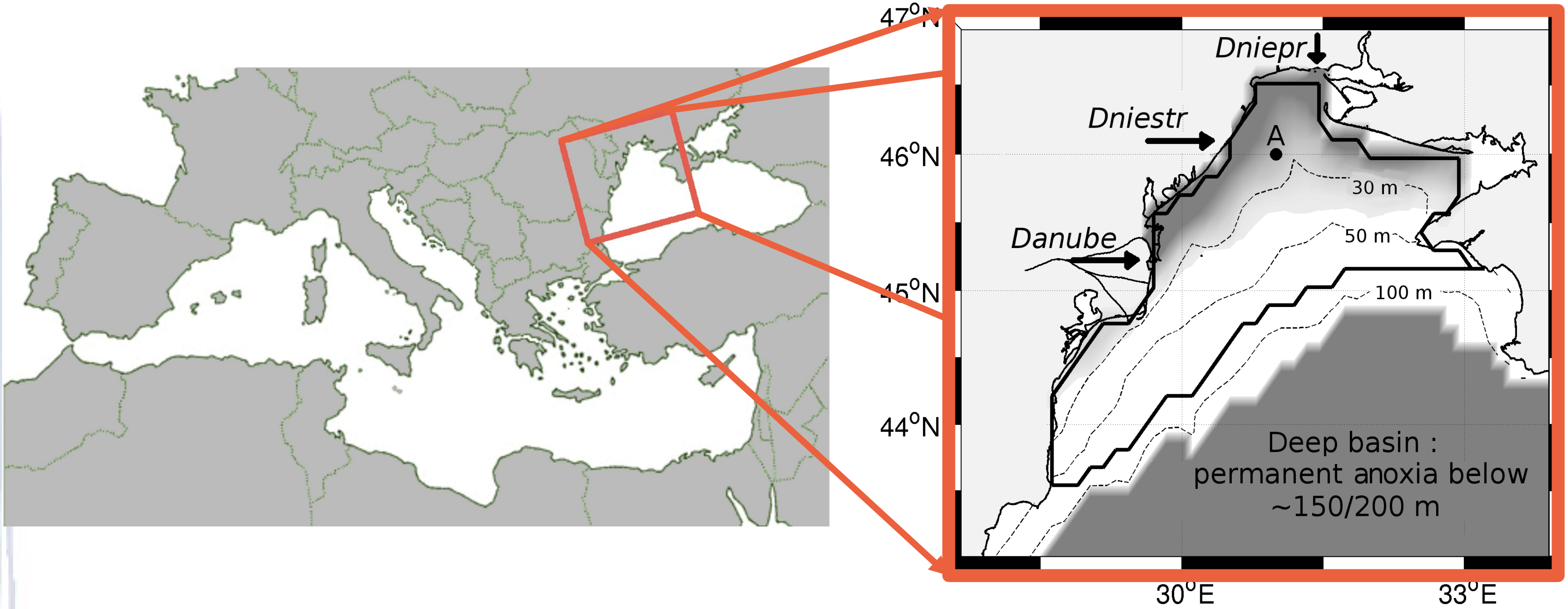
Arthur Capet, Jean-Marie Beckers, Marilaure Grégoire

From Scylla to Charybdis: **Eutrophication** and **climatic** drivers of hypoxia in the Black Sea northwestern Shelf



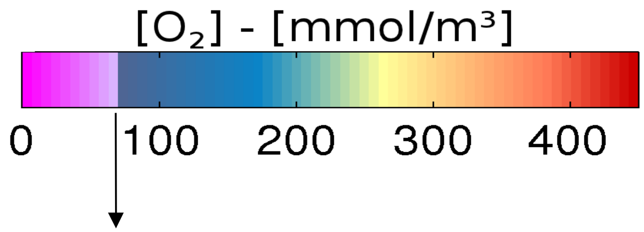
PERSEUS
POLICY-ORIENTED MARINE ENVIRONMENTAL RESEARCH IN THE SOUTHERN EUROPEAN SEAS

MARE
INTERFACULTARY CENTER FOR MARINE RESEARCH - LIEGE UNIVERSITY

GHER
GeoHydrodynamics and Environment Research

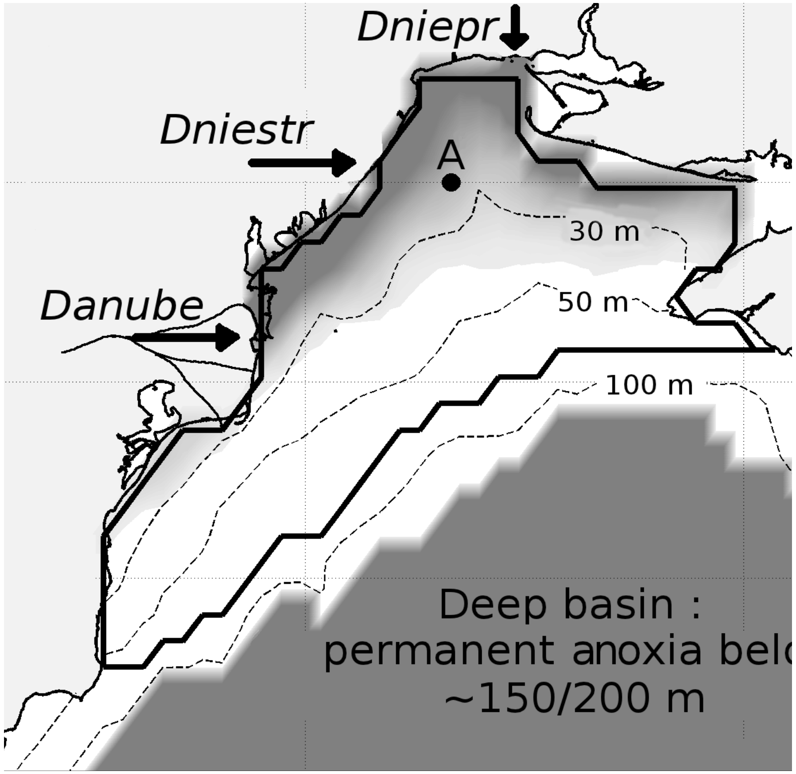
Université de Liège

What is hypoxia ?

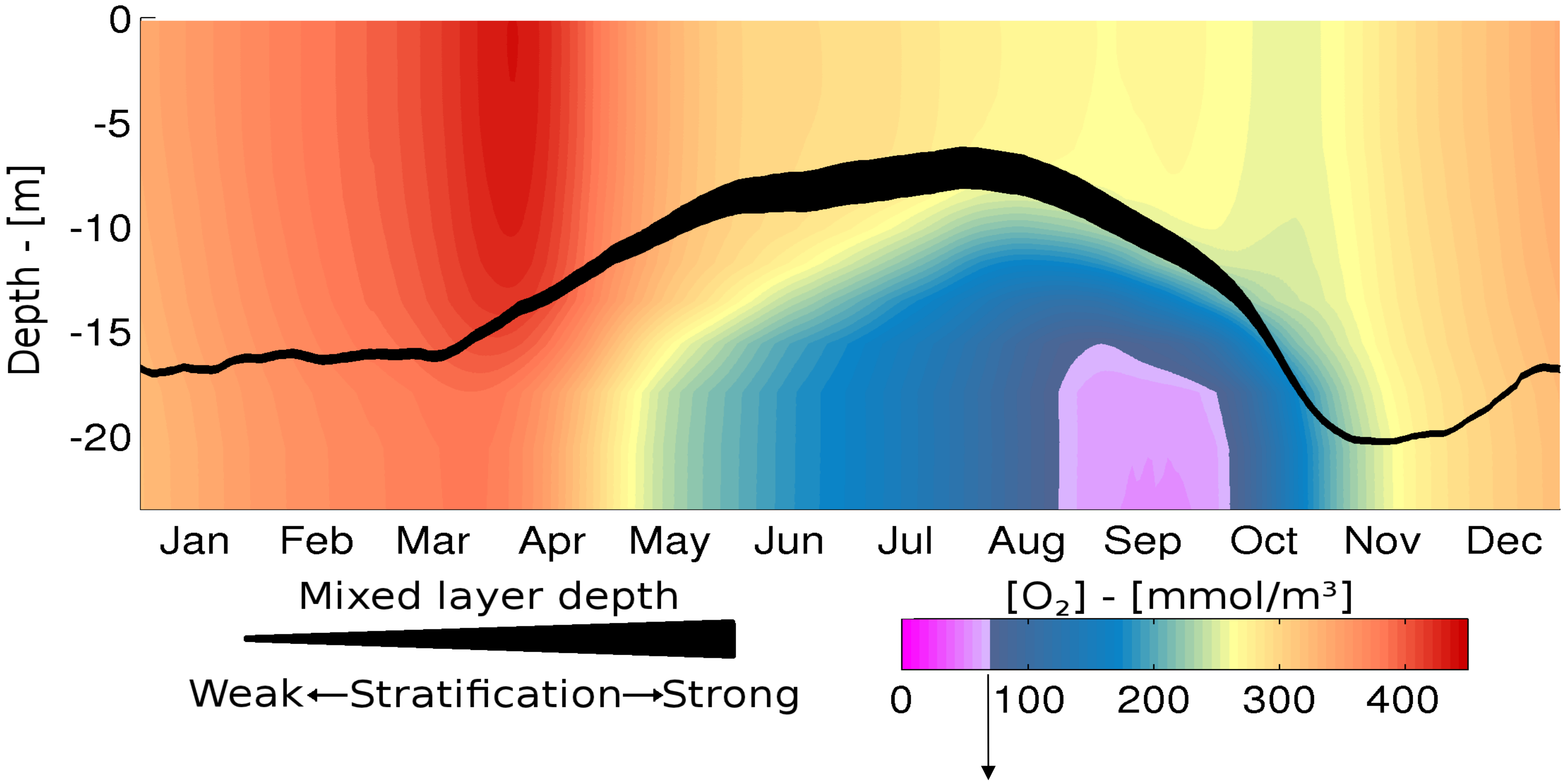


Hypoxic thresold : [O_2] < **62 mmol/m^3 (2 mg/l)**

Why does hypoxia occurs ?


Dniepr
Dniestr
A
30 m
Danube
50 m
100 m
Deep basin :
permanent anoxia belo
~150/200 m

Seasonal Hypoxia



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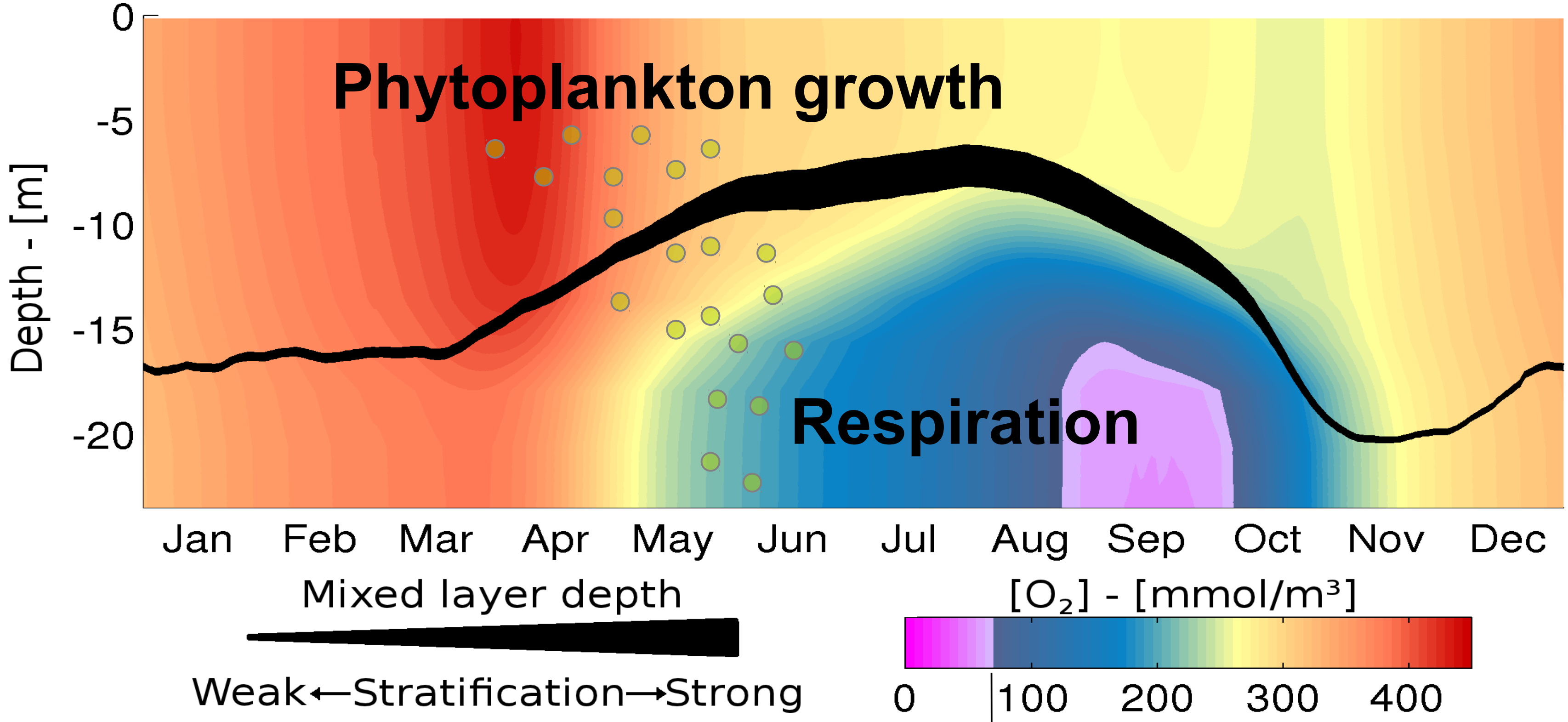
Seasonal Hypoxia



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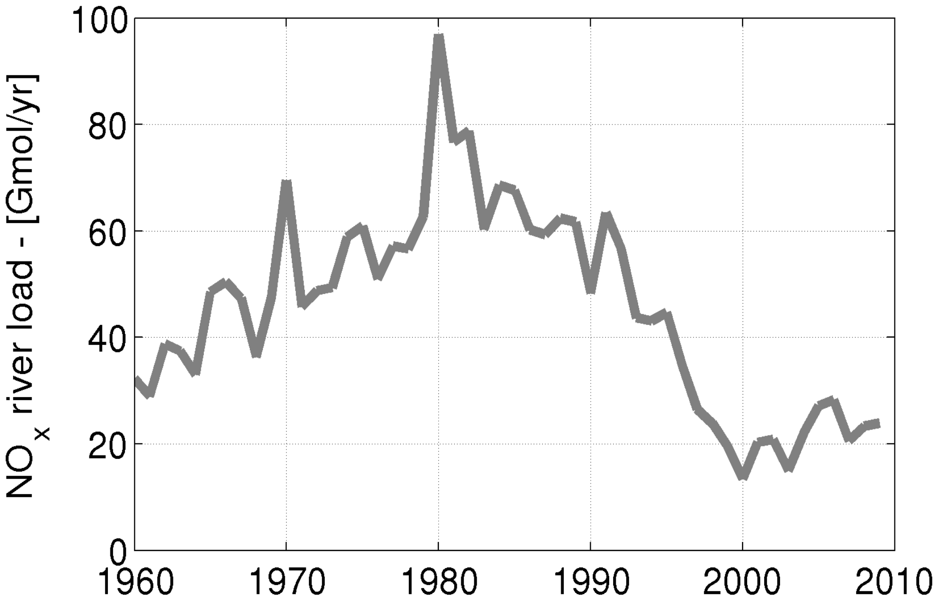
Seasonal Hypoxia in the BS-NWS



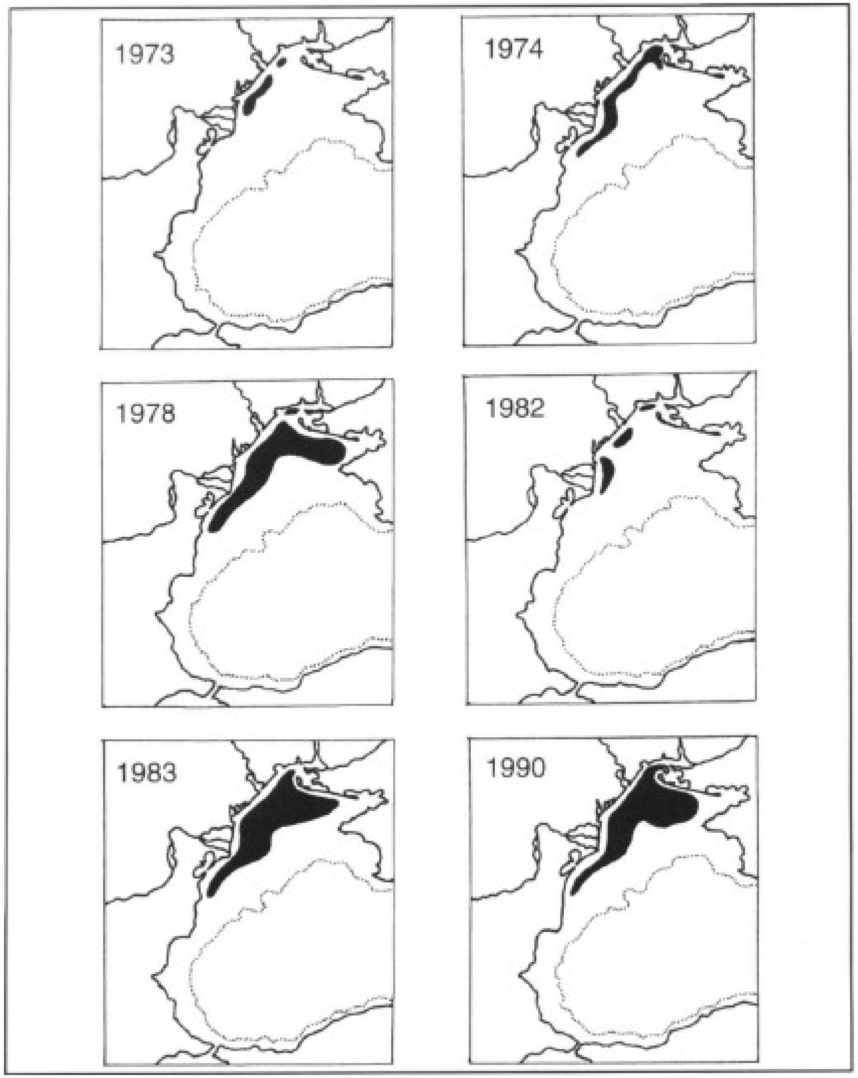
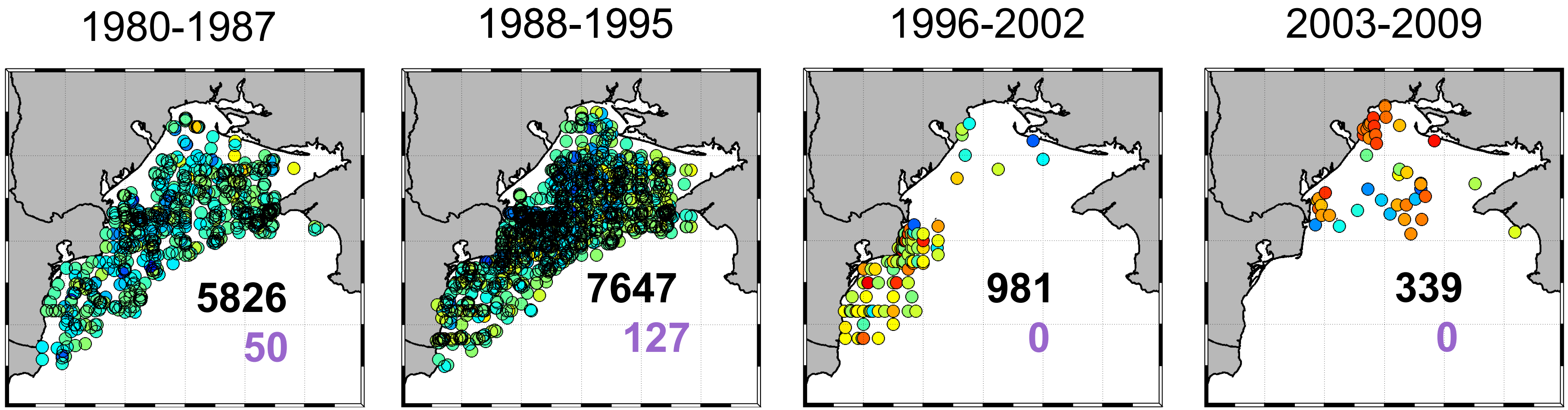


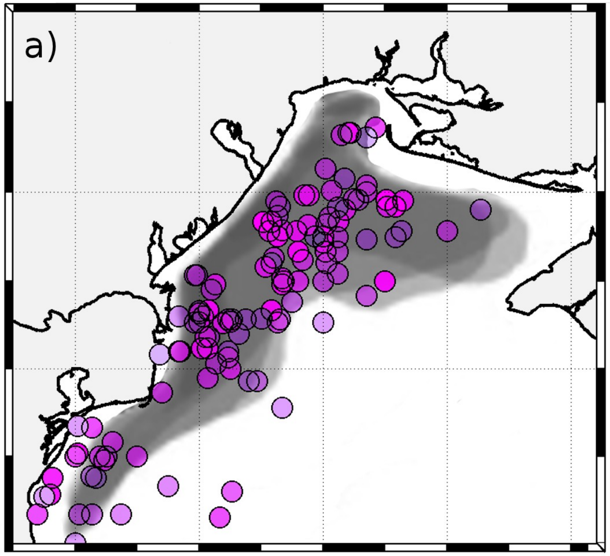
Fig 15. Expansion of seasonal hypoxic and anoxic zones on the north-western shelf (from Zaitsev, 1992(a)).

Recovery ?


1980-1987 1988-1995 1996-2002 2003-2009

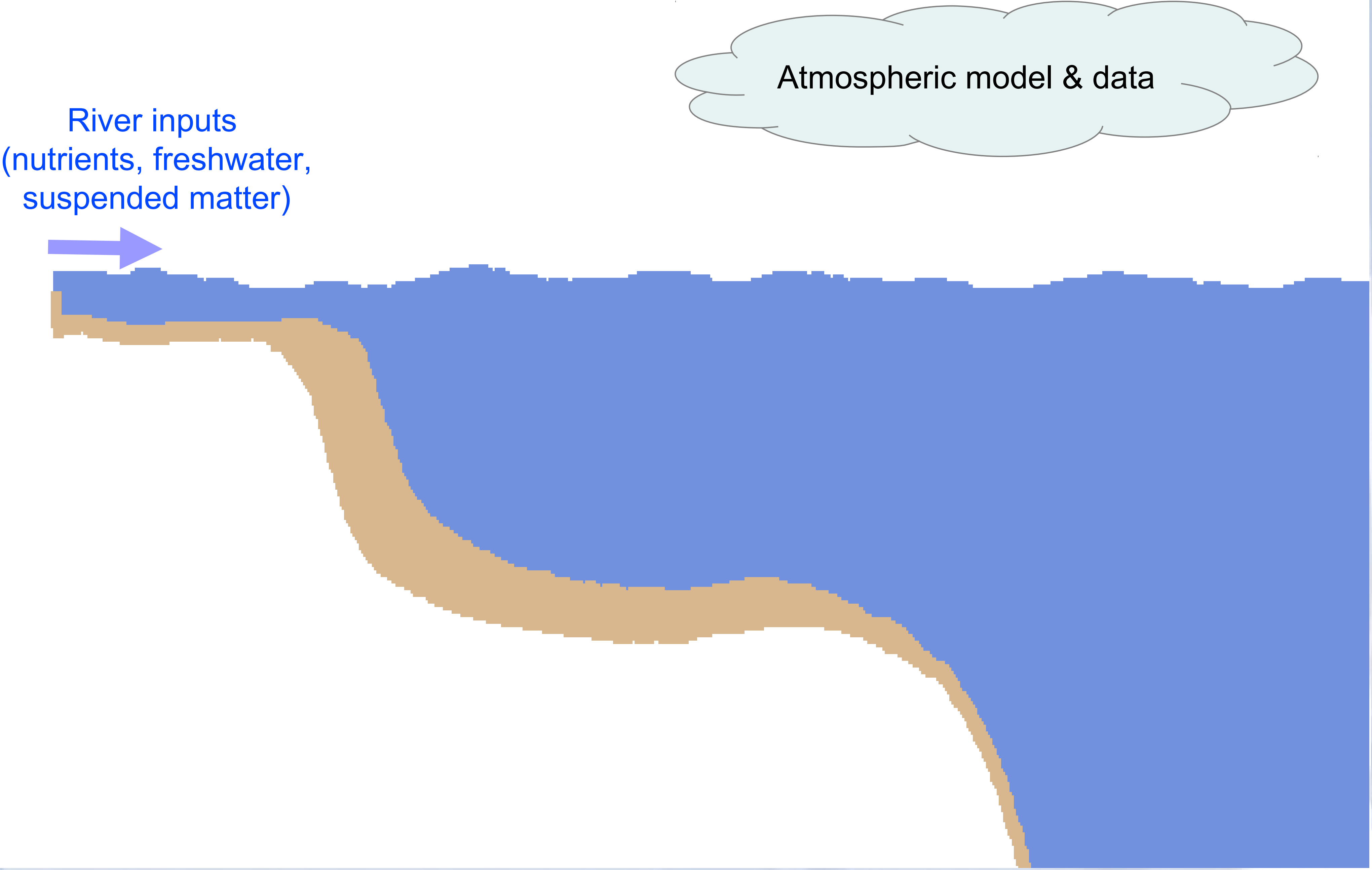
Oxygen records
(World ocean atlas, Seadatanet, Black Sea Comission data)

Hypoxic records
(<62 mmol O/m³)



Studying Hypoxia with a 3D model

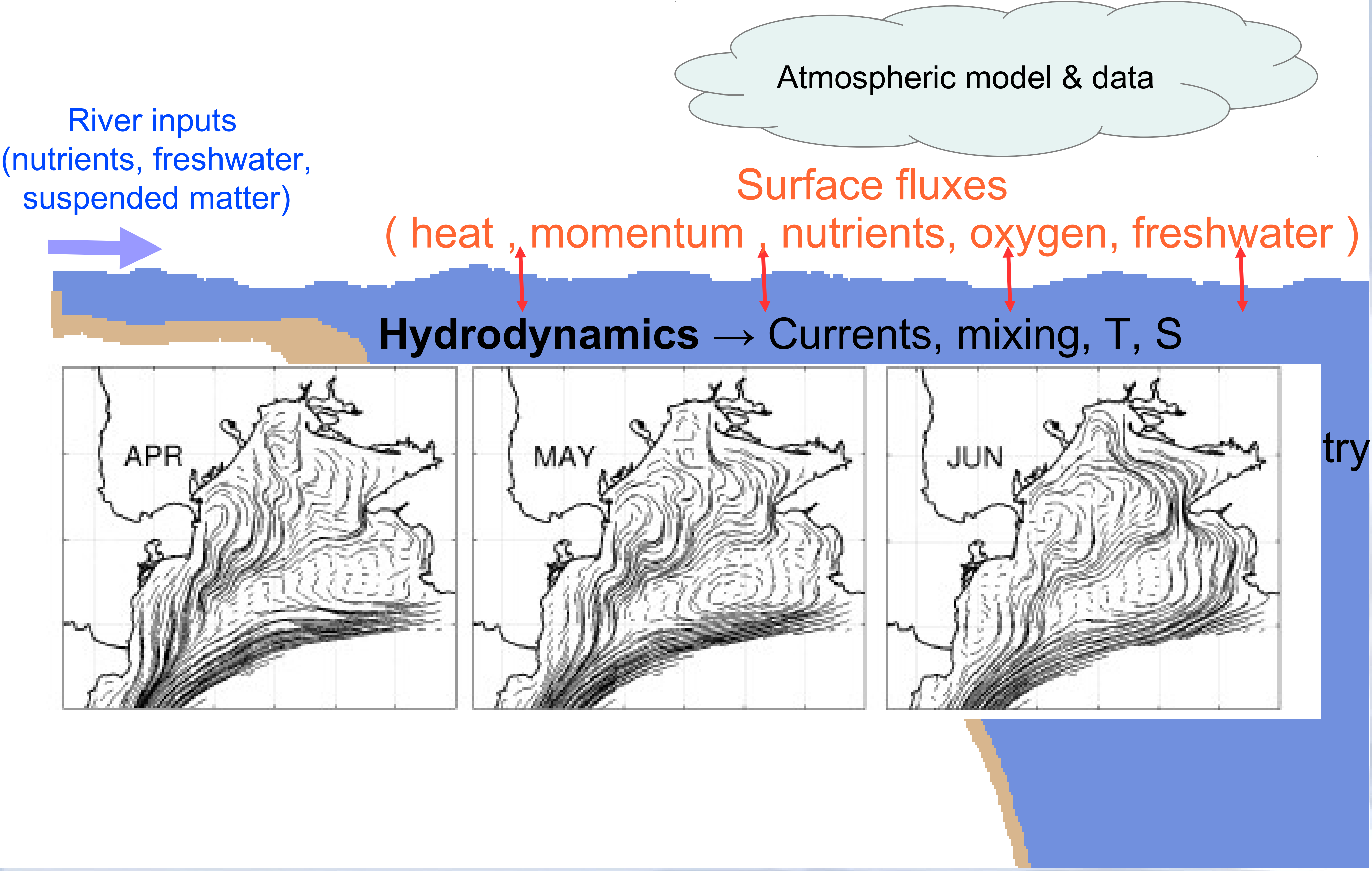
GHER 3D biogeochemical model



Atmospheric model & data

River inputs
(nutrients, freshwater,
suspended matter)

GHER 3D biogeochemical model



Atmospheric model & data

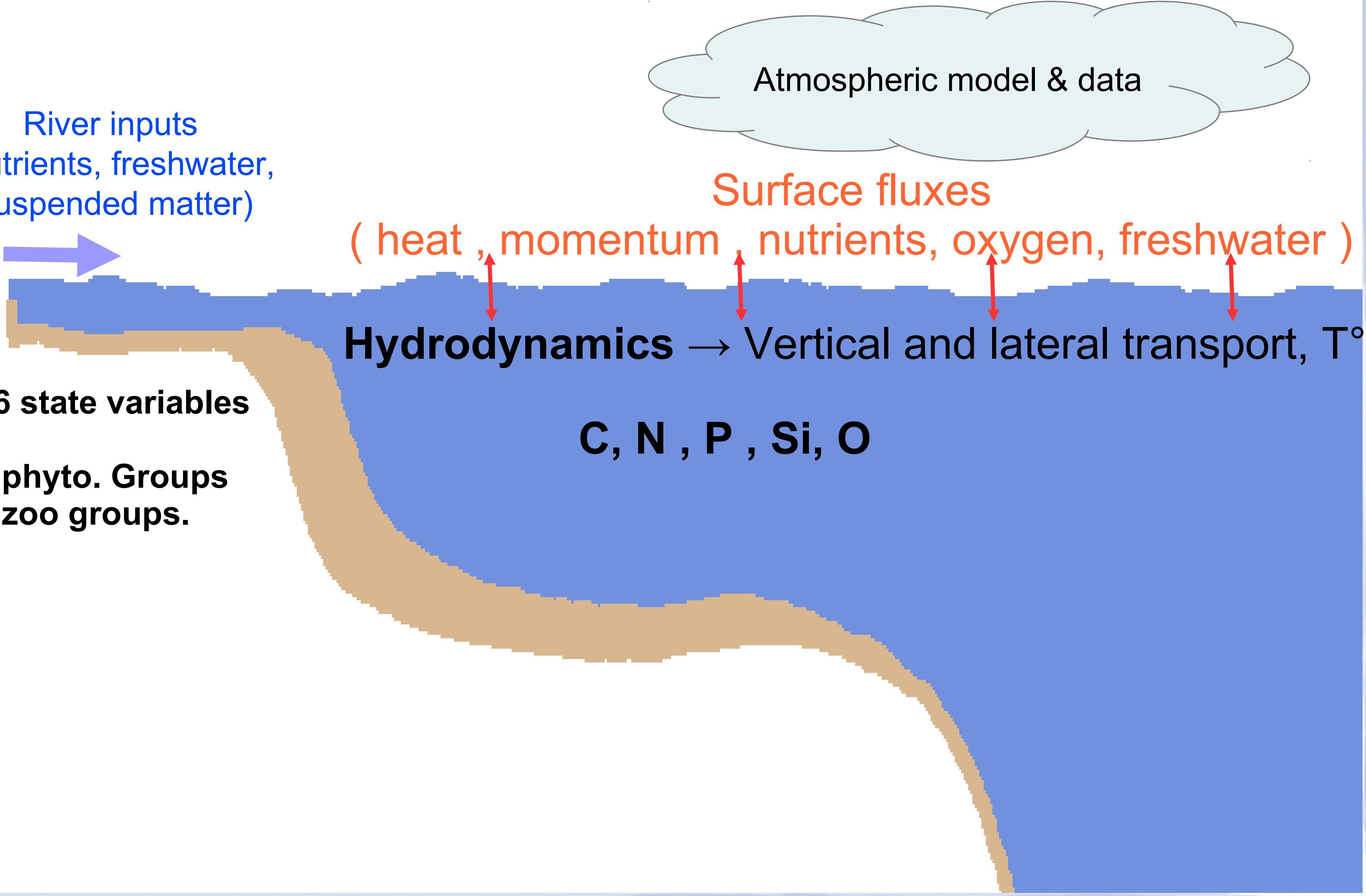
River inputs
(nutrients, freshwater,
suspended matter)

Surface fluxes
(heat , momentum , nutrients, oxygen, freshwater)

Hydrodynamics → Currents, mixing, T, S

try

GHER 3D biogeochemical model



Atmospheric model & data

River inputs
(nutrients, freshwater,
suspended matter)

Surface fluxes
(heat , momentum , nutrients, oxygen, freshwater)

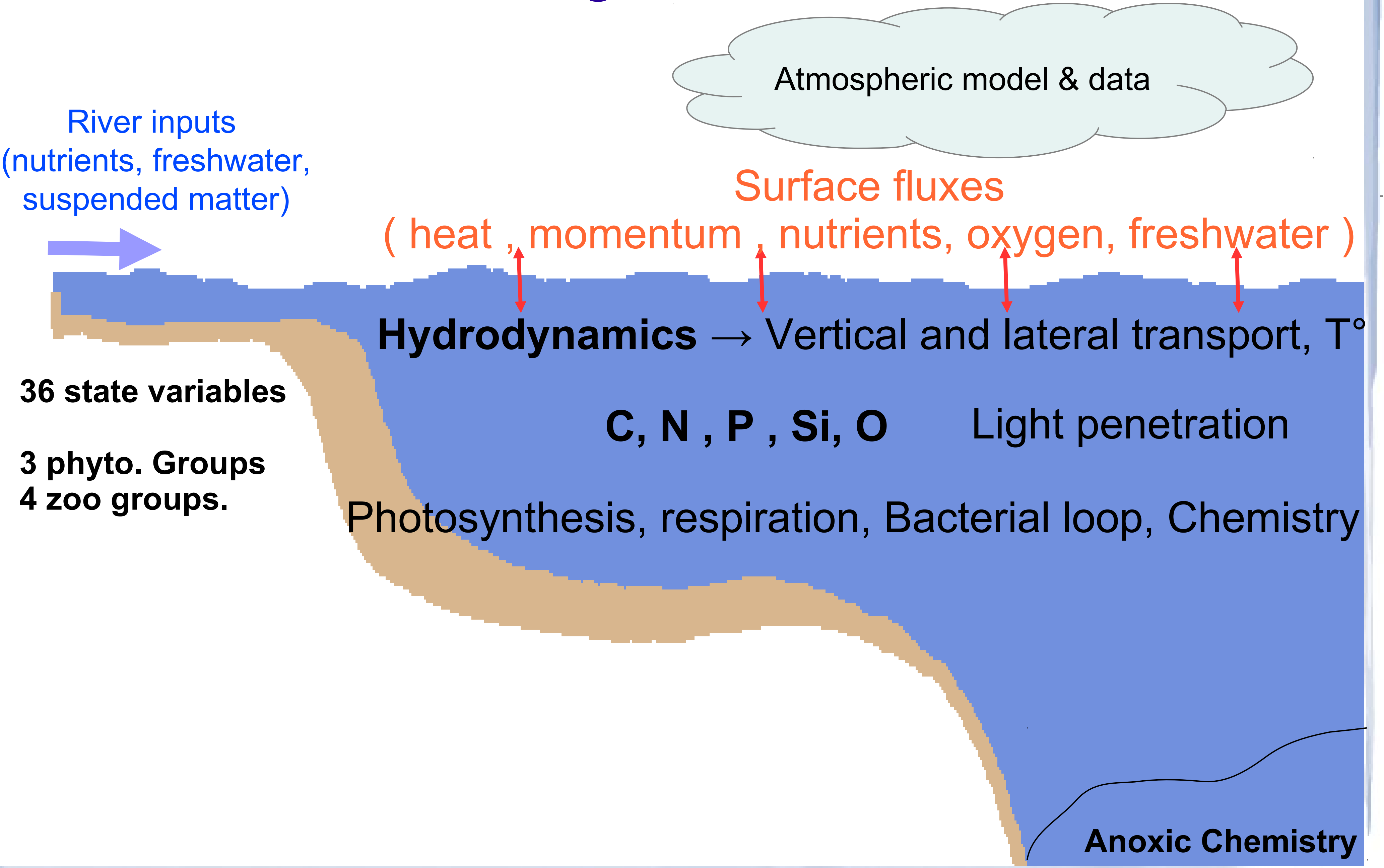
Hydrodynamics → Vertical and lateral transport, T°

36 state variables

3 phyto. Groups
4 zoo groups.

C, N , P , Si, O

GHER 3D biogeochemical model



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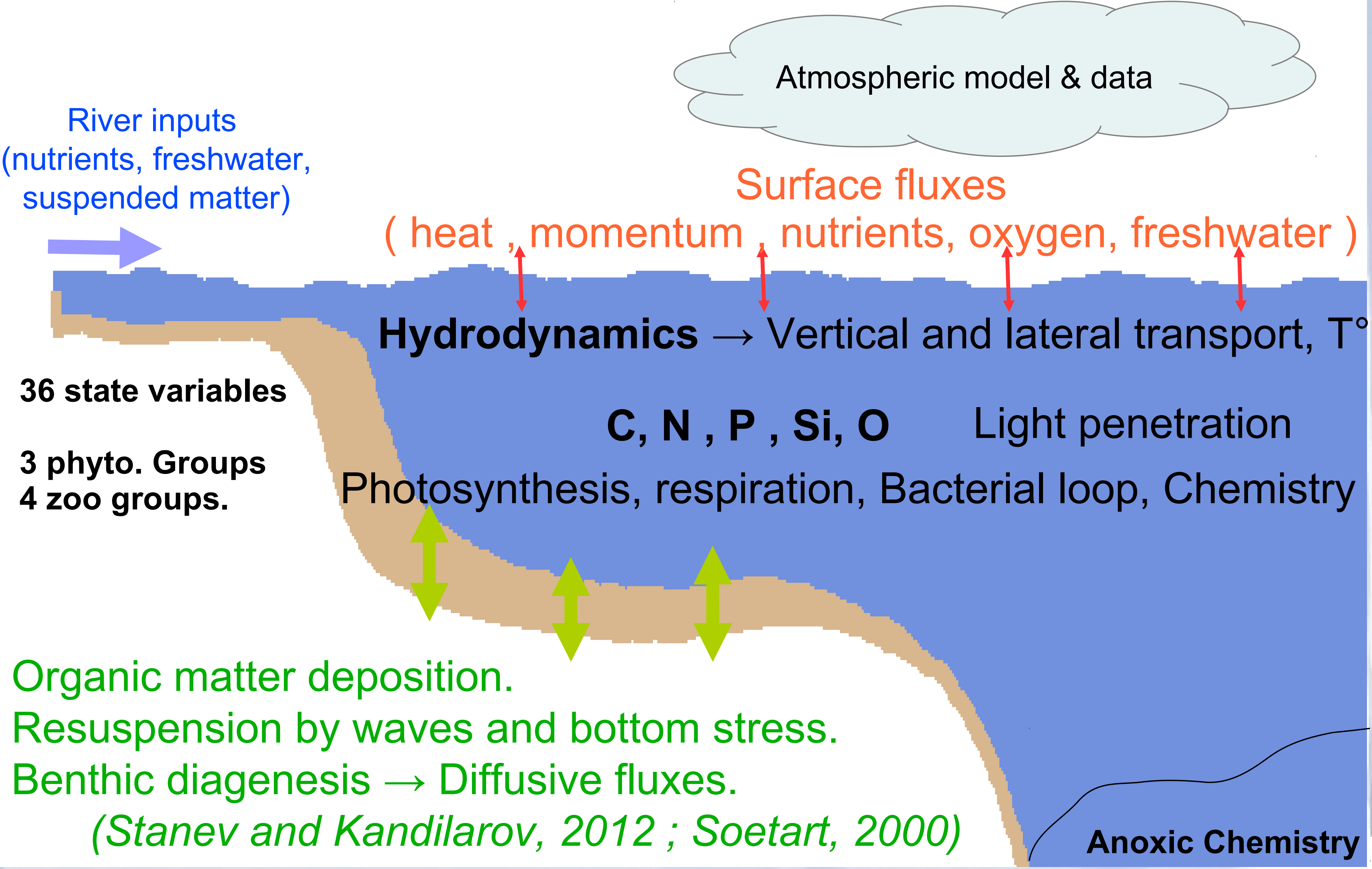
Light penetration

Photosynthesis, respiration, Bacterial loop, Chemistry

Anoxic Chemistry

GHER 3D biogeochemical model



Atmospheric model & data

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(nutrients, freshwater,
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Surface fluxes
(heat , momentum , nutrients, oxygen, freshwater)

Hydrodynamics → Vertical and lateral transport, T°

36 state variables

C, N , P , Si, O Light penetration

3 phyto. Groups
4 zoo groups.

Photosynthesis, respiration, Bacterial loop, Chemistry

Organic matter deposition.
Resuspension by waves and bottom stress.
Benthic diagenesis → Diffusive fluxes.
(Stanev and Kandilarov, 2012 ; Soetart, 2000)

Anoxic Chemistry

Model validation

Does the model adequatly resolves ...

the horizontal distribution

the seasonal distribution

the interannual distribution

the vertical distribution

the specific occurrence of hypoxia

... reflected by in situ observations ?

Model validation

Does the model adequatly resolves ...

the horizontal distribution

the seasonal distribution

the interannual distribution

the vertical distribution

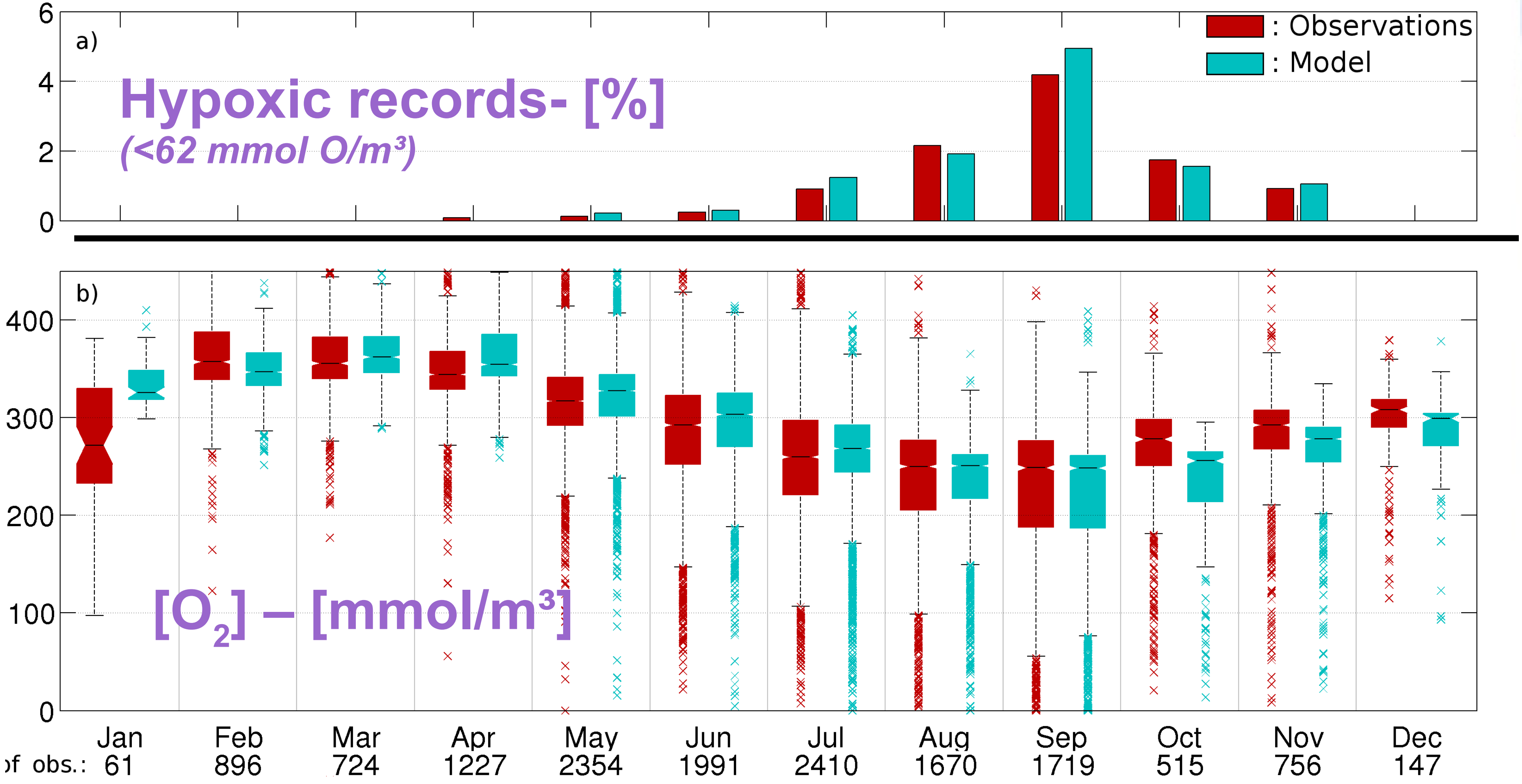
the specific occurrence of hypoxia

... reflected by in situ observations ?

Yes , yes , yes, yes and yes

Model Validation : Point-to-point

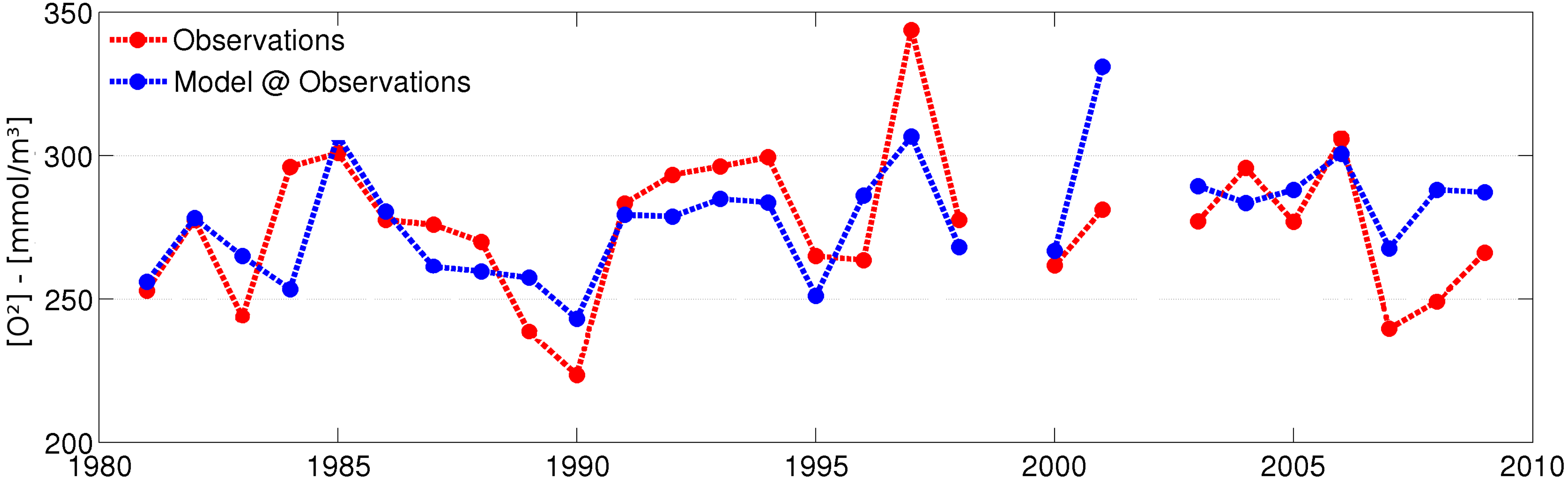
Merged by months → validation of the seasonal cycle


Hypoxic records- [%]

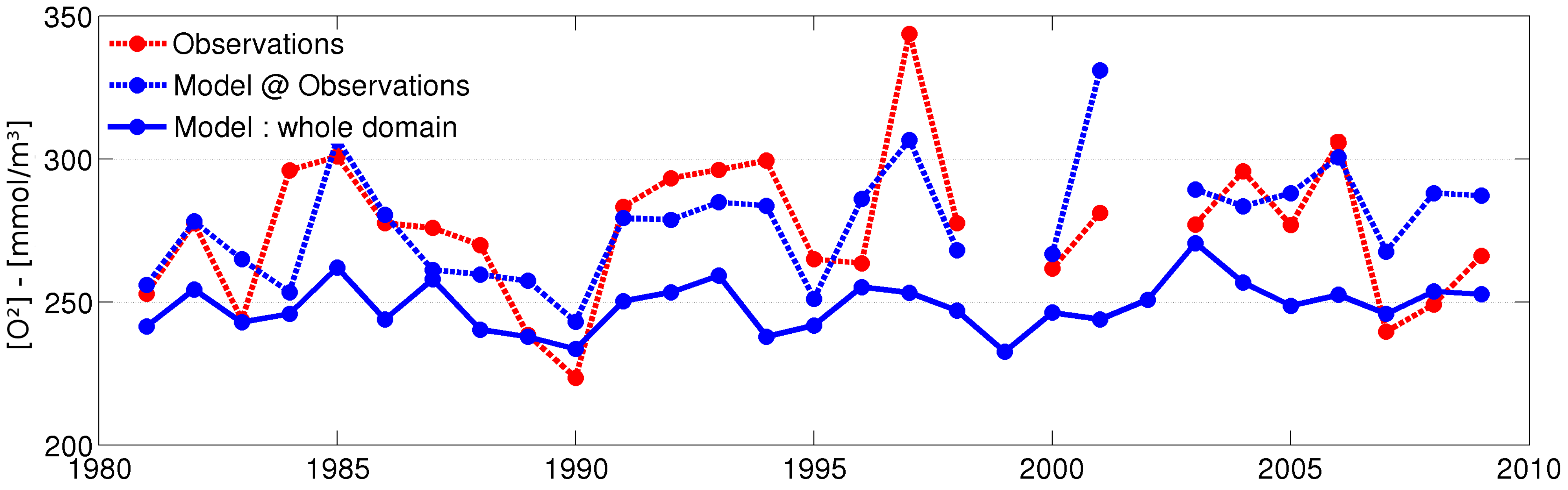
(<62 mmol O/m³)

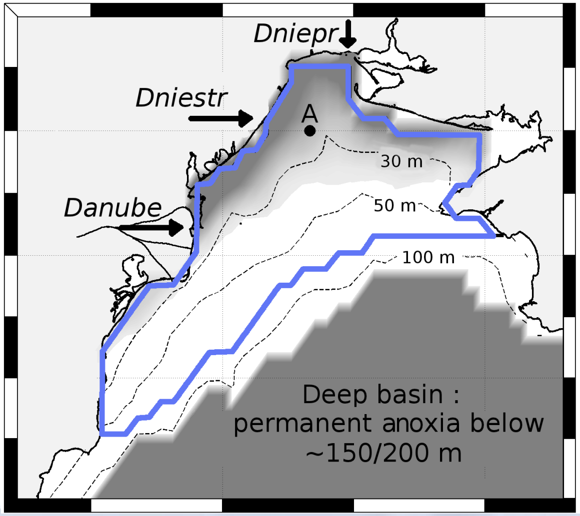
[O_2] – [mmol/m³]

Interannual variability

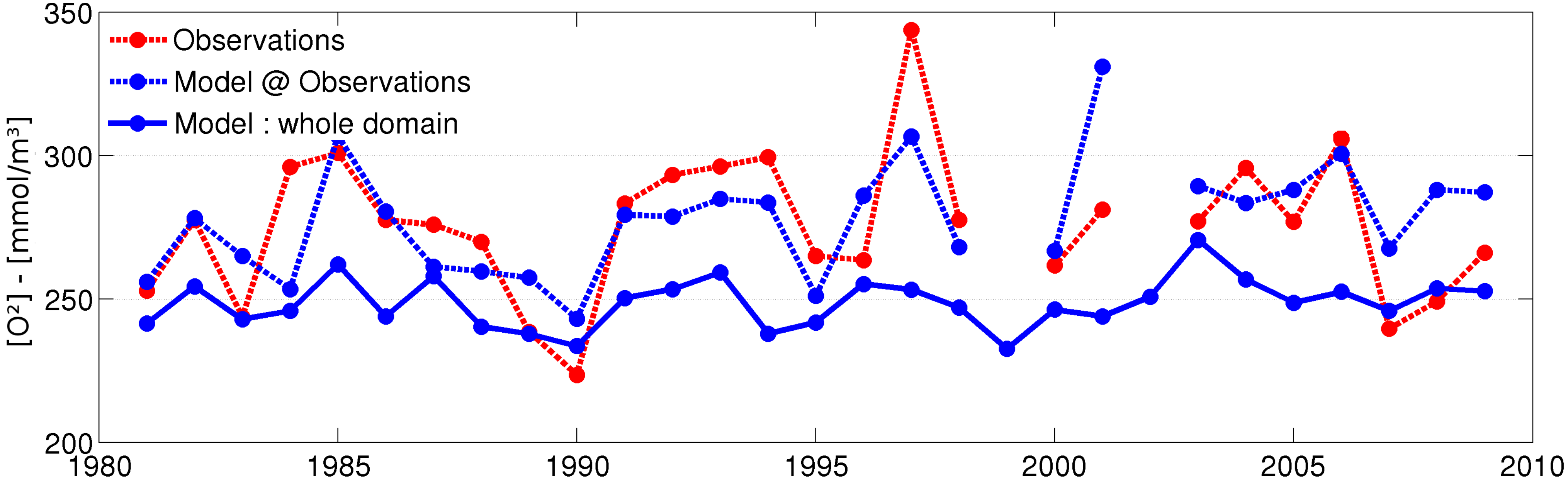


Interannual

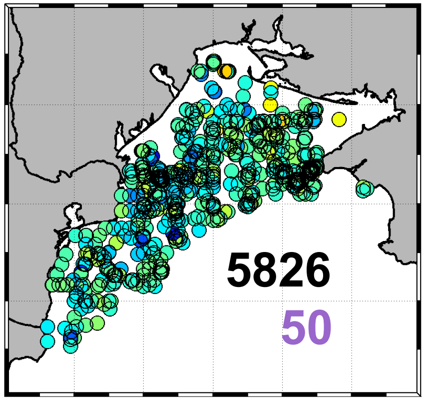




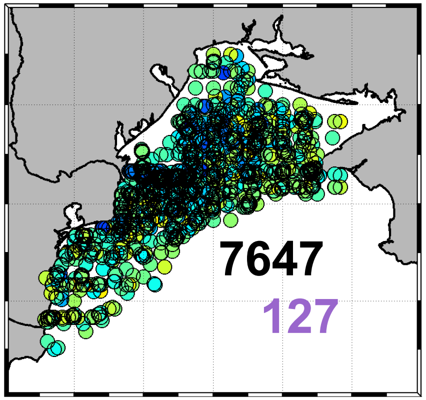
Interannual



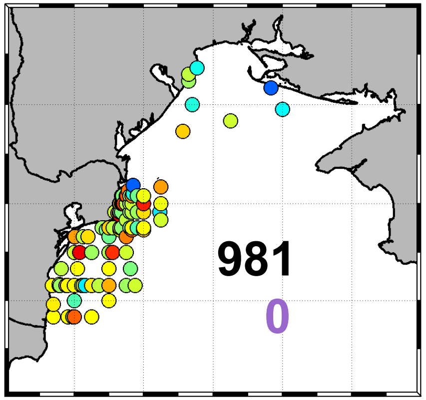
1980-1987



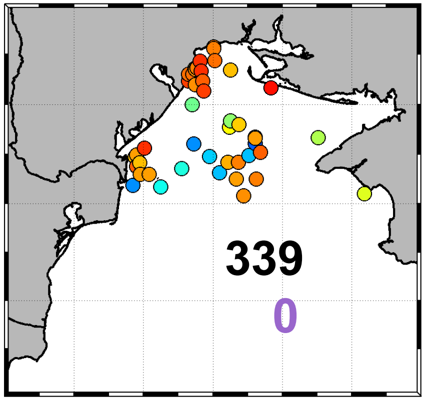
1988-1995



1996-2002



2003-2009



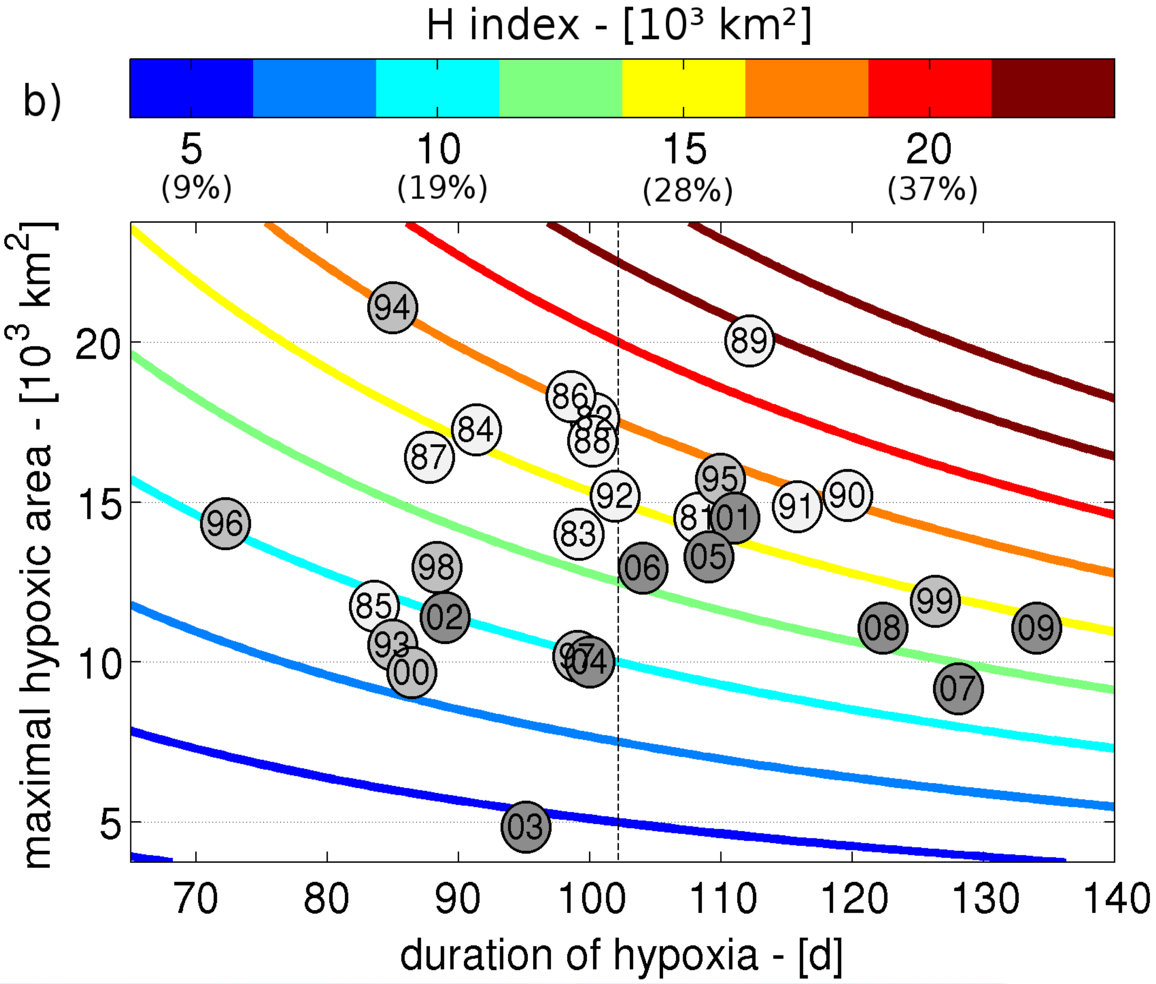
Interannual variability

The H-index

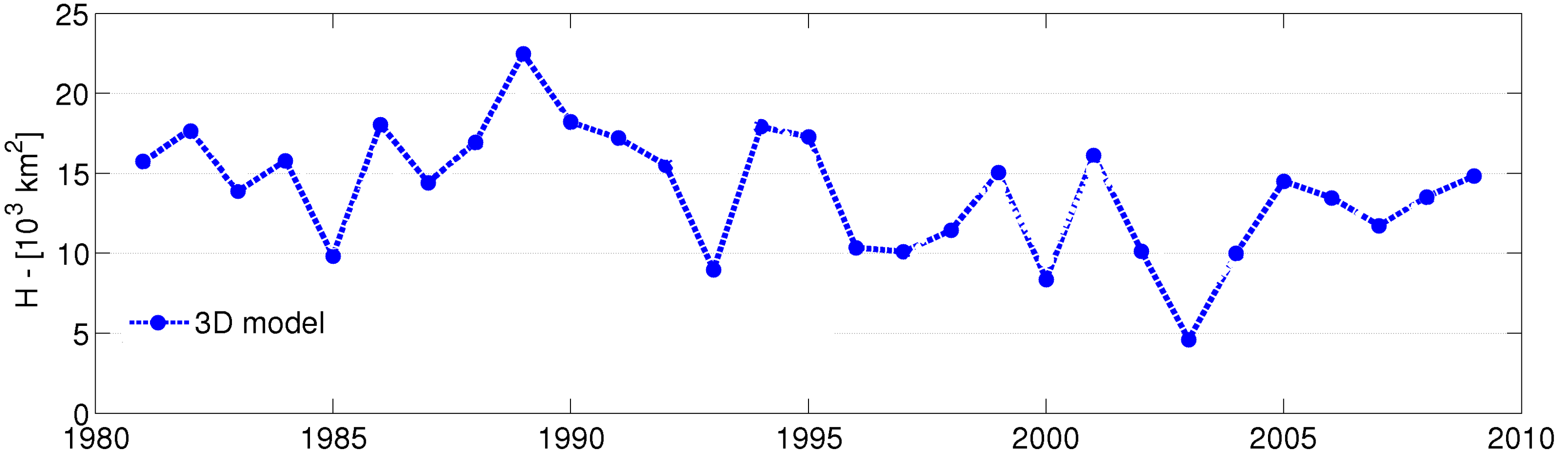
An Index to quantify the intensity of hypoxia as an environmental pressure on ecosystems

The H-index express
the spatial extension
of hypoxia..

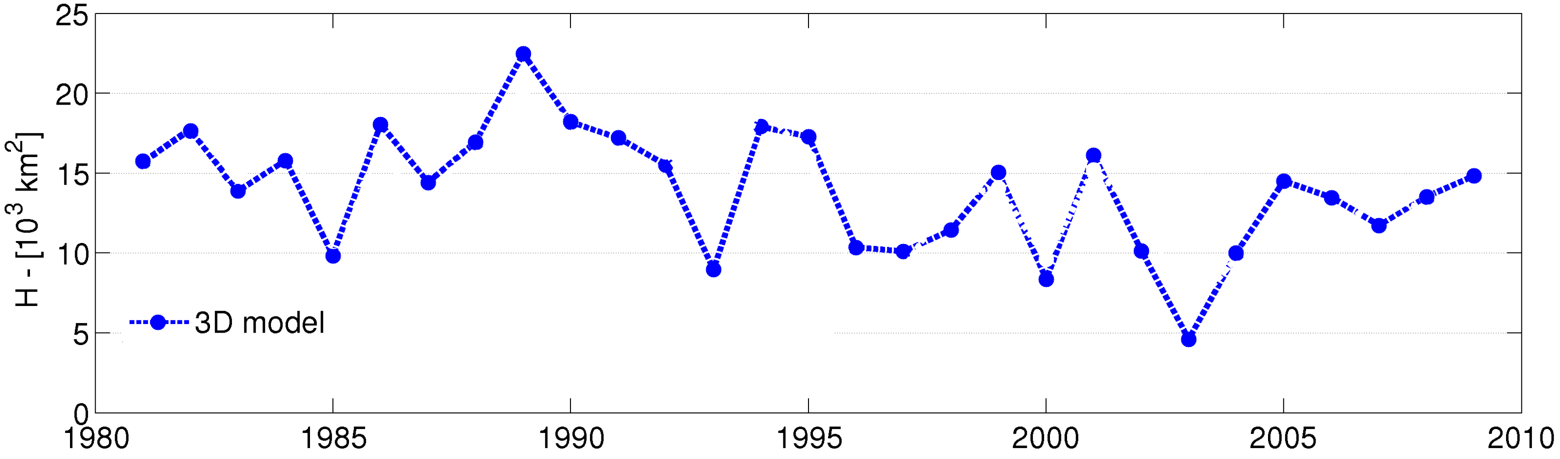
.. modulated by the
duration of hypoxia



Interannual variability of Hypoxia

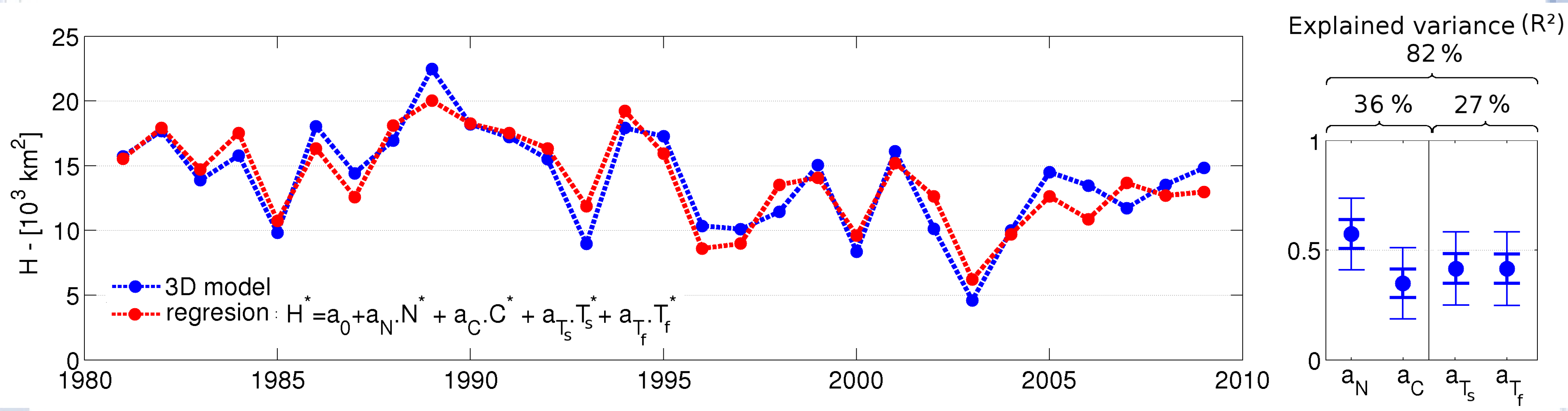


Interannual variability of Hypoxia



What are the drivers of this interannual variability ?

Interannual variability of Hypoxia



Eutrophication **and** **climate**

(1) High nitrogen riverine discharge.

(2) High sedimentary organic carbon content.

(3) Warm springs.

(4) Warm summers.

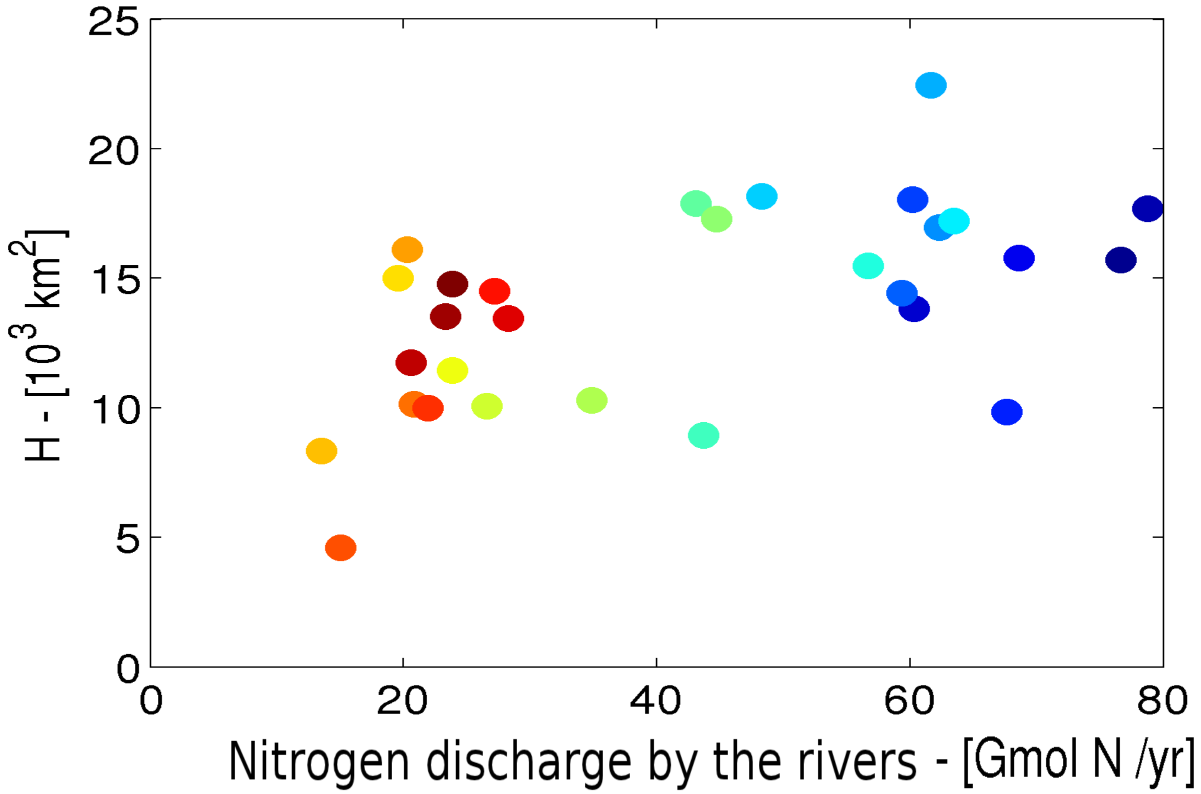
36 %

27 %

82 %

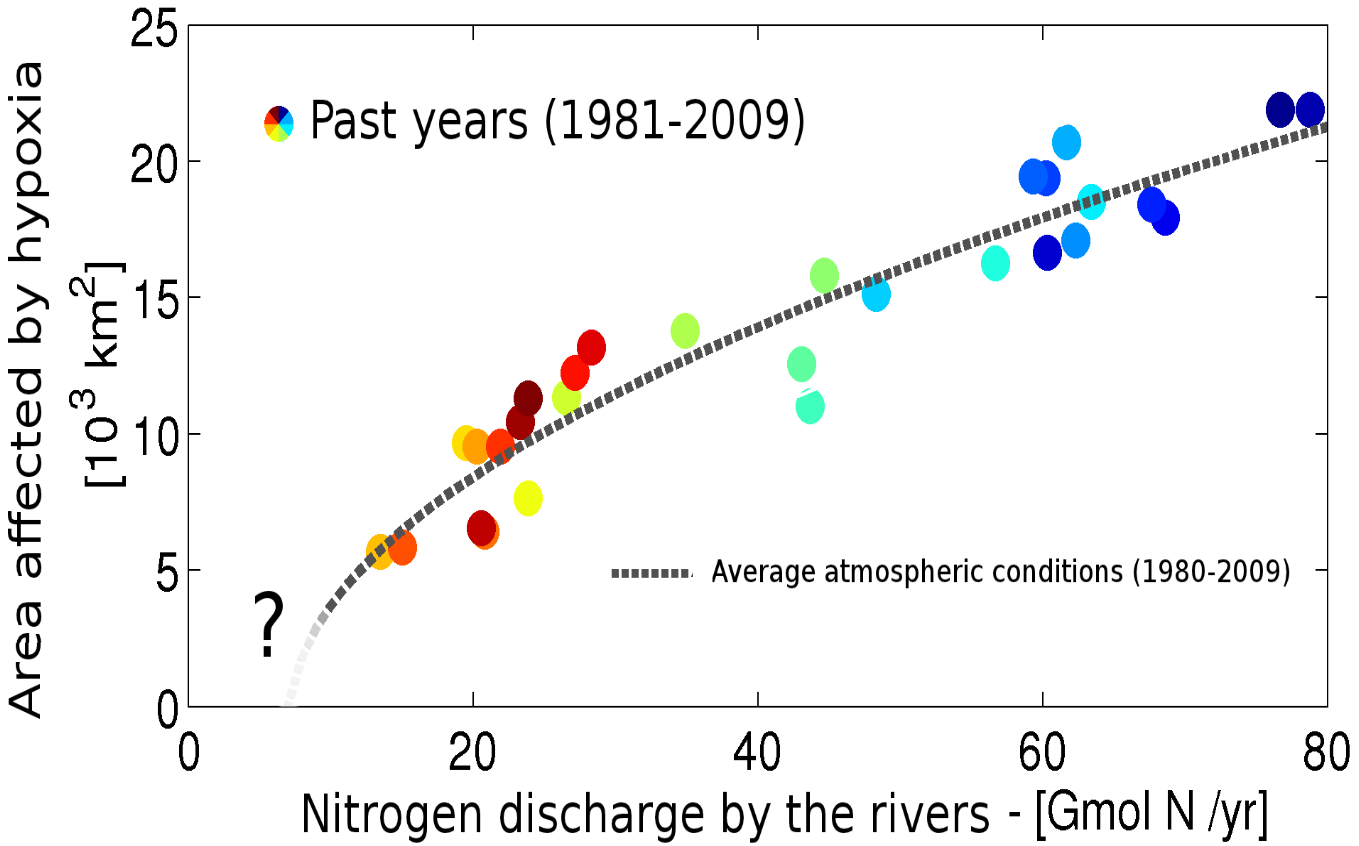
Can we exploit this knowledge
for management purposes ?

Hypoxia response to N discharge



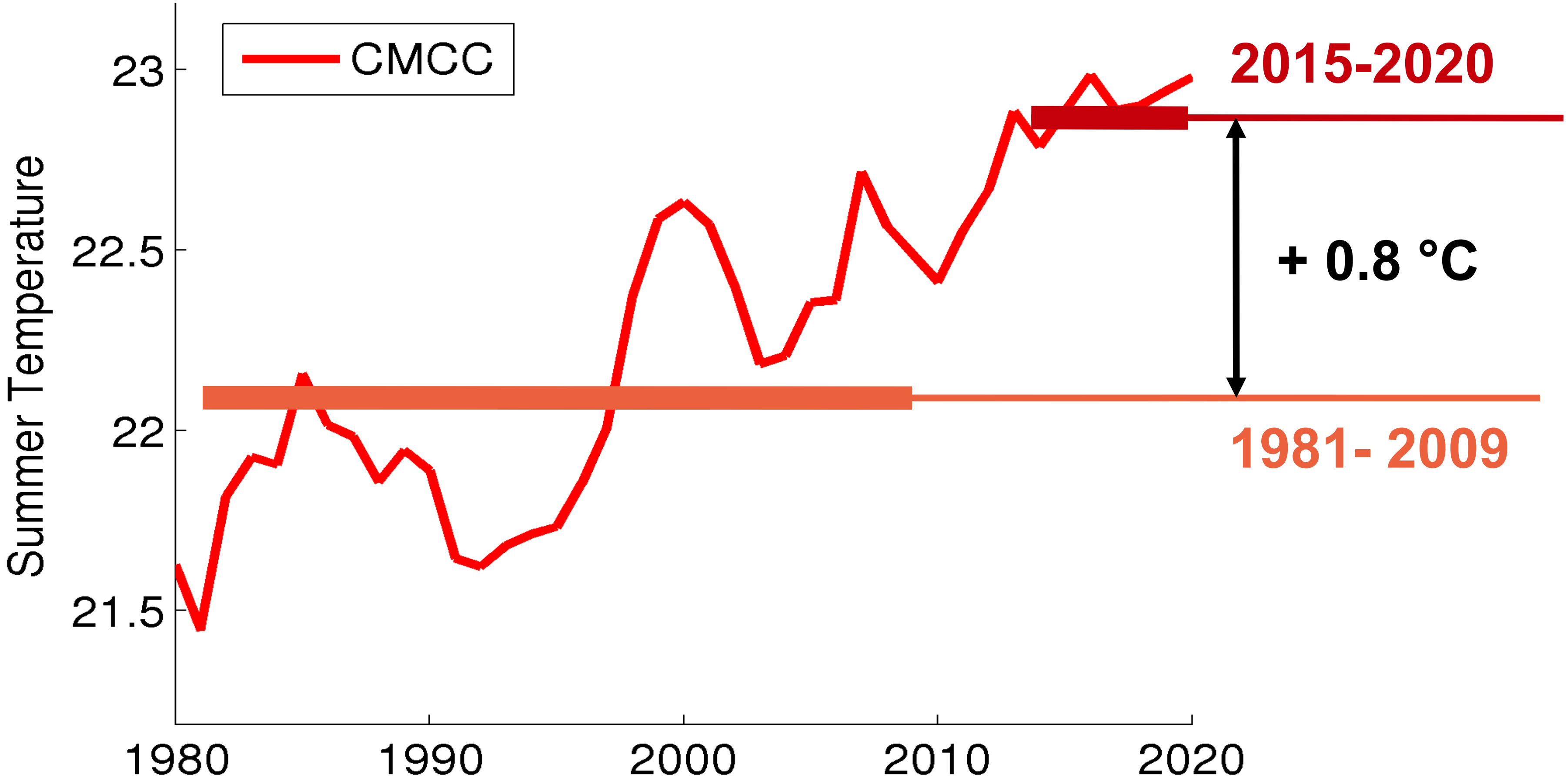
Includes the year specific influences
of climatic and sediments drivers

Hypoxia response to N discharge

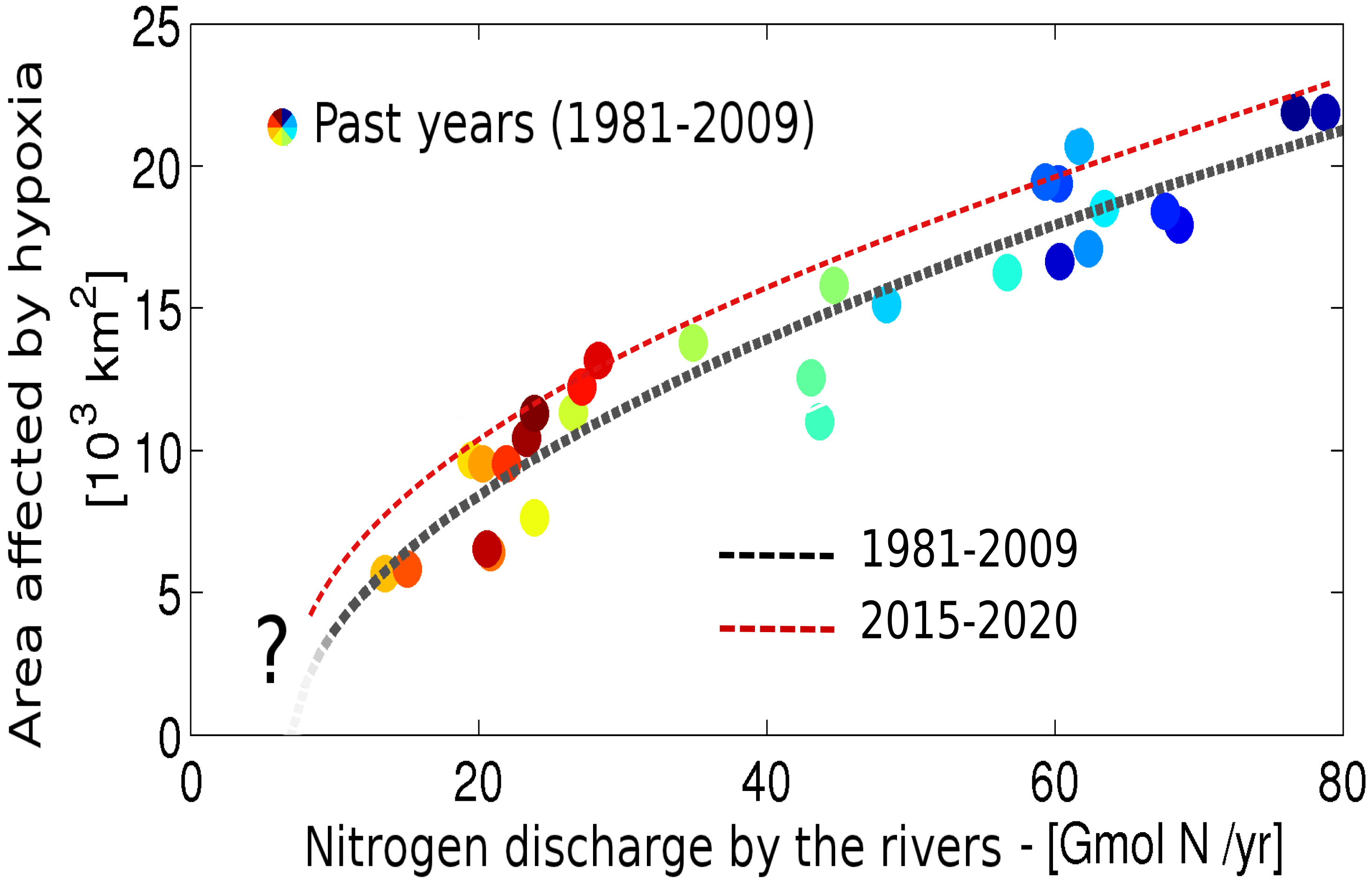


Response curve for average atmsopheric conditions (1980-2009)

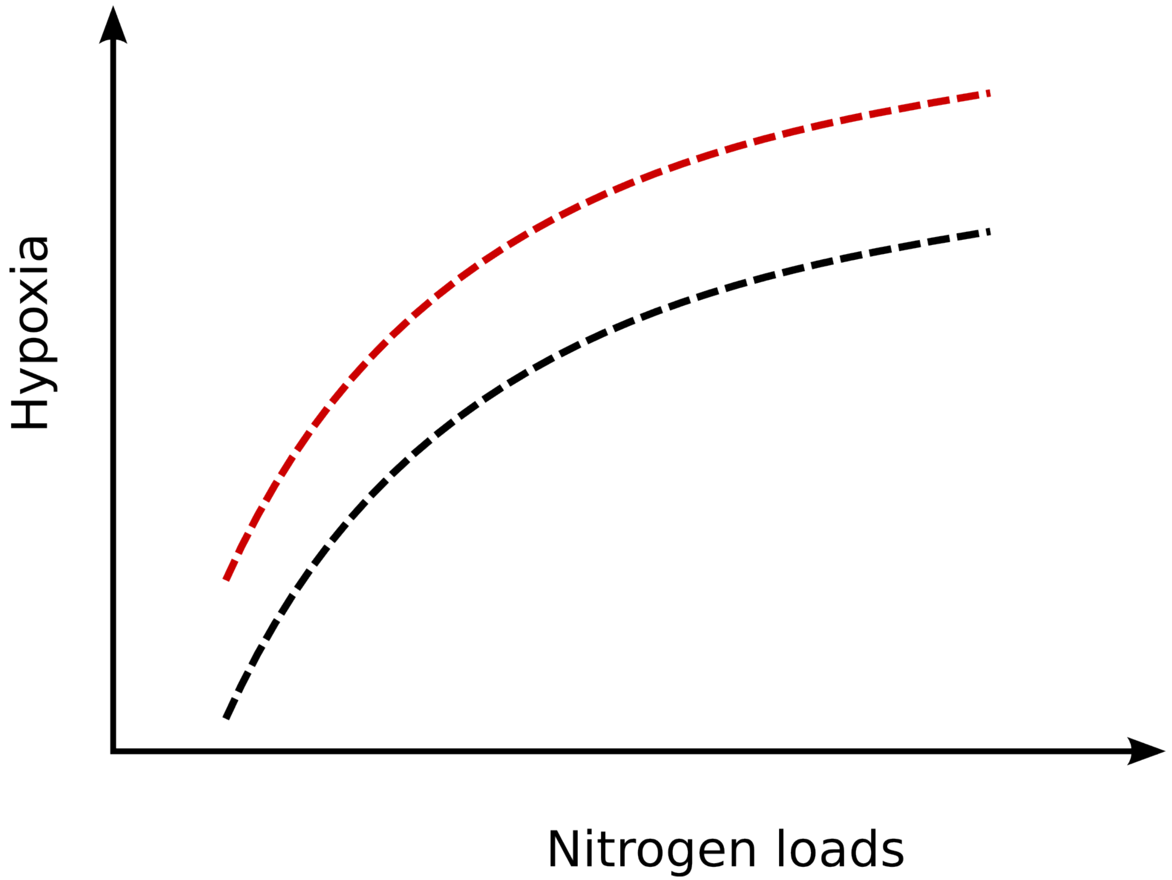
These average atmospheric conditions are not valid anymore



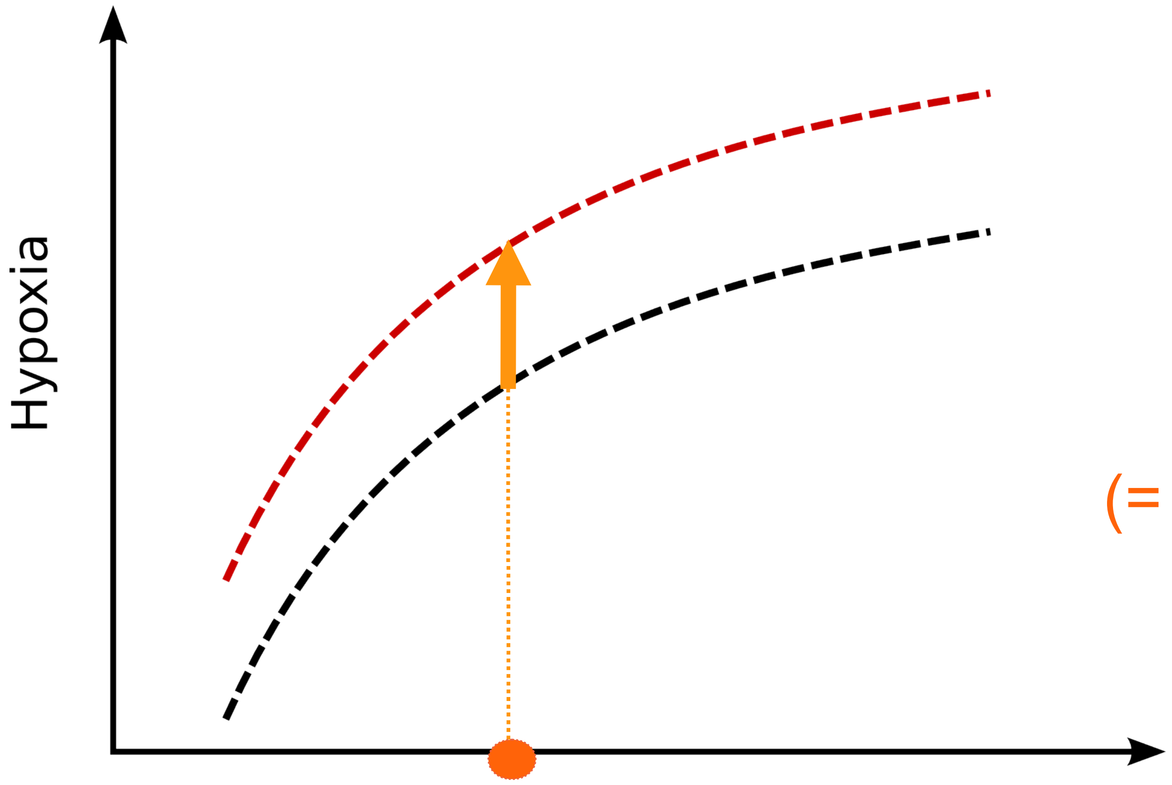
Hypoxia as a function of N



The cost of warming



The cost of warming

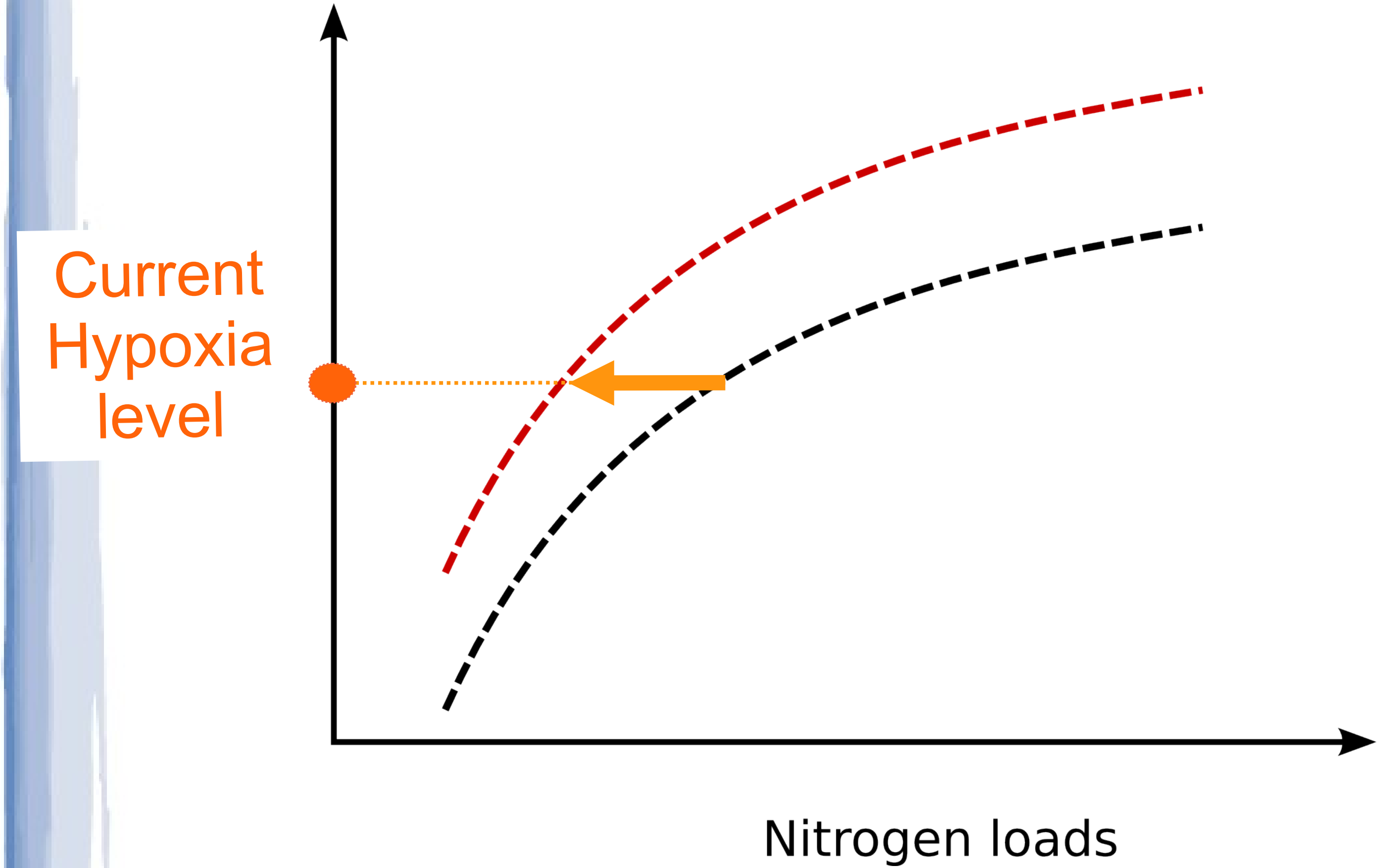


Current Nitrogen loads

Environmental cost
20 % increase
of Hypoxia

(= +3% of the shelf area)

The cost of warming



<u>Economical cost</u>
24 % reduction of
nutrient loads

Conclusion

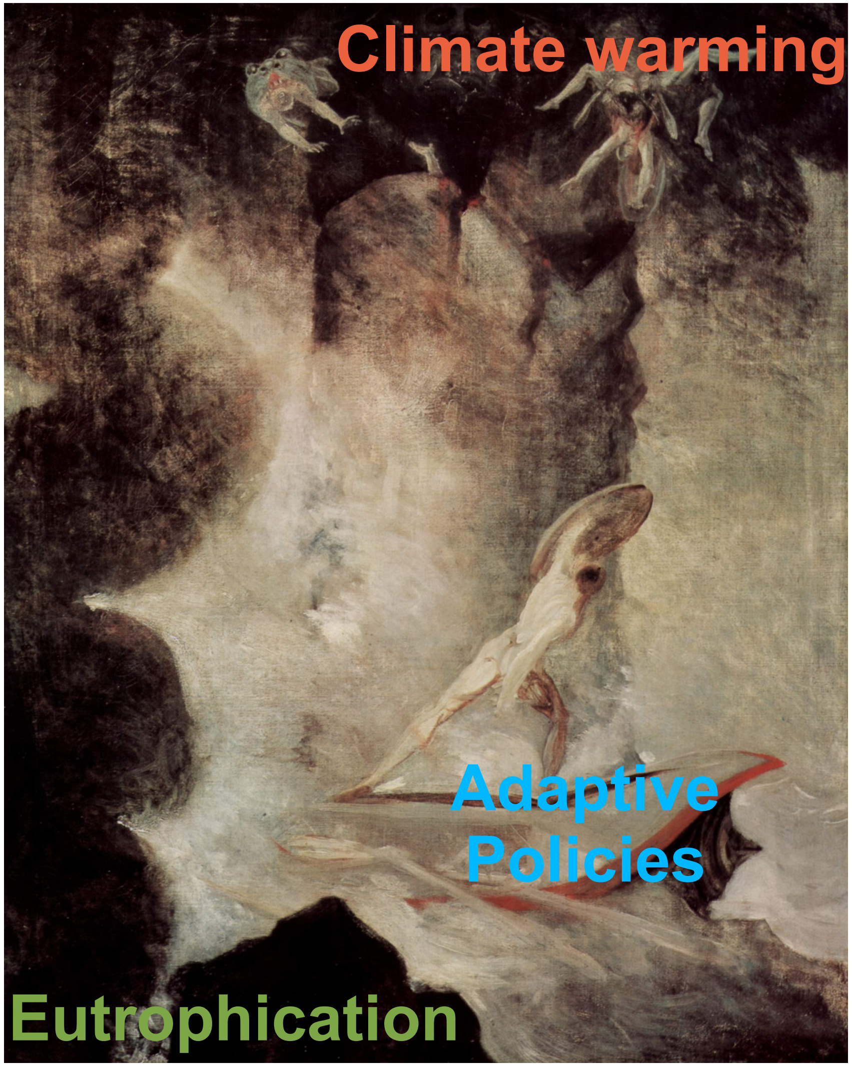
Climate warming strongly enhances the threat of hypoxia.

Conclusion

Climate warming strongly enhances the threat of hypoxia.

→ The management of hypoxia trough restriction of **nutrient loads** should account for **climate warming**.

Conclusion



Climate warming strongly enhances the threat of hypoxia.

→ The management of hypoxia trough restriction of **nutrient loads** should account for **climate warming**.

= Adaptive Policies

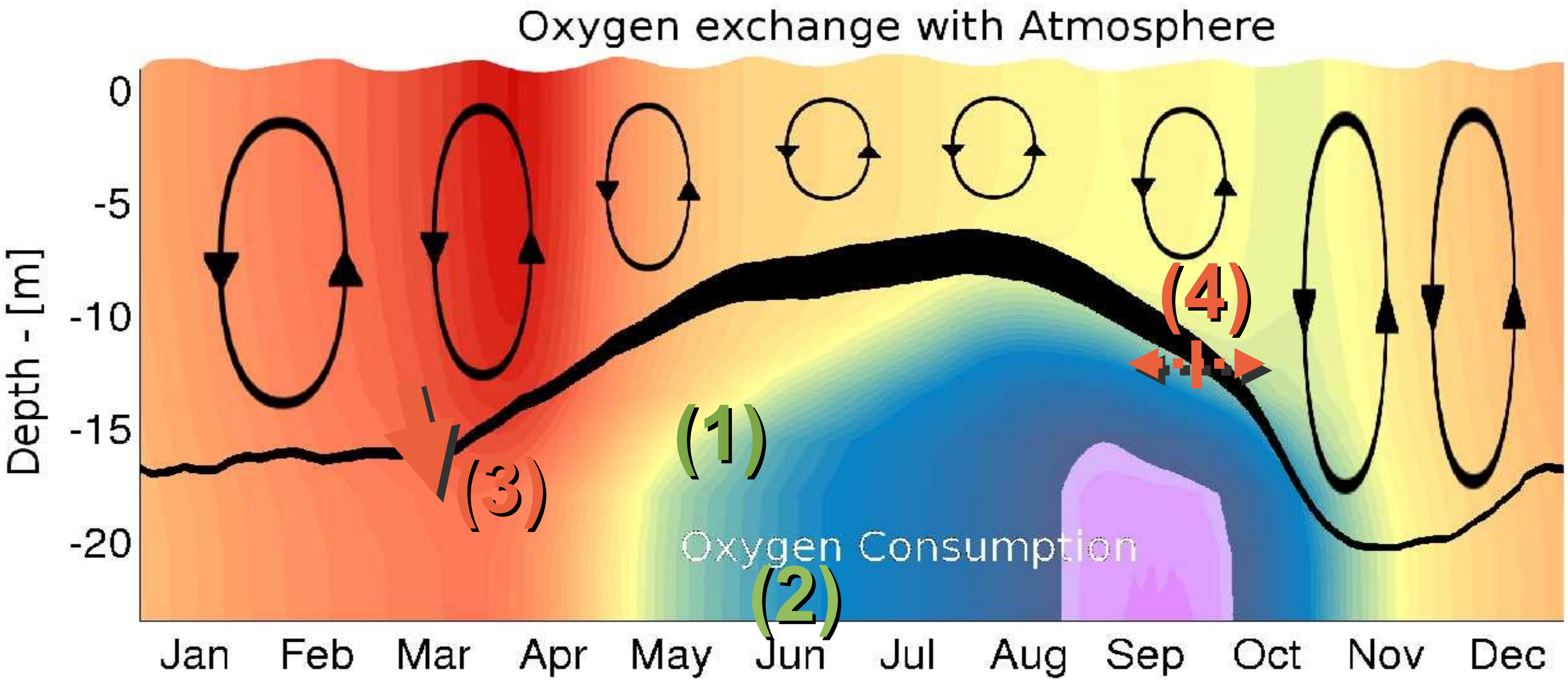
Interannual variability of Hypoxia

(1) High nitrogen riverine discharge enhance the influx of organic matter to bottom waters

(2) High sedimentary organic carbon content enhances the benthic oxygen consumption.

(3) Warm springs reduce the ventilation and set summer bottom temperature.

(4) Warm summers extend the duration of the stratified period.

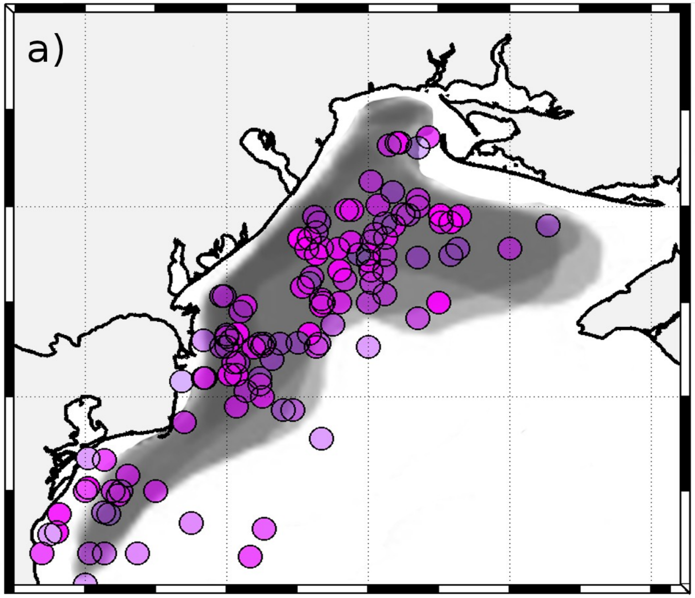


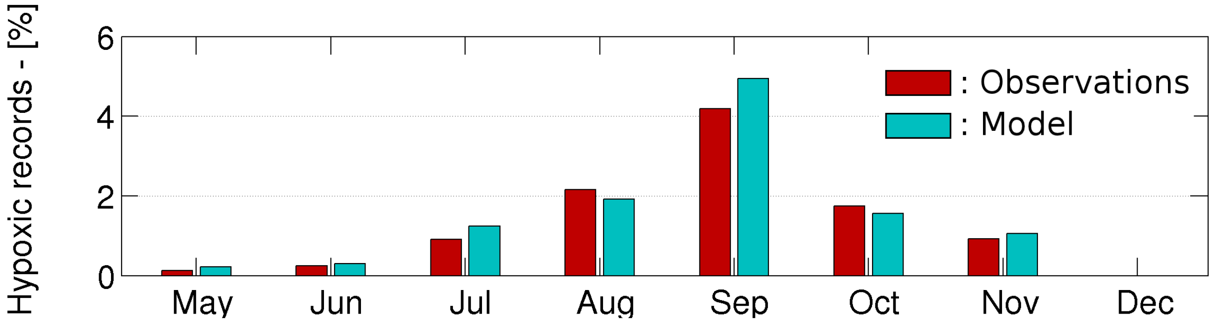
Take-home Messages (3)

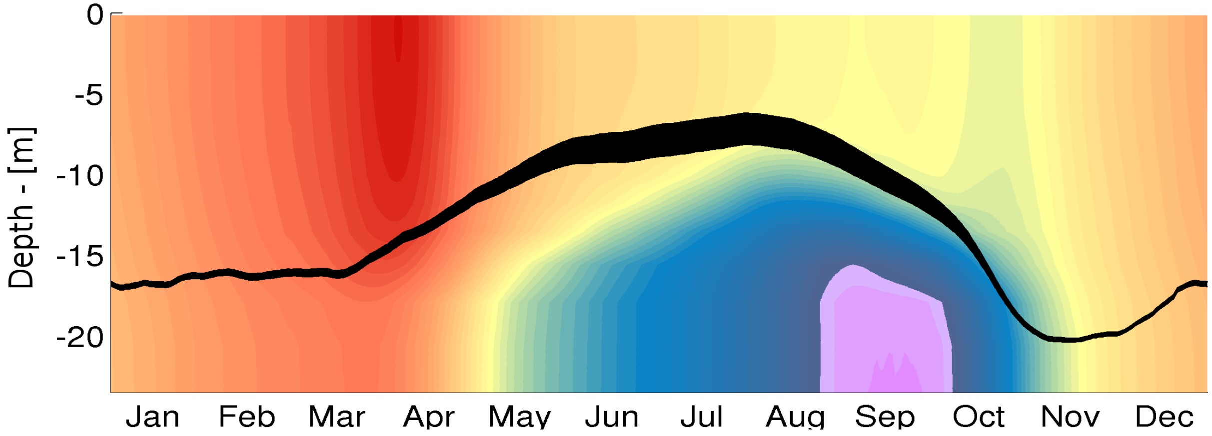
Take-home Messages (1/3)

Hypoxia is still ongoing in the Black Sea NWS

Monitoring should be focused on the area, months and depth of known hypoxia occurence







Take-home Messages (2/3)

Hypoxia is intensified by year-to-year accumulation of organic matter in the sediments

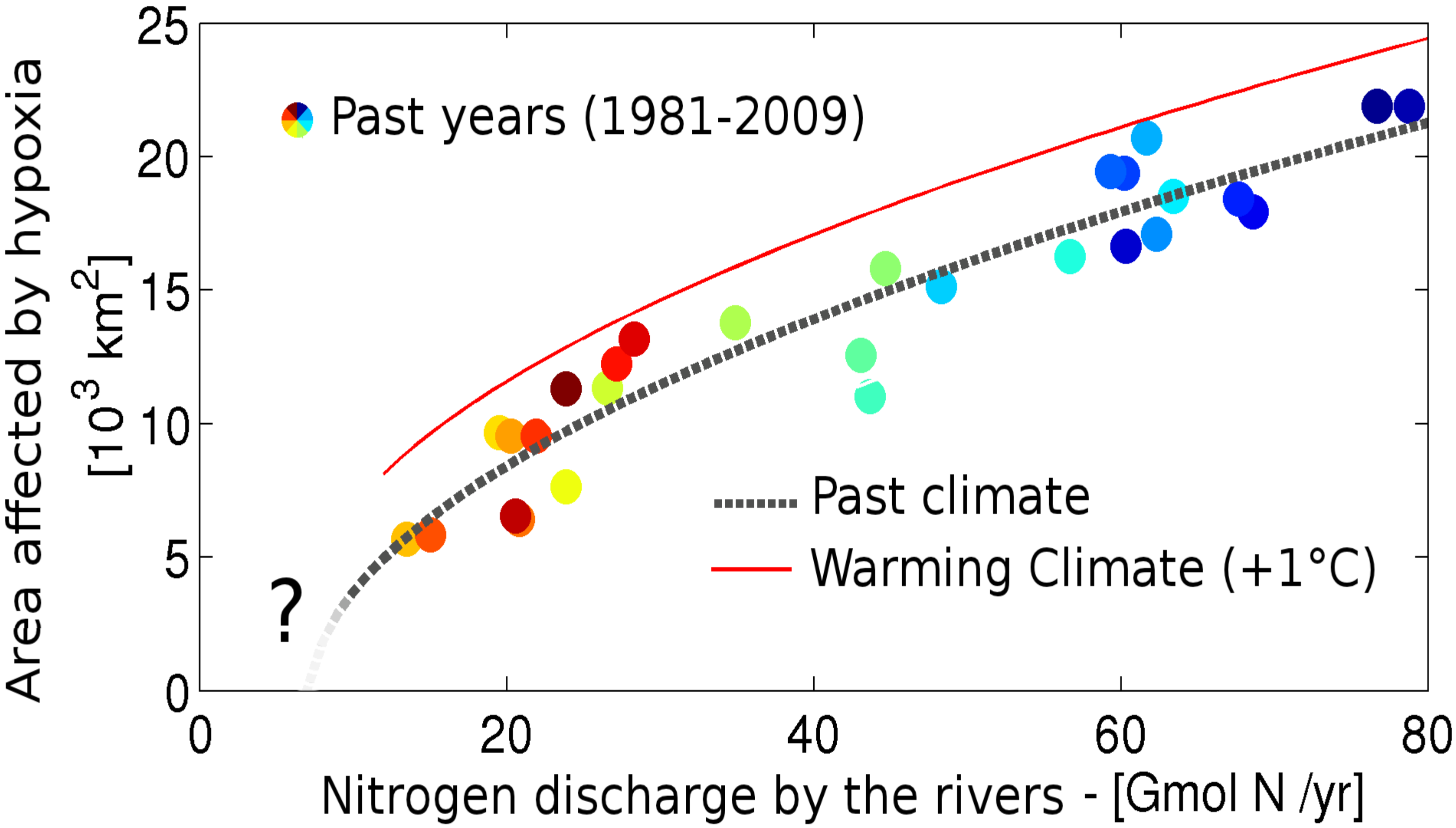
Systems with decreasing N → inertia in the recovery process.

Systems with increasing N → increase of the H/N ratio. *(Turner, 2008)*

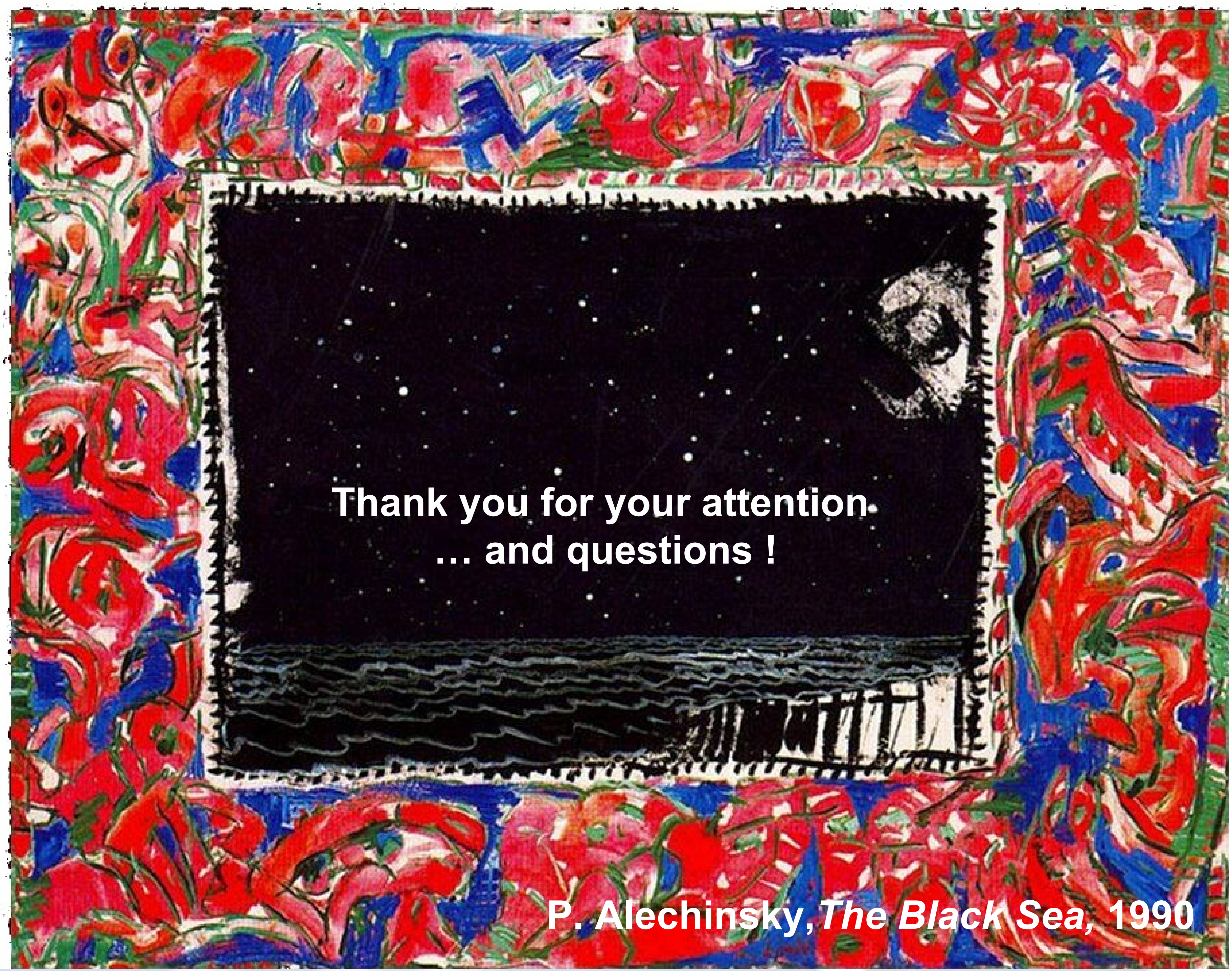
.

Take-home Messages (3/3)

Climate impacts almost as much as eutrophication



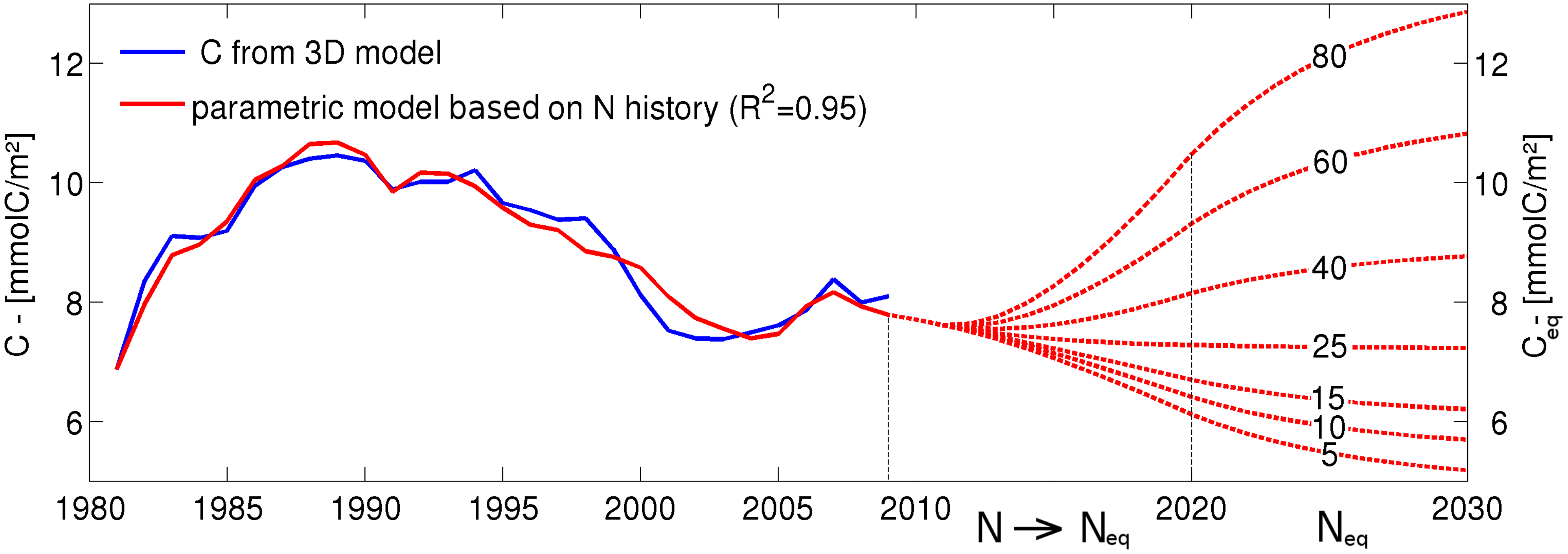
Nutrient reduction policies should account for realistic climatic scenarios

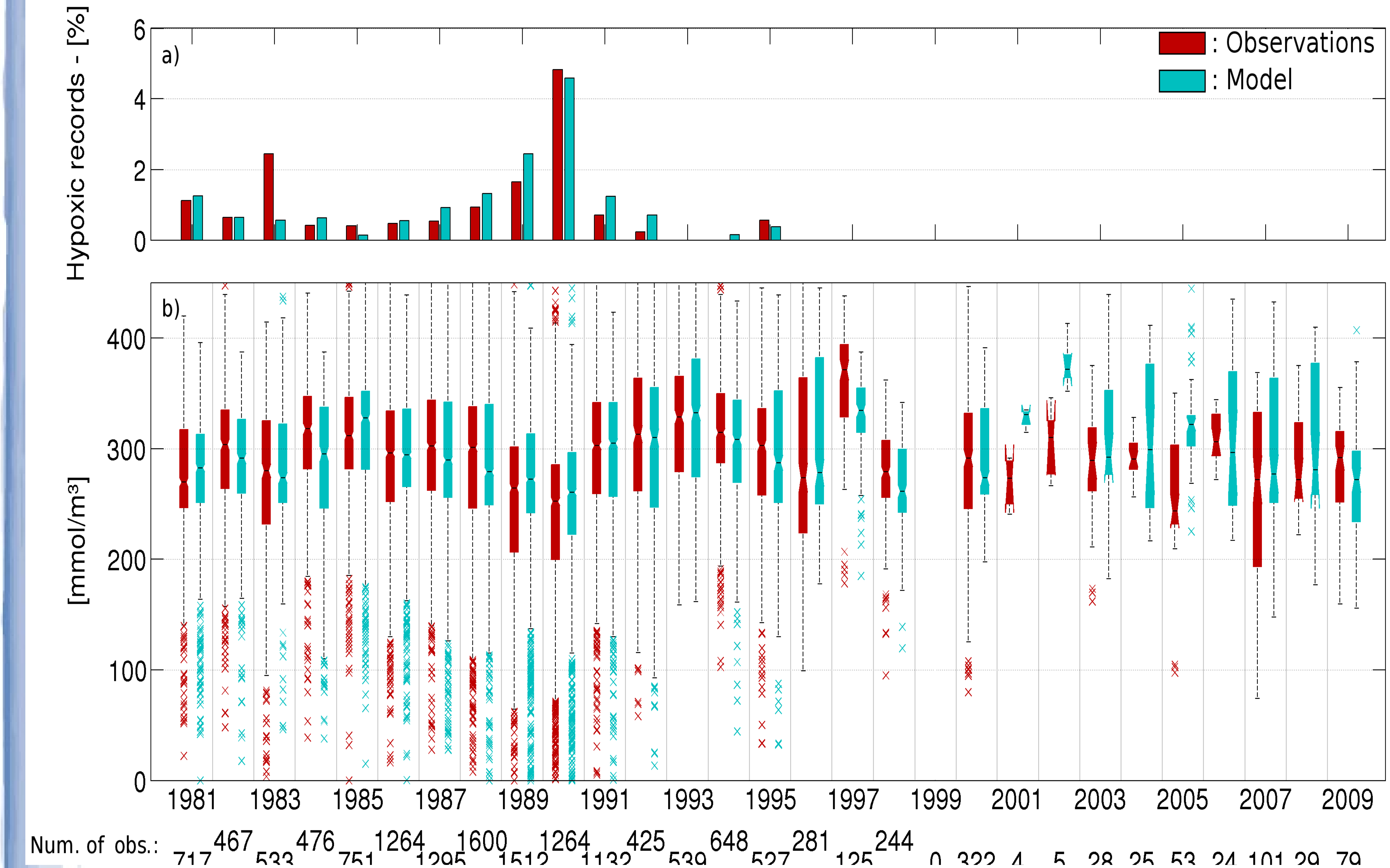


Thank you for your attention
… and questions !

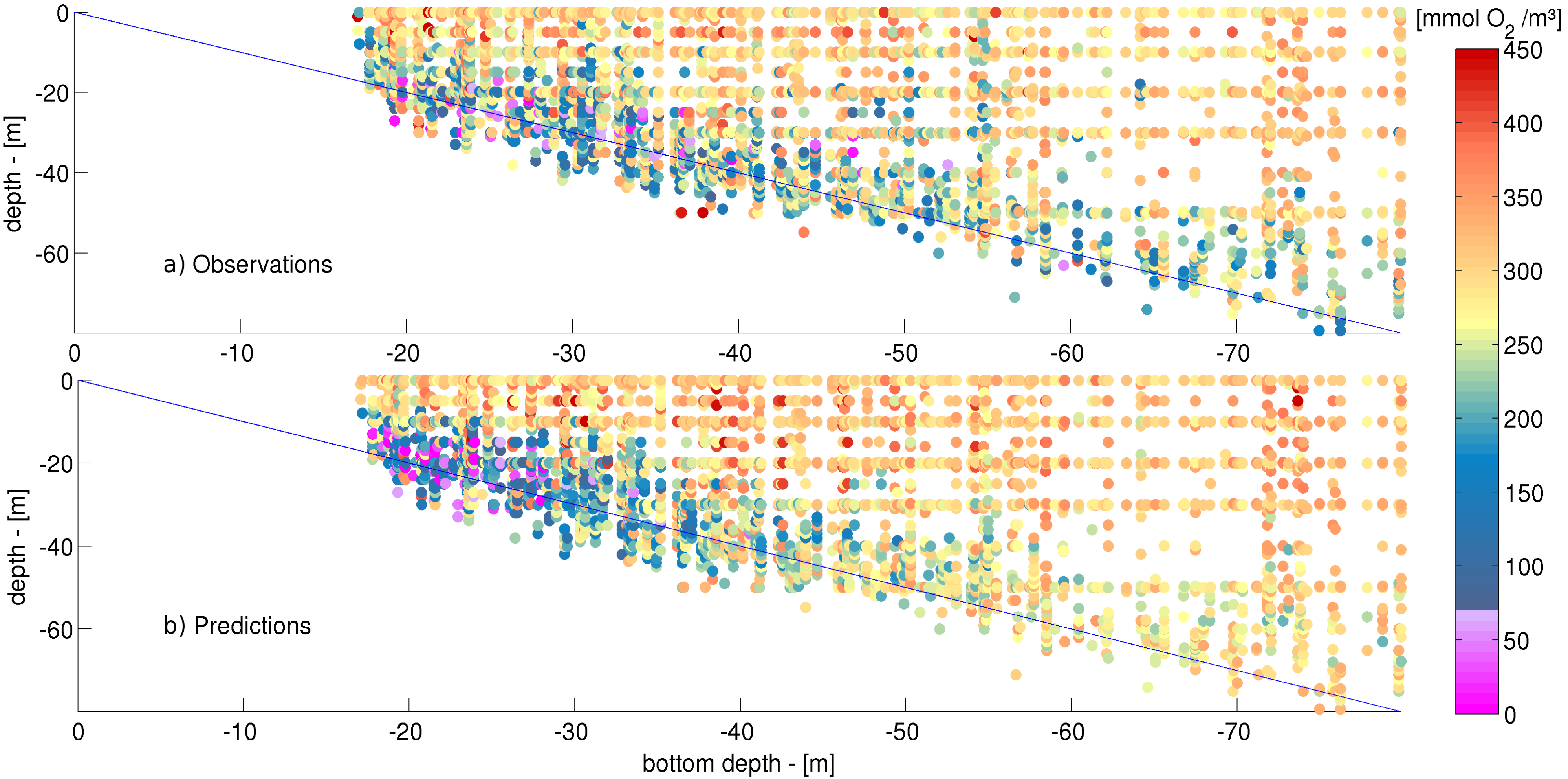
P. Alechinsky, *The Black Sea*, 1990

Organic matter accumulates in the sediments




Hypoxic records - [%]
a)
6
4
2
0
🟥 : Observations
🟦 : Model
b)
[mmol/m³]
400
300
200
100
0
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
Num. of obs.:
717 467 533 476 751 1264 1295 1600 1512 1264 1132 425 539 648 527 281 125 244 0 322 4 5 28 25 53 24 101 29 79

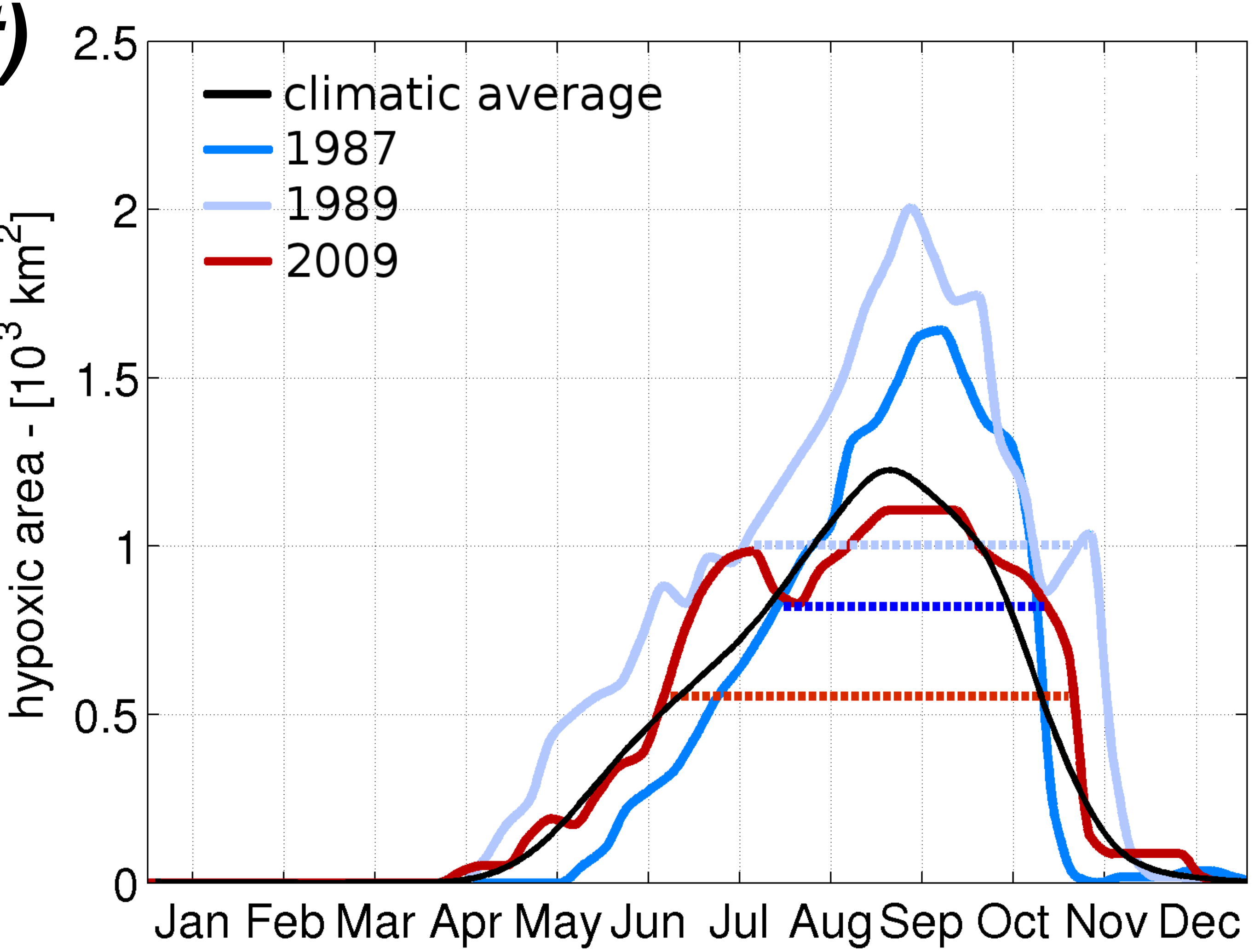
Model Validation : Point-to-point



$$D = \frac{1}{\max A(t)} \int_{year} A(t)\,dt,$$

$$H = \frac{1}{\overline{D}} \int_{year} A(t)\,dt,$$

A(t)



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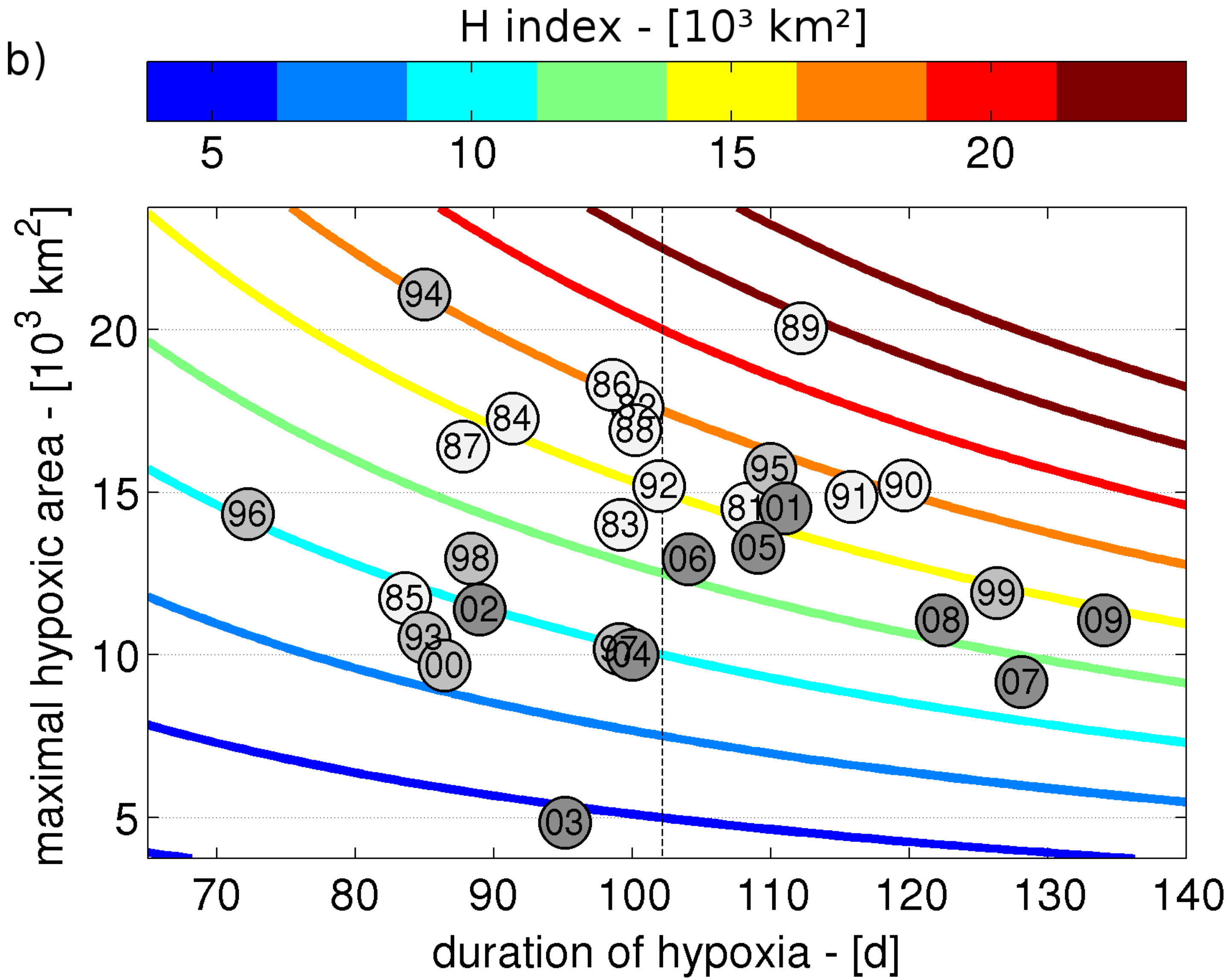
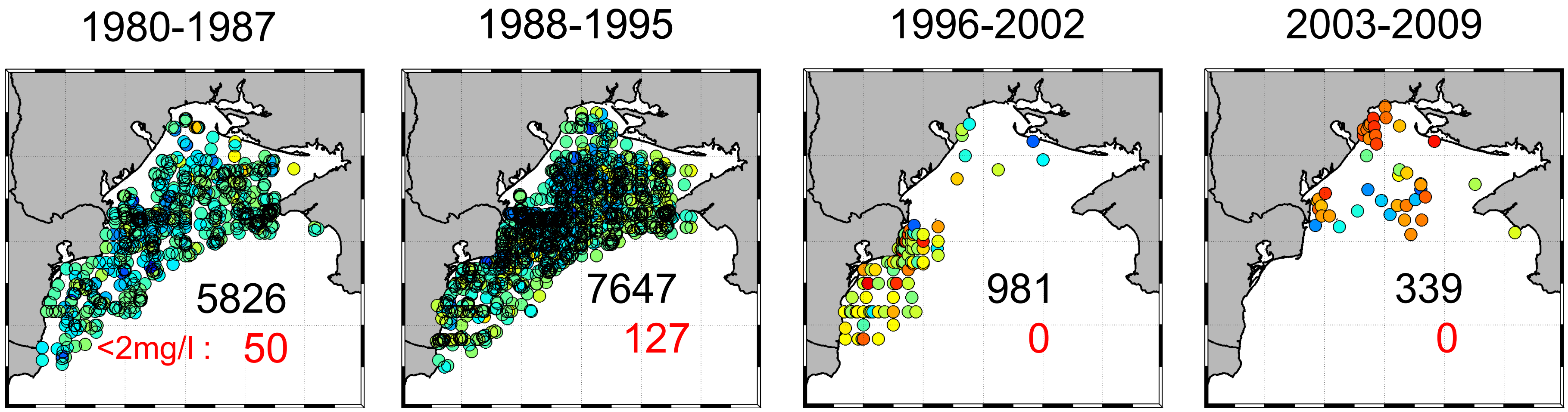
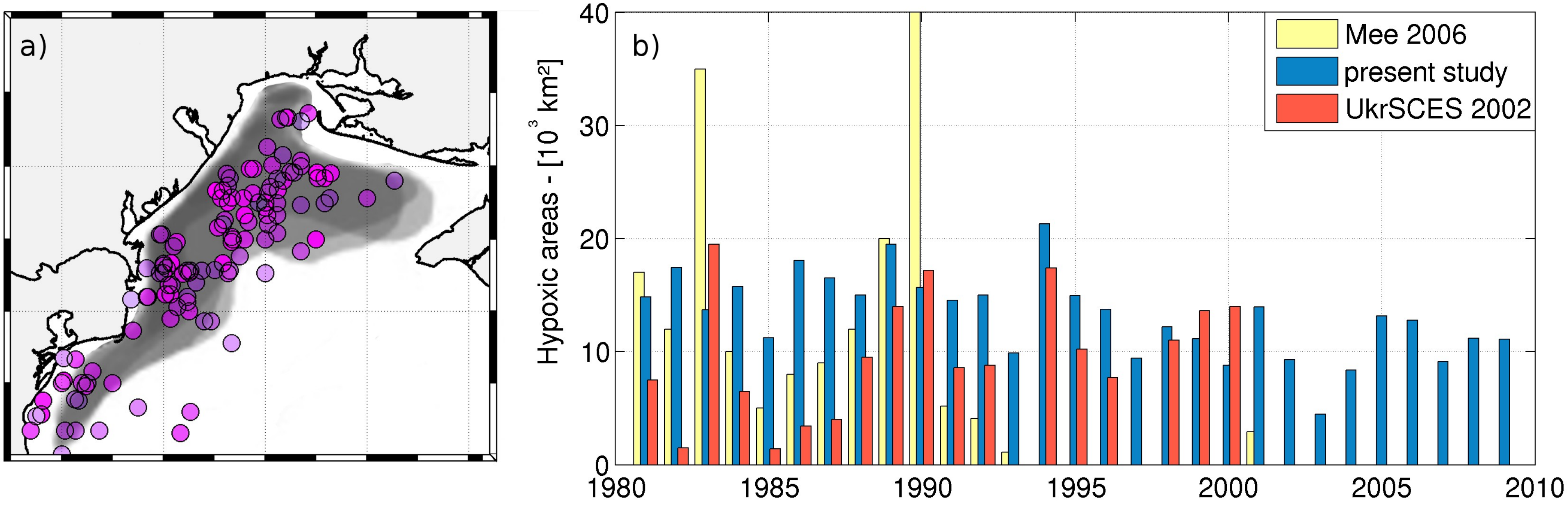
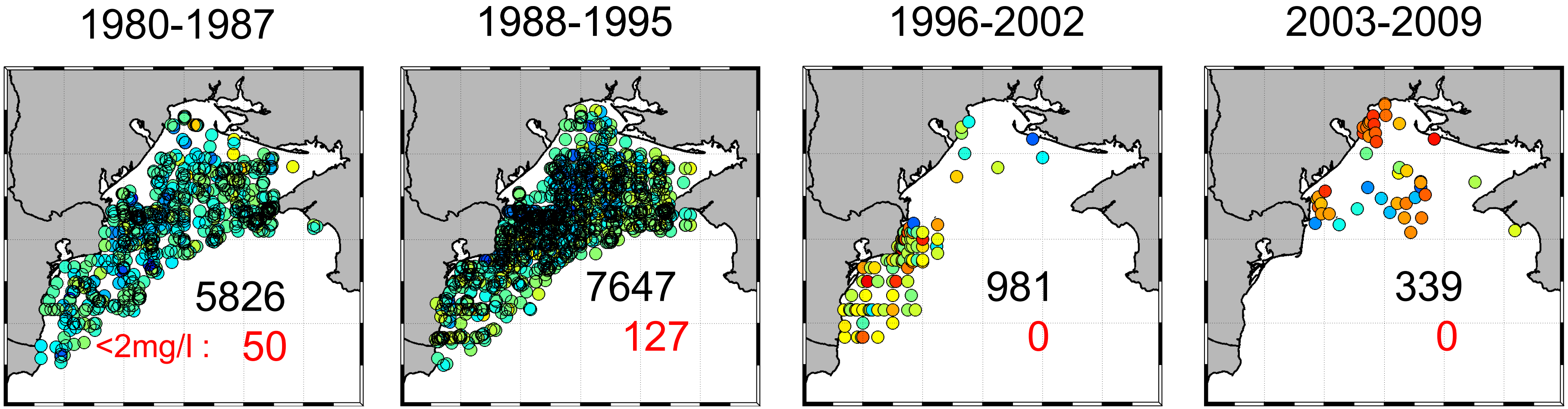


Recovery ?


1980-1987
5826
<2mg/l : 50
1988-1995
7647
127
1996-2002
981
0
2003-2009
339
0


a)
b)
Hypoxic areas - [10^3 km²]
0
10
20
30
40
1980
1985
1990
1995
2000
2005
2010
Mee 2006
present study
UkrSCES 2002

Recovery ?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5826
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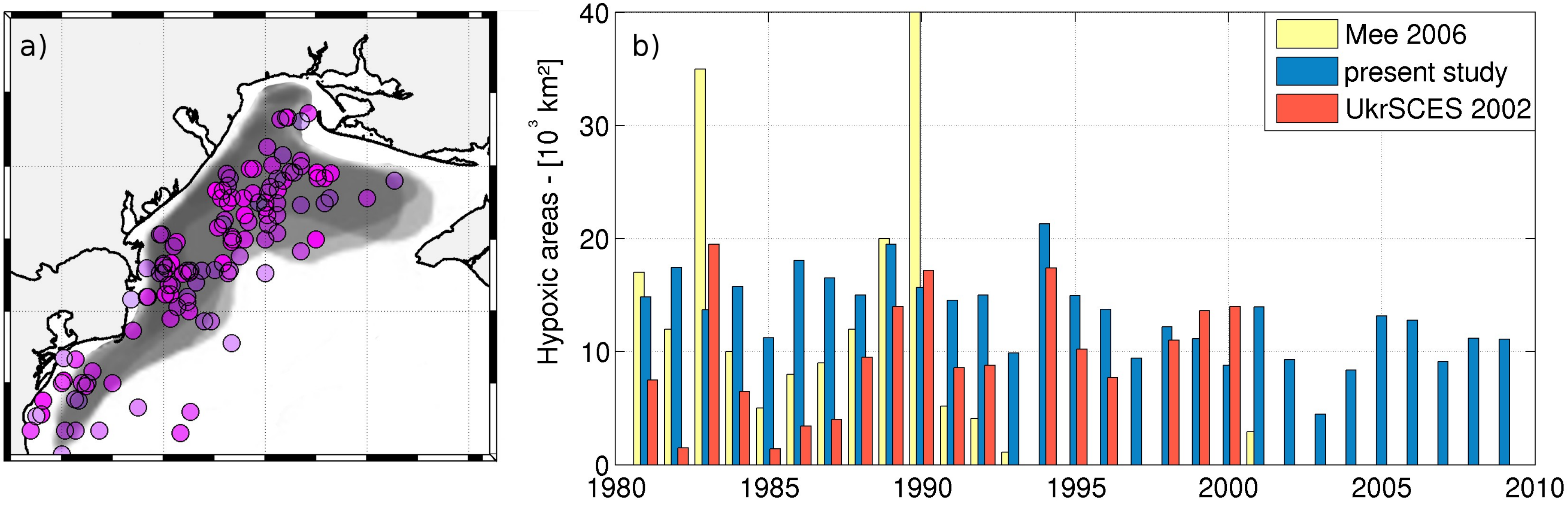
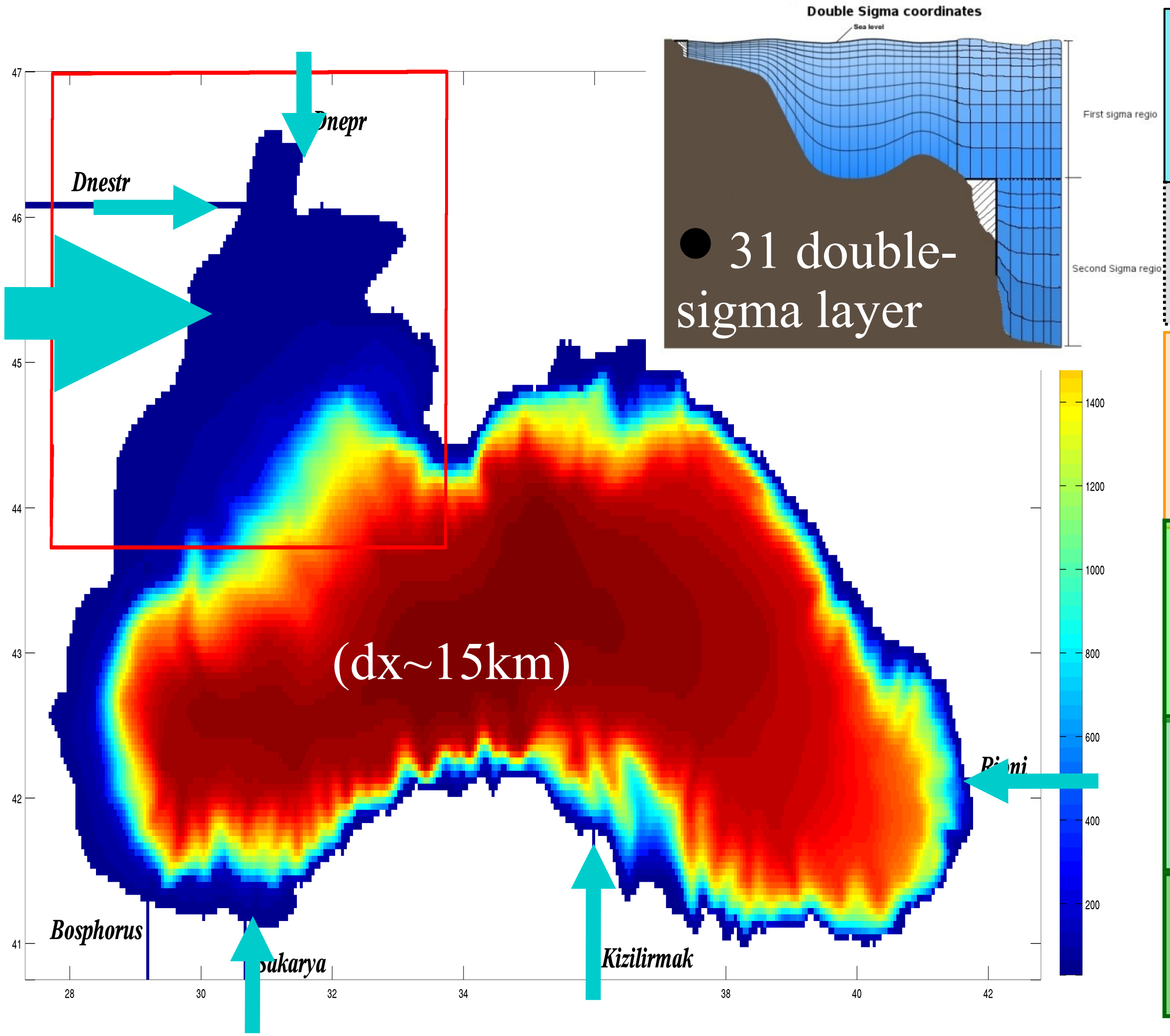

a)
b)
Hypoxic areas - [10^3 km²]
0
10
20
30
40
1980
1985
1990
1995
2000
2005
2010
Mee 2006
present study
UkrSCES 2002

The Model



- 31 double-sigma layer

(dx~15km)

Monthly RIVERS fluxes and nutrients flows (from L. Wolfgang & A. Cociasu)

6h-atmospheric forcings from ECMWF (1.125°). (from ERA40)

36 States variables

Physics (5)
Currents, T°, Salinity,
Surface elevation, Turbulence

Oxygen and Dissolved Inorganic Carbon (2)

Inorganic nutrients (5)
SiO,NO3,NH4,PO4,”Reducers”

3 Phytoplankton (6) (free C/N)
Diatoms,Flagellates, Small Flagellates

Zooplankton (2)
Micro-, Meso-.

Gelatinous zooplankton(2)
Omnivorous , Carnivorous

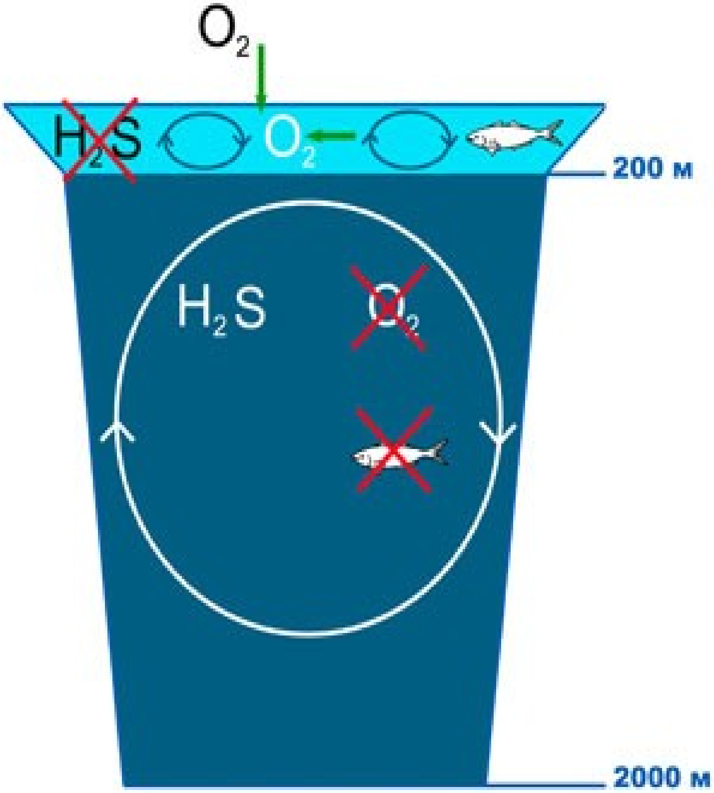
Detrital matter (8)
Particulate, Semi-labile and Labile forms
Silicious Detritus, Aggregates

Bacteria(1)

Model's Specificity

- <u>No data assimilation </u>: Necessity to construct specific Bosphorus representation to ensure conservation of volume and total salt content.

- <u>Anoxic waters</u> : The biological model explicitely includes anoxic chemistry trough the use of a variable 'Oxygen demanding Units', as a proxy for reducers acting in the anoxic zone.



- <u>Sediments compartiment</u>

- <u>Light absorption scheme</u>