The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2165-13

International MedCLIVAR-ICTP-ENEA Summer School on the Mediterranean Climate System and Regional Climate Change

13 - 22 September 2010

Ecosystems: Modelling and understanding the Mediterranean ecosystems: state-of-art, knowledge gaps and future developments

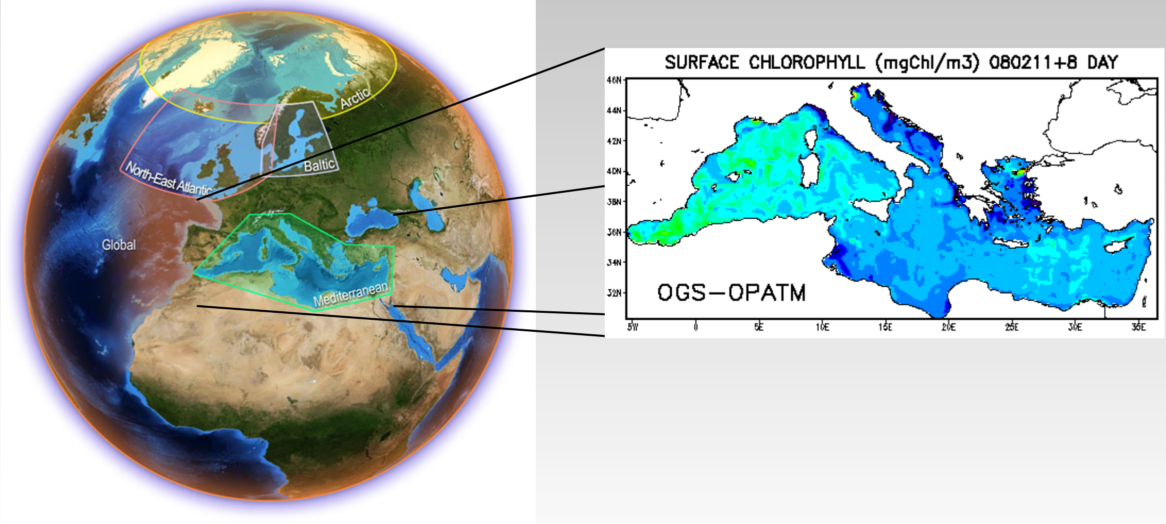
CRISE Alessandro
OGS
Trieste
Italy

International MedCLIVAR-ICTP-ENEA Summer School on the Mediterranean Climate System and Regional Climate Change

Modelling and understanding the Mediterranean ecosystems: state-of-art, knowledge gaps and future developments

A. Crise

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale- OGS
+



Adriatico Guest House, Kastler Lecture Hall 13-22 September 2010

Outline

(*with a climatic flavour*)

- What is a marine ecosystem
- Different implementations
- A bit of recent history: toward ad increased complexity
- Predictability of marine ecosystems: a fact or a dream?
- Some examples:
  - Climatic prediction of Mediterranean ecosystem
  - Scenario analysis for the Venice Lagoon: a downscaling example
  - Operational forecast of biogeochemical variables for the Mediterranean area
- Conclusions

Man, climate, ecosystems

- “In a geological perspective, Life has played a key role in shaping the atmosphere composition and geosphere structure and today, Man (with his work and ideas) is the most relevant geological force”

  (*V.I.Vernadskij,1945*)

- “Concentrations of man-made greenhouse gases are driving irreversible and dramatic changes to the way the ocean functions, with potentially dire impacts for hundreds of millions of people across the planet.
- The impacts of climate change on the world’s oceans include decreased ocean productivity, altered food web dynamics, reduced abundances of habitat-forming species, shifting species distributions, and a greater incidence of disease.
- Further change will continue to create enormous challenges and costs for societies worldwide, particularly those in developing countries” *(Hoegh-Guldberg & Bruno (2010)*

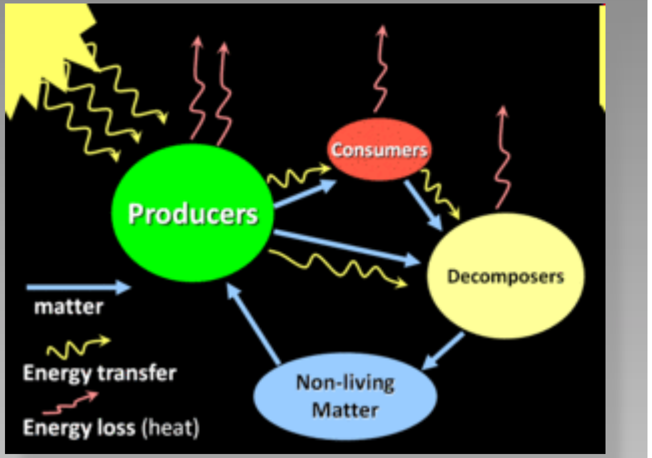
Ecosystem definition

Ecosystems include:

- living organisms in the same habitat
- the dead organic matter produced by them
- the abiotic environment within which the organisms live
- and the interactions between these components.

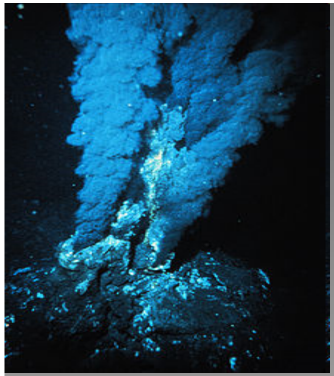
(from Encyclopedia of Earth http://www.eoearth.org/article/ecosystem)

Ecosystem concept

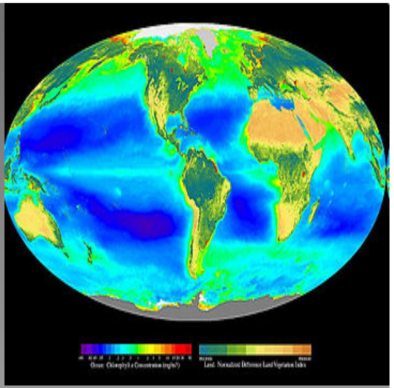


- living organisms continually interact with each other and with the environment to produce **complex systems** with **emergent properties**, such as the nutrient cycles
- "*the whole is greater than the sum of its parts*" and "*everything is connected*".

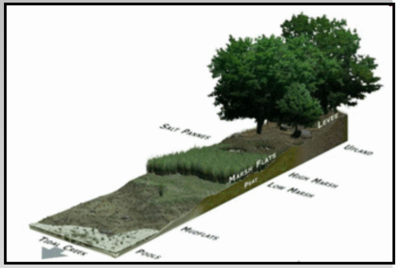
(from Encyclopedia of Earth http://www.eoearth.org/article/ecosystem)



Marine ecosystems

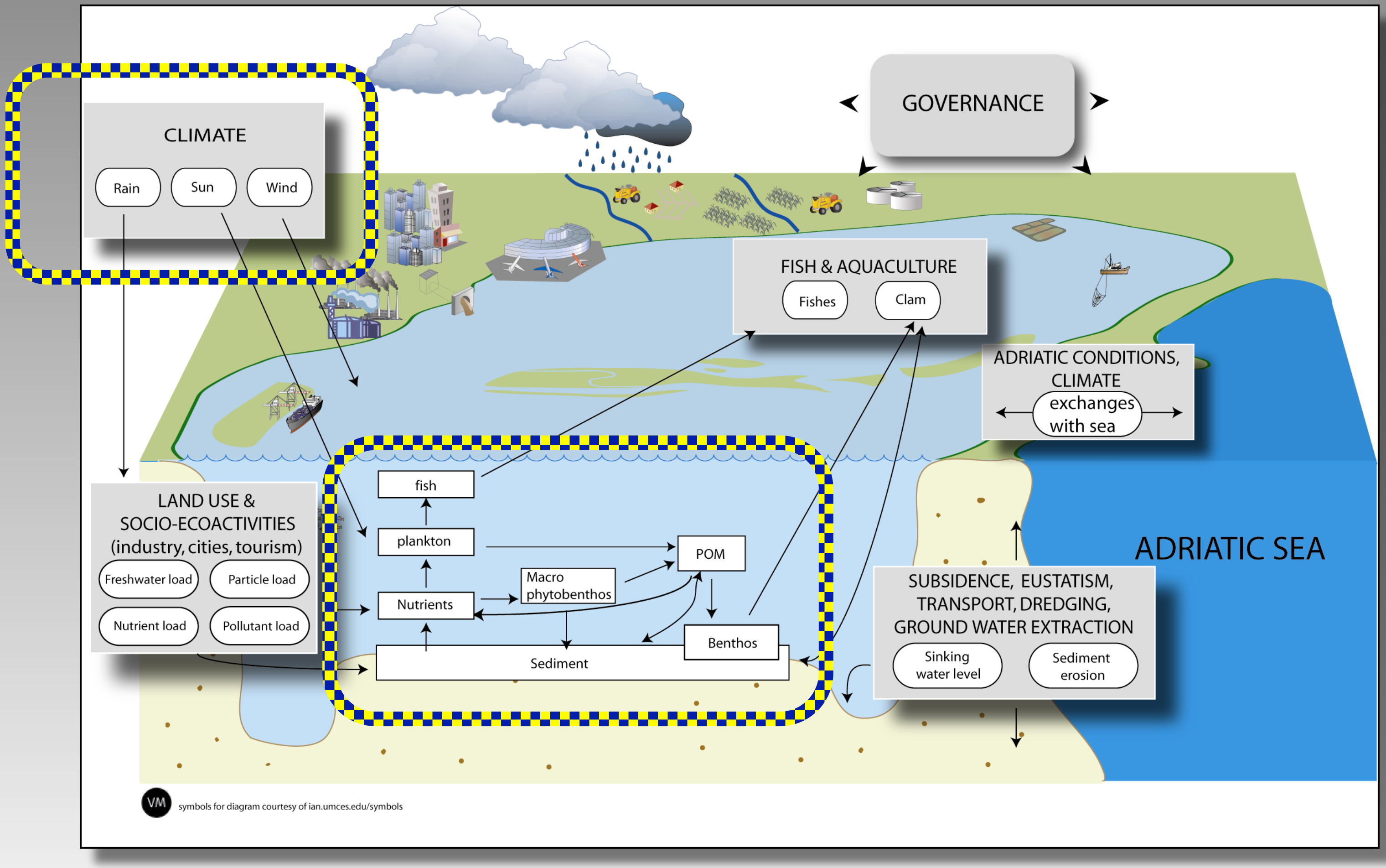


- **Marine ecosystems** are among the largest of Earth's aquatic ecosystems.
- They include ocean, salt marsh and intertidal habitats and communities, estuaries, lagoons mangrovies, coral reeefs, deep sea and sea floor
- Peculiarities of **marine ecosistems**
  - Largest in the world
  - The habitats are fully three-dimensional
  - Light penetration and estintion create different regions depending on seawater biogeochemical properties



The structure of marine ecosystems and the Socio-economic approach to the coastal zone management

Conceptual scheme: *Driver*-*Pressure*-*Stress*-**Impact**-*Response*



Coastal Lagoons
Critical Habitats of Environmental Change
Edited by Michael J. Kennish, Hans W. Paerl

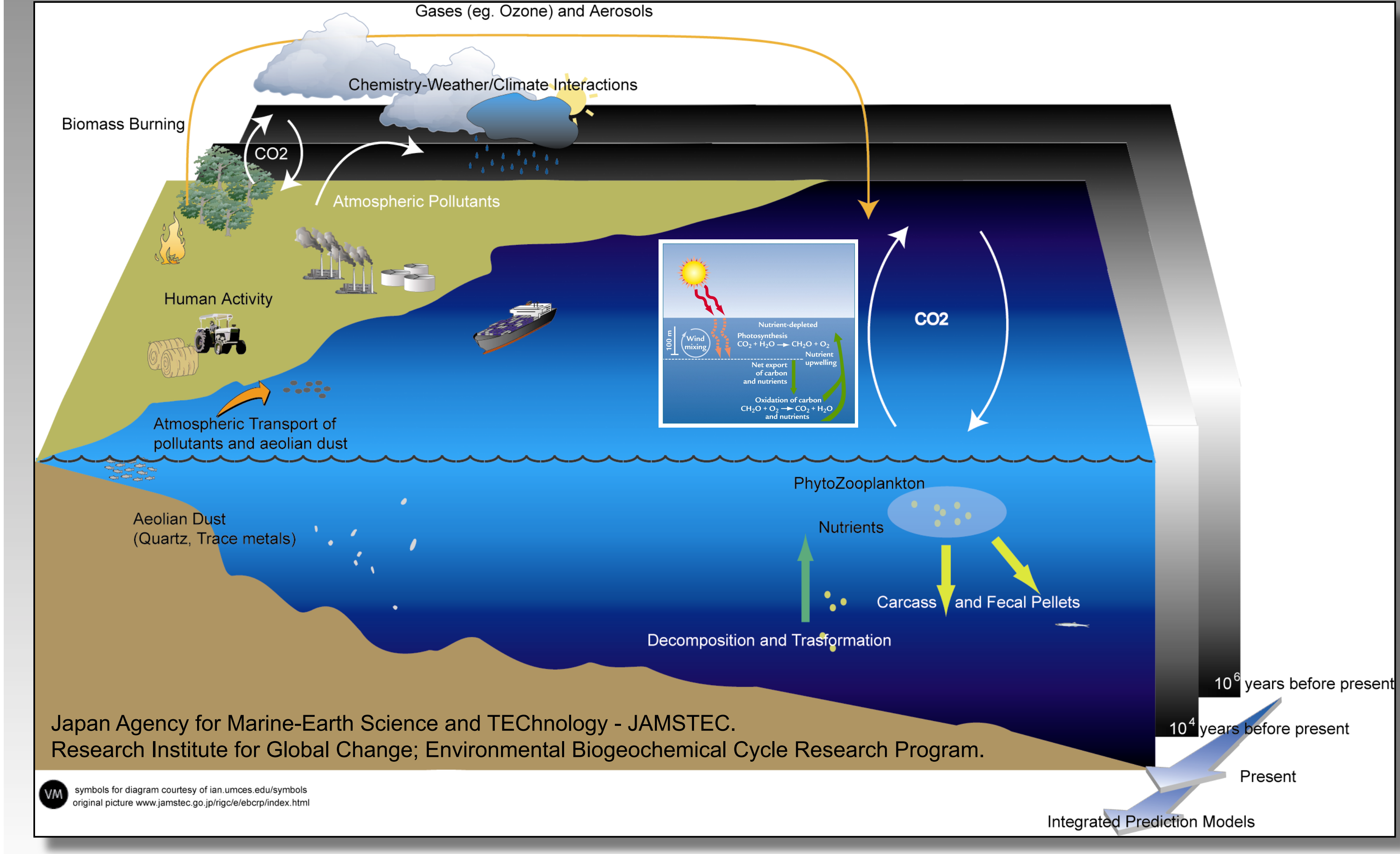
Response of Venice Lagoon Ecosystem to Natural and Anthropogenic Pressures over the Last 50 Years.

C. Solidoro, V. Bandelj, F. A. Bernardi, E. Camatti, S. Ciavatta, G. Cossarini, C. Facca, P. Franzoi, S. Libralato, D. M. Canu, R. Pastres, F. Pranovi, S. Raicevich, G. Socal, A. Sfriso, M. Sigovini, D. Tagliapietra, and P. Torricelli

The role of marine ecosystems in climate

.Carbon cycle is on of the most relevant process for climate

Coupling between atmospheric-ocean processes and Ecosystem functioning drives the carbon cycle



Japan Agency for Marine-Earth Science and TEChnology - JAMSTEC.
Research Institute for Global Change; Environmental Biogeochemical Cycle Research Program.

VM symbols for diagram courtesy of ian.umces.edu/symbols
original picture www.jamstec.go.jp/rigc/e/ebcrp/index.html

The climate impact on marine ecosystems 1

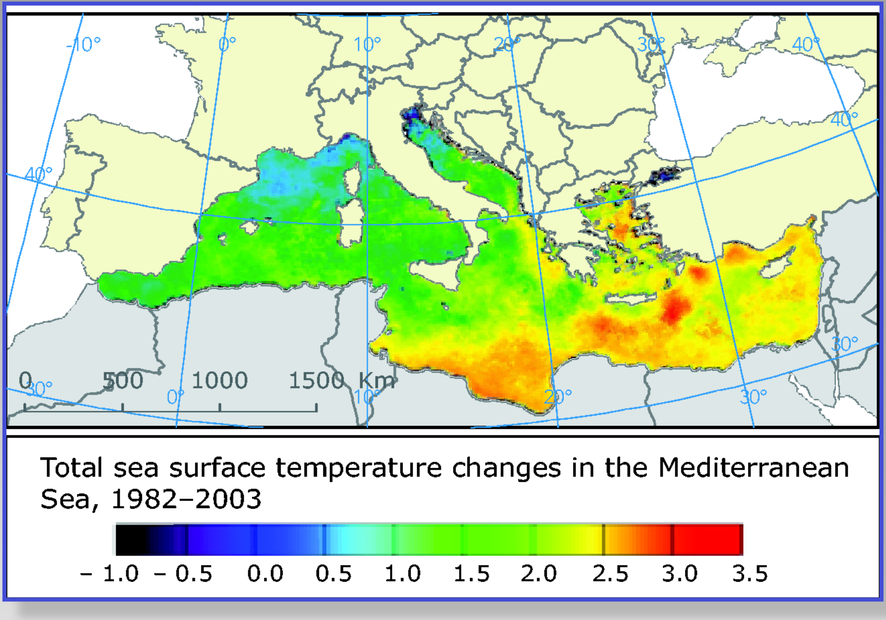
The global warming and its impact on Sea Temperature ans Sea level rise and their effects on biota

Temperature high rates of change will probably result in local if not total **extinction of some species**, the **alteration of species distributions**

major **changes in their interactions with other species**,

modifications in the flow of energy and cycling of materials within

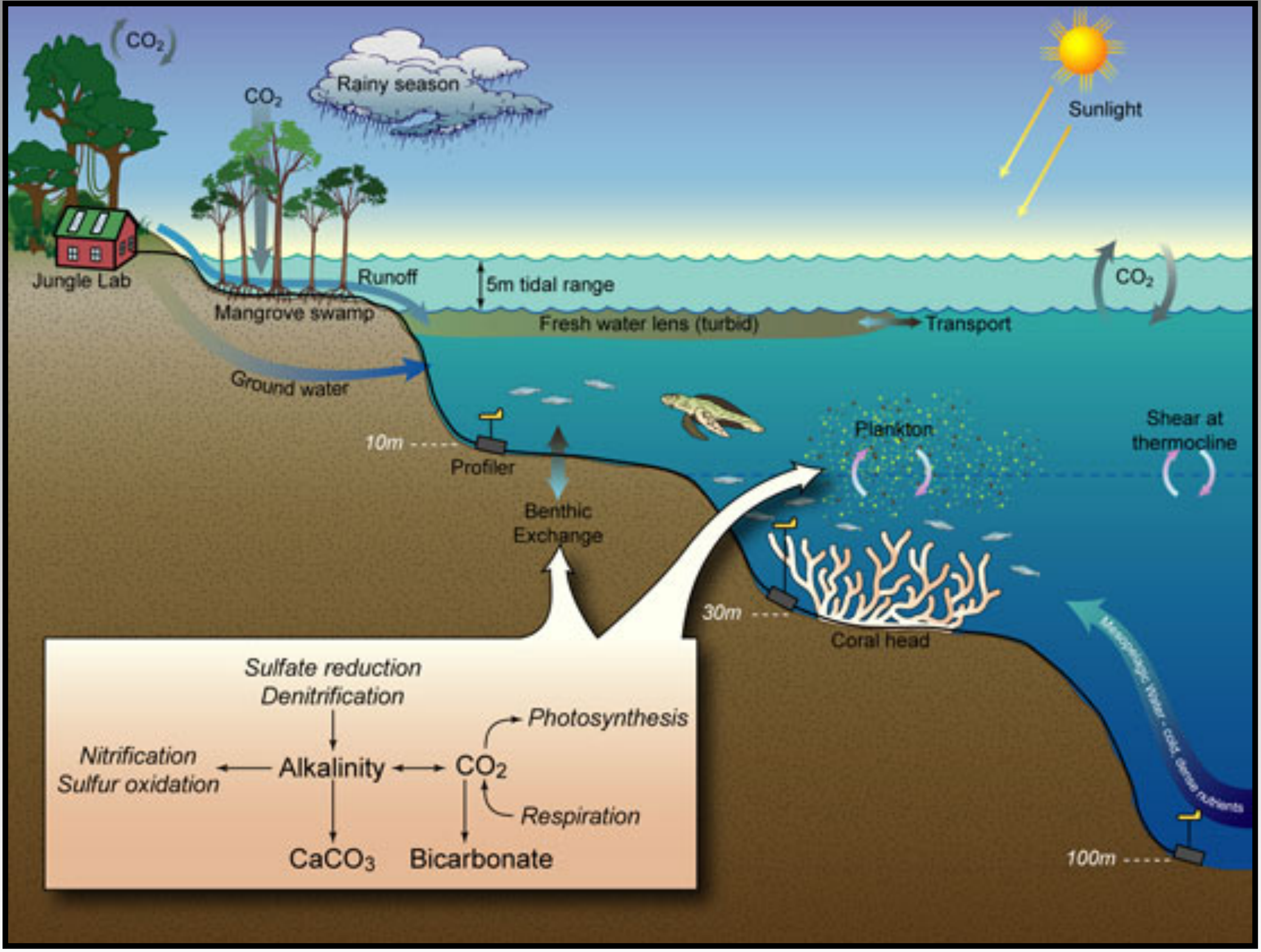
"Coastal and Marine Ecosystems and Global Climate Change: Potential Effects on U.S. Resource Report, 2010"



Total sea surface temperature changes in the Mediterranean Sea, 1982–2003

The climate impact on marine ecosystems - 2

The carbon cycle and its impact on ocean acidification



(Courtesy of Scott Gallager, Woods Hole Oceanographic Institution)

Carbon cycle characteristic reservoir size and associated timescales

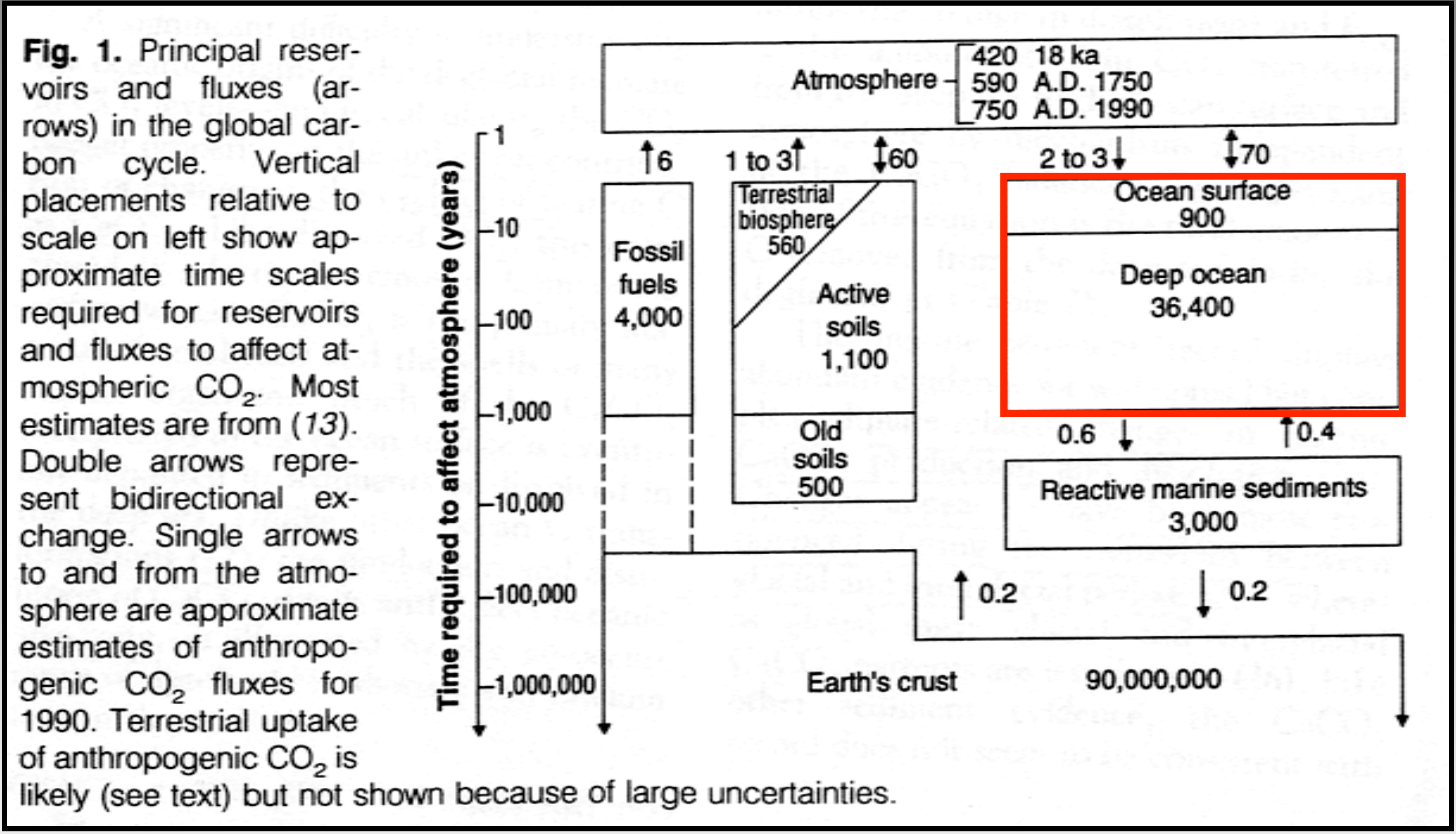
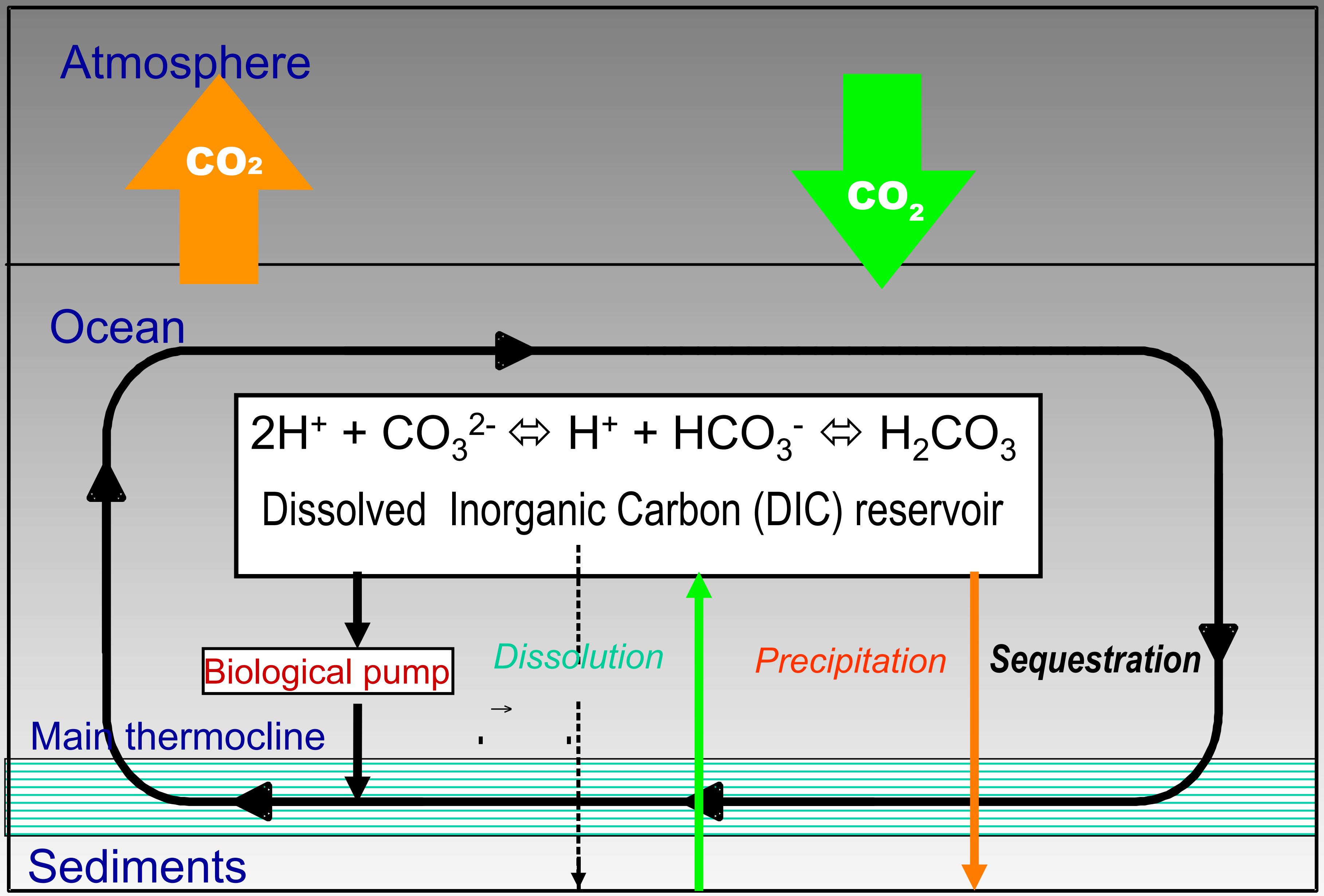


Fig. 1. Principal reservoirs and fluxes (arrows) in the global carbon cycle. Vertical placements relative to scale on left show approximate time scales required for reservoirs and fluxes to affect atmospheric CO_2. Most estimates are from (*13*). Double arrows represent bidirectional exchange. Single arrows to and from the atmosphere are approximate estimates of anthropogenic CO_2 fluxes for 1990. Terrestrial uptake of anthropogenic CO_2 is likely (see text) but not shown because of large uncertainties.

Reservoir Sizes in [Gt C]
Fluxes in [Gt C / yr]

Sundquist (*Science, 1993*)

Carbon Cycle: the Physical Pump



Atmosphere

CO_2

CO_2

Ocean

$2H^+ + CO_3^{2-} \Leftrightarrow H^+ + HCO_3^- \Leftrightarrow H_2CO_3$

Dissolved Inorganic Carbon (DIC) reservoir

Biological pump

Dissolution

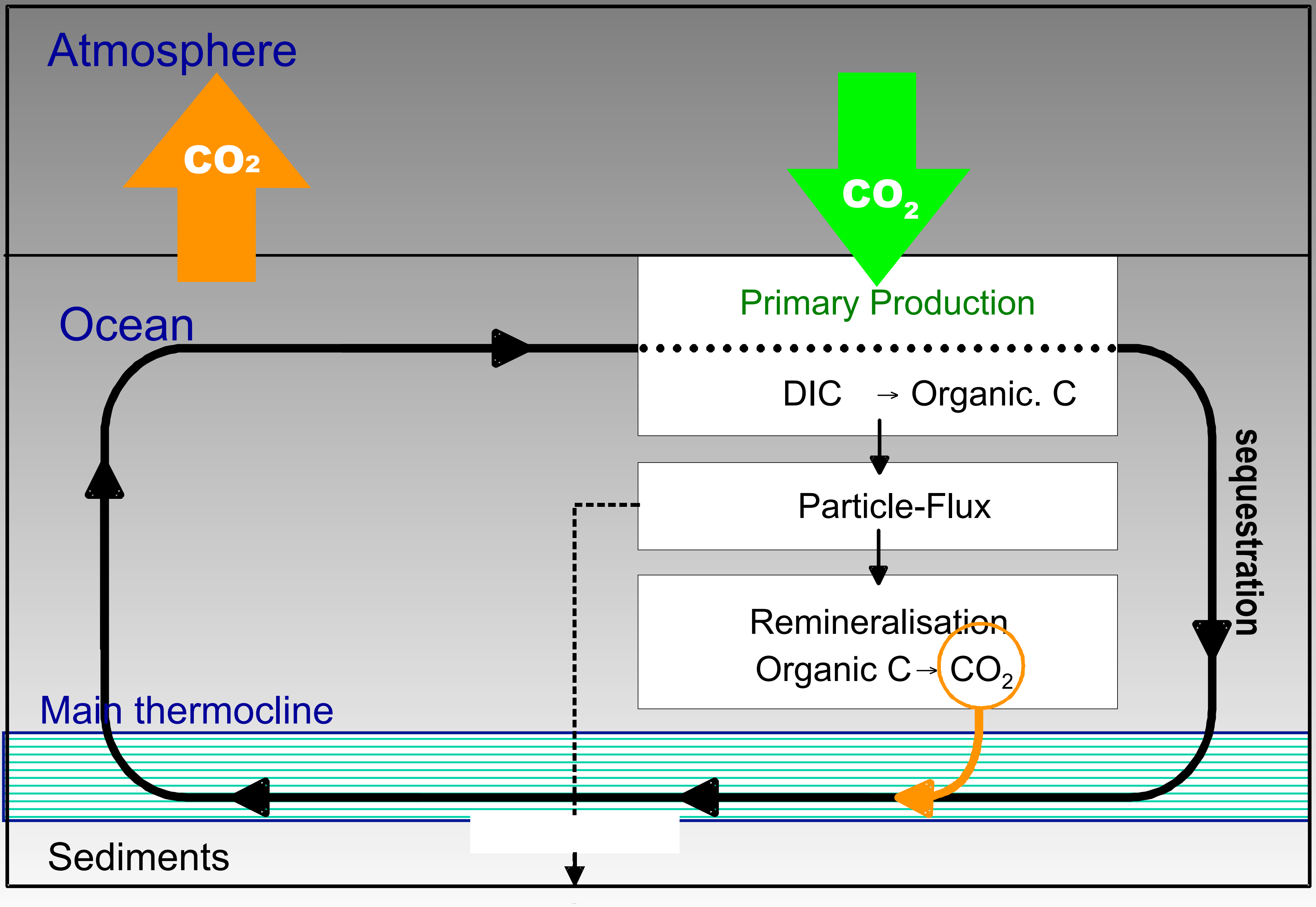
Precipitation

Sequestration

Main thermocline

Sediments

Carbon Cycle: the Biological Pump



From A. Körtzinger, modified

Ecosystem models

- **The ecosystem models are mathematical formal descriptions of (parts of) ecosystem structure (habitat, biotic community composition, etc.) and its functioning**
- **The ecosystem models** include both the **biotic community** dynamics and the interactions with the **abiotic component** (e.g. physical and chemical properties of the sea water, ocean dynamics, light intensity and spectral distribution)
- The **ecosystem models** simplify the description of mutual interactions thar govern the community functioning by identifying the main components (organized in **trophic levels**) and by quantifying them as number of organisms, biomass, or concentration of some key chemical elementl

Early marine biological models

One of the earliest and most well-known, ecological models is the predator-prey model of Alfred J. Lotka (1925) and Vito Volterra(1926). This model takes the form of a pair of ordinary differential equations, one representing a prey species, the other its predator.

$$\frac{dX}{dt} = \alpha.X - \beta.X.Y \qquad \frac{dY}{dt} = \gamma.\beta.X.Y - \delta.Y$$

where,

- X is the number/concentration of the prey species;
- Y is the number/concentration of the predator species;
- α is the prey species' growth rate;
- β is the predation rate of Y upon X;
- γ is the assimilation efficiency of Y;
- δ is the mortality rate of the predator species

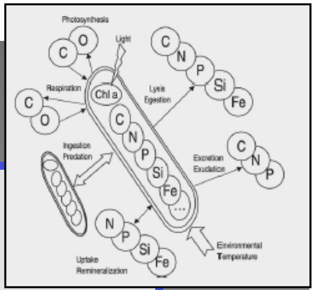
Volterra originally devised the model to explain fluctuations in fish and shark populations observed in the Adriatic Sea after the First World War (when fishing was curtailed).

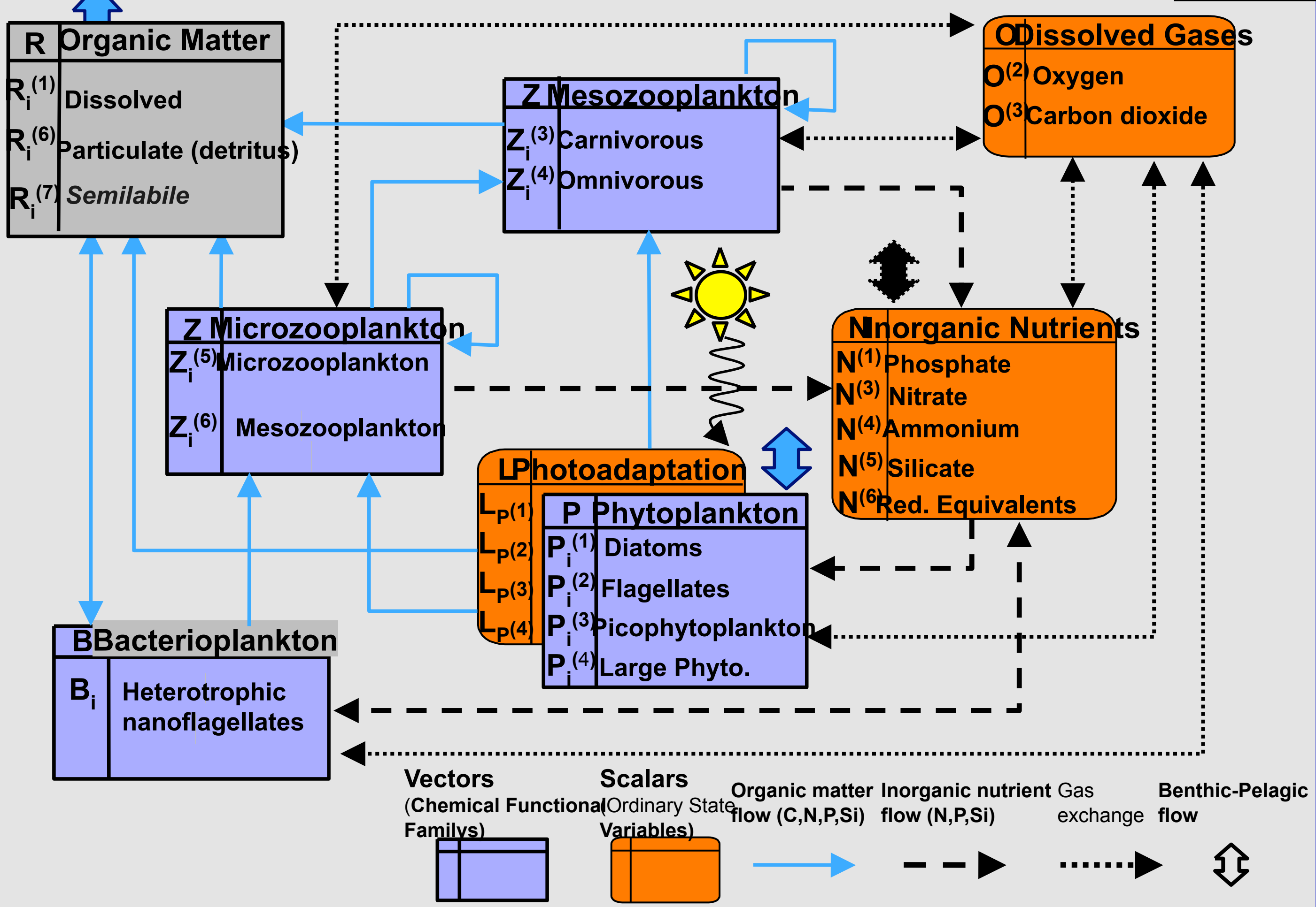
(From Wikipedia)

Classification of modern ecosystem models

- Individual based models (key species population dynamics)
- Biogeochemical models (lower trophic levels including physical forcing)
- Ecosystem models (higher trophic levels)
- End-to-End models (integration of biogeochemical and ecosystem models)

The Biogeochemical Flux Model

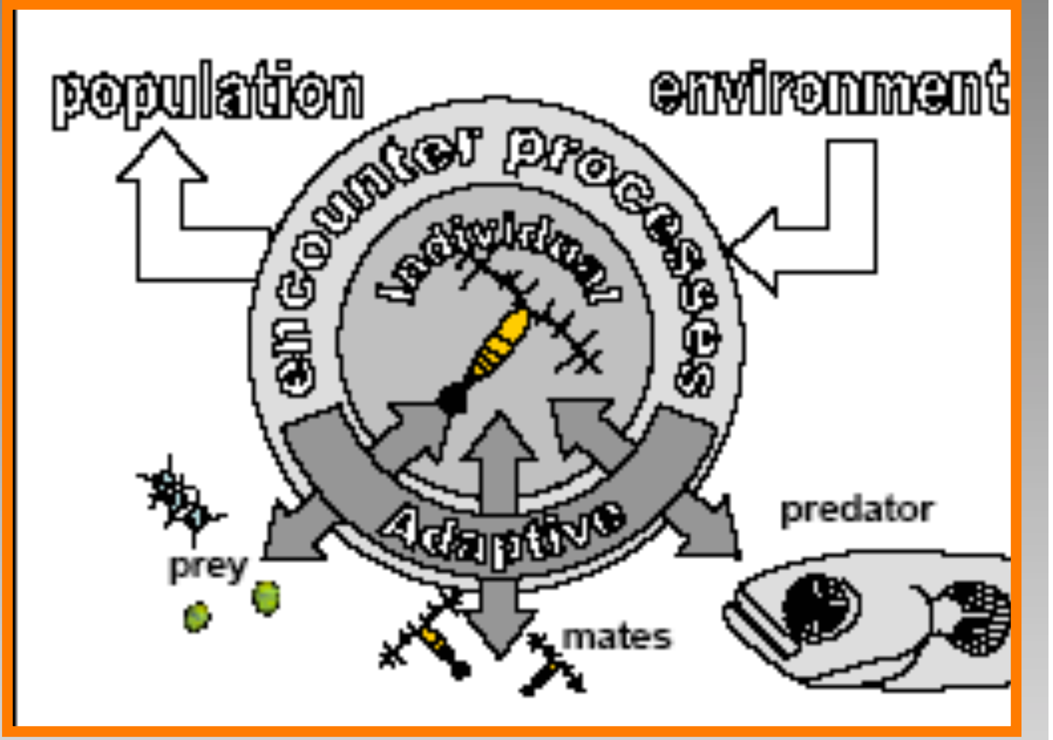




(Vichi et. Al., 2007), Lazzari et al., 2010)

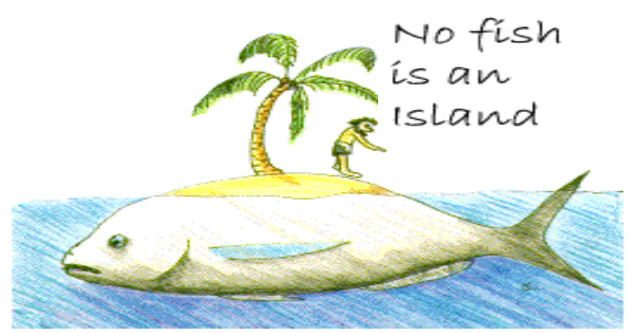
Conceptual Framework of Individual Based Ecology (deYoung et al, 2006)

'Individual based zooplankton ecology seeks to find the fundamental rules by which zooplankton interact and optimise their behaviour and to predict population level patterns as emergent properties'

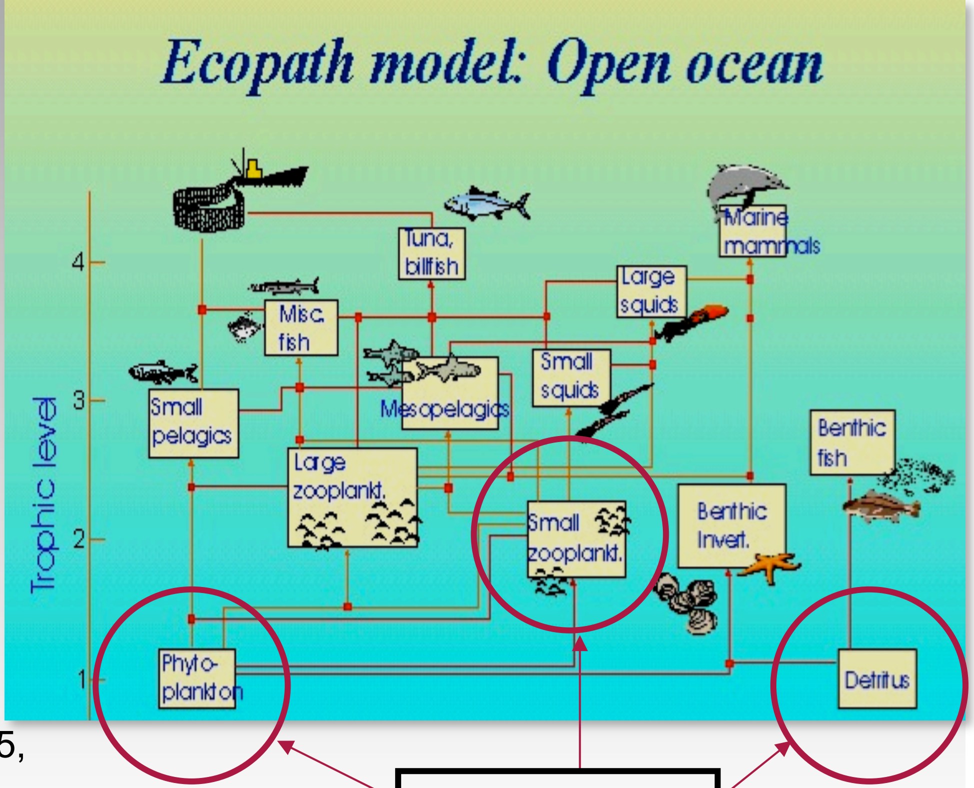


An individual interacts with predators, prey and mates through encounter processes that are in part regulated by adaptive behaviours

Ecosystem-Based Management Tools Network
Ecopath - Ecosim



Long time series for relevant large and small pelagic fishes



Environmental data

Some Mediterranean applications (Coll et, al, 2005,
Zucchetta et al., 2003)

EUR-OCEANS Naples Workshop (2005)

- **difficulty to create one generic "ideal" model capable to answer all questions from end to end**

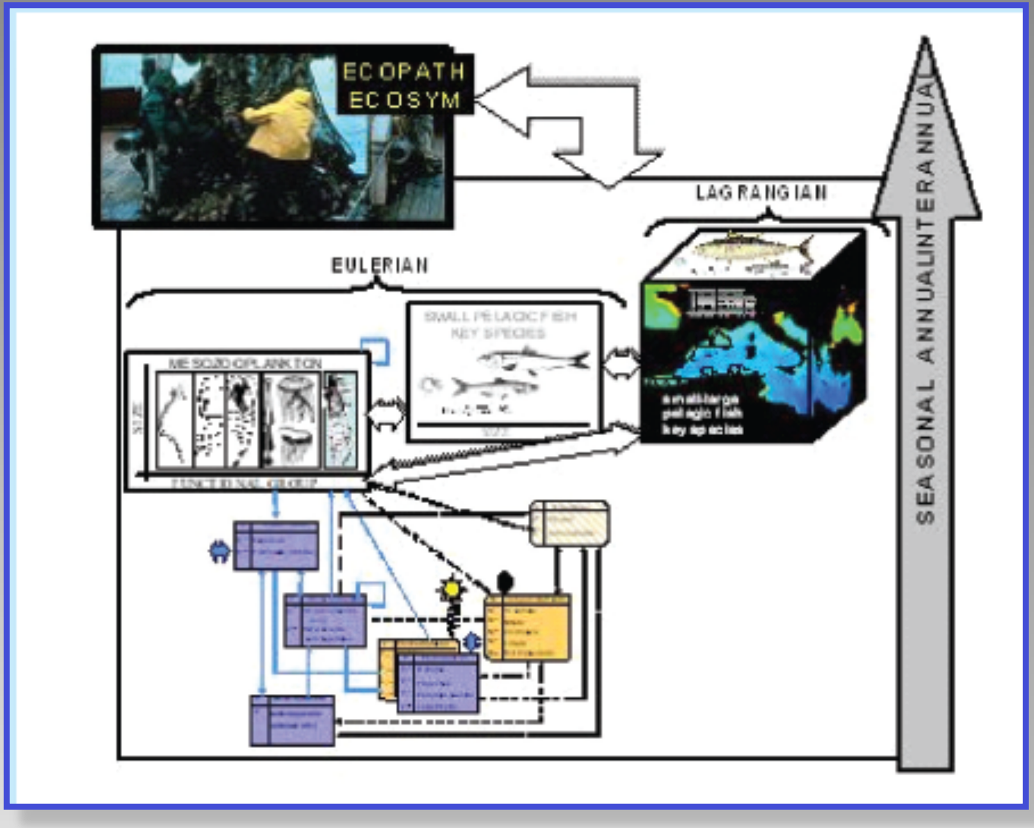
- **generic modelling approach**: "as simple as possible and as complex as needed".

Key species are not present as in other seas

Size/age models too cumbersome to be fully Implemmented

BFM class of models seems to incorporate the basic mechanisms up to the level of mesozooplankton. The abundance (of tunicates and cladocerans) and effect have been traditionally neglected,and we lack knowledge on the relative importance of the groups in planktonic food webs (Agawin et al.,2000)
At this and higher trophic levels, key species, Individual Base Models (IBMs) or ECOPATH/ECOSIM might be alternative modelling approaches as far as they are linked to the dynamics of functional groups at lower trophic levels.

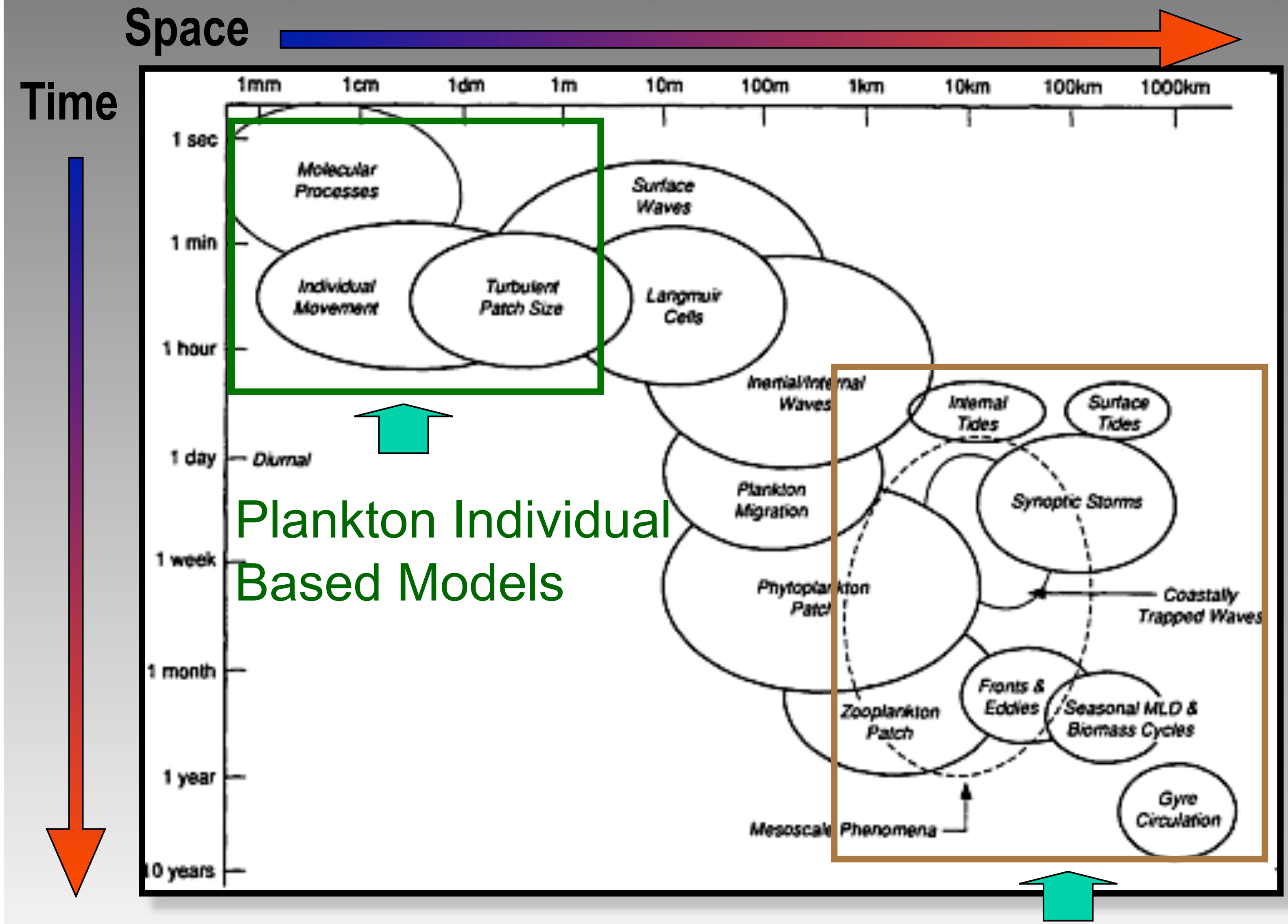
Conceptual structure of a **meta-model** (model of models)



(Ruiz et, al. 2007)

Meta-model of the Mediterranean Marine Ecosystem adopted as guideline for the development/integration of new model within SESAME IP

Physical-Biological Scales Coupling



Plankton Individual Based Models

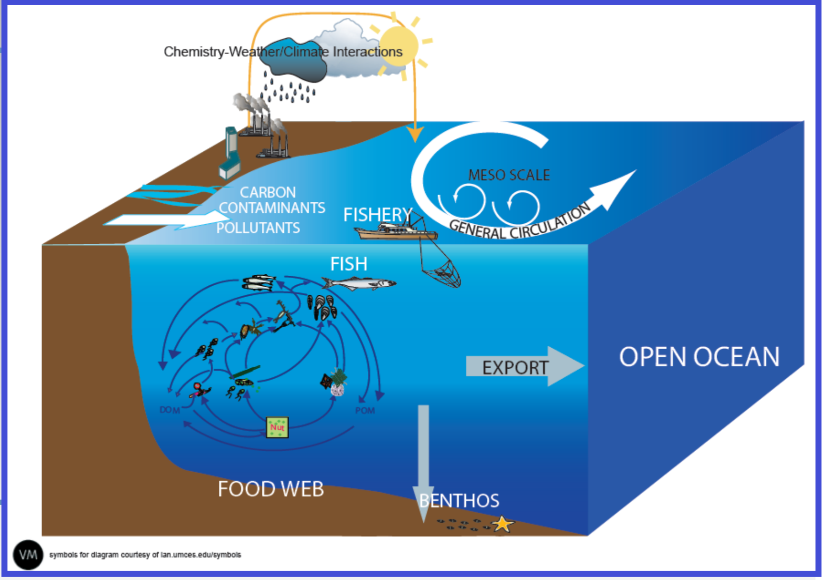
Nutrient cycles models

Generic formal structure of a biogeochemical model

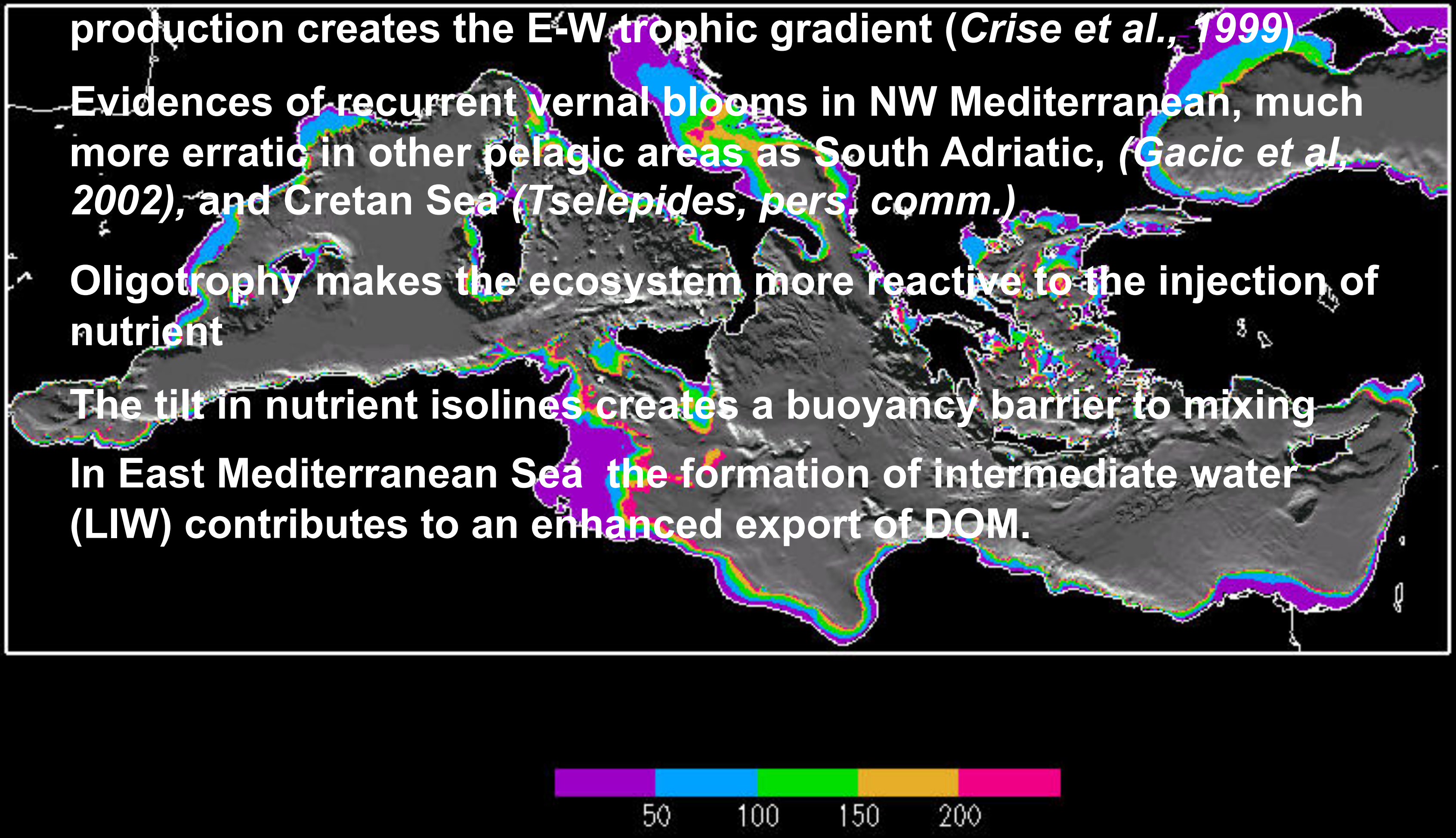
TRANSPORT – REACTION PDE set

$$\frac{\partial c_i}{\partial t} = -\mathbf{U}\cdot\nabla c_i + (-1)^{n+1} k_h \nabla_h^{2n} c_i + \frac{\partial}{\partial z}\left[k_v \frac{\partial c_i}{\partial z}\right] + w_{si}\frac{\partial c_i}{\partial z} + R_{bio}(c_i, c_1 \ldots c_N, T, I \ldots)$$

c	generic BGC variable concentration
$\mathbf{U}$	velocity
k	eddy diffusivity coefficients
W_{si}	sinking velocity
R_{bio}	0D non-linear biological-physical term
T	Temperature
I	Irradiance



symbols for diagram courtesy of ian.umces.edu/symbols



The estuarine inverse thermohaline circulation and export production creates the E-W trophic gradient (*Crise et al., 1999*)

Evidences of recurrent vernal blooms in NW Mediterranean, much more erratic in other pelagic areas as South Adriatic, *(Gacic et al, 2002), and Cretan Sea (Tselepides, pers. comm.)*

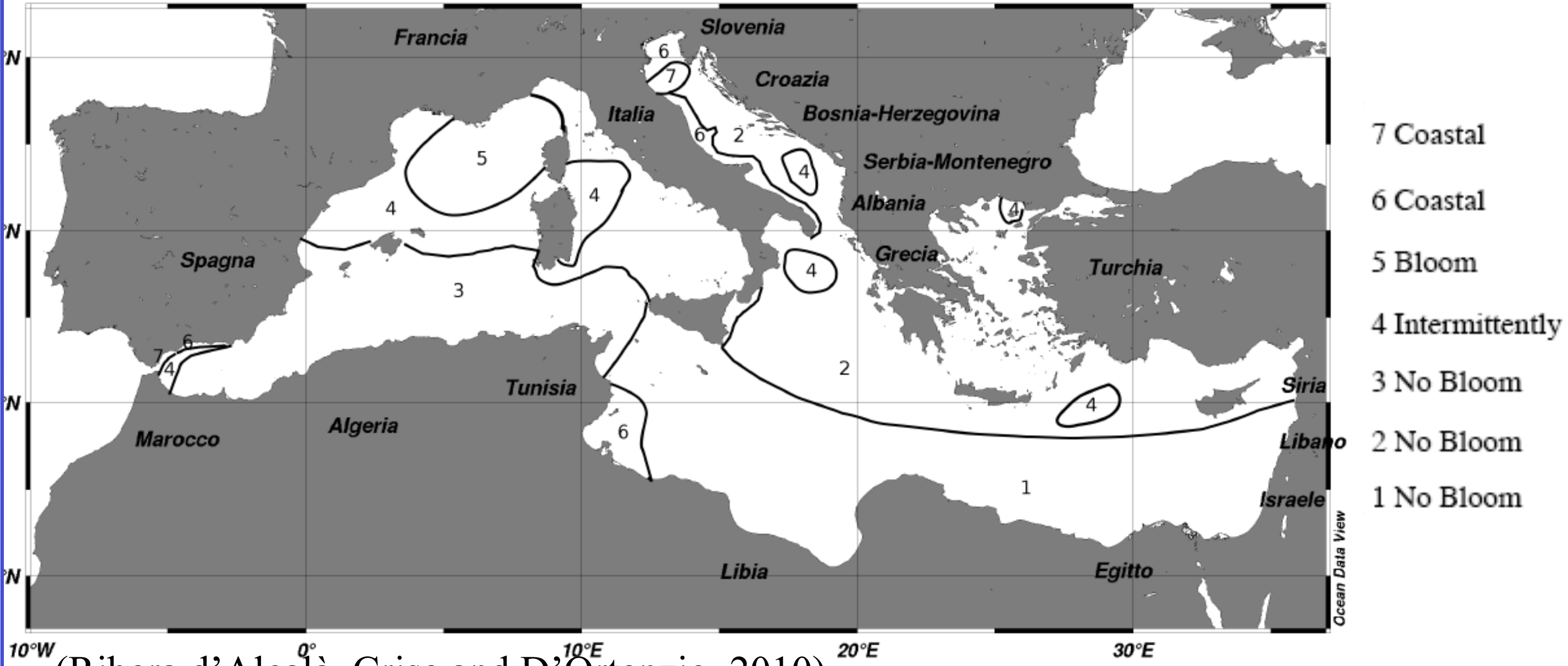
Oligotrophy makes the ecosystem more reactive to the injection of nutrient

The tilt in nutrient isolines creates a buoyancy barrier to mixing

In East Mediterranean Sea the formation of intermediate water (LIW) contributes to an enhanced export of DOM.

Peculiarities of the Mediterranean Basin

Mediterranean bioprovinces: a analysis from satellite observations



(Ribera d'Alcalà, Crise and D'Ortenzio, 2010)

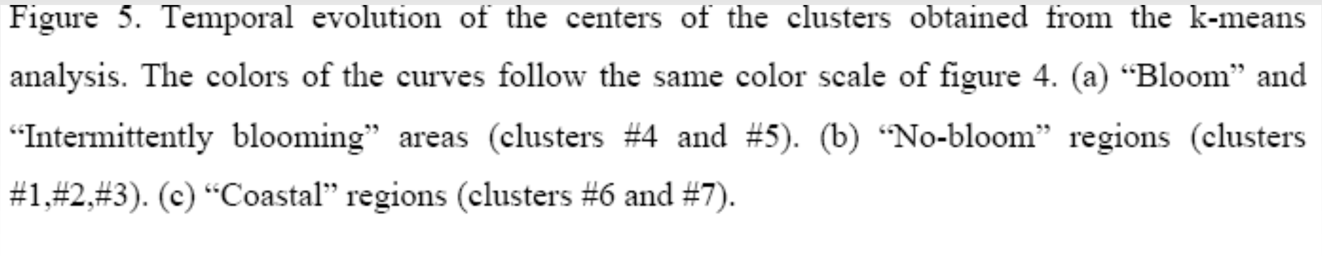
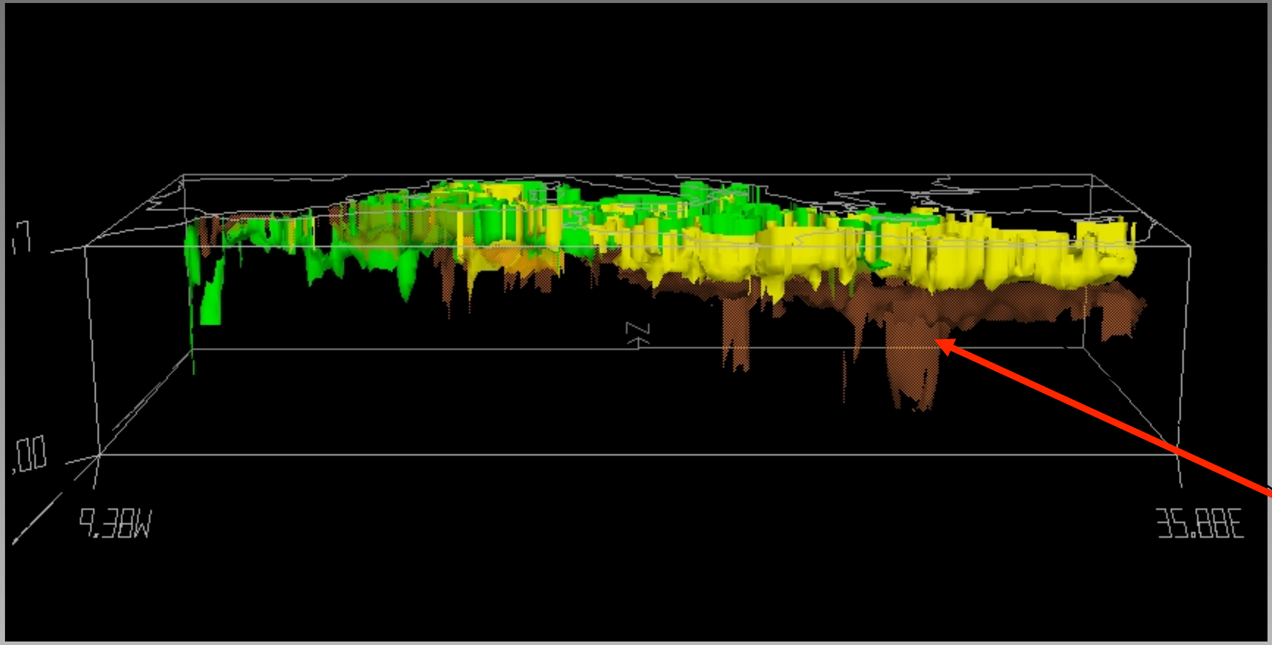


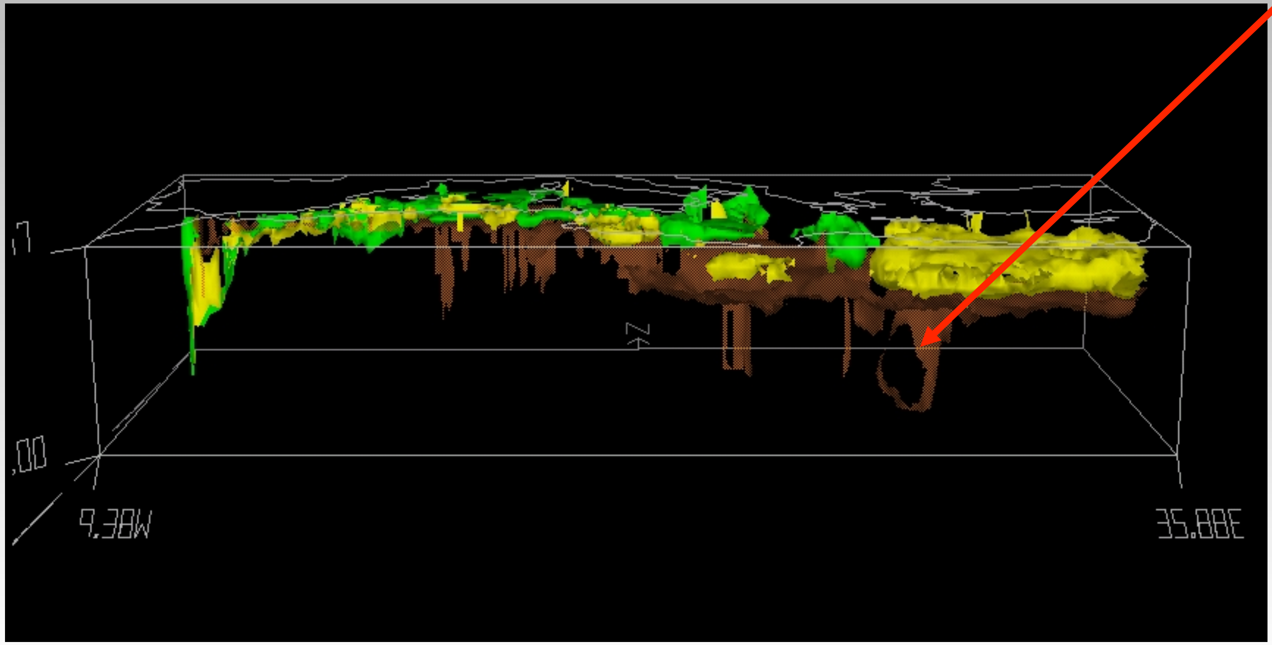
Figure 5. Temporal evolution of the centers of the clusters obtained from the k-means analysis. The colors of the curves follow the same color scale of figure 4. (a) "Bloom" and "Intermittently blooming" areas (clusters #4 and #5). (b) "No-bloom" regions (clusters #1,#2,#3). (c) "Coastal" regions (clusters #6 and #7).



January

NO3 isosurface

(2 uMN/l)



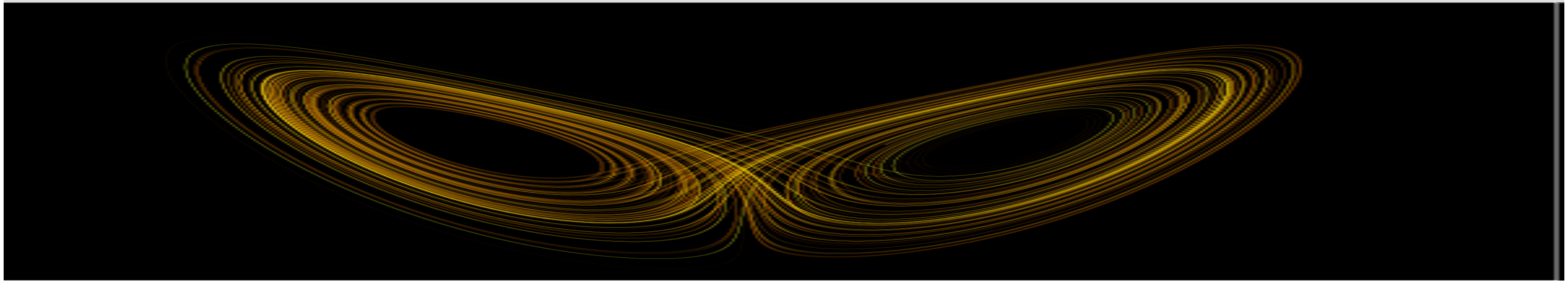
August

Predictability

Systems described by non-linear equations are prone to develop deteministic chaos.
This in priciple imposes severe limitations to the predictability of the systems (e.g. Lorenz, 1961)

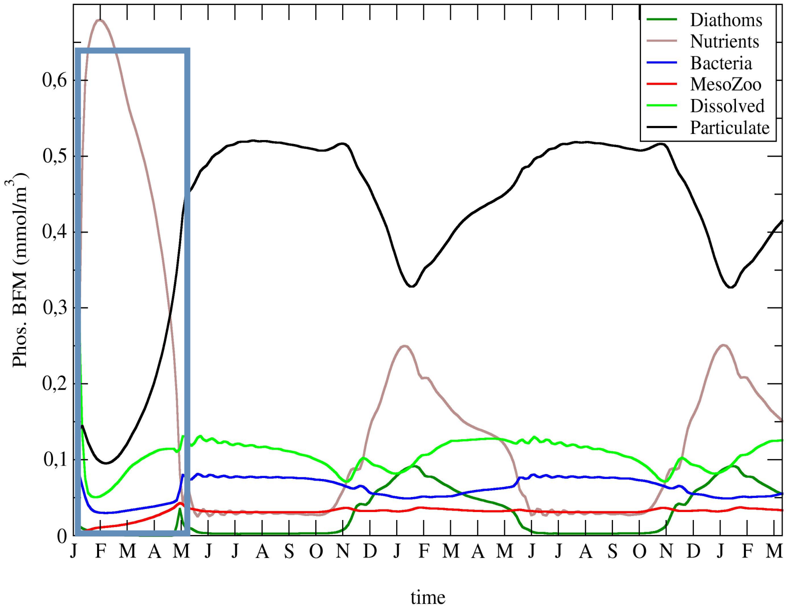
In some simple cases, even non-linear systems representing the Nitrogen cycle in the marine ecosystems can be unconditionally stables (Crise et. Al.,1998, Crispi et al., 1999)

The biotic community structure and functioning in some cases regulates ecosystem predictability (McGrady-Steed[1] et al., *Nature,* 1997)

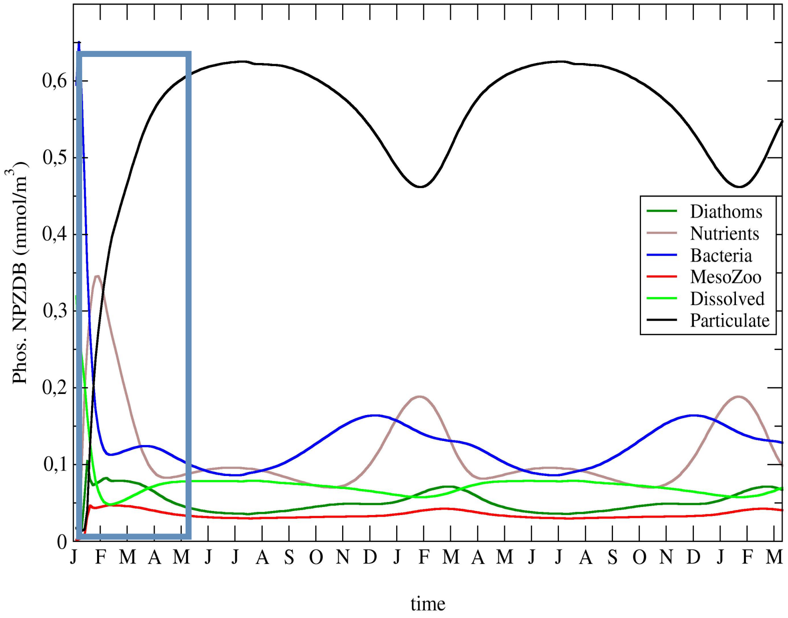


Predictability: response to the seasonal irradiance forcing by two biogeochemical 0D models

BFM multinutrient



NPZDB (excerpted from BFM)



Full 0D BFM (53 state variables

Phosphorus cycle 0D (6 variables)

Describing N,P,Si and C cycles

External forcing: mid-latitude irradiance seasonal cycle

Predictability and three-dimensional models

- . In three-dimesional models the biological reactors can be considered as forced oscillators in far-from-the equilibrium conditions.

  - *"a far-from-equilibrium system that constitutes and maintains itself establishing an organizational identity of its own, a functionally integrated unit based on a set of energetic couplings between internal self-constructing processes, as well as with other processes of interaction with its environment"*

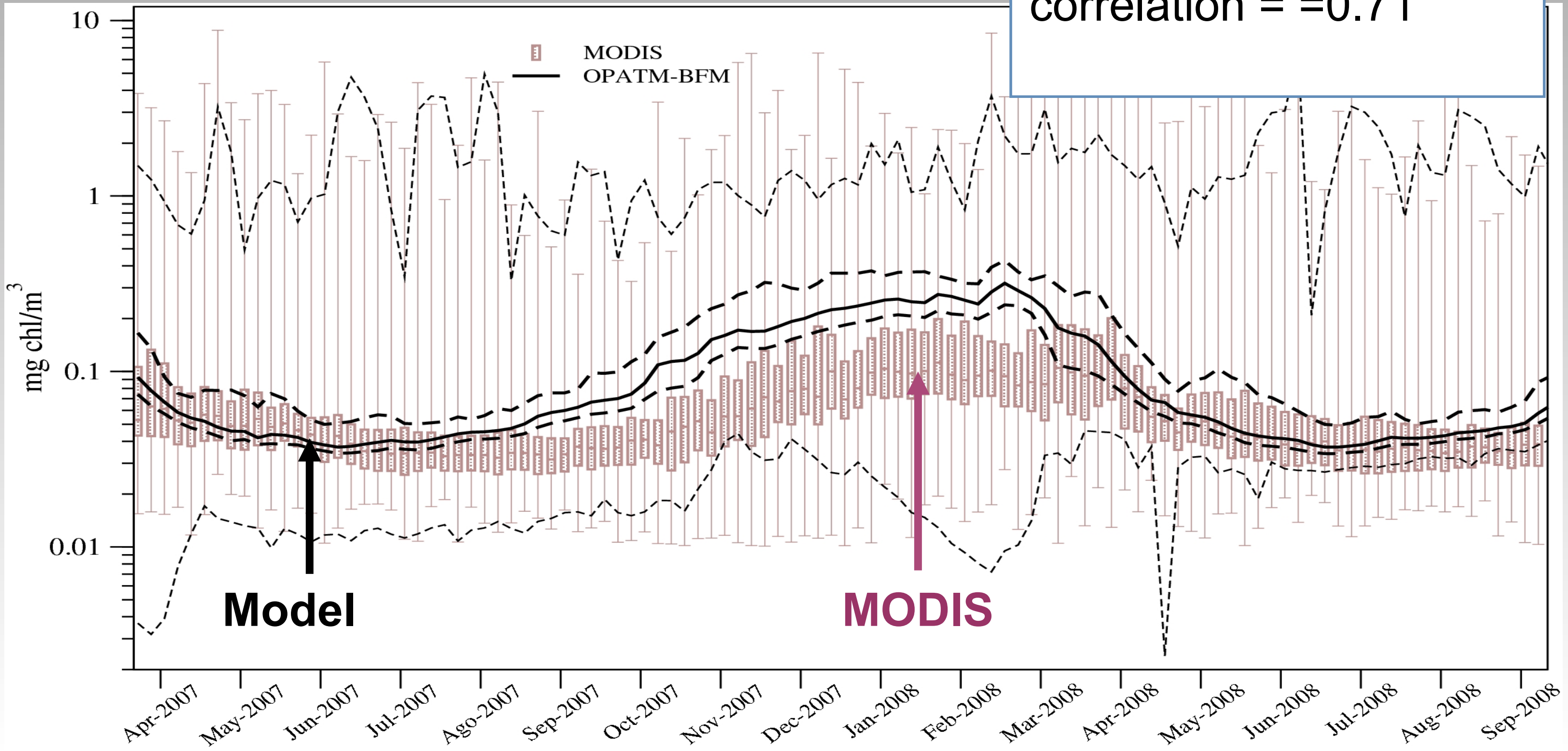
Kepa Ruiz-Mirazo, Juli Peretó and Alvaro Moreno, *A Universal Definition Of Life: Autonomy And Open-ended Evolution (2004) (modified)*

Predictability:a Mediterranean example

Comparison of the temporal evolution of the surface chlorophyll concentration over the Mediterranean Sea. (Aprile2007-September 2008)

OPATM-BFM and satellite data (MODIS)

Median Spearman correlation = =0.71



Model

MODIS

Operational Oceanography

“**Operational Oceanography** can be defined as the activity of systematic and long-term routine measurements of the seas and oceans and atmosphere, and their rapid interpretation and dissemination.

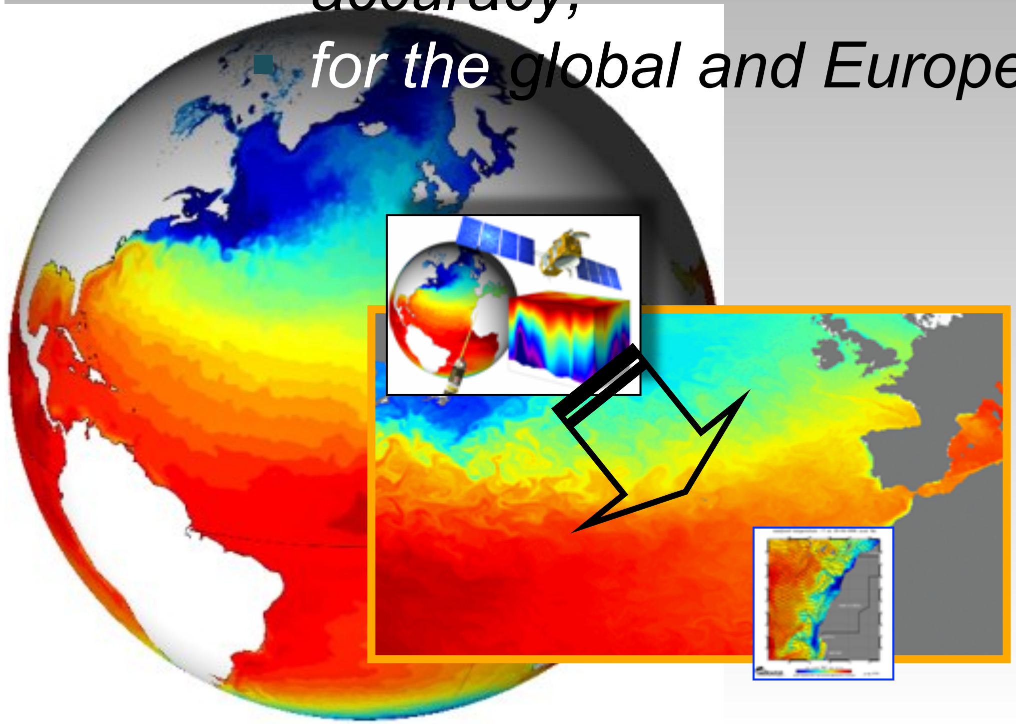
Important products derived from operational oceanography are:

- nowcasts
- forecasts
- hindcasts
- reanalyses

GMES Marine Core Services are the first example of a coordinated pre-operational initiative for the Ocean montoring and forecast (project MyOCEAN)

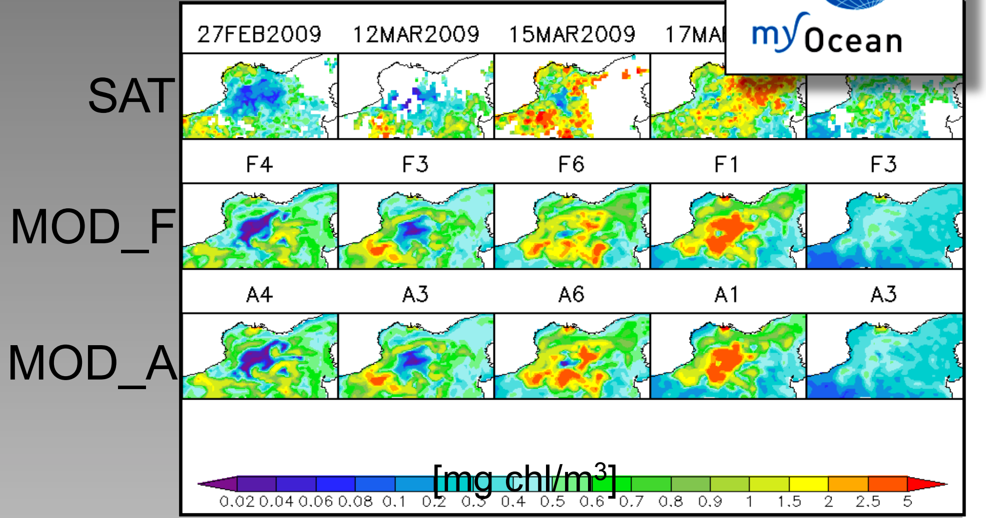
MyOCEAN activities

- MyOcean will
  - *“deliver **regular and systematic reference information** (processed data, elaborated products) on the state of the oceans and regional seas:*
  - *at the resolution required by **intermediate users & downstream service providers**, of known quality and accuracy,*
  - *for the global and European regional seas.”*



- Physical state of the ocean, and primary ecosystem
- For global ocean, and main European basins and seas
- Large and basin scale ; mesoscale physics
- Hindcast, Nowcast, Forecast
- Data, Assimilation and Models

Validation for V0 phase products

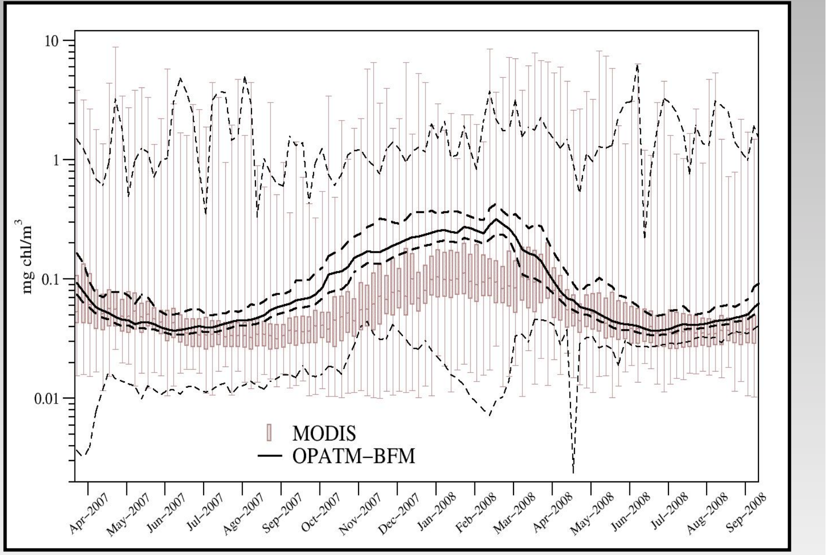


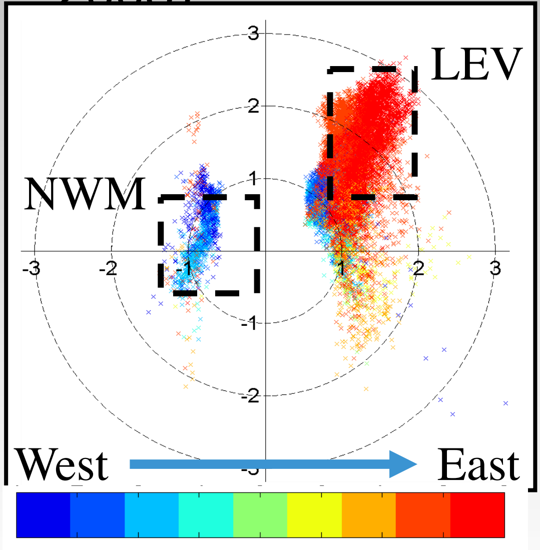
Class 4 MERSEA Metrics

Available data:

- concentration sup. chl from Ocean Colour (via GOS- ISAC, WP12)

- Qualitative comparison
- Non-paramemtric statistcs
- Skill diagrams (Jolliff et al. JMS, 2008)





x: RMSD unbiased

y: bias

Distance from the origin proportional to RMSD

Lazzari et al., OS6, 2010

Examples

- Climatic trends in Mediterranean primary production
- Climatic impact on Venice Lagoon ecosystem

Climatic trends in Mediterranean Primary Production

This activity has been carried out within SESAME IP and VECTOR projects

- Model configuration

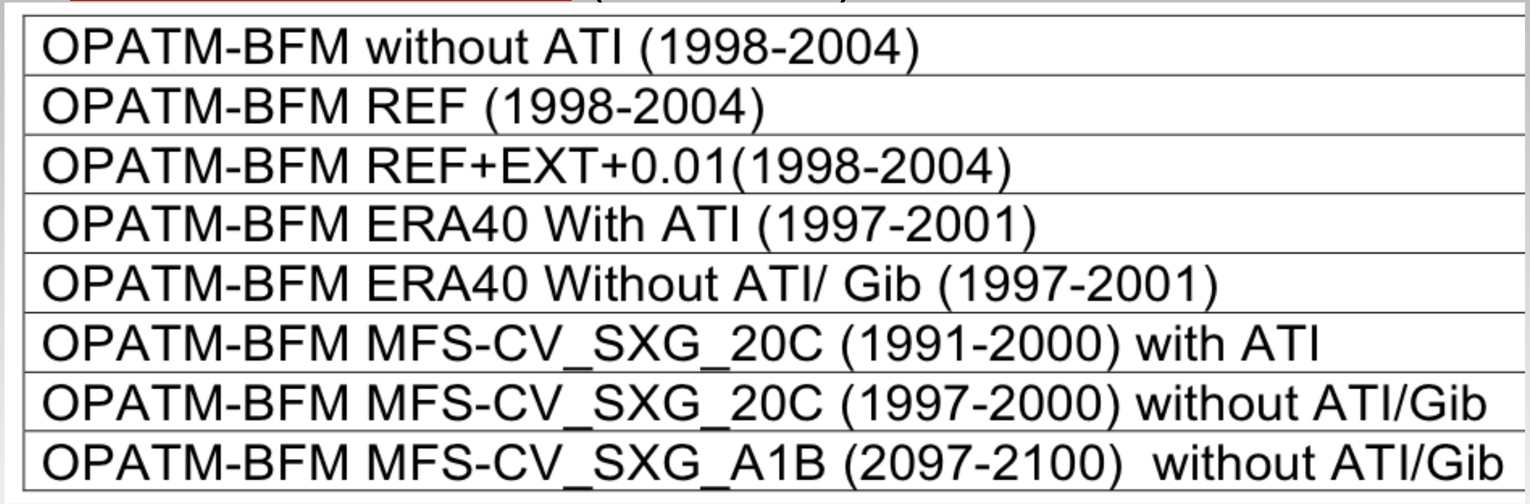
- Results on present simulations
    - current status of Mediterranean Sea

- Results on future simulations
    - comparison between present and future

Protocols for the numerical experiments

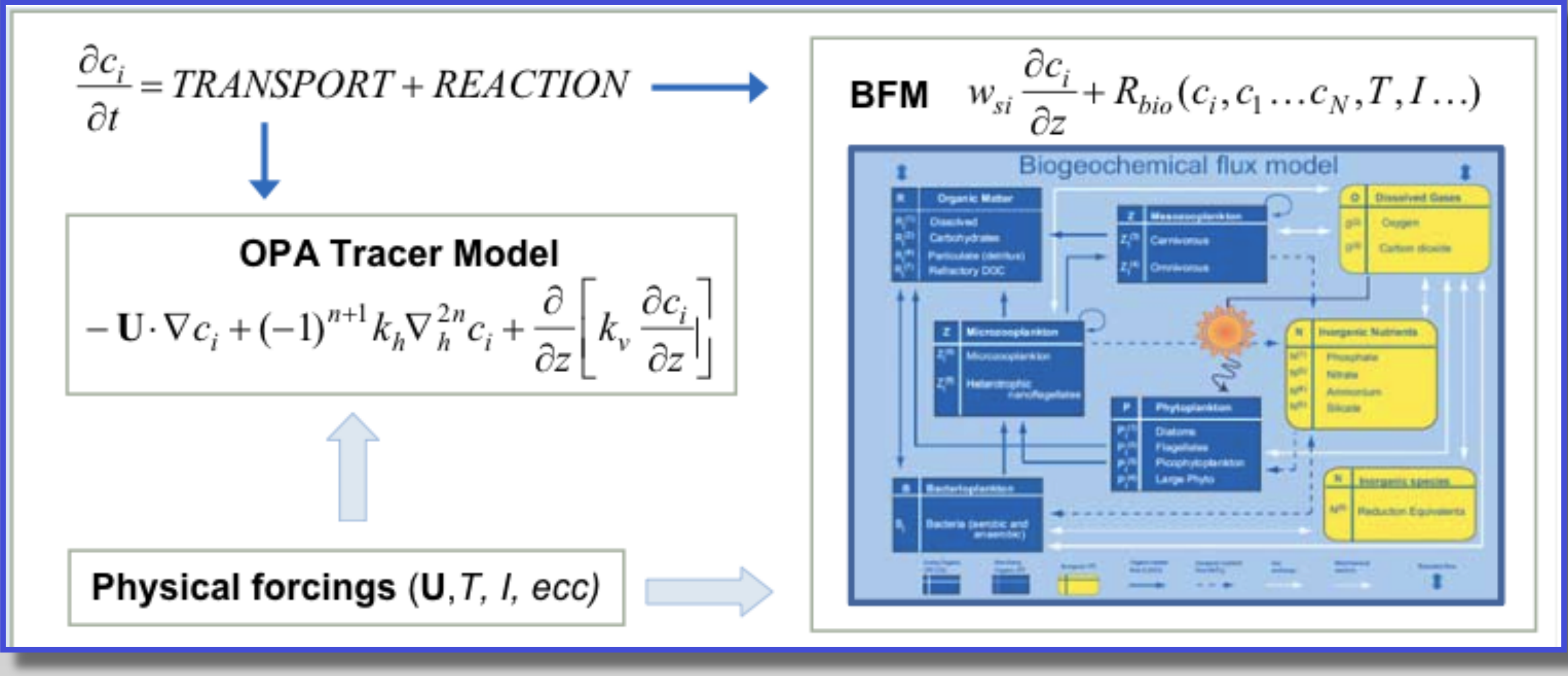
- Present Simulations (using 3 different physical forcings: ECMWF,ERA40, SXG-20C)

- Scenario Simulations (SXG-A1B)



OPATM-BFM without ATI (1998-2004)
OPATM-BFM REF (1998-2004)
OPATM-BFM REF+EXT+0.01(1998-2004)
OPATM-BFM ERA40 With ATI (1997-2001)
OPATM-BFM ERA40 Without ATI/ Gib (1997-2001)
OPATM-BFM MFS-CV_SXG_20C (1991-2000) with ATI
OPATM-BFM MFS-CV_SXG_20C (1997-2000) without ATI/Gib
OPATM-BFM MFS-CV_SXG_A1B (2097-2100) without ATI/Gib

The model used: OPATM-BFM



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

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

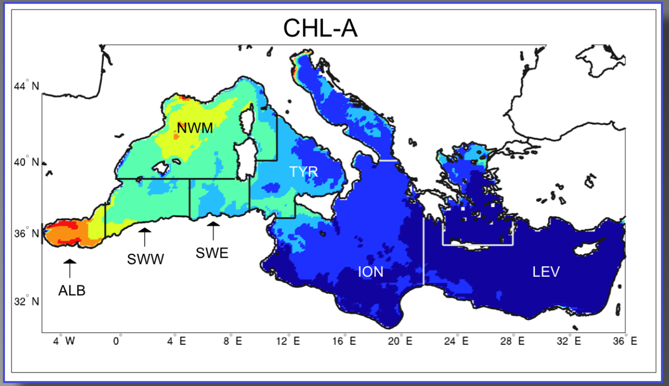
- ☐ Horizontal Resolution: 1/8° (Physics 1/16°)
- ☐Vertical Resolution: 43/72 levels
- ☐ Timestep 1800 s
- ☐ 1 year simulated in 1 day
- ☐ Output saved every 10 dd

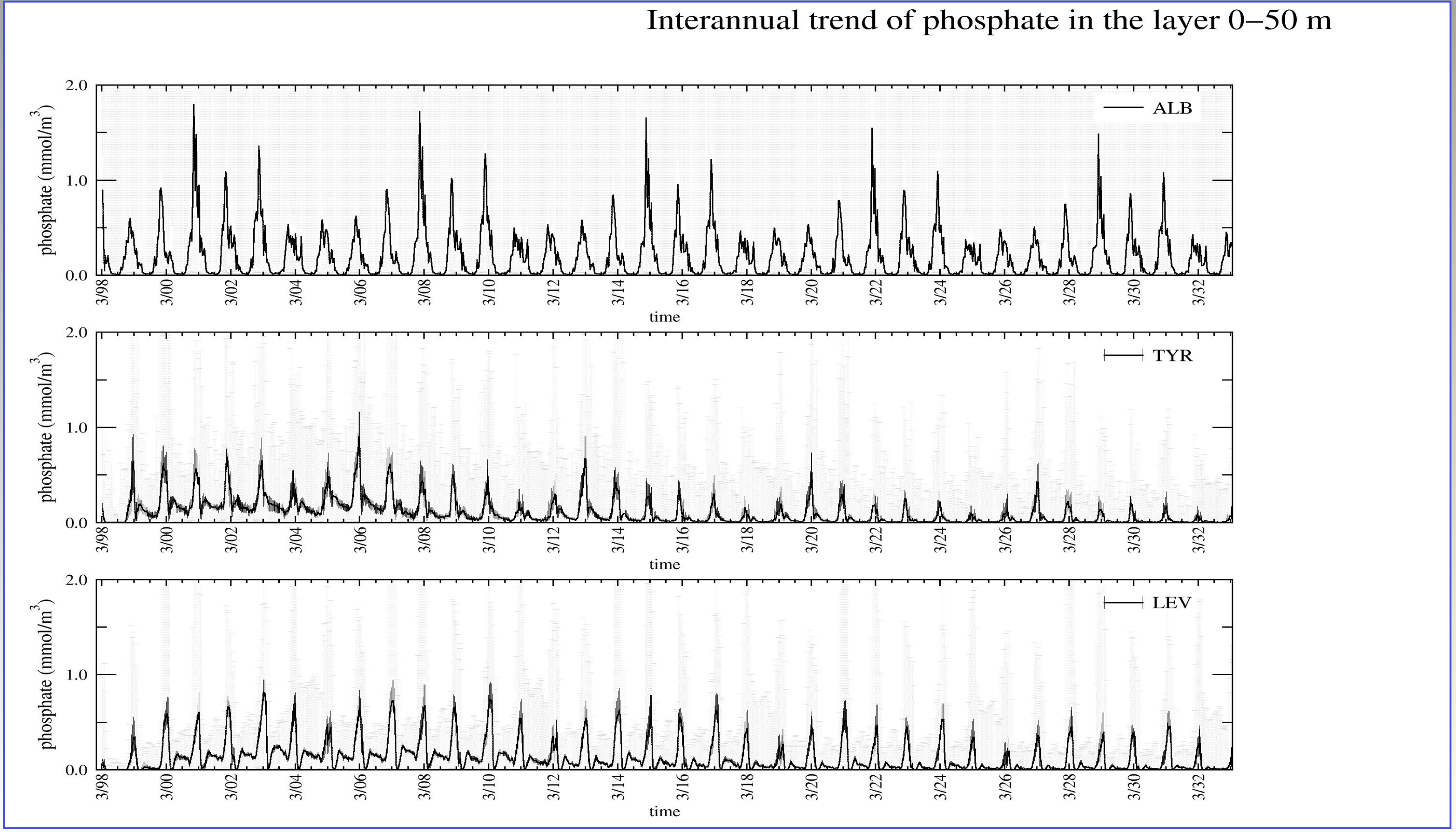
OPATM-BFM Boundary Conditions

- **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)
- **Light extintion coefficient** – satellite derived from SeaWIFs , time and space dependent (seasonal climatology)

Present state simulations: OPATM-BFM Model stability

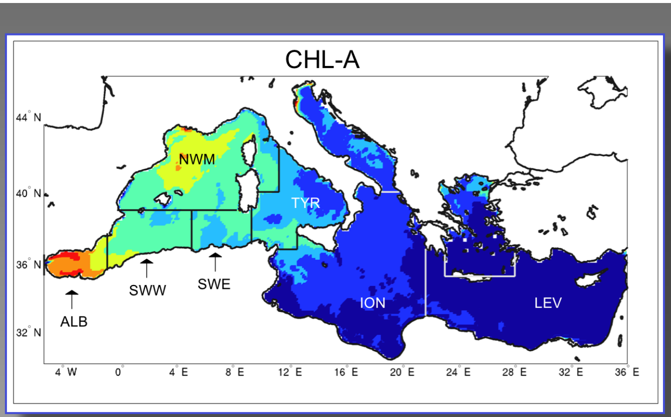
- Repeated 1998-2004 physical forcings
- 60 years simulation (35 shown)
- ECMWF atmospheric forcing

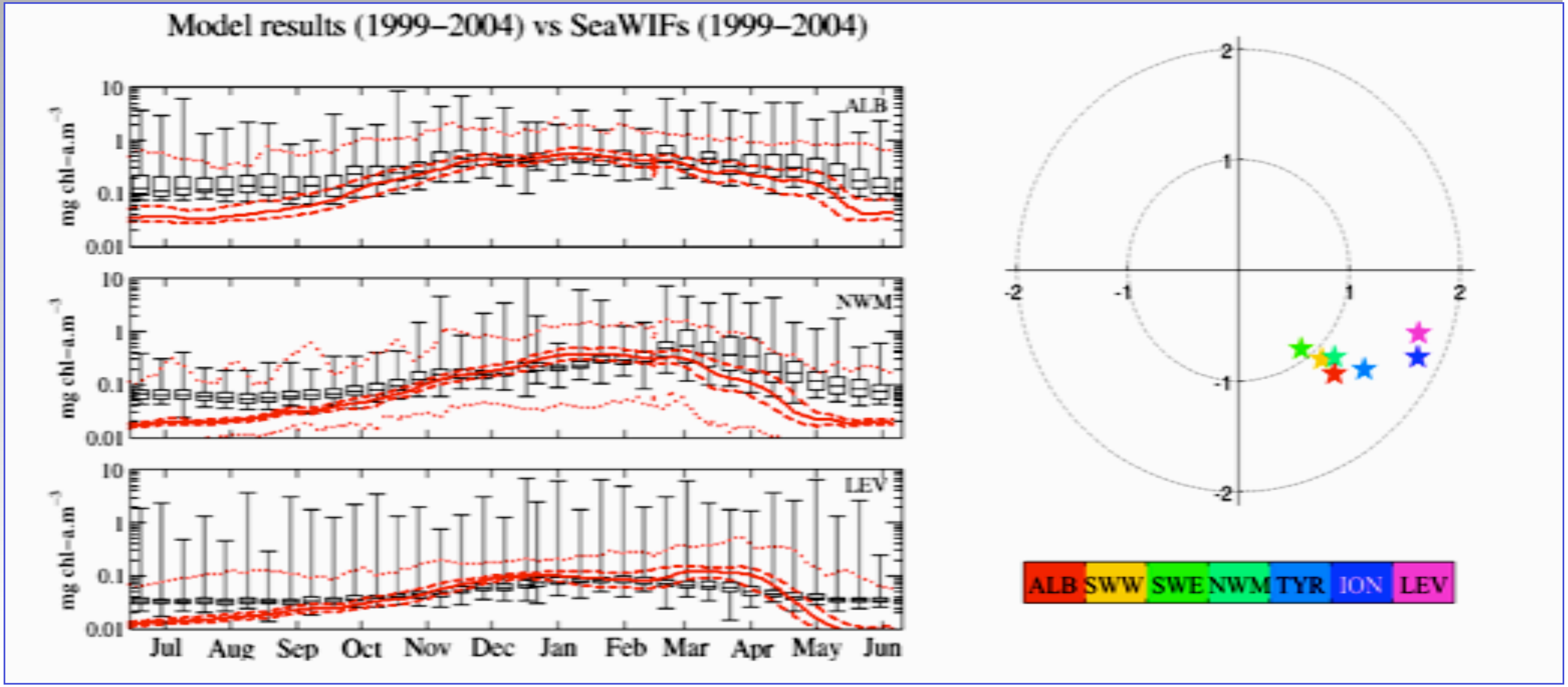



Interannual trend of phosphate in the layer 0–50 m

Med Present State

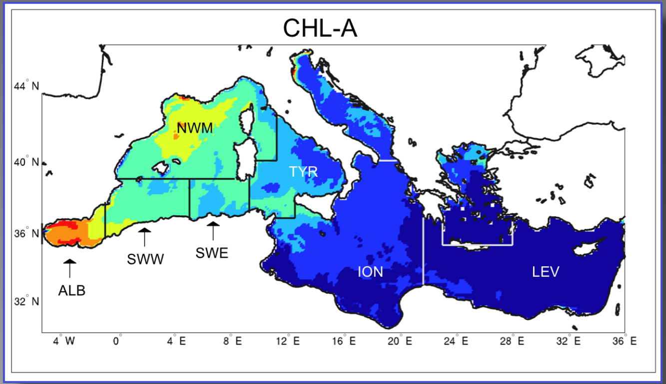
Modelled vs Measured Chlorophyll-a dynamics

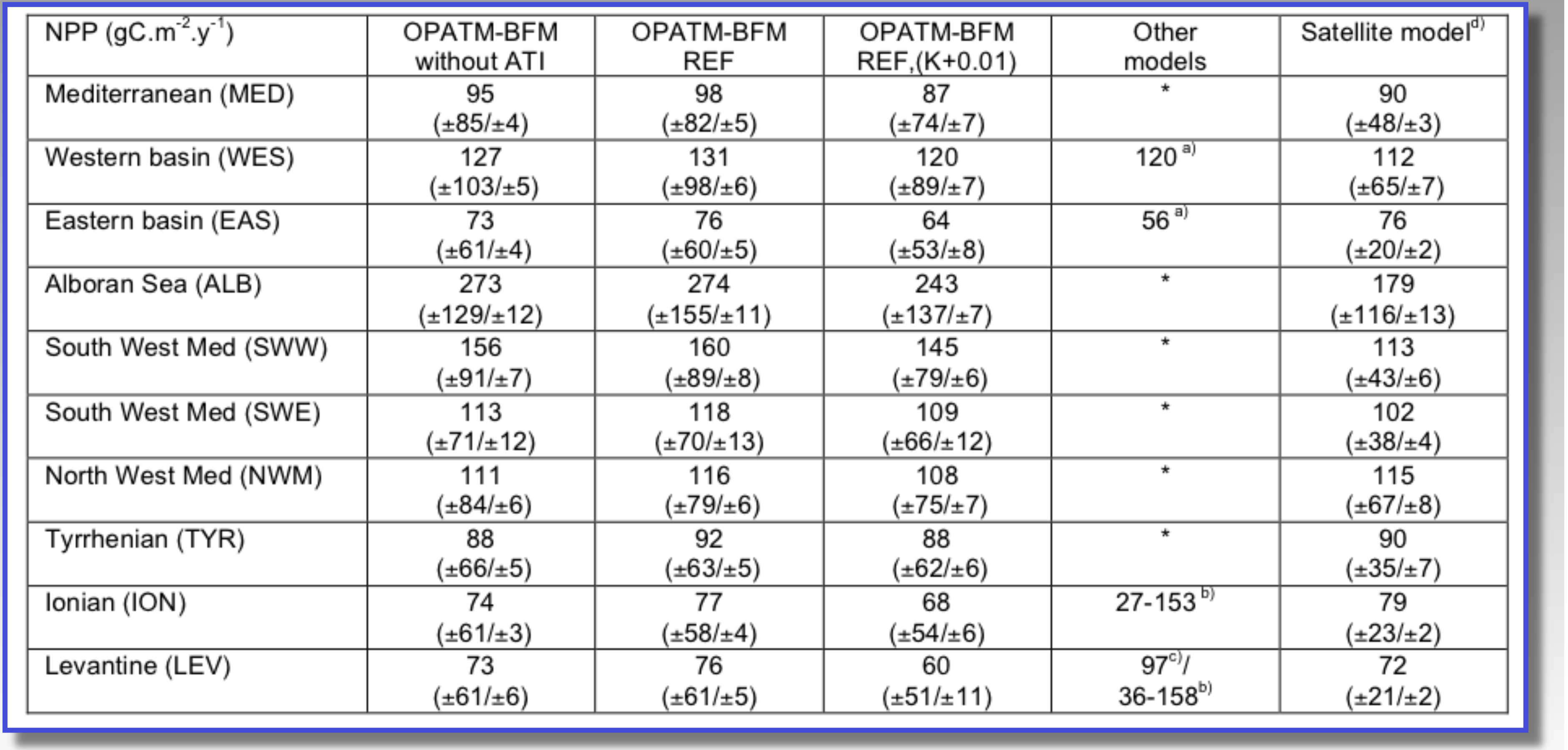



Model results (1999–2004) vs SeaWIFs (1999–2004)

Med Primary Production

Annual budgets

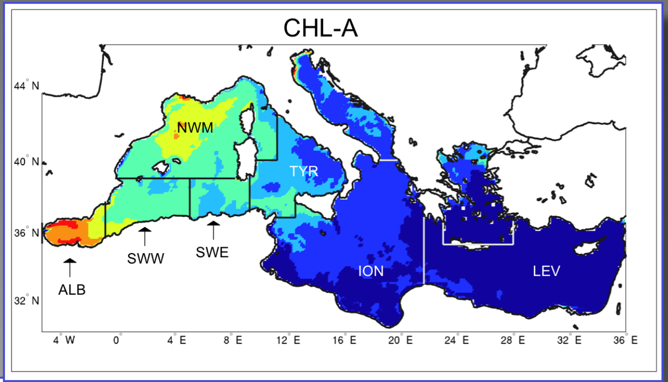


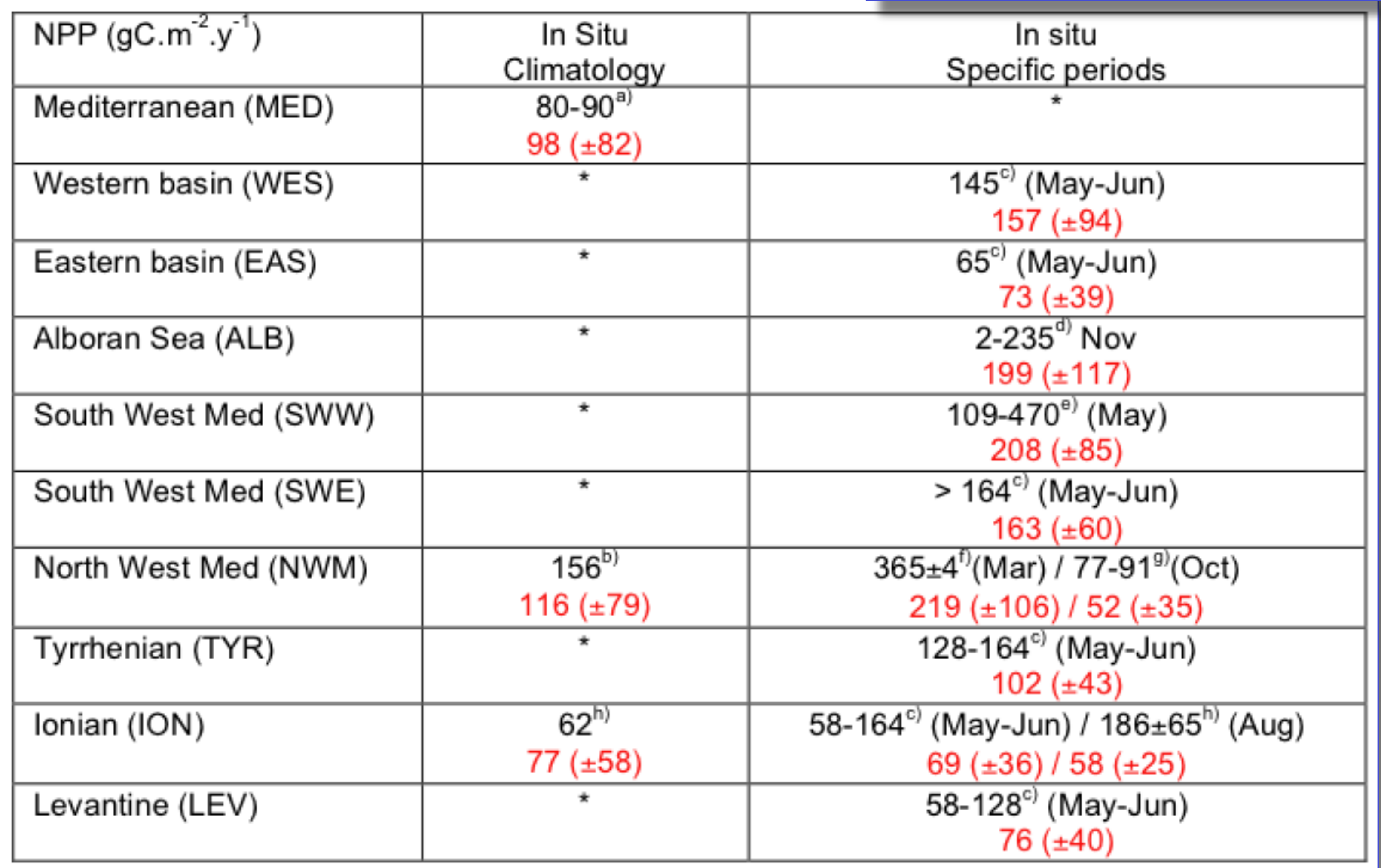


NPP ($gC.m^{-2}.y^{-1}$)	OPATM-BFM without ATI	OPATM-BFM REF	OPATM-BFM REF,(K+0.01)	Other models	Satellite model d)
Mediterranean (MED)	95 (±85/±4)	98 (±82/±5)	87 (±74/±7)	*	90 (±48/±3)
Western basin (WES)	127 (±103/±5)	131 (±98/±6)	120 (±89/±7)	120 a)	112 (±65/±7)
Eastern basin (EAS)	73 (±61/±4)	76 (±60/±5)	64 (±53/±8)	56 a)	76 (±20/±2)
Alboran Sea (ALB)	273 (±129/±12)	274 (±155/±11)	243 (±137/±7)	*	179 (±116/±13)
South West Med (SWW)	156 (±91/±7)	160 (±89/±8)	145 (±79/±6)	*	113 (±43/±6)
South West Med (SWE)	113 (±71/±12)	118 (±70/±13)	109 (±66/±12)	*	102 (±38/±4)
North West Med (NWM)	111 (±84/±6)	116 (±79/±6)	108 (±75/±7)	*	115 (±67/±8)
Tyrrhenian (TYR)	88 (±66/±5)	92 (±63/±5)	88 (±62/±6)	*	90 (±35/±7)
Ionian (ION)	74 (±61/±3)	77 (±58/±4)	68 (±54/±6)	27-153 b)	79 (±23/±2)
Levantine (LEV)	73 (±61/±6)	76 (±61/±5)	60 (±51/±11)	97 c)/ 36-158 b)	72 (±21/±2)

Med Primary Production

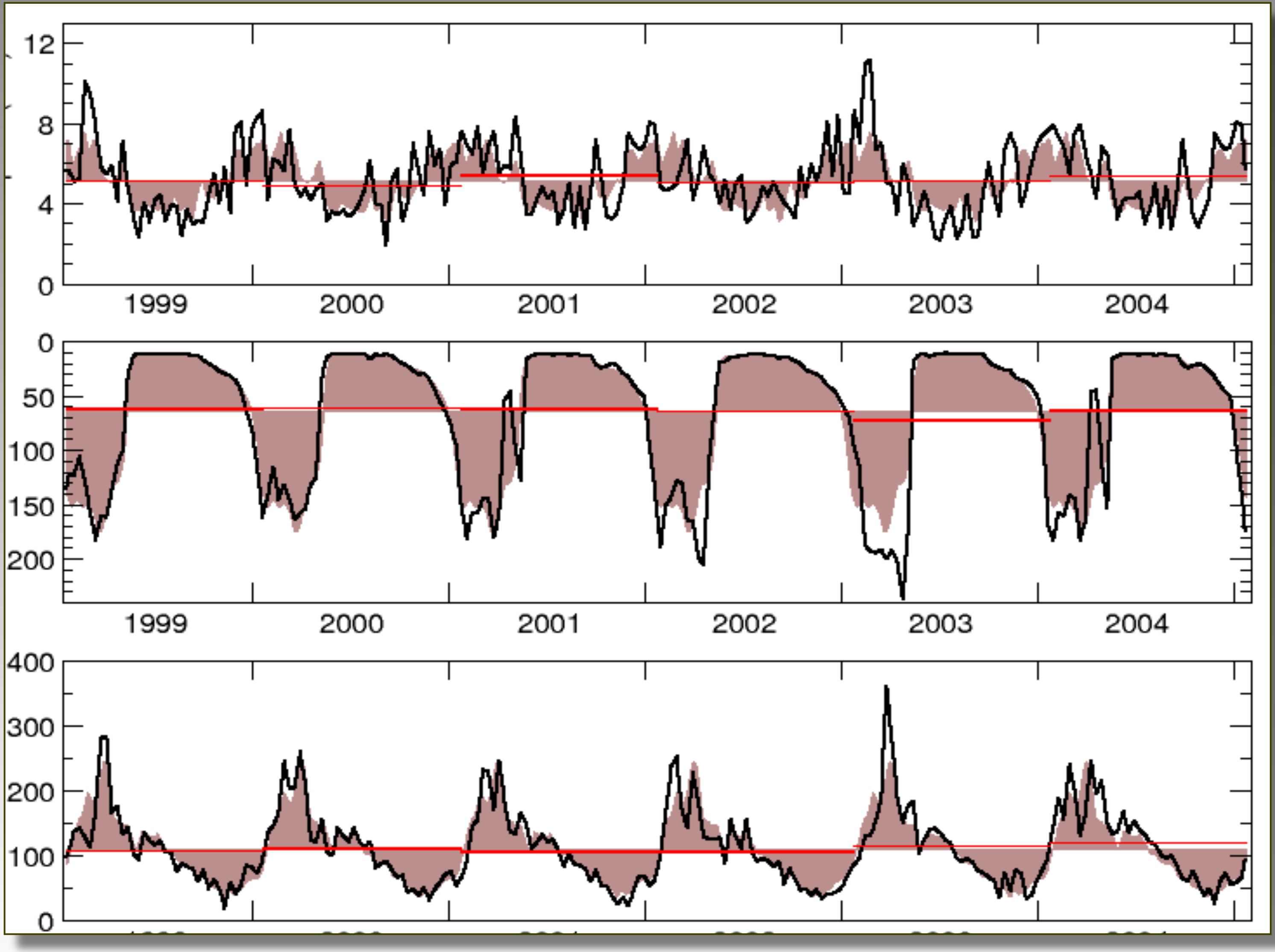
Comparison with in-situ measurements





NPP (gC.m^{-2}.y^{-1})	In Situ Climatology	In situ Specific periods
Mediterranean (MED)	80-90[a] 98 (±82)	*
Western basin (WES)	*	145[c] (May-Jun) 157 (±94)
Eastern basin (EAS)	*	65[c] (May-Jun) 73 (±39)
Alboran Sea (ALB)	*	2-235[d] Nov 199 (±117)
South West Med (SWW)	*	109-470[e] (May) 208 (±85)
South West Med (SWE)	*	> 164[c] (May-Jun) 163 (±60)
North West Med (NWM)	156[b] 116 (±79)	365±4[f](Mar) / 77-91[g](Oct) 219 (±106) / 52 (±35)
Tyrrhenian (TYR)	*	128-164[c] (May-Jun) 102 (±43)
Ionian (ION)	62[h] 77 (±58)	58-164[c] (May-Jun) / 186±65[h] (Aug) 69 (±36) / 58 (±25)
Levantine (LEV)	*	58-128[c] (May-Jun) 76 (±40)

Physical-biological coupling: wind, MLD, Net Primary Production (1999-2004)



Wind speed
($m.s^{-1}$)

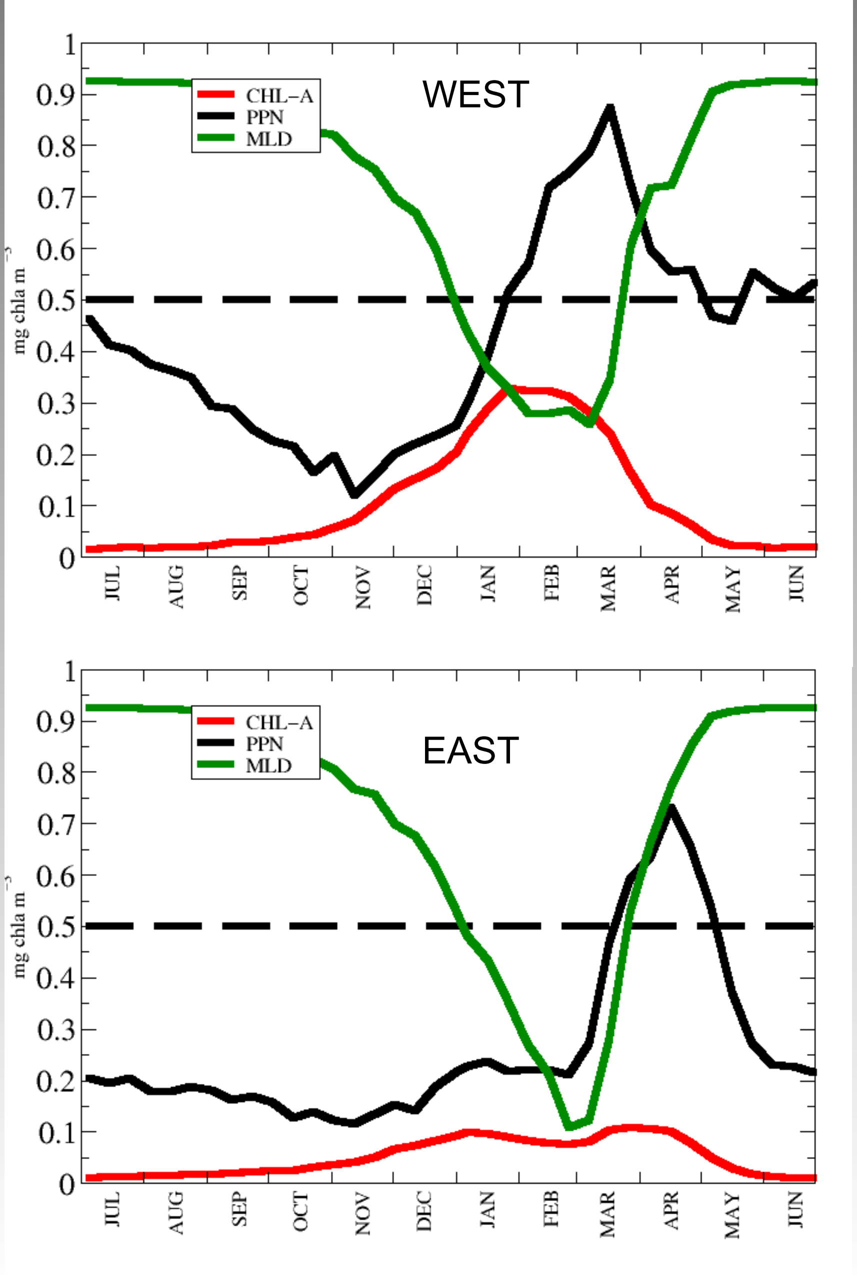
↓

MLD
(m)

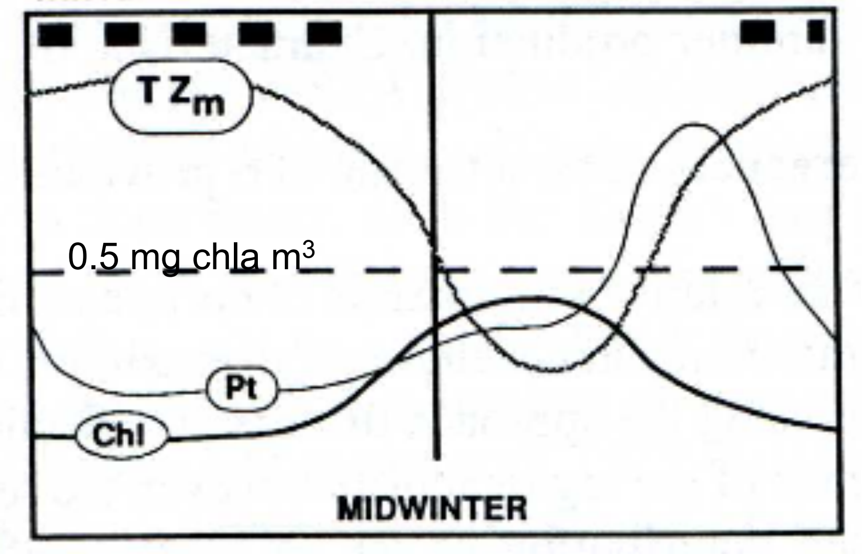
↓

NPP
(gC. $m^{-2}.y^{-1}$)

Primary production Seasonal Cycle



SUBTROPICAL NUTRIENT-LIMITED, WINTER-SPRING PRODUCTION PERIOD (Longhurst, 1995)

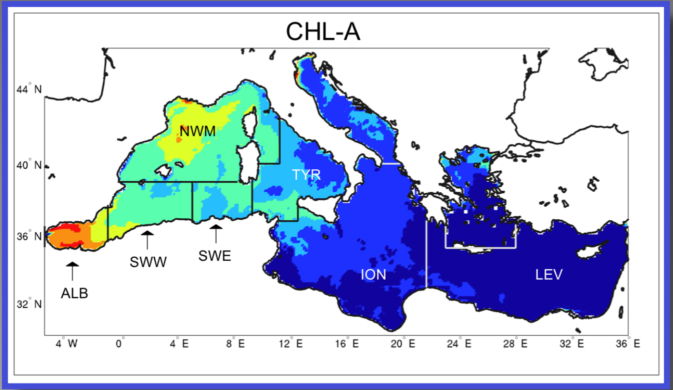


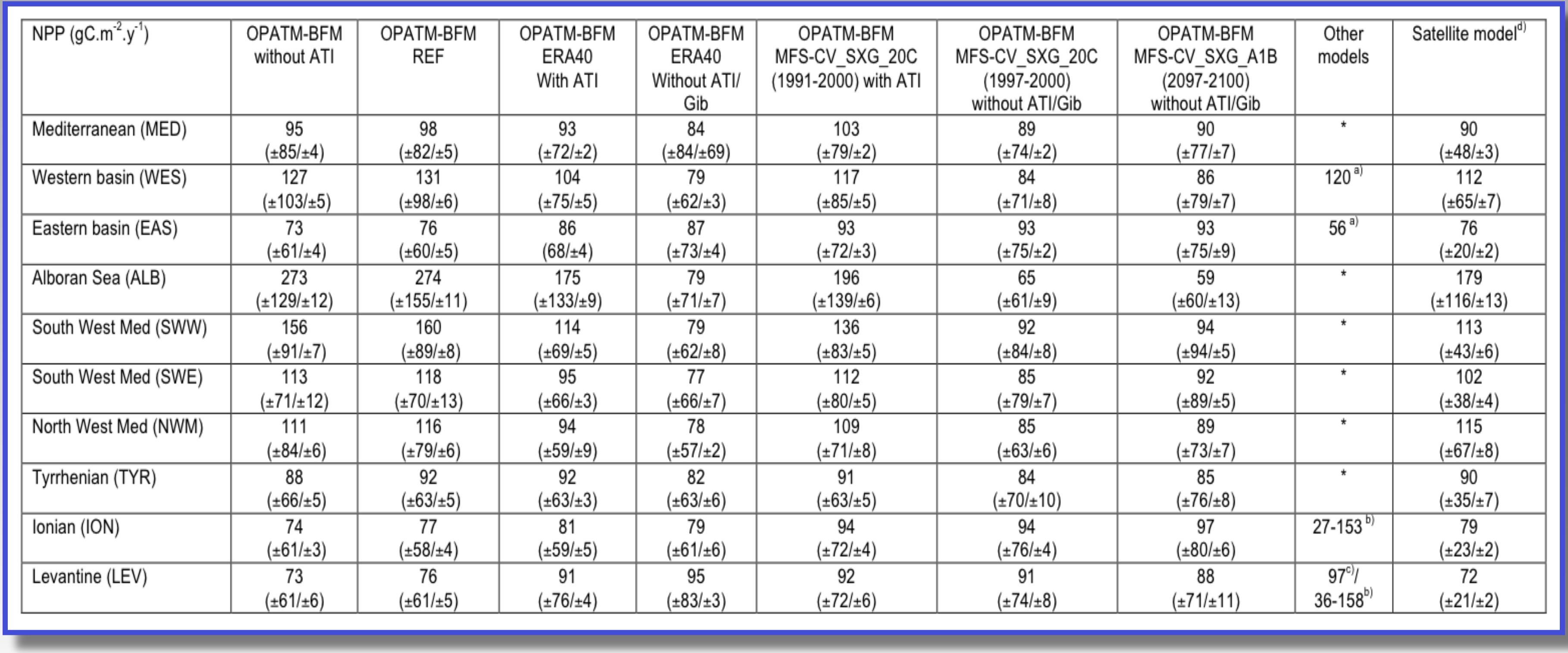
XXI Century Scenarios

- ☐ Protocol of numerical experiments:
- ☐ Control run with 20th Century forcing with SXG-20C forcings
- ☐ Reference run with the ’best forcings’ (ERA40 reanalises)
- ☐ Simulation with SXG-A1B with A1B scenario forcings

- ☐ These results are obtained within SESAME IP project where the forcings are provided by CMCC

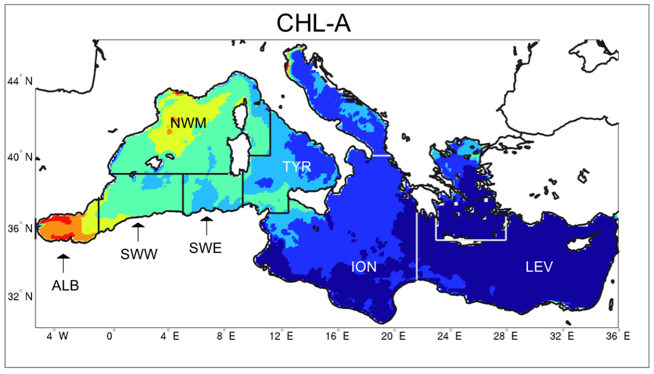
Med Primary Production Annual budget

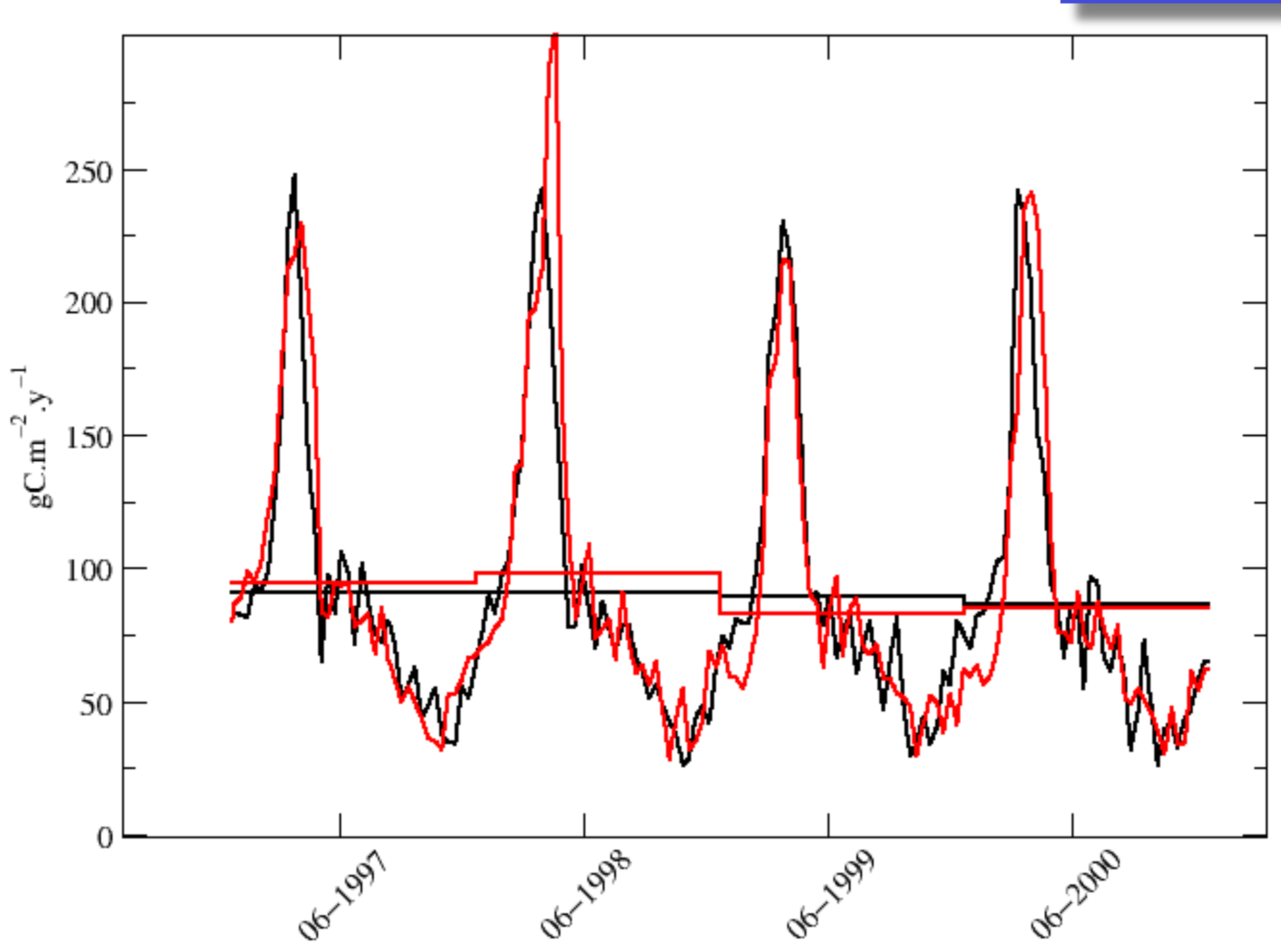




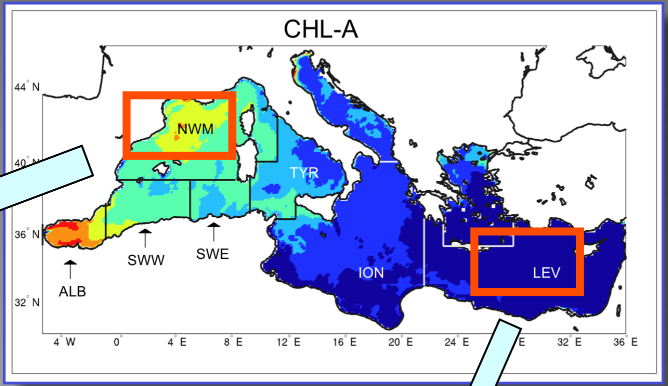
NPP (gC.m^{-2}.y^{-1})	OPATM-BFM without ATI	OPATM-BFM REF	OPATM-BFM ERA40 With ATI	OPATM-BFM ERA40 Without ATI/ Gib	OPATM-BFM MFS-CV_SXG_20C (1991-2000) with ATI	OPATM-BFM MFS-CV_SXG_20C (1997-2000) without ATI/Gib	OPATM-BFM MFS-CV_SXG_A1B (2097-2100) without ATI/Gib	Other models	Satellite model[d)]
Mediterranean (MED)	95 (±85/±4)	98 (±82/±5)	93 (±72/±2)	84 (±84/±69)	103 (±79/±2)	89 (±74/±2)	90 (±77/±7)	*	90 (±48/±3)
Western basin (WES)	127 (±103/±5)	131 (±98/±6)	104 (±75/±5)	79 (±62/±3)	117 (±85/±5)	84 (±71/±8)	86 (±79/±7)	120 [a)]	112 (±65/±7)
Eastern basin (EAS)	73 (±61/±4)	76 (±60/±5)	86 (68/±4)	87 (±73/±4)	93 (±72/±3)	93 (±75/±2)	93 (±75/±9)	56 [a)]	76 (±20/±2)
Alboran Sea (ALB)	273 (±129/±12)	274 (±155/±11)	175 (±133/±9)	79 (±71/±7)	196 (±139/±6)	65 (±61/±9)	59 (±60/±13)	*	179 (±116/±13)
South West Med (SWW)	156 (±91/±7)	160 (±89/±8)	114 (±69/±5)	79 (±62/±8)	136 (±83/±5)	92 (±84/±8)	94 (±94/±5)	*	113 (±43/±6)
South West Med (SWE)	113 (±71/±12)	118 (±70/±13)	95 (±66/±3)	77 (±66/±7)	112 (±80/±5)	85 (±79/±7)	92 (±89/±5)	*	102 (±38/±4)
North West Med (NWM)	111 (±84/±6)	116 (±79/±6)	94 (±59/±9)	78 (±57/±2)	109 (±71/±8)	85 (±63/±6)	89 (±73/±7)	*	115 (±67/±8)
Tyrrhenian (TYR)	88 (±66/±5)	92 (±63/±5)	92 (±63/±3)	82 (±63/±6)	91 (±63/±5)	84 (±70/±10)	85 (±76/±8)	*	90 (±35/±7)
Ionian (ION)	74 (±61/±3)	77 (±58/±4)	81 (±59/±5)	79 (±61/±6)	94 (±72/±4)	94 (±76/±4)	97 (±80/±6)	27-153 [b)]	79 (±23/±2)
Levantine (LEV)	73 (±61/±6)	76 (±61/±5)	91 (±76/±4)	95 (±83/±3)	92 (±72/±6)	91 (±74/±8)	88 (±71/±11)	97[c)]/ 36-158[b)]	72 (±21/±2)

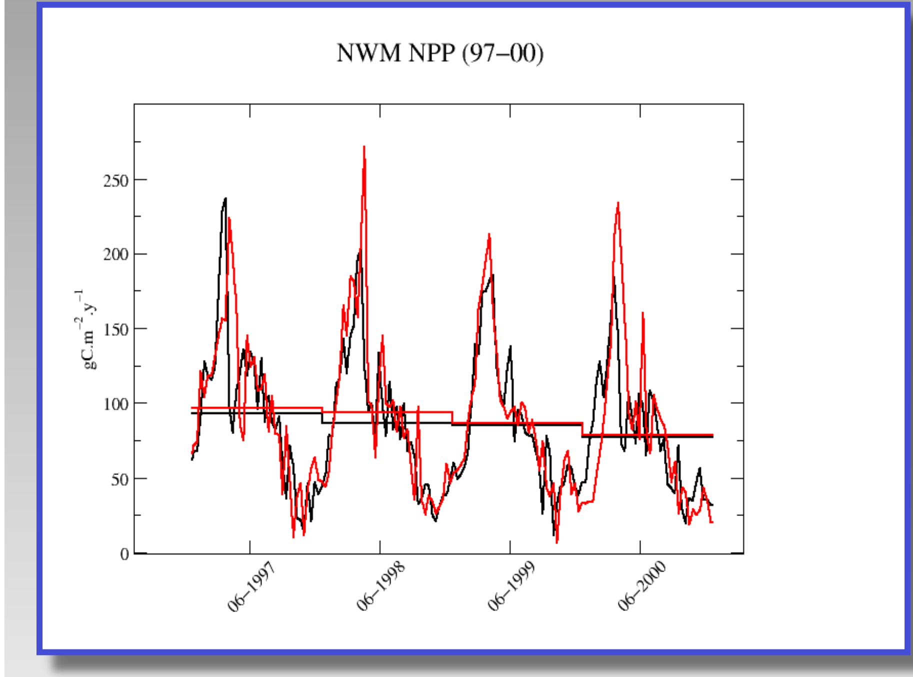
Med Primary Production Time series

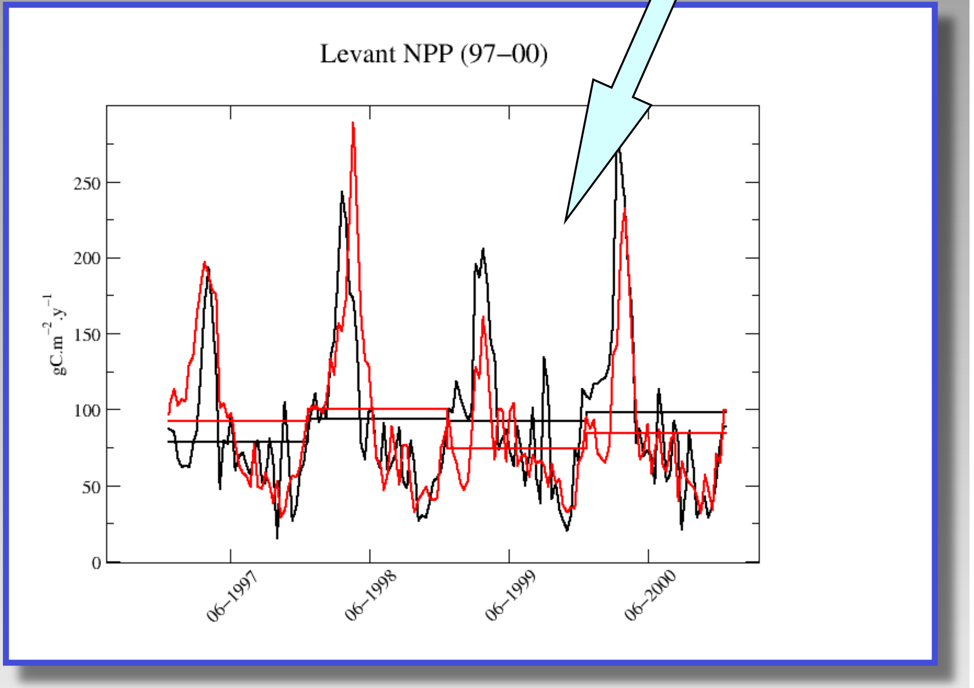




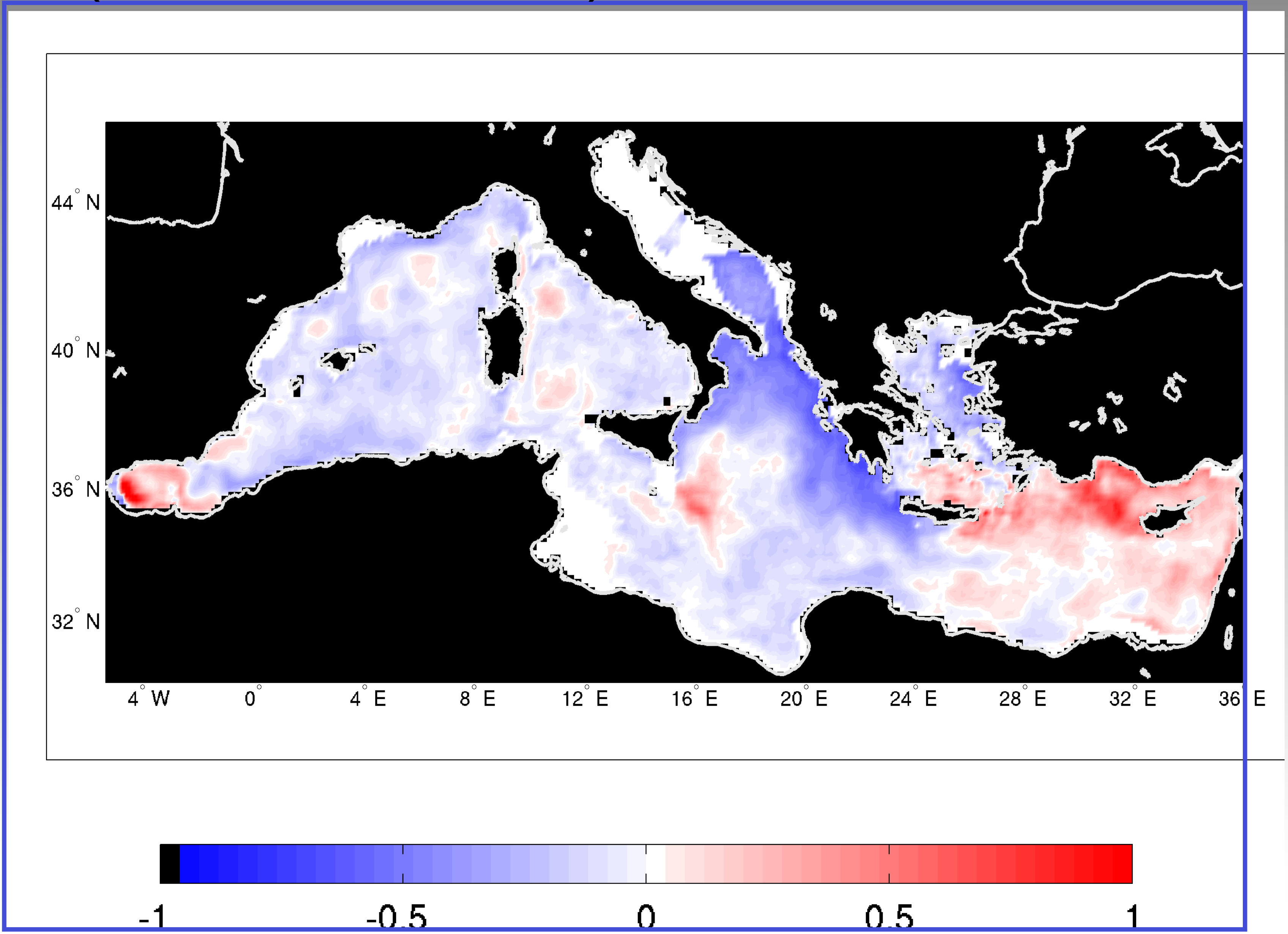
Med Primary Production Time series


CHL-A


NWM NPP (97–00)

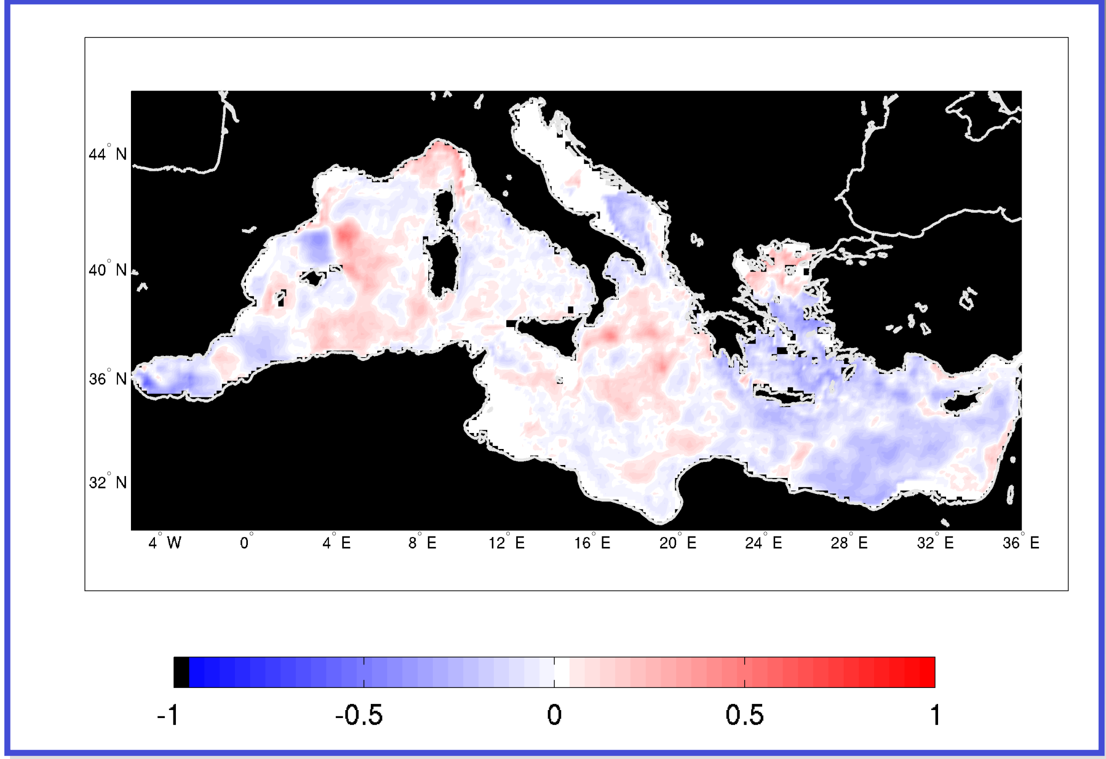

Levant NPP (97–00)

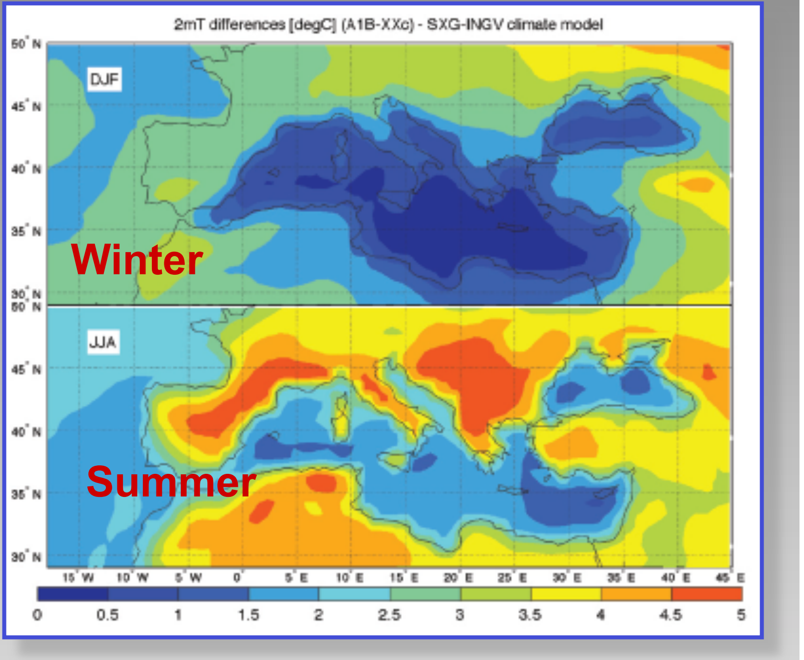
Net Primary Production Anomaly map (ERA40-SXG20C)/SXG20C 1996-2001



Net Primary Production Anomaly Map

(SXGA1B-SXG20C)/SXG20C, 1996-2000, 2096-2100



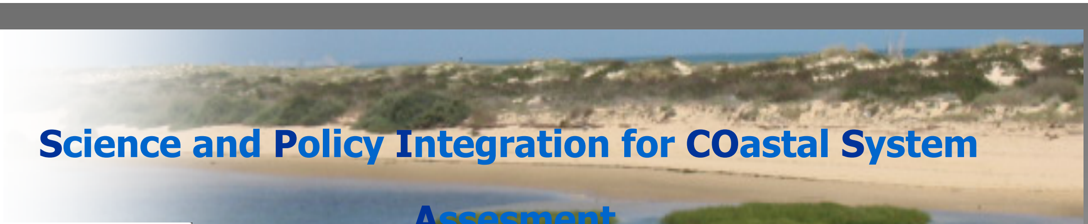


(Gualdi et al., 2009)

Limited relative variations in NPP:
Convection areas, E.Med less productive
Algerian Basin, Ionian Sea more productive

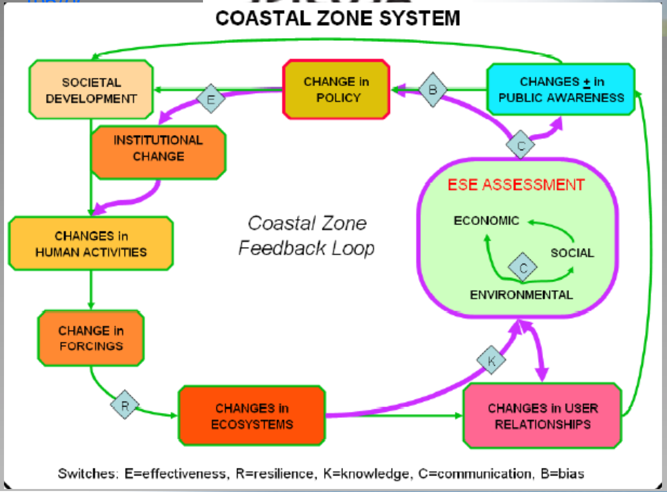
Winter: Temperature at 2m
Exibits changes below 1°C
Summer: Temperature at 2m
can exceed 2 °C

http://
cordis.europa.eu/
fp6/dc



Science and Policy Integration for COastal System Assessment

http://ec.europa.eu/
sustainable



COASTAL ZONE SYSTEM

SOCIETAL DEVELOPMENT

CHANGE in POLICY

CHANGES ± in PUBLIC AWARENESS

INSTITUTIONAL CHANGE

ESE ASSESSMENT

ECONOMIC

SOCIAL

ENVIRONMENTAL

Coastal Zone Feedback Loop

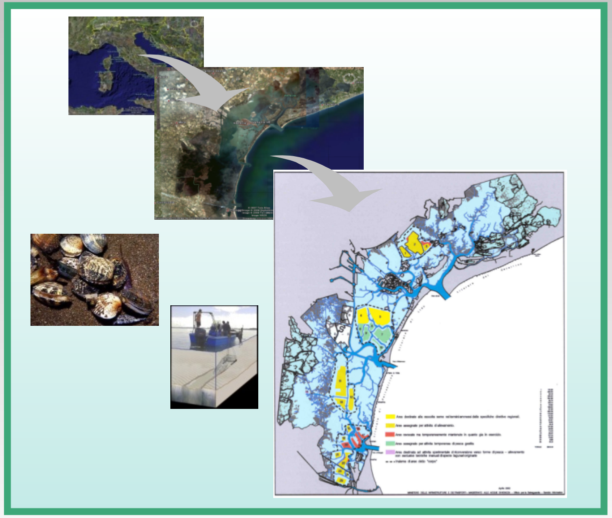
CHANGES in HUMAN ACTIVITIES

CHANGE in FORCINGS

CHANGES in ECOSYSTEMS

CHANGES in USER RELATIONSHIPS

Switches: E=effectiveness, R=resilience, K=knowledge, C=communication, B=bias



SSA Venice team: CoRiLa, OGS, University of Venice, University of Padua

Issue

Sustainable aquaculture of clam *Tapes philippinarum*

goal

Sustainable use of Lagoon Ecosystem *and Tapes philippinarum* stock.

SCENARIOS definition (by researchers, local stakeholders and policy makers)

Model tools: **Integrated Ecological Socio-Economic Model**

exploring the sensitivity of the system to:

Changes in biological parameters (density, mortality rate)

-Changes in economic parameters (costs, investments)

- Changes in coastal planning (Size and location of the areas under concession)

- Changing Climate Scenarios

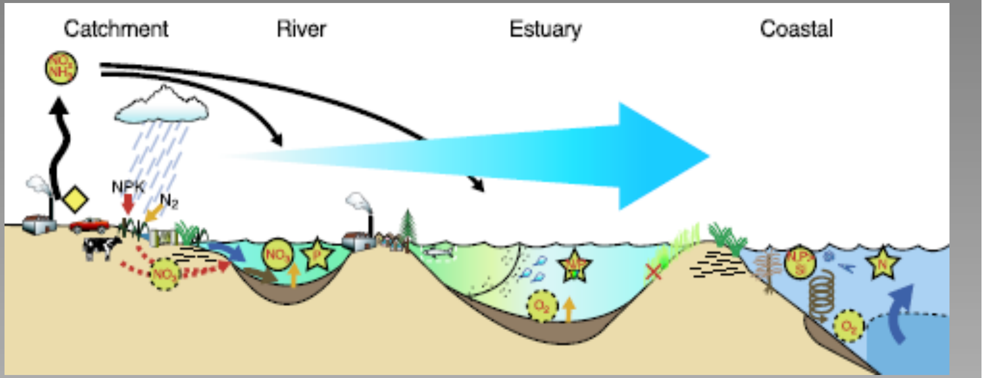
Effects of changes in precipitation patterns on clam aquaculture

Clima-dpsir

Climate changes projections for 21st century are expected to cause a number of potential impacts (IPCC 2007).

While changes in sea level appears the most obvious threat to costal areas, **changes in precipitation patterns** and therefore in **timing** and **volume** of **freshwater** and **nutrient delivery** to coastal wetlands will also be critical

Scavia et al., 2003

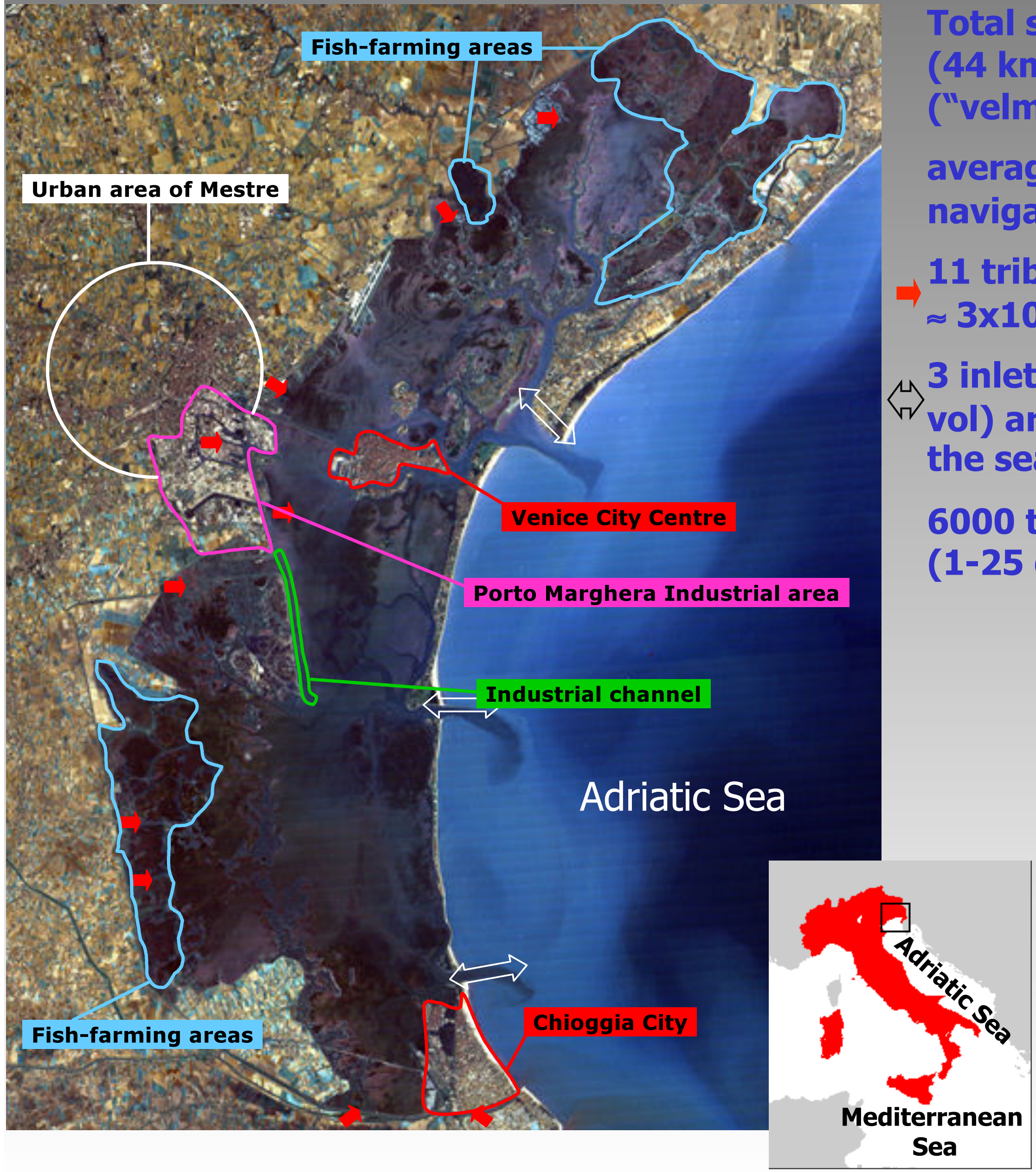


Aim: assessing the potential impact of changes on **seasonal precipitation patterns** on the biogeochemistry and – in turn- on clam aquaculture in the lagoon of Venice

Cossarini et al., 2008, Salon et al., 2008, Solidoro et al., 2009,

Melaku Canu et al., 2009 under rev.

Application to the Venice Lagoon



Total surface of 550 km^2, made up of islands (44 km^2), wetlands ("barene") and tidal flats ("velme")

average depth 1m; deep channels allow navigation (65 km^2).

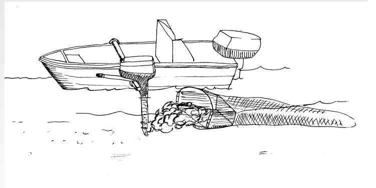
➡ 11 tributaries: average freshwater discharge ≈ 3x10^6 m^3 day^{-1}

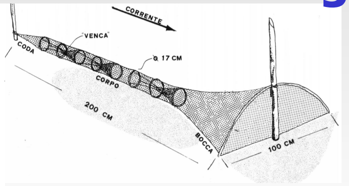
⇔ 3 inlets: ≈ 3.85x10^8 m^3 day^{-1} of water (1/3 vol) are exchanged through the inlets with the sea.

6000 tN/y 250tP/y Residence time 3 days (1-25 days)

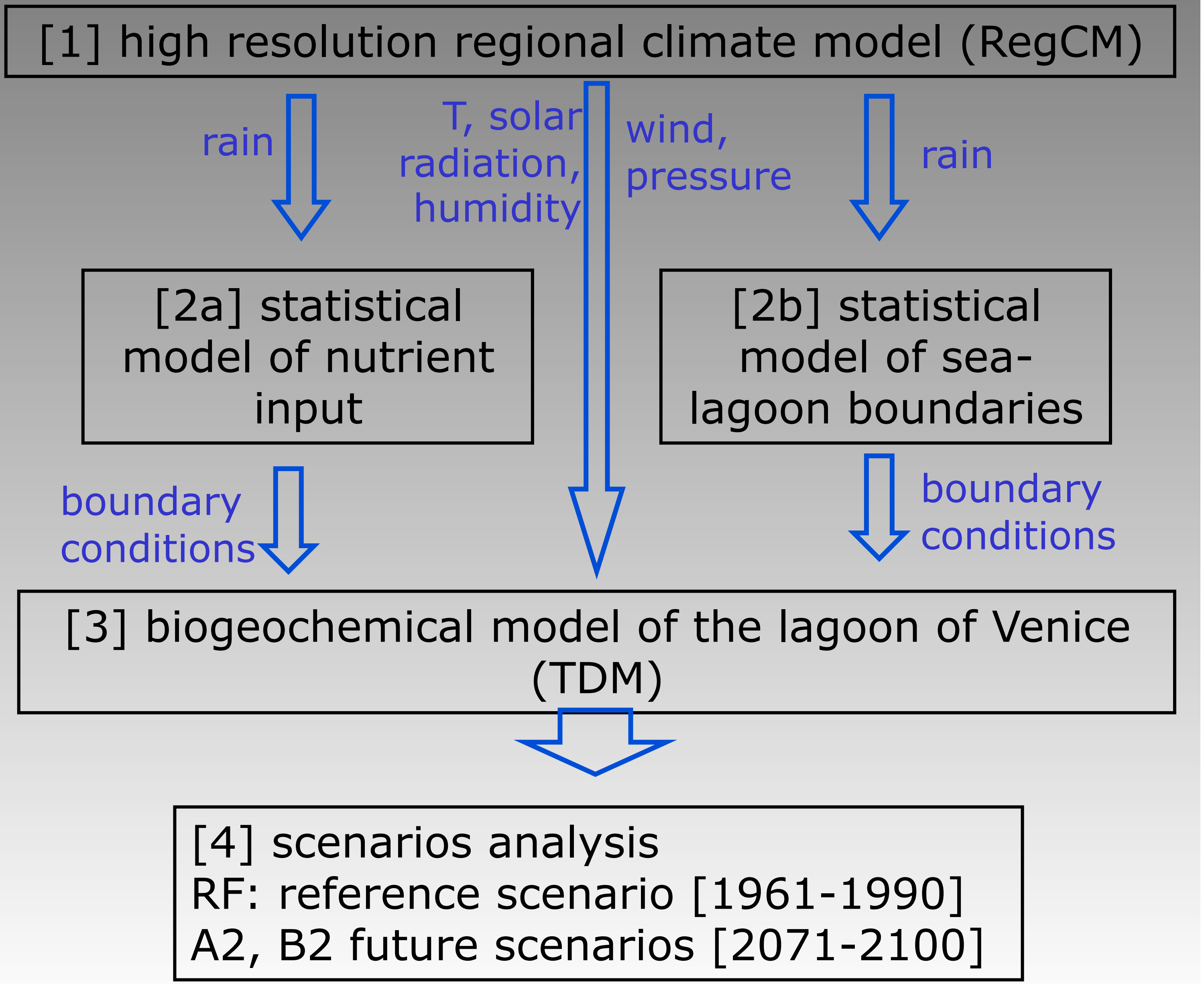
Open system, highly productive, with strong antropogehinc Impacts

Artisanal fishery & Mechanical clam harvesting





Downscaling GLOBAL effect to LOCAL scale



[1] high resolution regional climate model (RegCM)

rain

T, solar radiation, humidity

wind, pressure

rain

[2a] statistical model of nutrient input

[2b] statistical model of sea-lagoon boundaries

boundary conditions

boundary conditions

[3] biogeochemical model of the lagoon of Venice (TDM)

[4] scenarios analysis
RF: reference scenario [1961-1990]
A2, B2 future scenarios [2071-2100]

Downscaling and linking

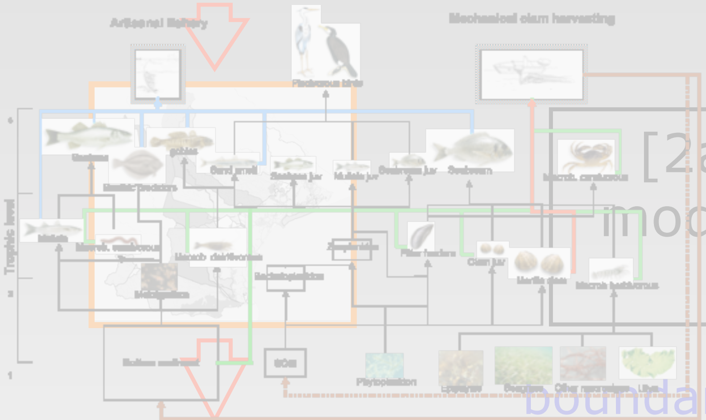
[1] high resolution regional climate model (RegCM)

rain

T, solar radiation, humidity

wind, pressure

rain



[2a] statistical model of nutrient input

boundary conditions

conditions

[3] biogeochemical model of the lagoon of Venice

Plankton productivity

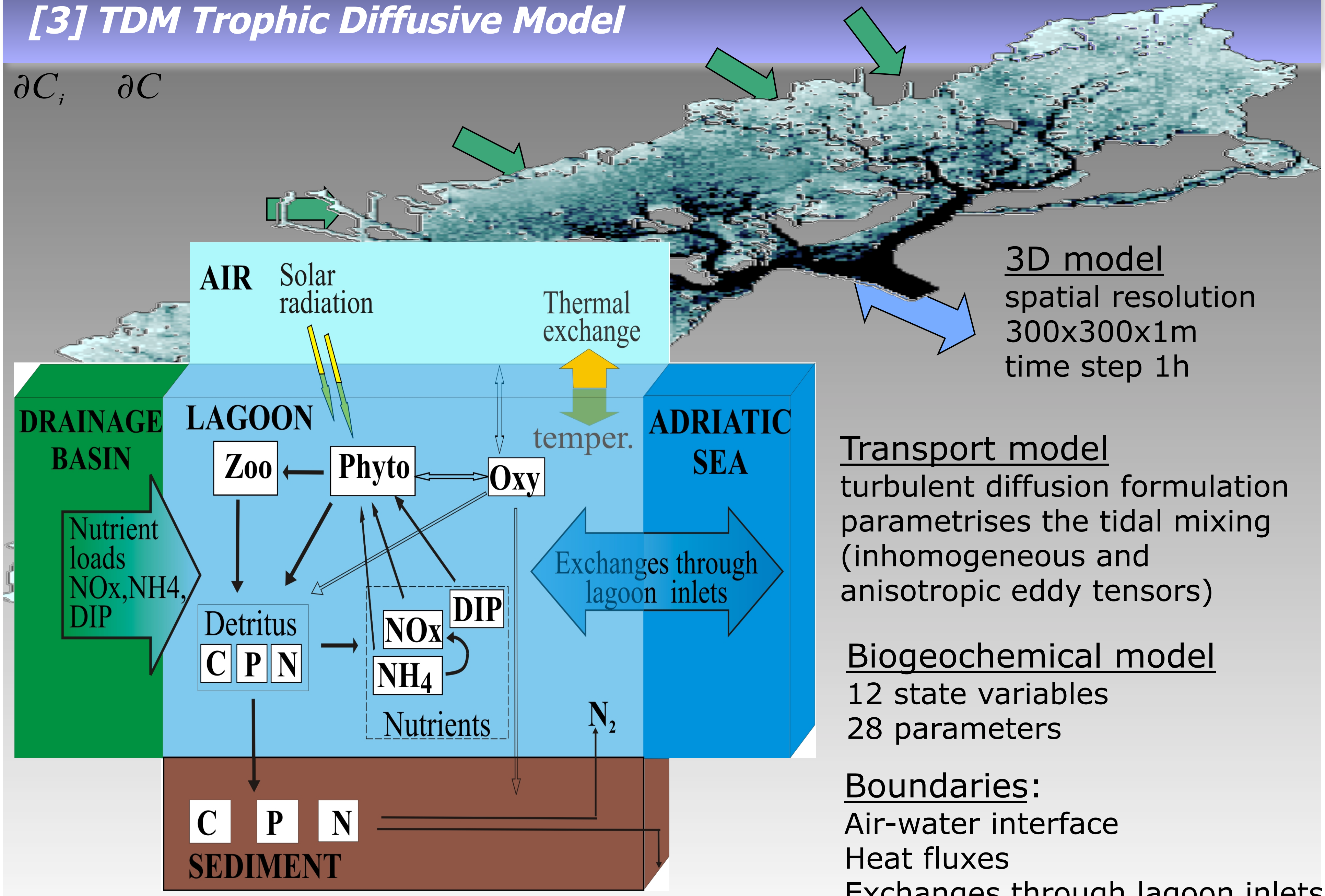
[4a] Food web model

[4b] Hab suit model

[4c] clam bioenerg model

[3] TDM Trophic Diffusive Model

$\partial C_i \quad \partial C$



Dejak et al.,1998; .. Solidoro et al., 2005 EcolMod

3D model
spatial resolution
300x300x1m
time step 1h

Transport model
turbulent diffusion formulation parametrises the tidal mixing (inhomogeneous and anisotropic eddy tensors)

Biogeochemical model
12 state variables
28 parameters

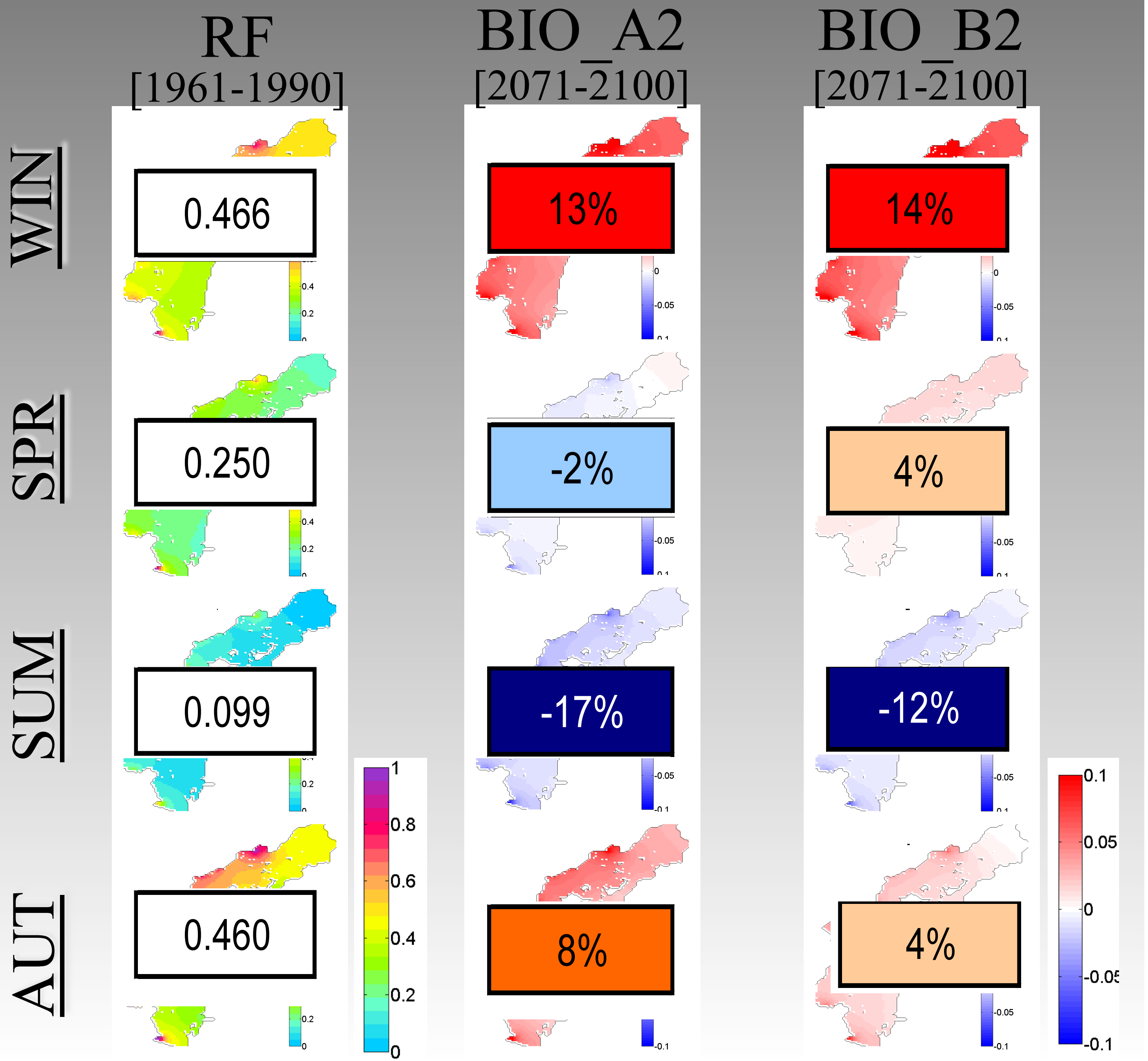
Boundaries:
Air-water interface
Heat fluxes
Exchanges through lagoon inlets
Nutrients loads

EFFECT ON BIOGEOCHEMISTRY

Scenarios of the Venice Lagoon biogeochemical processes

Seasonal averages (over 30 years)

DIN [mg/l]



Scenarios of the Venice Lagoon biogeochemical processes

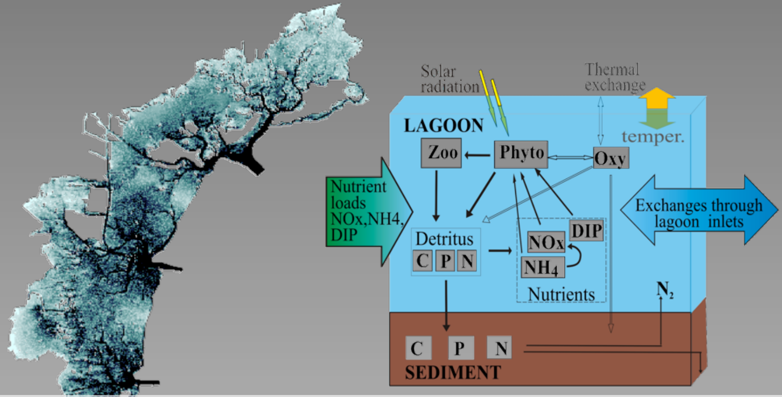
Seasonal averages & anomalies for state variables and fluxes

		INPUT N [tN/y]	DIN [mg/l]	P. PRI. [tN/y]	P. SEC. [tN/y]	PHYTO [mg/l]	ZOO [mg/l]	EXPORT TO THE SEA [tN/y]
BIO_RF	win	1304	0.466	1352	499	0.290	0.259	-988
	spr	1629	0.250	4412	1295	0.702	0.459	-1119
	sum	1290	0.099	4712	1135	0.924	0.348	-806
	aut	1710	0.460	1507	509	0.292	0.269	-1325
BIO_A2	win	12%	13%	-2%	0%	-2%	0%	13%
	spr	-4%	-2%	0%	1%	-1%	2%	1%
	sum	-9%	-17%	-6%	-13%	-3%	-13%	-11%
	aut	8%	8%	2%	3%	1%	2%	7%
BIO_B2	win	15%	14%	0%	2%	0%	3%	14%
	spr	-1%	4%	3%	5%	0%	6%	7%
	sum	-6%	-12%	-3%	-10%	0%	-11%	-5%
	aut	6%	4%	1%	2%	0%	2%	0%

<-10% | -10%<x<-5% | -5%<x<-1% | -1%<x<1% | 1%<x<5% | 5%<x<10% | x>10%

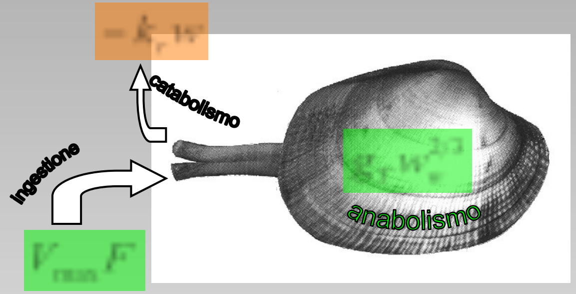
EFFECT ON CLAM
integrated bioenergetic model (dynamic 2D)

Focus on Manila clam for its economic importance



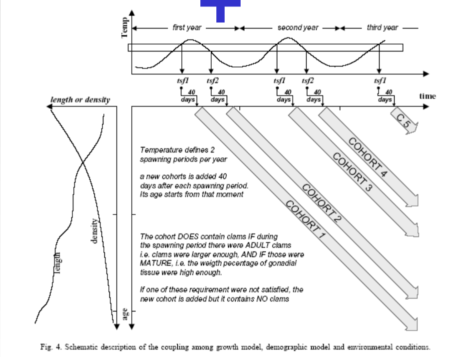
Biogeochemical model (TDM)

+



Bioenergetic clam model

+



Temperature defines 2 spawning periods per year

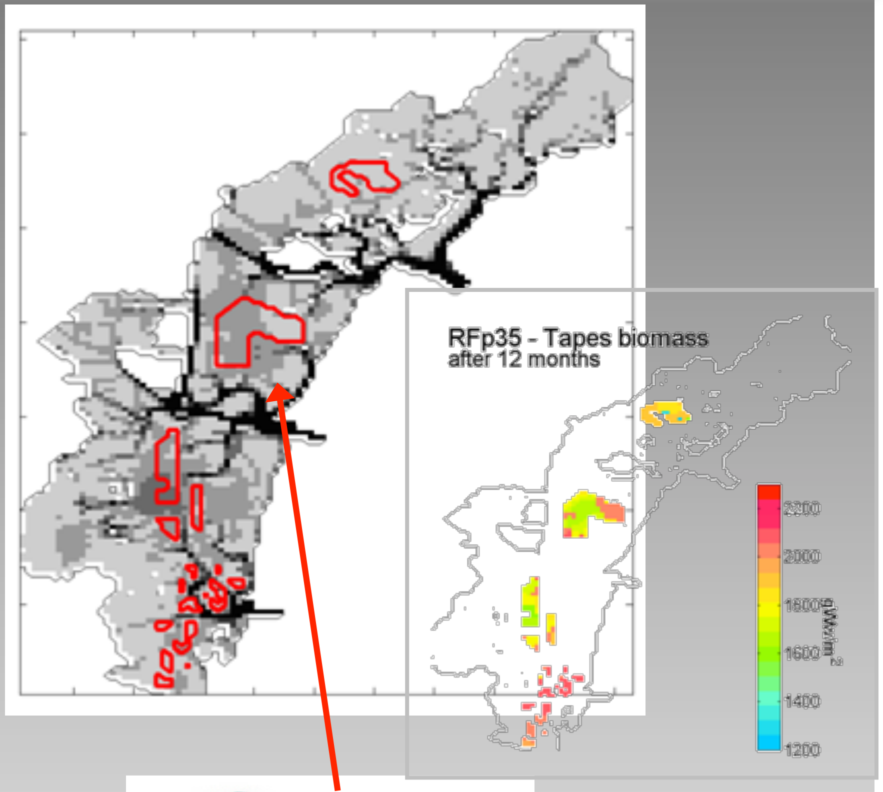
a new cohorts is added 40 days after each spawning period. Its age starts from that moment

The cohort DOES contain clams IF during the spawning period there were ADULT clams i.e. clams were larger enough, AND IF those were MATURE, i.e. the weigth pecentage of gonadial tissue were high enough.

If one of these requirement were not satisfied, the new cohort is added but it contains NO clams

Fig. 4. Schematic description of the coupling among growth model, demographic model and environmental conditions.

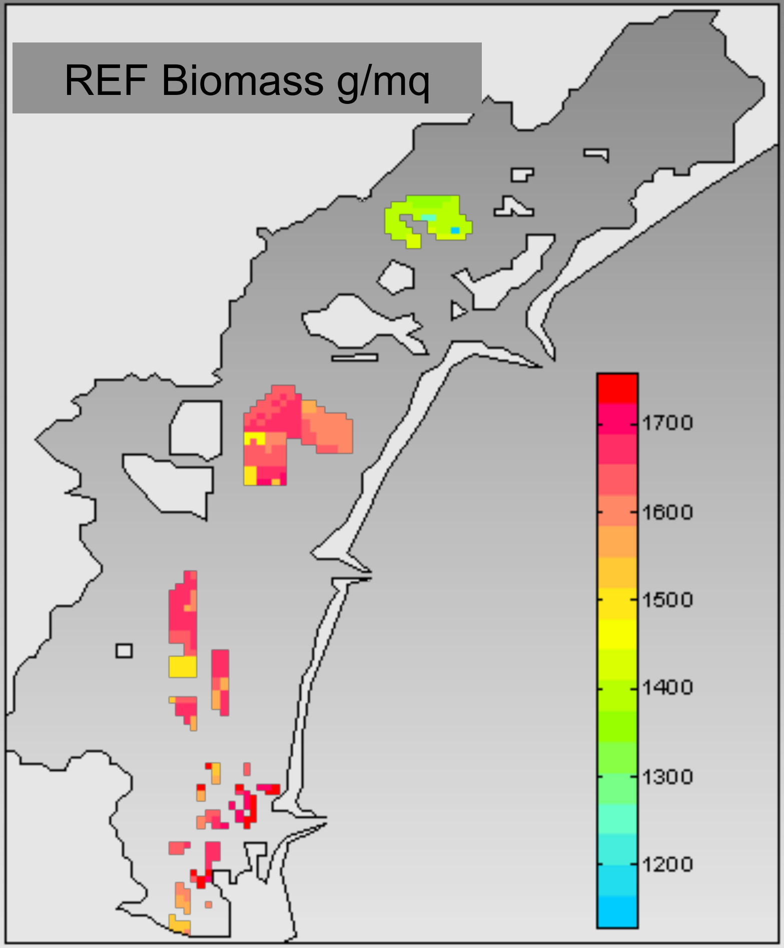
Demographic clam model

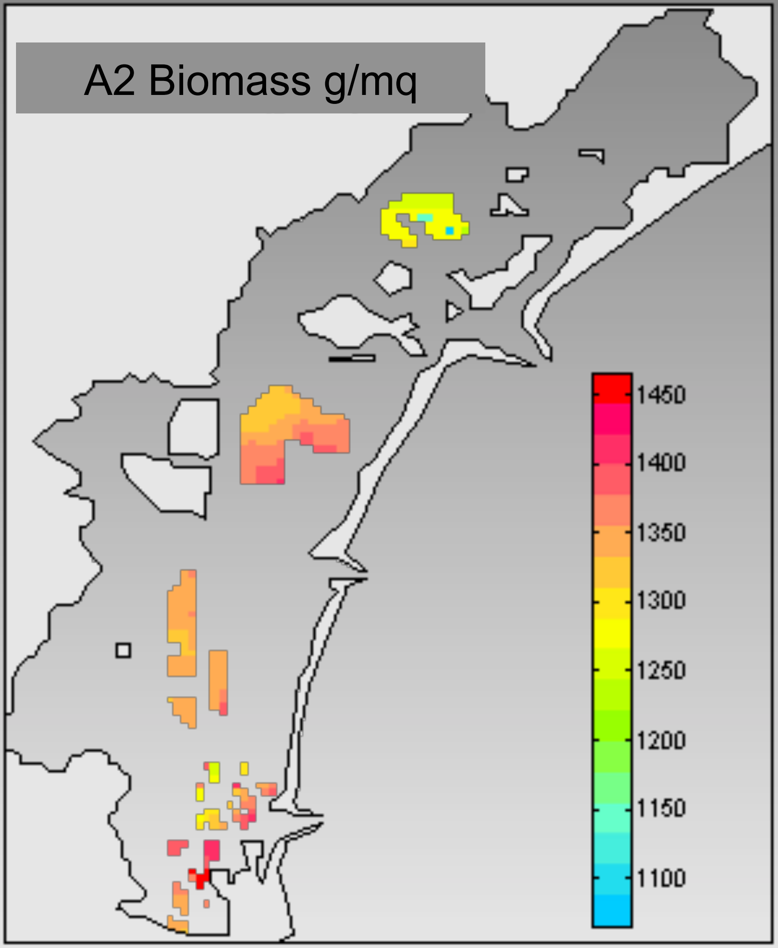


seeding specimen in controlled areas (areas defined for extensive clam aquaculture)

Solidoro et al 2000, 2003 Pastres et al 2001

Comparison REF /A2 scenarios





Tapes philippinarum annual production

BIOMASS
-20%

Conmclusion: all models agree in the indication of a reduced suitability for clam under future scenarios

‘It’s very difficult to make predictions, especially about the future!’