Mesoscale turbulence and biogeochemistry

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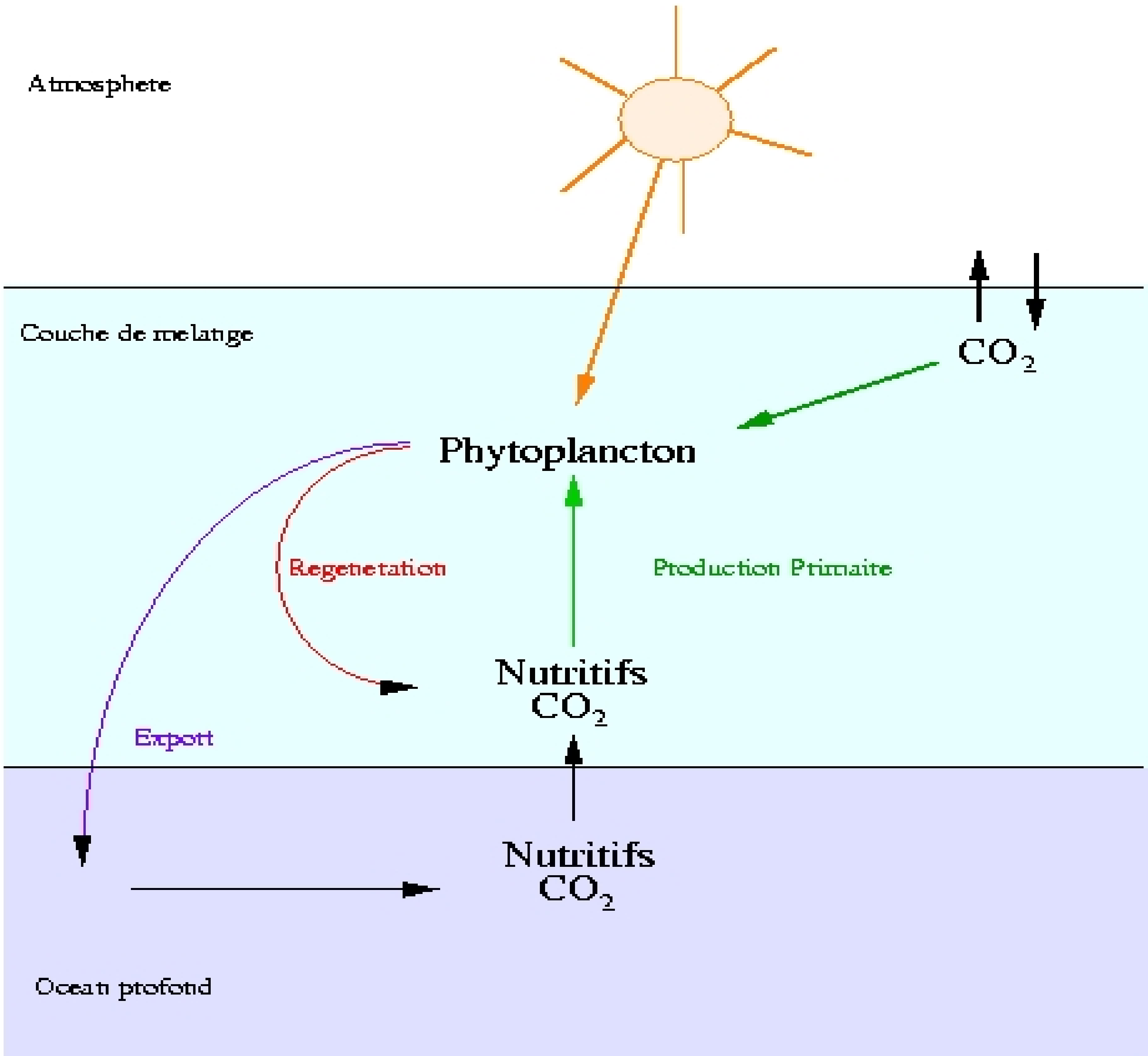
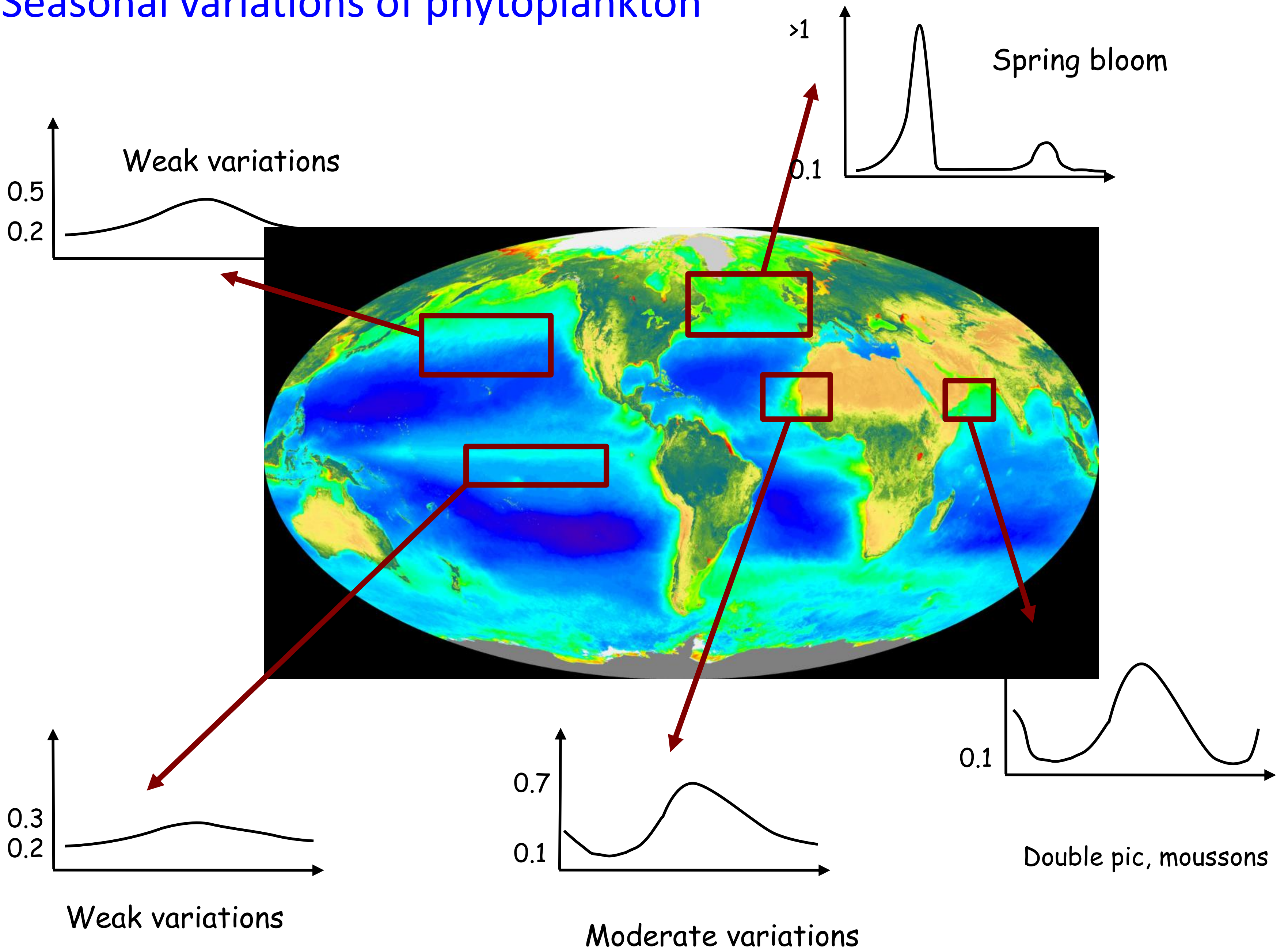


Atmosphere
Couche de melange
CO_2
Phytoplancton
Regeneration
Production Primaire
Nutritifs
CO_2
Export
Nutritifs
CO_2
Ocean profond

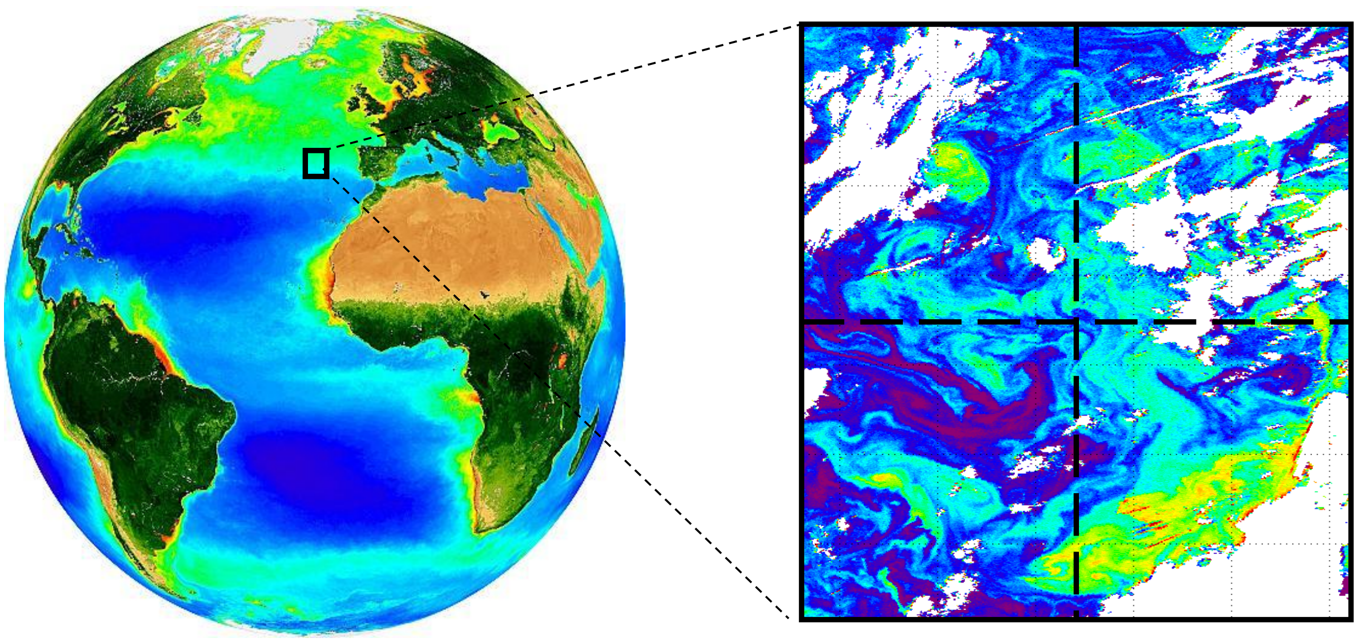
Seasonal variations of phytoplankton



Large scale / Sub-mesoscale variations of phytoplankton

Climatology
1998-2006

March 30 2001



Phytoplankton (SEAWIFS*)*

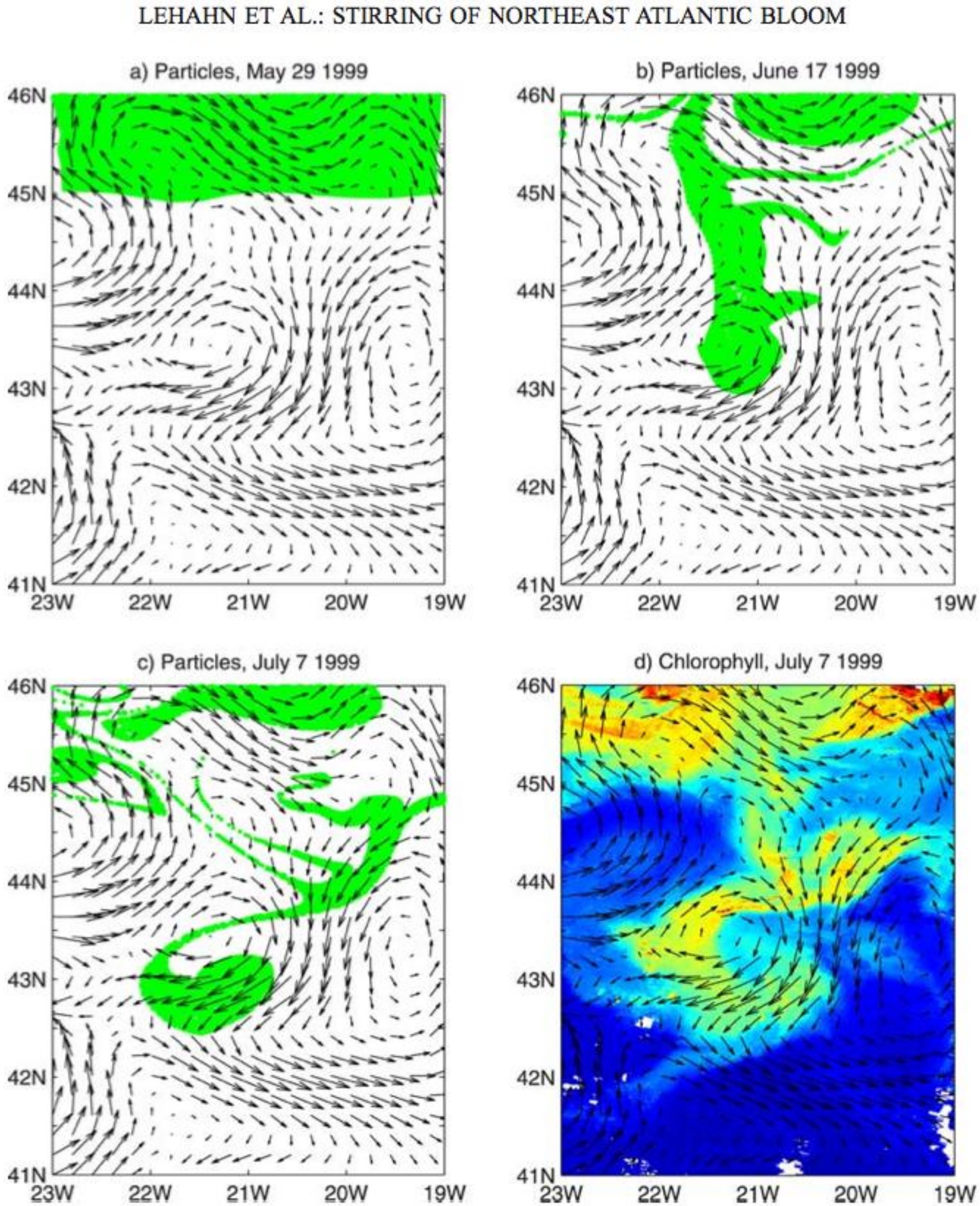
Outline

Why is phytoplankton structured at the sub-mesoscale ?

1- Lateral stirring
2- Vertical advection
3- Mixed-layer depth variations

(Can the underlying processes be observed (from space) ?)

Lateral stirring



Shows how well can we predict horizontal stirring from current resolution of altimeters

Stirring:

. not so important for giogeochemical budgets

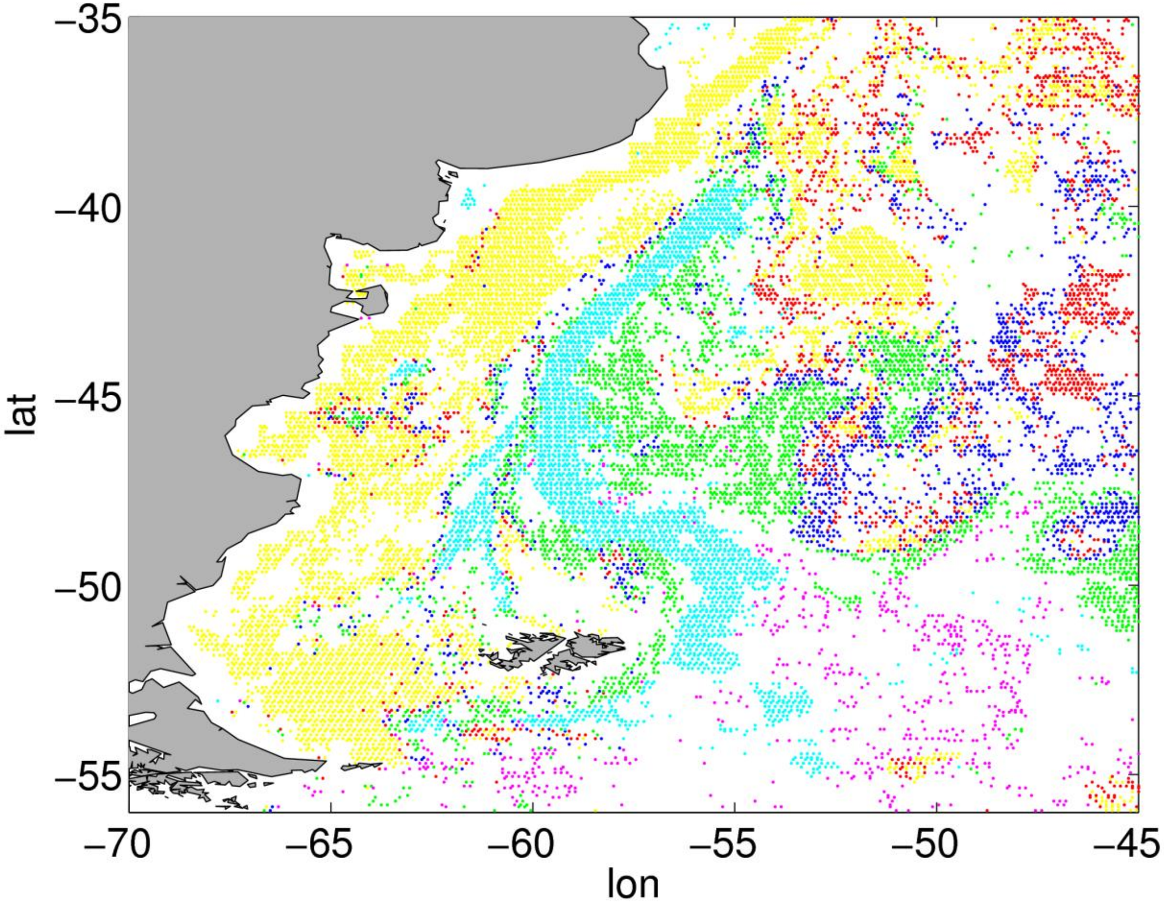
. important for sampling strategies

Lehahn et al., JGR, 2007

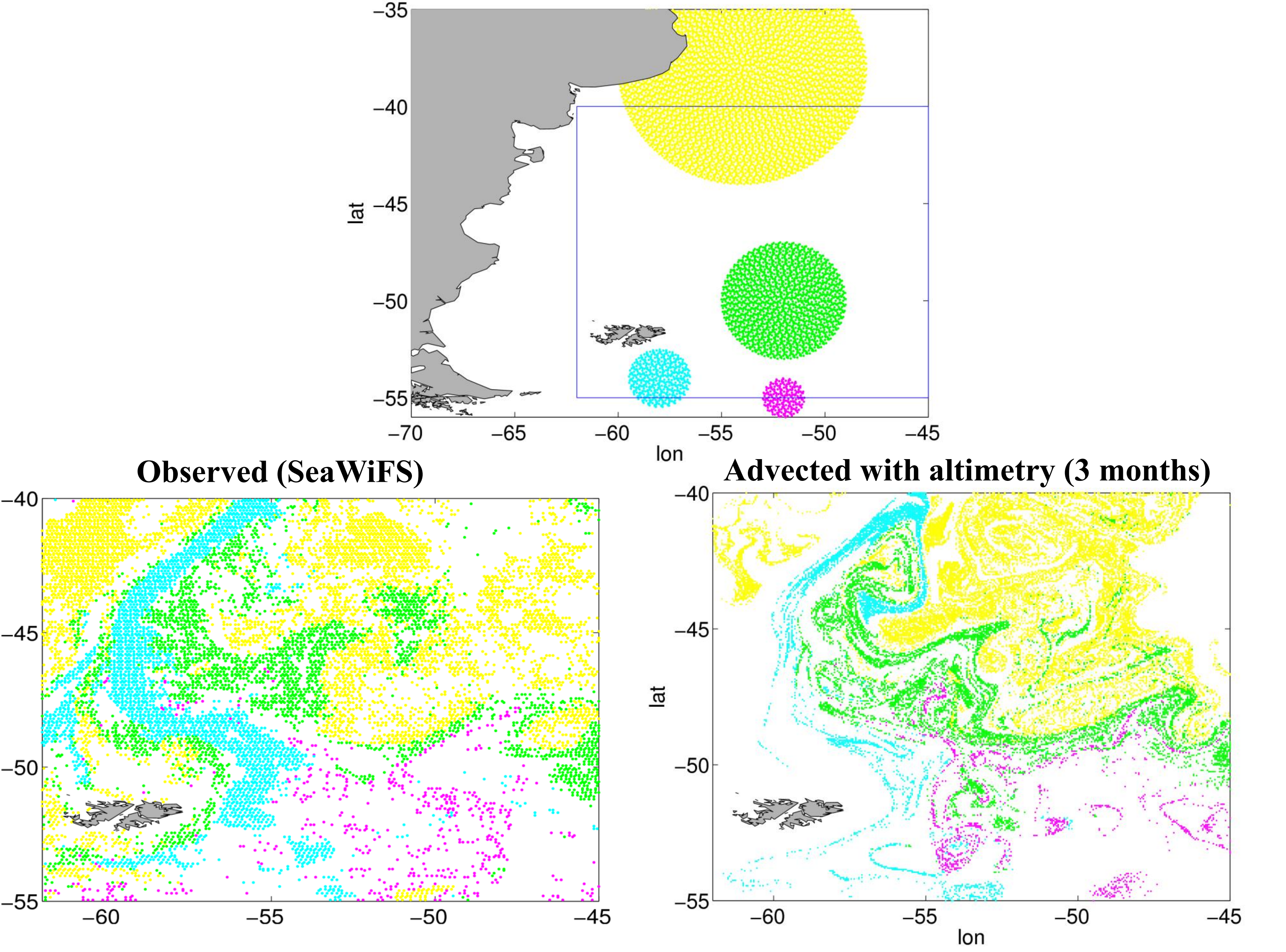
Fluid dynamical niches of phytoplankton types

Francesco d'Ovidio[a,b,1,2], Silvia De Monte[c,1], Severine Alvain[d], Yves Dandoneau[b], and Marina Lévy[b]

(PNAS, in press)



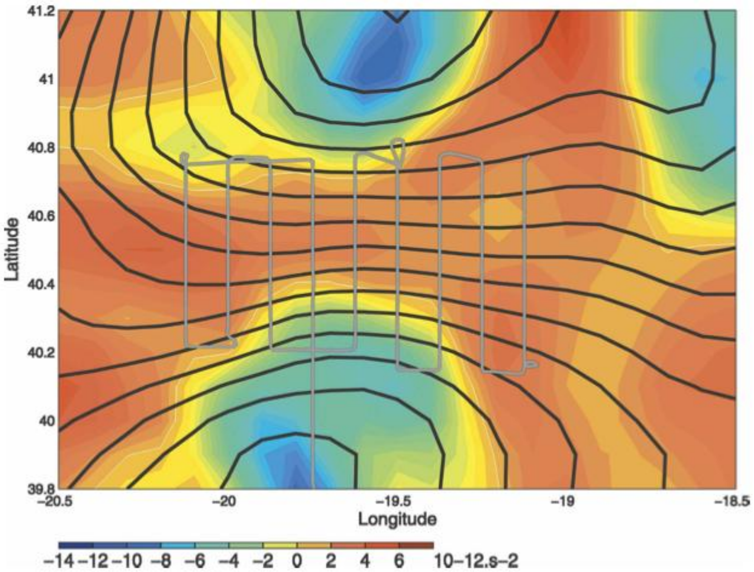
Diatoms
Nanoeukariotes
Phaeocystis
Coccolithophorides



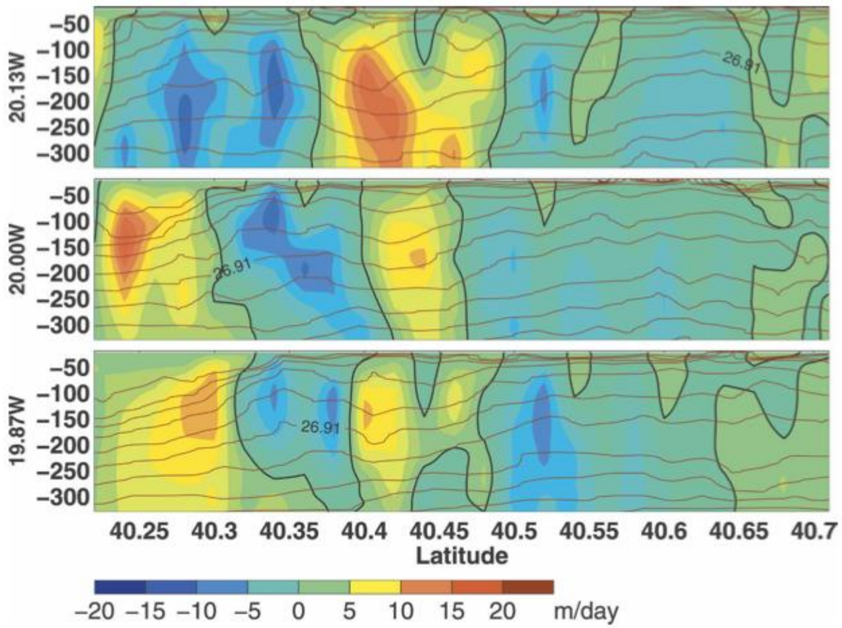
−35
−40
−45
−50
−55
lat
−70
−65
−60
−55
−50
−45
lon
Observed (SeaWiFS)
−40
−45
−50
−55
−60
−55
−50
−45
Advected with altimetry (3 months)
−40
−45
−50
−55
lat
−60
−55
−50
−45
lon

Vertical advection

Vertical velocities (estimates from observations)



SeaSor survey between two eddies

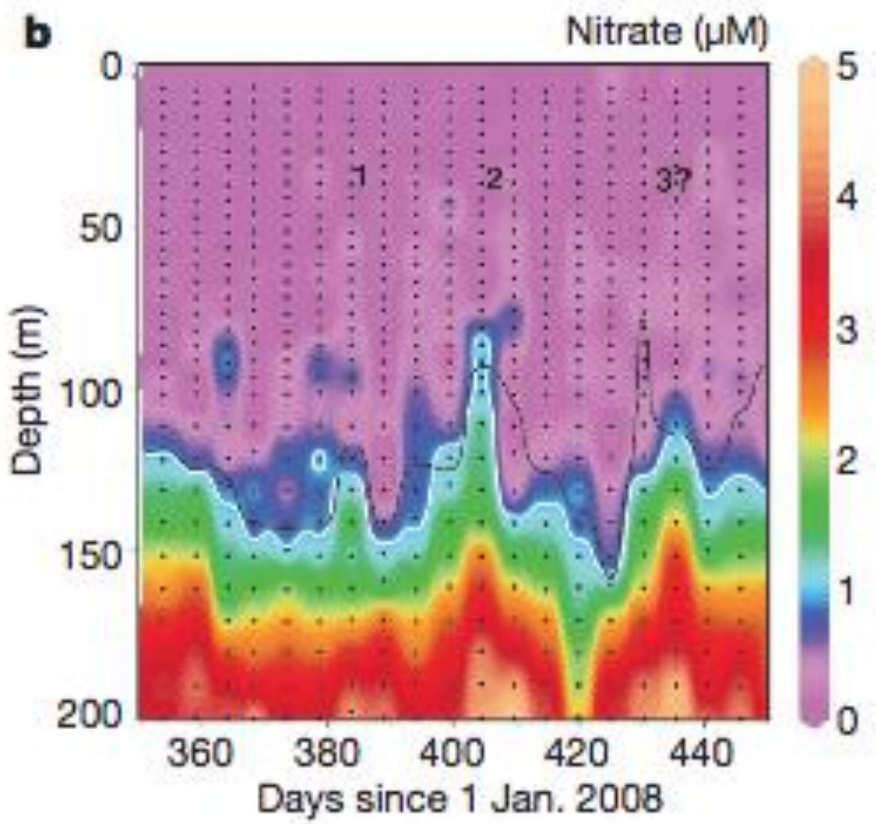


Vertical structure of W

Large positive and negative vertical velocities within sub-mesoscale filaments

Legal et al., JPO, 2007

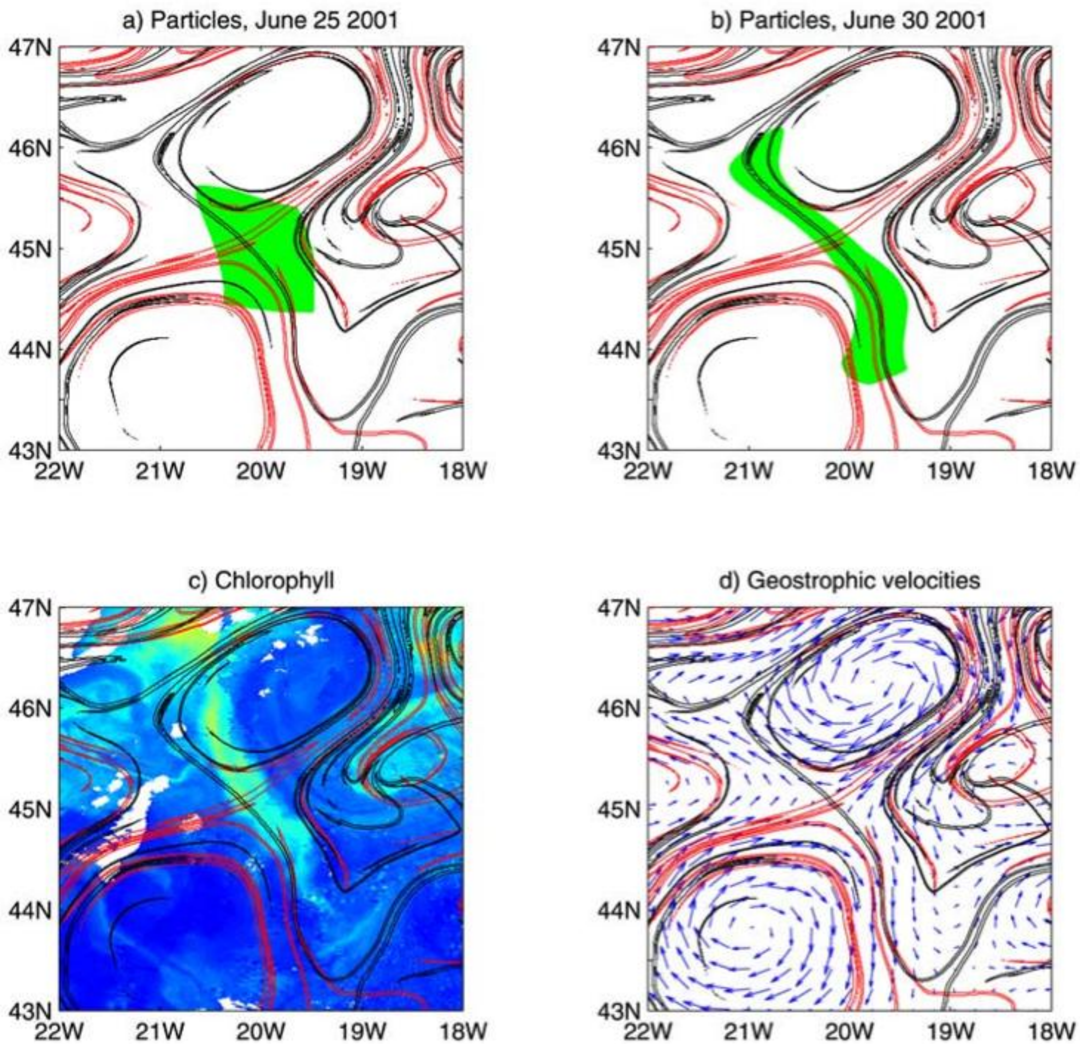
Vertical distribution of Nitrate (limiting nutrient)



Float observations in the oligotrophic North Pacific Gyre (vicinity Hawaii)

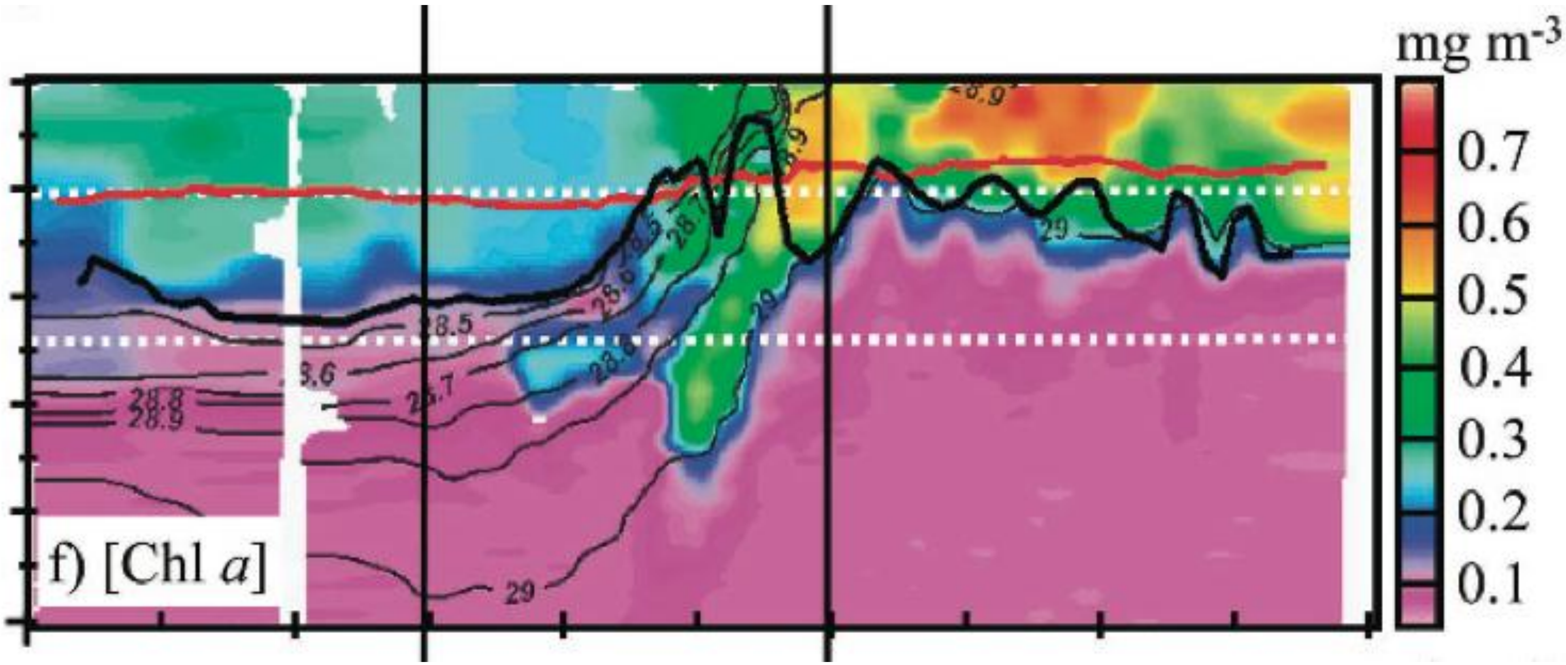
Johnson et al., Nature, 2010

Enhancement of primary production
through sub-mesoscale upwelling of limiting nutrients



Lehahn et al., JGR, 2007

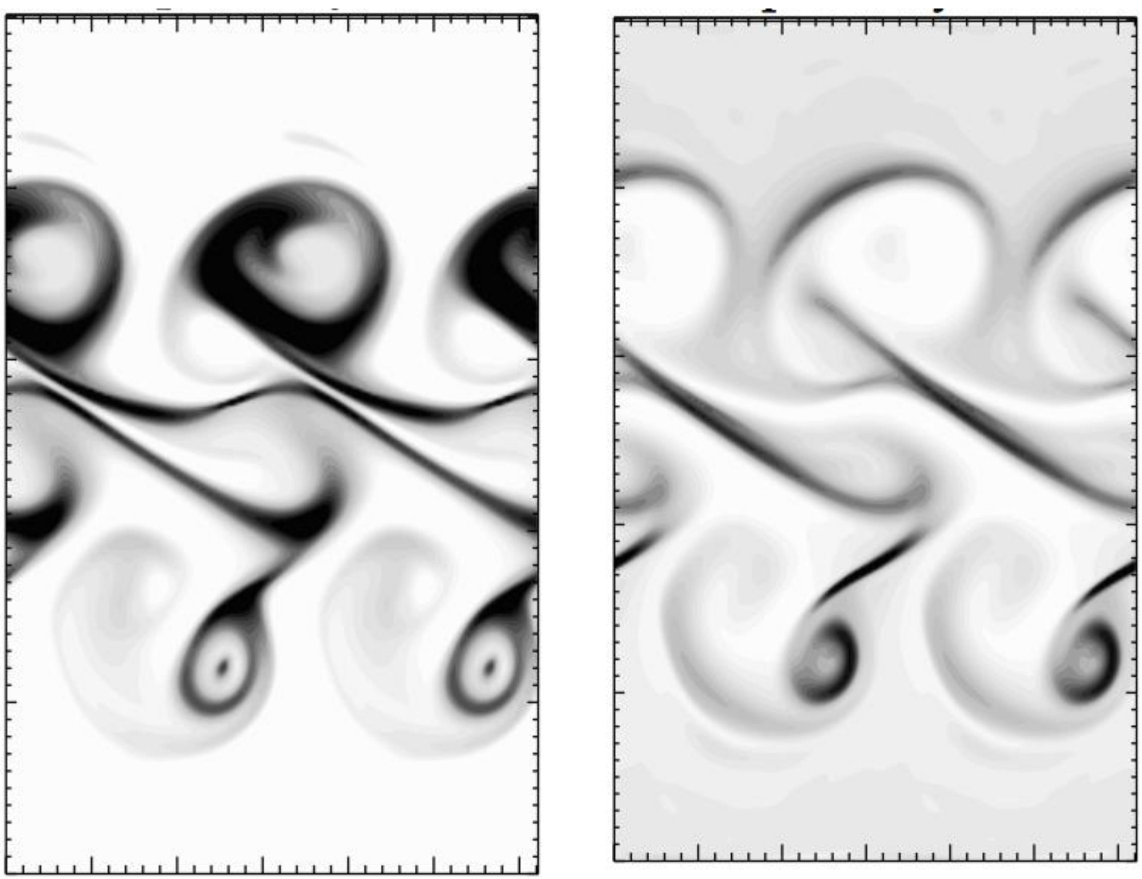
Subduction of phytoplankton



Niewiadomska et al., limnol & ocean, 2008

Glidder observations

Phyto, 0-100m   Phyto, 100m-200m

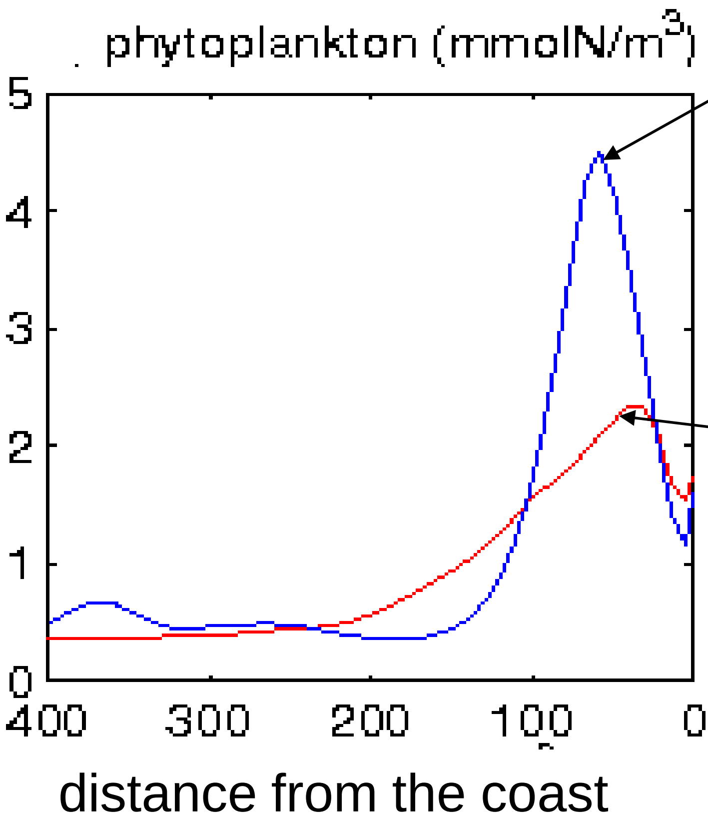


Spin-down of a front
Oligotrophic system

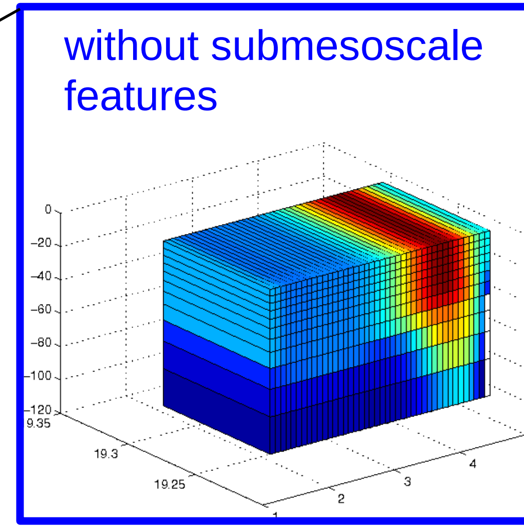
Increase of Phytoplankton production by factor 2

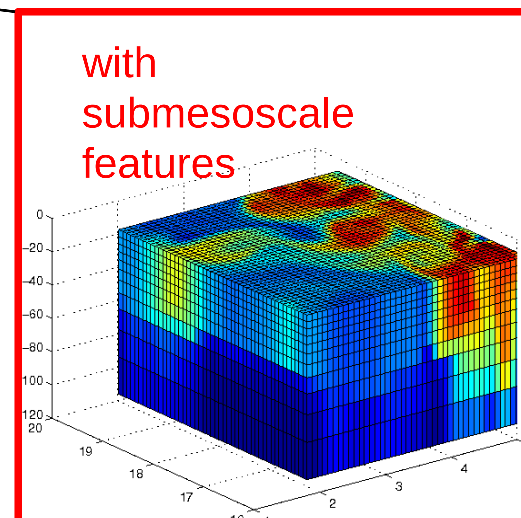
Lévy et al., JMR, 2001

-> 50 % less phytoplankton in
the simulation with submesoscale features

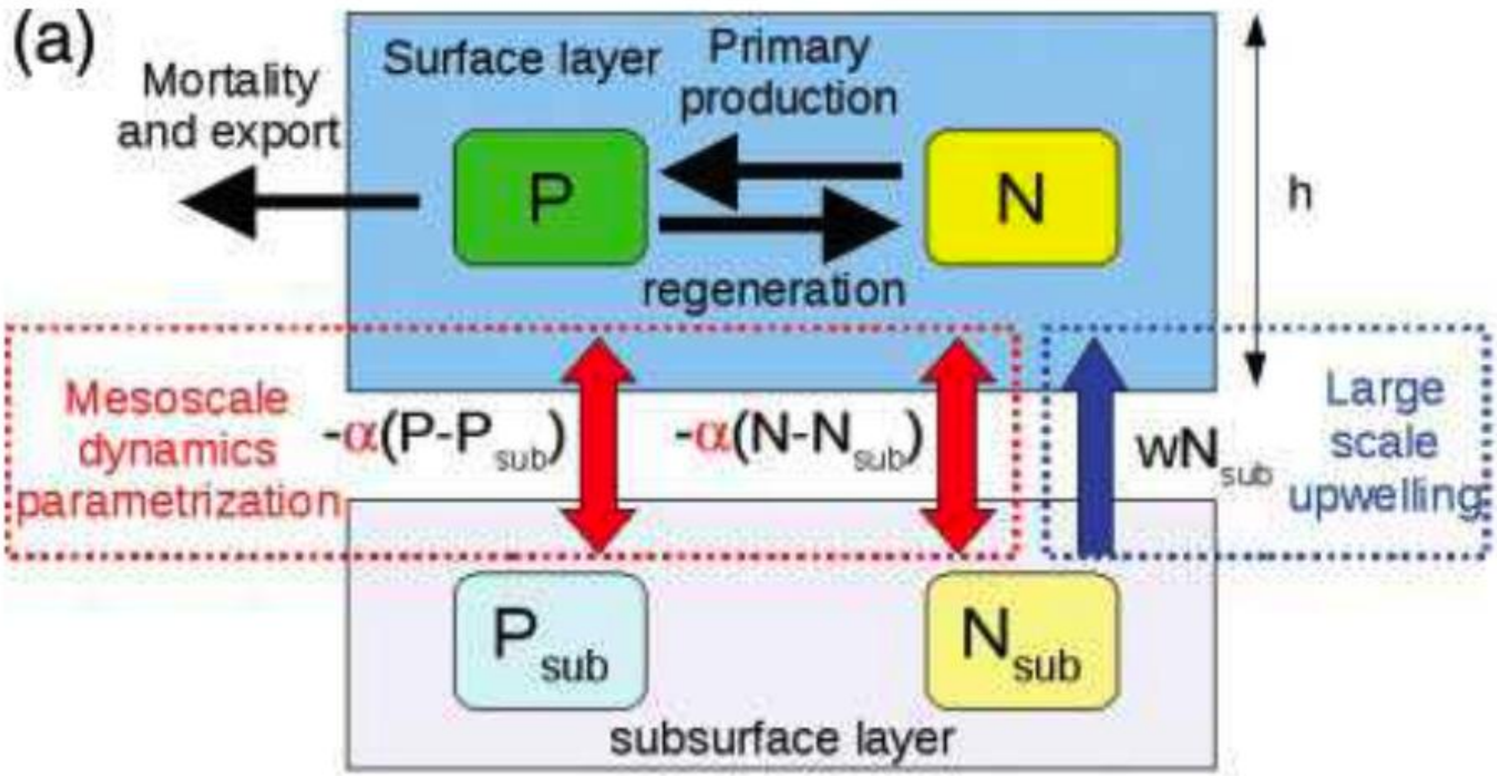


-50%





Lathuilière et al., JGR, 2010



Lathuilière, Lévy, Echevin, J. Plankton Res., in press

$$\frac{\mathrm{d}N}{\mathrm{d}t} = -\mu NP + \gamma mP + \frac{\alpha + w}{H} N_{\mathrm{sub}}$$

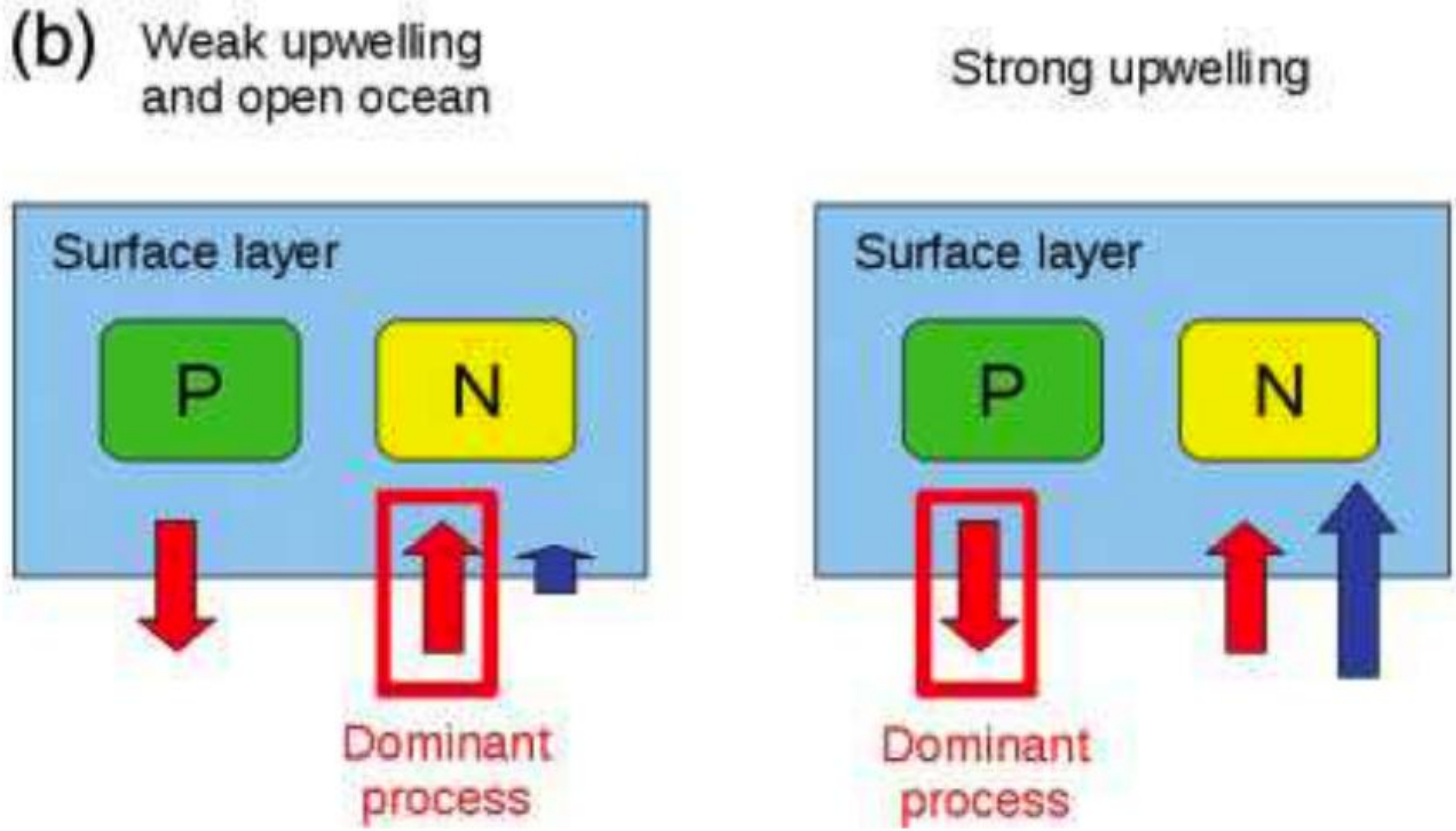
$$\frac{\mathrm{d}P}{\mathrm{d}t} = \mu NP - mP - \frac{\alpha}{H} P$$

$$N_{\mathrm{e}} = \frac{\alpha + mH}{H\mu}$$

$$\frac{\mathrm{d}P_e}{\mathrm{d}\alpha} = \frac{w_{\mathrm{c}} - w}{(\alpha + w_{\mathrm{c}})^2} N_{\mathrm{sub}}$$

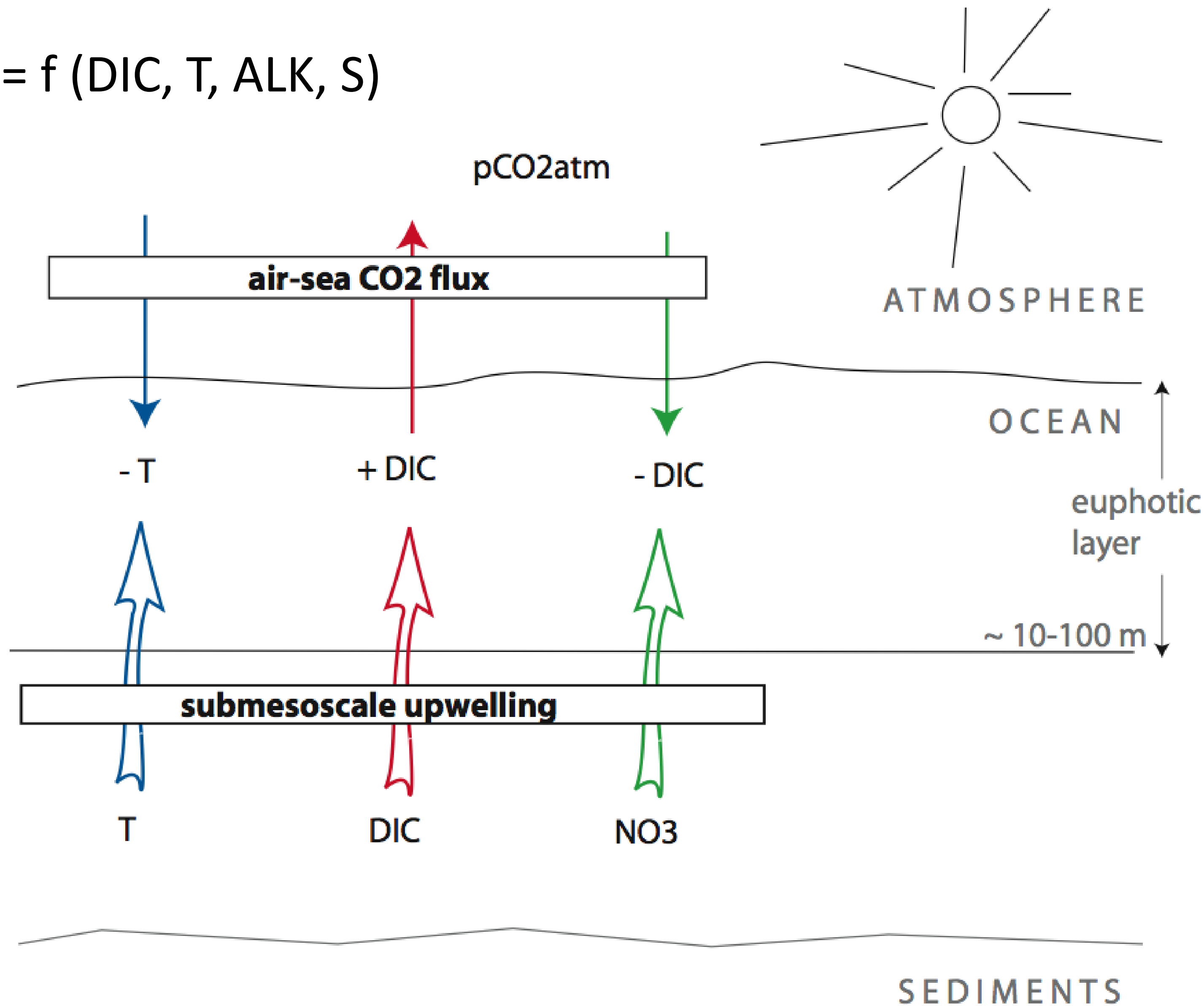
$$P_{\mathrm{e}} = \frac{\alpha + w}{\alpha + w_{\mathrm{c}}} N_{\mathrm{sub}}$$

$$w_{\mathrm{c}} = (1 - \gamma) mH$$


(b)
Weak upwelling and open ocean
Strong upwelling
Surface layer
P
N
Dominant process
Surface layer
P
N
Dominant process

Impact of submesoscale vertical advection on pCO2

$pCO_2 = f\,(DIC, T, ALK, S)$



Potential change of pCO2 due to small scale upwelling

$$\frac{\Delta pCO_2}{pCO_{2s}} = \text{TEMP effect + DIC effect + ALK effect + BIO effect}$$

$$\begin{aligned}
\text{TEMP effect} &= -\frac{\kappa\Delta t}{H}\left(\beta\frac{\partial T}{\partial z}\right) \\
\text{DIC effect} &= -\frac{\kappa\Delta t}{H}\left(\frac{\xi}{DIC}\frac{\partial DIC}{\partial z}\right) \\
\text{ALK effect} &= -\frac{\kappa\Delta t}{H}\left(\frac{\xi_A}{ALK}\frac{\partial ALK}{\partial z}\right) \\
\text{NO}_3\text{effect} &= \frac{\kappa\Delta t}{H}R_{C:N}L\frac{\partial NO_3}{\partial z}.
\end{aligned}$$

κ strength of mixing

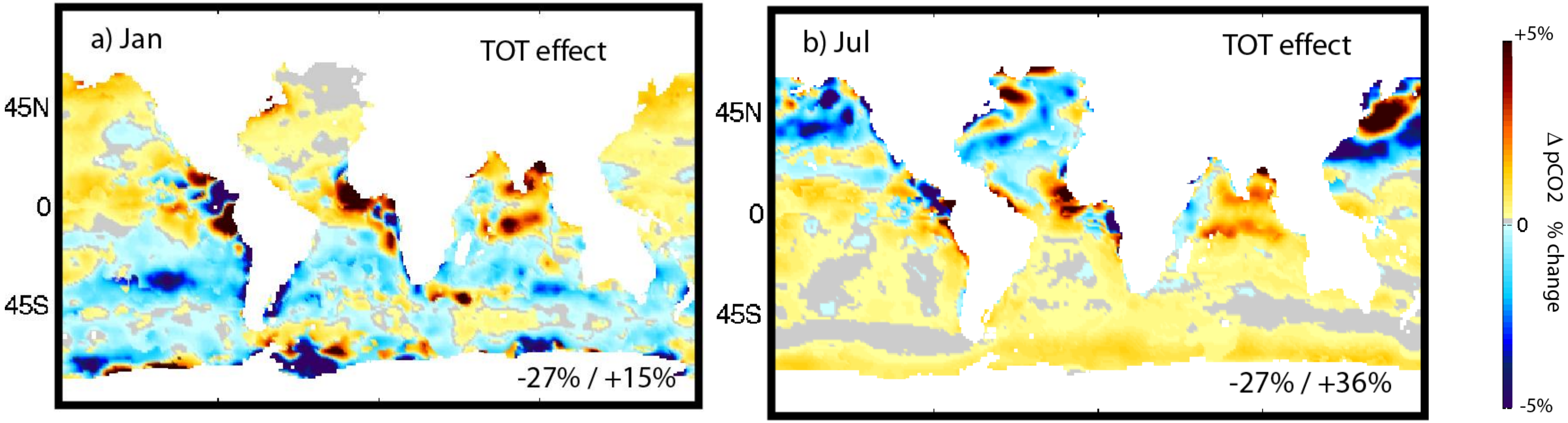
Estimate the different effects using available climatologies:

- De Boyer Montegut Mixed-layer depth climatology
- Levitus climatology for T, S, NO3
- GLODAP climatology for DIC, ALK

Mahadevan et al., in press, Proc. Roy Soc.

Global estimate of % pCO_2 change due to localized upwelling

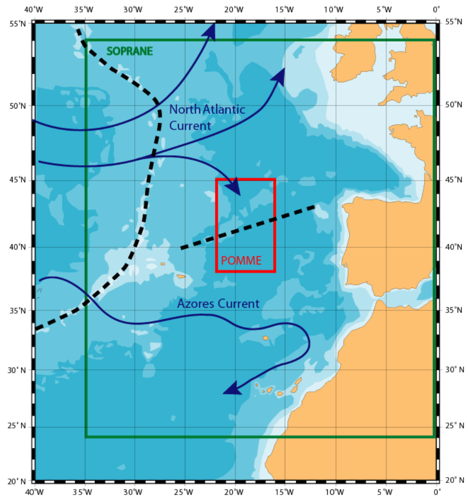
for a given strength of mixing κ=1.e^{-3} m^2/s^2 and for Δt= 1 day



- •Large areas show little sensitivity due to compensating effects
- •Some regions indicate an increase in pCO_2, others a decrease
- •Large seasonality

The 2001 POMME experiment in the NE Atlantic

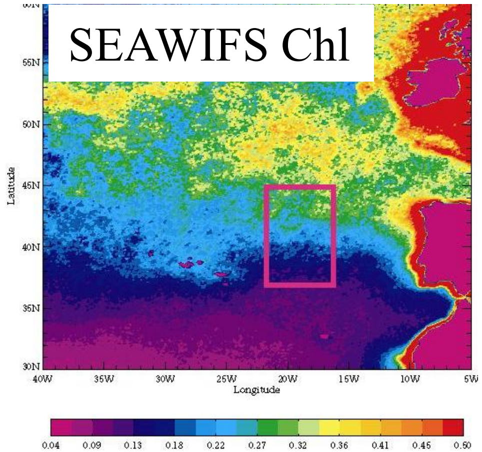
Program **O**cean **M**ultidisciplinary **ME**soscale

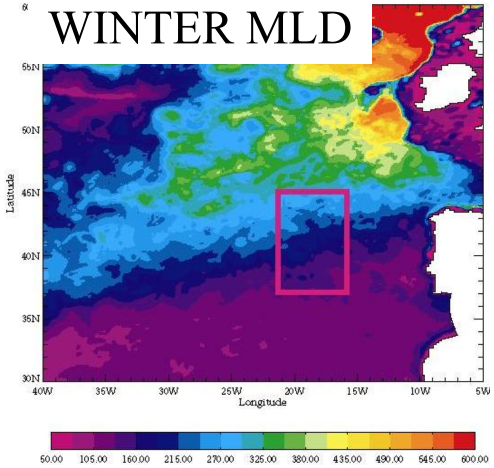


Pomme area

•Mixed-layer depth gradient

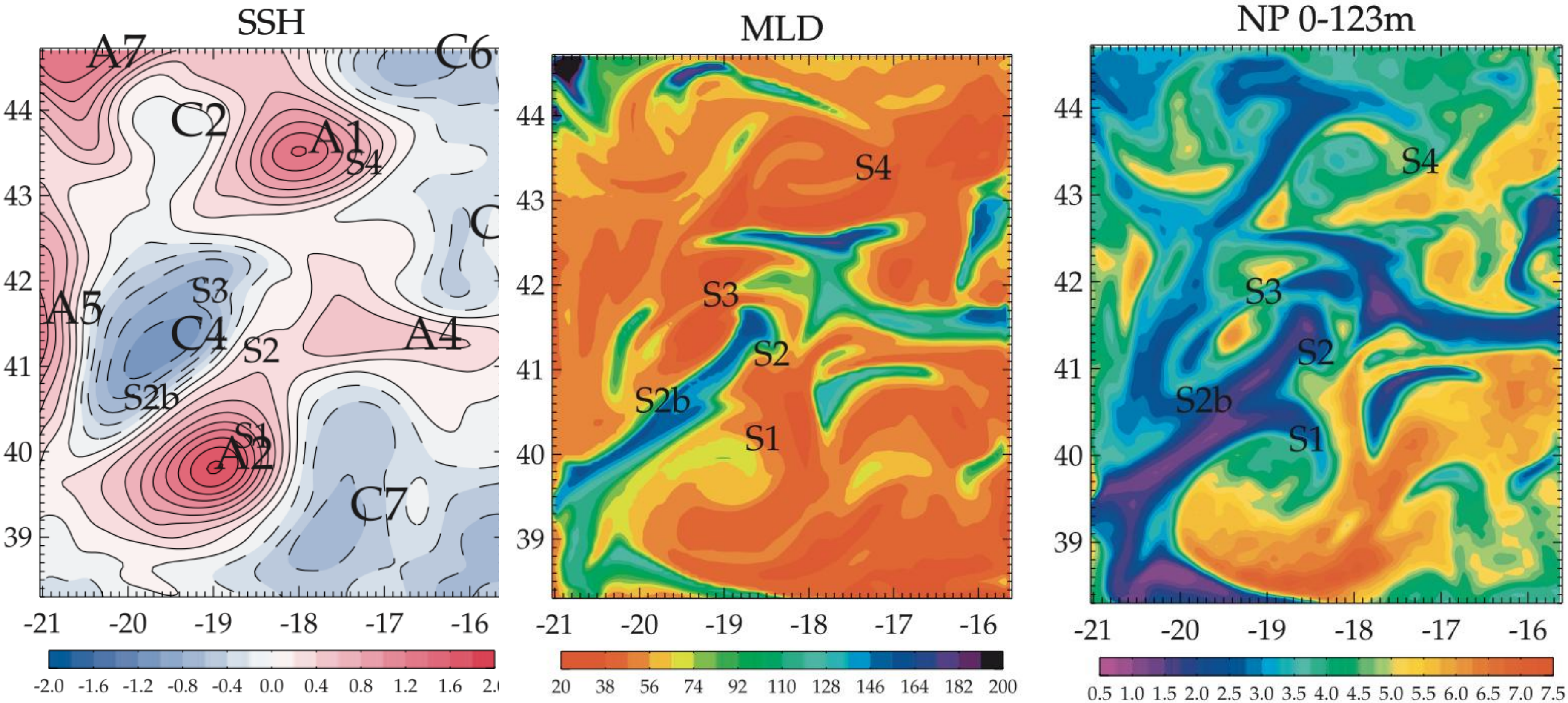
•Spring phytoplankton bloom





Memery et al., JGR, 2005

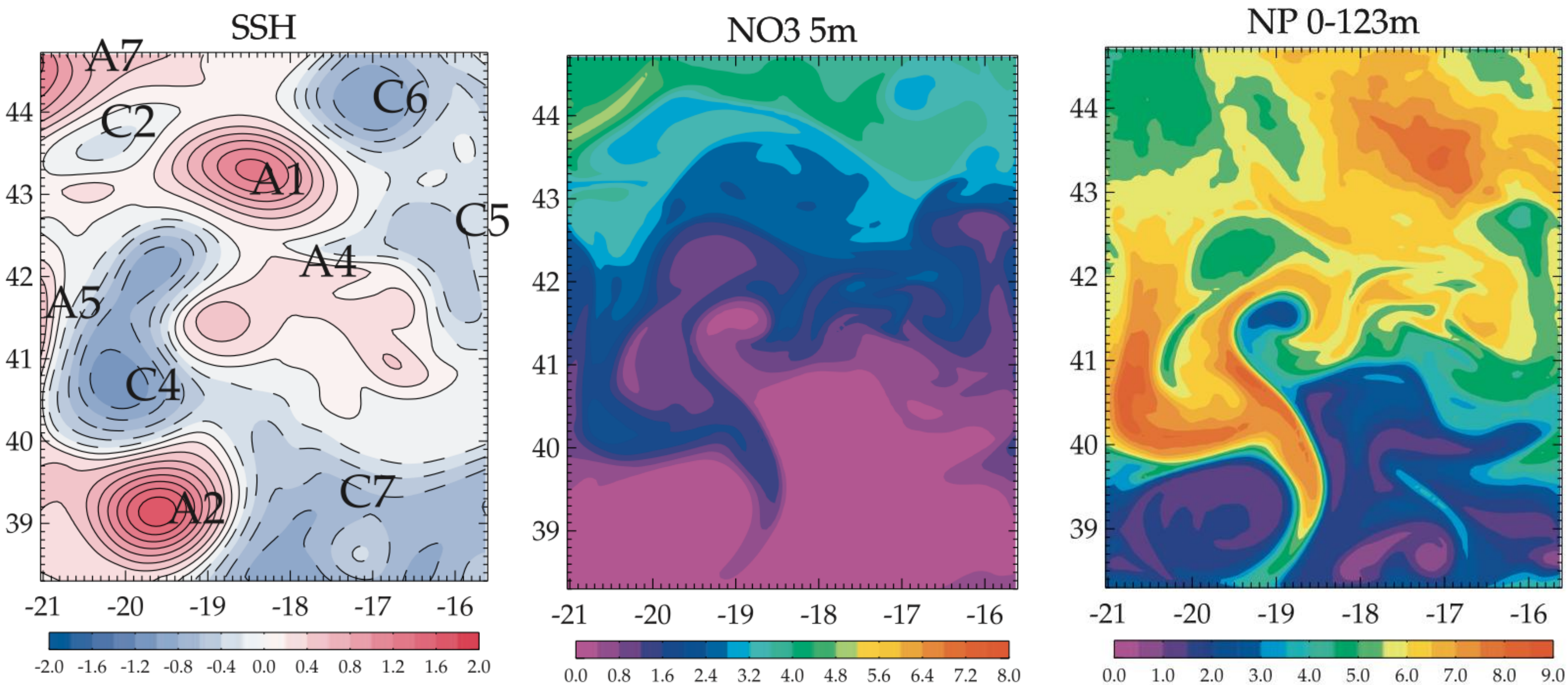
Early bloom : strong modulation of PP by variations of MLD



Lévy et al., JGR, 2005

Could not be observed : requires high spatial and high temporal resolution

Late bloom : PP modulated by horizontal stirring of N-S gradient



Lévy et al., JGR, 2005

Conclusions

Different processes affect phytoplankton/pCO2 at the submesoscale
- Lateral stirring
- Vertical advection (nutrient upwelling + phyto downwelling)
- Mixed-layer variations

Requires synoptic observations of
- Lateral currents
- Vertical velocities
- Mixed-layer depth

Combined with large scale distribution of phytoplankton and nutrients
at surface and at sub-surface

SWOT (+ SQG) :
- Better evaluation / localisation of stirring : field experiments
- Estimation of W
- MLD ???