Lecture 17: Biological-physical coupling

- Topics:
  - Finish zooplankton
    - Herbivore growth
    - Secondary production
    - Some examples of zooplankton behavior
  - Scales of variability
    - Scales < 1 km, **Scales < 1000 km,** Scales ~1000's of km
    - Mesoscale eddies (today and finish on Monday)

Exam #3

- Wed., March 17th
- Duration: 1 h, 45 min (you will have 2 h to complete the exam)
- Format:
  - short answer (20 points)
  - 3 longer answer (there will be choice) [e.g. choose 3 out of 4] (30 points)
  - Total: 50 points, 20% of grade

Monday

- Integration and review for exam
- Assignment due Tuesday, March 16^{th}, 5 pm

Evaluation of secondary production (2ºP)

(1) Physiologic method:

- $2^oP = \Gamma A - R - E - M$
  - Allometry: Rate of growth = $a(\text{Weight})^b$

(2) Summing of growth x biomass:

(A) Vidal (1980)

- Growth is a function of temperature, food availability and size of individual
- Fit to an Ivlev curve:

$$R = R_{max}\,(1-e^{-\lambda F})$$

  - R = rate controlled by limiting factor with availability 'F'
  - R is max as F → infinity
  - λ is slope of the curve

- Vidal substituted food concentration for F

Evaluation of secondary production (2ºP)

(2) Summing of growth x biomass:

- Evaluate growth directly from field observations of the increase in size of individuals in a cohort

(B) Jensen (1919) equation:

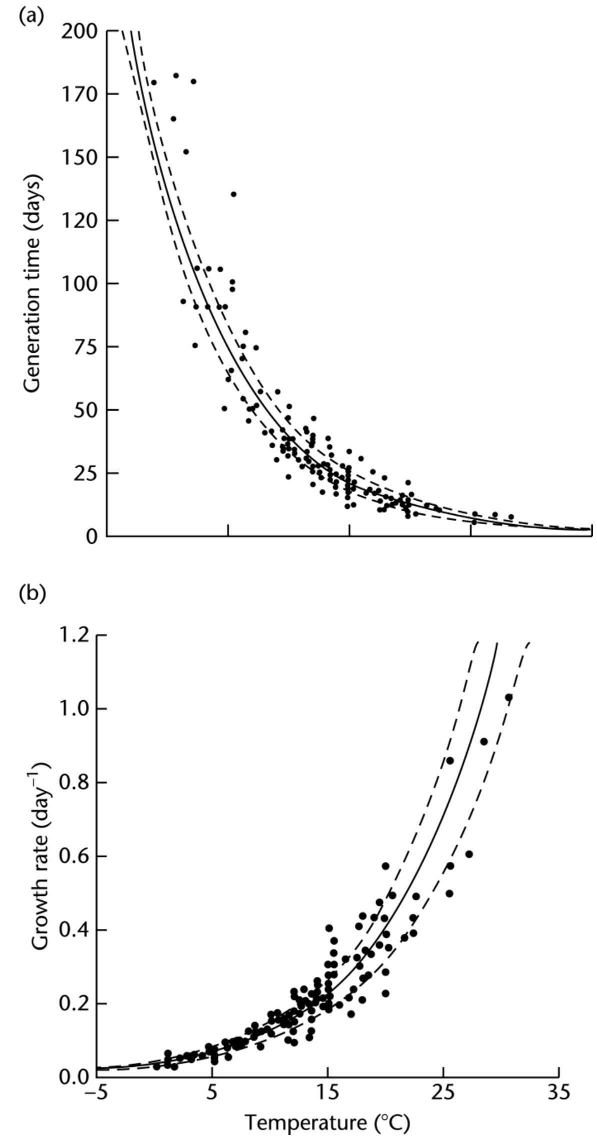
$$2^{o}P = \sum_{i=1}^{adult} G_i B_i$$

  - *i* = life cycle stage
  - G_i = weight-specific growth rate of *i*th stage
  - B_i = mean biomass of life cycle stage in the habitat

- Measure growth of different stages separately and add them up

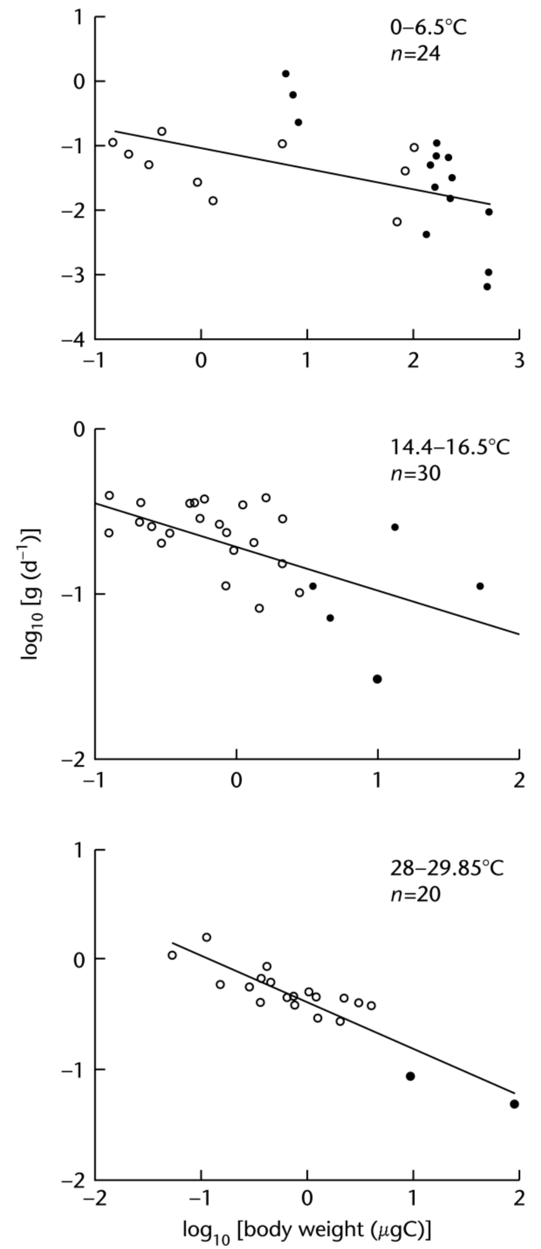
Controls on secondary production

- Temperature (Huntley-Lopez model)
  - Everything can be explained by a temperature relationship
    - Adult mass = egg mass x e^{gD} (g is growth rate, D is development time from egg to adult)
    - $g = 0.0445e^{0.111T}$



Huntley and Lopez, 1992

- Hirst and others: development time, body size, spawning mode, food availability
    - Secondary production has little to no relation to temperature
- No consensus



Hirst and Sheader, 1997

Phenology

The relationship between a periodic biological phenomenon and climatic conditions

- For zooplankton:
  - **Feeding** (match-mismatch hypothesis, D.H. Cushing)
  - **Diapause**: means to survive predictable, unfavorable or adverse environmental conditions, such as temperature extremes or reduced food availability
    - Often observed in arthropods

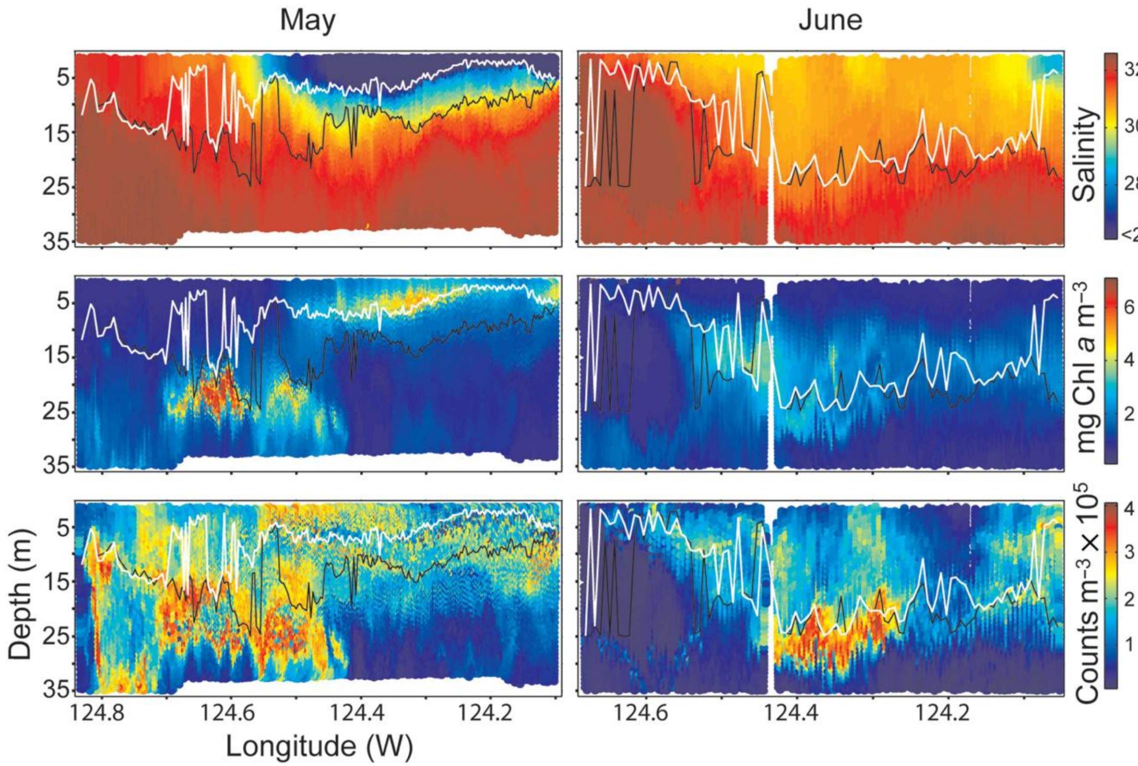
Other important behavior patterns

- Diel vertical migration (covered in earlier lecture)
- Creators of turbulence in low-turbulence environments (Kunze et al., 2006; Katija & Dabiri, 2009)
- Aggregation at or near fronts

Zooplankton in the Columbia River plume

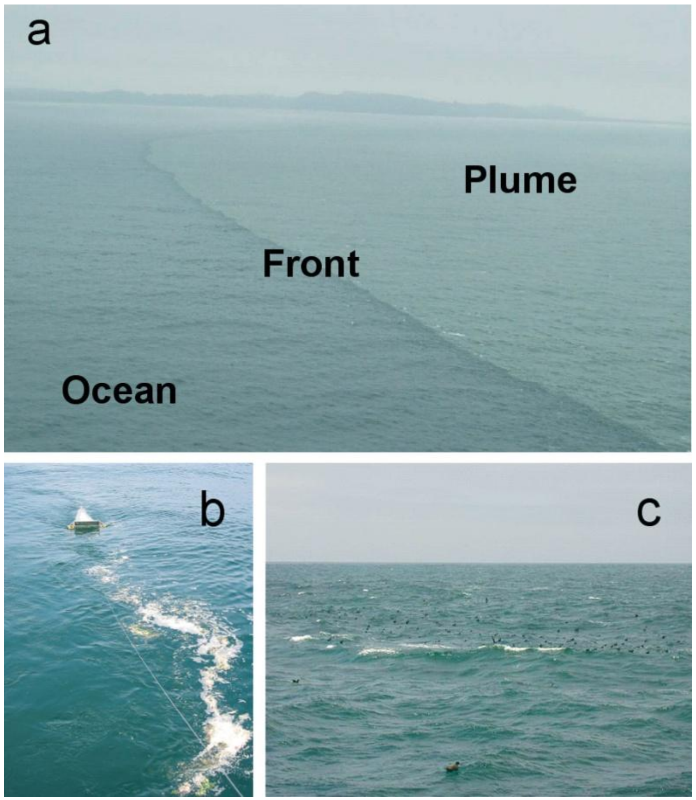
Peterson & Peterson, 2008
(ICES J. Mar Sci)

LOPC data

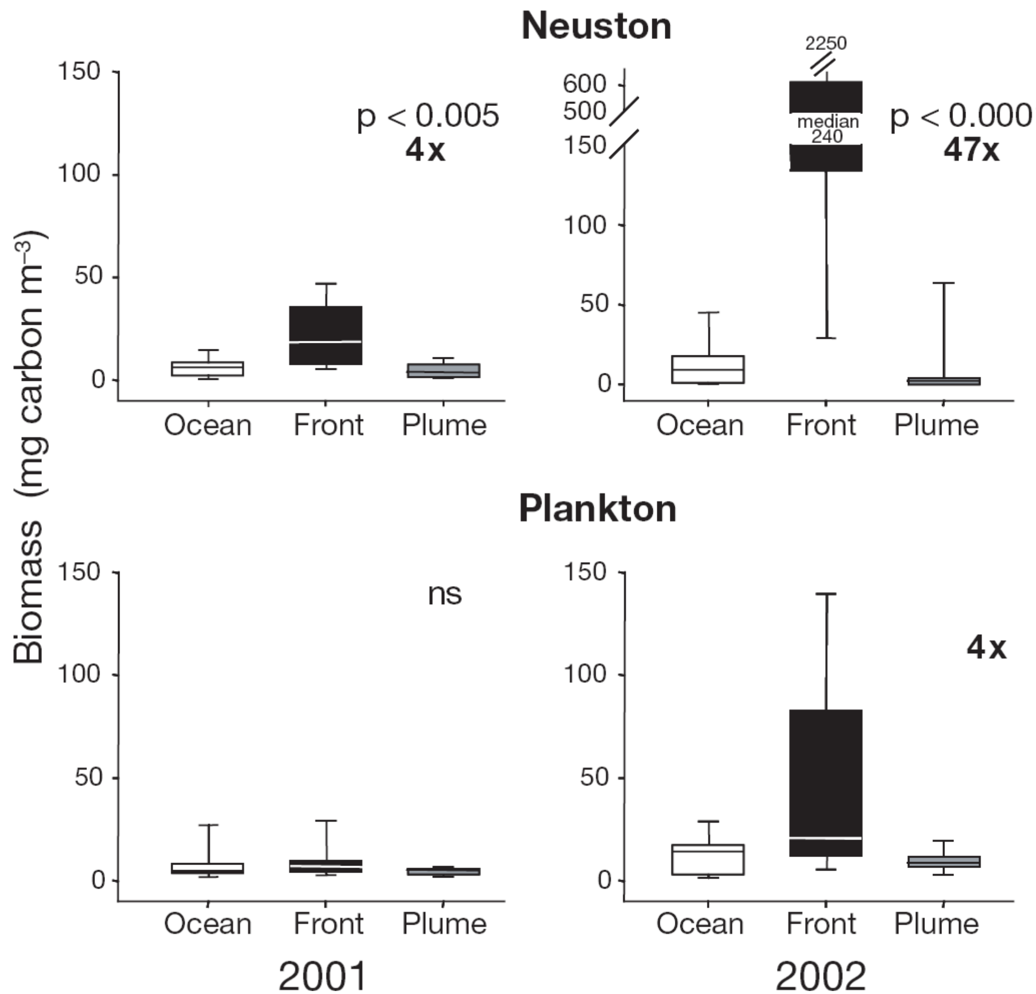


Peterson & Peterson (2008), Figure 2. Salinity (top), Chl a (middle), and zooplankton abundance (bottom) along cross-shelf transects (indicated by arrows in Figure 1) just south of the Columbia River mouth during the May (left) and June (right) surveys. The pycnocline (solid white line) and thermocline (solid black line) are shown in each panel.

Zooplankton accumulate at fronts, especially near the surface



Data from microscopic counts



Morgan et al. (2005), Mar. Ecol. Prog. Ser., 299: 19-31.

Processes on scales < 1 km

- Turbulent motion
  - Turbulent energy
- Viscosity
  - Reynolds number (Re) → from last class: ratio of intertial to viscous forces
  - Low Re, viscous world (laminar flow); high Re, turbulent world (turbulent flow)
- Drag effects
- Sinking & swimming
- Detection of food particles (zooplankton)
- Vertical mixing

Scales < 1 km
Turbulent energy and viscosity

- Turbulence: departure from smooth (laminar) flow
- **Energy cascade**: transfer of energy from larger scales of motion to smaller ones
  - does not change total energy in turbulence, nor does it convert the kinetic energy of the turbulent motion to another form of energy
- When turbulent eddies become small enough, velocity gradients across eddy become large, shear is great and **molecular viscosity** acts to resist and smooth out the gradients in velocity
  - energy in turbulence is converted to heat and dissipated
  - Molecular viscosity: internal resistance of water
  - Kolmogorov length scale: scale at which viscosity counteracts turbulence (=size of smallest turbulent eddy)

Scales 10-100's of km (mesoscale)

- Account for much of variability in the ocean
- Equivalent to 'weather'
  - River plumes
  - Coastal upwelling regions
  - Mesoscale eddies and meanders
  - Coastal fronts
  - Tides, tidal mixing, internal waves
- Rossby radius – a length scale
- *Rossby number – indicator of importance of Earth's rotation for the process being studied*

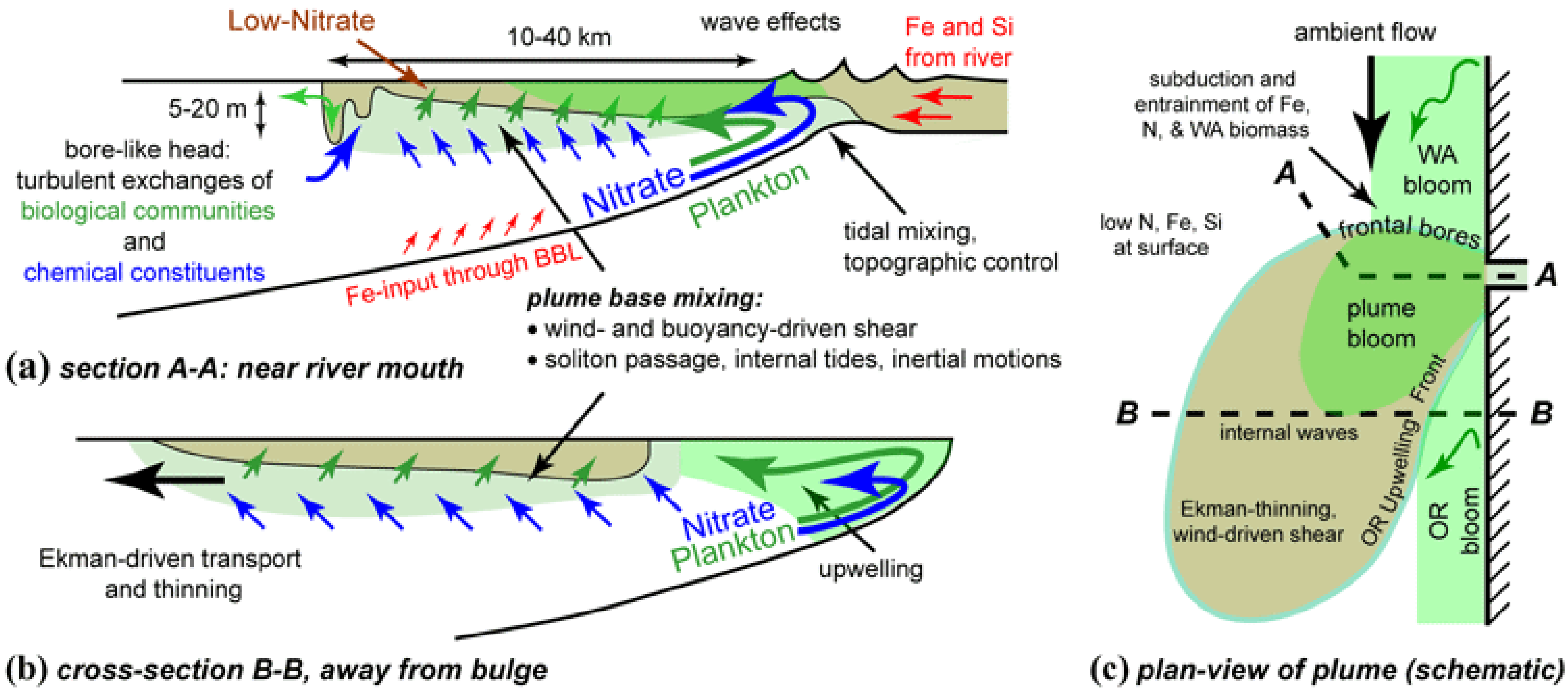
Scales > 1000's of km

  - Ocean basin circulation: major currents, gyres, deep ocean circulation

Scales 10-100's of km

Biological effects of river plumes

- Direct effects of materials carried by the river on biological production
- Entrainment (and potentially upwelling of nutrient-rich water), which may enhance primary and secondary production
- Enhancement of the stability of the water column, which may enhance PP in spring, but depress PP due to suppression of vertical mixing


Low-Nitrate
10-40 km
wave effects
Fe and Si from river
5-20 m
bore-like head: turbulent exchanges of biological communities and chemical constituents
Nitrate
Plankton
tidal mixing, topographic control
Fe-input through BBL
plume base mixing:
• wind- and buoyancy-driven shear
• soliton passage, internal tides, inertial motions
(a) section A-A: near river mouth
Ekman-driven transport and thinning
Nitrate
Plankton
upwelling
(b) cross-section B-B, away from bulge
ambient flow
subduction and entrainment of Fe, N, & WA biomass
A
WA bloom
low N, Fe, Si at surface
frontal bores
A
plume bloom
Front
B
B
internal waves
Ekman-thinning, wind-driven shear
OR Upwelling
OR bloom
(c) plan-view of plume (schematic)

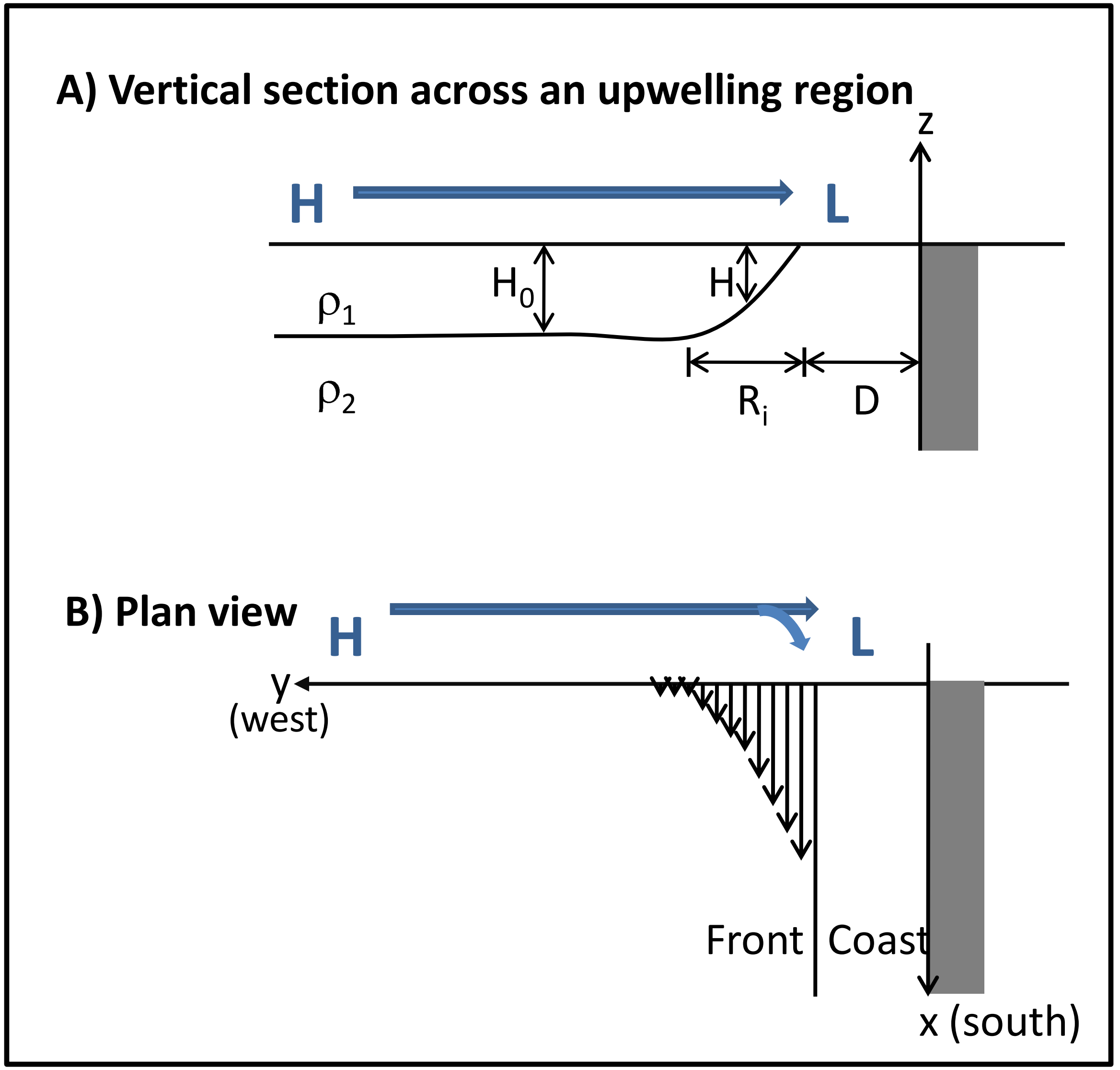
Coastal upwelling regions

- Upwelling is wind-driven
- Ekman transport (= Ekman drift) - net water movement 90^o to the right in NH;
- Depth of Ekman layer depends on wind speed and latitude:
  - $D_E \approx 4.3\ W / (\sin\theta)^{1/2}$
- How do we calculate Ekman transport (M_E)?
  - $M_E = -\tau/f$
    - τ = wind stress at the surface (e.g. 0.1 N m^{-2})
    - f = Coriolis parameter(varies by latitude)
    - $f = 2\Omega \sin\theta$, where Ω is the earth's rotational velocity and θ is the latitude (at 45^{o}N, ~10^{-4} s^{-1})
  - M_E = 1000 kg m^{-1} s^{-1} to the right (NH)
- Along-shore currents generated due to a resulting horizontal pressure gradient

- Density and pressure gradients caused by offshore Ekman transport (to the right) → *pressure gradient toward coast*
- Flow returns toward shore, but is deflected due to Coriolis, resulting in equatorward, *along-shore current (surface-intensified jet)*

D = distance of front from shore (~10-25 km)

R_i = width of the region where the interface between upper and lower layers rises to the surface = **Rossby internal deformation scale** (= internal Rossby radius)



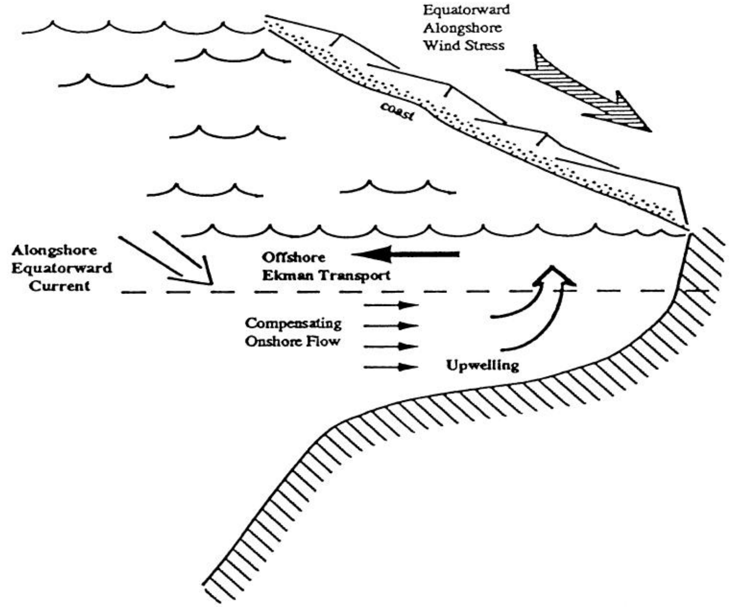
$$R_i = \frac{(g'H)^{1/2}}{f}$$

G is reduced gravity: g' = $\Delta\rho/\rho$ g

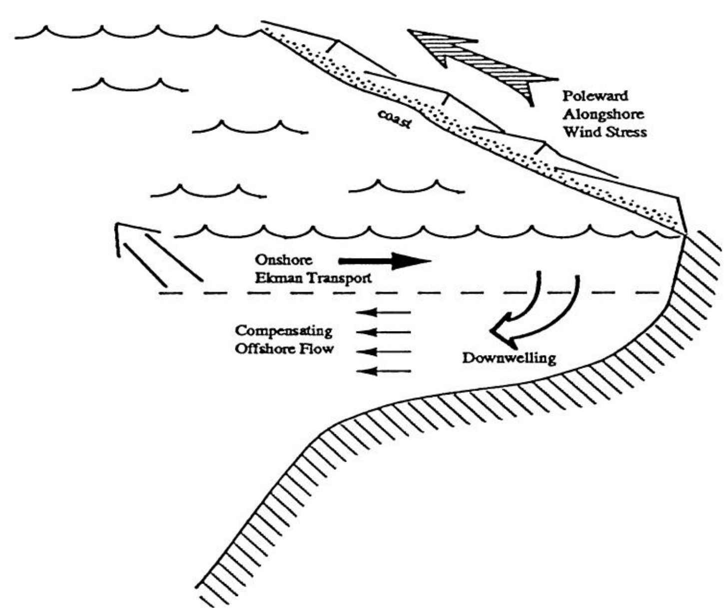
H is depth of upper layer

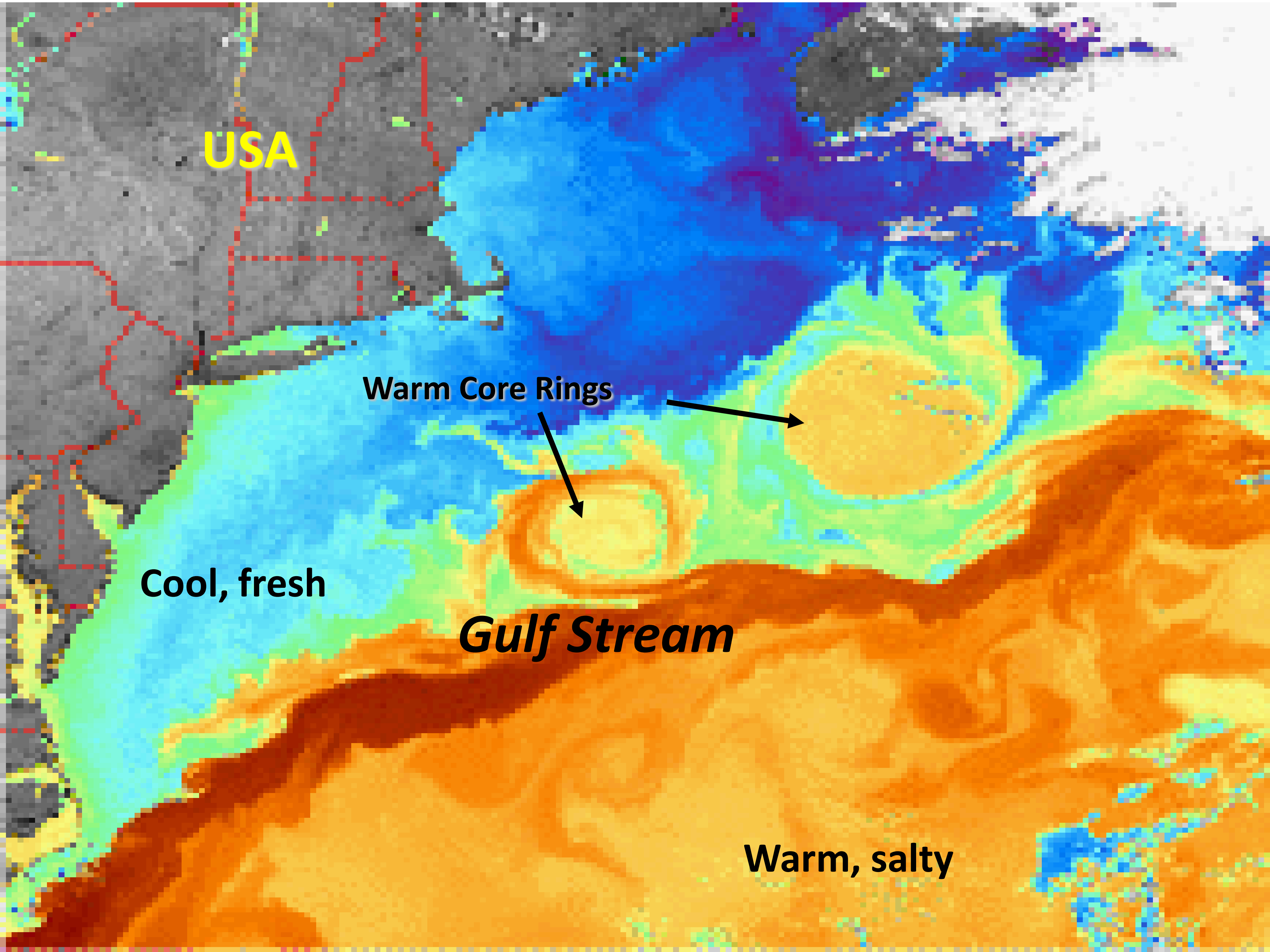
f is Coriolis parameter

Spring - Summer (Upwelling)

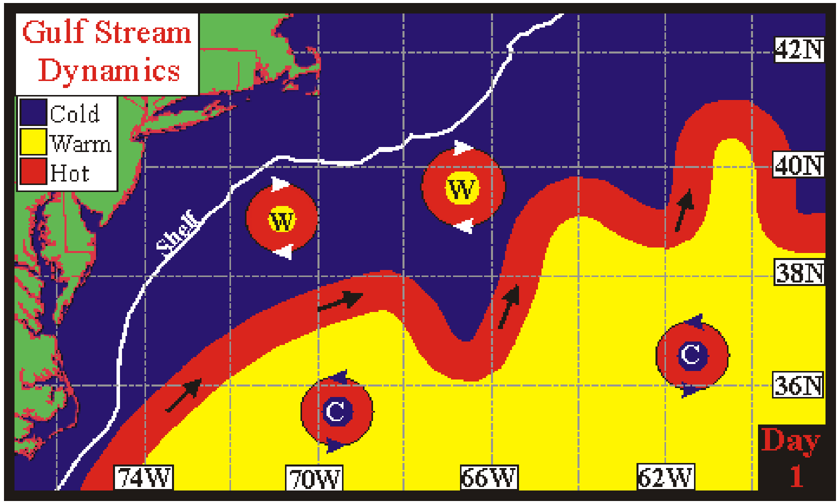


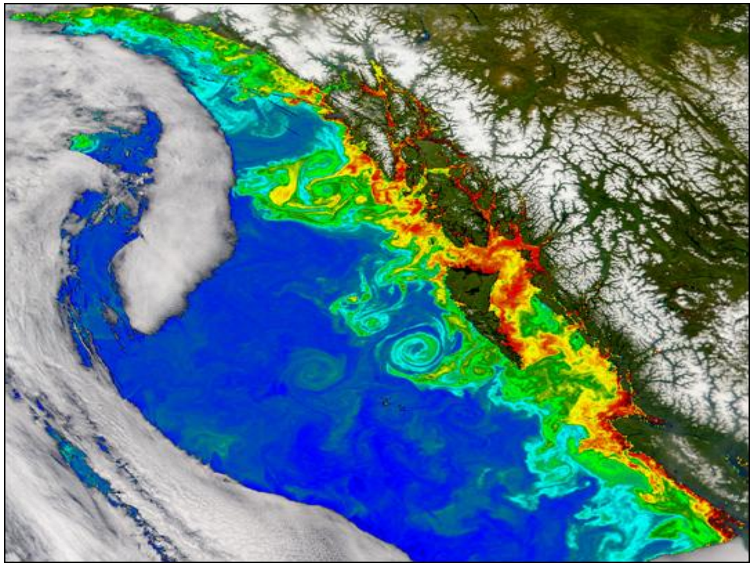
Fall - Winter (Downwelling)

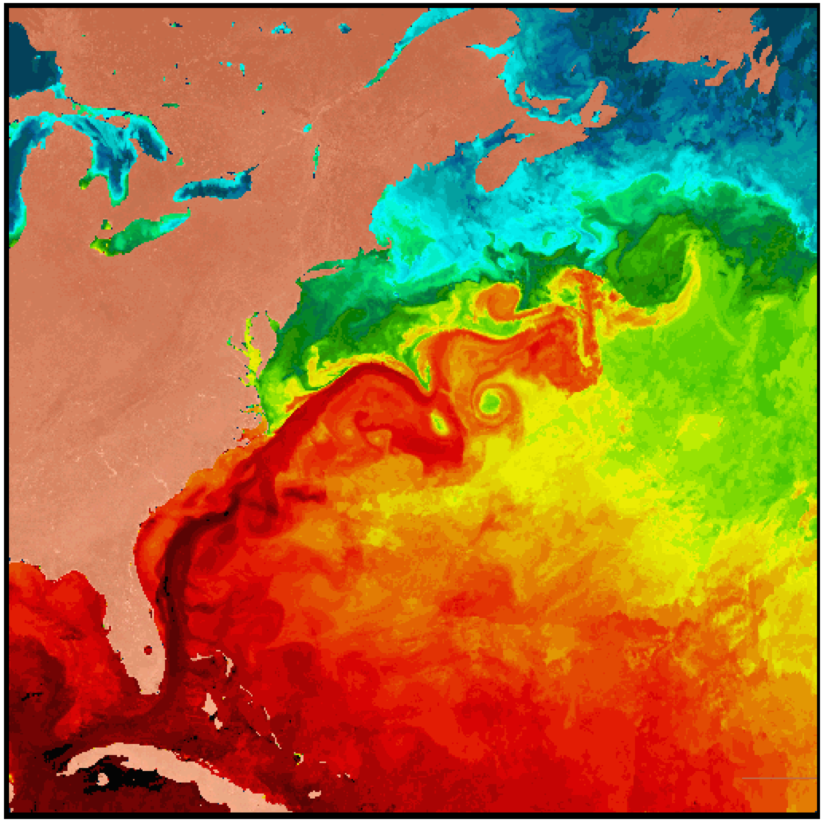



USA
Warm Core Rings
Cool, fresh
Gulf Stream
Warm, salty

Eddies and meanders

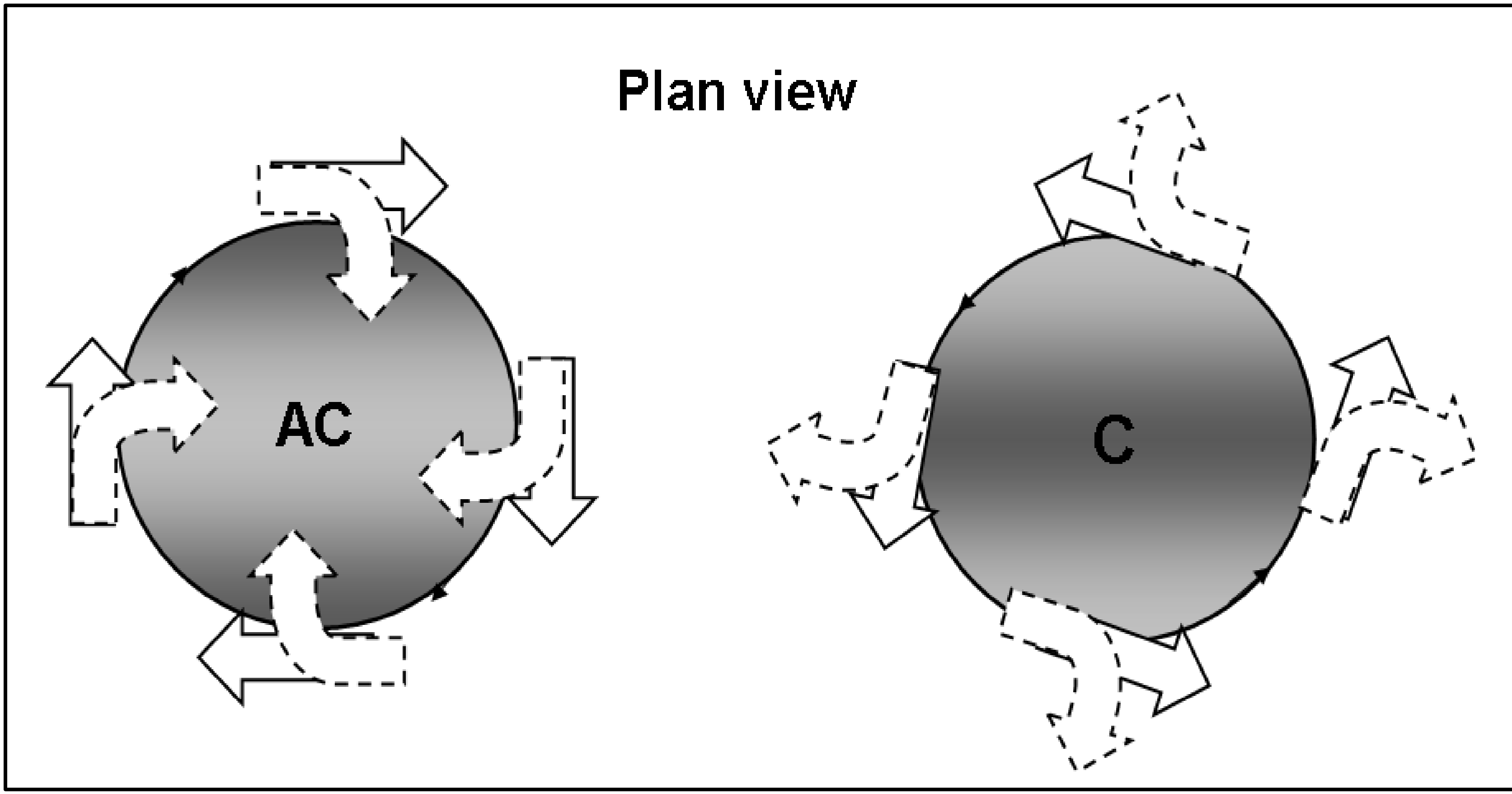






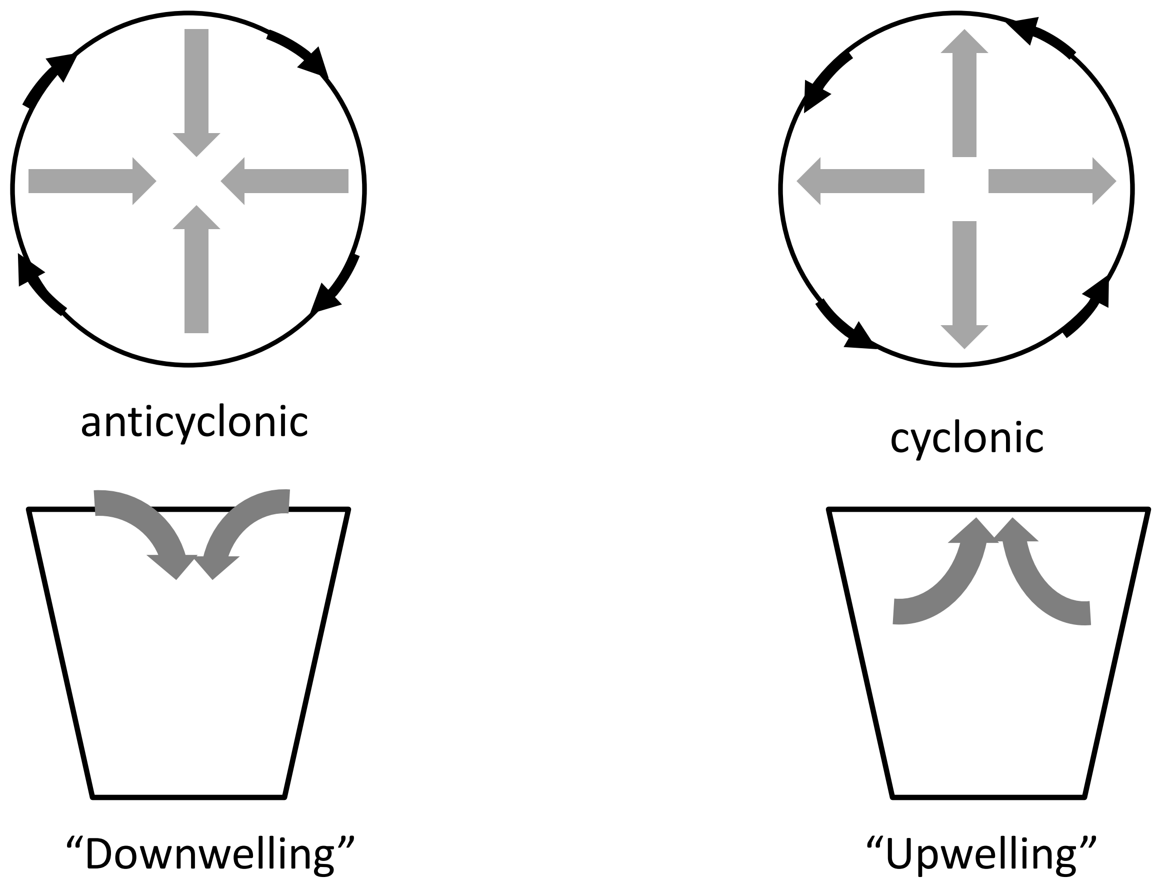
Often formed from instabilities

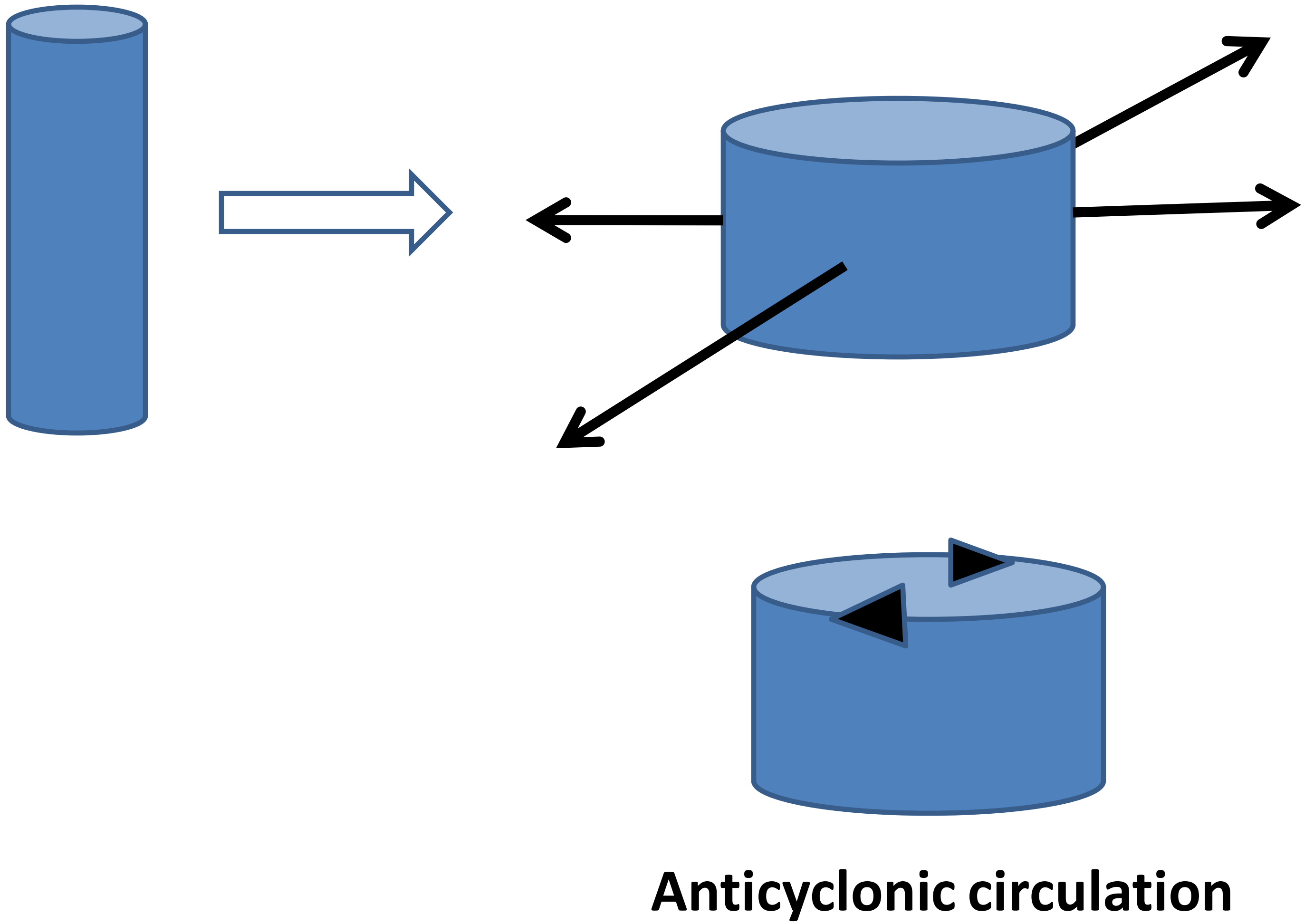
Anticyclonic and cyclonic eddies



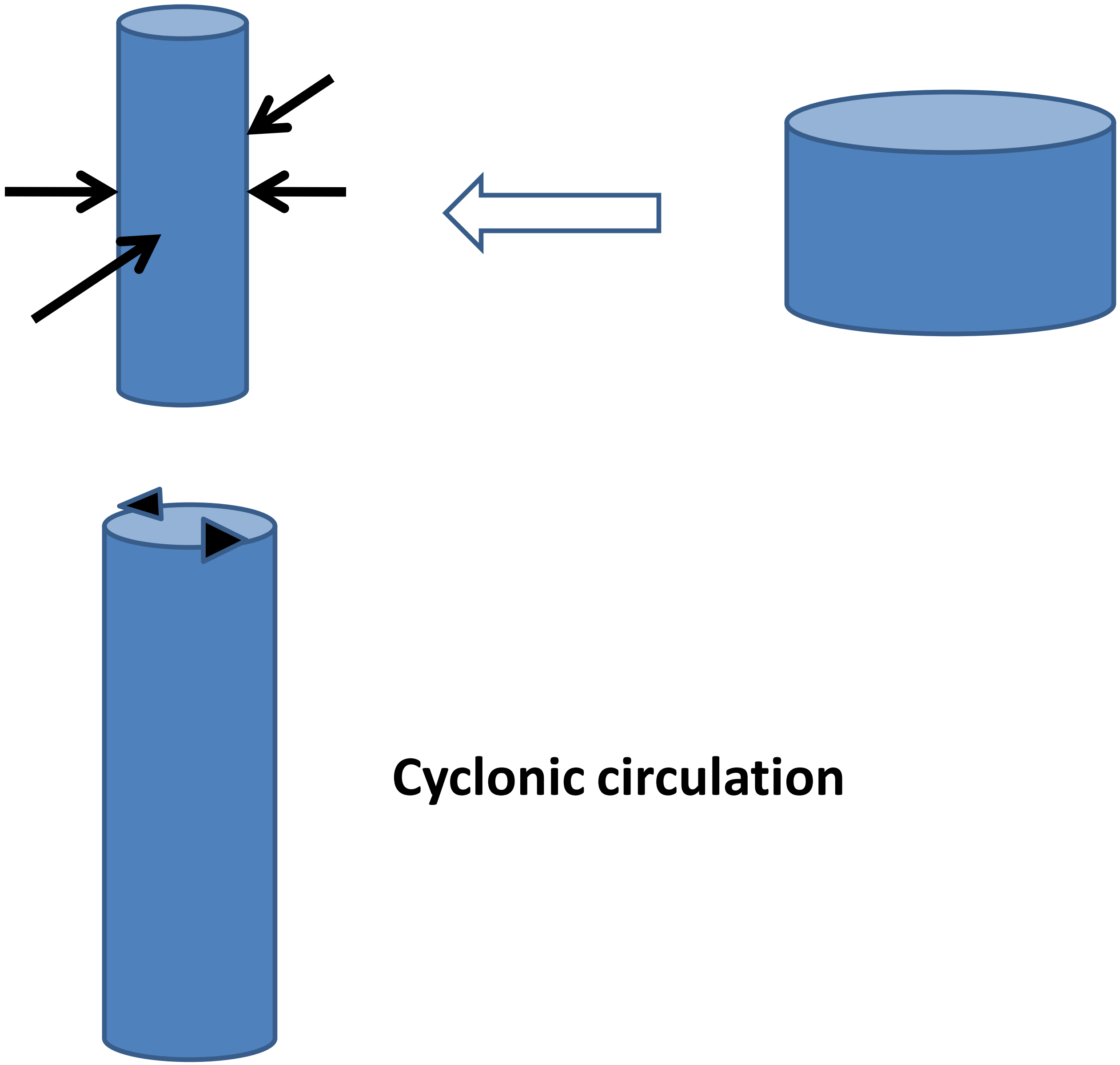
Mesoscale eddies

- Rotating vortices between 10-250 km in diameter
- Clockwise (anti-cyclonic) or counter-clockwise (cyclonic)

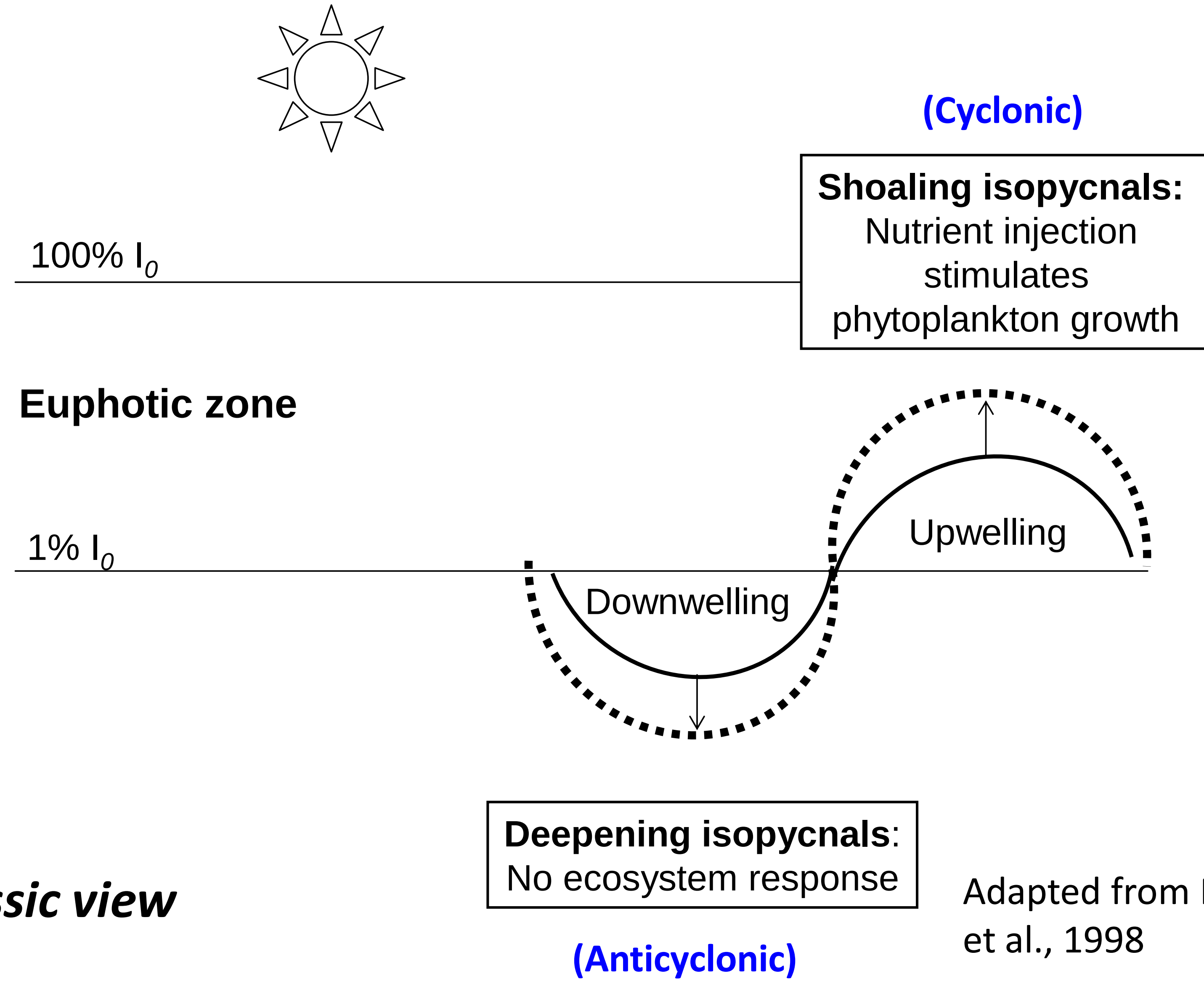




Flow over topography


Cyclonic circulation

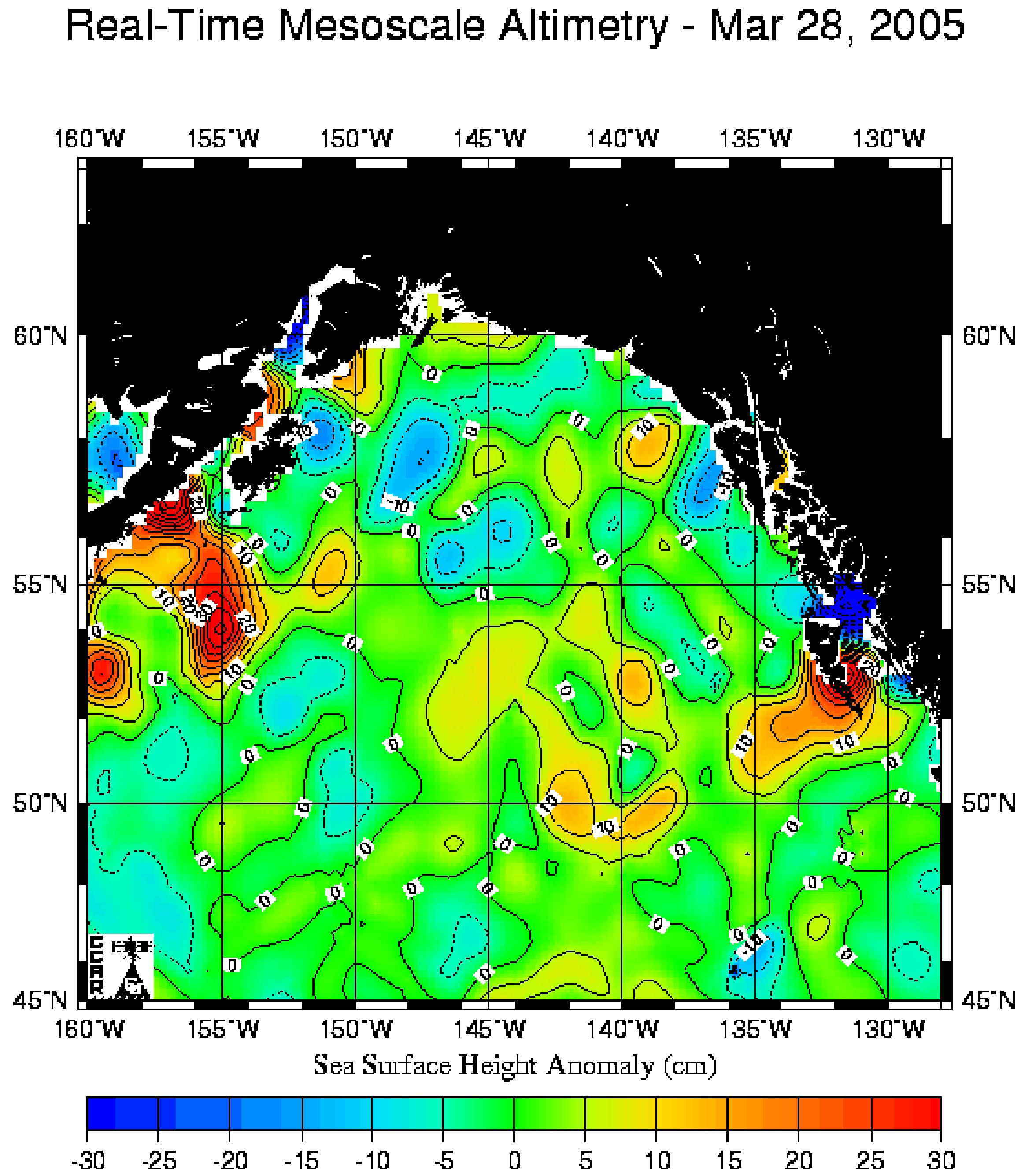
Influence of mesoscale eddies on oceanic primary production: Nutrient supply



Classic view

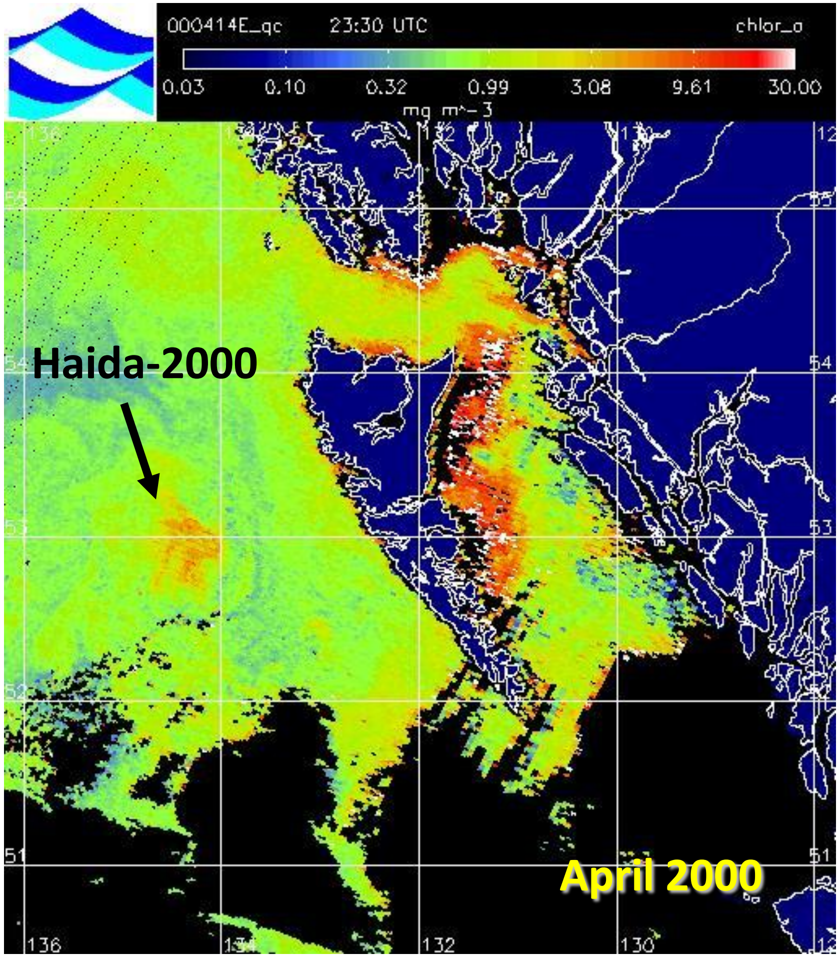
Adapted from McGillicuddy et al., 1998

Radar altimetry reveals sea surface height anomalies that are associated with eddies



Colorado Center for Astrodynamics Research, CCAR, UC Boulder

High chl *a* observed at the center of an anticyclonic eddy



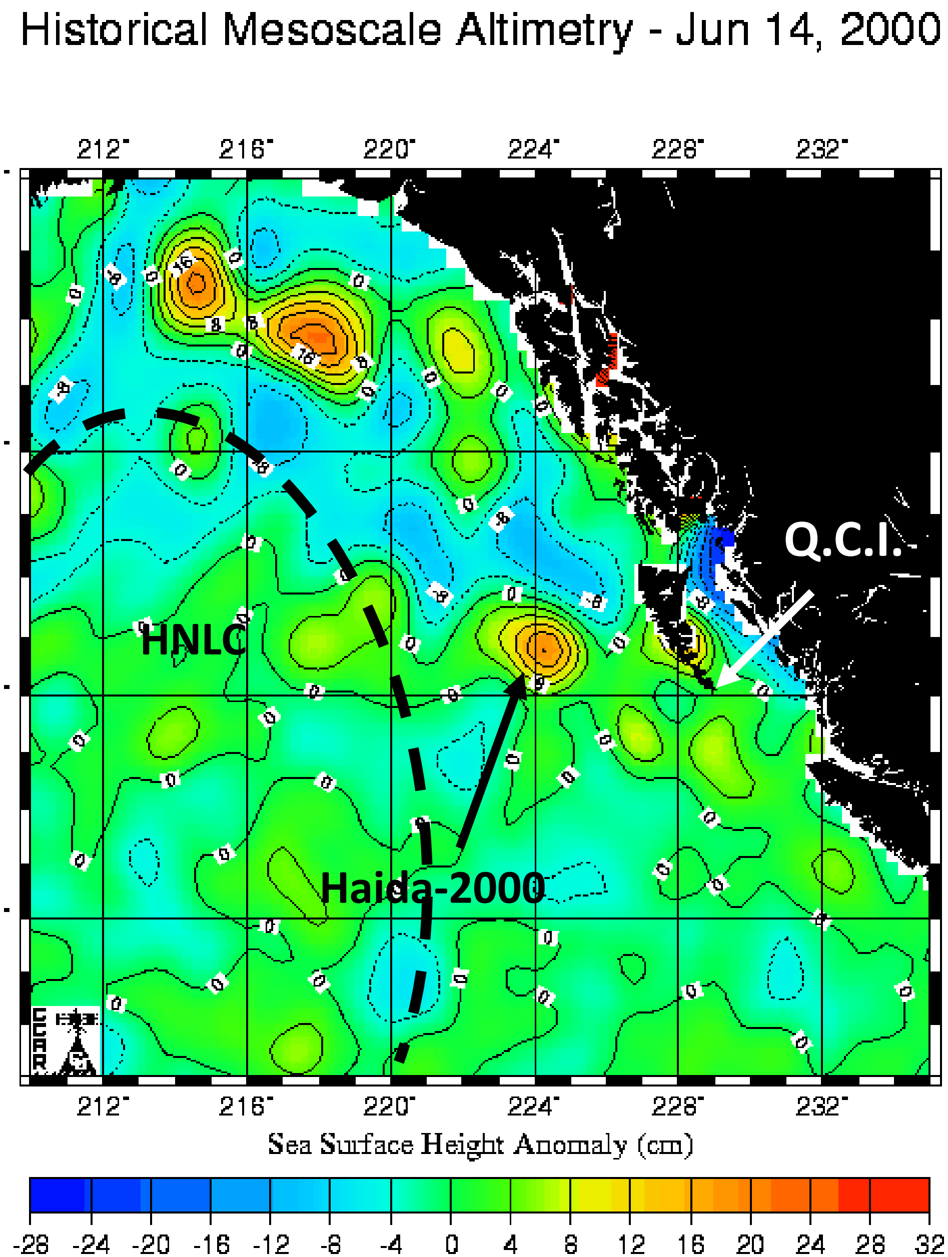
There are 2 reasons why this might occur;

But first, we will cover the basics of anticyclonic mesoscale eddy features.

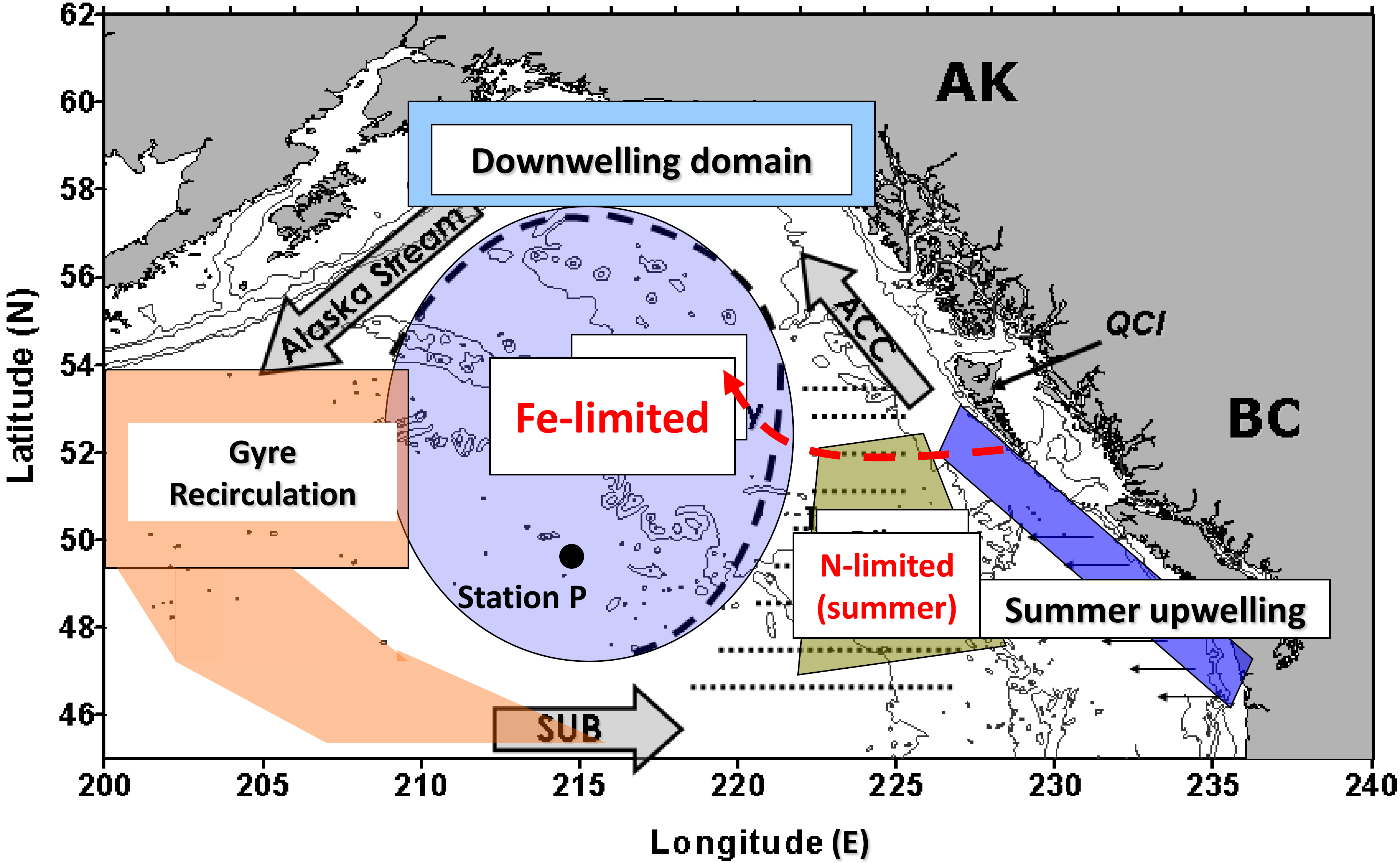
SeaWiFS images courtesy of J.F.R. Gower, IOS

Haida Eddies

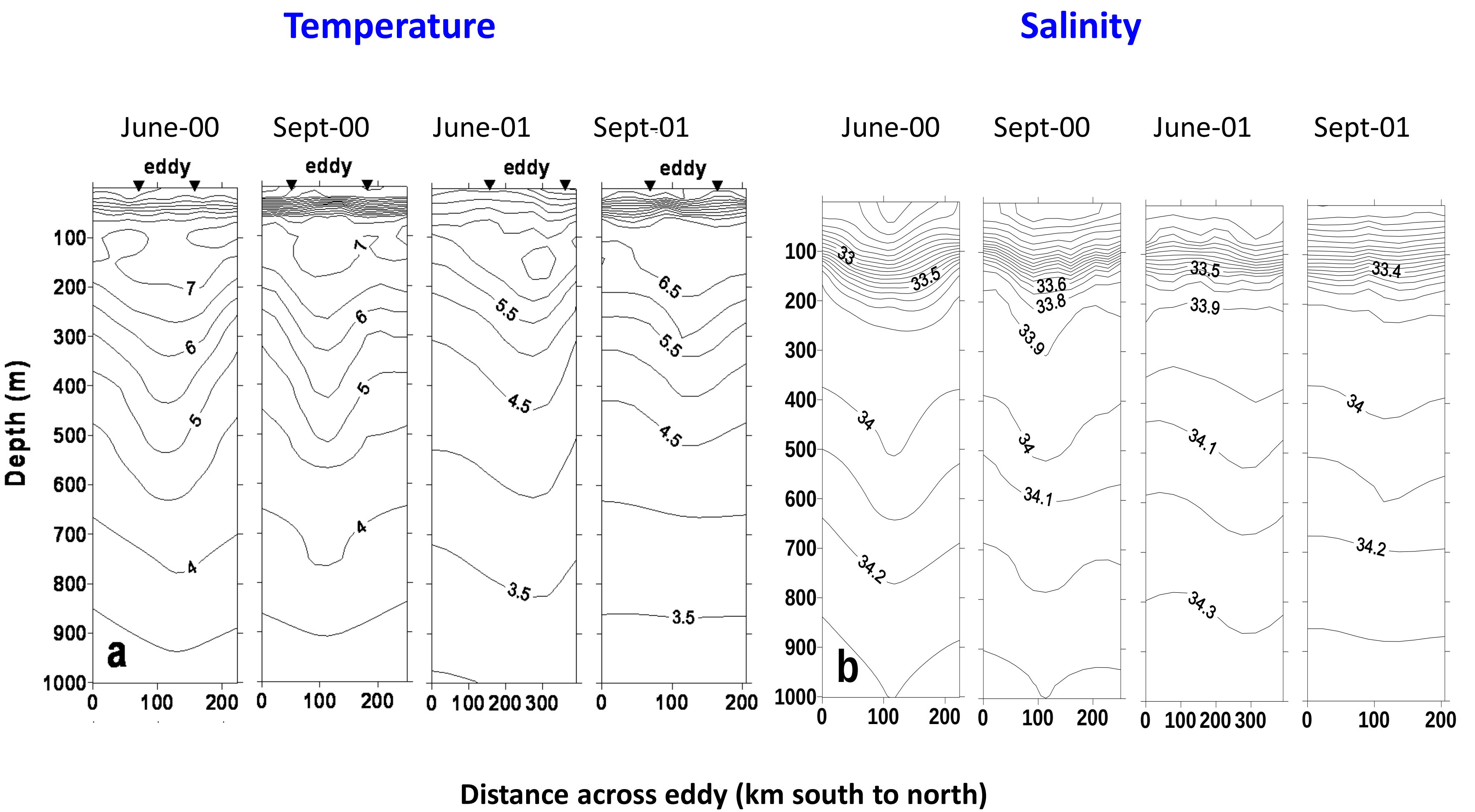
- Anticyclonic eddies Formed off southern tip of Queen Charlotte Islands each winter
- Source of coastal water
  - <u>Warm</u> and <u>fresh</u>
- Long-lived (> 1 year)
- Large (150 – 300 km in diameter)
- Anecdotal evidence of high productivity around eddies (squid, marine mammals, etc.)



Study area: Nutrient domains in Gulf of Alaska



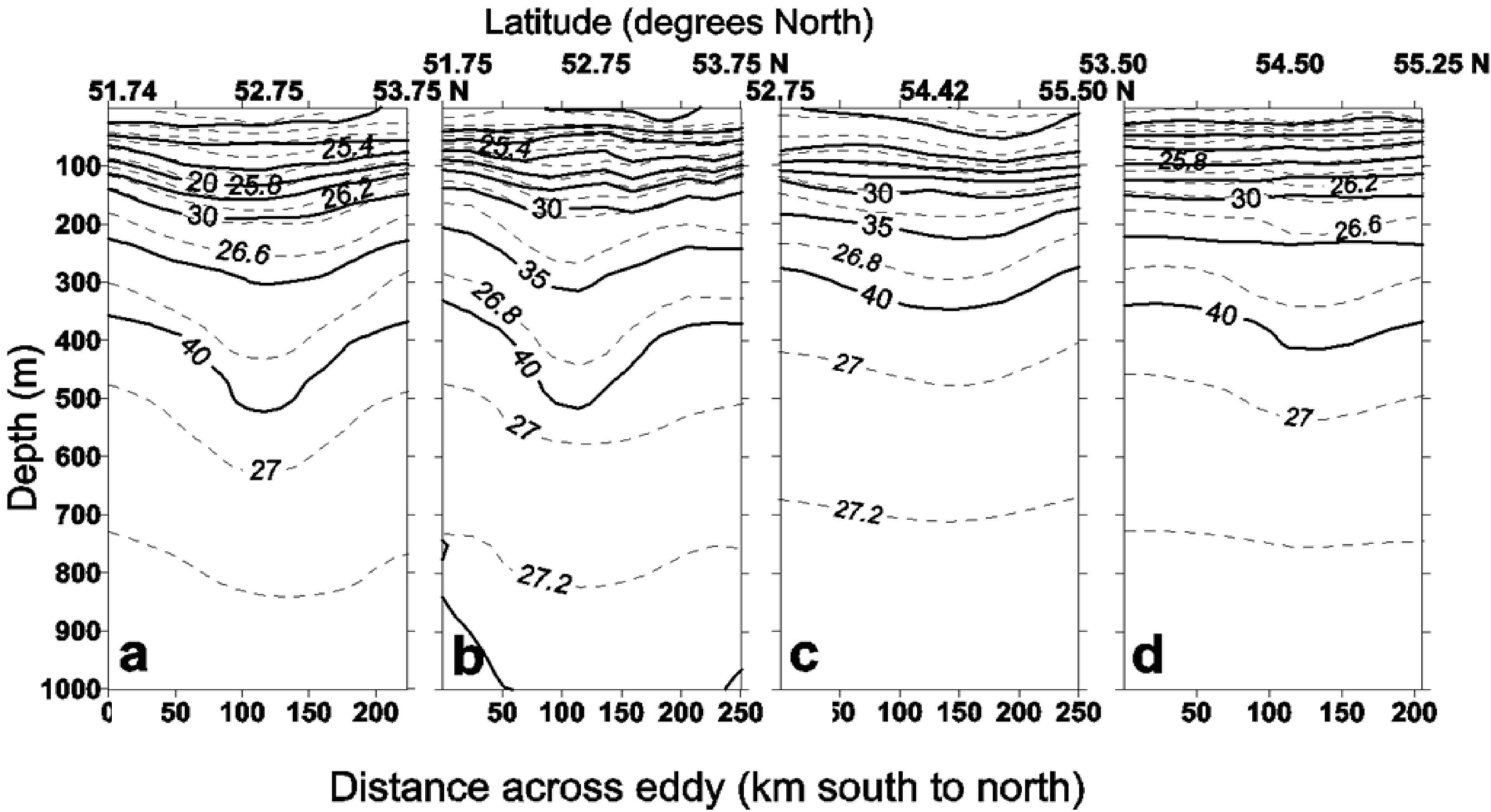
Structure of an AC eddy at 4 time points



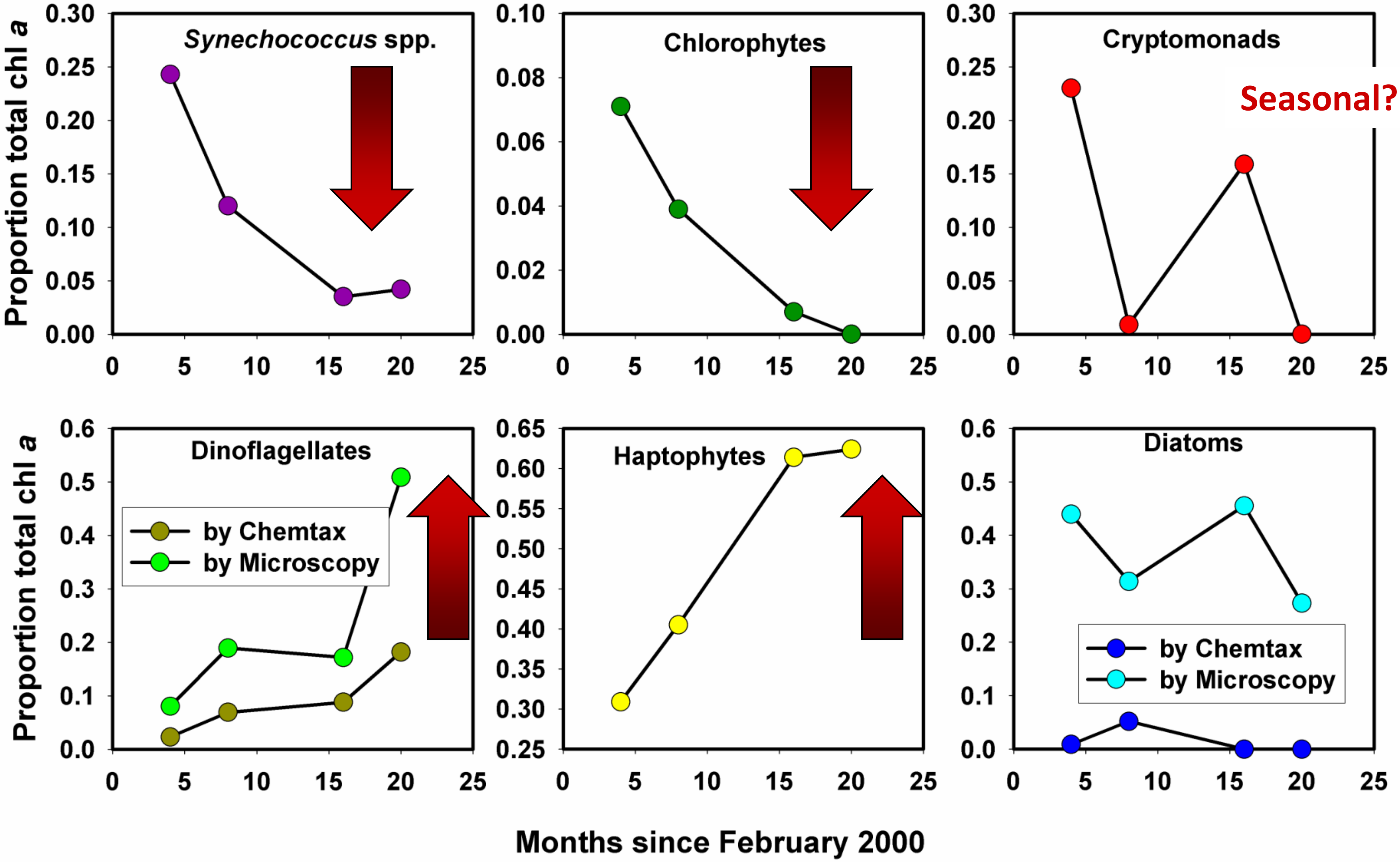
In this example, the eddy is warm and fresh compared to surroundings

Structure of an AC eddy : Nitrate and sigma-θ

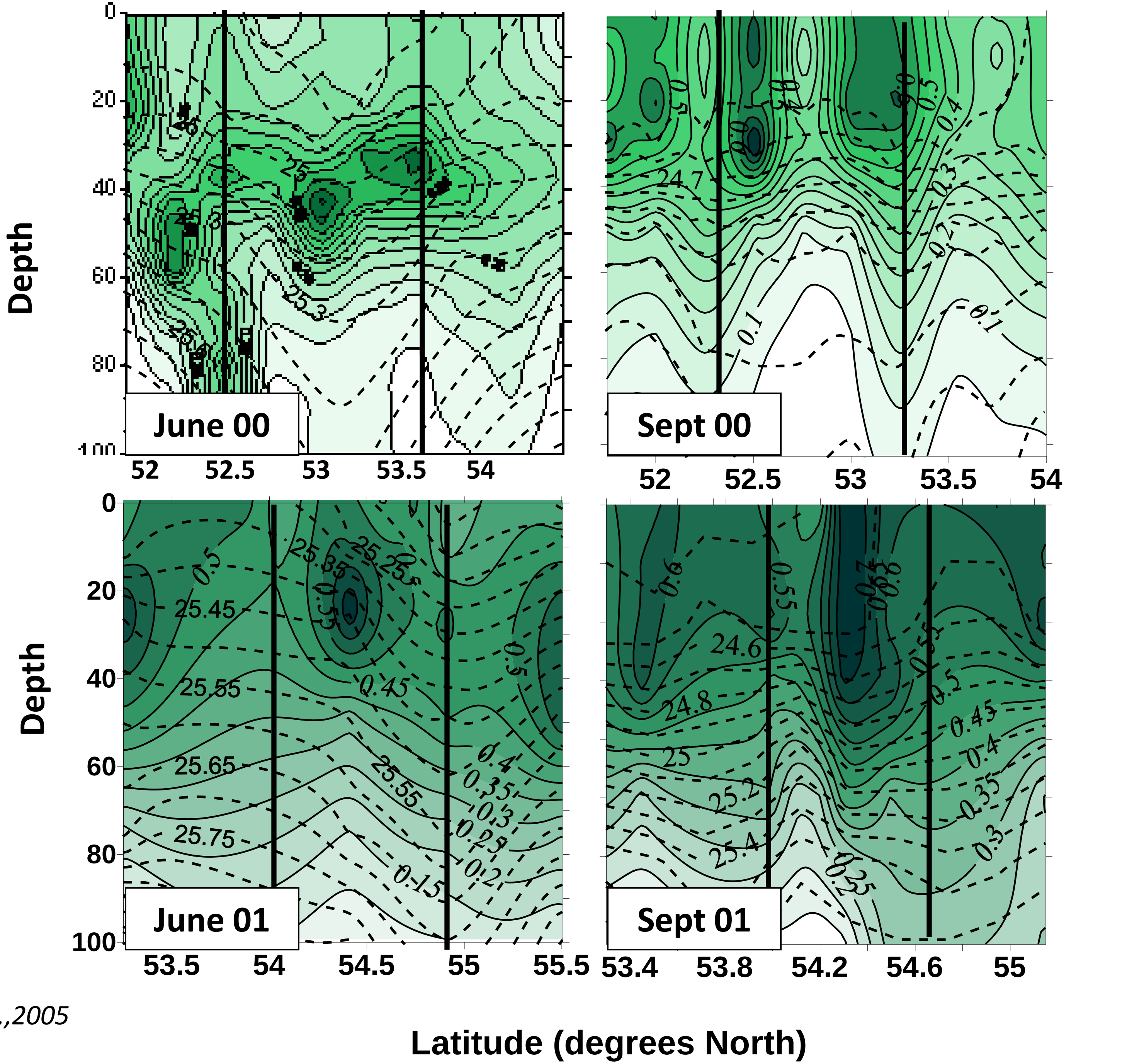
June 2000 **Sept 2000** **June 2001** **Sept 2001**



Changes in phytoplankton assemblage occur over time at eddy centre

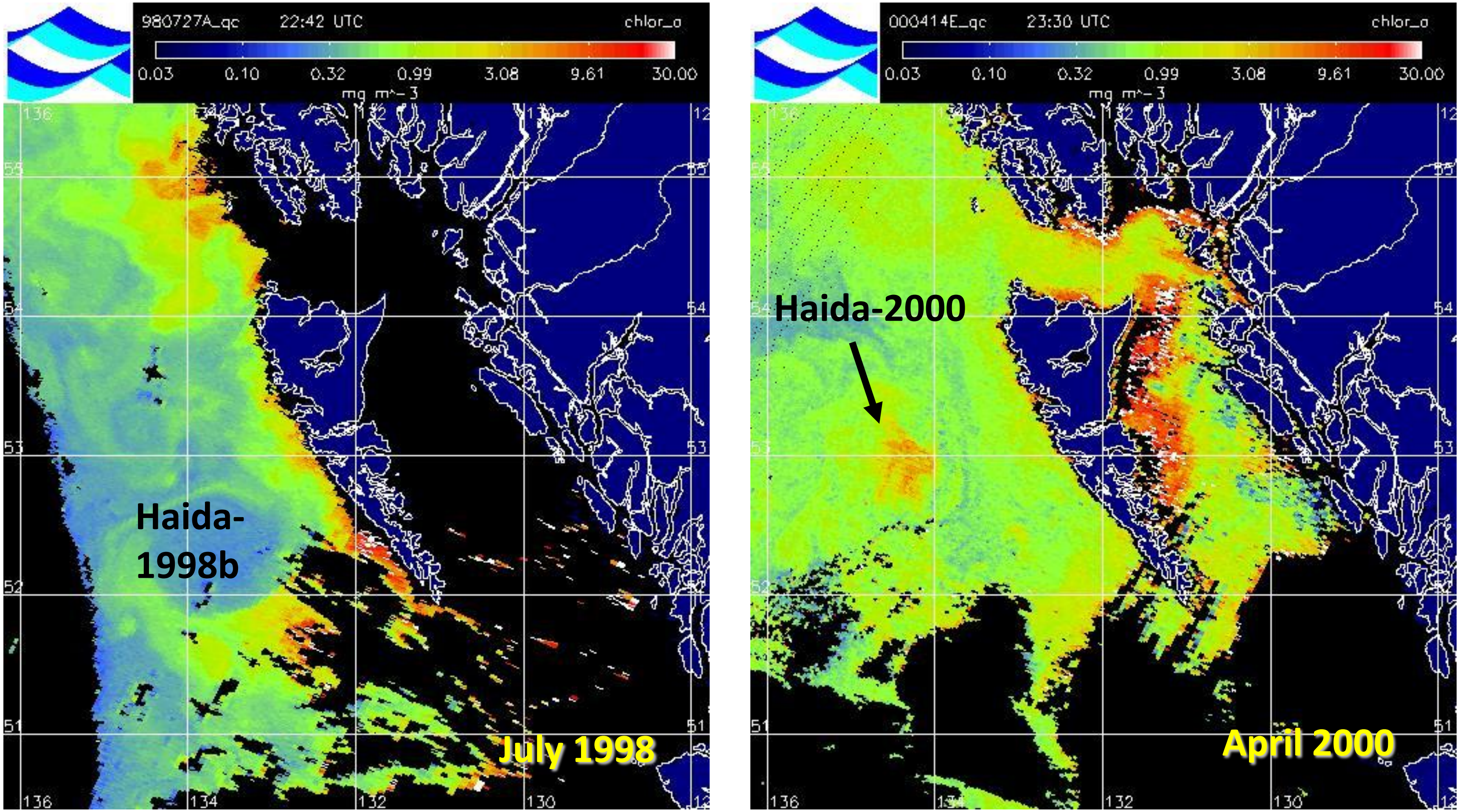


Chl *a*: cross-sections at 4 time points



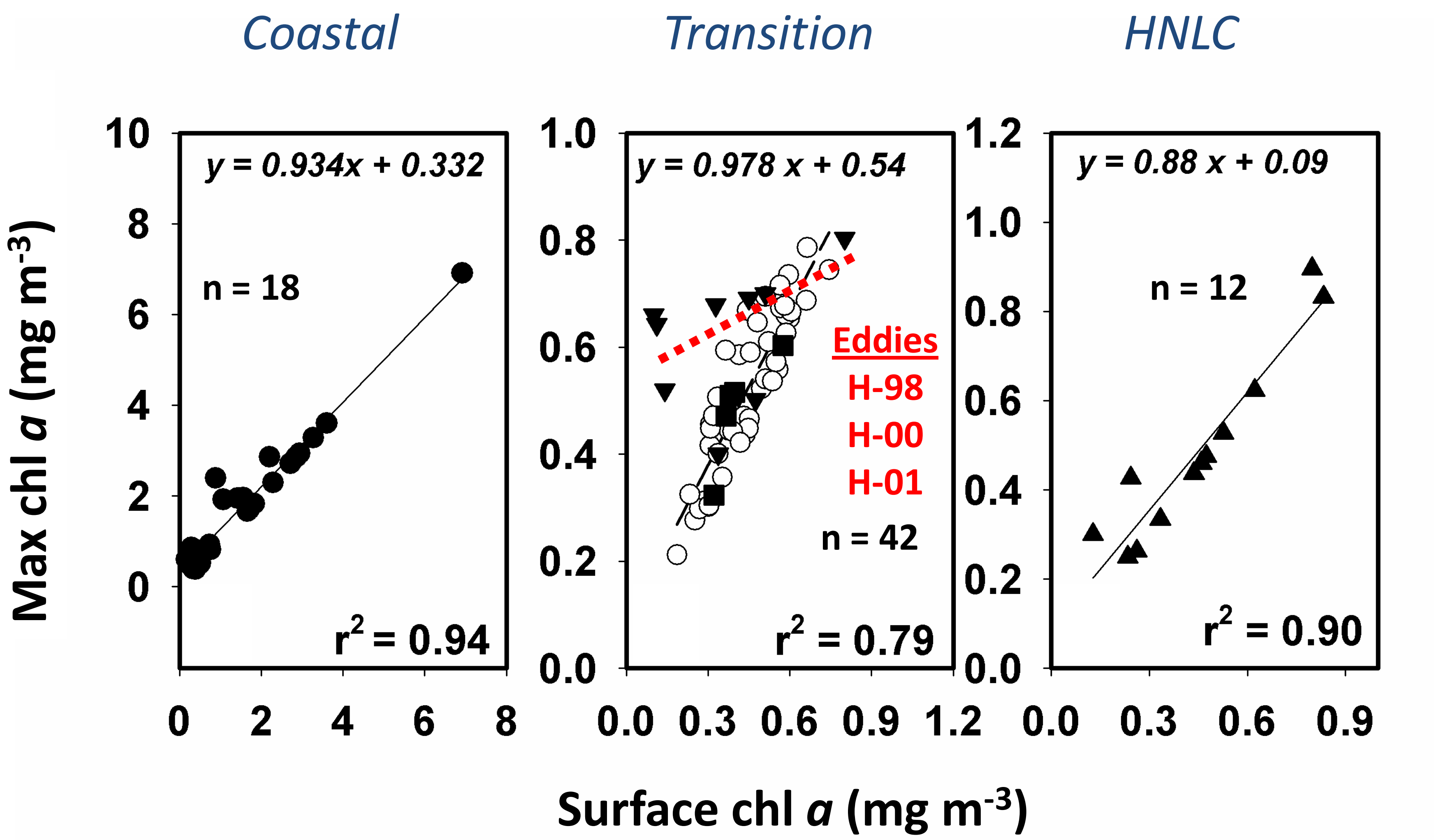
Modified from Crawford et al.,2005

Distribution of chl *a*: surface



SeaWiFS images courtesy of J.F.R. Gower, IOS

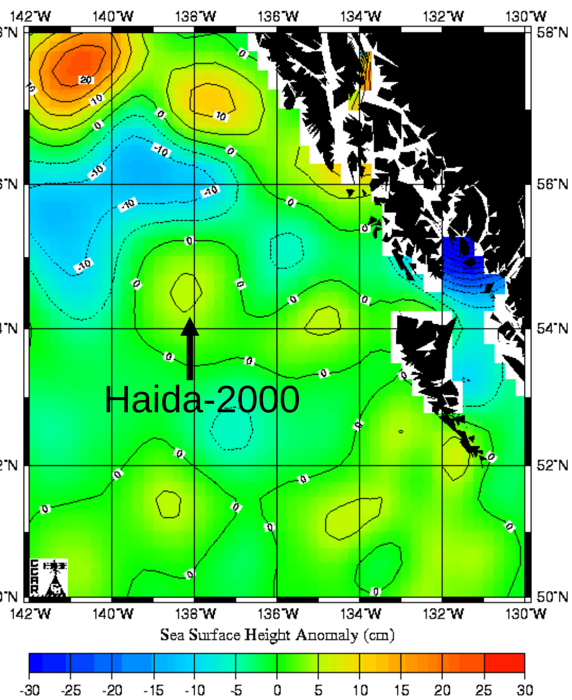
Haida Eddies and vertical distribution of chl *a*



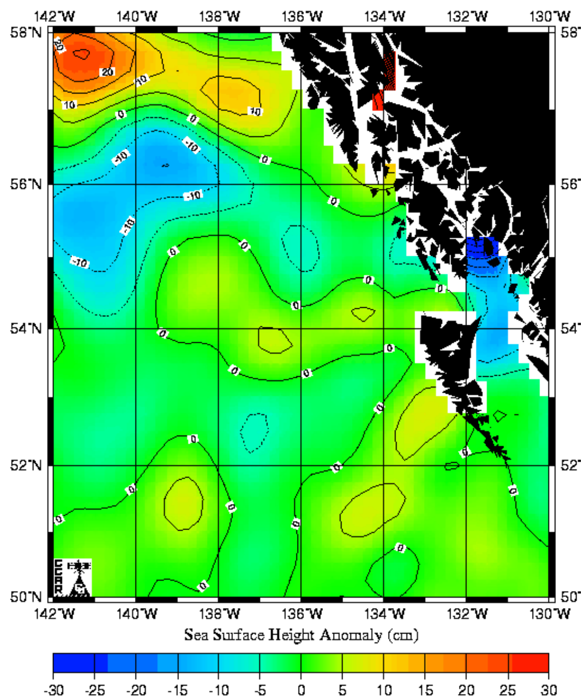
Eddies show subsurface chlorophyll maxima

Eddy coalescence (vortex-vortex interactions)

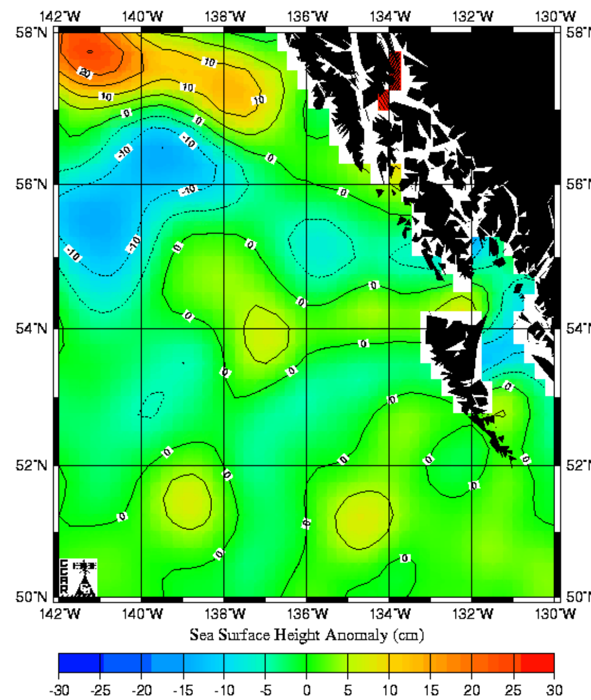
Historical Mesoscale Altimetry - Jun 6, 2001



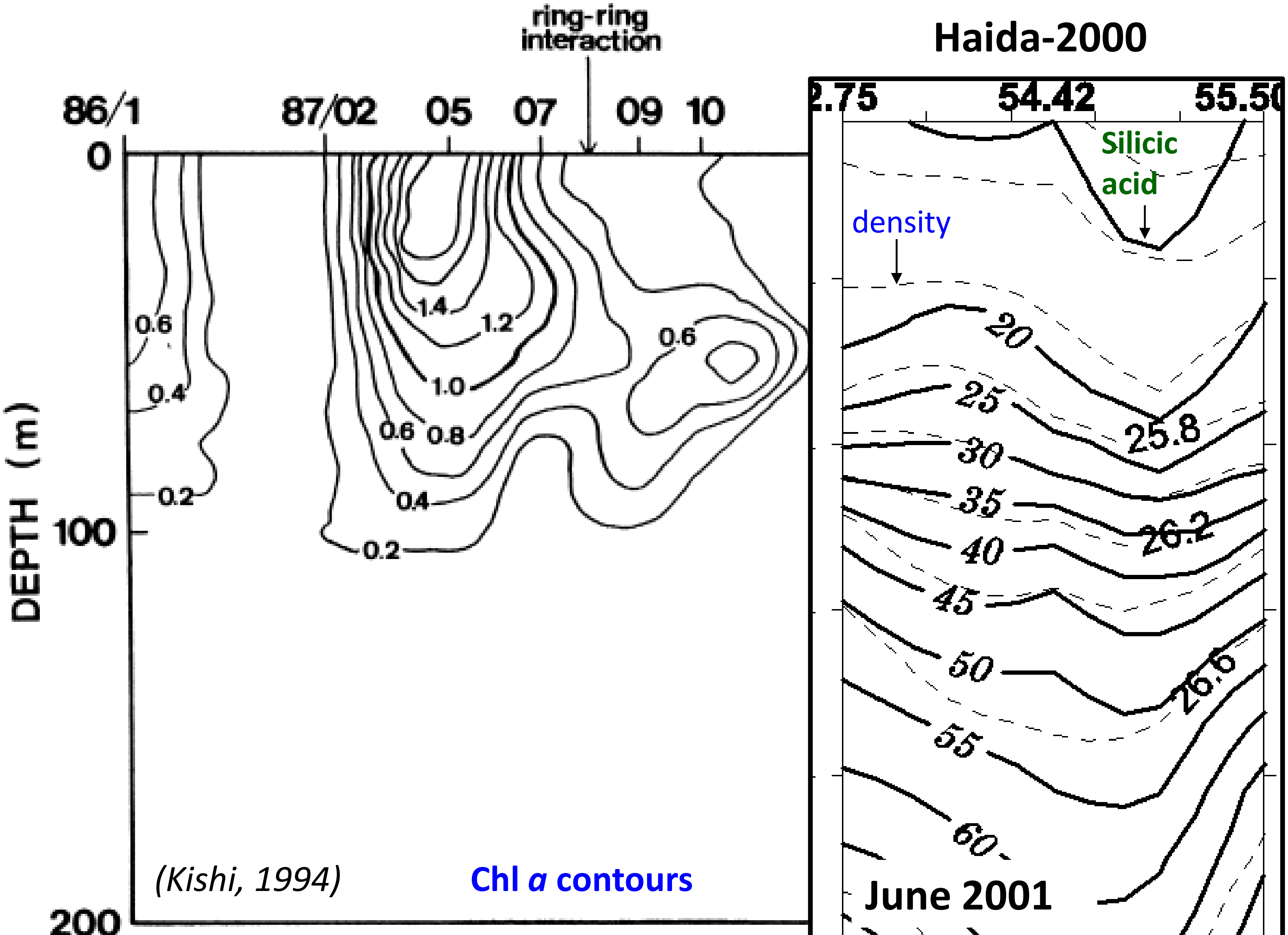
Historical Mesoscale Altimetry - Jun 18, 2001



Historical Mesoscale Altimetry - Jun 27, 2001

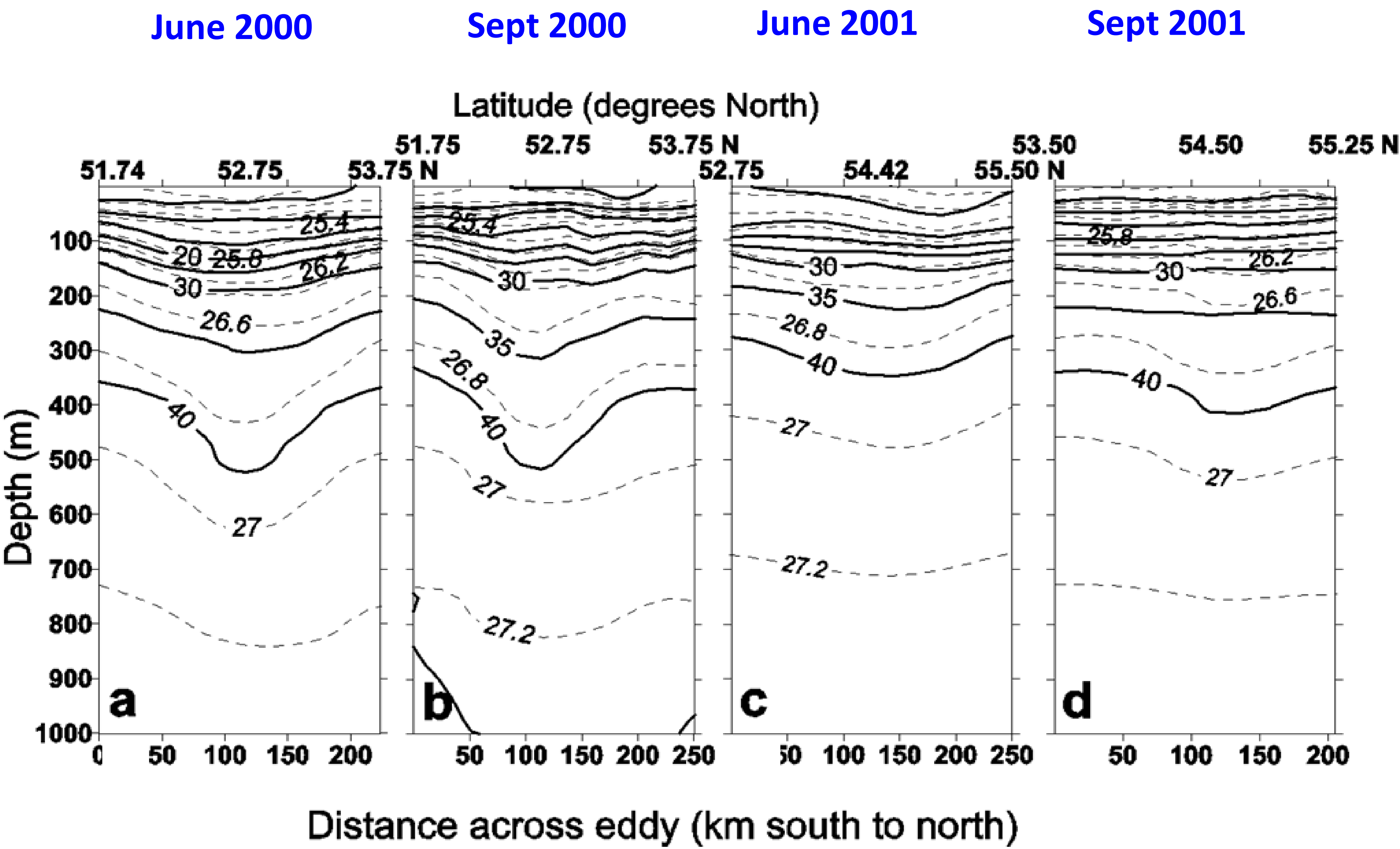


Haida-2000



ring-ring interaction
86/1
87/02
05
07
09
10
0
100
200
DEPTH (m)
0.6
0.4
0.2
1.4
1.2
1.0
0.6
0.8
0.4
0.2
0.6
(Kishi, 1994)
Chl *a* contours
2.75
54.42
55.50
Silicic acid
density
20
25
25.8
30
35
26.2
40
45
50
26.6
55
60
June 2001

Structure of an AC eddy : Nitrate and sigma-θ

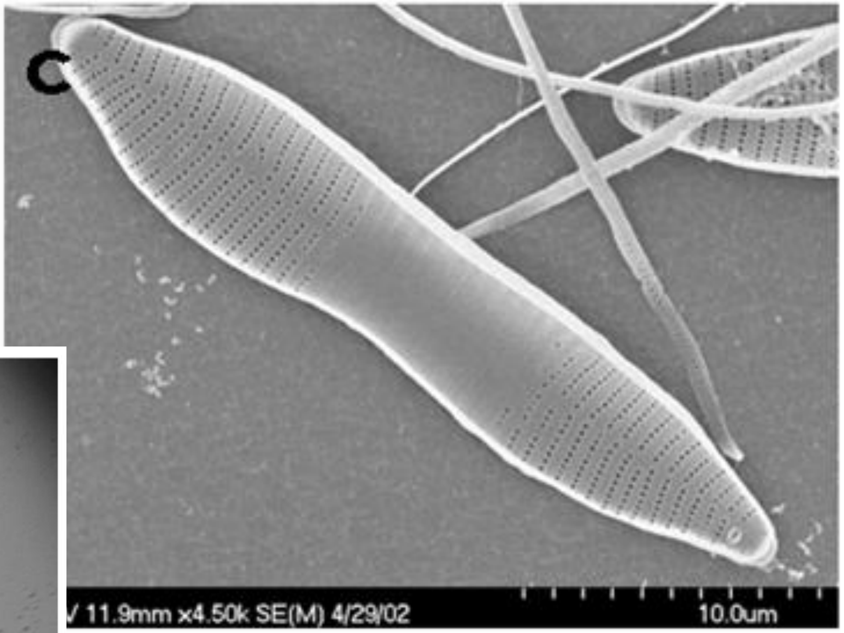


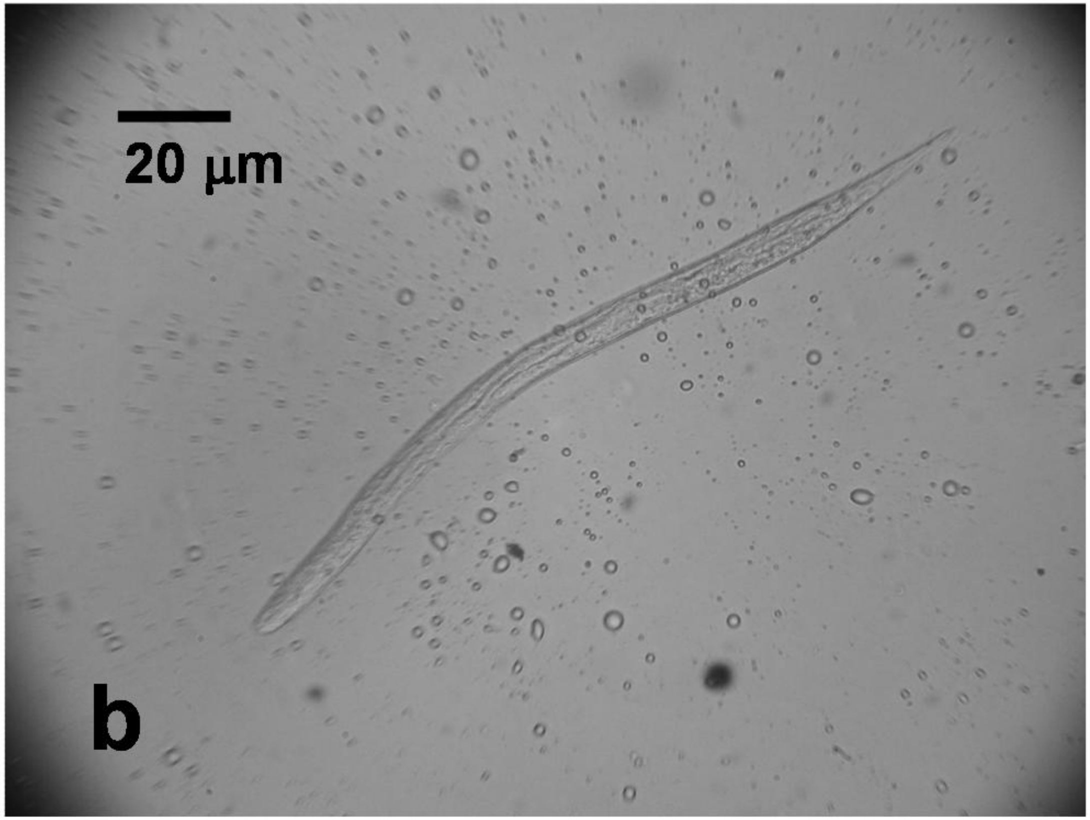
Influence of coalescence on phytoplankton assemblages:

-benthic organisms

-Increased abundance of cryptomonads

-mixture of oceanic and coastal species





Coastal/benthic taxa

-*Vexallifera* (amoeba)

-*Fossula arctica* (ice margin diatom)

-nematodes (benthic worm)

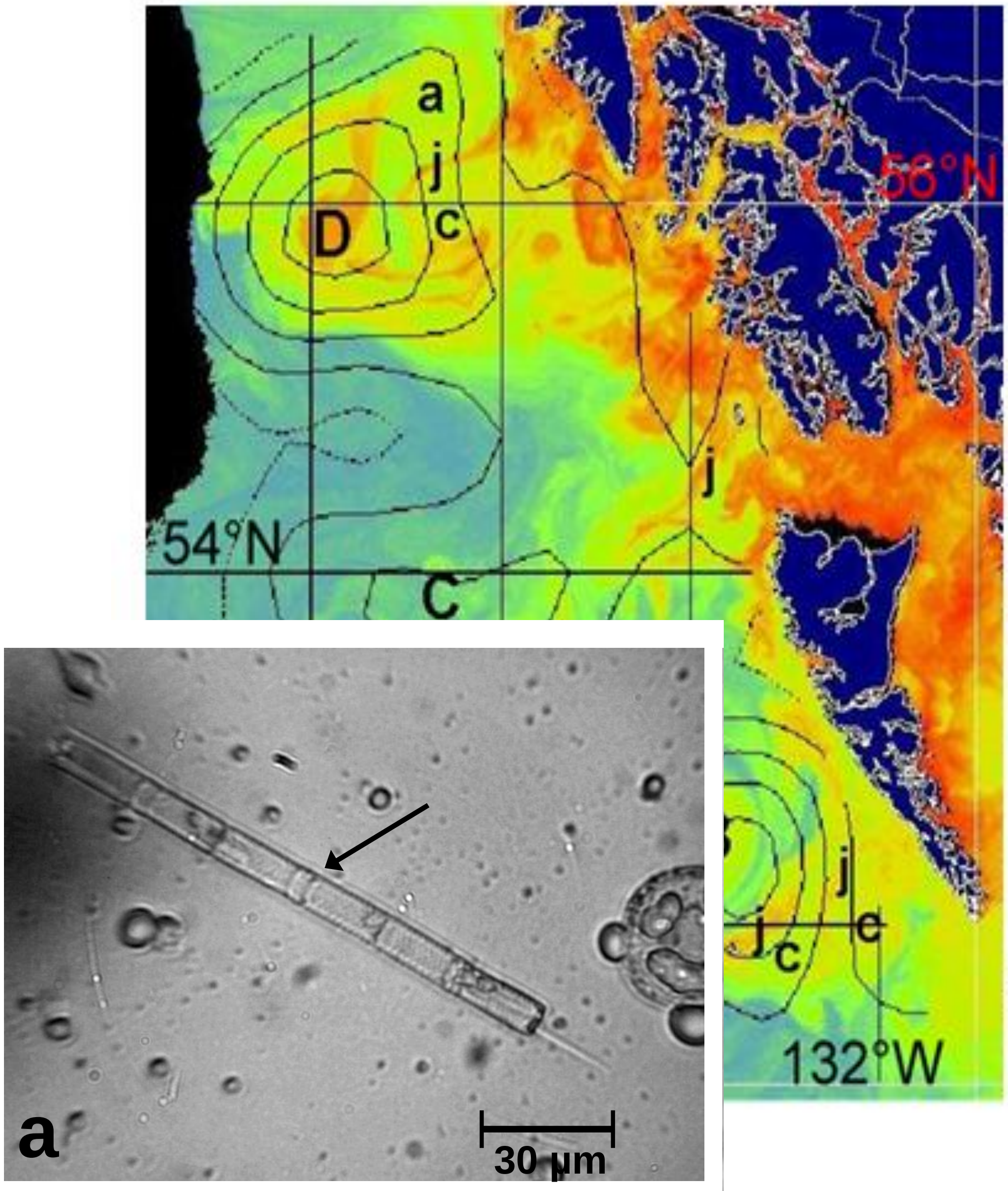
-*Aulacoseira granulata* (fresh water diatom)

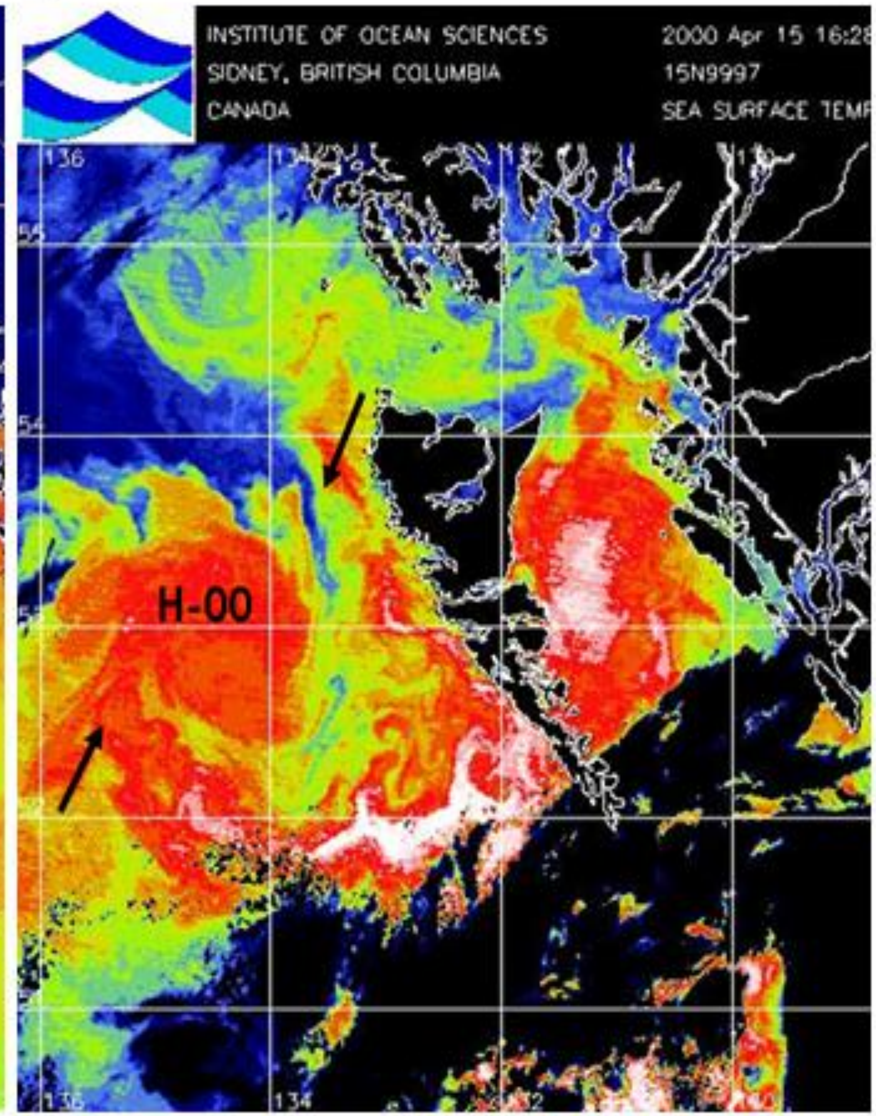
"Oceanic" species

-*Nitzschia cylindriformis*

-*Emiliania huxleyi*

Advection


a
j
c
D
58°N
j
54°N
C
j
j
c
c
132°W
a
30 µm


INSTITUTE OF OCEAN SCIENCES
SIDNEY, BRITISH COLUMBIA
CANADA
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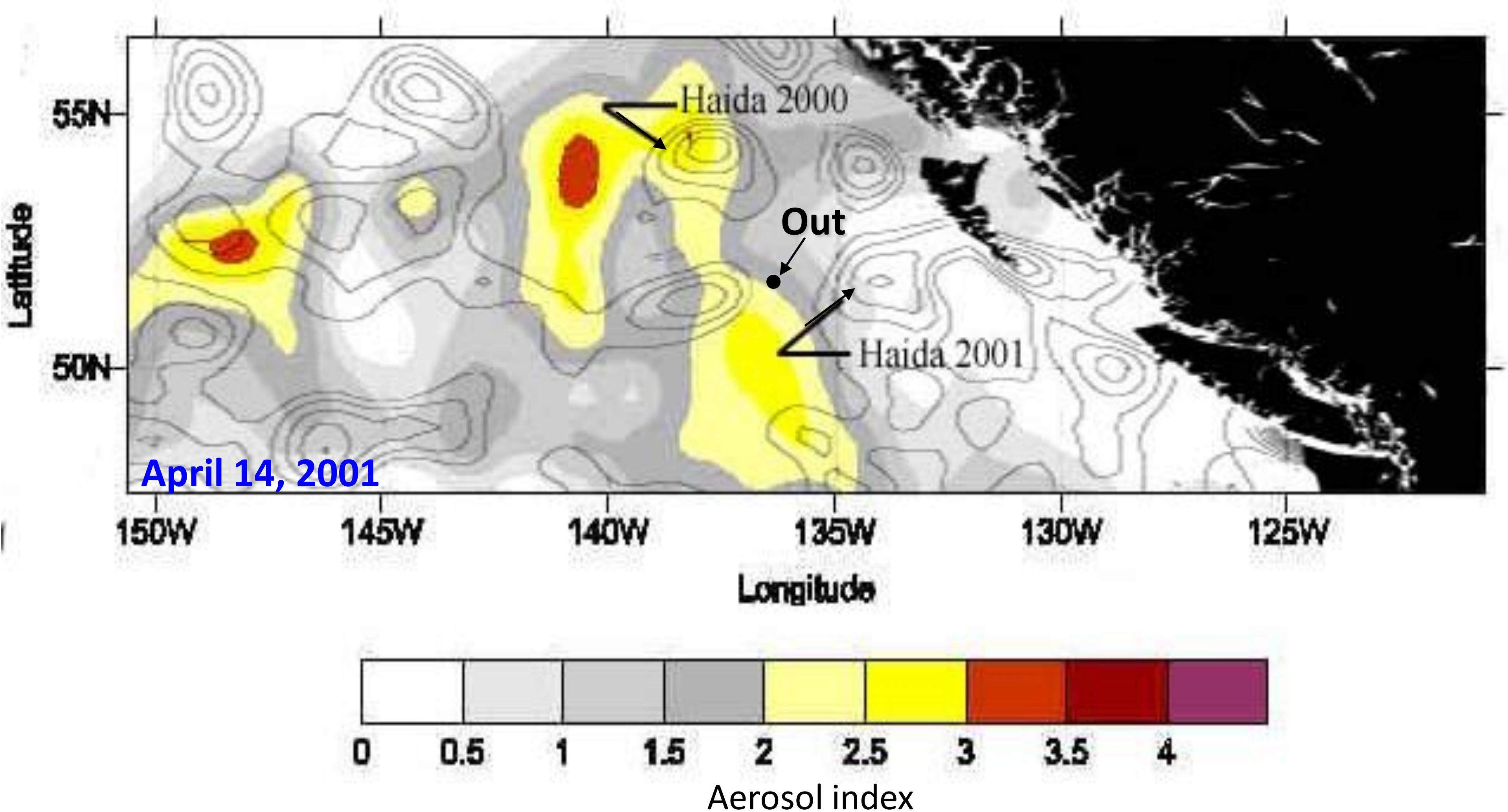
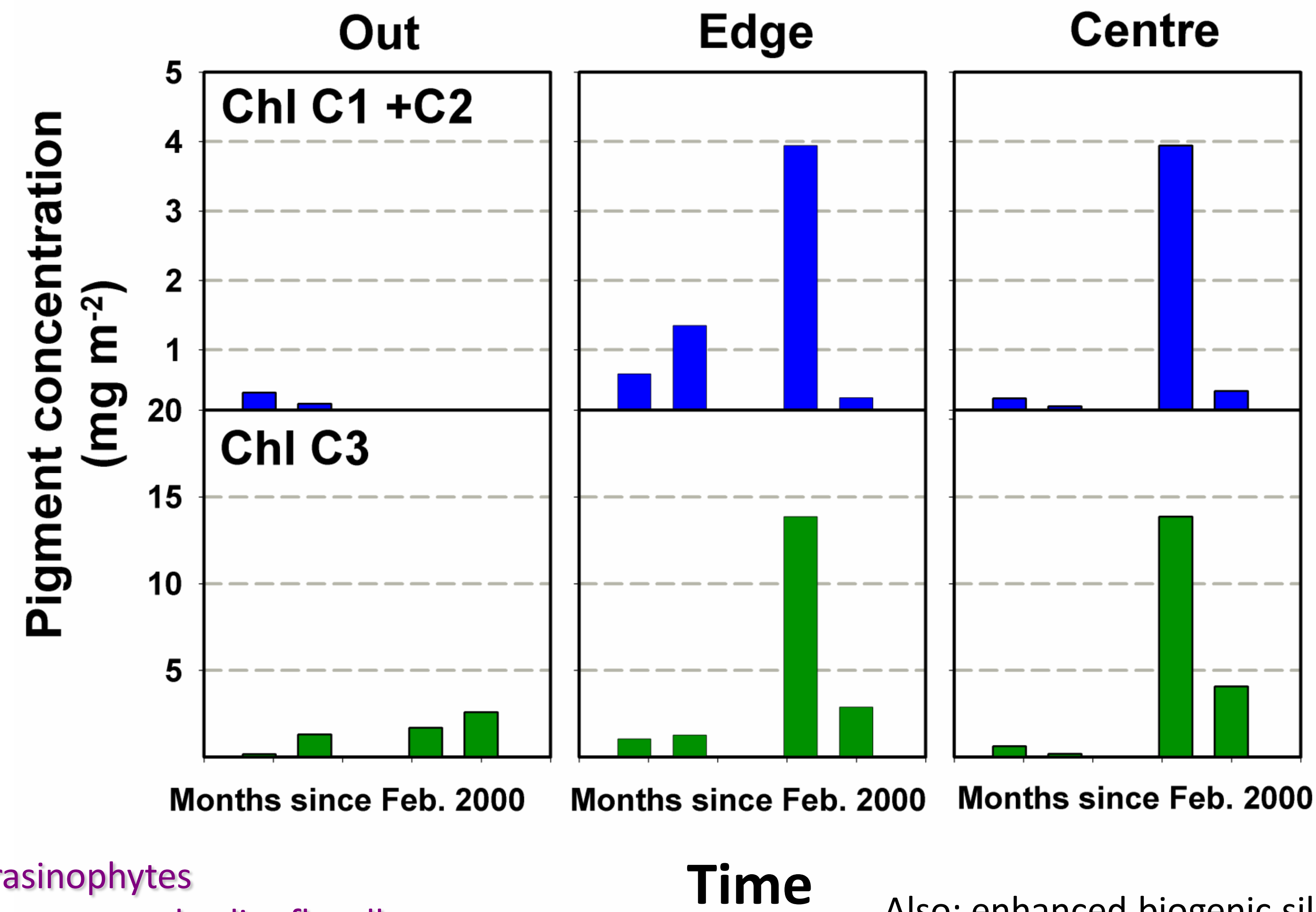
Atmospheric flux & deposition of Fe



Data from CCAR and TOMS

From Crispo et al., 2004

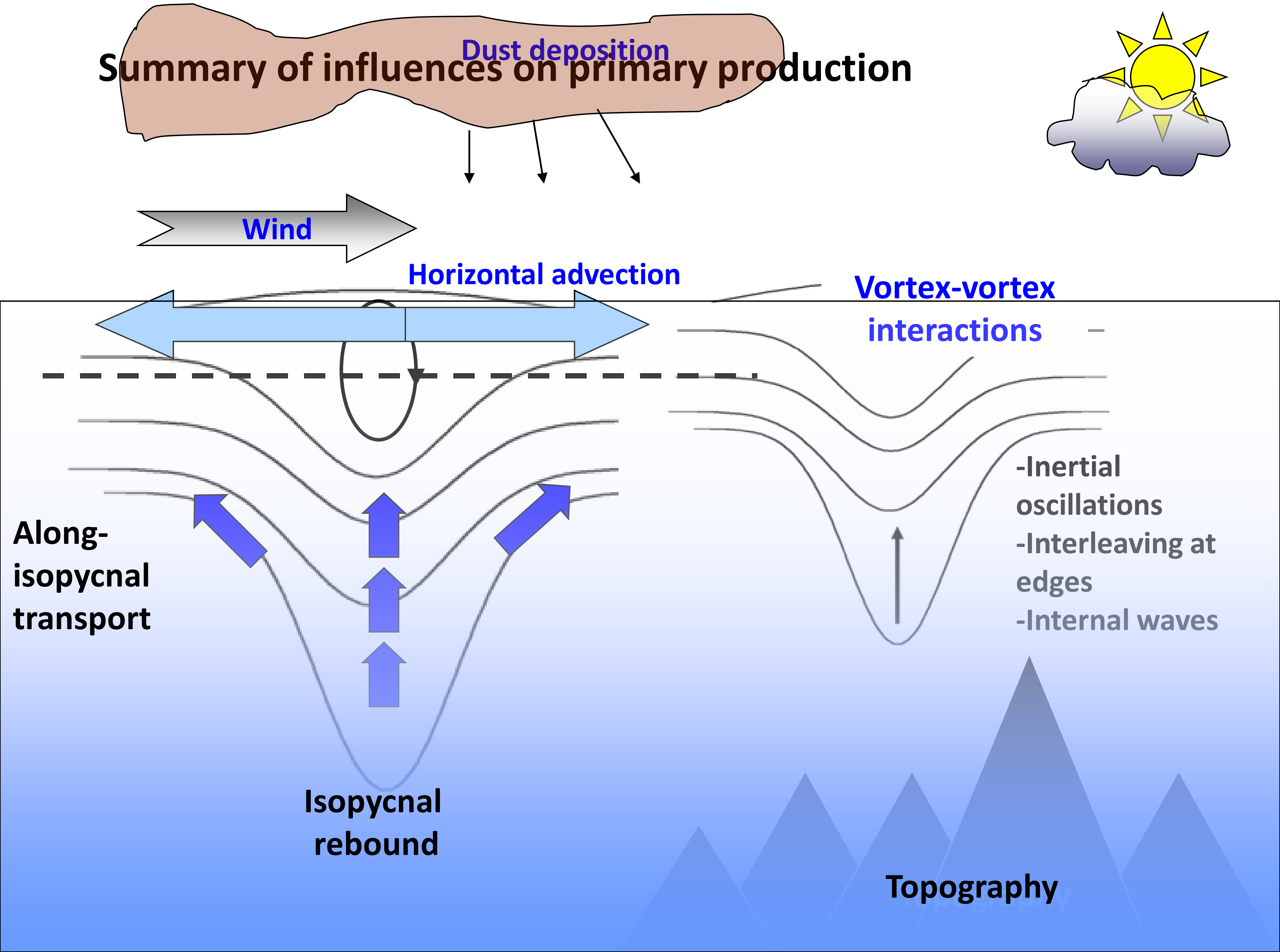
Integrated pigments



Chl c_1: prasinophytes
Chl c_2: cryptomonads, dinoflagellates, *E. huxleyi*, chrysophytes
Chl c_3: haptophytes, pelagophytes

Also: enhanced biogenic silica
No effect seen off Hawaii
(Johnson et al.)

Summary of influences on primary production



Why might anticyclonic eddies be more productive than their surroundings?

- Enhanced buoyancy early in the season promotes earlier blooming of phytoplankton

- Isopycnal rebound provides a mechanism for the injection of nutrients into the upper mixed layer