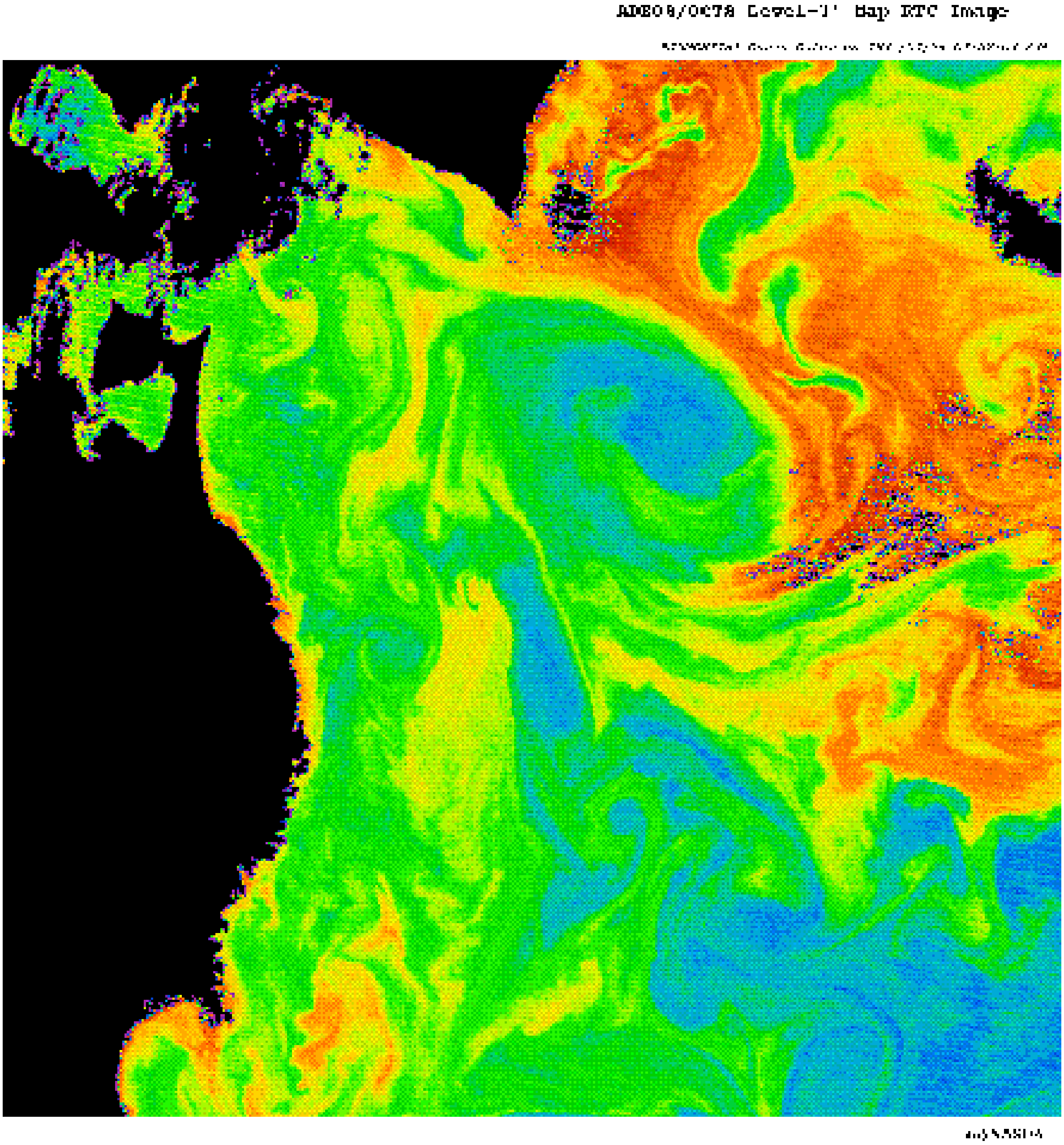
Impacts of sub-mesoscale physics on phytoplankton growth and distribution

M. Lévy, P. Klein and A.-M. Tréguier



Mesoscale : ***20-100 km***

scale of oceanic eddies

Sub-mesoscale : ***1-20 km***

scale of filaments, strong vorticity gradients

° Review the main processes that have been proposed

to explain the observed phytoplankton
mesoscale and sub-mesoscale variability

° New insight on sub-mesoscale physics :

double impact on phytoplankton
1 - reinforcement of mesoscale physics
2 - appearence of small-scale frontogenesis

large amplification of vertical velocities
and therefore of vertical transport of nutrients

° New insight on the mesoscale distribution of phytoplankton

within cyclones / anticyclones
during the period of formation of the eddies

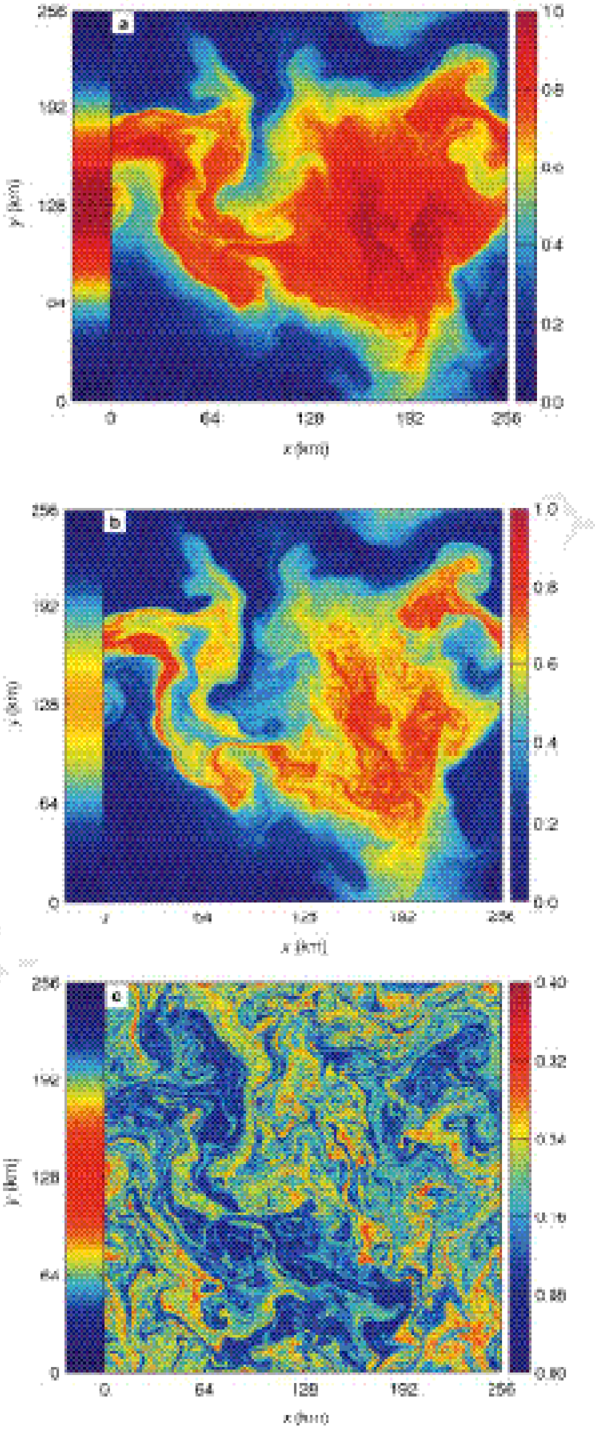


Figure 2 Image fields at the end of a high-resolution model run. The model follows equations 1–3, with τ = 25 d and α = 3, corresponding to a high P and low Z regime. **a**, Carrying capacity; **b**, phytoplankton; **c**, zooplankton. The strip at the left shows the zonally varying distributions the populations would have in the absence of advection, while the bar on the right gives the values associated with the different colours. The distortion due to turbulent stirring is clearly visible.

Abraham, Nature, 1998

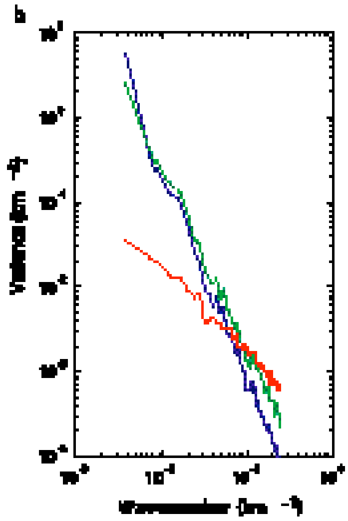


Figure 3 A representative transect and the corresponding spectra. Graphs show carrying capacity (blue), phytoplankton (green) and zooplankton (red). **a**, A transect through the image field in Fig. 2 (at x = 128 km). The simplicity of the underlying population dynamics is not apparent. **b**, The corresponding spectra have a power-law form over an order of magnitude range. The spectra from 256 evenly spaced transects are averaged to form those shown here. The spectral exponents (mean ± s.d.) of the populations at this time are b_1 = 2.3 ± 0.26, b_2 = 2.1 ± 0.20 and b_3 = 1.0 ± 0.15.

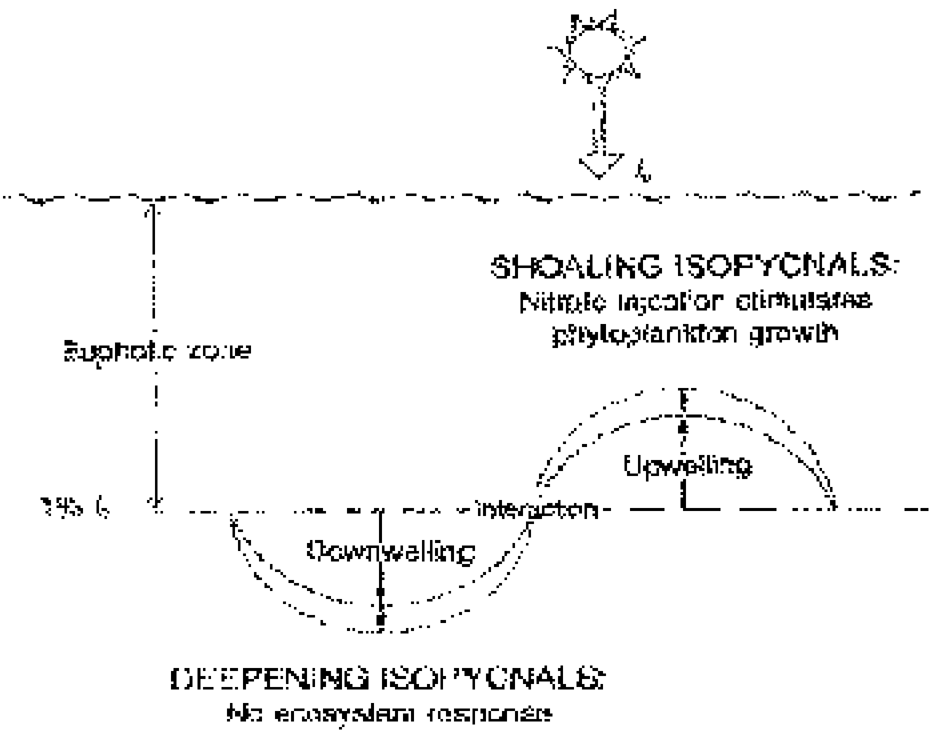
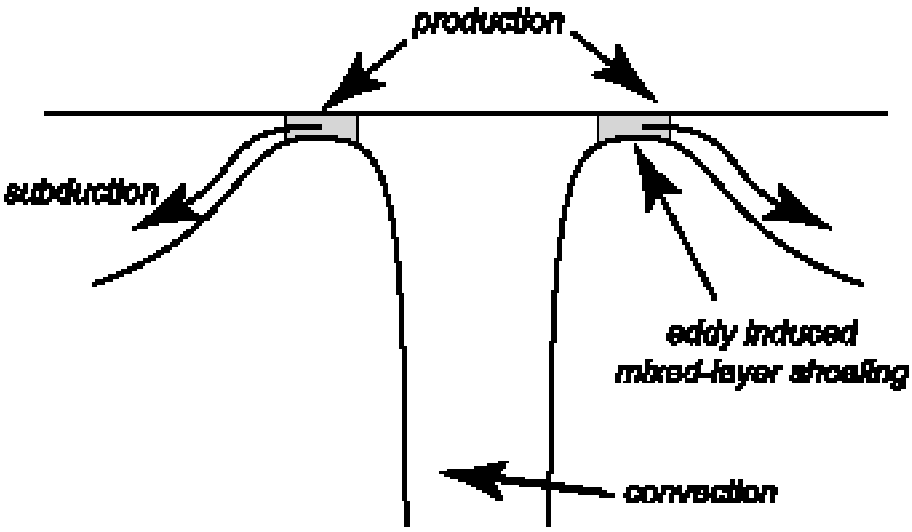
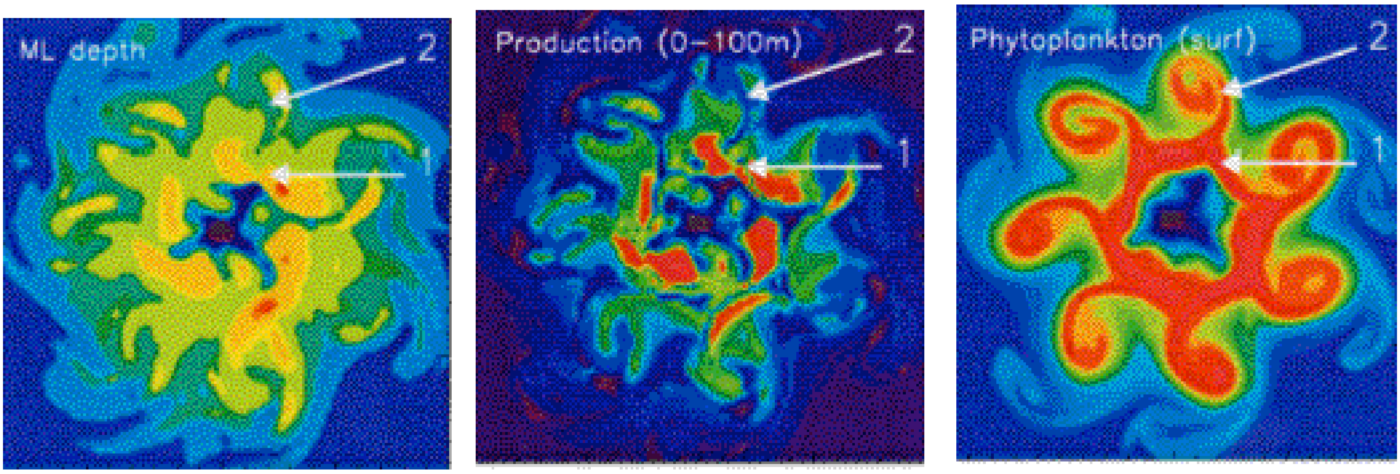


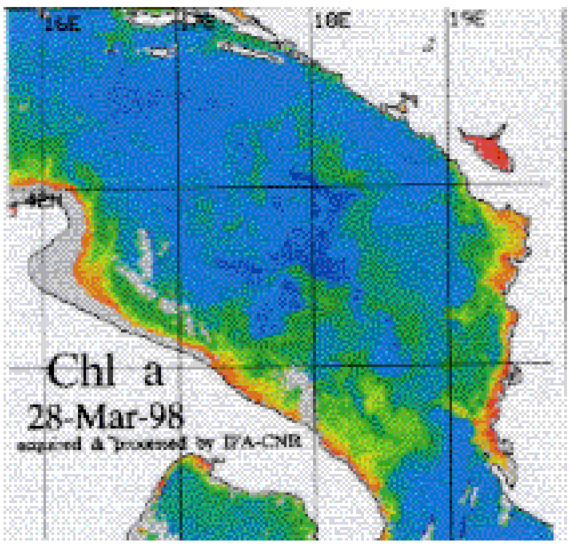
Figure 1 A schematic representation of the eddy upwelling mechanism. The line depicts the vertical deflection of an individual isopycnal caused by presence of two adjacent eddies of opposite sign. The dashed line indicates how the isopycnal might be subsequently perturbed by interaction of the two eddies. I_0 represents incident solar radiation, and 1% I_0 the base of the euphotic zone.

McGillicuddy et al., Nature, 1998



Levy et al, 1999, DSR





Santoleri et al, 2001

Sub-mesoscale processes

1- Nitrate injection can occur at sub-mesoscales

Due to the phase relationship between vertical velocities and strain

Whereas Abraham (1998) scenario is mostly 2D

2- New production can be enhanced in anticyclonic regions : during the period of formation of the eddies and in the absence of wind

Due to the redistribution of water masses by the baroclinic instability.

Numerical protocol

Mesoscale and Submesoscale dynamics result from the nonlinear equilibration of an unstable baroclinic jet

- Zonal jet periodic in the zonal direction
- Rossby radius of deformation Rd = 30 km
- Regime with Rossby number O(1) : use of Primitive Equations
- Mixed-layer model
- No atmospheric forcing

Progressive increase of horizontal resolution :

from Rd/3 to Rd/30

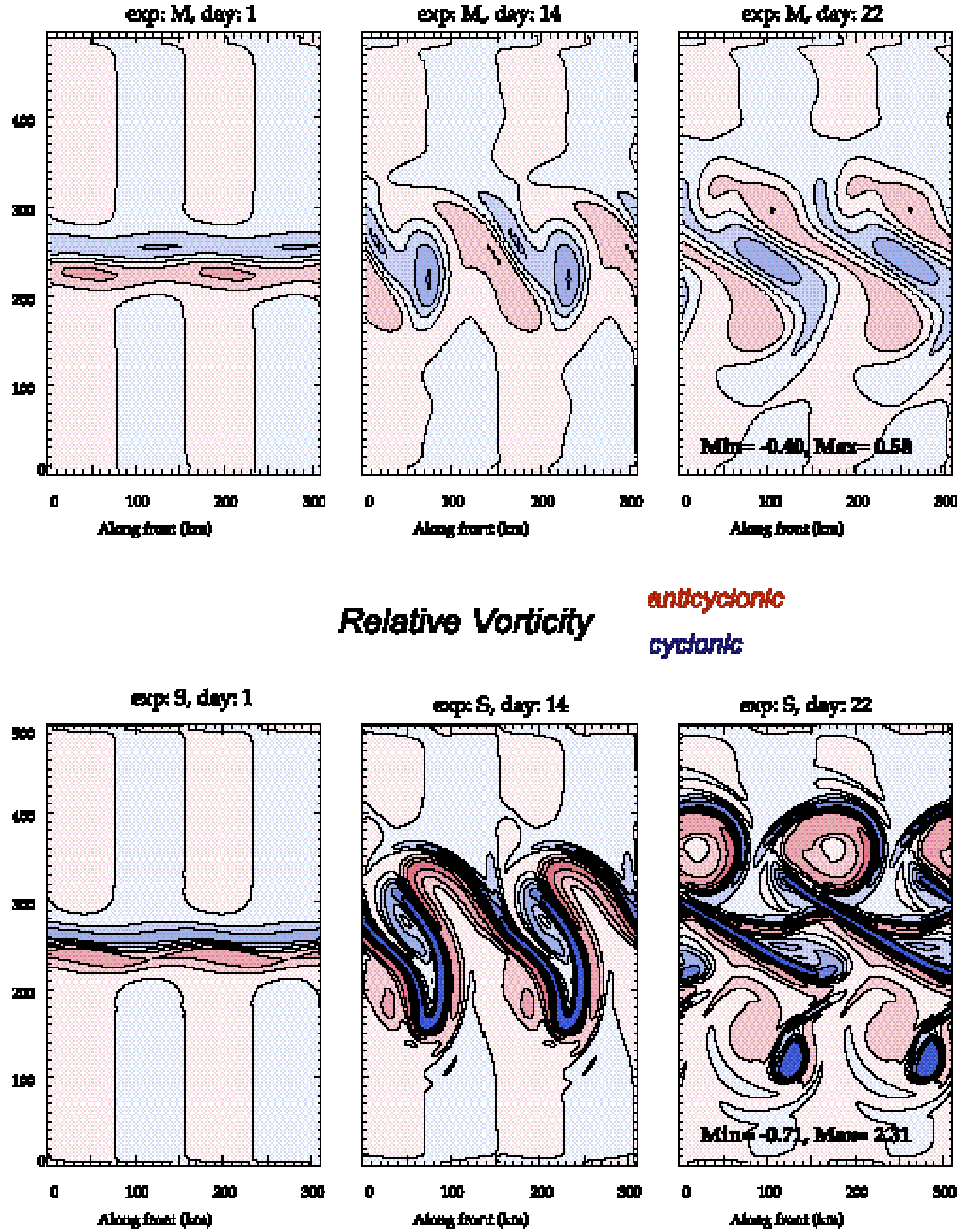
Experiment M (mesoscale) : 6 km resolution
Experiment S (sub-mesoscale) : 2 km resolution

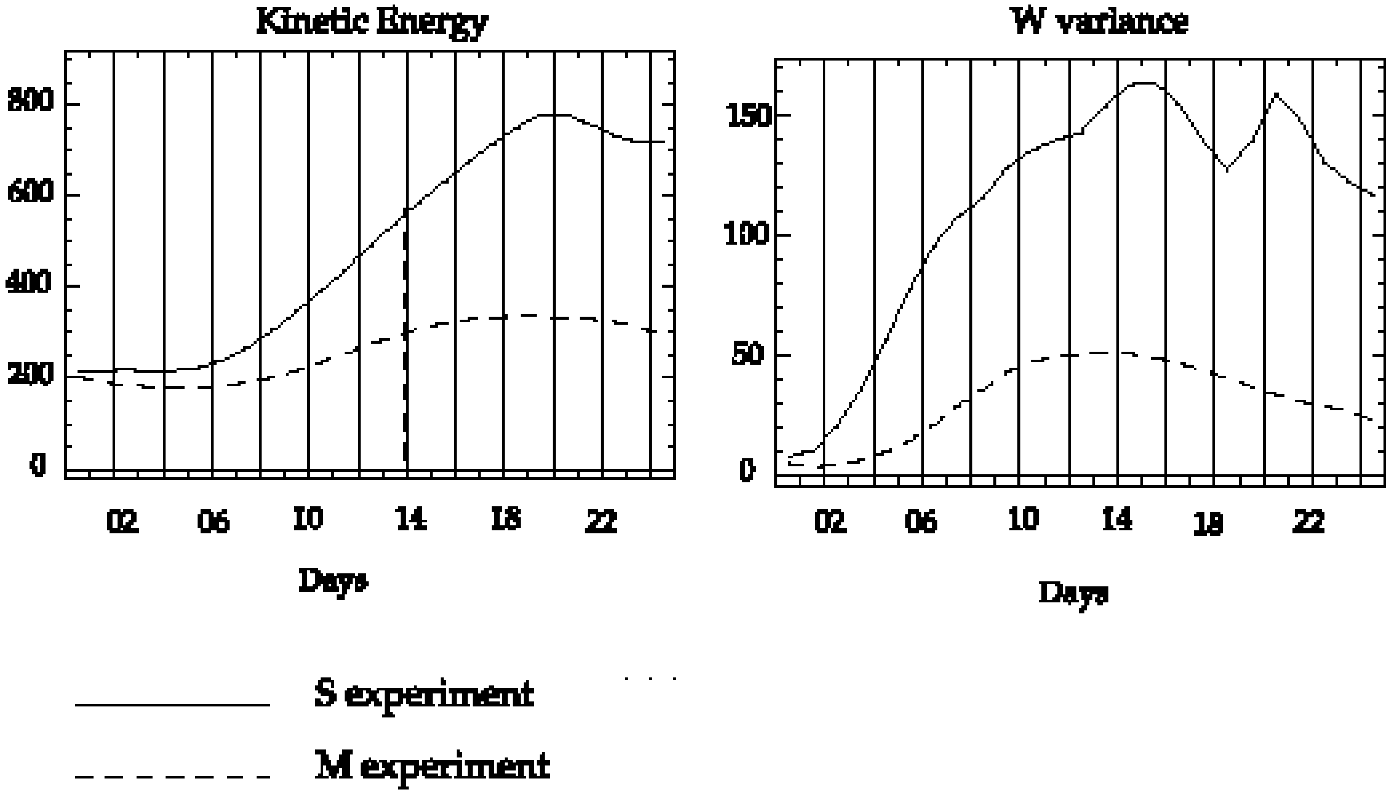
Oligotrophic regime

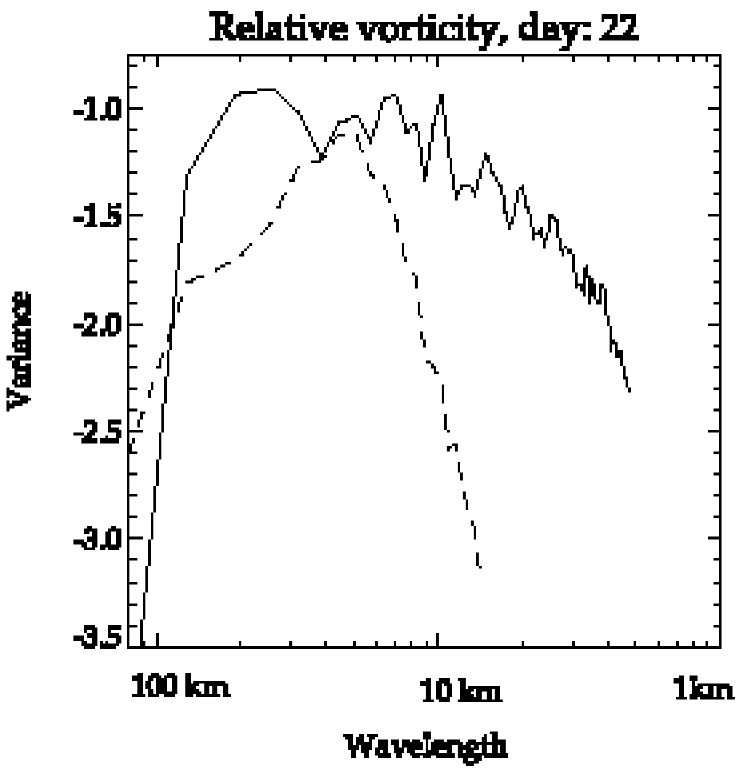
Nutrients are initially depleted from the euphotic layer

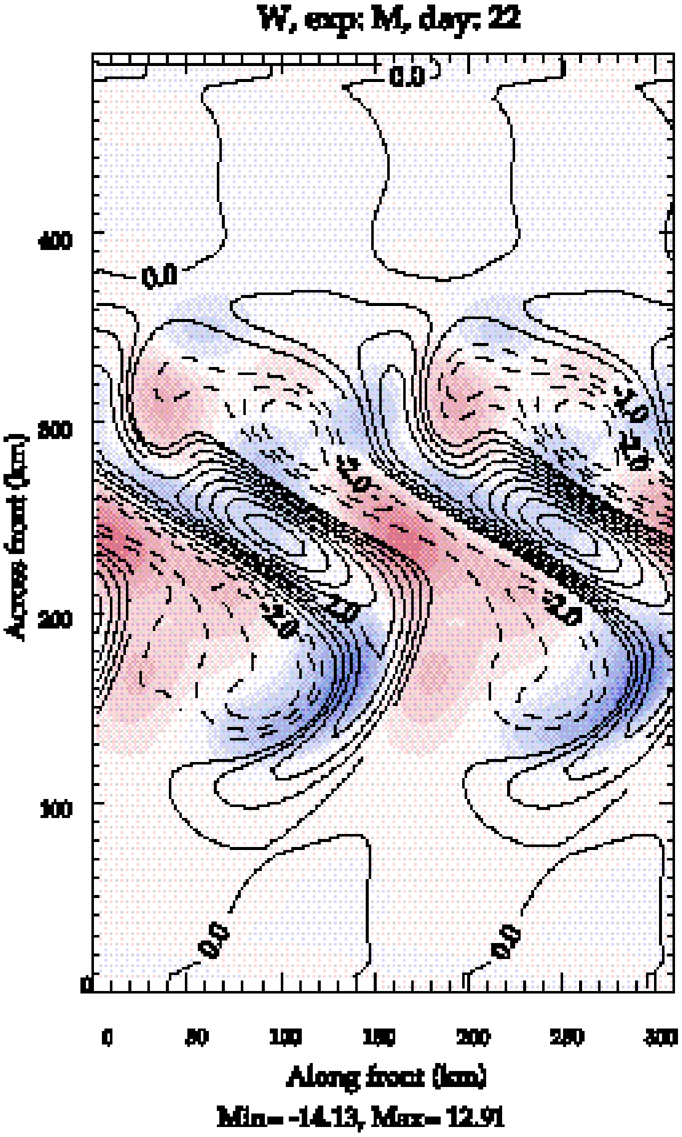
Bloom regime

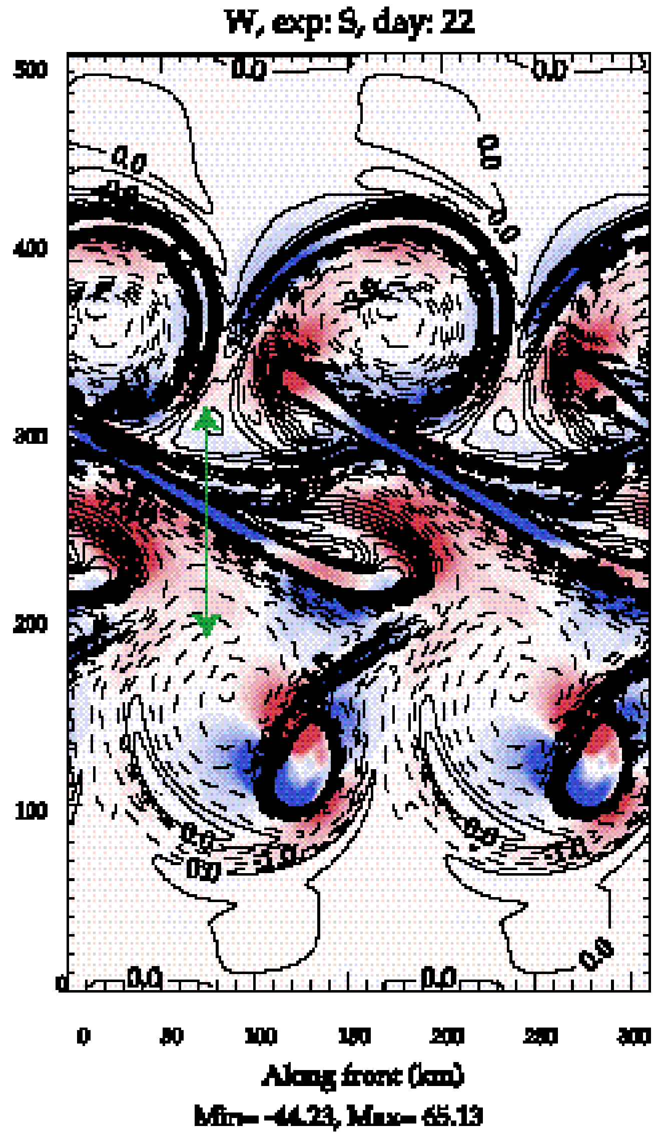
Meridional nutrient gradient at the surface


exp: M, day: 1
exp: M, day: 14
exp: M, day: 22
Min= -0.40, Max= 0.58
Along front (km)
Relative Vorticity
anticyclonic
cyclonic
exp: S, day: 1
exp: S, day: 14
exp: S, day: 22
Min= -0.71, Max= 2.31
Along front (km)

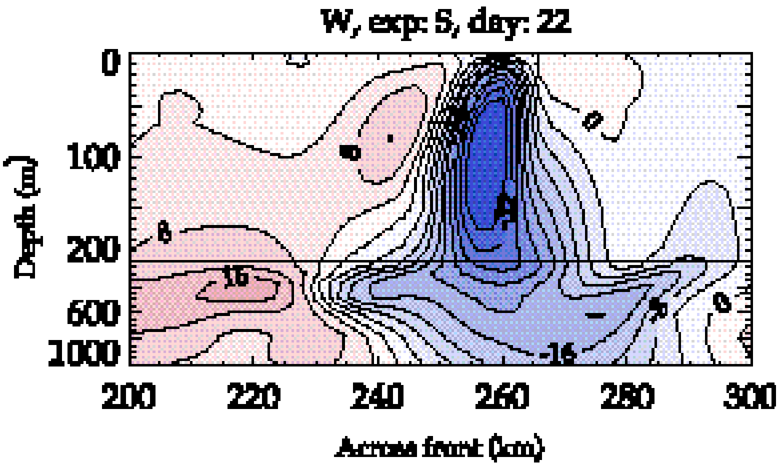

Kinetic Energy
800
600
400
200
0
02
06
10
14
18
22
Days
W variance
150
100
50
0
02
06
10
14
18
22
Days
S experiment
M experiment


Relative vorticity, day: 22
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
Variance
100 km
10 km
1km
Wavelength

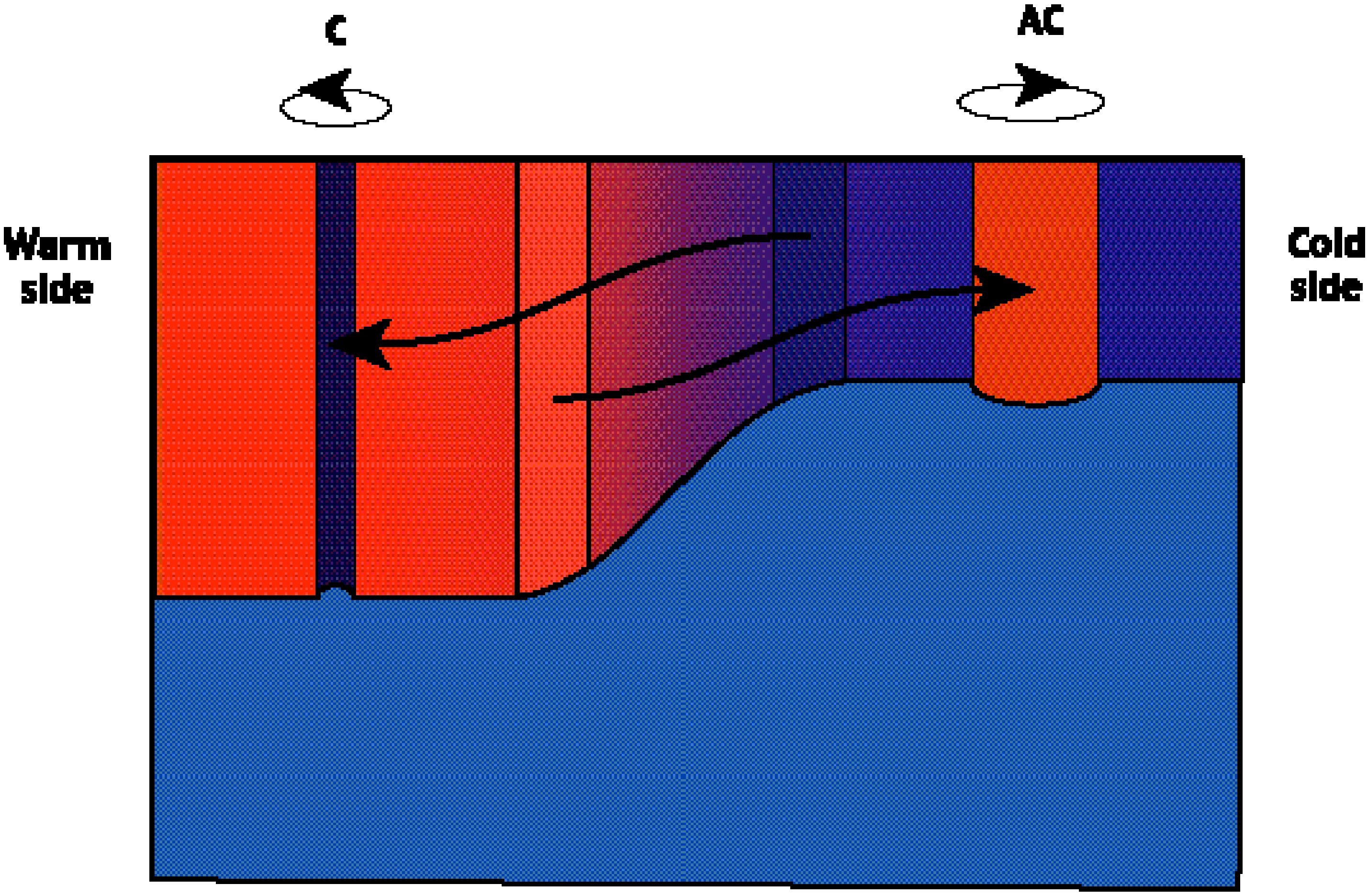




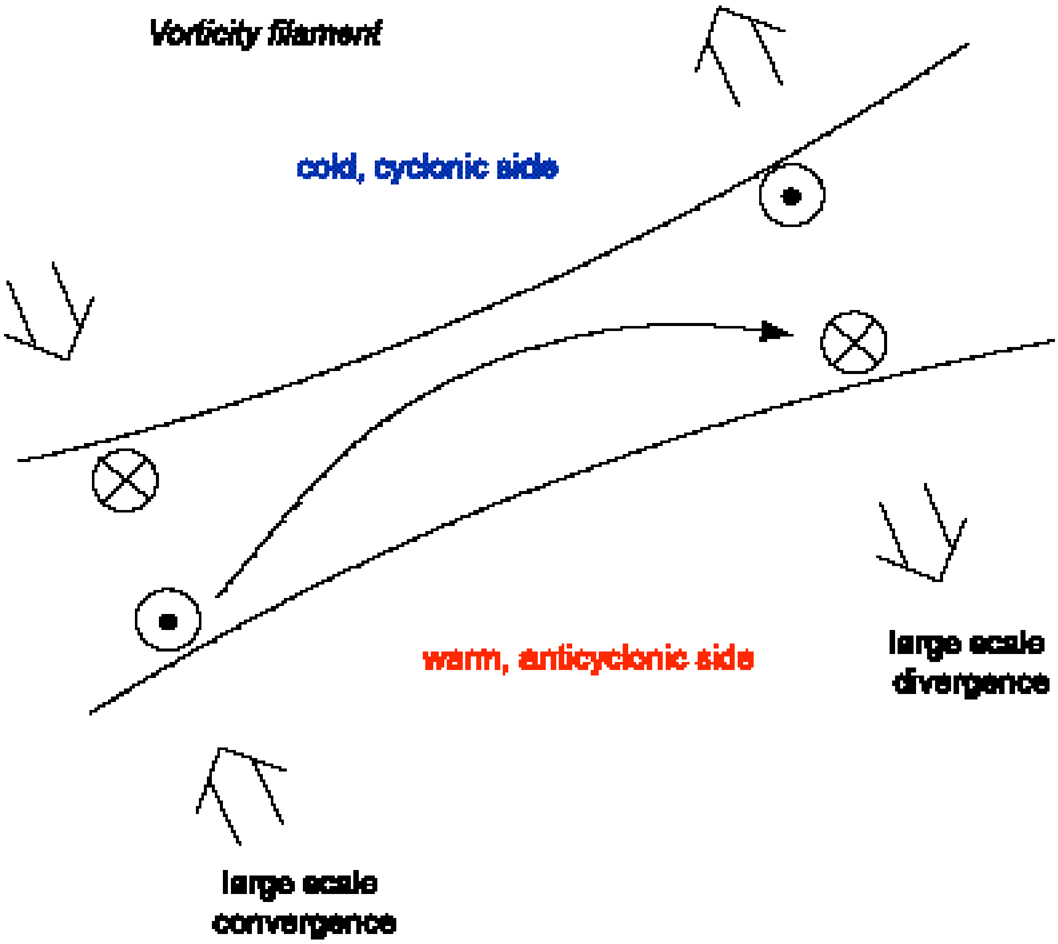
Vertical velocities

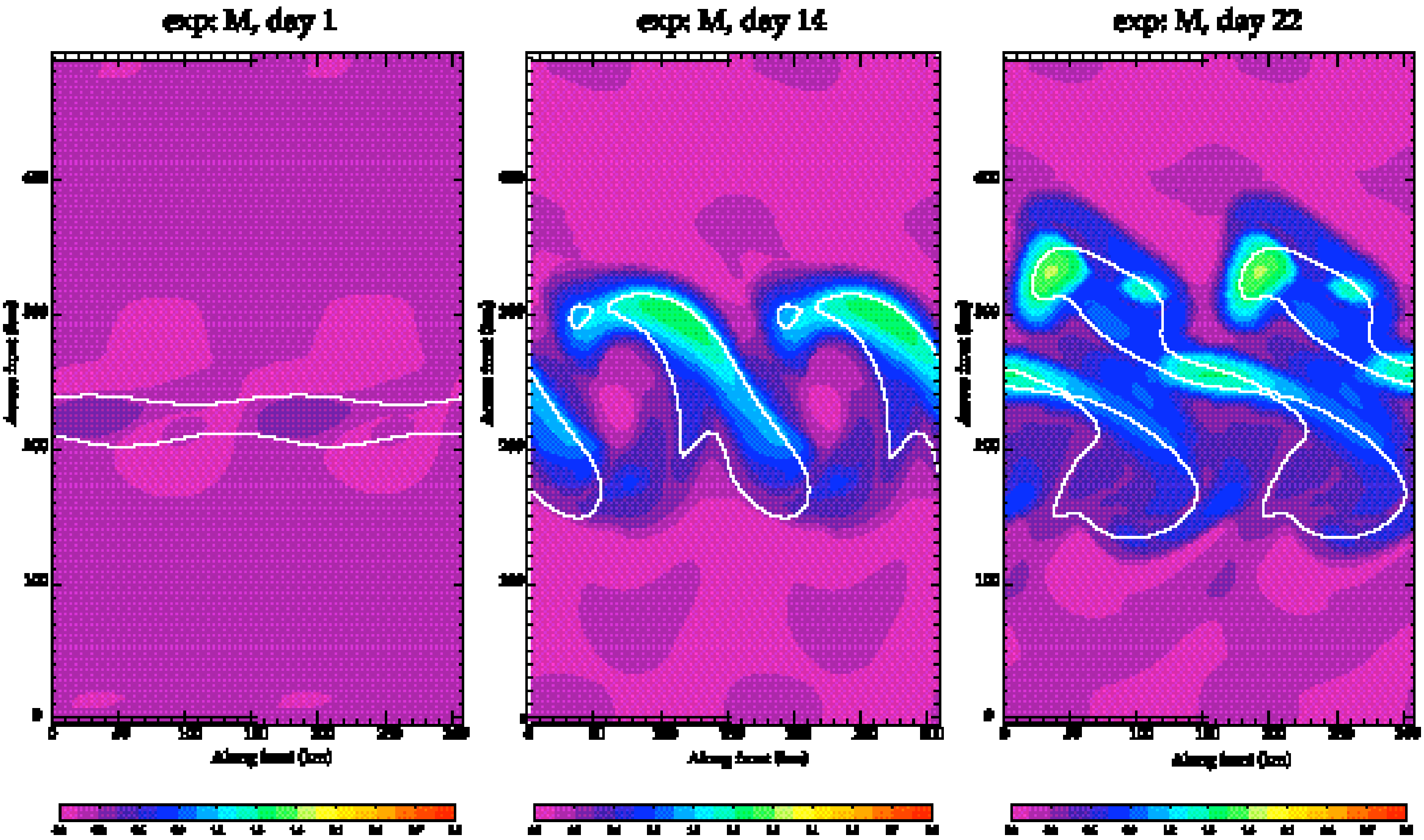


Baroclinic Instability

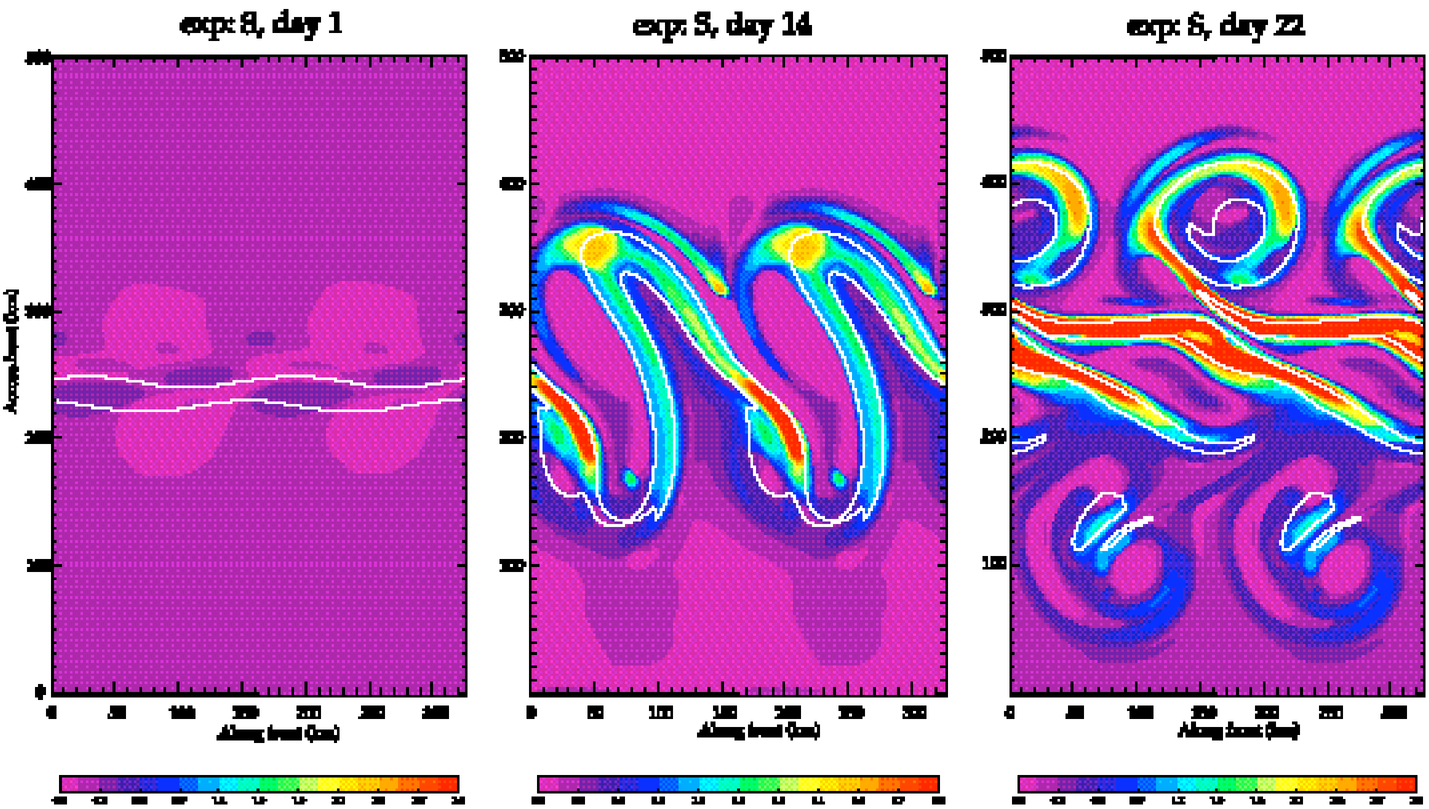


Small scale frontogenesis

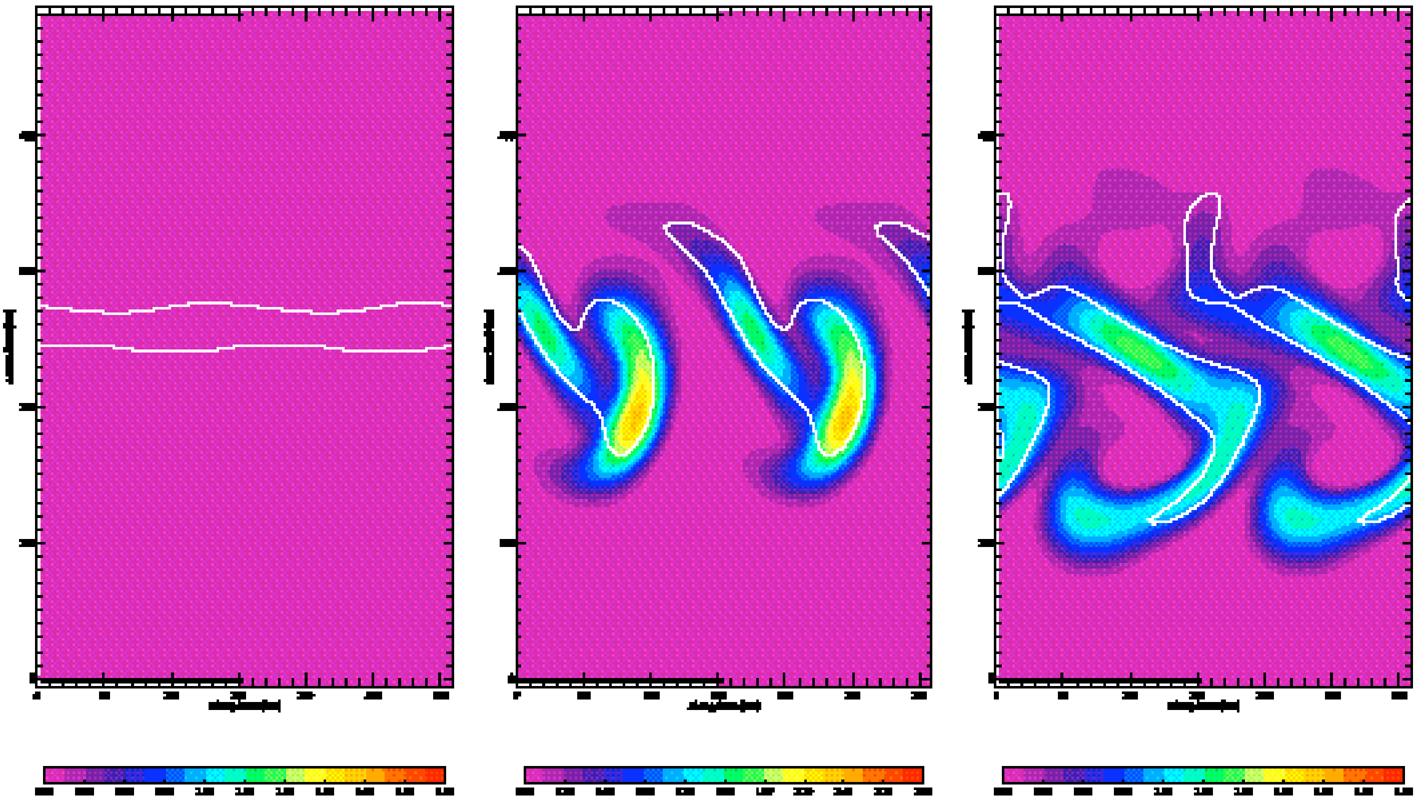




New Production

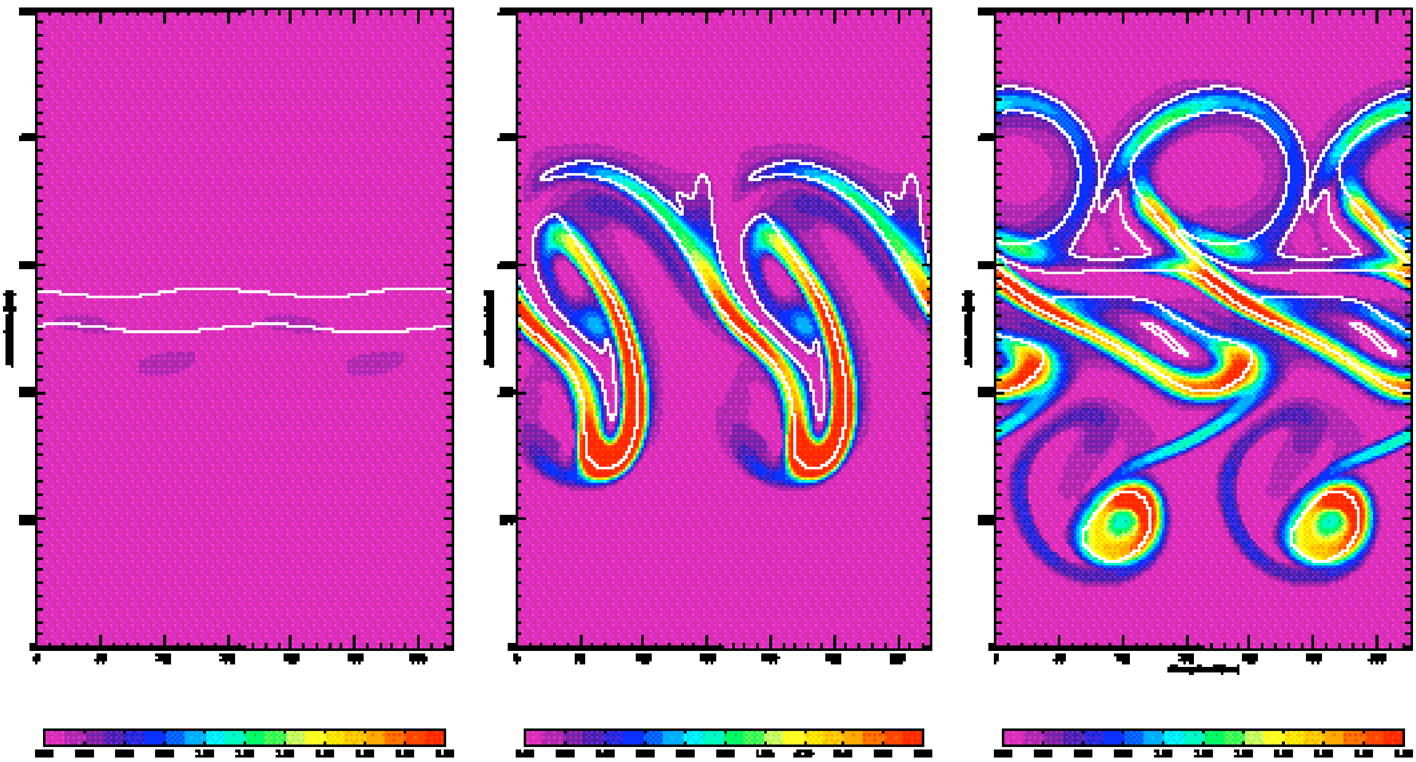


M experiment



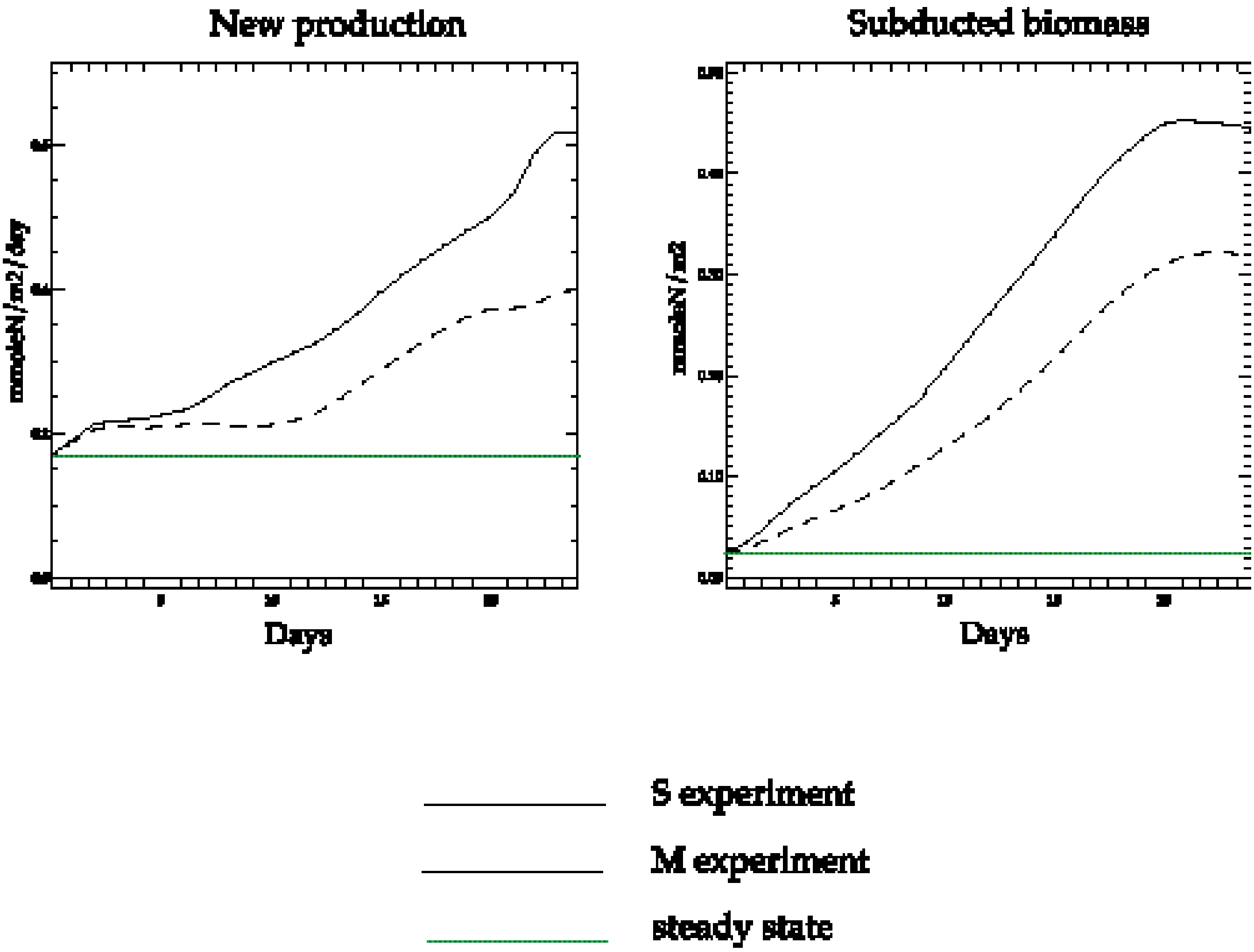
Subducted biomass

S experiment

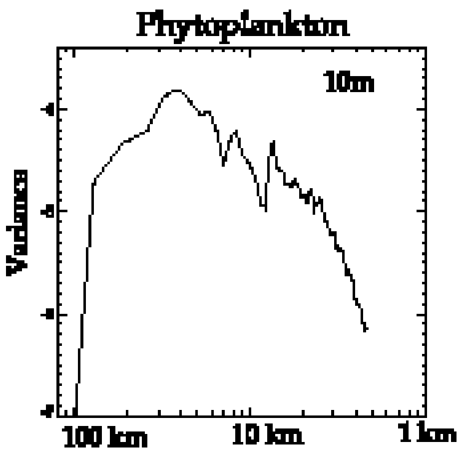


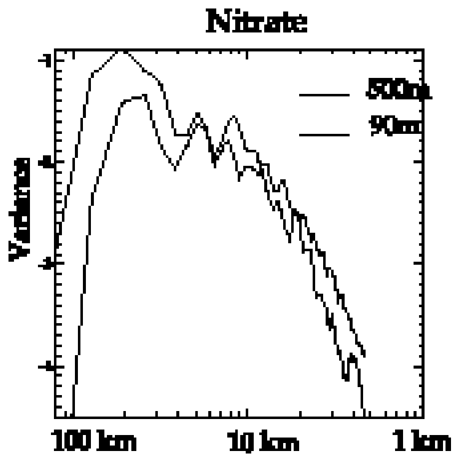
Global biogeochemical budgets

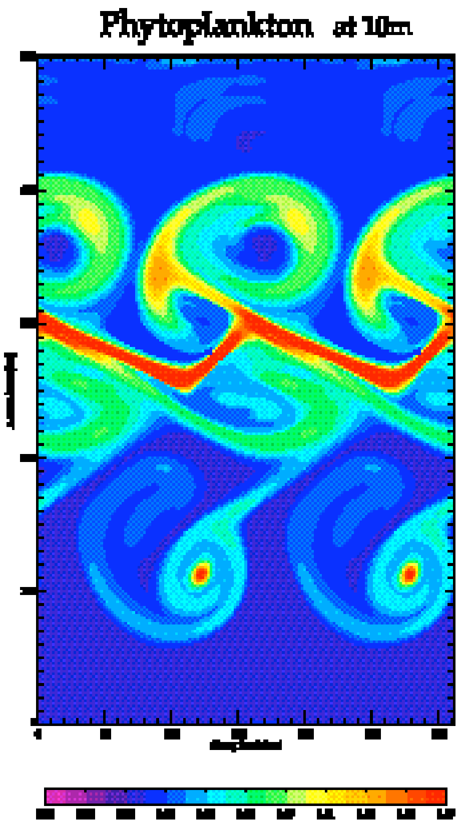
Oligotrophic conditions

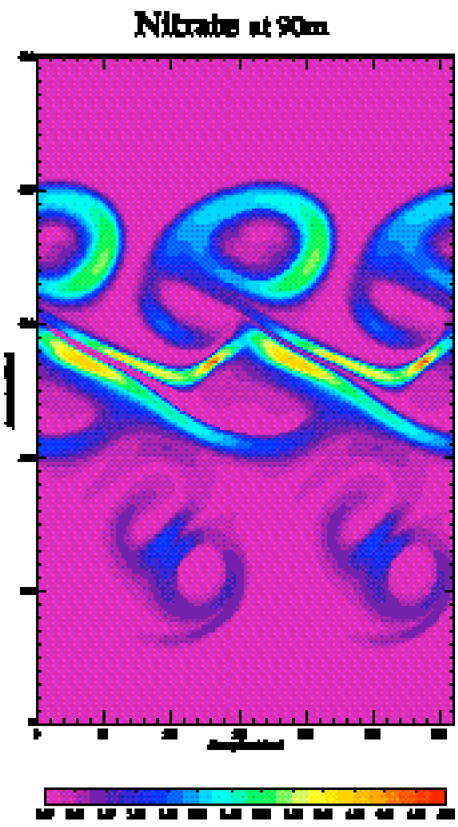


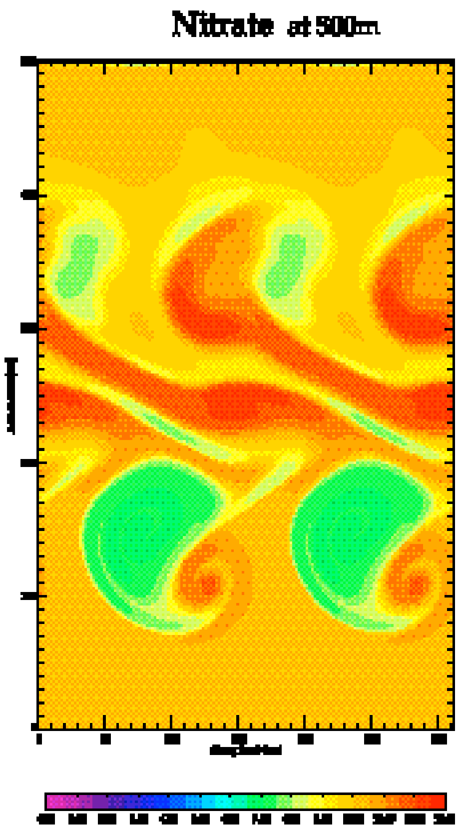
Evidence for sub-mesoscale Nitrate injection

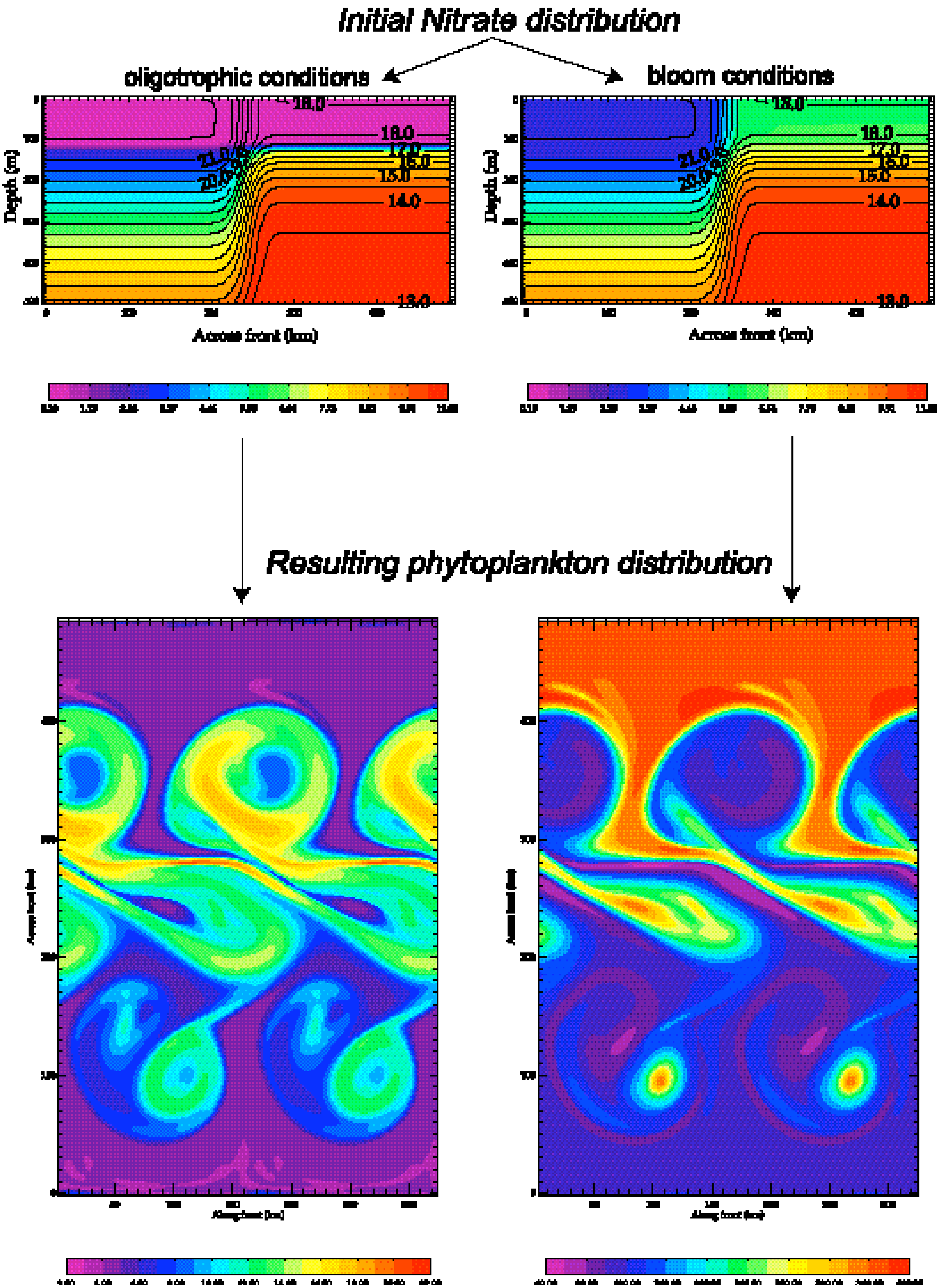






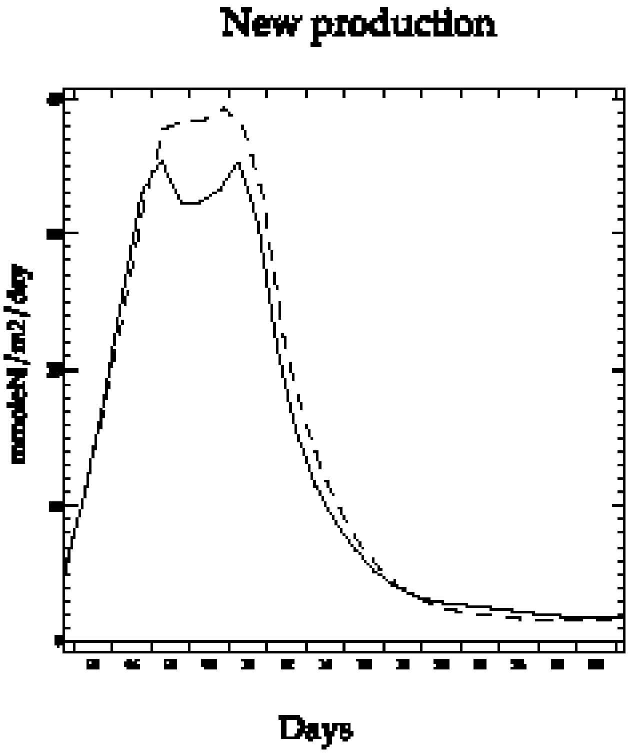


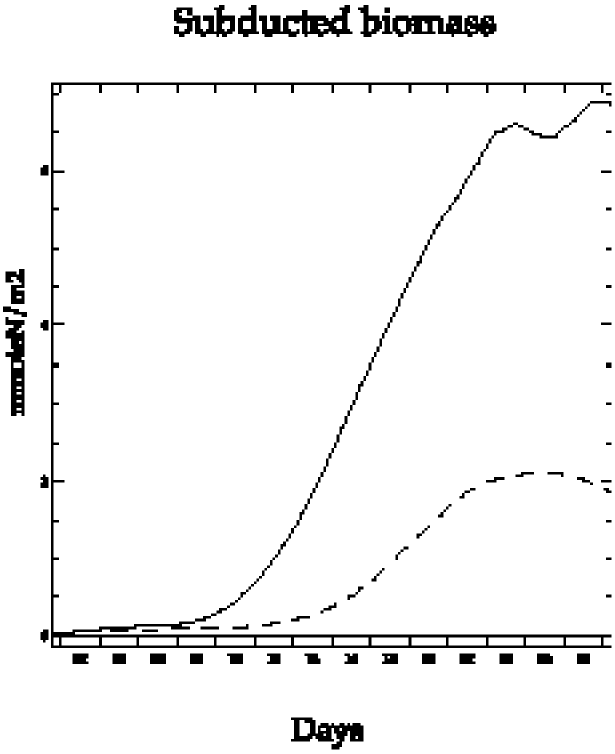



Initial Nitrate distribution
oligotrophic conditions
bloom conditions
Depth (m)
Across front (km)
Resulting phytoplankton distribution

Global biogeochemical budgets

Bloom conditions





S experiment

M experiment

Conclusions

Two effects of sub-mesoscale physics :

1- Reinforcement of mesoscale dynamics

2- Appearance of small-scale frontogenesis

Both effects are responsible for a large increase
of the vertical velocities

at mesoscale
at sub-mesoscale

At sub-mesoscale

Small scale frontogenesis is responsible for nutrient inputs at sub-mesoscale

Sub-mesoscale New Production accounts for a large part of total NP in oligotrophic regions

At mesoscale

NP is enhanced in anticyclonic eddies (baroclinic instability)

but phytoplankton distribution can be more important in cyclonic eddies depending on the biogeochemical context in the region where the eddy is formed

Open questions

role of the atmospheric forcing,
aging of the ecosystem, decay of the eddies