A 38 years hindcast of a coupled physical-biogeochemical model and derived indices for fisheries oceanography

Martin Huret[1], Pierre Petitgas[1], Marc Sourisseau[2], Caroline Struski[1], Fabien Léger[3] and Pascal Lazure[2]

Introduction

Operational oceanography rapidly progresses and its products become easy to access to a large community, among them fisheries scientists. The products cover both near real-time environment information (on scales of days to weeks) but also retrospective analysis providing long time series of environment parameters. Here we describe a 38 years hindcast of a coupled physical-biogeochemical model of the Bay of Biscay as well as the indices and major information that were derived from it.

The validation process

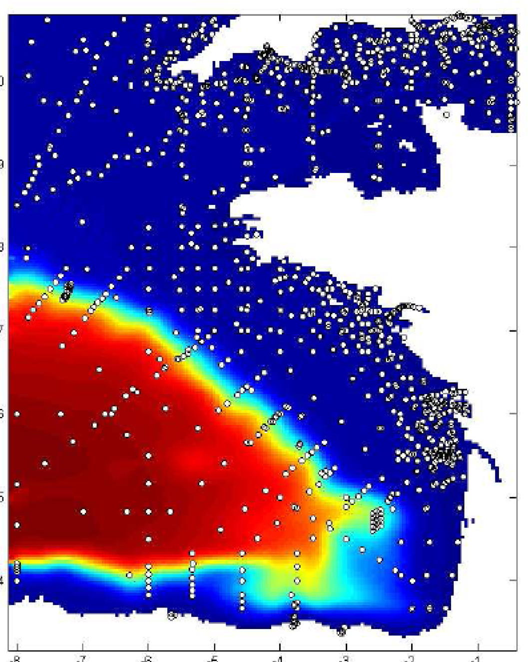


Figure 1: Spatial distribution of the dataset.

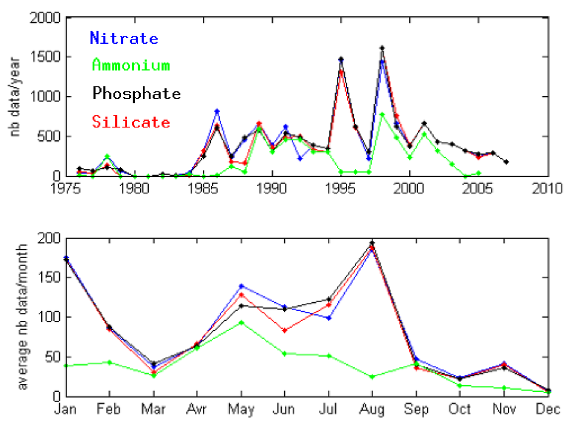


Figure 2: Temporal distribution of the dataset.

- Origin : ICES data center / SISMER

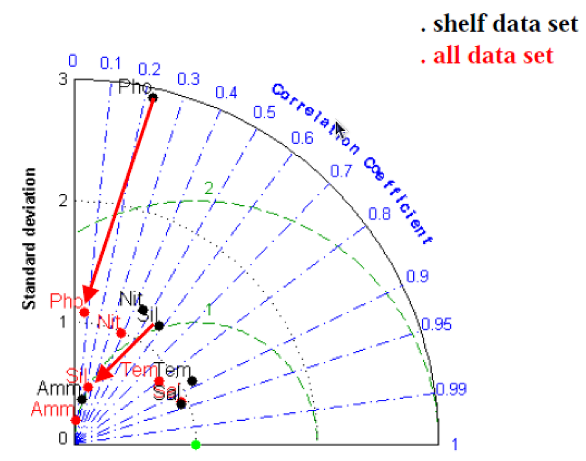


Figure 3: Taylor diagram for T, S and nutrients. Distance to the green point (representing the dataset) is the centered RMS difference between the simulated and observed fields.

- Best results for physical variables (S then T)
- For nutrients (Si, NO3$^-$, NH4$^+$ and then PO$_4^{3-}$ in best fit order)

The coupled physical-biogeochemical model ECOMARS3D

Initial and boundary conditions

T,S : Reynaud climatology

Surface elevation: from a 2D configuration

Bio: WOA 2005

Atmospheric forcing

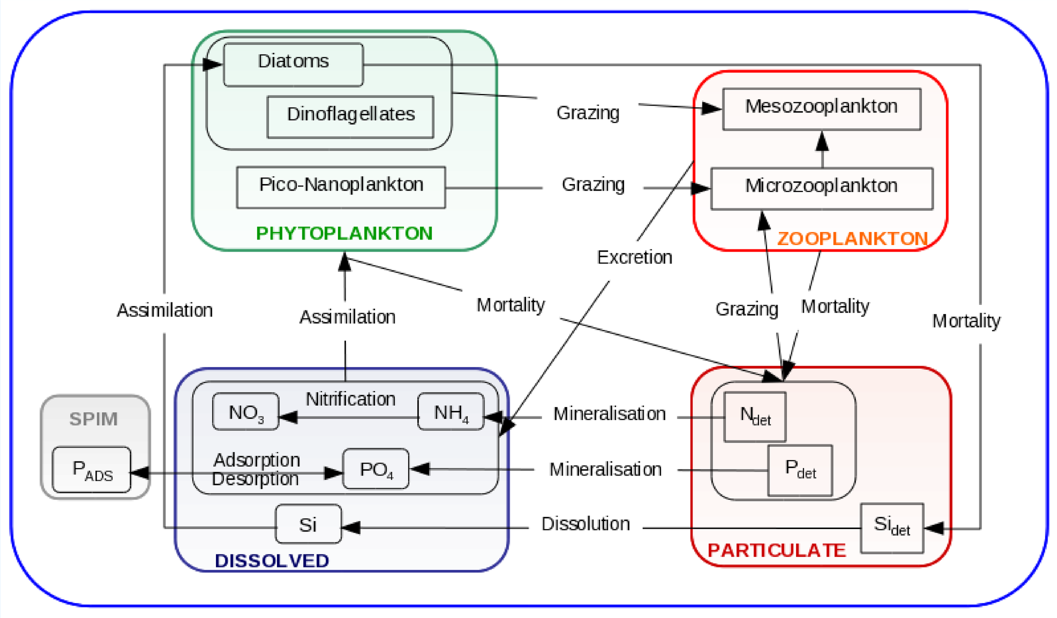
ERA40 + ARPEGE (from 2002)
Wind, Air Temp., Atm. pressure, cloud cover

River loads

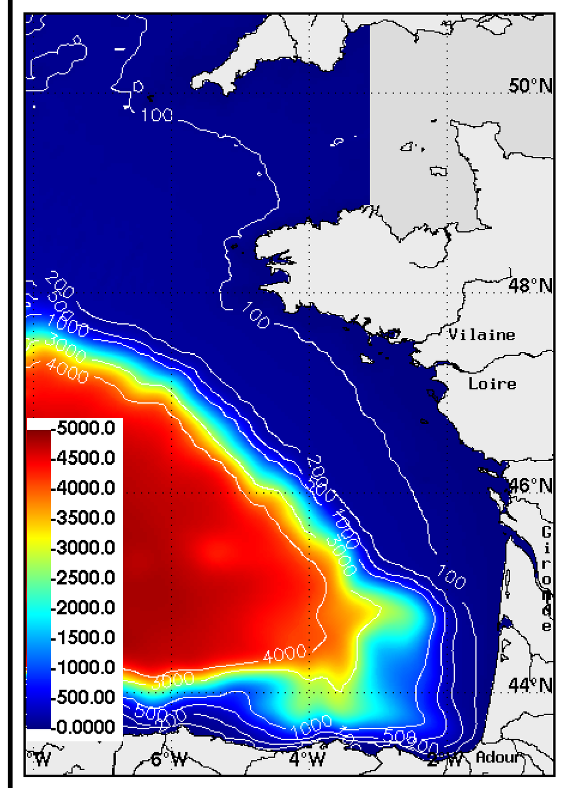
daily runoff from 4 rivers

+ NH4, NO3, PON, SiO2, PO4, POP from empirical relations
SPM: sat. clim.

3D prognostic ocean model MARS3D *(Lazure et al., 2008, 2009)* + **ECOMARS model** ***($N_3P_3Z_2D$ model)***



Configuration – simulation



Grid: 4 km horizontal resolution
30 σ levels

Extension: 43.2ºN – 50.8ºN
8ºW – 0.4ºW

Simulation period: 1971-2009

Output: 3 days frequency and averaging

Mesoscale and biological indices

Stratification indices
Deficit of potential energy
Max. vertical gradient in temperature
Max. vertical gradient in density
Depth of thermocline
Depth of pycnocline
Depth of halocline
Frontal indices
Thermal front from Deficit in pot. energy
Density front from Deficit in pot. energy
Thermal front from Max. vertical gradient
Density front from Max. vertical gradient
Upwelling indices
Integrated vertical velocities
Plume indices
Surface salinity at 3m
Equivalent freshwater depth
Eddy indices
Vorticity (at 10m depth)
Okubo-Weiss (at 10m depth)
Biological indices
Surface chlorophyll-a concentration
Integrated primary production

Table 1: List of derived indices. They are calculated on the 3 days averaged fields from the hindcast.

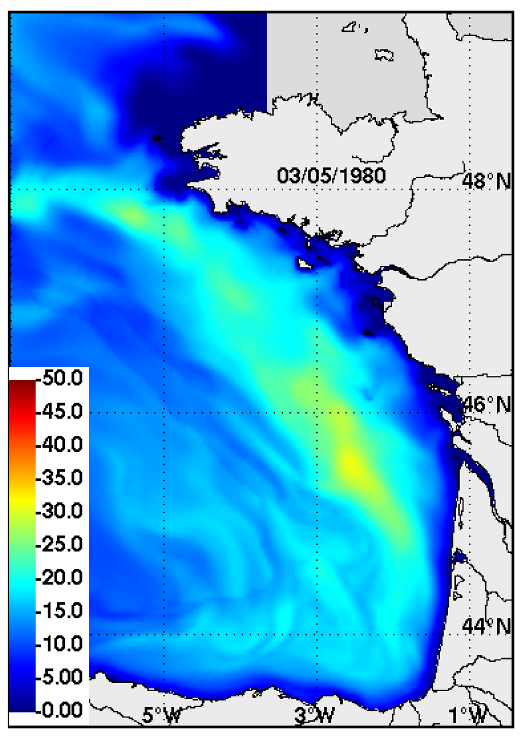


Figure 4: Snapshot of thermal stratification from deficit of potential energy (kg.m^{-1}.s^{-2}).

$$Deficit\ potential\ Energy = \frac{1}{H_0+\xi}\int_{-H}^{\xi}(\bar{\rho}-\rho_z)gz\,dz$$

with H the bathymetry and ξ the free surface elevation

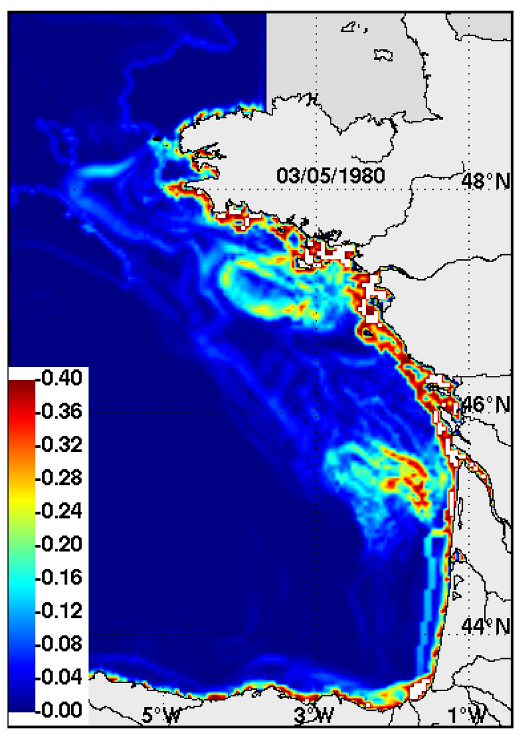


Figure 5: Snapshot of the front index from maximum vertical gradient of density (x10^{-4} kg.m^{-3}.m^{-2}).

$$Front\ index(i,j) = \frac{1}{2}max\left(\frac{Strat_{(i+1,j)}-Strat_{(i-1,j)}}{dx_{i,j}}, \frac{Strat_{(i,j+1)}-Strat_{(i,j-1)}}{dy}\right)$$

with *Strat* an index of stratification based on :

- the deficit of potential energy or
- the maximum vertical gradient of temperature, salinity, or density.

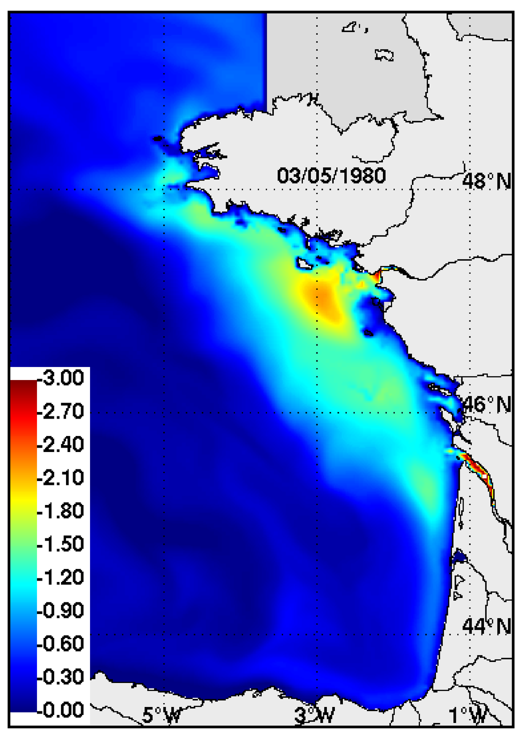


Figure 6: Snapshot of equivalent freshwater depth (in meter).

$$Eq.\ freshwater\ depth = \int_{-H}^{\xi}\frac{S_0-S_z}{S_0}dz$$

with S_0 a reference salinity

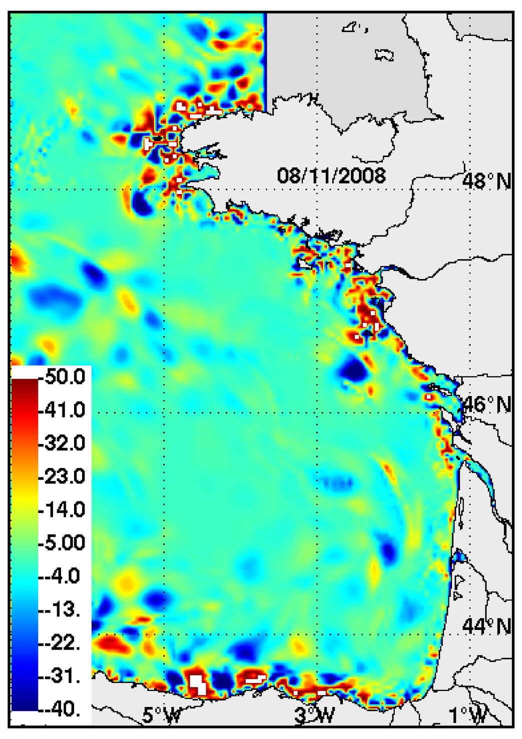


Figure 7: Snapshot of the eddy index from Okubo-Weiss at 10m depth (x10^{-12}.s^{-2}).

$$Okubo\ Weiss = \left(\frac{\partial u}{\partial x}-\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2-\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)^2$$

First two terms refer to the shear stress, last one refer to vorticity. Eddies are low values delineated by high values.

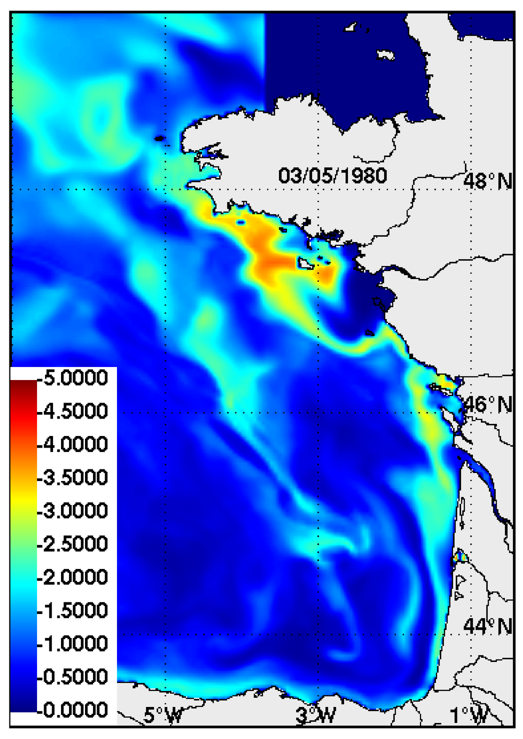


Figure 8: Snapshot of integrated primary production (gC.m^{-2}.day^{-1}).

Evaluating the environment variability with the indices

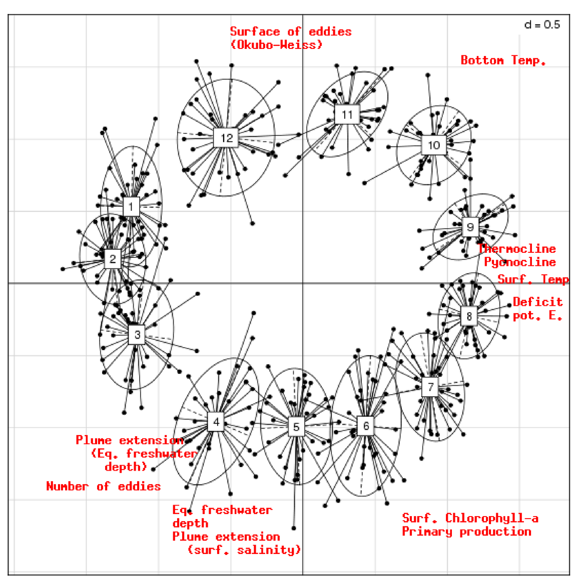


Figure 9: First factorial plan (74% of the variance explained) of a Multi-Factorial Analysis (MFA) on monthly values of indices averaged over the Bay of Biscay. Points represent each month of each year.

- Stratification and surface temperature separates winter and summer months
- Plume extension characterizes spring months
- Number of eddies max. in spring, surface of eddies max. in autumn
- Primary production highest in spring to summer months

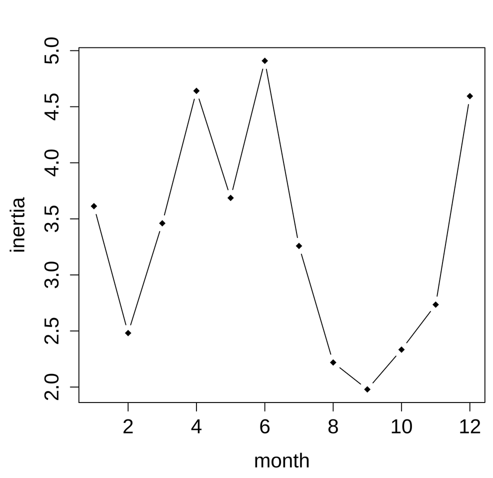


Figure 10: Variability for each month based on the MFA (see Fig. 9) : inertia around the centre of gravity per month.

- Maximum inter-annual variability in the environment in spring and December
- Minimum variability in late summer to autumn, and in February

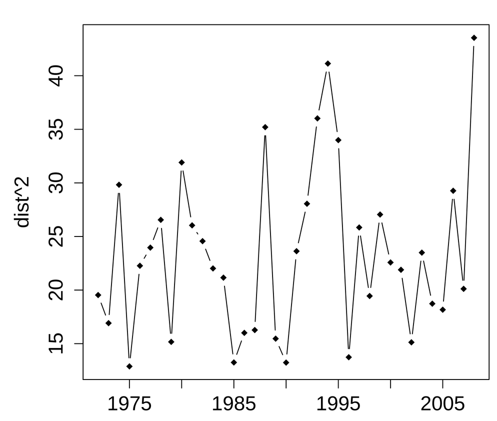


Figure 11: Difference to the mean seasonal pattern for each year based on the MFA (see Fig. 9) : sum of the distances to the centre of gravity by month for each year, normalized by the variance per month.

- The method extracts singular years (1988, 1993 to 1995, 2008) from the years close to the average pattern (1975, 1985, 1990, 1996)
- Note that interannual variability has only local origin (meteo and river), boundary conditions do not vary among years

Temporal trends in the time-series

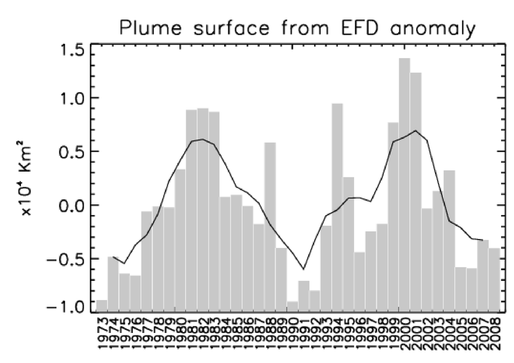


Figure 12: Anomalies of annual mean of plume surface based on the equivalent freshwater depth index.

- 2 periods of high freshwater influence over the shelf with peaks in 1981-1983 and 2001-2002.

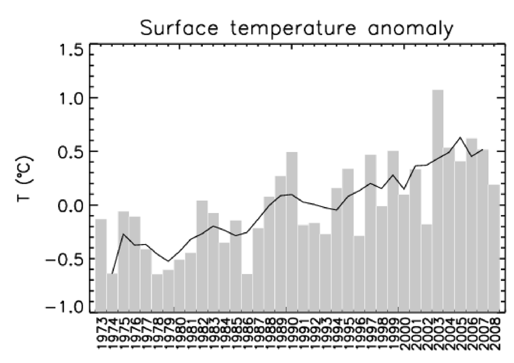


Figure 13: Anomalies of annual mean in surface temperature.

- Increase trend in surface temperature over the hindcast period
- 0.165°C/decade ($p < 0.001$) over the whole period
- 0.336°C/dec. ($p < 0.01$) from 1985

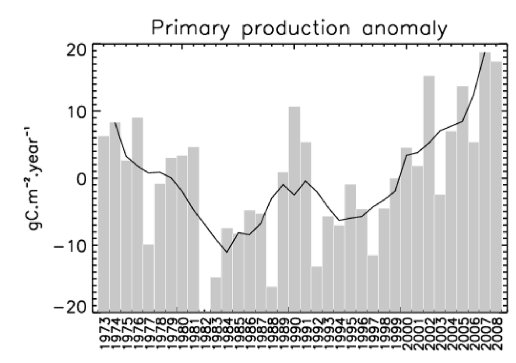


Figure 14: Anomalies of total annual primary production.

- Decrease until the early 80's, then increase of the total annual PP
- Potential effect of river load increase in nutrients (as parameterised in the forcing with empirical relationship)

Hindcast use for fisheries application : anchovy

- Modelling of potential fish habitat (Planque et al. 2007)
- Recruitment-environment relations → potential negative effect of river run-off (Planque et al. 2008)
- Forcing conditions for fish dynamic modelling (Struski et al., 2009)
- Ecosystem assessment in relation to fish life cycles (Petitgas et al., 2009; Woillez et al. 2010)
- Larval dispersal kernel → retention in the SE Bay with current spawning pattern (Huret et al. 2010)

References

Huret M., Struski C., Léger F., Petitgas P., Lazure P. and Sourisseau M. (2009)
Modélisation couplée physique-biogéochimie du golfe de Gascogne sur la période 1971-2007.
R.INT.DOP/EMH/ 2009-01

Huret, M., Petitgas P. and Woillez M. (2010)
Dispersal kernels and their drivers captured with a hydrodynamic model and spatial indices : a case study on anchovy (*Engraulis encrasicolus*) early life stages in the Bay of Biscay.
Progress in Oceanography, in revision.

Lazure P. and Dumas F. (2008)
An external-internal mode coupling for a 3D hydrodynamical Model for Applications at Regional Scale (MARS).
Advances in Water Resources, 31(2):233-250.

Lazure P., Garnier V., Dumas F., Herry C. and Chifflet M. (2009)
Development of a hydrodynamic model of the Bay of Biscay. Validation of hydrology.
Continental Shelf Research, 29: 985-997.

Petitgas P., Huret M., Léger F., Peck M.A., Dickey-Collas M. and Rijnsdorp A.D. (2009)
Patterns and schedules in hindcasted environments and fish life cycles.
ICES CM 2009/E:25

Planque, B., Bellier, E. and Lazure, P. (2007)
Modelling potential spawning habitat of sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) in the Bay of Biscay.
Fisheries Oceanography, 16: 16-30.

Planque B. and Buffaz L. (2008)
Quantile regression models for fish recruitment-environment relationships : four case studies.
Marine Ecology Progress Series, 357:213-223.

Struski, C., Petitgas, P. and Huret, M. (2009)
Long-term hindcast and climate change forecast of habitat unsuitability using bioenergetics and physical-biogeochemical models: anchovy in the Bay of Biscay and the North Sea.
ICES CM 2009/E:22,

Woillez M., Petitgas P., Huret M., Struski C. and Léger F. (2010)
Statistical monitoring of spatial patterns of environmental indices for integrated ecosystem assessment, application to the Bay of Biscay pelagic zone.
Progress in Oceanography, in revision

[1]IFREMER, Centre de Nantes, Département EMH, BP21105, 44311 Nantes, France,
[2]IFREMER, Centre de Brest, Département DYNECO, BP 70, 29280, Plouzané, France,
[3]LEGOS/OMP, 14, Av. Edouard Belin - 31400 Toulouse, France.

Mail: martin.huret@ifremer.fr