Multi-scaling properties of remotely sensed oceanic chlorophyll maps

L. de Montera

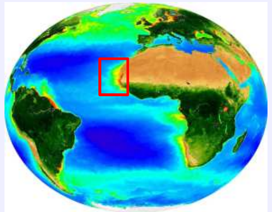
LOCEAN, Paris, France (Laboratoire d'Océanographie et du Climat : Expérimentation et Approches Numériques)

Abstract: The analysis of chlorophyll maps measured by the SeaWiFS orbiting sensor shows multifractal properties that are consistent with the statistical theory of turbulence. Therefore, within this scale range (1-128km), turbulent mixing seems to be the dominant effect explaining phytoplankton variability. Moreover, multifractal patchiness can cause significant biases in the nonlinear terms involved in biogeochemical numerical models.

Experimental dataset (1)

The Senegalo-Mauritanian Upwelling

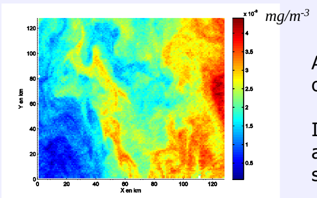
- High chlorophyll concentration
  - => low relative noise
- Very sunny weather
  - => large zone of available data



10-26°N / 14-26°W

100 SeaWiFS chlorophyll maps with no cloud cover

*(128*128km, resolution 1*1km, product L2, period: 07/2003-06/2004)*

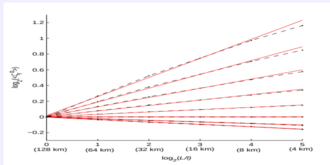


All maps were check manually because of isolated unrealistic pixels.

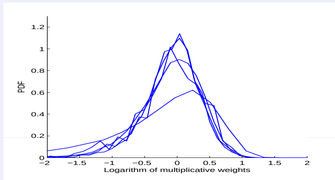
Is it possible to describe these chaotic and highly heterogeneous data in a simple way?

Multifractal model and validation (2)

FIF model (Fractionnaly Integrated Flux, Schertzer & Lovejoy, 1987)



Scaling of statistical moments



PDF of log of cascade weights for each resolution

Kolomogorov-like law for chlorophyll concentration:

$$\Delta Chl_l \simeq \zeta l^H$$

Multifractal intermittency:

$$\langle \zeta_l^{\,q} \rangle \simeq (L/l)^{K_\zeta(q)}$$

$$K_\zeta(q) = \frac{C_{1\zeta}}{\alpha_\zeta - 1}\left(q^{\alpha_\zeta} - q\right)$$

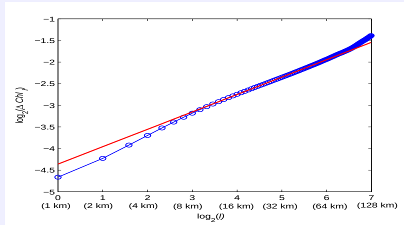
Multifractal parameters:

H=0.4 α=1.92 C_1=0.12

Multifractal analysis technique

1- Plot 1st order structure function and verify it is linear

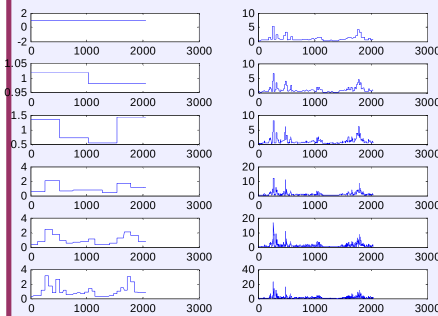
2- Average to cut-off these noisy high frequencies



First order structure function of the 100 SeaWiFS images

3- Fractionally differentiate the process (or take the norm of the gradient)

4- Reconstitute the cascade by successive averaging of contiguous data



Example of the reconstitution of a multiplicative cascade

5- Estimate the multifractal parameters with the scaling of the moments for each order and scale

Link with Kolmogorov-Obukhov-Corrsin theory (3)

Semi-theoretical prediction of parameter H

If variability is due to turbulent mixing, then it is like a passive scalar:

$$\Delta Chl_l \simeq \chi^{1/2} \varepsilon^{-1/6} l^{1/3} \quad \Rightarrow \quad H = 1/3 + K_\varepsilon(1/6) - K_\chi(1/2)$$

$K_\varepsilon(1/6)$ is due only to turbulence and is well-known (equal to -0.05)

$K_\chi(1/2)$ has to be estimated using multifractal parameters of ζ:

$$\alpha_\chi \approx \alpha_\zeta \text{ and } C_{1\chi} \approx 2^{\alpha_\zeta} C_{1\zeta} \quad \Rightarrow \quad K\chi(1/2) = -0.11$$

Finally H=0.33-0.05+0.11=0.39 which is consistent with the empirical value

In the studied scale range, turbulence seems to be the main cause explaining the observed variability

Possible application in numerical simulations (4)

The hypothesis of homogeneity at the pixel scale biases the nonlinear terms of the equations in numerical simulations

Parameters obtained in laboratory are not valid at a larger scale!

Therefore it is necessary to correct the parameters involved in numerical simulations by using empirical multifractal parameters.

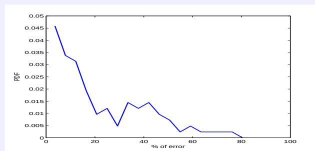
Example:

1/ Suppose a term of the form $\beta.Chl^2$

1/ Compute Chl^2 at 1*1km resolution

2/ Compute Chl^2 at 128*128km resolution

3/ Plot the distribution of the difference



Error on parameter β: 22%