# Sub-daily to seasonal and submesoscale to mesoscale processes and interaction with ocean biology

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#### Histogram of surface chlorophyll from MODIS 2003-2010 (9 km daily) 25 N Jonsson et al. (in prep)





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### **2. Subpolar Gyres** strong seasonality: light, MLD variation

## What dynamics underlie this variability?

### **3. Coastal Margins** strong horizontal gradients

#### 1. Subtropical Gyres

weak horizontal gradients, low seasonality

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#### When physics (advection) is important $L \sim Ut$

#### Submesoscale

 $L \sim O(0.1 - 10 \, km), \ t \sim O(days)$ 

(~ Biological time scales)

Mesoscale  $L \sim O(10 - 100 \text{ km}), t \sim O(weeks - months)$ 

## What dynamics underlie this variability?

#### PHYSICS —

#### Supply of nutrients / Exposure to light

Blooms occur when nutrient and light limitation are overcome

## Variability: Physically or biologically mediated?

$$\frac{\partial P}{\partial t} + \mathbf{u} \cdot \nabla P = \mu P,$$
$$t_{phy} = \frac{L}{U} \text{ or } \frac{D}{W}$$
$$t_{bio} = \frac{1}{\mu}$$

where  $\mu = \mu(I, N)$ 

Physics: Horizontal or vertical advection?

 $t_{bio} \gg t_{phy}$ 

#### Subtropical Gyres

46N

#### Mesoscale eddies stir the phytoplankton

441

43N

421

~1000 km<sup>2</sup> mg/m3 Seawifs 22 Nov 1997 0137Z chloroph But vertical nutrient fluxes dominated by submesoscale frontal processes

45N



a) Particles, May 29 1999

c) Particles, July 7 1999



Lehahn et al. (2007)



20W

19W

Composite of SST fronts Ulman and Cornillon (1995)

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#### Submesoscale upwelling?

At higher (1 km) model resolution, we find that:

The largest vertical velocities O(100m/day) occur where the Rossby number becomes O(1). Circulation not in geostrophic / thermal-wind balance -- has a large vertical component.



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Mesoscale Experiment 480 km x 960 km (5 km grid resol)





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An (over-simplified) model for nutrient and phytoplankton production



Nutrient-like tracer and phytoplankton

#### Evolution of phytoplankton distribution with time?

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JGR



N. Atlantic Bloom 2008 D'Asaro, Perry, Fennel, Lee

No Nutrient Limitation Yr Day 95-145 Alkire et al. (submitted)

200

#### Blooms: Growth rate becomes large



8 um



Winter: Mixed layer is deep and the average light in the mixed layer is low Spring: Mixed Layer Shallows and the average light is higher

#### Sverdrup critical depth hypothesis

 $\begin{array}{lll} \mbox{Production rate} & P(z) = \alpha I_0 \exp(-kz) & \mbox{Respiration rate} & R(z) = R_0 \\ \mbox{Critical depth} & z_{cr} \mbox{ where } & \hline \int_0^{z_{cr}} P(z) dz = \int_0^{z_{cr}} R_0 dz \end{array}$ 

#### Satellite Chl (south of Iceland) 2008



#### **Restratification of the mixed layer by eddies**

#### Fox-Kemper et al., 2008





#### Fronts → Eddies → Restratification → More ave light → Bloom





#### Does eddy restratification matter?

(area averaged) time series from model





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#### High vorticity and strain rate in submesoscale filaments





Upwelling occurs on the lighter side of the front. Filaments emanate from the denser side- support strong export.

#### Advection and biological growth - affect variability Submesoscale physics has a significant impact

- strong vertical velocities
- restratification
- filaments strong lateral and vertical advection

Biological vs. physical variability How can these be separated?



#### Discussion

### Should we care about variability if we are interested in the big picture (climate) ?

#### Submesoscale processes contribute to biogeochemical fluxes

In creased productivity in limited region studies -

but .... Global to basin scale X (Levy et al., 2011)

Nonlinear interactions

 $\overline{p'q'} \neq \overline{p'} \ \overline{q'}$ 

Chl has a lognormal distribution (indicative of multiplicative processes) Mean is not a good representation

Parameterize biogeochemical eddy fluxes?

#### Discussion

Biological / physical variability - Lagrangian approaches
Vertical structure of variability is important
Other biogeochemical properties - CO2, O2, ...
Grazing - variability exercised from top-down control
Community structure (auto-/hetero-trophic)
Export is highly variable

Vertical structure important - light / nutrients / mixing ChI (color), Nutricline (black line), MLD (red line) - Cariaco Basin

(Omand et al., in prep)



#### Other biogeochemical properties - pCO2

# pCO2 change due to localized upwelling positive (red), negative (blue)



Mahadevan et al., 2010

+5%