Noxious effects of the increasing eutrophication of coastal marine ecosystems: how far should we reduce the terrestrial nutrient loading?

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Ifremer/Brest

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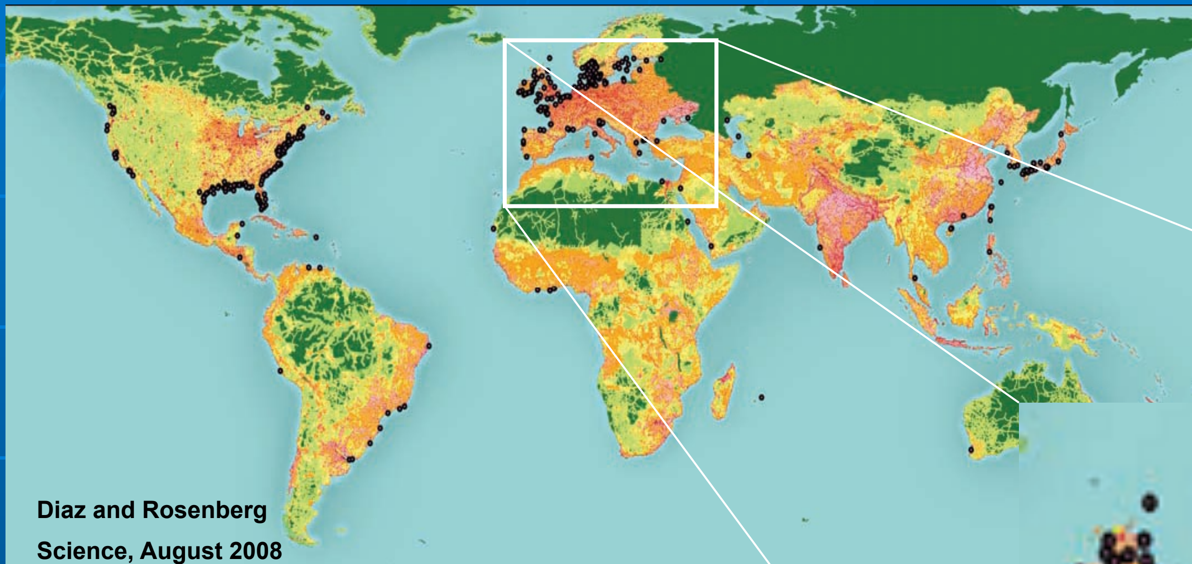
- Eutrophication symptoms
- Main causes
- Management aspects
- The modelling tool
- Off-line scenario results
- On-line real-time modelling of risks
- Conclusion

Eutrophication symptoms

The ultimate threat: the « dead zones »



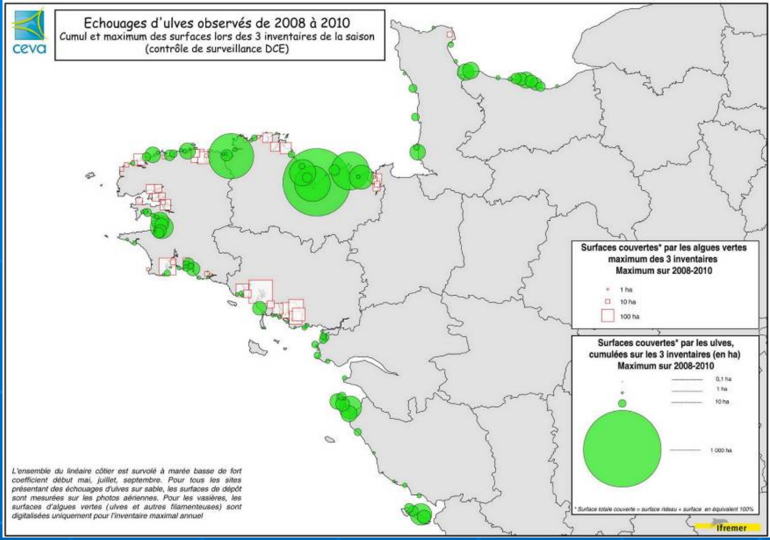
Hypoxia sites in the world

Hypoxia sites in Europe

- Baltic Sea
- Skagerrak, Kattegat
- North Sea
- British and French estuaries
- Northern Adriatic Sea and mediterranean lagoons
- Black Sea

Macroalgal proliferations

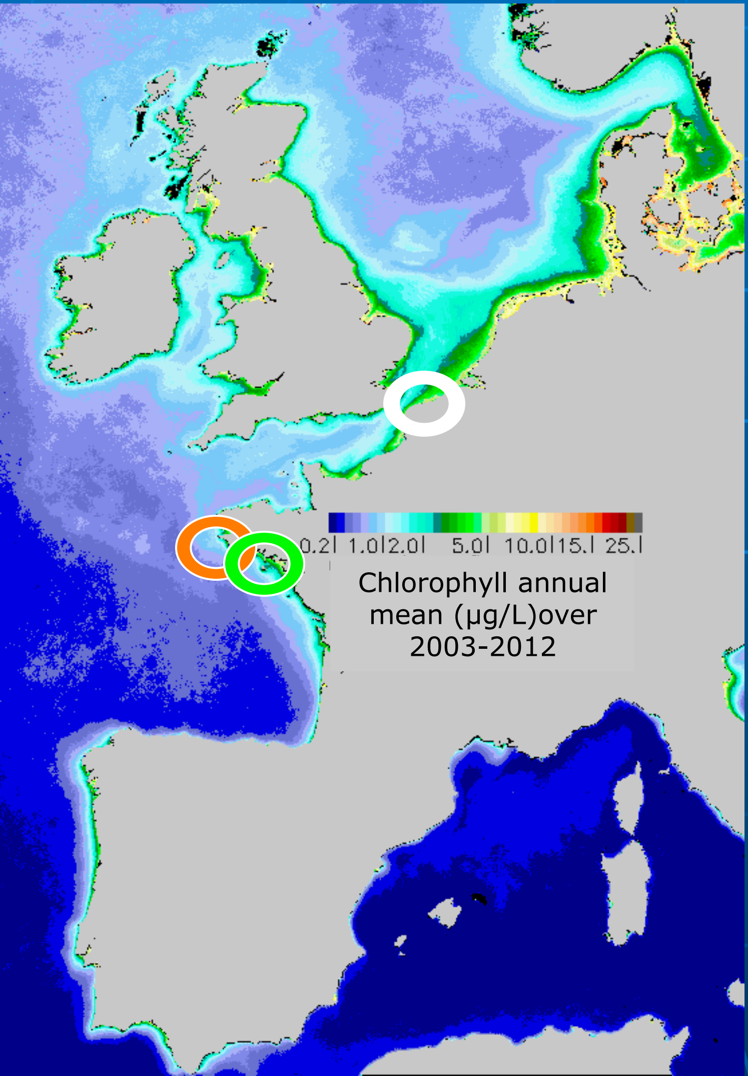
« green tides »

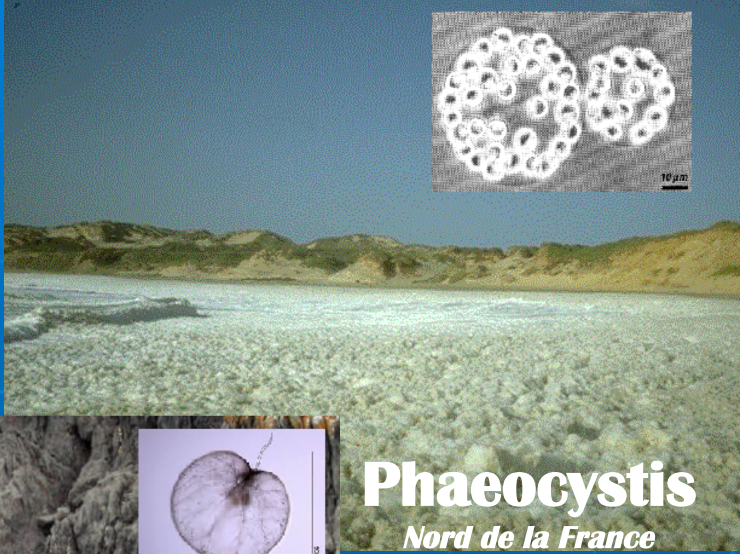


The most **visible** form of eutrophication is made by green algae accumulation in very shallow areas:

- bottom-fixed Enteromorpha in estuaries
- free-floating Ulva on sandy beaches

Phytoplanktonic proliferations
« coloured waters »

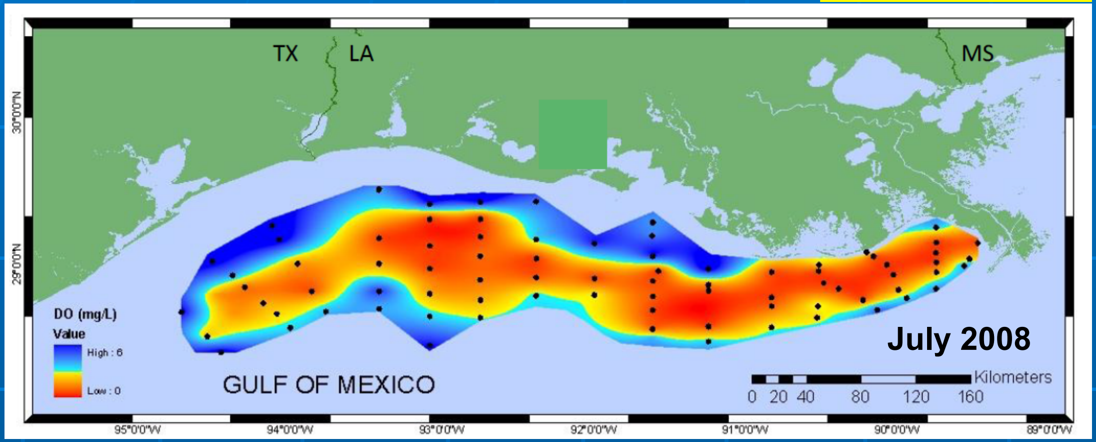


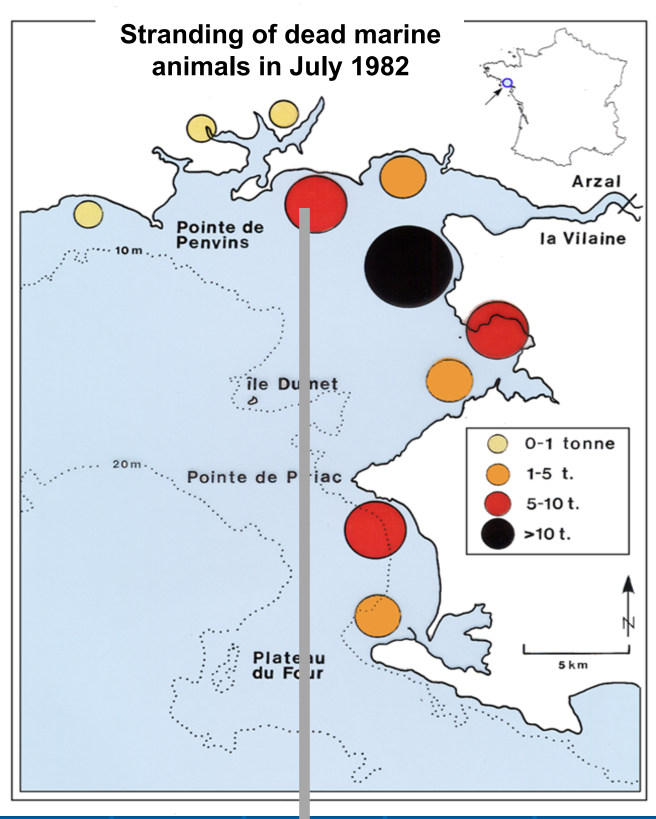


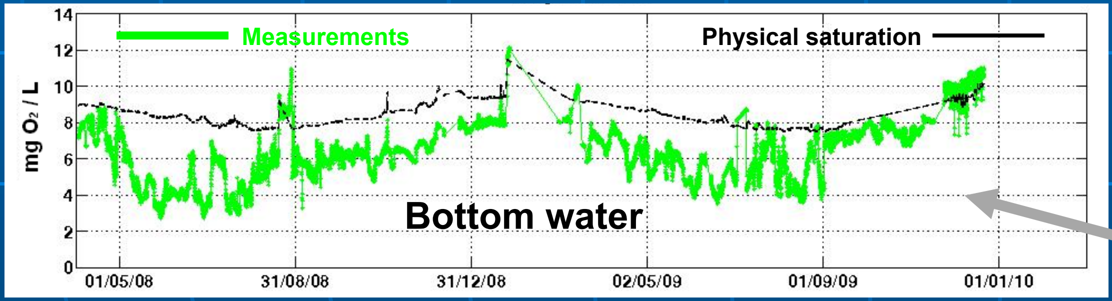
Hypoxic episodes

~ 200 km²

~ 20 000 km²



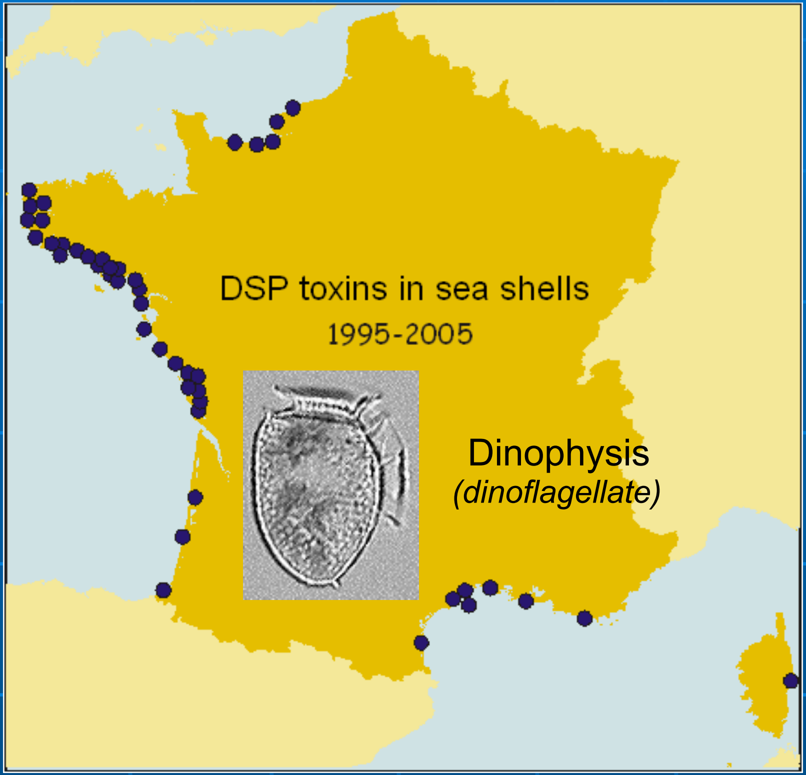


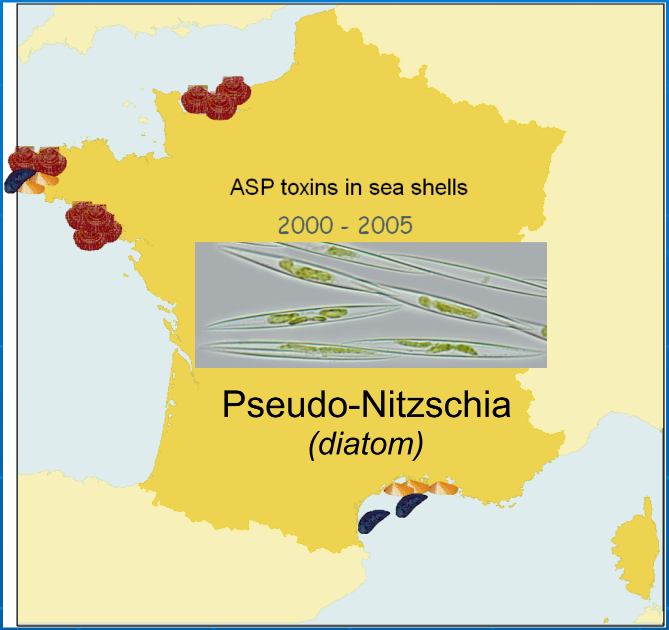


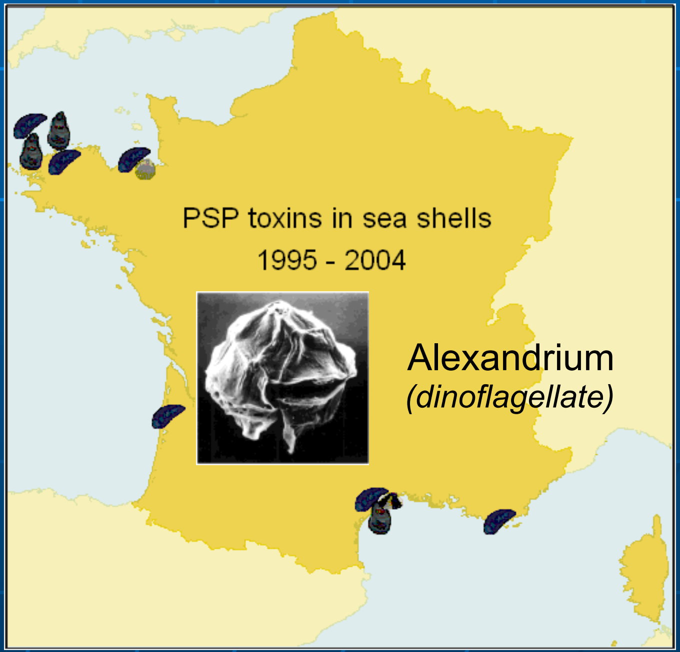
2008-2009 measurements by the MOLIT buoy in the Vilaine bay

The most **harmful** form of eutrophication **for the ecosystem** is made by coloured waters in the plumes of enriched rivers leading to **hypoxia in bottom layer**

Toxic phytoplankton



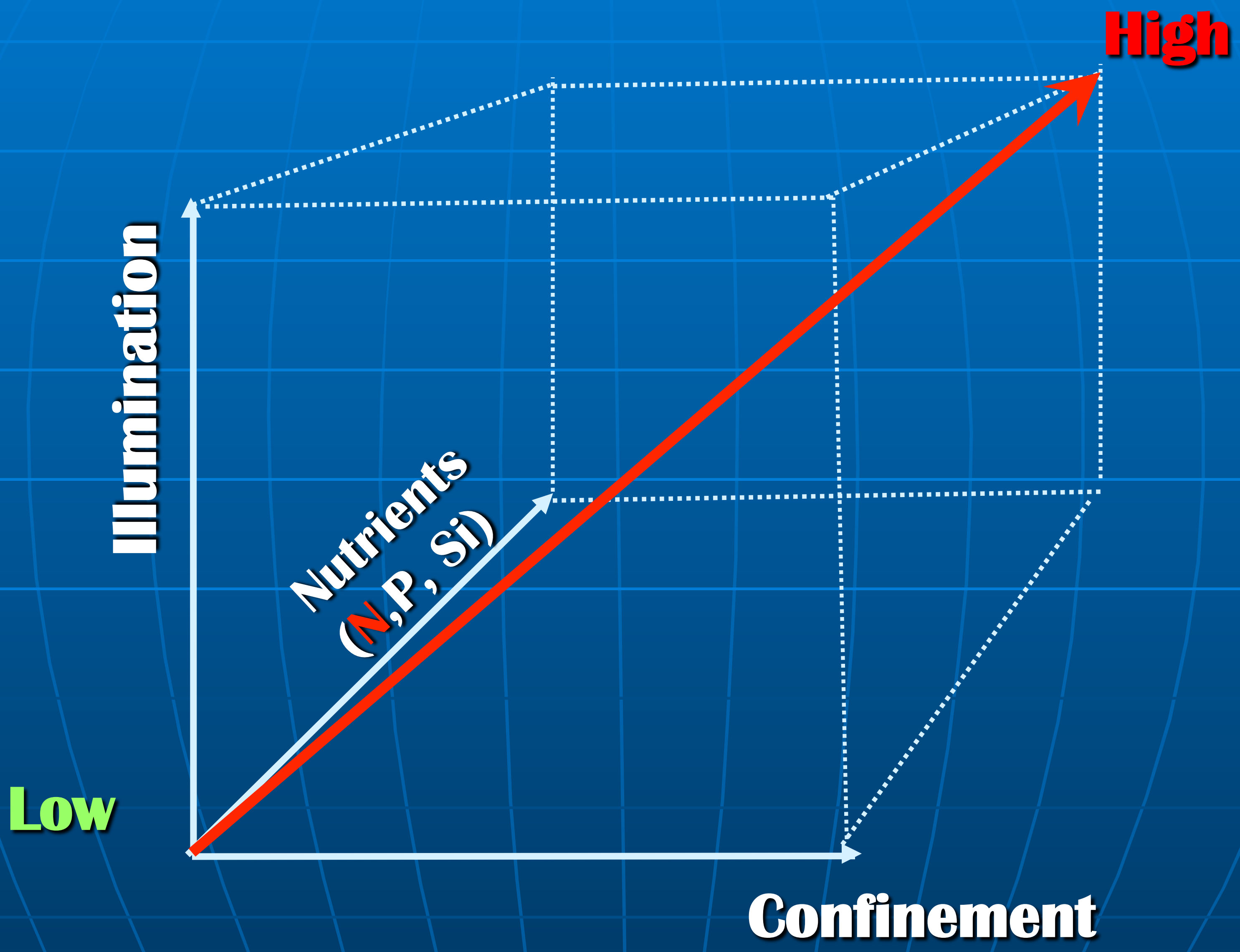




The most **harmful** form of eutrophication **for the human consumer** is made by blooms of toxic phytoplanktonic species leading to **seashell contamination**. **N/P/Si increase enhances toxin production**

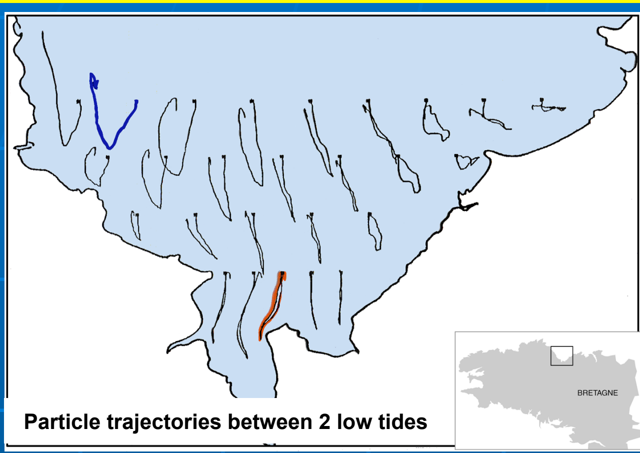
Main causes

The eutrophication tripod

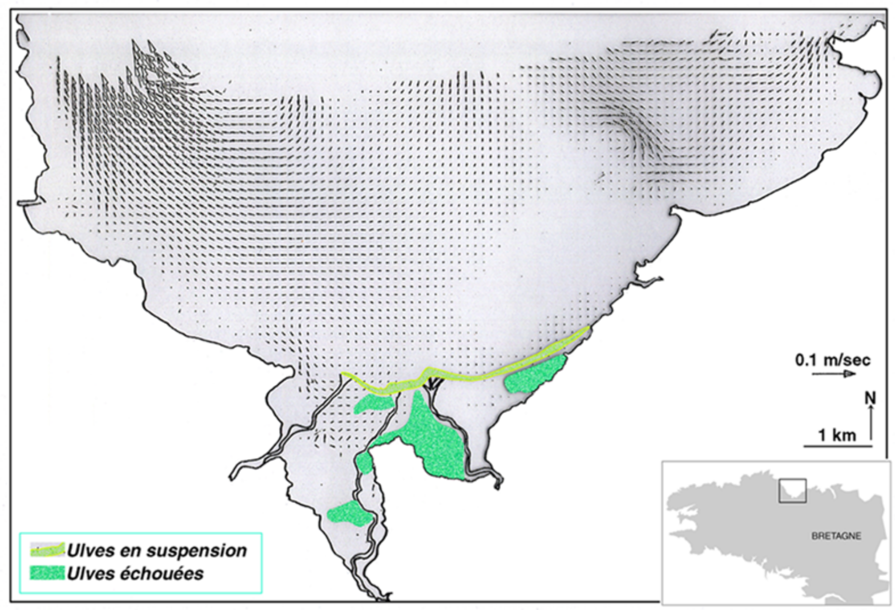


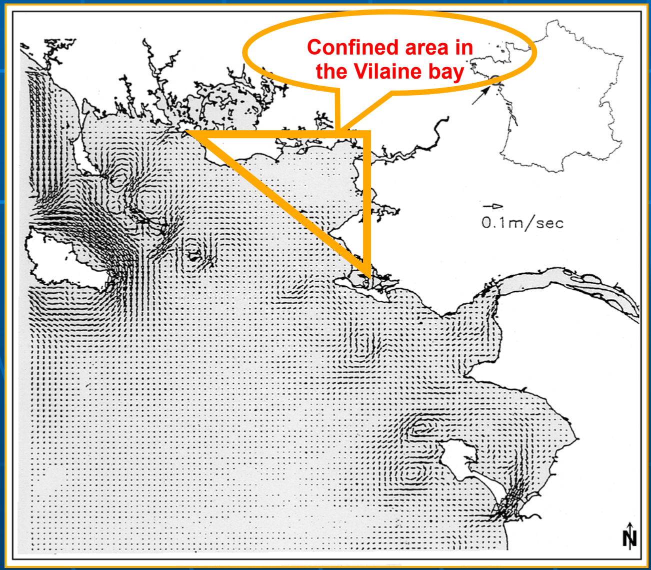
Confinement

Horizontal weak residual currents

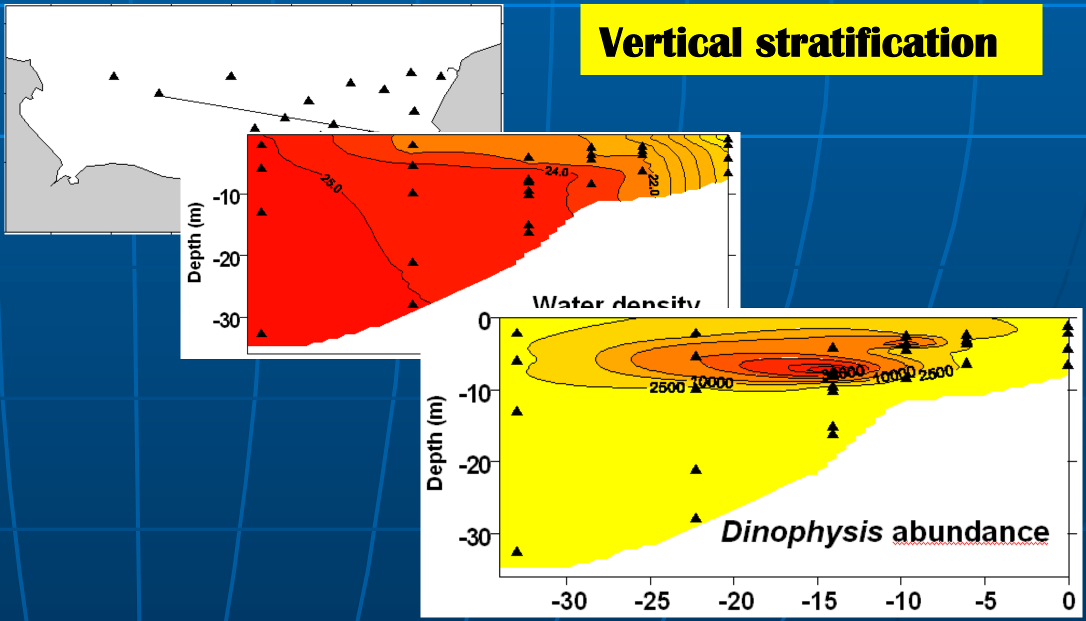


Particle trajectories between 2 low tides



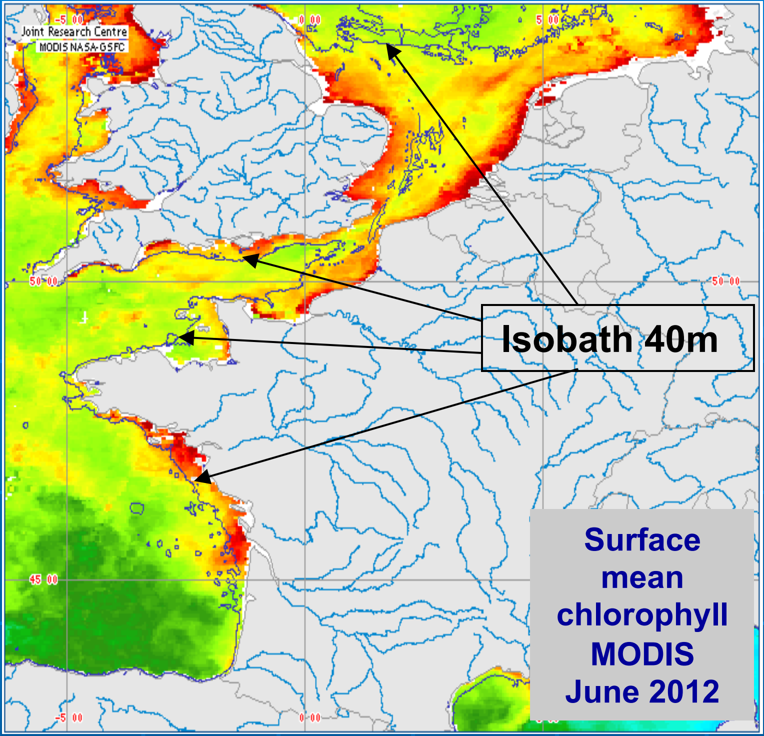


Vertical stratification

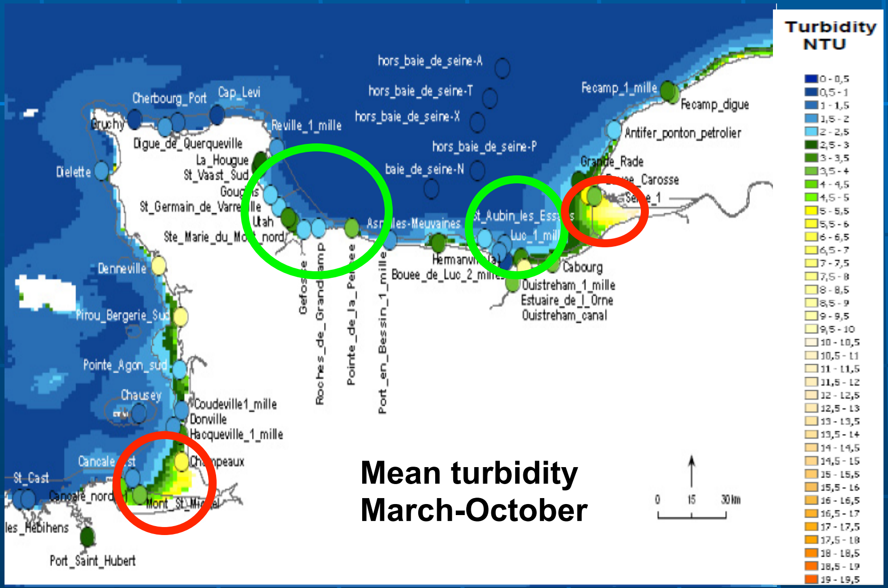


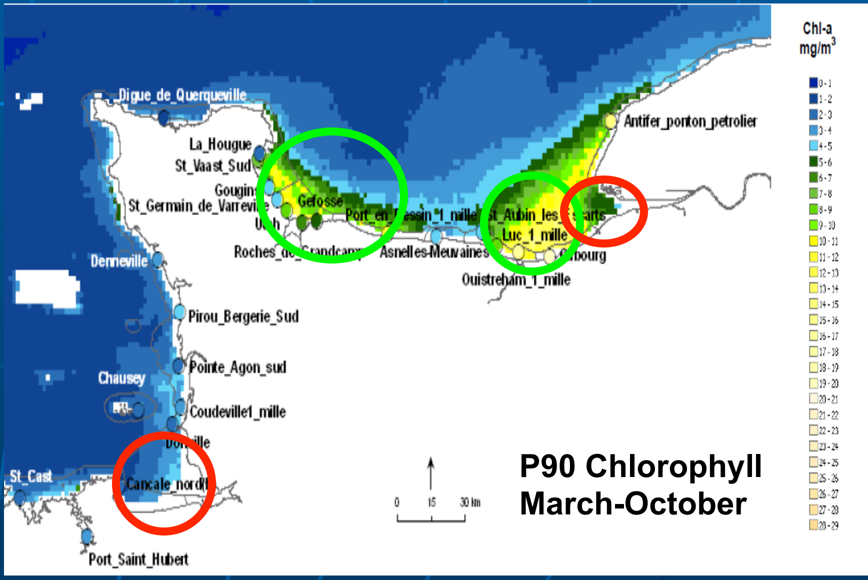
Illumination

Shallow waters

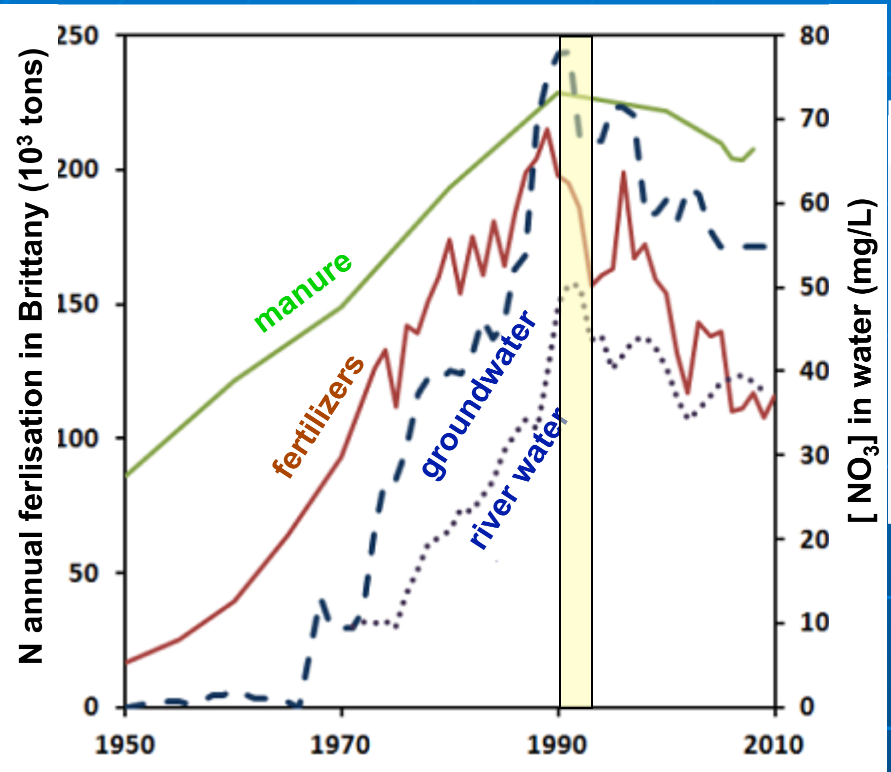


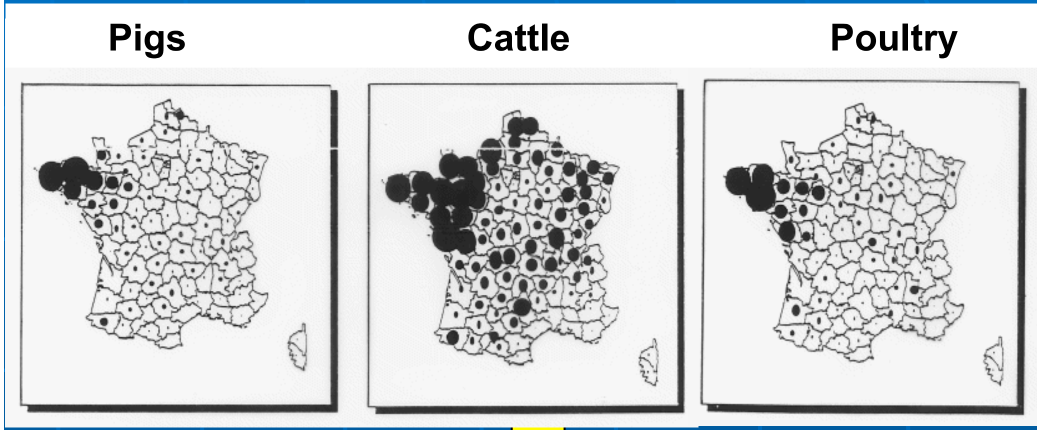
Clear waters

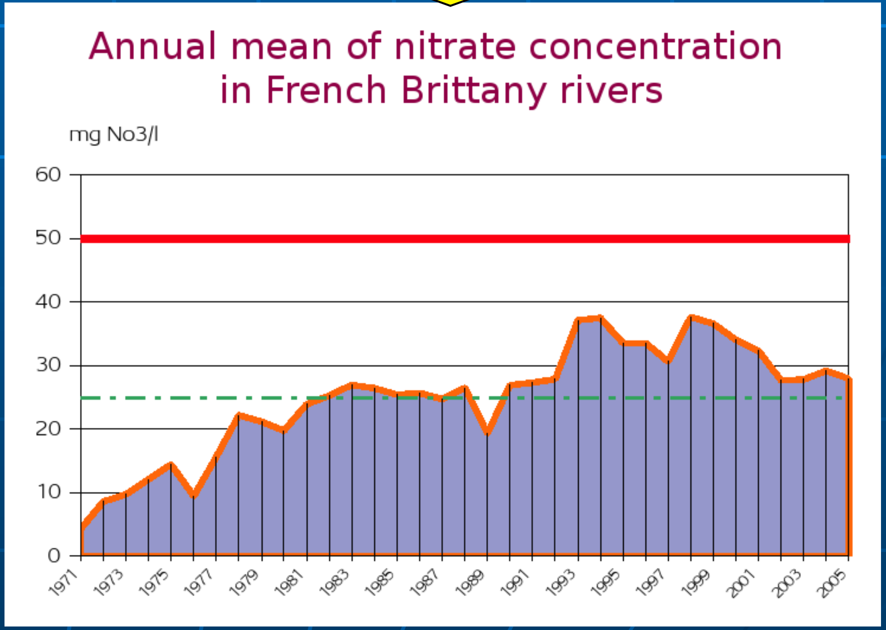




Nitrogen increase (case of Brittany)



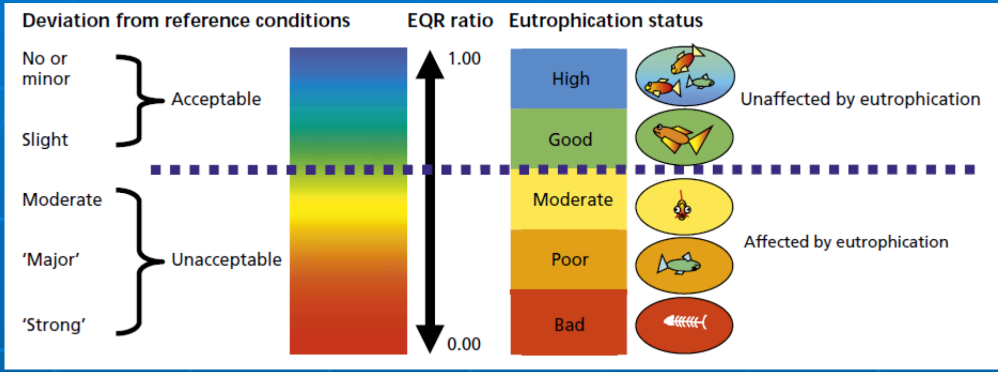




Intensive livestock farming has increased land fertilization by a factor 10 during the 1960-1990 period

Management aspects

The European Directives point of view

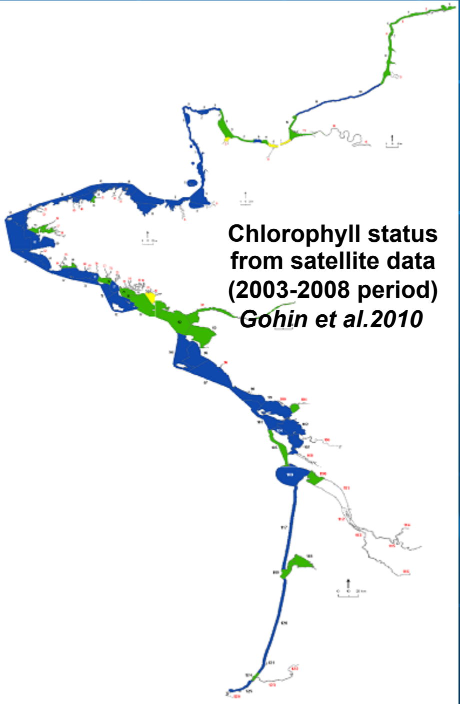


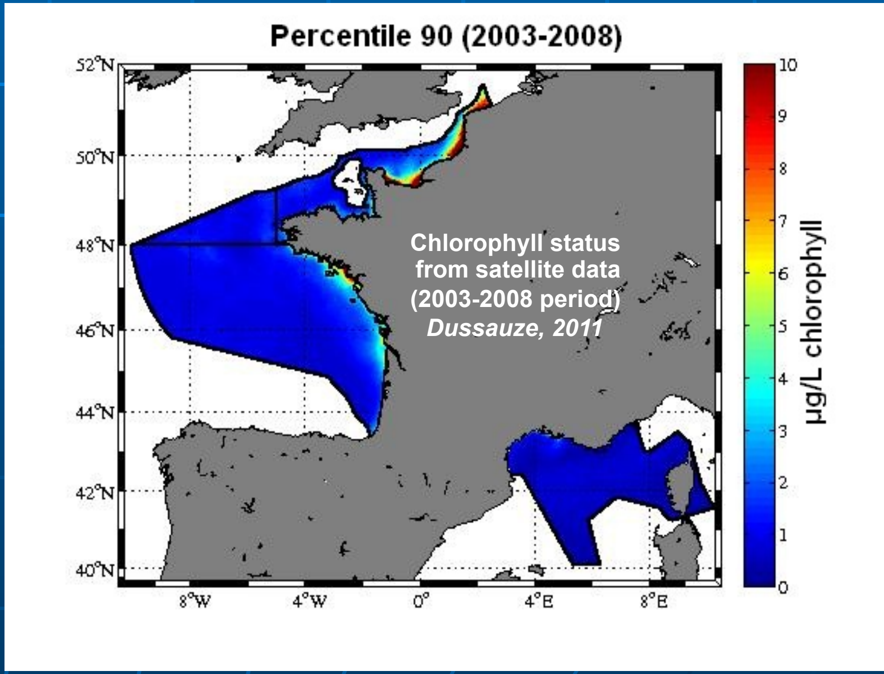
GES

Good Environmental Status of the EU's marine waters by 2020

Water Frame Directive (2000)
(for coastal water masses only)

Marine Strategy Frame Directive (2008)
(for continental shelf sub-regions)





But…

<u>No legal threshold for marine nutriments</u> !

For NO_3, the 50mg/L maximum admissible concentration is only for drinkable freshwater ;

50 mg/L NO_3 ≈ 10 times the freshwater pristine concentration

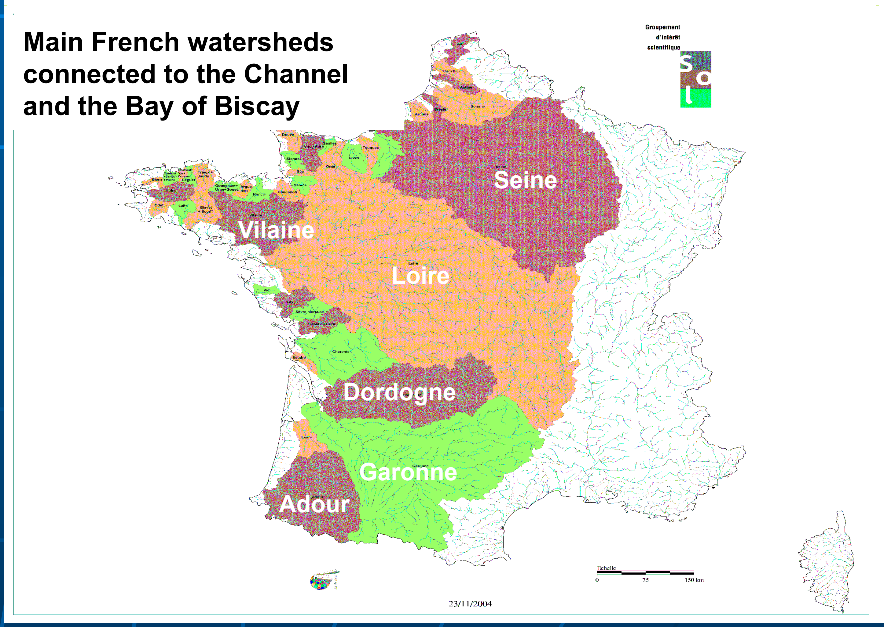
≈ 100 times the coastal marine pristine concentration !

<u>Various national thresholds for marine chlorophyll</u> !

Percentile 90:

For France (Atlantic):	5	10	20	40	µg/L chlorophyll
For UK:	10	15	20	25	µg/L chlorophyll
For Spain (Biscay):	2	5	10	15	µg/L chlorophyll

<u>Many small watersheds and few big ones involved in coastal marine enrichment</u>

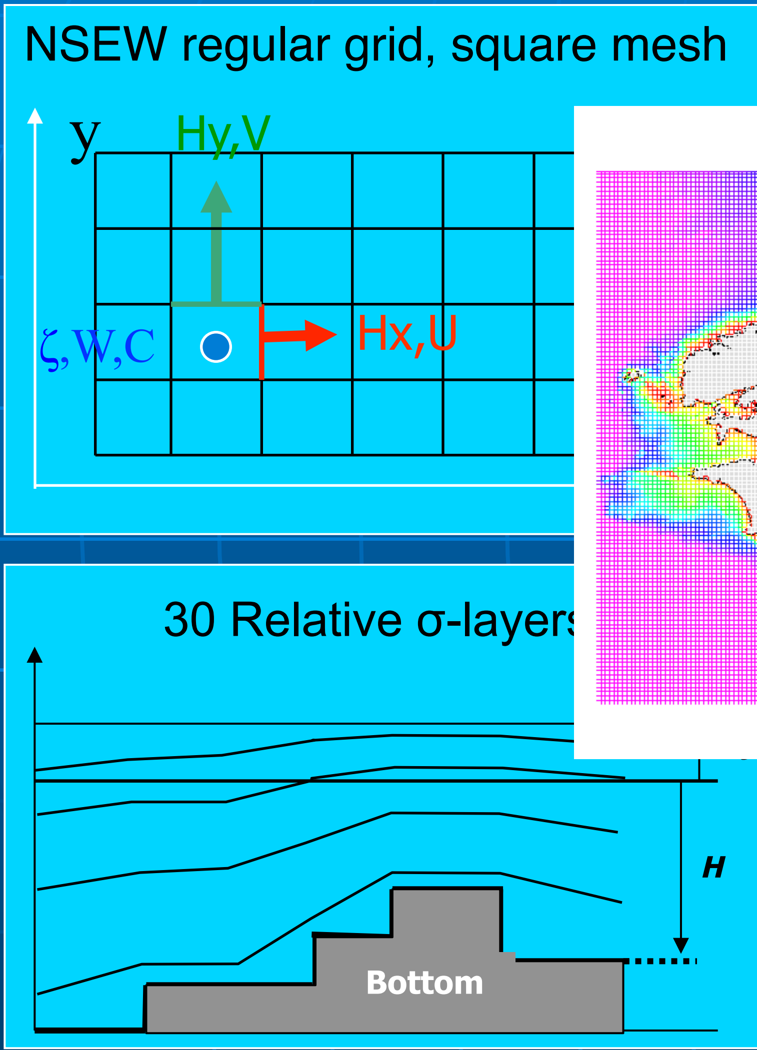


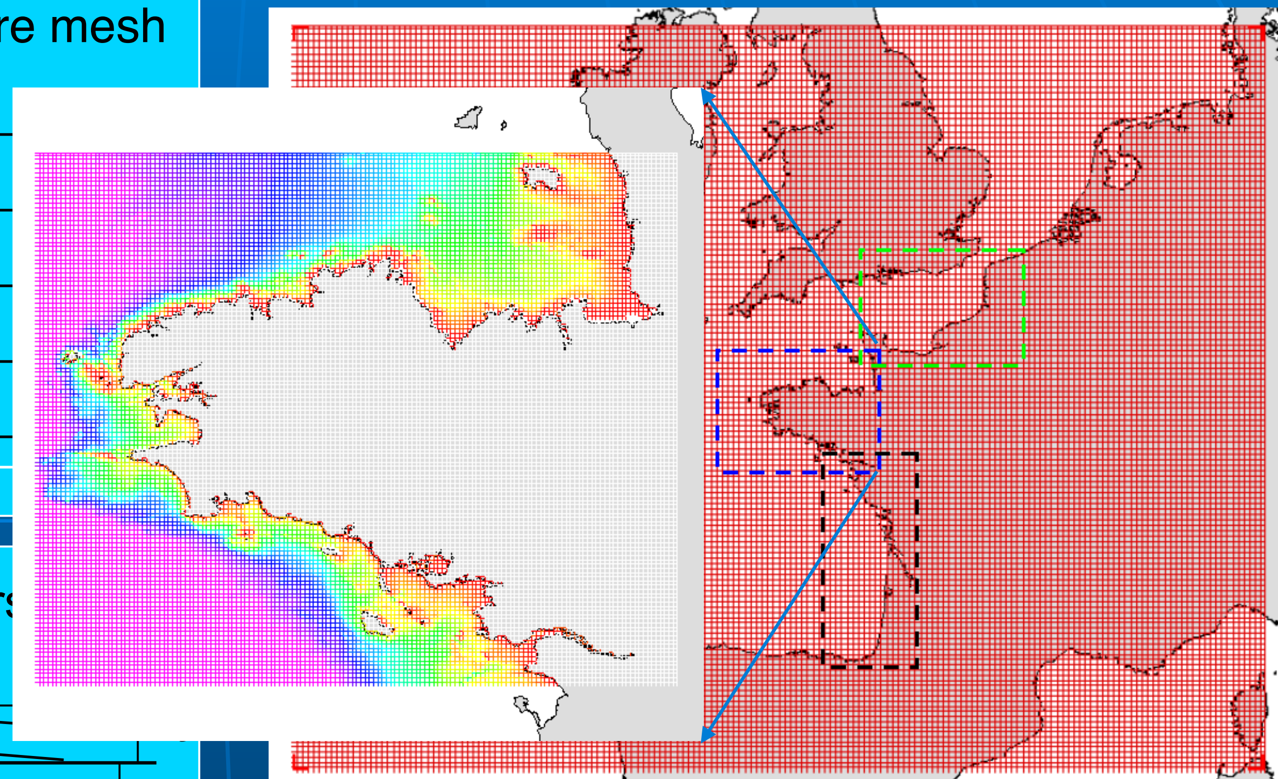
4 recurrent questions:

- What is the marine area influenced by each river?
- When several plumes merge in a coastal zone, what is the respective influence of each plume on the eutrophication?
- What would be the optimal nutrient reduction scenario for a given marine target?
- Can we provide real-time maps of risk for hypoxia or toxicity?

The modelling tool

The hydrodynamic MARS-3D model

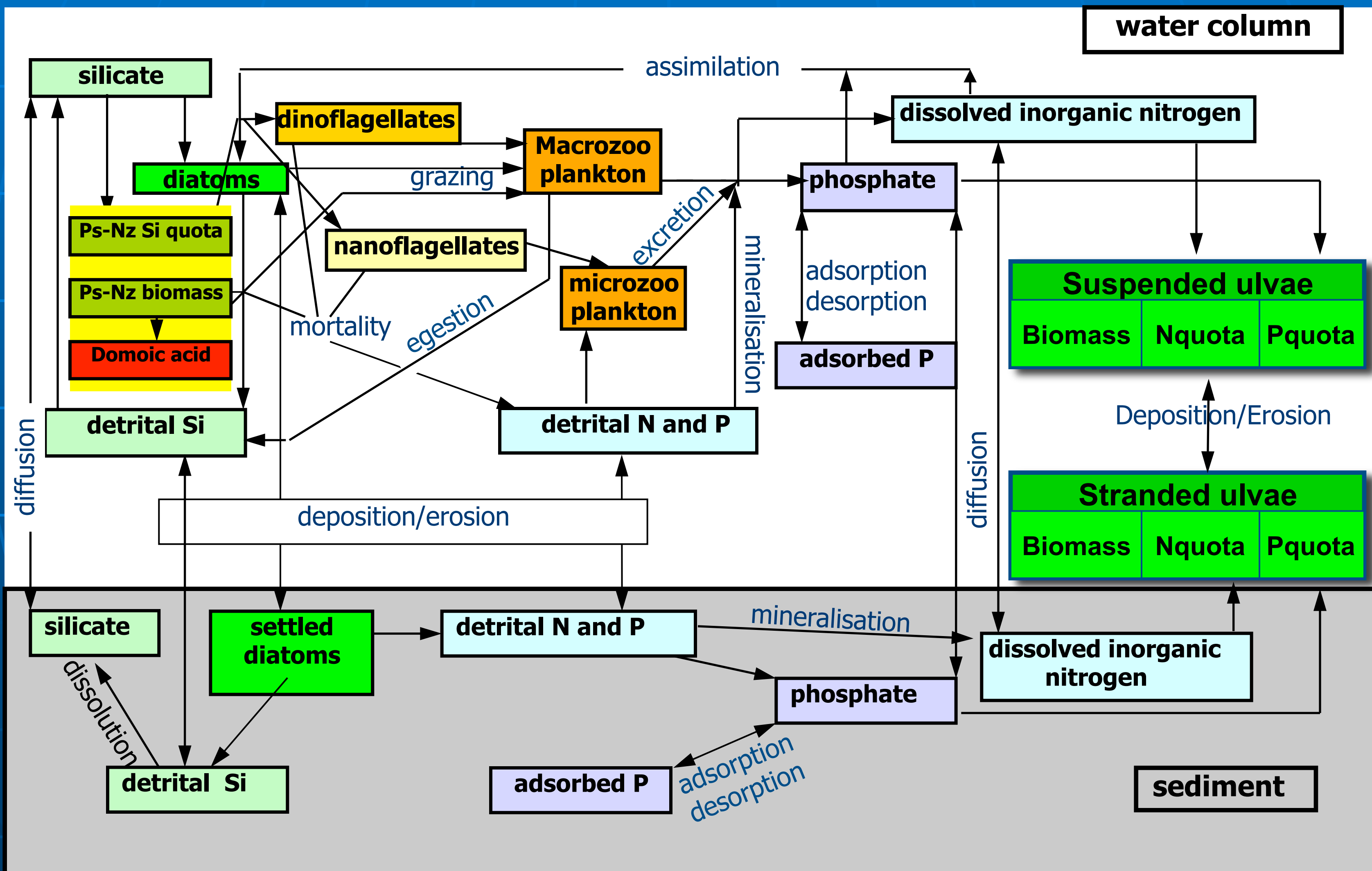




Basic grid → 4x4 km meshes

Grids for small plumes → 1x1 km meshes

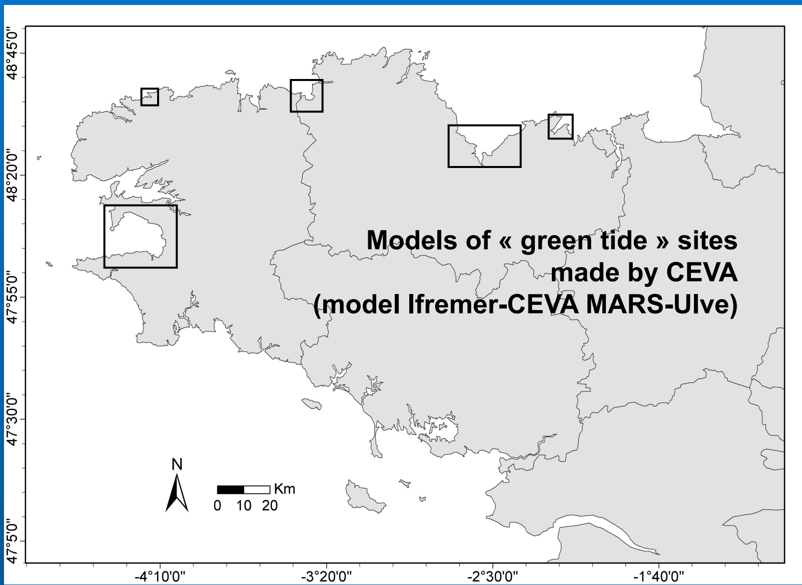
The biogeochemical model ECO-MARS3D



Off-line scenario results

1/ Case of on-shore « green tides »

Simulation of reduction scenarios of nitrate river loading



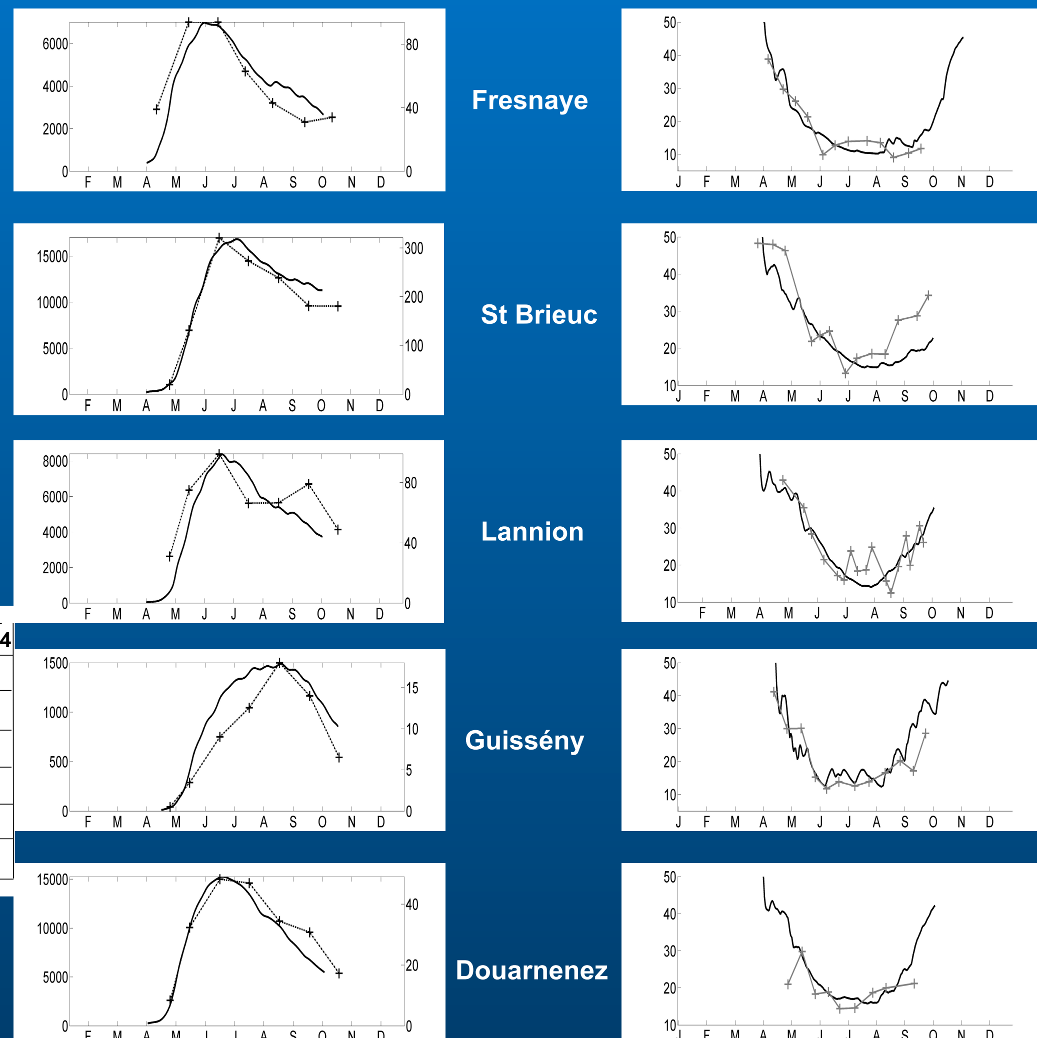
	Lannion 2005	Douarnenez 2005	St-Brieuc 2002	Guissény 2005	Fresnaye 2004
5 mg.l^{-1}	69	77	54	71	74
10 mg.l^{-1}	51	60	41	53	62
15 mg.l^{-1}	36	44	30	41	51
20 mg.l^{-1}	23	29		31	42
25 mg.l^{-1}	13	15		25	31
30 mg.l^{-1}	6	8		18	24

Simulated decrease (%) of the green tide for various nitrate concentrations in rivers

10mg/L NO_3 is necessary to halve the green tides

Measured coverage (ha) and simulated biomass (tons of fresh weight)

Ulva nitrogen content (‰ dry weight) measured and simulated

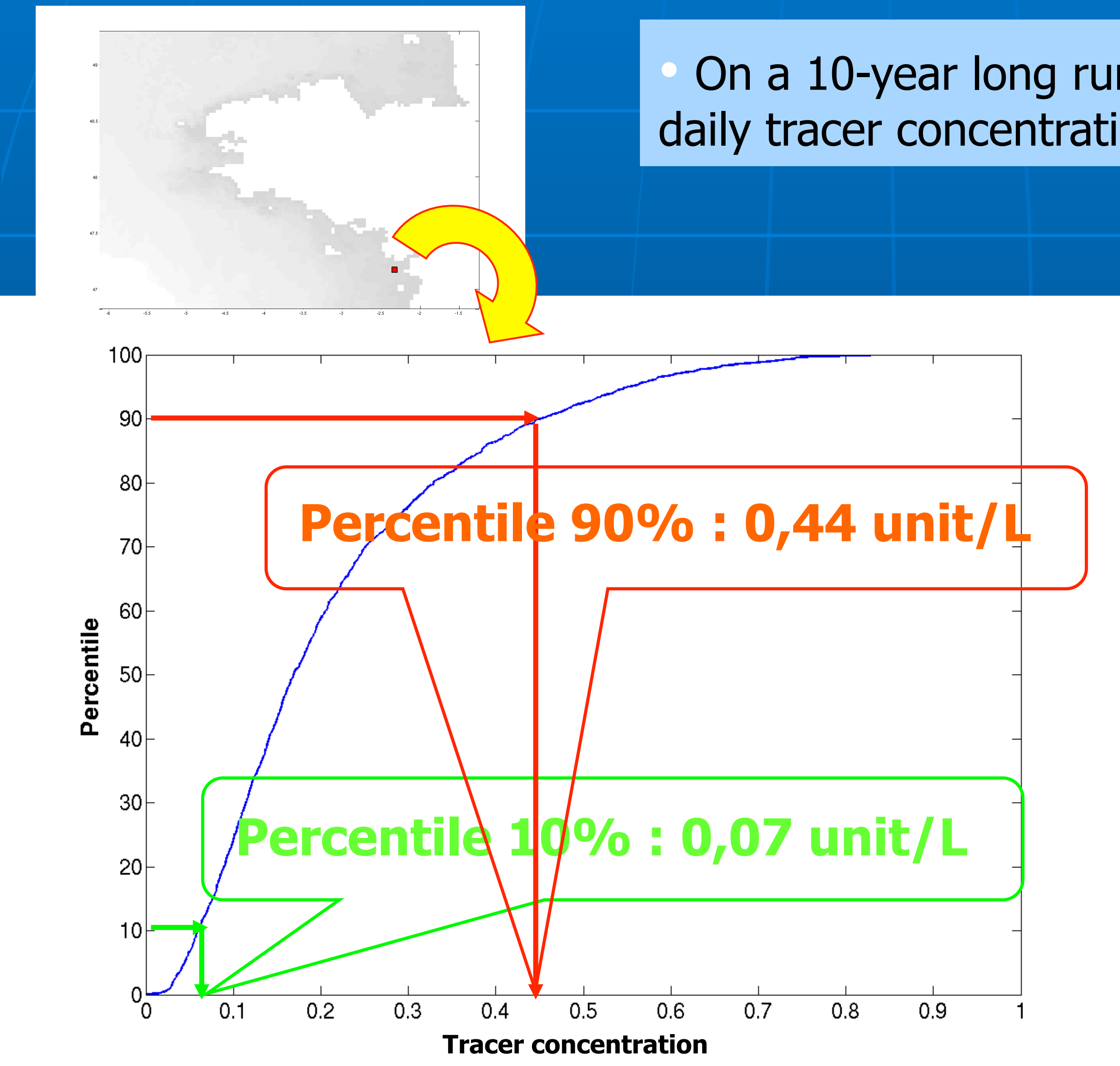


Ifremer

2/ Case of off-shore « coloured waters »

Computing the statistical region of influence of a river

- A conservative tracer is permanently forced to 1 in the river under study



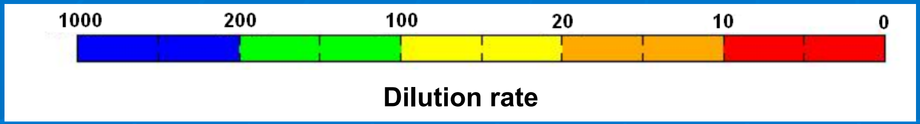
- On a 10-year long run, the model provides 3650 daily tracer concentrations in every mesh

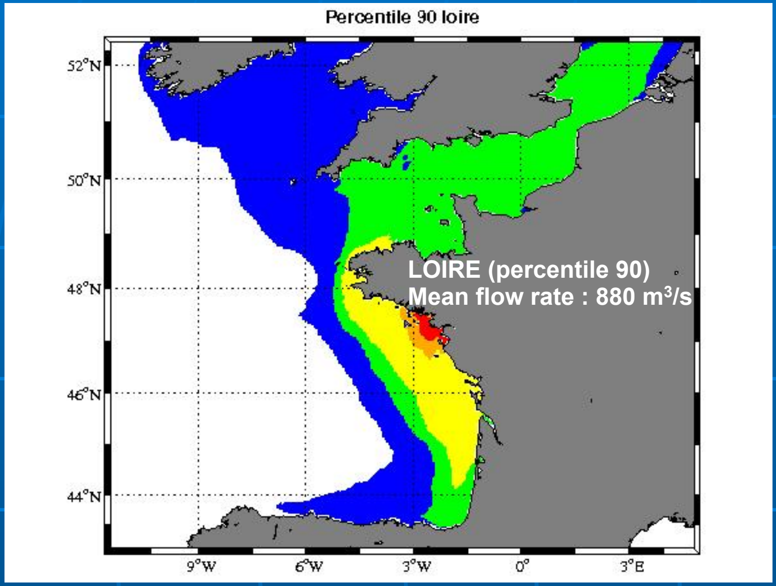
- In every mesh, the distribution function of these 3650 values can be computed

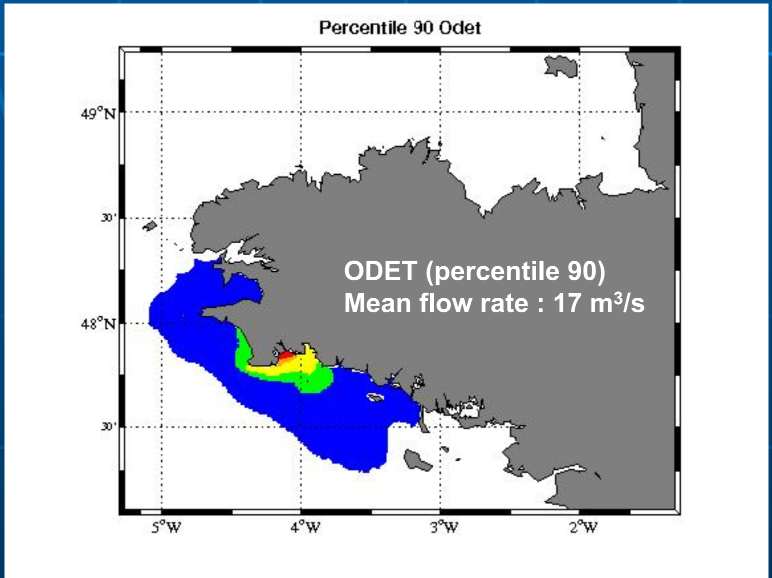
- Any percentile value can be deduced:
  e.g. the median and the percentiles 10% and 90%

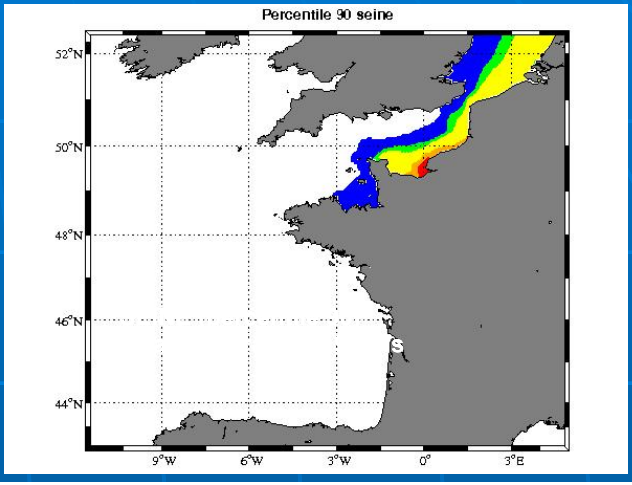
- A map can be drawn for any specific percentile

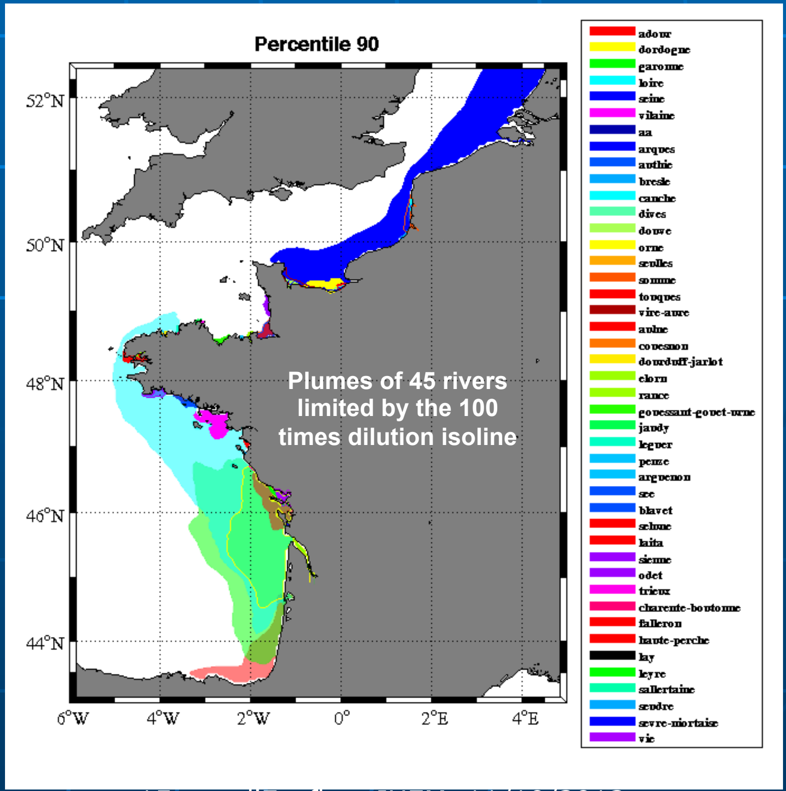
Some results along the Atlantic-Channel coast











Optimising global nitrate reduction

(ONEMA-Ifremer project)

Principle: In winter, nitrate is a conservative tracer

➔ Anywhere, marine nitrate concentration is a linear combination of diluted river loadings and oceanic background

➔ Linear optimization technique (Simplex) applies

Questions:

- Which is the Good Ecological Status marine level?

➔ **15 µmol/L NO_3 or more ?**

- Which is the price of a 1mg/L NO_3 reduction in a river?

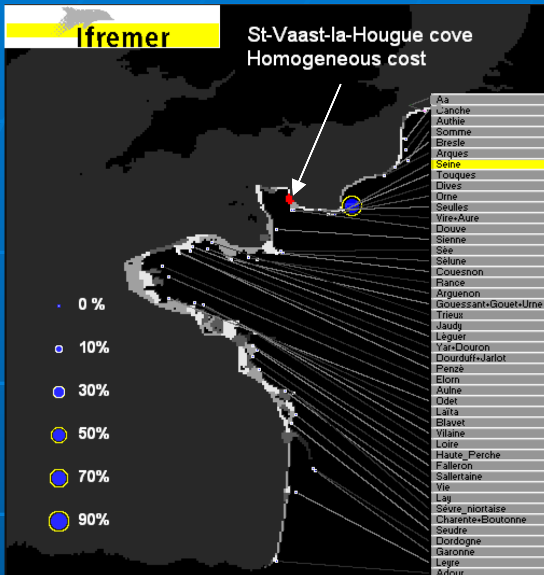
➔ **Homogeneous or Proportional to watershed area ?**

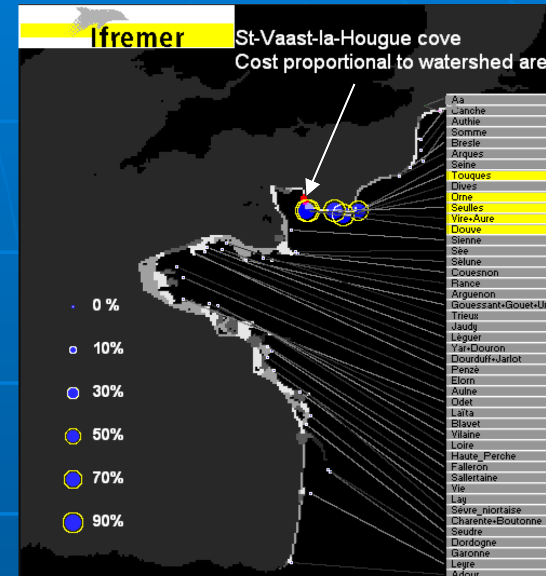
- Which is the target area ?

➔ **A single WFD mass ?**
All the WFD masses together ?
A MSFD sub-region ?
A bathymetric stratum ?

Various optimised nitrate reductions

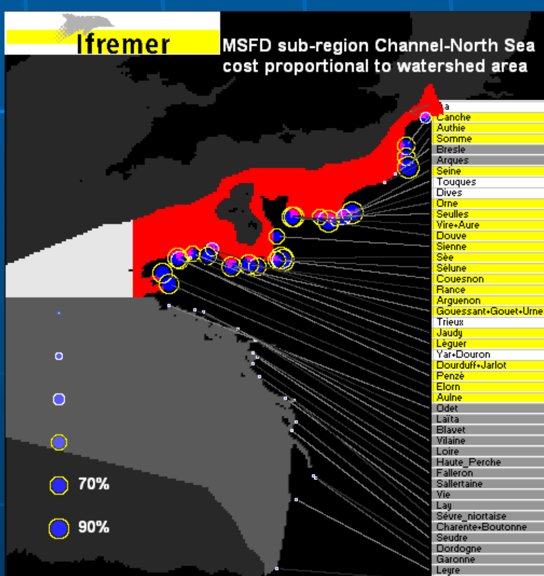
(ONEMA-Ifremer project)

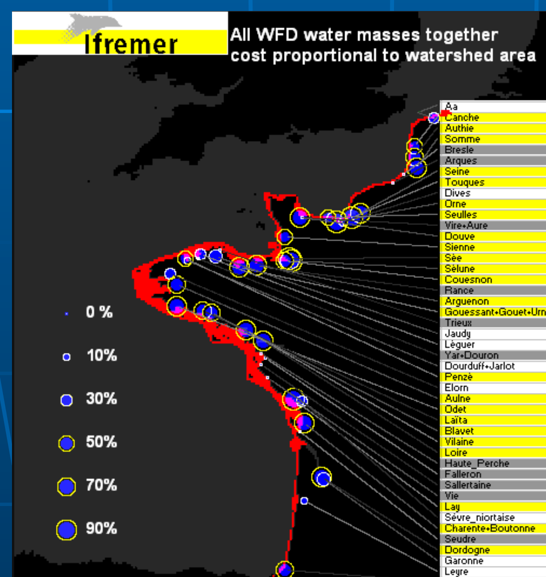


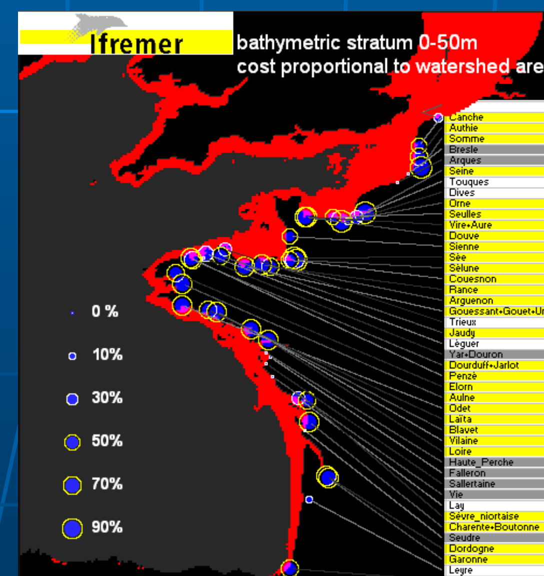


For a single WFD water mass, different rivers may be chosen depending on the cost of nitrate reduction

Extending the target area involves more and more rivers

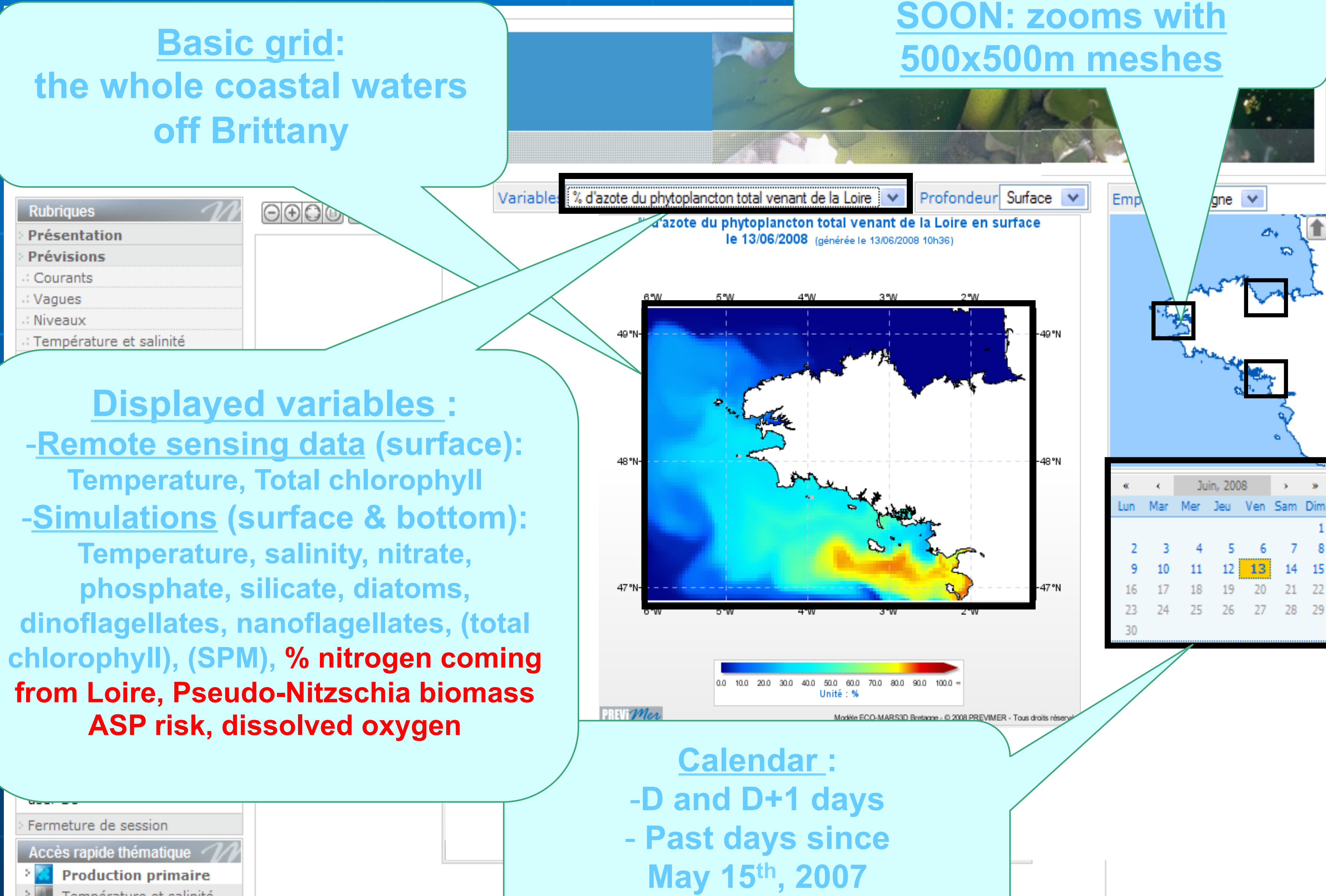






On-line real-time modelling of risks

On-line previsions on previmer.org website



Basic grid:
the whole coastal waters off Brittany

SOON: zooms with 500x500m meshes

Displayed variables :

-Remote sensing data (surface):
Temperature, Total chlorophyll

-Simulations (surface & bottom):
Temperature, salinity, nitrate, phosphate, silicate, diatoms, dinoflagellates, nanoflagellates, (total chlorophyll), (SPM), % nitrogen coming from Loire, Pseudo-Nitzschia biomass ASP risk, dissolved oxygen

Calendar :

-D and D+1 days

- Past days since May 15th, 2007

- Animations 12, 24 et 48 d

Tracking river nitrogen on-line!

Concept : Tracking any evolutive signature in a distributed trophic network

Ménesguen et al., 1997 MEPS ; Ménesguen et al., 2005 Limnol. Oceanogr.

For the biogeochemical state variable B_i, having the signature $S(B_i)$:

- the current mass evolution equation is:

$$\frac{dB_i}{dt} = sources(B_1,B_2,..B_n,t) - sinks(B_1,B_2,..B_n,t)$$

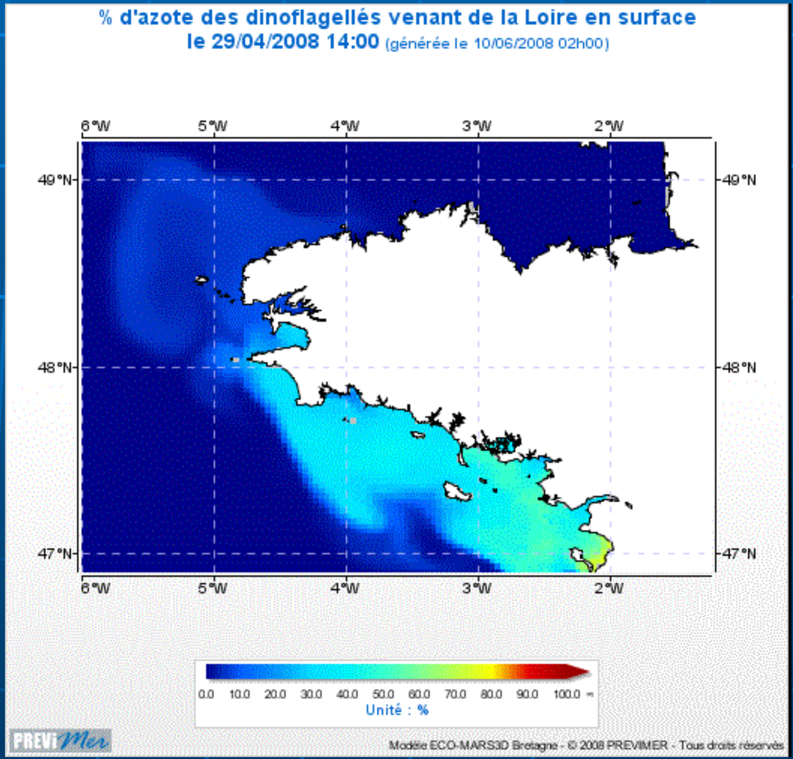
- the new « signed mass » evolution equation is:

$$\frac{dBs_i}{dt} = sources(B_1,B_2,..B_n,t) \times S(source) - sinks(B_1,B_2,..B_n,t) \times S(B_i)$$

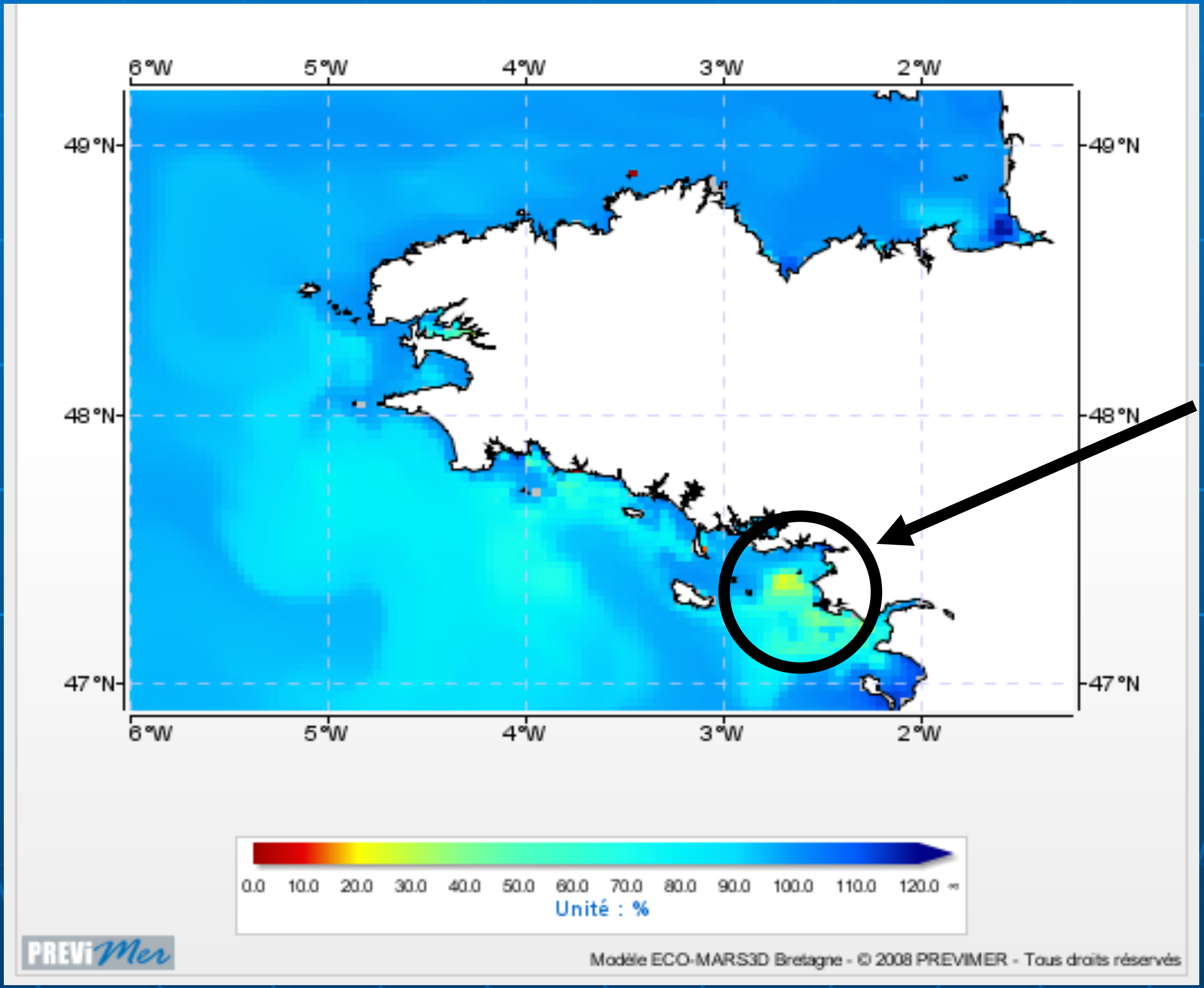
- the signature $S(B_i)$ is:

$$S(B_i) = Bs_i / B_i$$

Application : Diatom nitrogen fraction (%) coming from Loire river

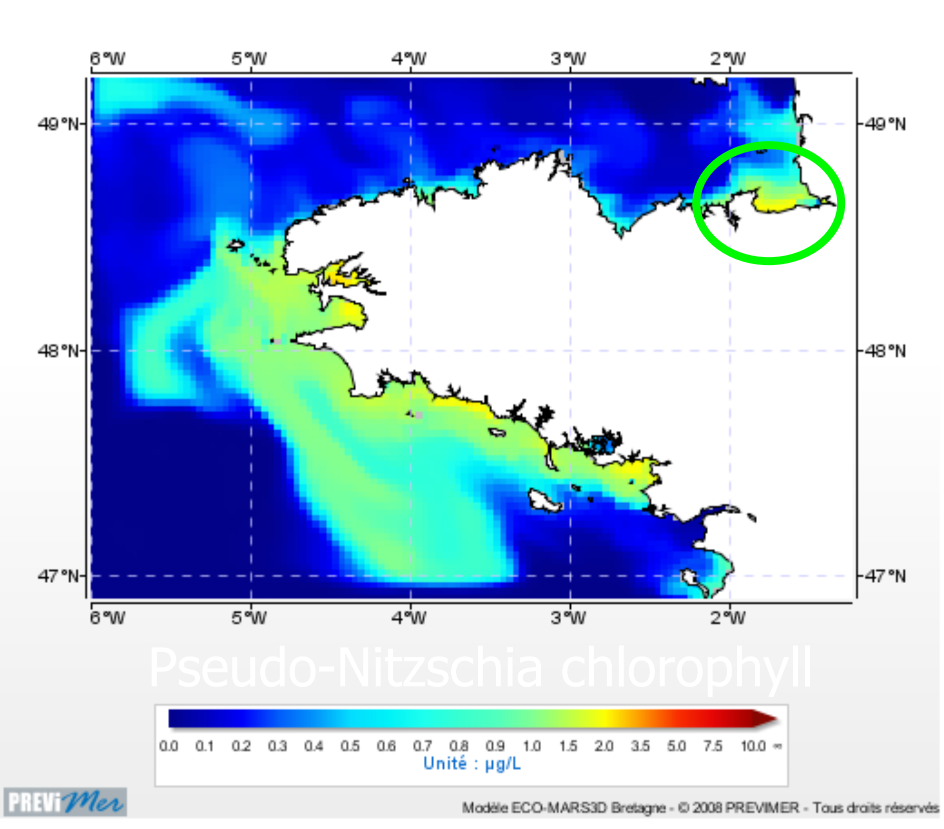


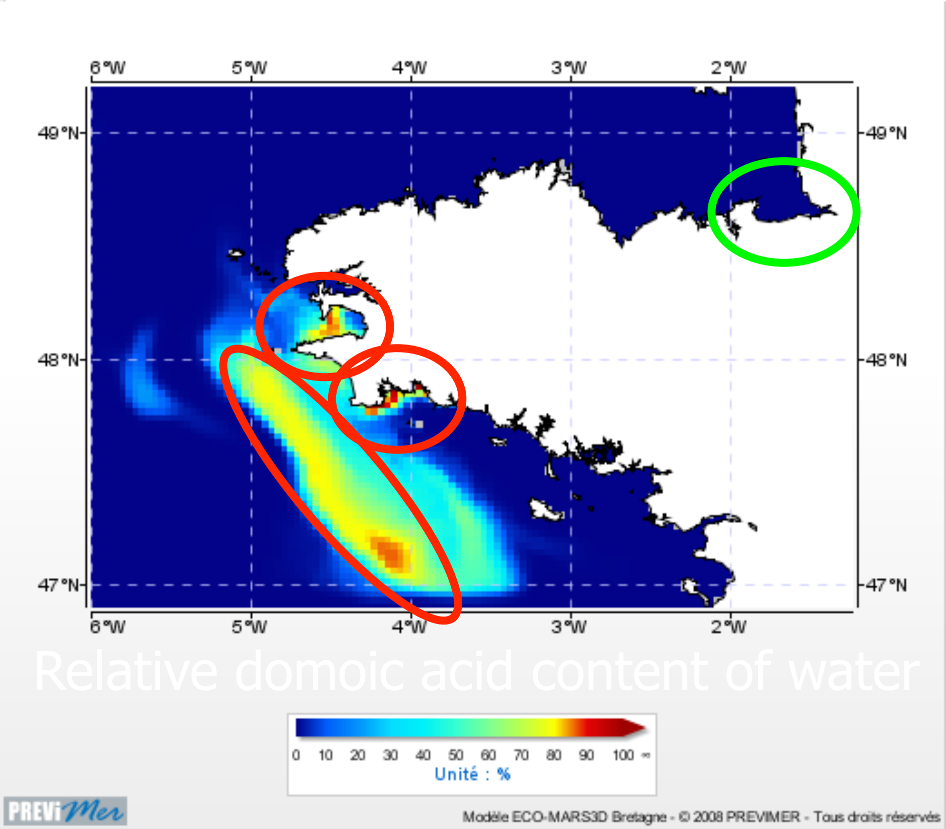
Hypoxia alert on July 27th, 2007



Bottom saturation: 20%

ASP alert on May 12th, 2008





CONCLUSION

- Eutrophication of many coastal waters is a multisource phenomenon, that will continue for many years. 3D modelling can help to determine more accurately in space and time the nutrient sources which are the most responsible.

- Hydrodynamical models can delineate the statistical marine receiving area of any watershed.
- Eco-hydrodynamical models can track the chemical inputs of any watershed in the global trophic web all over the domain.

- Nitrogen remains a dominant control variable in marine coastal ecosystems, and scenarios modelling points to 10mg/L NO_3 in river waters as a good target for marine Good Ecological Status

- Today, results of operational 3D biogeochemical models of the shelf can daily provide on the Internet some eutrophication descriptors: dissolved oxygen, total chlorophyll, toxic species abundance…

Thank you
for your attention