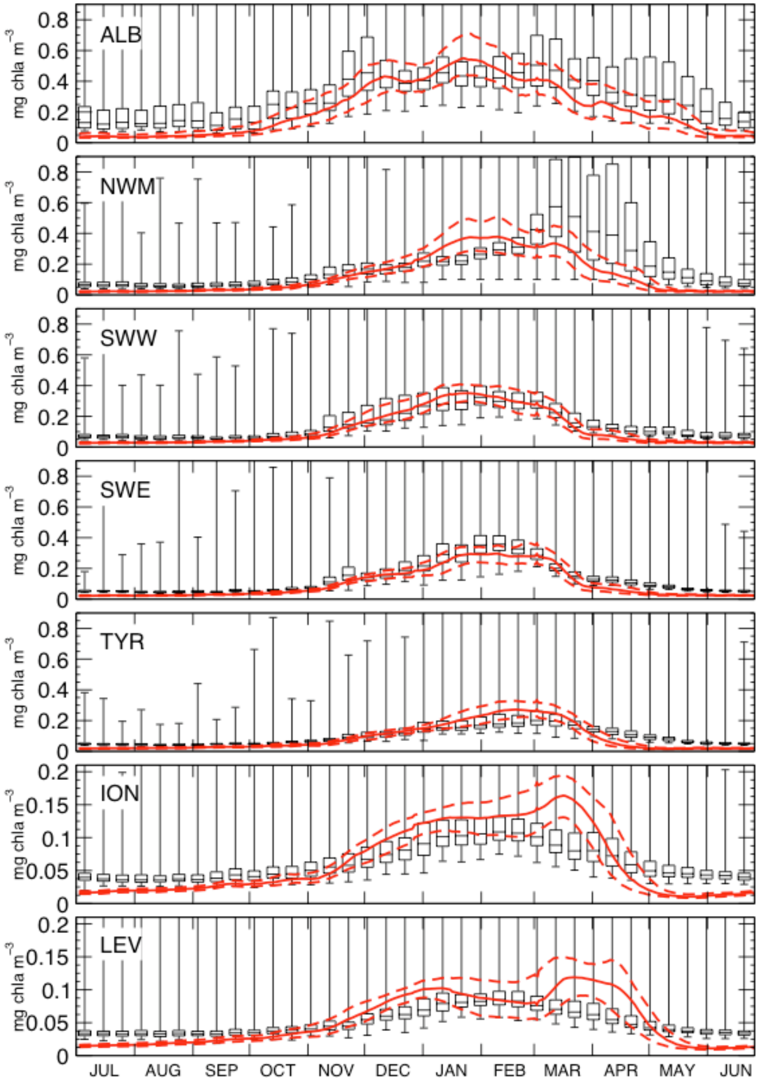




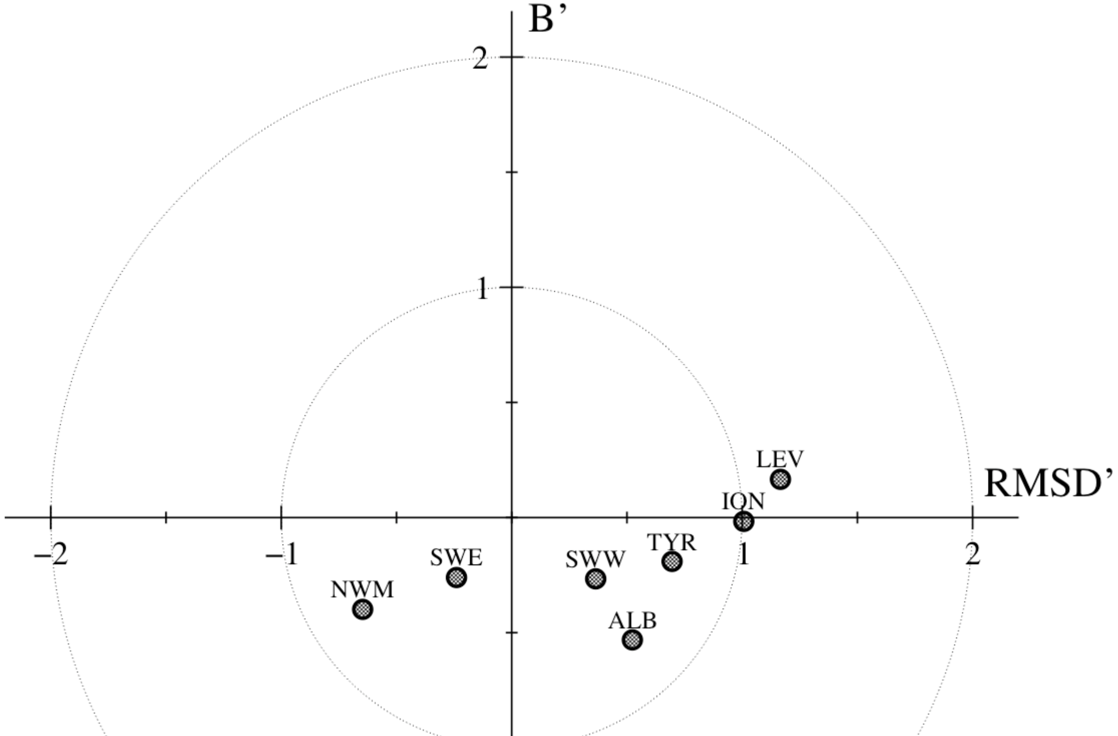
Period 1999-2004

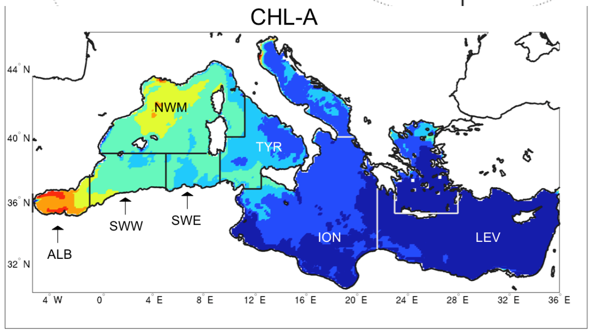
Temporal variability: chl*a* satellite SeaWIFs

SEASONAL CYCLE 1999-2004



TARGET DIAGRAM

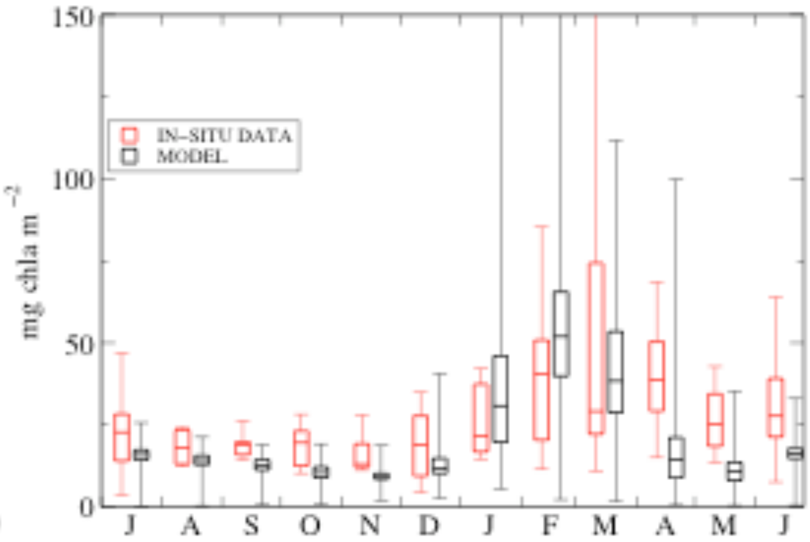




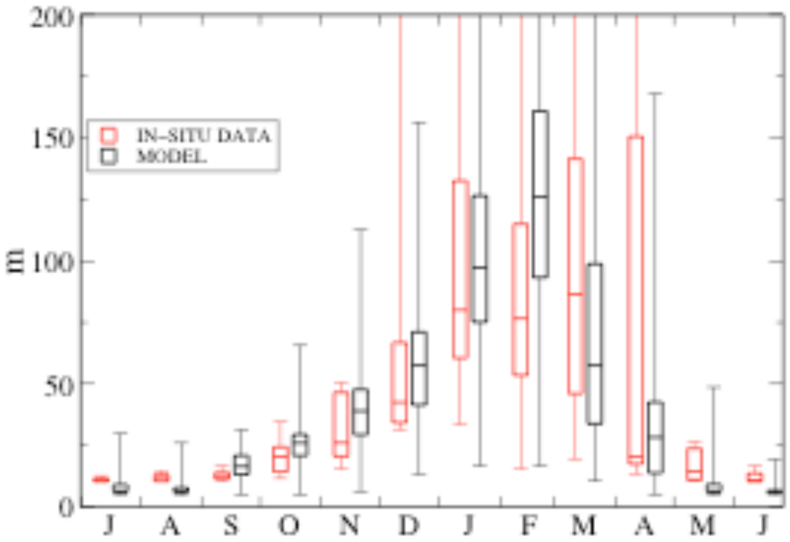
Model validation: in situ data (DYFAMED)

✓ Climatology of chl*a* and MLD from in situ data (sensu D’Ortenzio et al., 2005)

✓ MLD controlling mechanism for winter chl*a* accumulation



b)

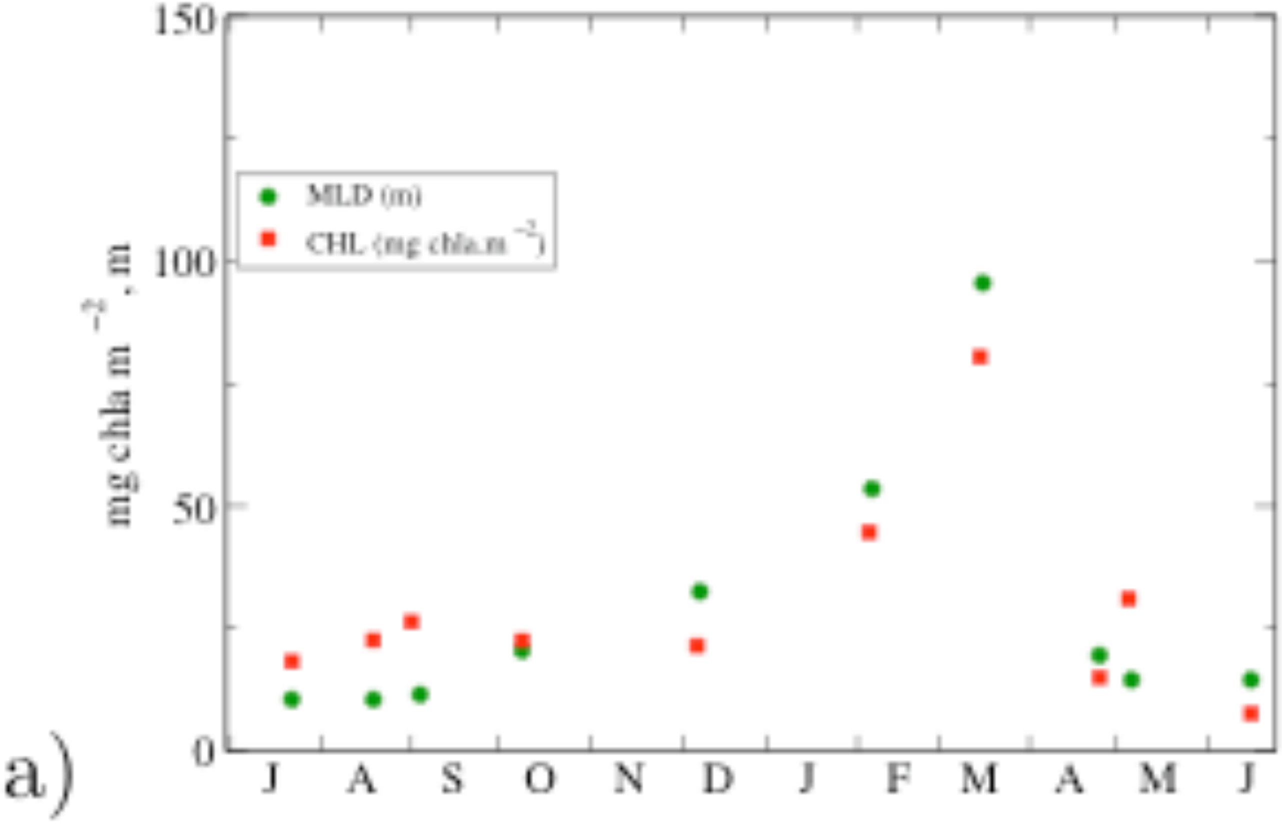


c)

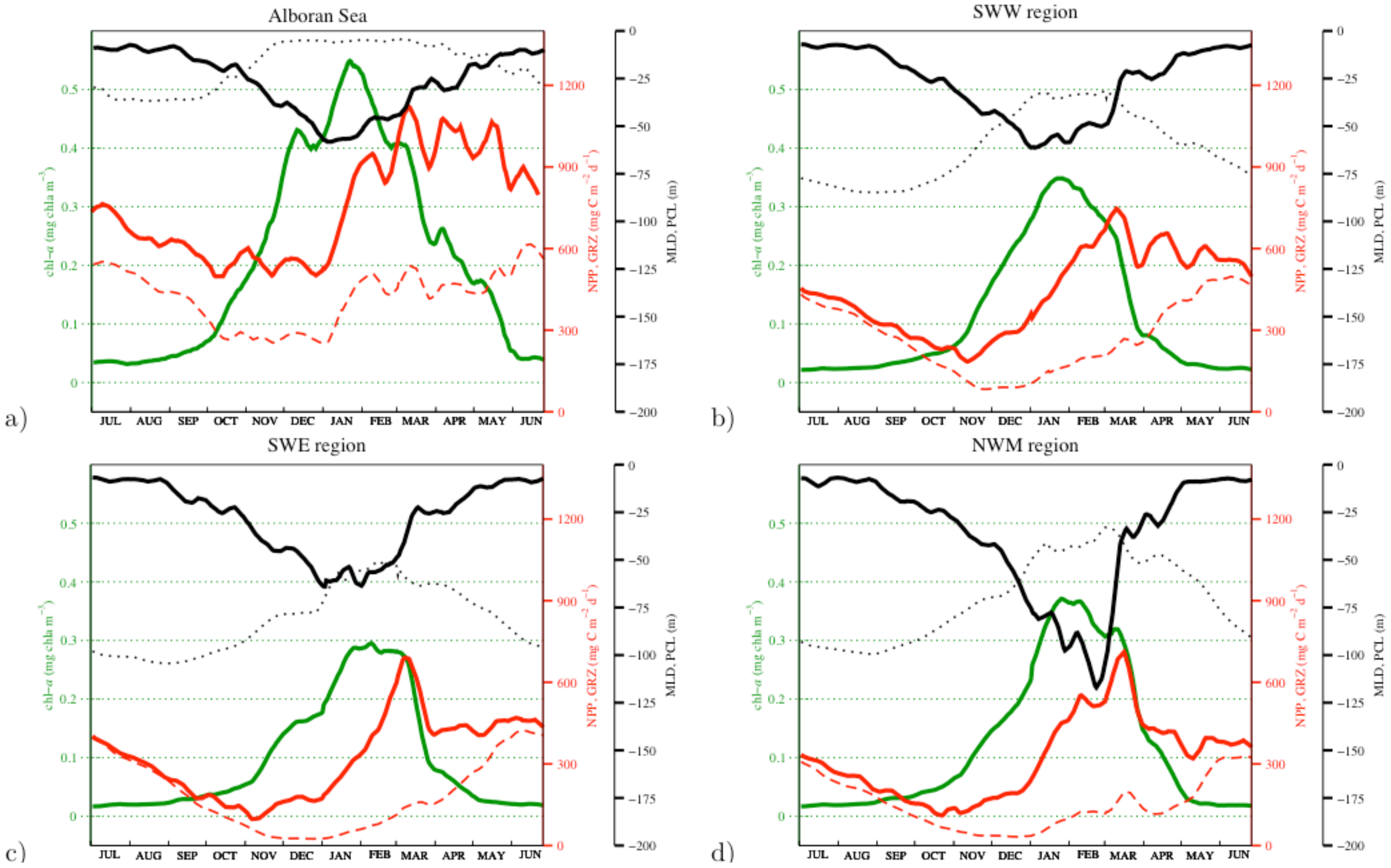
Model validation: in situ data (DYFAMED)

✓ **In situ data year 1998 at DYFAMED station (NWM)**

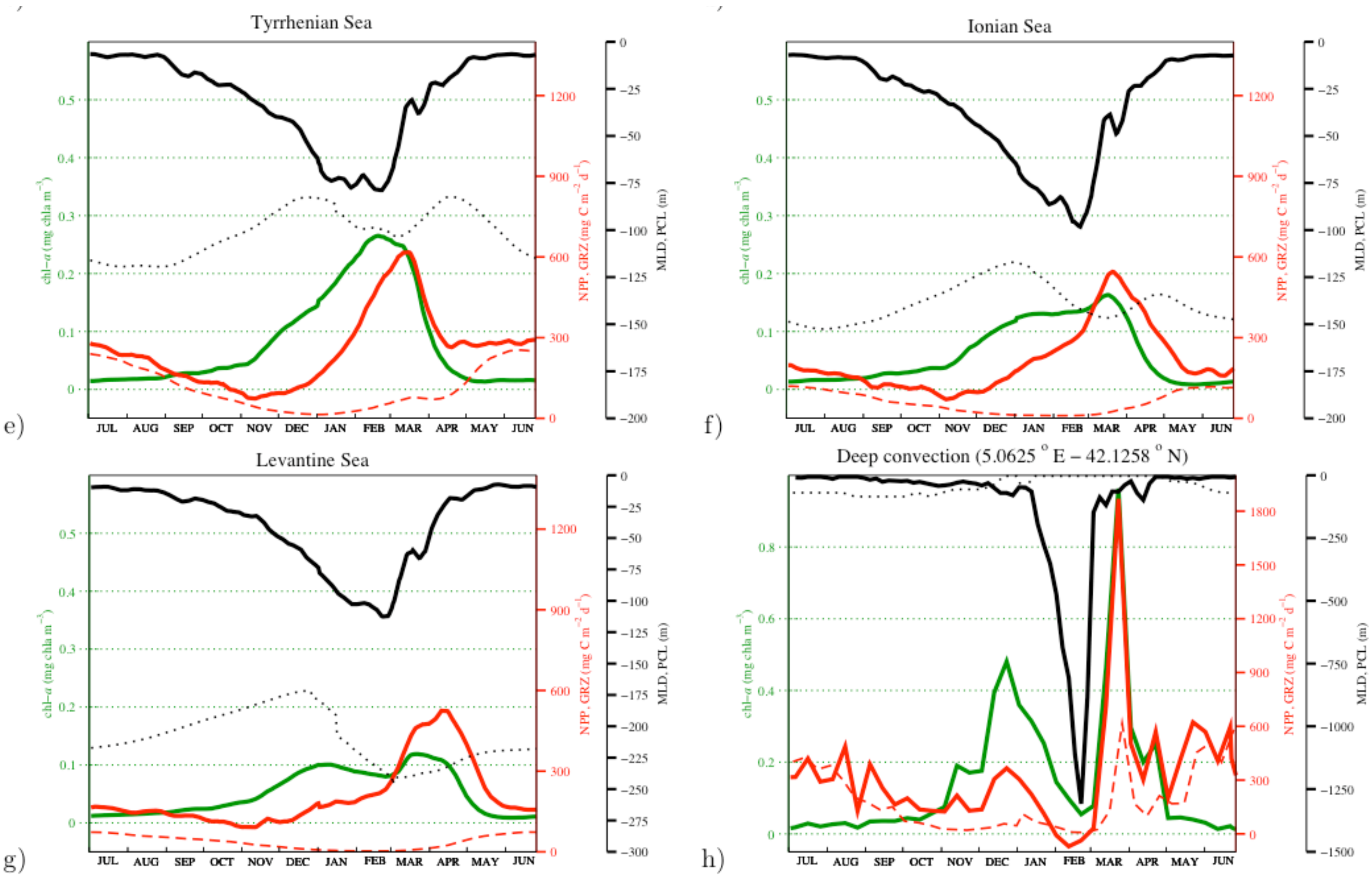
✓ **Syncronization between MLD deepening and vertically integrated chl*a* maximum (Behrenfeld et al., 2010, North Atlantic Sea)**



Synthesis: Longhurst diagrams



Synthesis: Longhurst diagrams



NPP budgets: Literature data

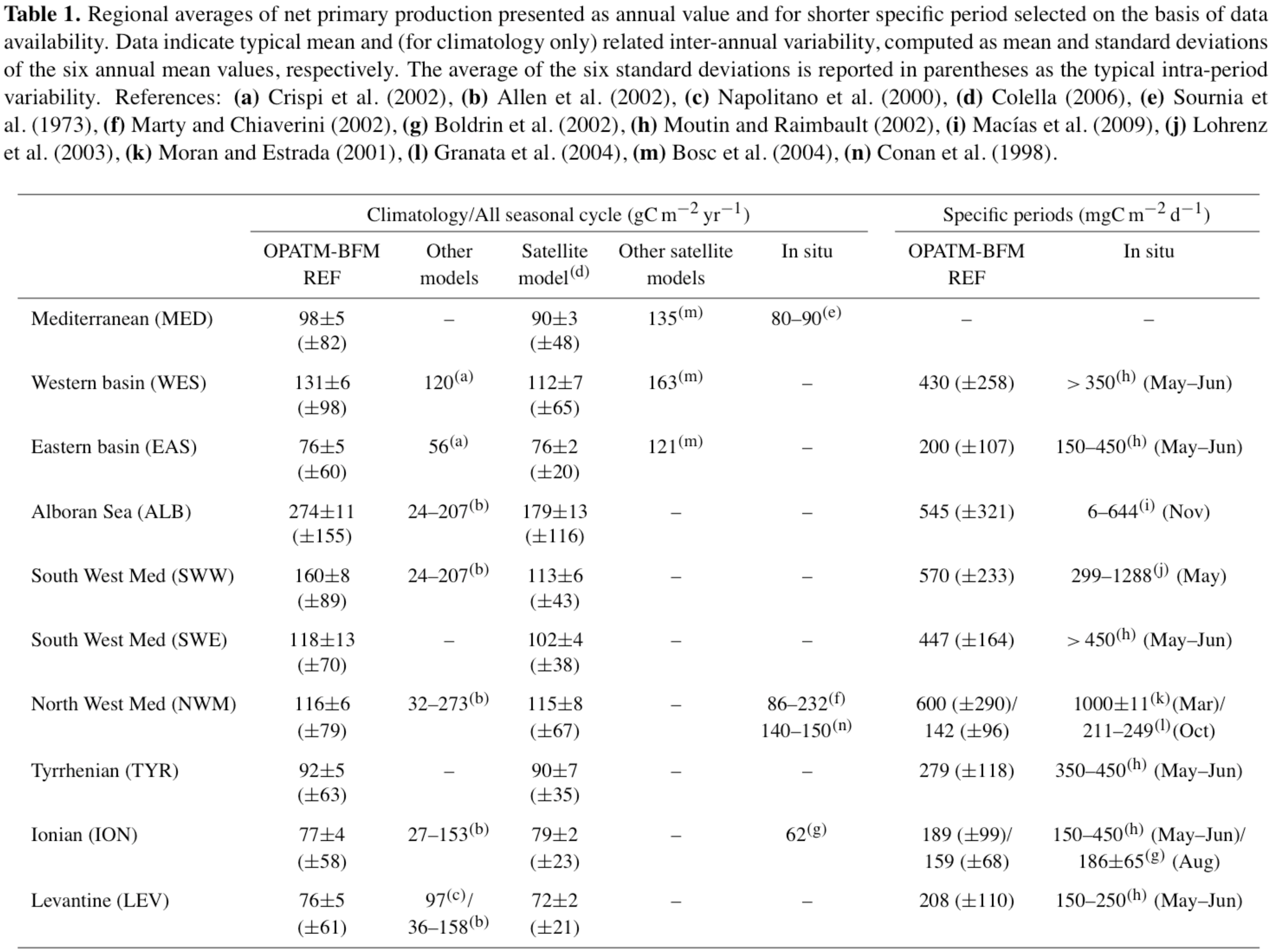


Table 1. Regional averages of net primary production presented as annual value and for shorter specific period selected on the basis of data availability. Data indicate typical mean and (for climatology only) related inter-annual variability, computed as mean and standard deviations of the six annual 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

✓ **The impact of atmospheric and terrestrial inputs on the annual budget of the integrated NPP (new production) is in the range of 3-5gC$m^{-2}yr^{-1}$.**

✓ **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)

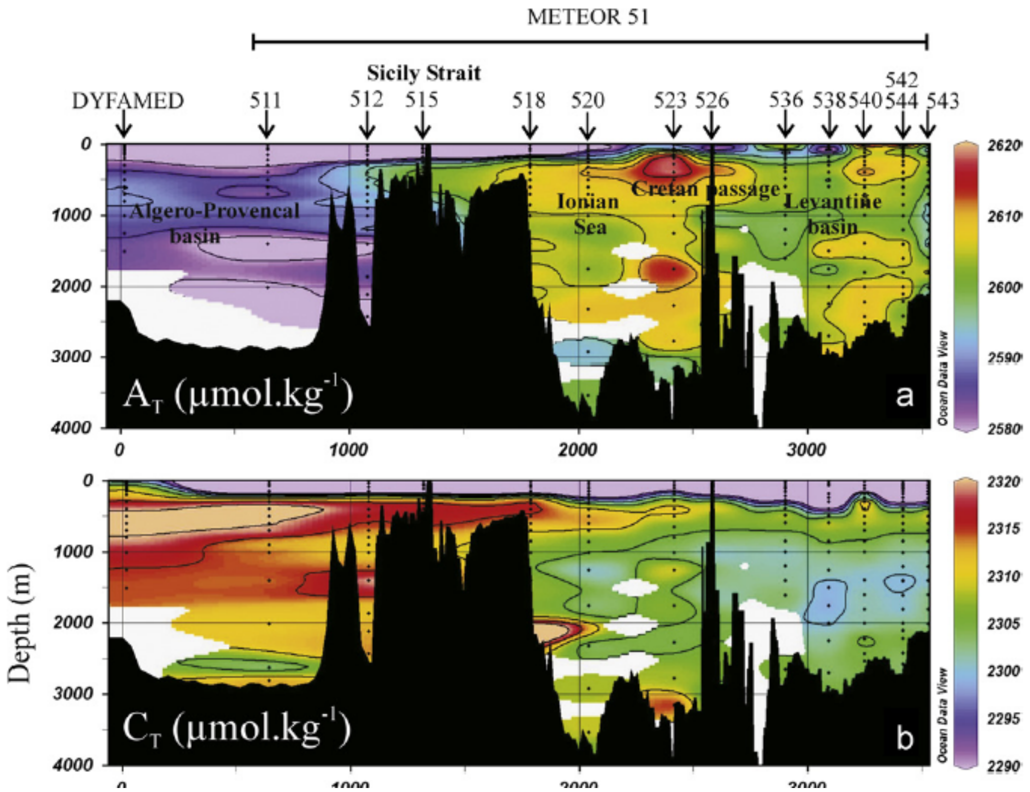
Carbonate system relevance

Peculiarities of the carbonate system in the Mediterranean Sea:

Values of DIC and Alkalinity of MedSea are 10-20% higher than Atlantic Ocean and 15-30% lower than the Black Sea

Observed west – to – east gradient for Alkalinity, DIC

Shape of profile with increasing values at depth

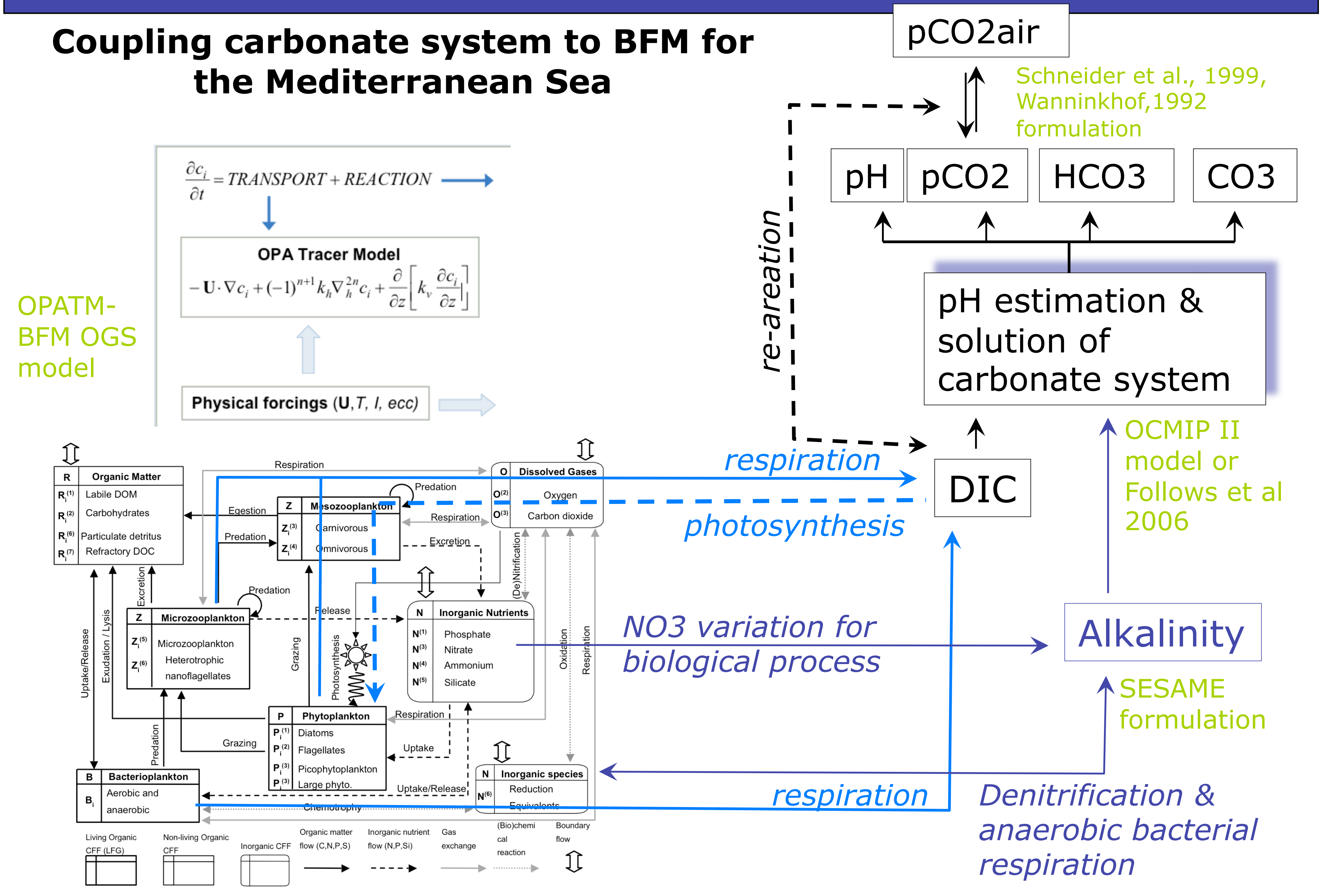


F. Touratier, C. Goyet / Deep-Sea Research I 58 (2011) 1–15

What are the key elements controlling those features?
- Boundary problem
- Contribution of E-P
- Contribution of river input
- Contribution of biological processes

Carbonate system relevance

Coupling carbonate system to BFM for the Mediterranean Sea



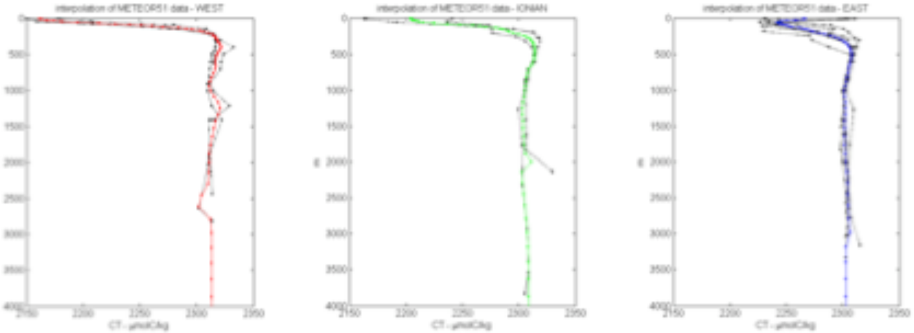
Carbonate system reconstruction of IC, BC

Influence of MAW on upper layers → lower concentration of DIC and Alkalinity

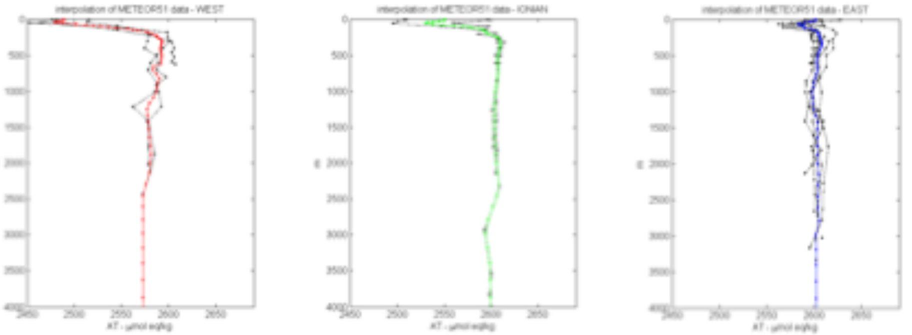
Eastern reaches →impacts of evaporation and terrestrial inputs

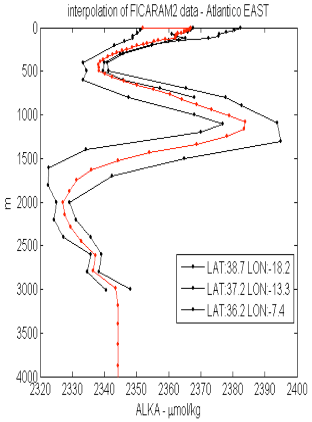
Data from Meteor 06MT20011018 cruise

DIC

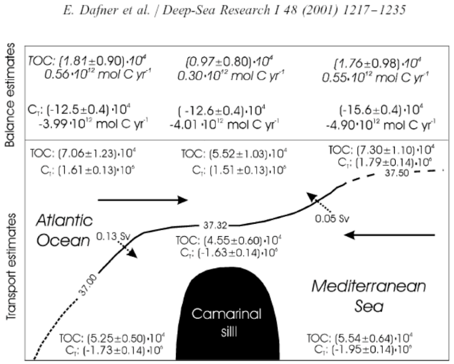


Alkalinity

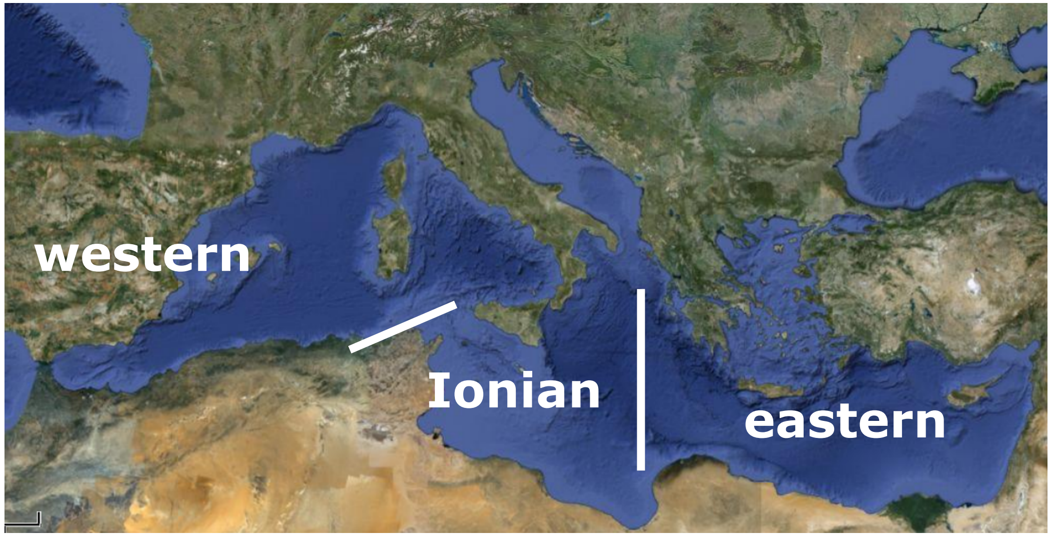




FICARAM2 Cruise, 2001



Dafner et al., 2001



Carbonate system terrestrial inputs

Very few informations for rivers and Dardanelles input

BASIN	DIC (mgC/m3)	ALK (mmol/m3)	DIC (kTon/y)	ALK (Gmol/y)
ALB	30375[a]	2960	123	12
SWE	30375[a]	2960	236	23
NWE	30375[b]	2960	2568	251
- Ebro	25950[c]	3200	316	31
- Rhone	34800[d]	2890	1673	163
TYR	58200	5675	1067	104
ADR	33225	2700	3925	319
- Po			2243	182
ION	33175	2200	408	27
CEN	33175	2200	136	9
AEG	37517	2620	14248	1265
- Dardanelles			12600	1150
NLE	33175	2200	688	45
SLE	38200	2200	594	34
- Nile		2200	559	32

Meybeck M., Ragu A., 1995 River Discarges to the Oceans: An Assessment of suspended solids, major ions and nutrients UNEP STUDY

From available data typical concentrations of ALK and DIC freshwaters for each subbasin.

This reconstruction was coupled with runoff estimates by Ludwig et al. (2009)

Carbonate system CO2 fluxes

CO2 flux at the air-sea interface and carbon pump

The carbon sink for the world ocean is equal to 2.3 Pg C yr−1 (Le Quéré et al., 2009)

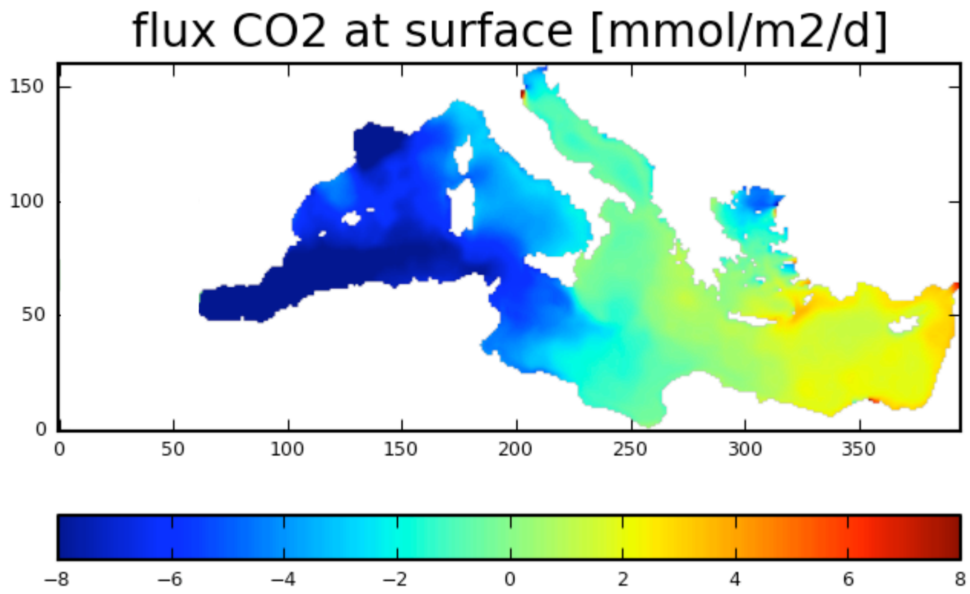
Contribution of the marginal seas: 0.33–0.36 Pg C yr−1 (Chen and Borges, 2009)

Surface of Mediterranean sea is 0.7% of the world ocean, but which is its contribution to the global carbon cycle?

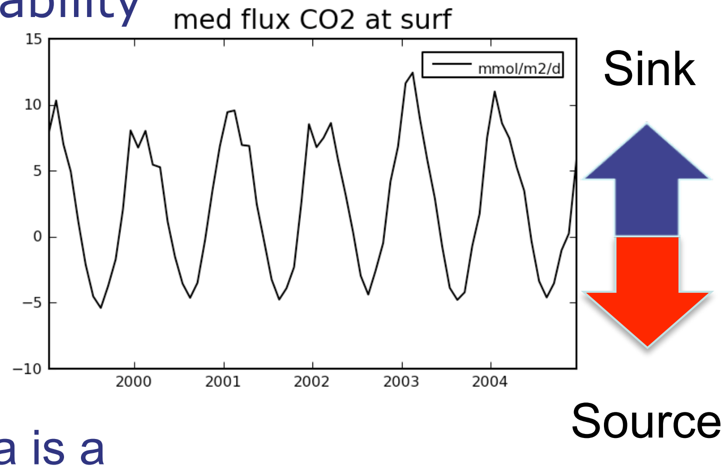
- presence of several sites of deep water formation
- areas (northern basins) with high biological productivity

- eastern basin highly oligotrophic
- warm condition in the eastern and southern parts

Carbonate system relevance



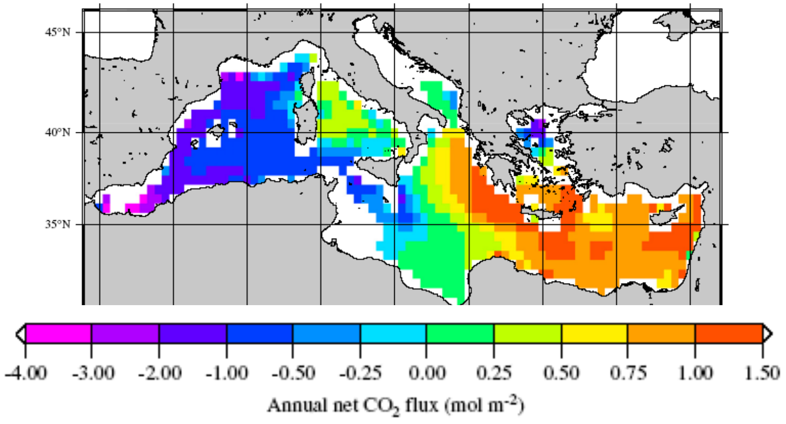
Model results:
Mean of 6 years of simulation 1999-2004 and high seasonal variability



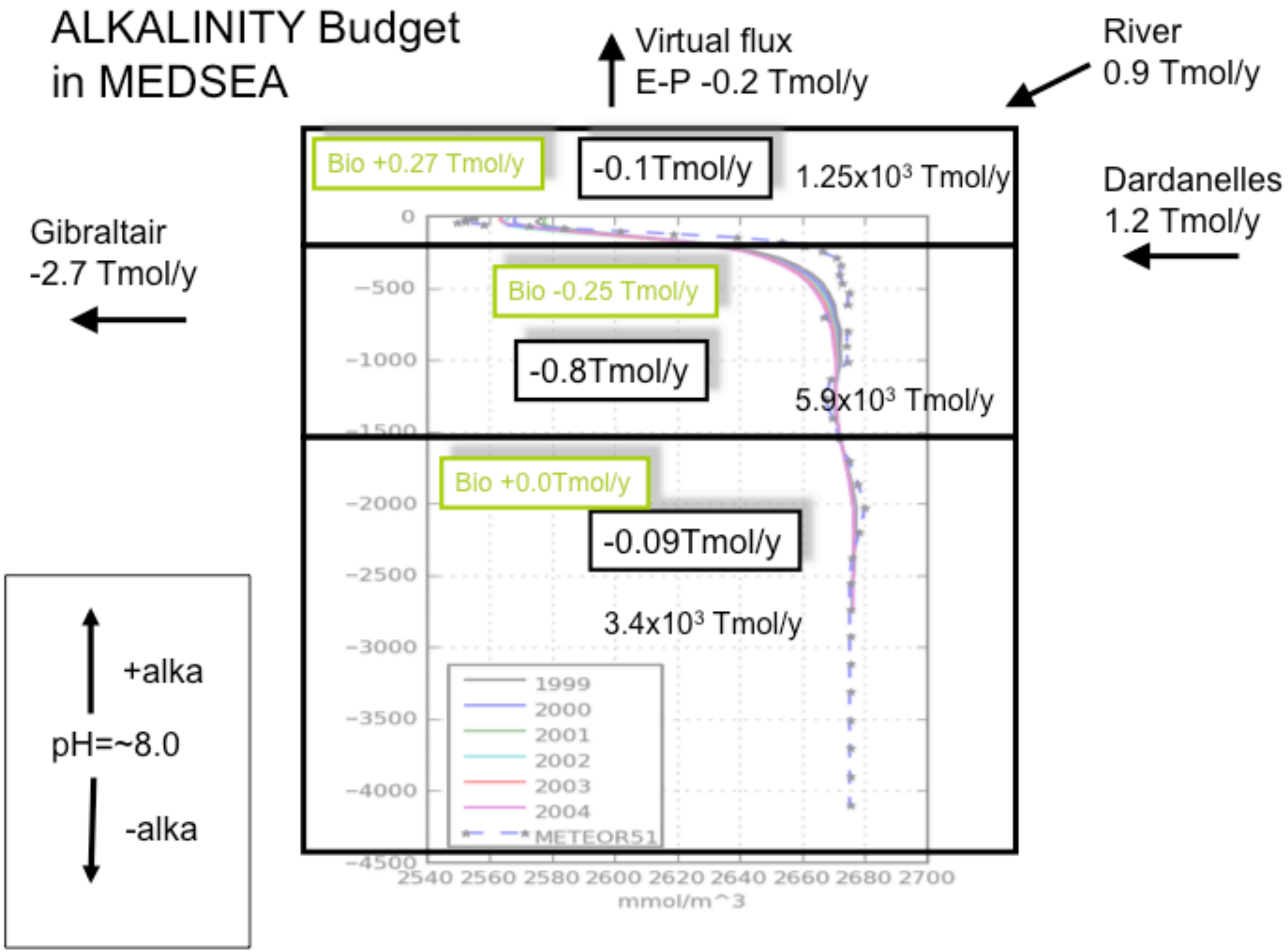
Average over the whole basin: The Mediterranean sea is a weak net sink compared to other marginal seas (Borges et al., 2009) of atmospheric CO2. 1.58 *10^12 moli/y (0.02 Pg C/y)

Model results spatially agree to those proposed by d'Ortenzio et al., 2009
0.02*10^12 moli/y

Copin-Montegut, data extrapolations 1993:
0.35-1.85 *10^12 moli/y



Carbonate system budgets -alkalinity



ALKALINITY Budget
in MEDSEA

Virtual flux
E-P -0.2 Tmol/y

River
0.9 Tmol/y

Dardanelles
1.2 Tmol/y

Gibraltair
-2.7 Tmol/y

Bio +0.27 Tmol/y

-0.1Tmol/y

1.25×10^3 Tmol/y

Bio -0.25 Tmol/y

-0.8Tmol/y

5.9×10^3 Tmol/y

Bio +0.0Tmol/y

-0.09Tmol/y

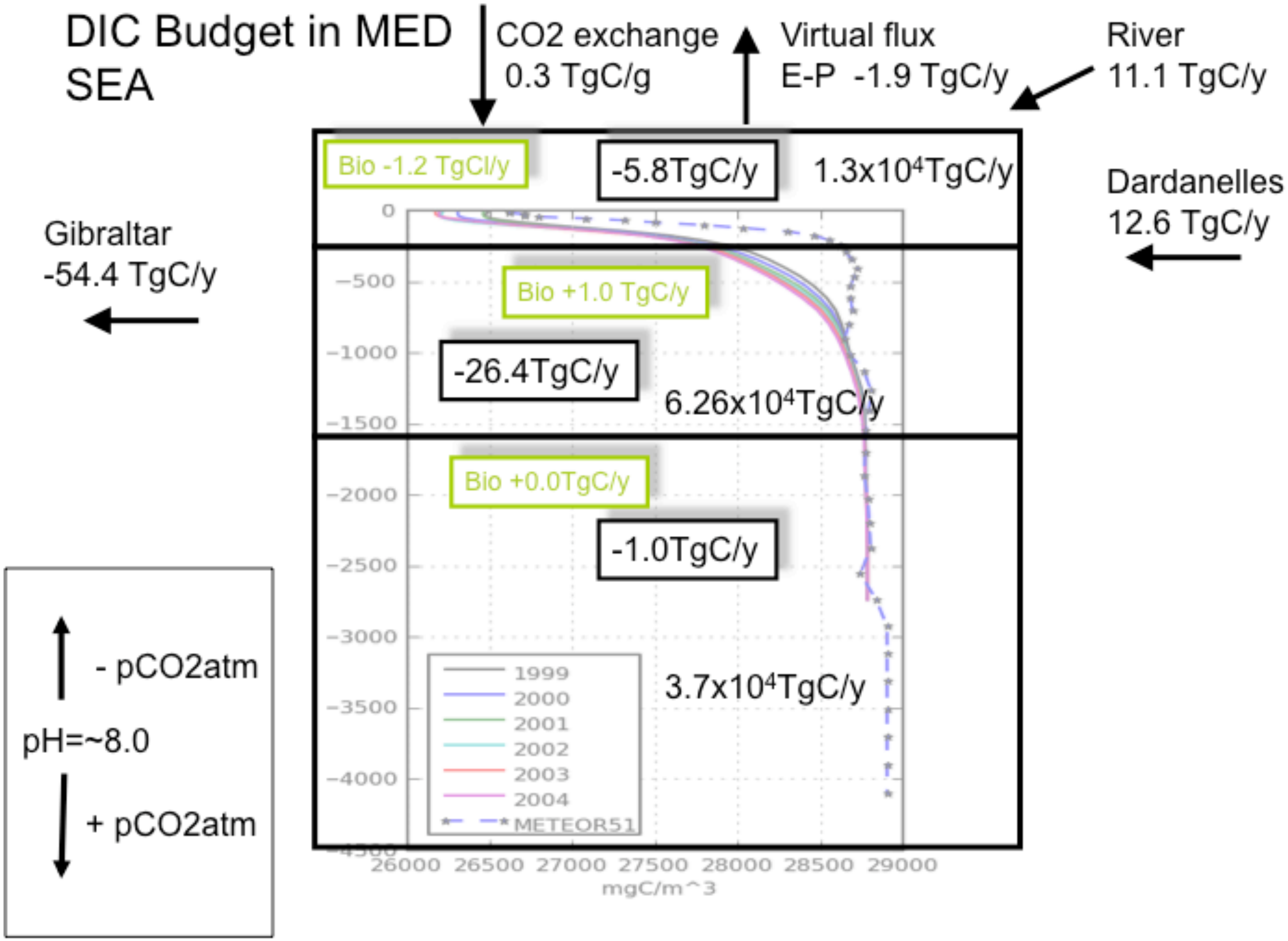
3.4×10^3 Tmol/y

+alka

pH=~8.0

-alka

Carbonate system budgets - DIC



DIC Budget in MED SEA

CO2 exchange
0.3 TgC/g

Virtual flux
E-P -1.9 TgC/y

River
11.1 TgC/y

Bio -1.2 TgCl/y

-5.8TgC/y

$1.3x10^4$TgC/y

Dardanelles
12.6 TgC/y

Gibraltar
-54.4 TgC/y

Bio +1.0 TgC/y

-26.4TgC/y

$6.26x10^4$TgC/y

Bio +0.0TgC/y

-1.0TgC/y

$3.7x10^4$TgC/y

- pCO2atm

pH=~8.0

+ pCO2atm

Conclusions I

✓ The seasonal cycle signal of the integrated NPP dominates over the inter-annual variability when large scale averages are considered.

✓ The horizontal averages over selected regions show a clear spatial gradient in NPP and chlorophyll standing stocks from west to east.

✓ On average the model results are in line with the Longhurst biological domain subtropical nutrient-limited winter-spring production period .

✓ Depth of nutricline and grazing rates are important parameters to explain spatial differences between MS regions which are not resolved using the Longhurst classification scheme (Longhurst, 1995).

✓ The impact of atmospheric and terrestrial inputs on the annual budget of the integrated NPP (new production) is in the range of 3-5$gCm^{-2}yr^{-1}$.

✓ Moreover, the impact of a 30% increase in the extinction factor *k* on the integrated NPP annual budget is approximately 10 $gC\ m^{-2}yr^{-1}$.

Scenario simulations Mediterranean Sea

SESAME

Southern European Seas: Assessing and Modelling Ecosystem changes

MedSeA

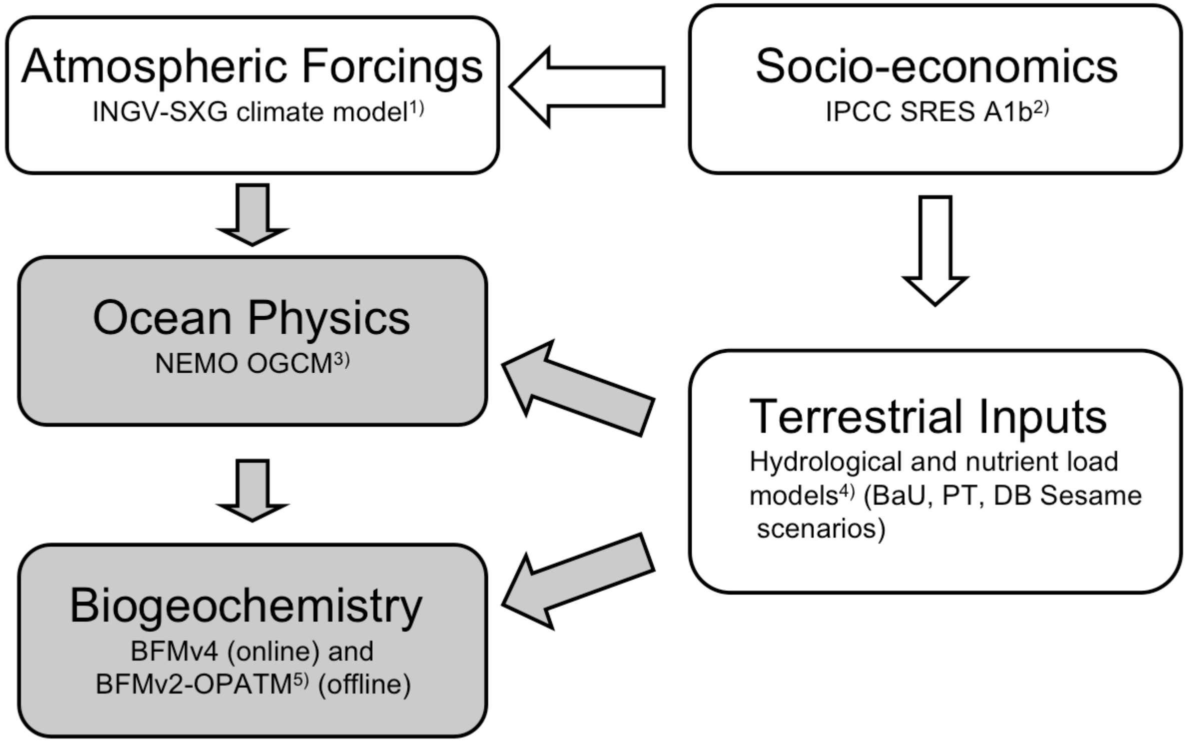
MEDITERRANEAN SEA ACIDIFICATION IN A CHANGING CLIMATE

Impact of ocean acidification in the Mediterranean in a changing climate

PERSEUS

POLICY-ORIENTED MARINE ENVIRONMENTAL RESEARCH IN THE SOUTHERN EUROPEAN SEAS

Conceptual scheme of the modelling hierarchy



Atmospheric Forcings
INGV-SXG climate model1)

Socio-economics
IPCC SRES A1b2)

Ocean Physics
NEMO OGCM3)

Terrestrial Inputs
Hydrological and nutrient load models4) (BaU, PT, DB Sesame scenarios)

Biogeochemistry
BFMv4 (online) and BFMv2-OPATM5) (offline)

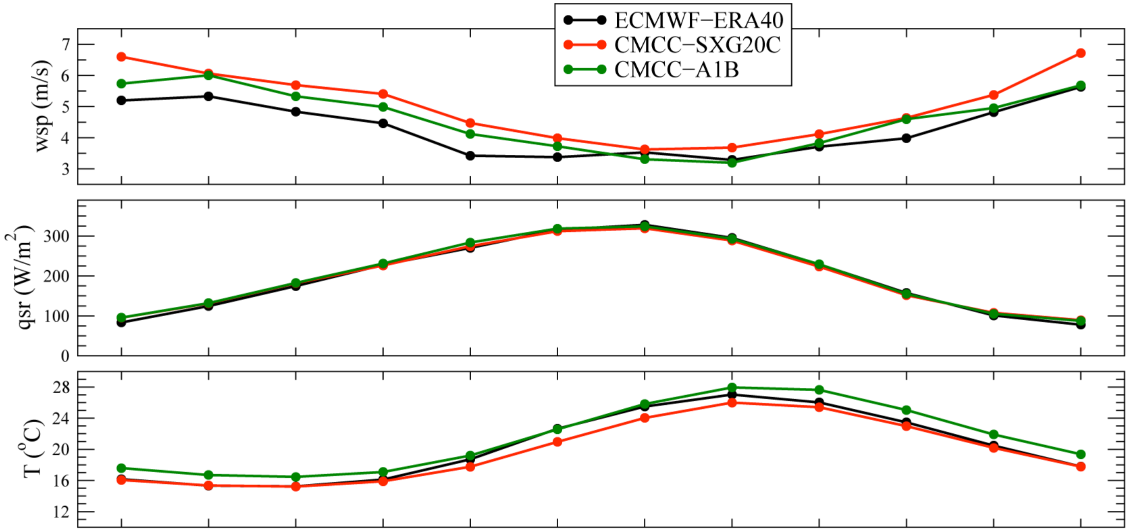
1) Gualdi et al. (2008); 2) Nakicenovic and Swart (2000); 3) Oddo et al (2009); 4) Ludwig et al. (2010); 5) Lazzari et al. (2011)

Ati parameterization

- ✓ **The Terrestrial input scenarios were calibrated on the Millennium Ecosystem Assessment (MEA), Ludwig et al., (2010).**
- ✓ **BaU is constructed projecting the future trends and policy responses in different sectors (i.e. agriculture, urbanization/coastal development).**
- ✓ **PT scenario same demographic trend of the baseline scenario BaU, although an increasing attention (in respect to BaU) toward environmental problems leads to a more environmentally-aware trans-national governance action**.
- ✓ **In DB scenario level the population growth is lower (with respect to BaU) and the economy is slower.**
- ✓ **This translates in nutrient discharge:**

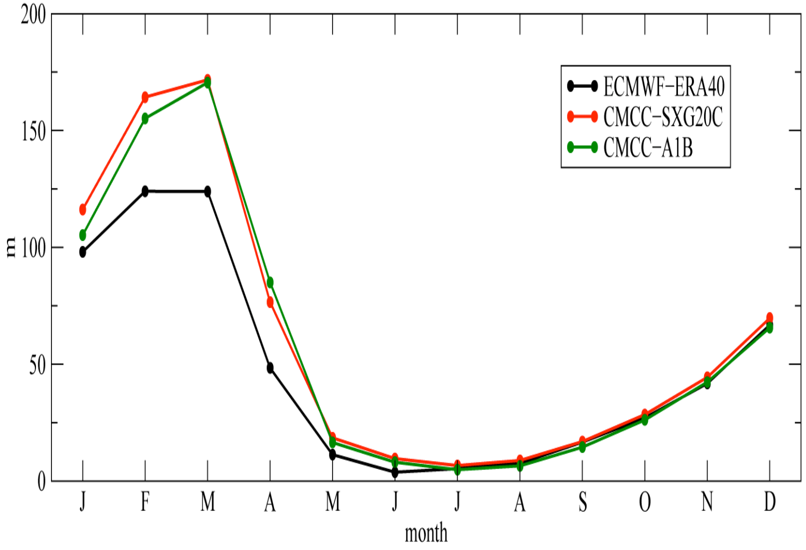
	20C 1990-2000	**BaU 2090-2100**	**PT 2090-2100**	**DB 2090-2100**
Rivers Kton P y^{-1}	60	107	106	72
Rivers Kton N y^{-1}	887	1325	719	324
Atm Kton P y^{-1}	16(W)/20(E)	16(W)/20(E)	16(W)/20(E)	16(W)/20(E)
Atm Kton N y^{-1}	580(W)/558(E)	580(W)/558(E)	580(W)/558(E)	580(W)/558(E)

Physical forcings CMCC-SXG model



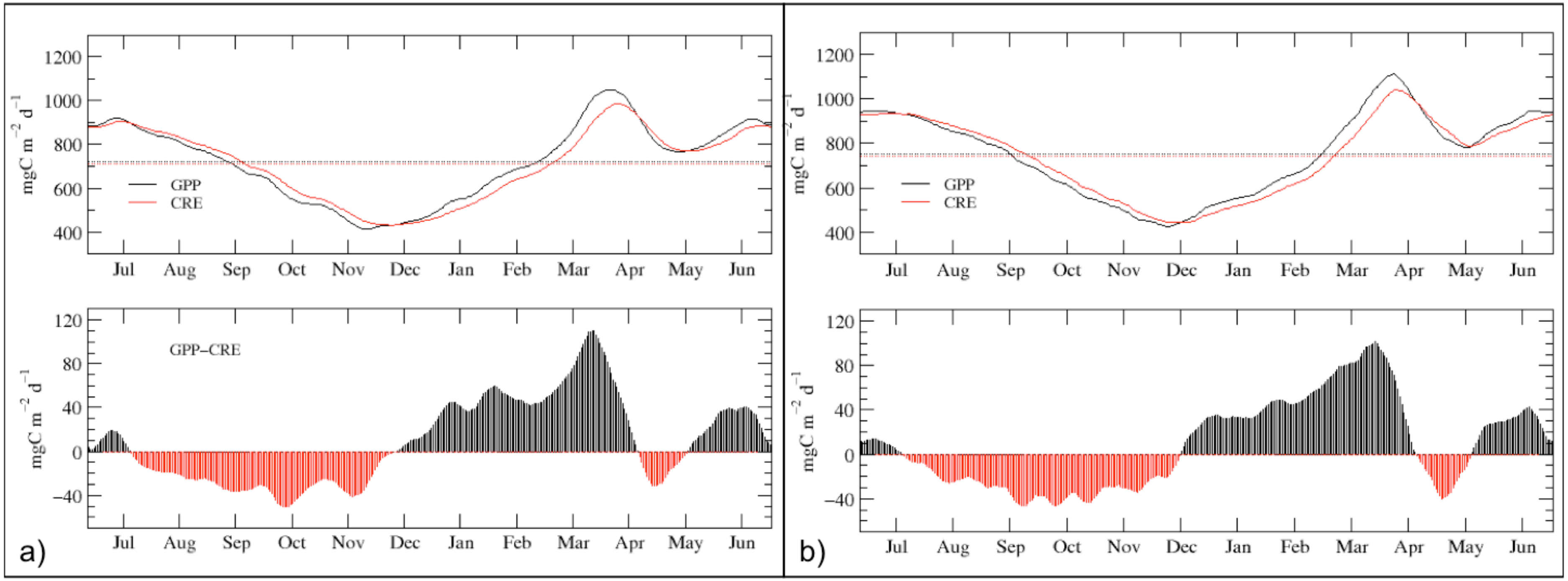
- ✓ **Increase of surface water temperature**
- ✓ **Seasonal cycle substantially synchronized with respect to present conditions**

- ✓ **Seasonality of MLD substantially congruent with respect to present conditions**



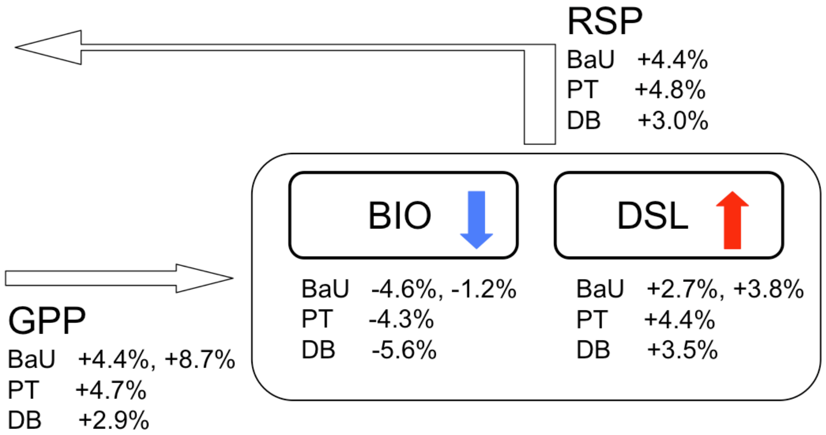
Large scale seasonal cycle

- ✓ **Large scale features in community dynamics are preserved**
- ✓ **Winter period (nutrient availability) positive net production, summer stratified period dominate community respiration**
- ✓ **NCP substantially balanced on annual budgets**



Anomalies of principal variables

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



RSP
BaU +4.4%
PT +4.8%
DB +3.0%

BIO
BaU -4.6%, -1.2%
PT -4.3%
DB -5.6%

DSL
BaU +2.7%, +3.8%
PT +4.4%
DB +3.5%

GPP
BaU +4.4%, +8.7%
PT +4.7%
DB +2.9%

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

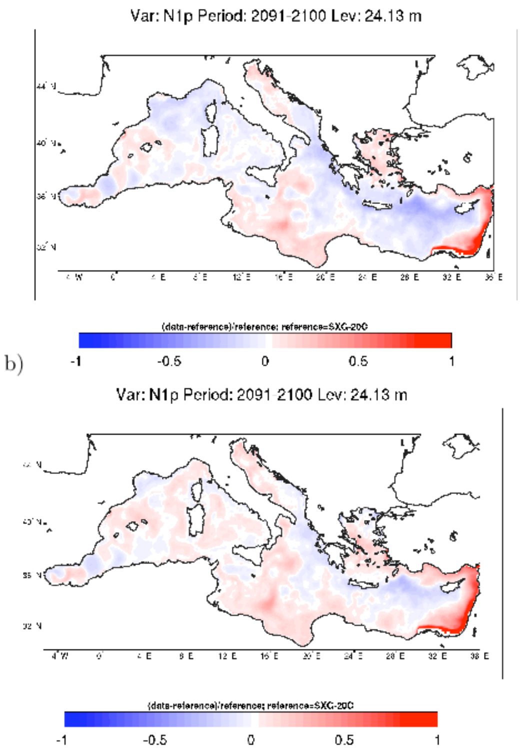
WESTERN BASIN

	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

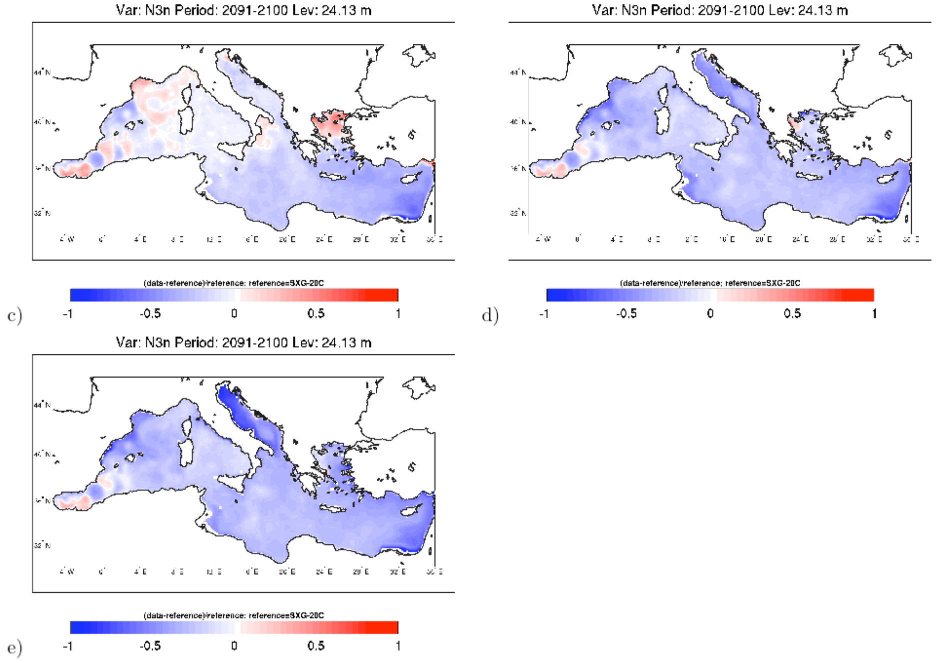
EASTERN BASIN

	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

Anomalies of inorganic nutriens

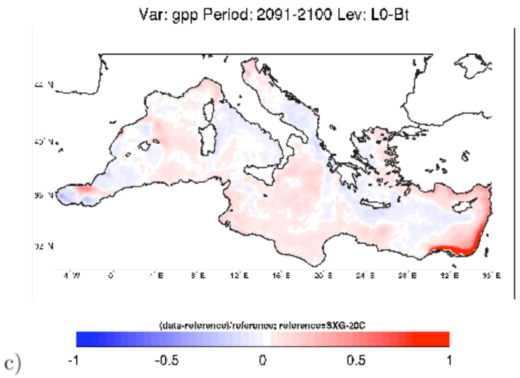


✓ **Strongest signal in correspondence to the Nile river, for all the scenarios for phosphates**

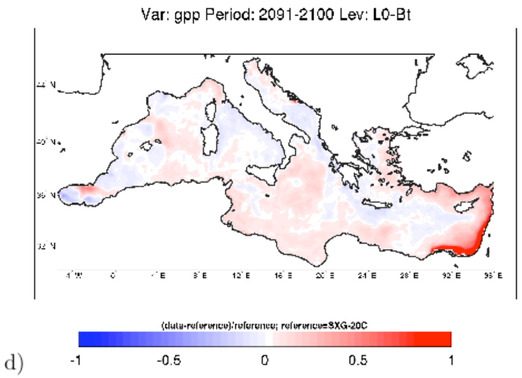


✓ **Decrease in term of inorganic nitrogen**

Anomalies of principal variables

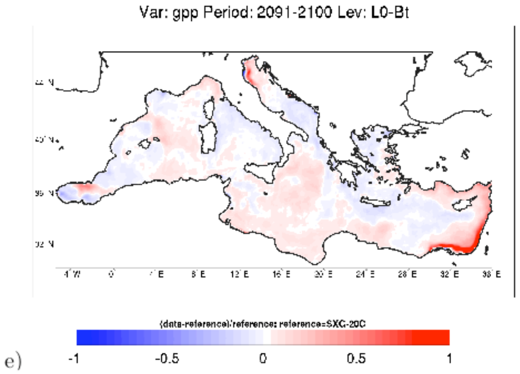


c)

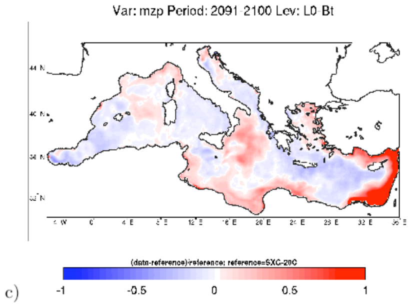


d)

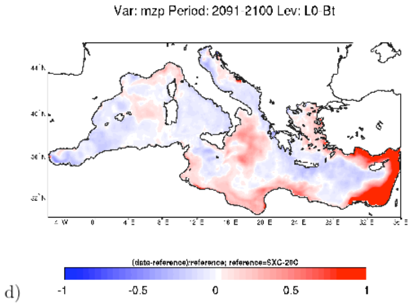
- ✓ Strongest signal in correspondence to the Nile river, for GPP



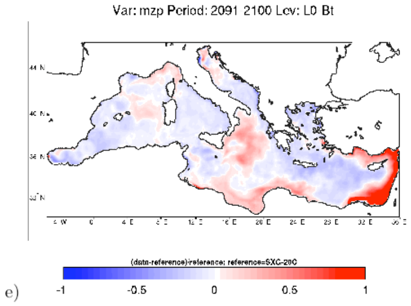
e)



c)



d)



e)

- ✓ Strongest signal in correspondence to the Nile river, for secondary production (Mesozoo)

Summary

✓ Under the scenarios considered, the water temperature increase augments mean metabolic rates (in the range 3 to 9 %).

✓ A reduction in system biomass and an increase in semi-labile dissolved organic matter is evident.

✓ Results suggest that further analyses with nested coastal models fully resolving the dynamics of hot spot areas would be useful.

✓Prognostic module to derive light extinction coefficient to account for water turbitidy changes

✓Analysis with coupling of other OGCM

Results from Med. Sea OGCM

	TEMP	MLD	MTHC	E-P-R-B	RUNOFF
Thorpe & Bigg, 1999 HadCM2-SUL experiment	+1.5 [2000 2100]	/	Reduction	Increase	/
Somot et al. 2006 IPCC A2	+3.1 [2000 2100]	-20% Aegean -80% NWM	- 40% LIW - 80% Deep	Increase +40%	Decrease (in particular Dardanelles)
Somot et al. 2008 IPCC A2	+2.6 [2000 2100]	/	/	/	/
CMCC SXG IPCC A1b	+1.5 [2000 2100]	~0	Reduction	increase	Reduction (Dardanelles constant)
Dell'Aquila et al, 2012 A1b	+1 [2000 2050]	/	/	increase	decrease
Gualdi et al. 2012 CIRCE	+1.5 [2000 2050]	/	/	increase 3% E, -9% P	/

Complex dynamics, interplay between many processes

- Stronger variability in MLD higher impacts on productivity rates

- Changes in circulations and runoff

ref/MTHC/RIV mmol /m3	West	East
Surface	P: 0.22 / 0.28 / 0.33 N: 4.22 / 6.5 / 7.7	P: 0.10 / 0.15 / 0.22 N: 3.03 / 5.2 / 6.8
Deep	P: 0.29 / 0.34 / 0.40 N: 6.03 / 8.6 / 10.5	P: 0.16 / 0.22 / 0.28 N: 4.81 / 7.75 / 10.0

T increase → increase in pCO2 in the water (non linear)

- Redution of inputs of DIC and Alk terrestrial inputs → pCO2 increase

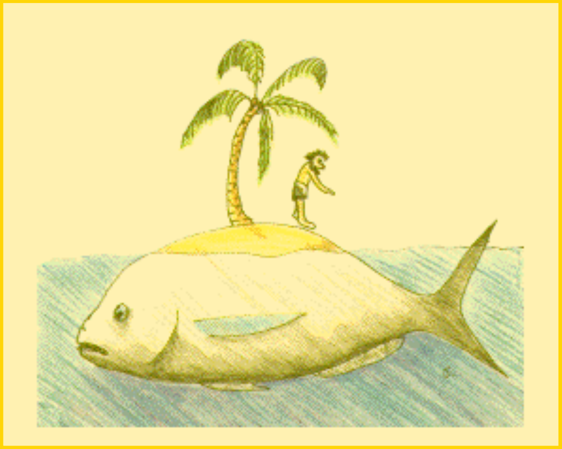
- Alk increase due to increase of evaporation,(Alkalinity inputs from Atlantic waters)→ pCO2 decrease

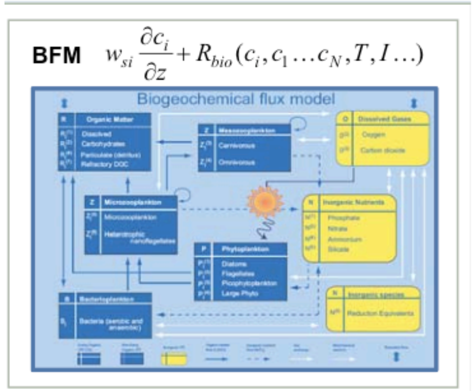
- Evaluate changes in PH and impacts on ecosystem

THANKS FOR YOUR ATTENTION!

Model chain: OGSTM

- ✓ COUPLING WITH ECOSIM (PERSEUS Project)
- ✓ COUPLING with other OGCM (MitGCM, ROMS)
- ✓ DEVELOPMENT in the FRAMEWORK of the BFM AGREEMENT





NEMO

MITgcm

ROMS