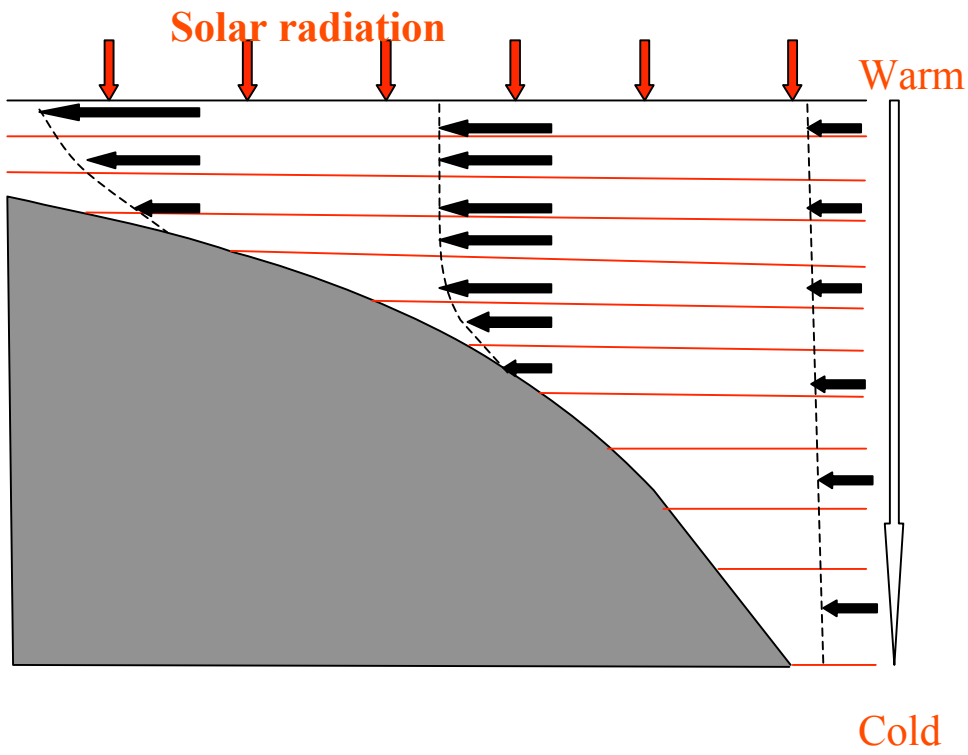
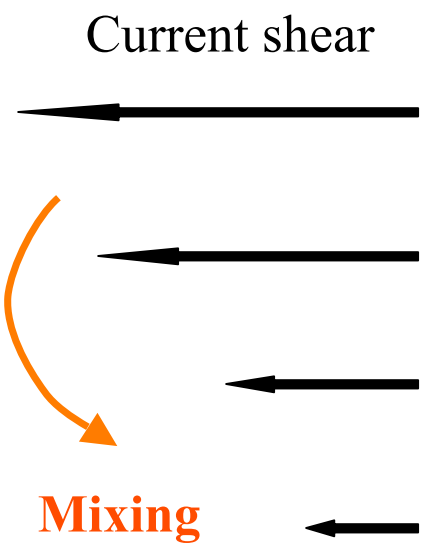
Lecture 25: Coastal Ocean Process-Oceanic Frontal System (Continued)

1. Tidal Mixing Front (Tidal Front)

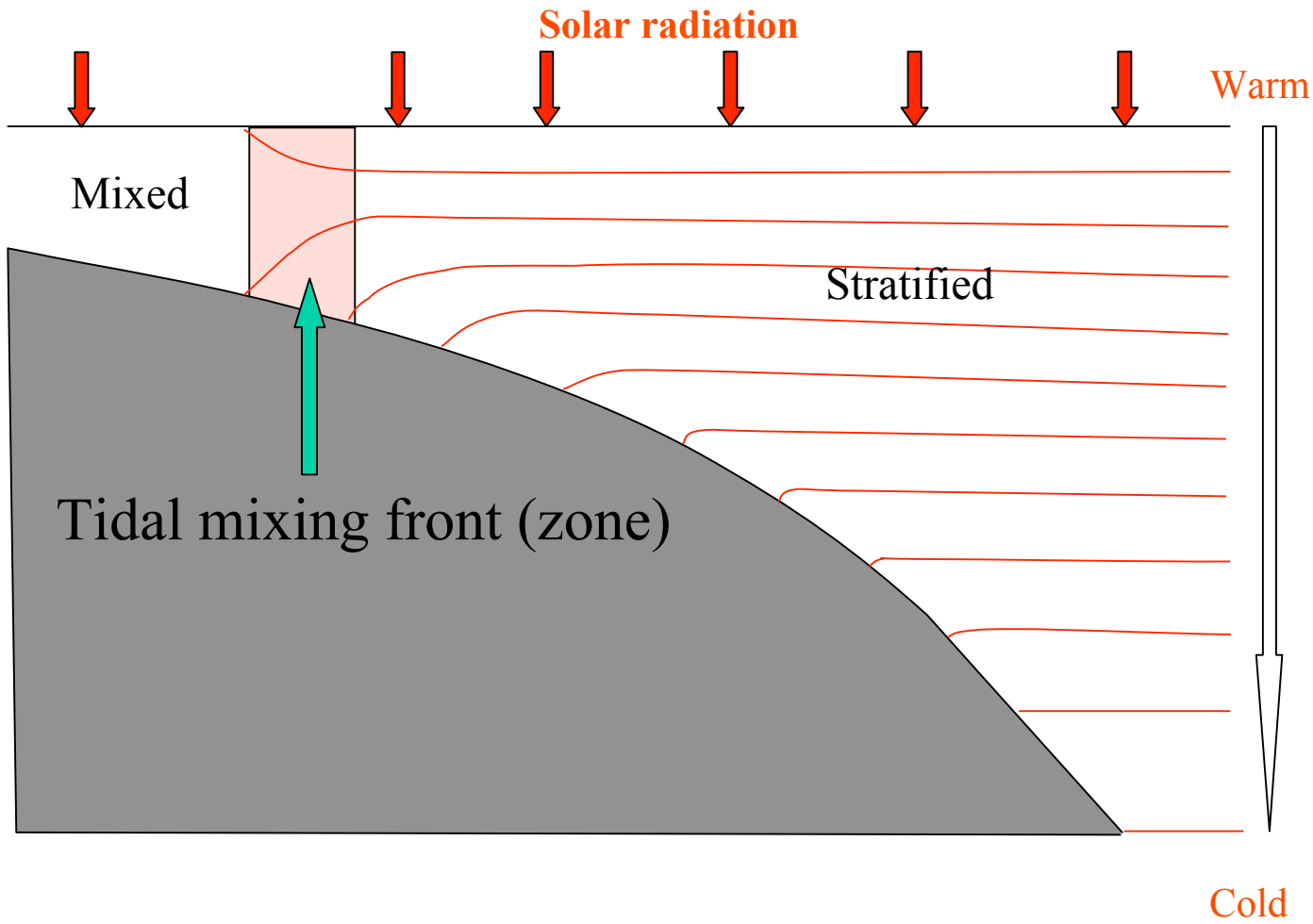




Two processes:

a) Surface buoyancy flux produced by the solar radiation: make the water stratified

b) Kinetic energy dissipation caused by tidal currents: mix the water



Tidal Mixing Front

H/U^3 **(Simpson and Hunter , 1974)**

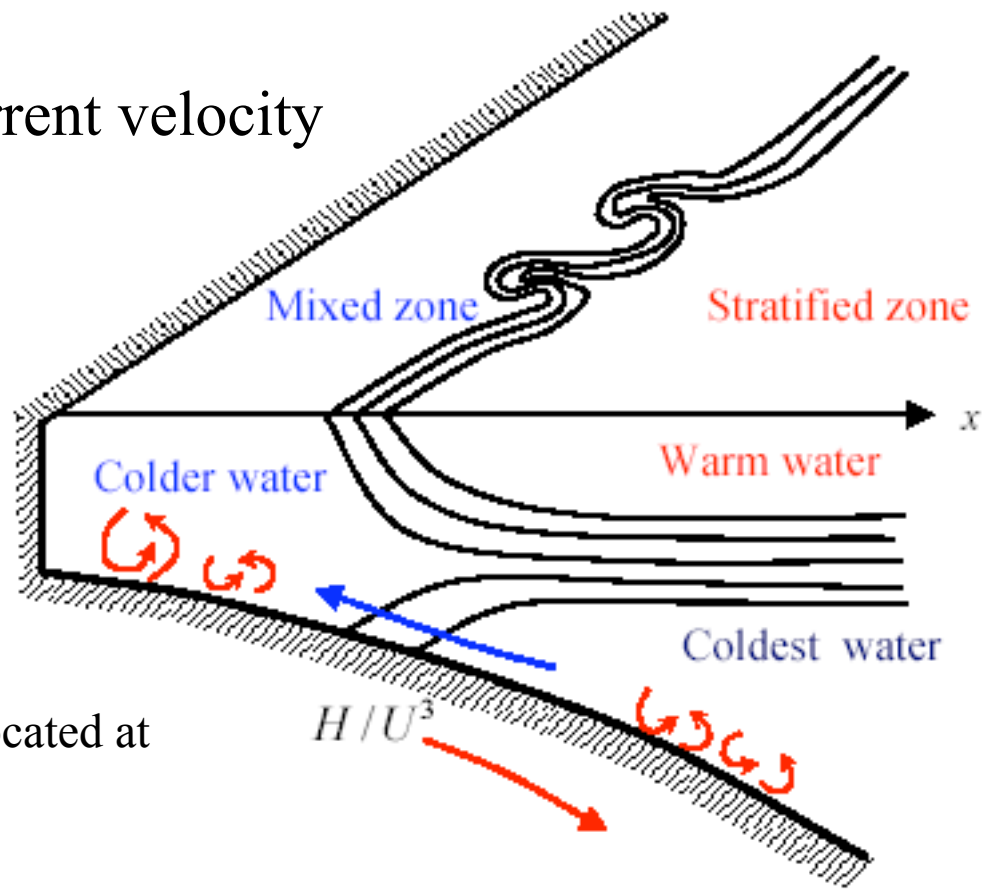
H: Water depth
U: Mean tidal current velocity

or

$$\log_{10}\frac{H}{D_t}$$

$$D_t = \rho C_D U^3$$

(turbulent dissipation)

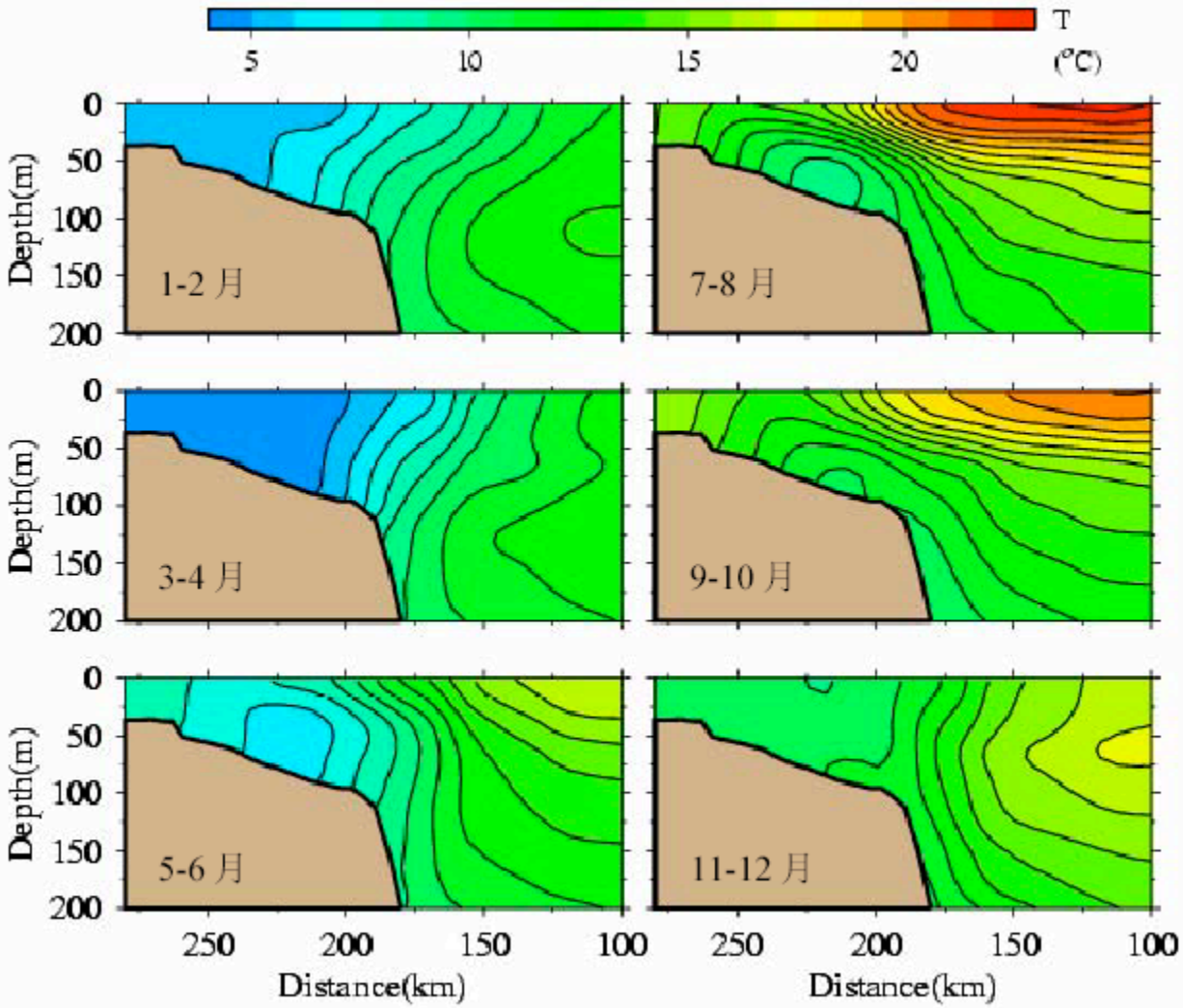


The tidal mixing front is located at

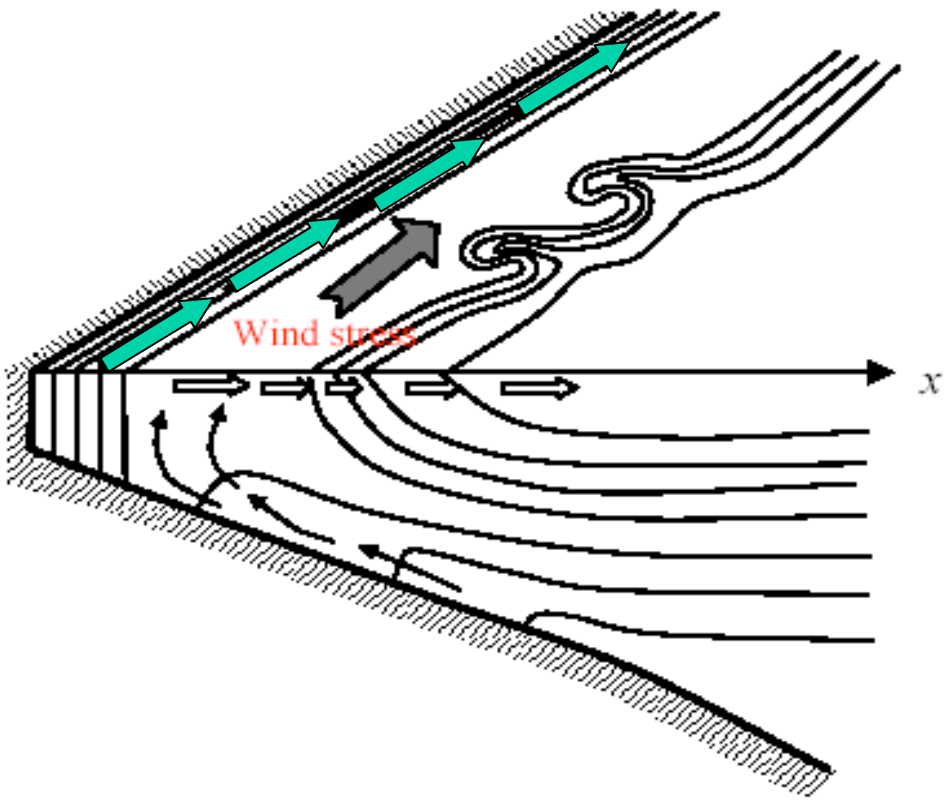
$$\log_{10}\frac{H}{D_t} = 1.9$$

Shelf-break Front

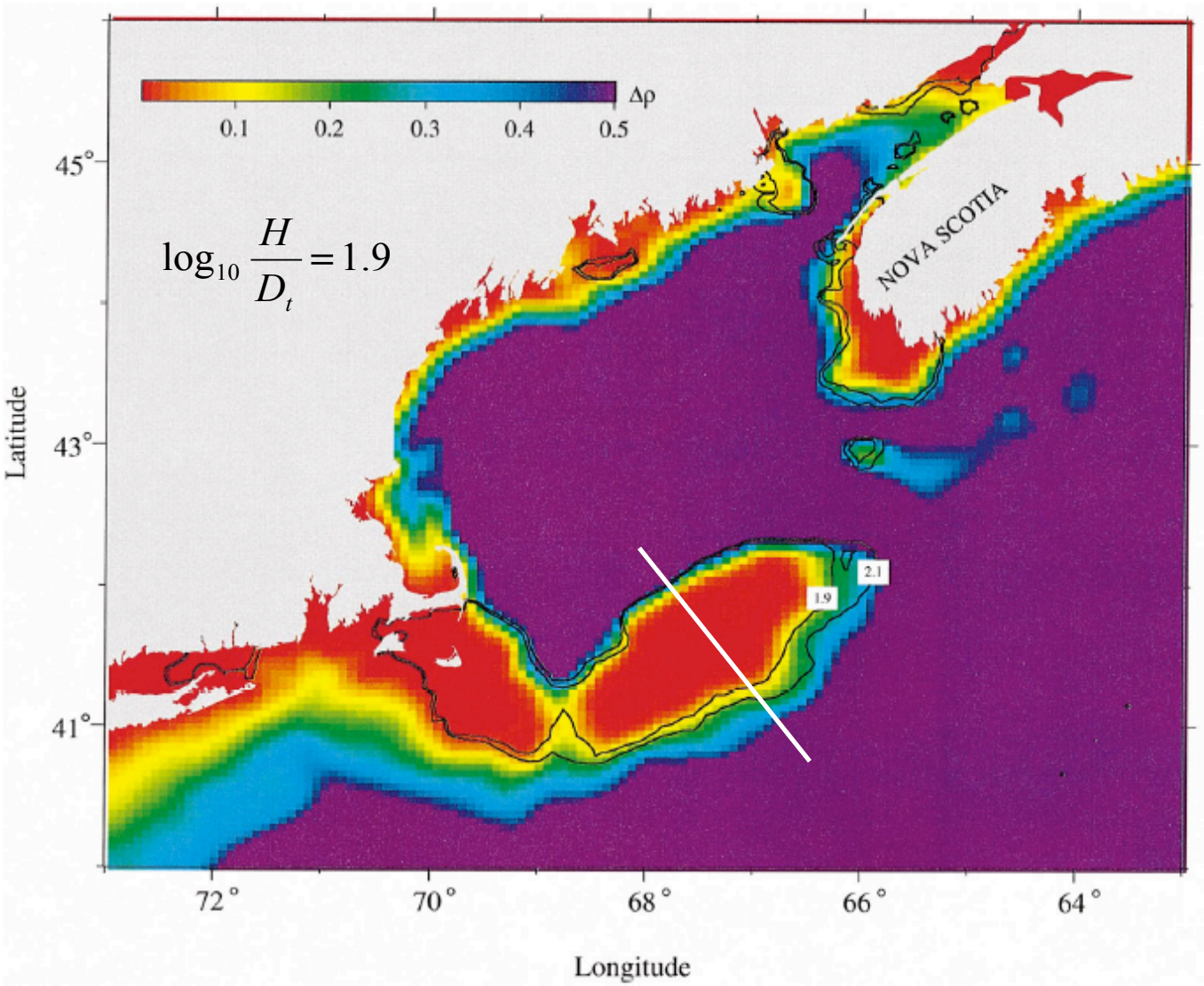
A transition zone between warmer and salt slope water and colder and less salt shelf water



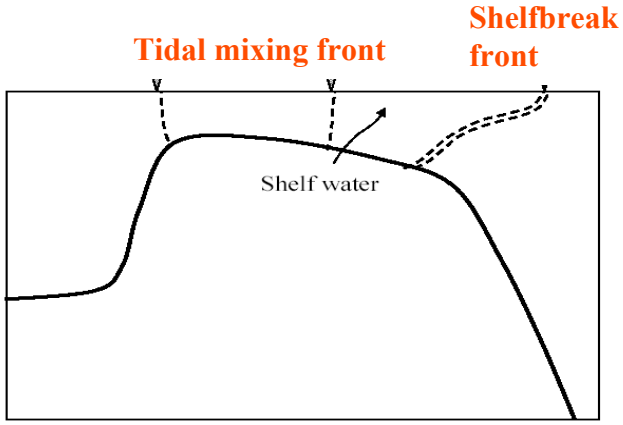
Upwelling Front



Tidal mixing region and tidal mixing front in the Gulf of Maine and Georges Bank regions



Georges Bank



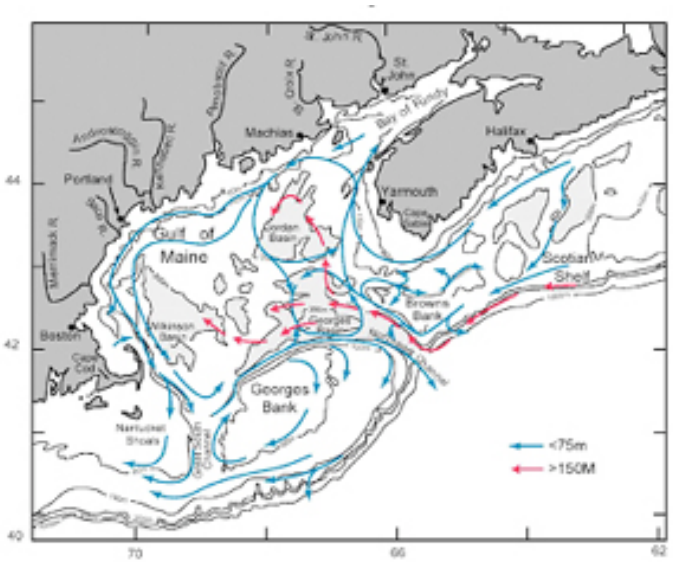
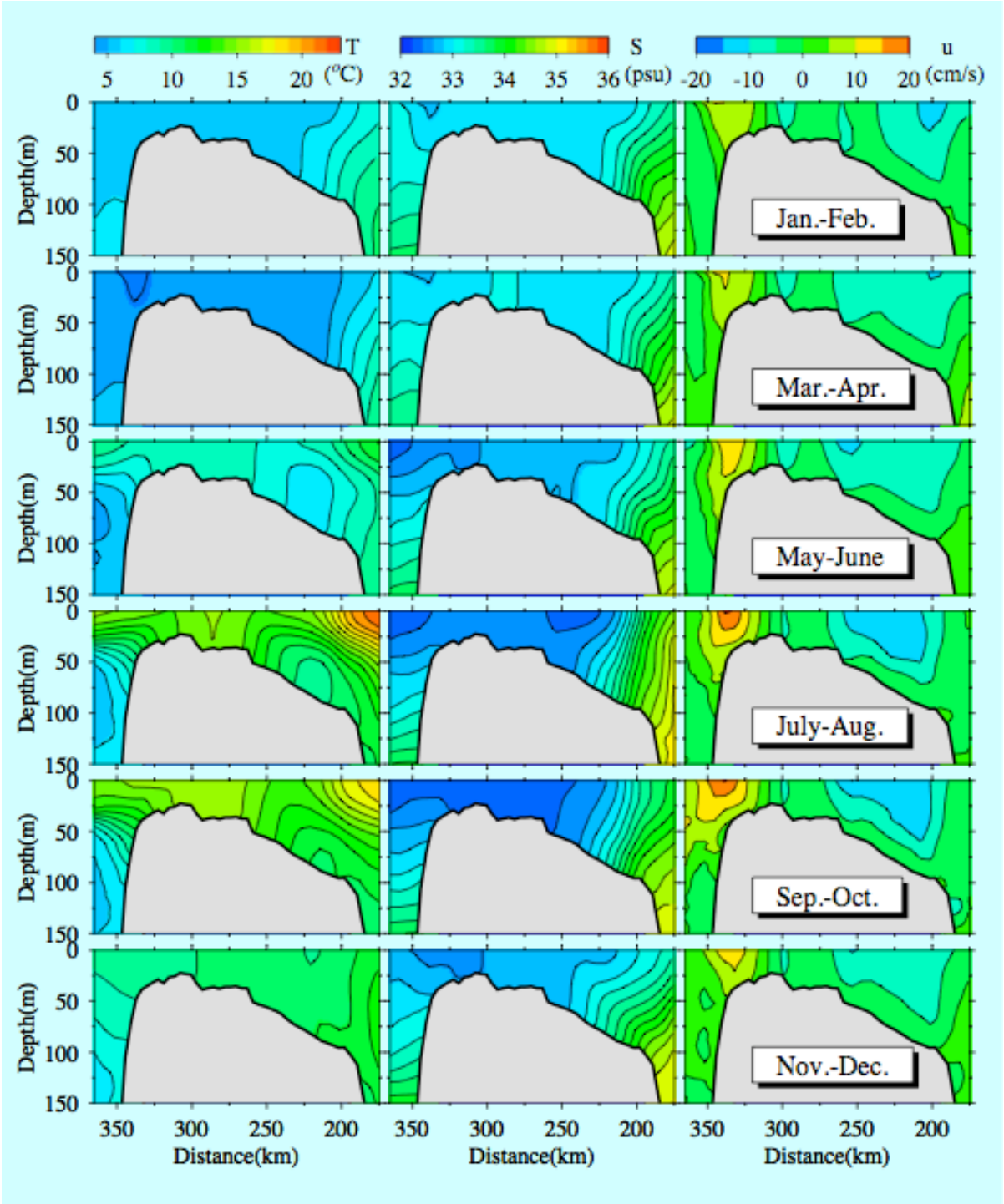
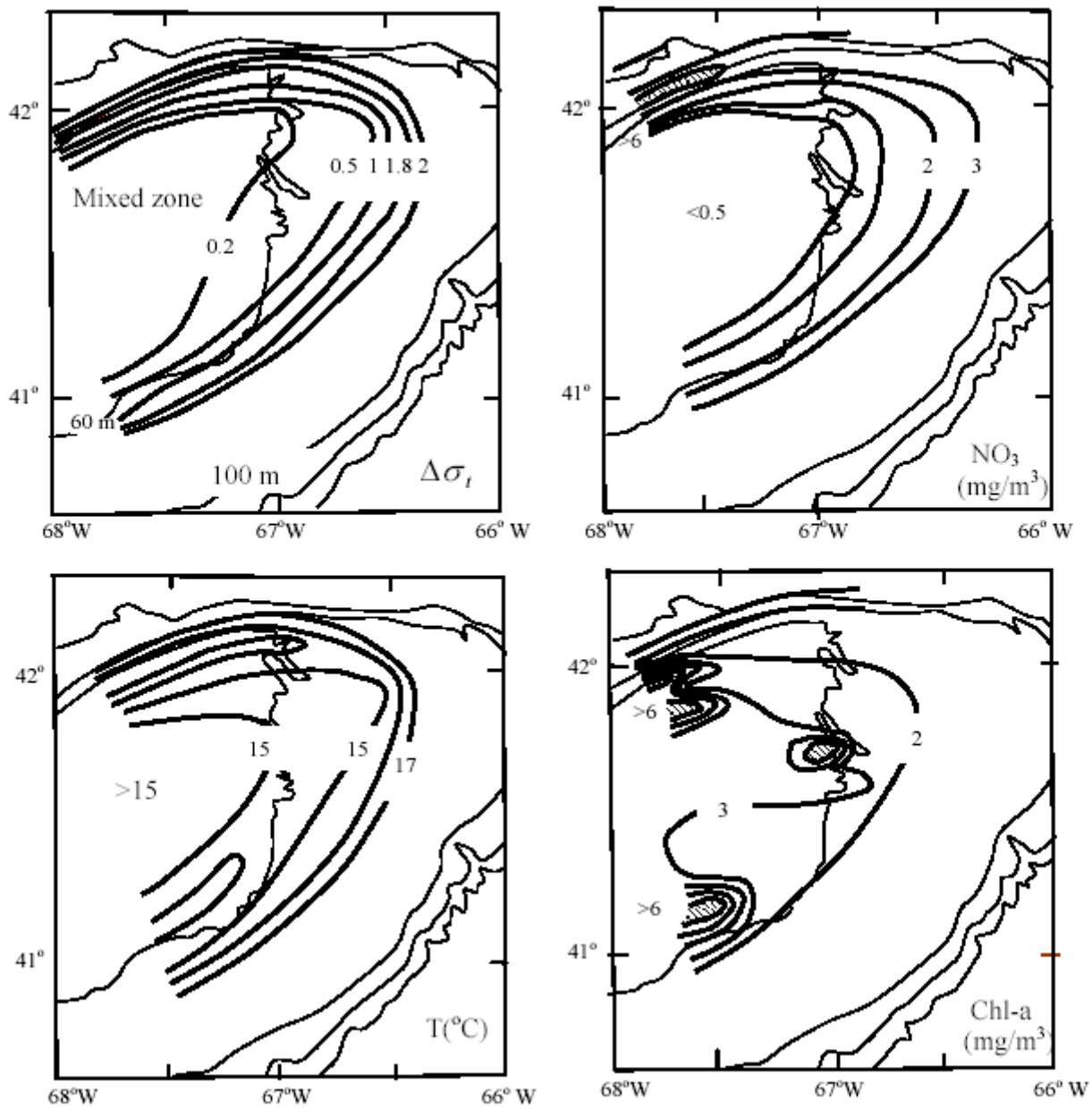
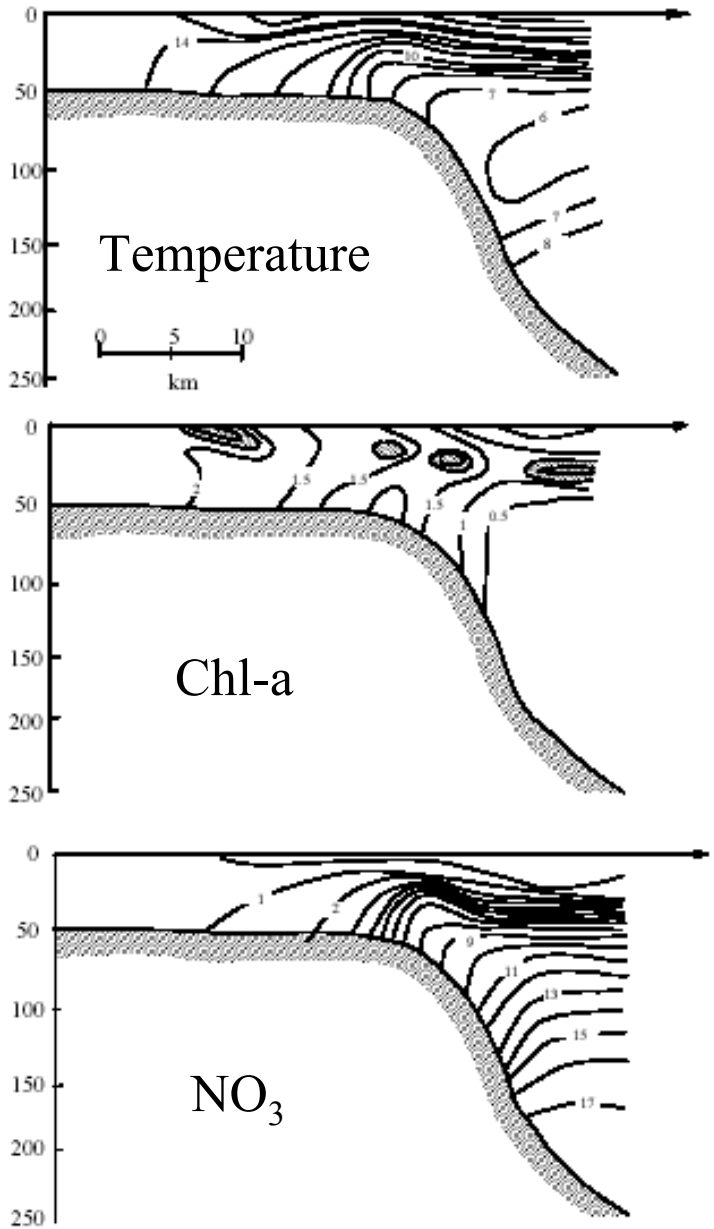
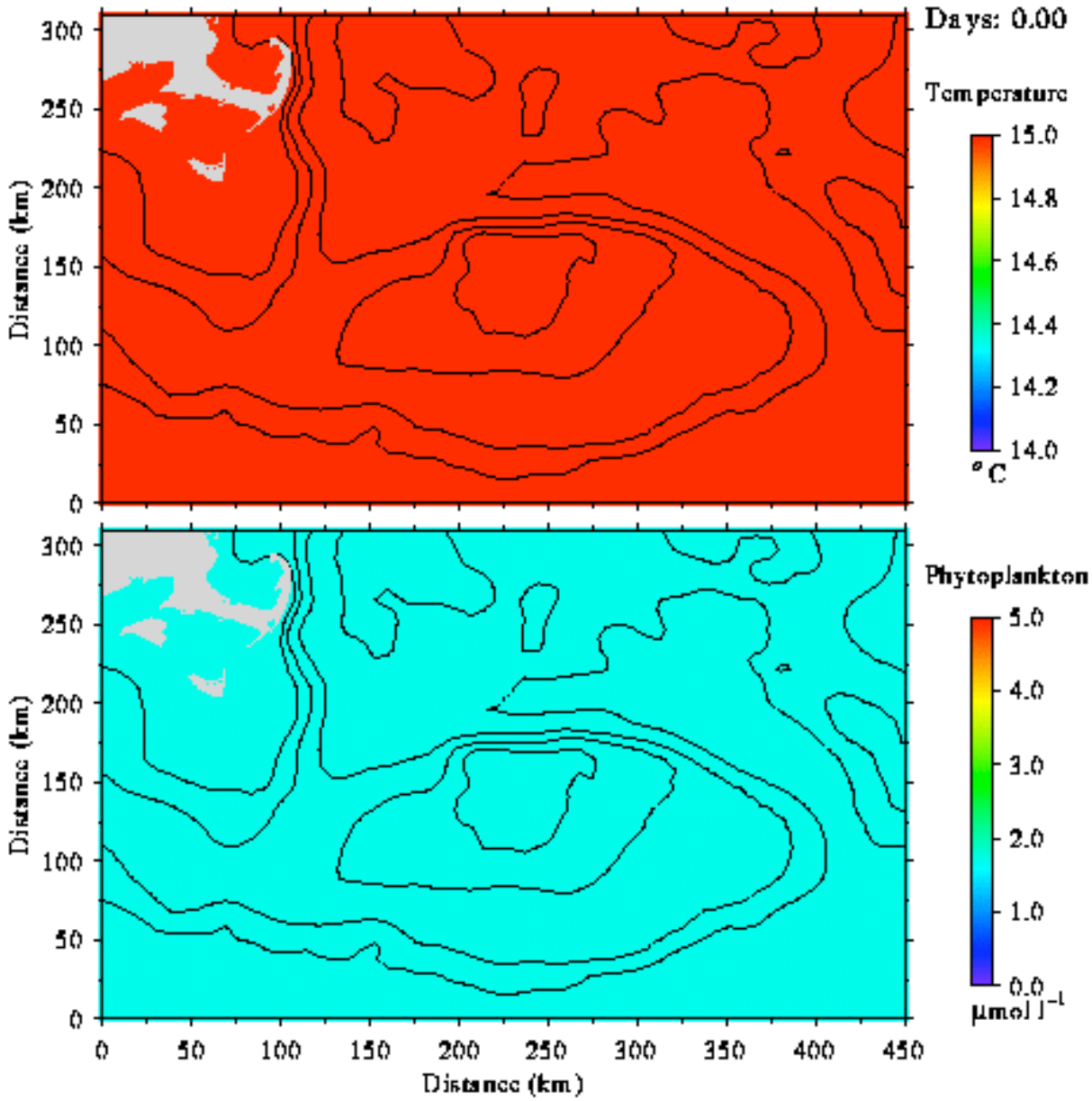


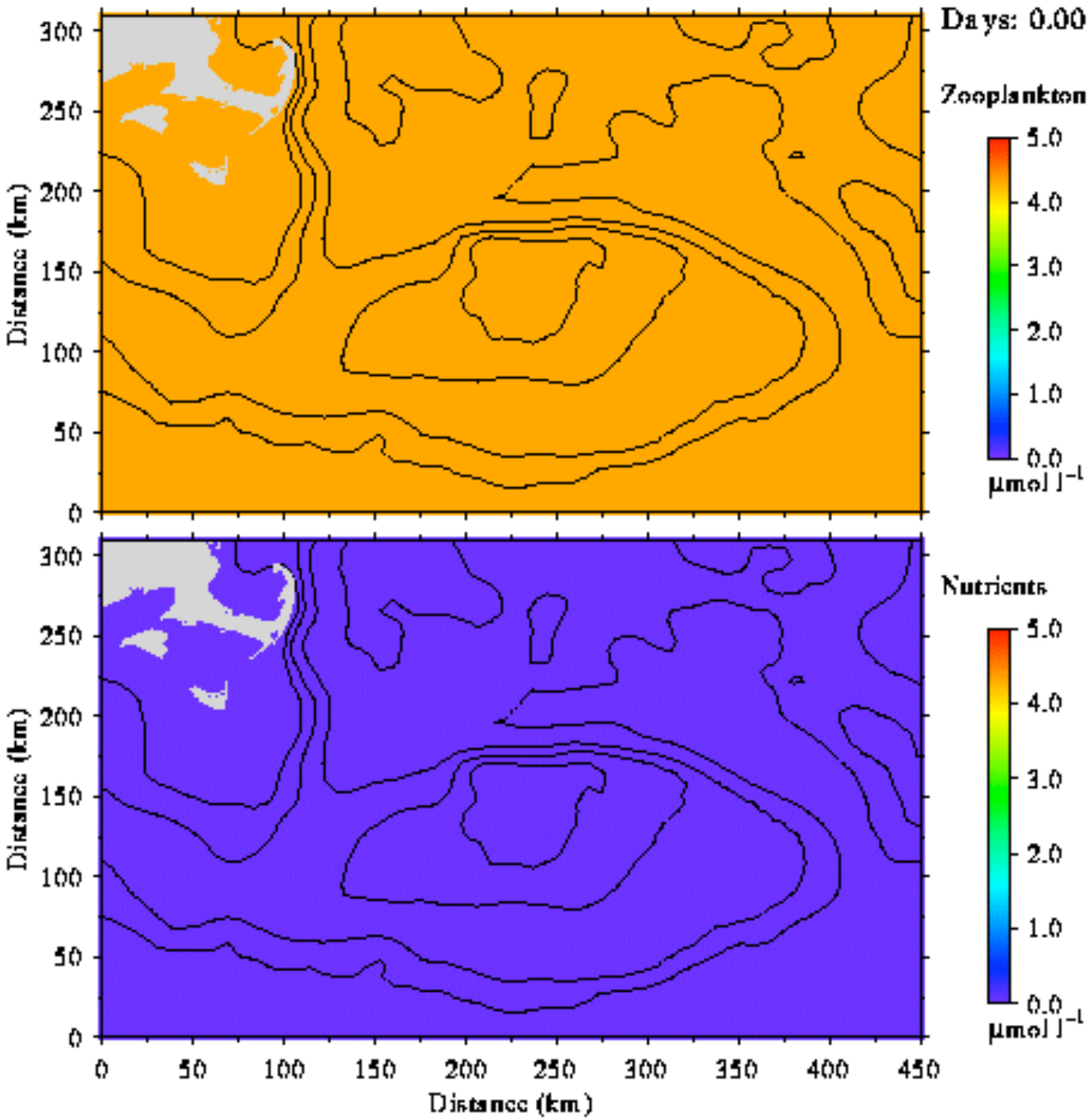
Fig. 1: Bathymetry of the Gulf of Maine/Georges Bank region and schematic of the general subtidal circulation during stratified season. This picture was provided by R. C. Beardsley at Woods Hole Oceanographic Institution.

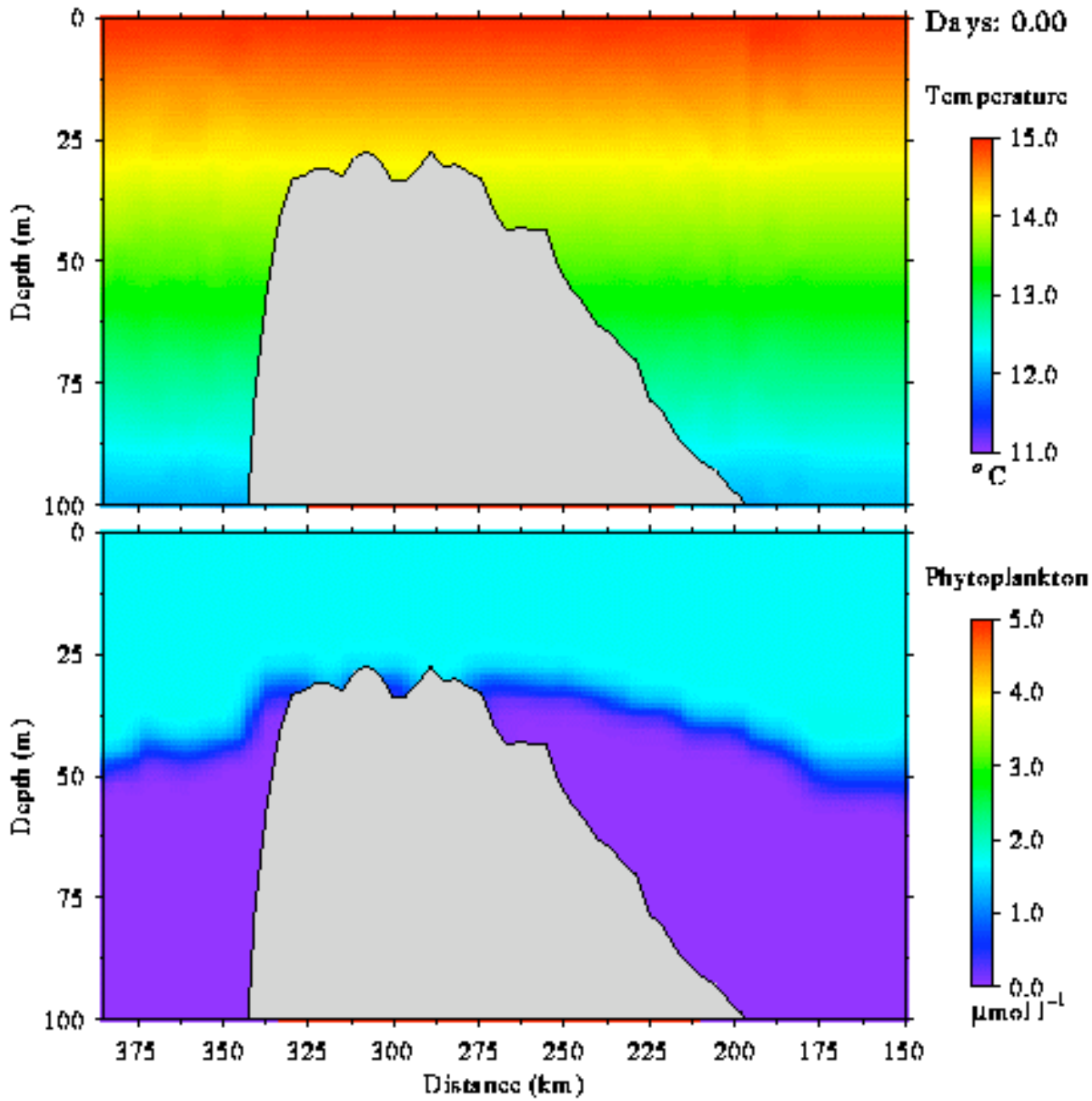


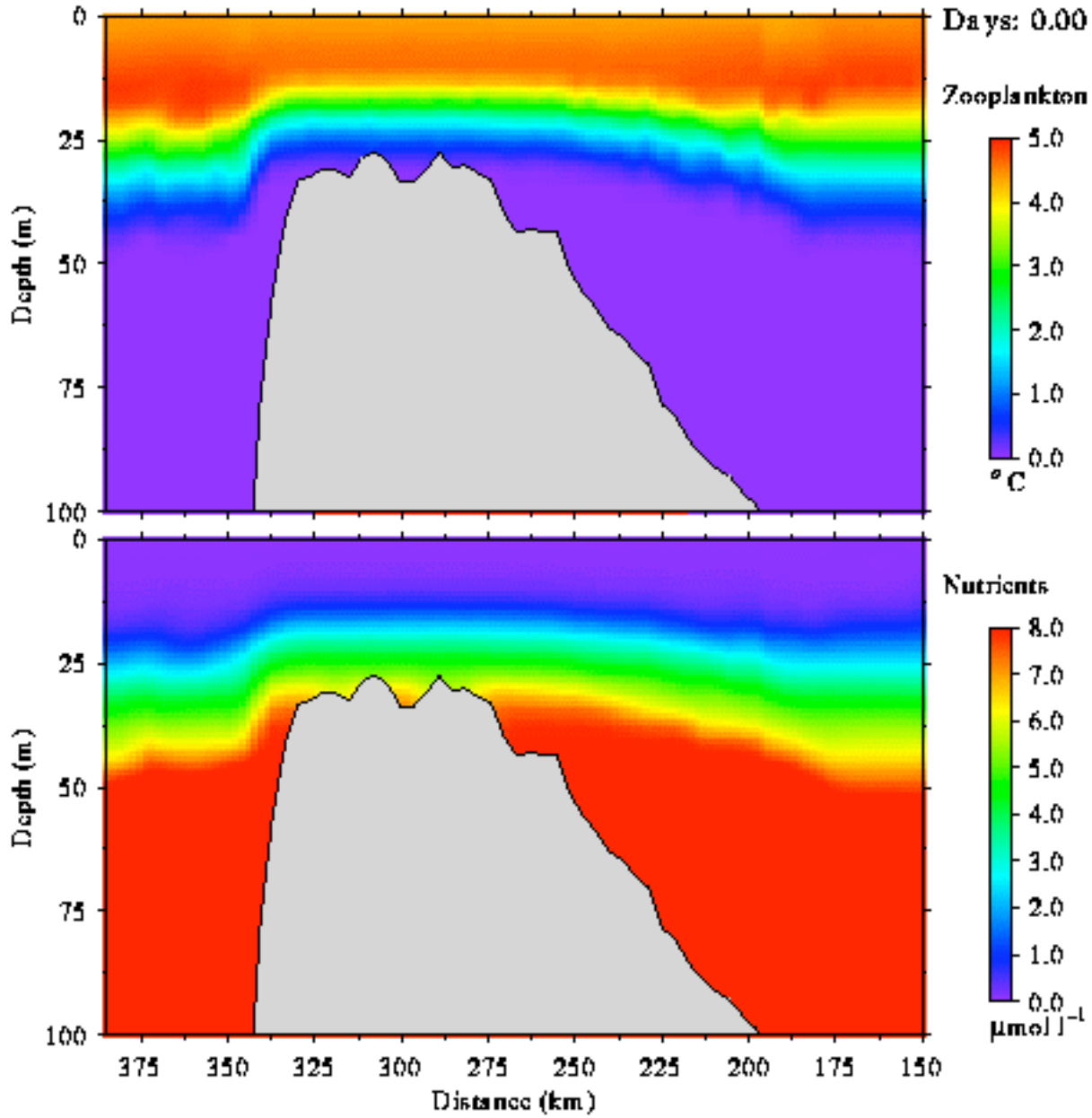

42°
41°
Mixed zone
0.5 1 1.8 2
0.2
60 m
100 m
$\Delta\sigma_t$
68°W
67°W
66° W
>6
<0.5
2
3
NO_3
(mg/m^3)
>15
15
15
17
T(°C)
>6
2
3
>6
Chl-a
(mg/m^3)

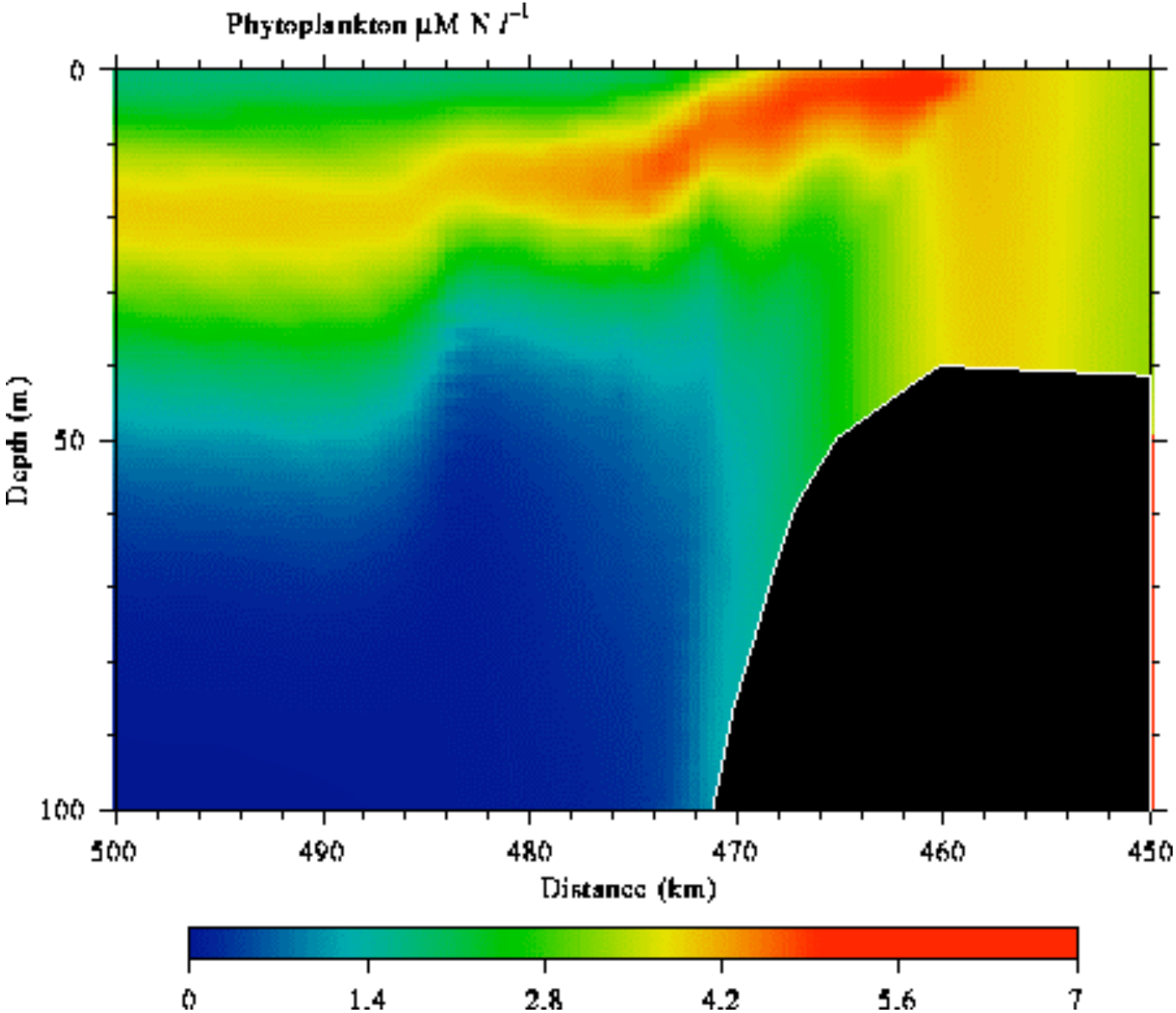

Temperature
Chl-a
NO_3
0
50
100
150
200
250
0 5 10
km

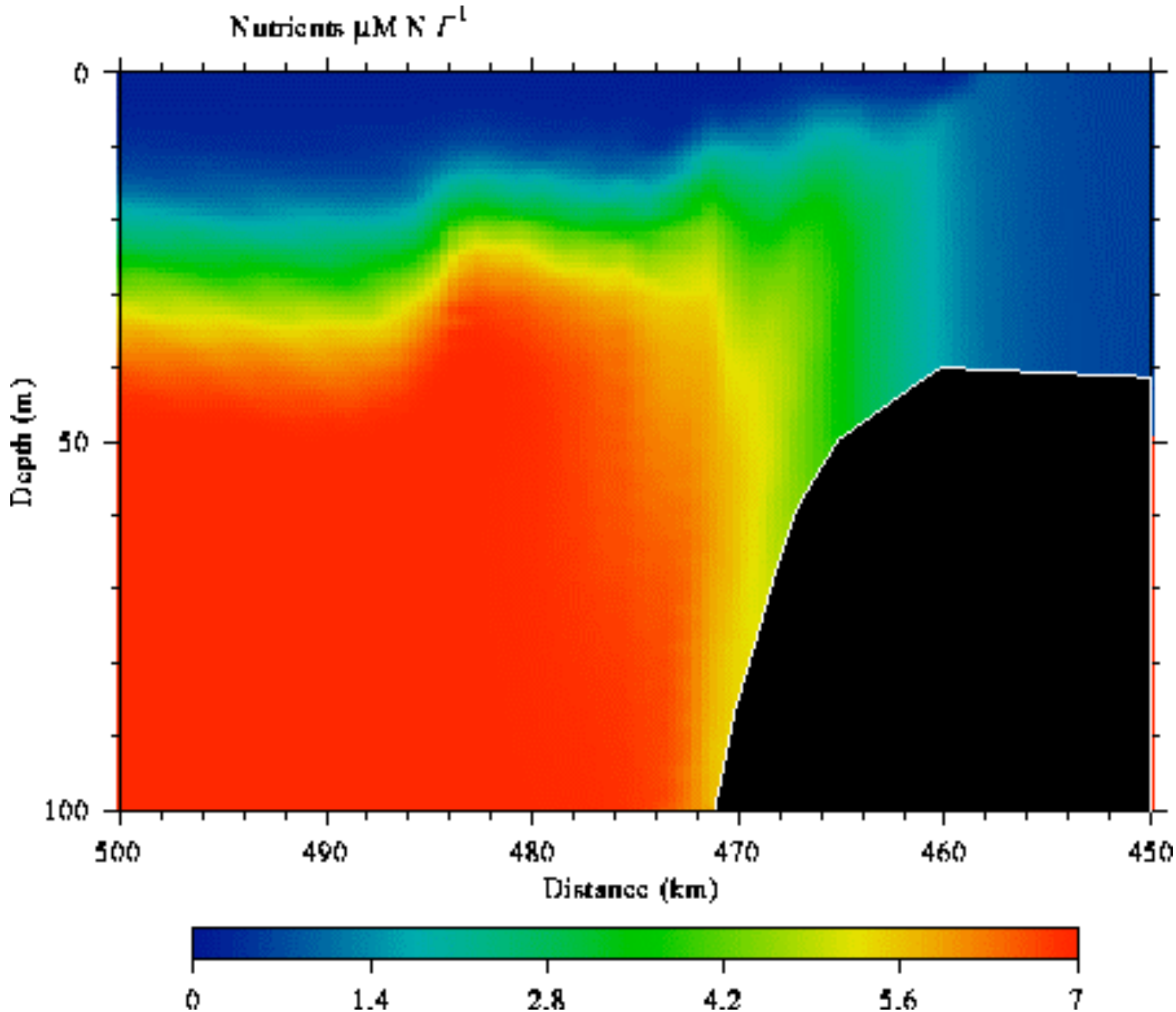

Days: 0.00
Temperature
15.0
14.8
14.6
14.4
14.2
14.0
°C
Phytoplankton
5.0
4.0
3.0
2.0
1.0
0.0
µmol l⁻¹
Distance (km)
Distance (km)
Distance (km)
0
50
100
150
200
250
300
350
400
450


Days: 0.00
Zooplankton
Nutrients
Distance (km)
Distance (km)
0
50
100
150
200
250
300
350
400
450
0.0
1.0
2.0
3.0
4.0
5.0
µmol l⁻¹


Days: 0.00
Temperature
15.0
14.0
13.0
12.0
11.0
°C
Phytoplankton
5.0
4.0
3.0
2.0
1.0
0.0
µmol l⁻¹
Depth (m)
0
25
50
75
100
375
350
325
300
275
250
225
200
175
150
Distance (km)


Days: 0.00
Zooplankton
5.0
4.0
3.0
2.0
1.0
0.0
°C
Nutrients
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
µmol l⁻¹
Depth (m)
0
25
50
75
100
375
350
325
300
275
250
225
200
175
150
Distance (km)


Phytoplankton µM N l⁻¹
0
50
100
Depth (m)
500
490
480
470
460
450
Distance (km)
0
1.4
2.8
4.2
5.6
7


Nutrients µM N l⁻¹
0
50
100
Depth (m)
500
490
480
470
460
450
Distance (km)
0
1.4
2.8
4.2
5.6
7

Generally theory:

The front acts like a barrier to limit the water exchange across the front. In biology, it acts like a "retention zone"-----longer residence time.

QS: How are the nutrients transported across the front?

Main physical processes:

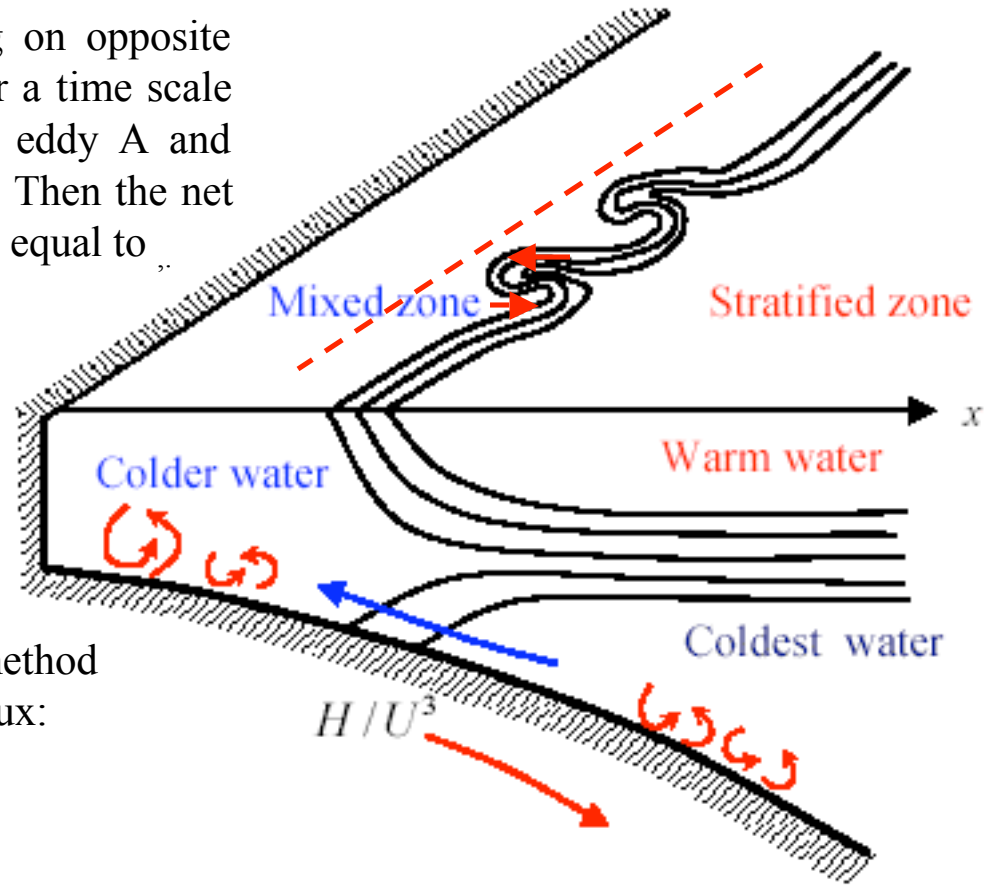
1) Frontal baroclinic instability-eddy formation
2) Nonlinear interaction of tidal currents
3) Asymmetric tidal mixing
4) Variable winds
5) Chaotic exchanges

1. Baroclinic instability

Simply an eddy like a cylinder with a depth of D and radius of $4L_R$, where L_R is the internal Rossby deformation radius ($L_R = \sqrt{g\Delta\rho D/\rho f^2}$),

Consider a pair of eddies moving on opposite directions in a length of 16 L_R over a time scale of T_E. Nutrient concentrations for eddy A and eddy B are specified as C_1 and C_2. Then the net nutrient flux across the front should equal to

$$Q_E = \frac{16L_R^2\pi D(C_2 - C_1)}{16L_R T_E} = \pi D\Delta C\frac{L_R}{T_E}$$



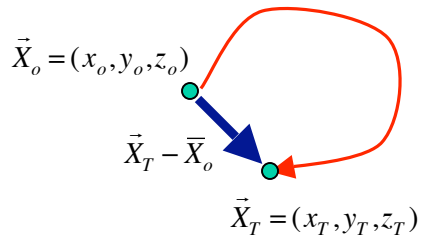
An alternative way is to use the method for the eddy-induced polar heat flux:

$$Q_E = \gamma\,\Delta C\sqrt{gD\frac{\Delta\rho}{\rho}} = \gamma\Delta C\sqrt{g'D}$$

where ΔC is the cross-frontal difference of nutrient concentration

2. Nonlinear interaction between tidal currents

Lagrangian velocity: $\vec{V}_L = \dfrac{\vec{X}_T - \vec{X}_o}{T}$



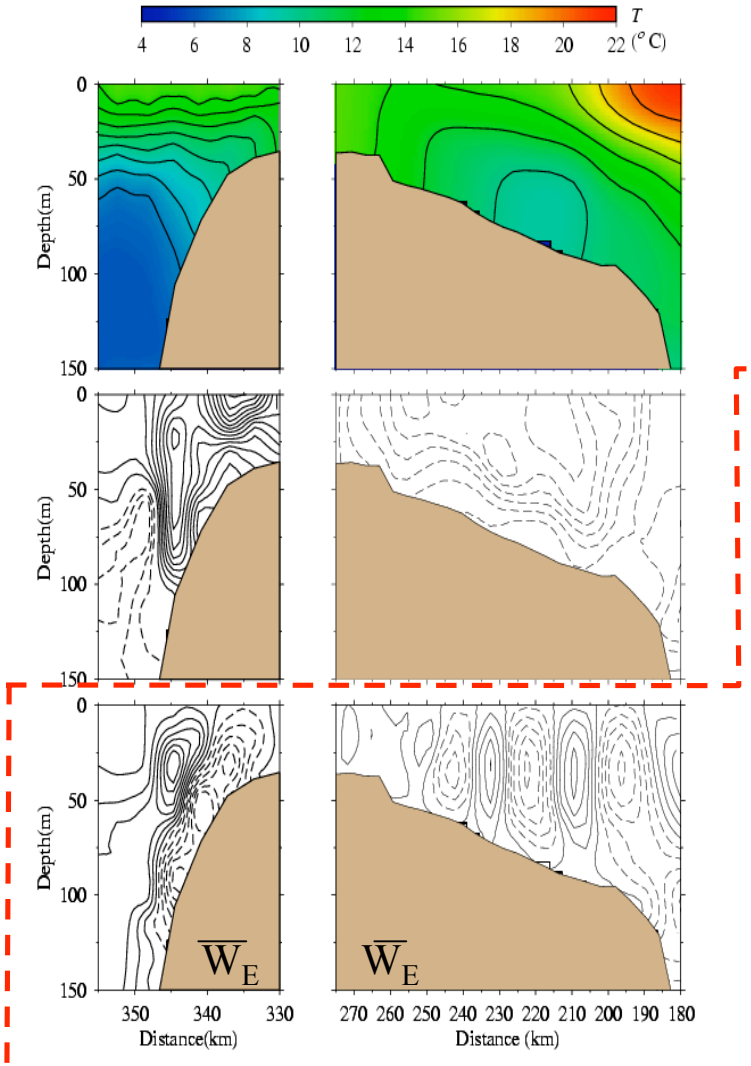
T : The M_2 tidal period,

$\vec{X}_o$, $\vec{X}_T$: The positions at starting point and end point over a tidal cycle.

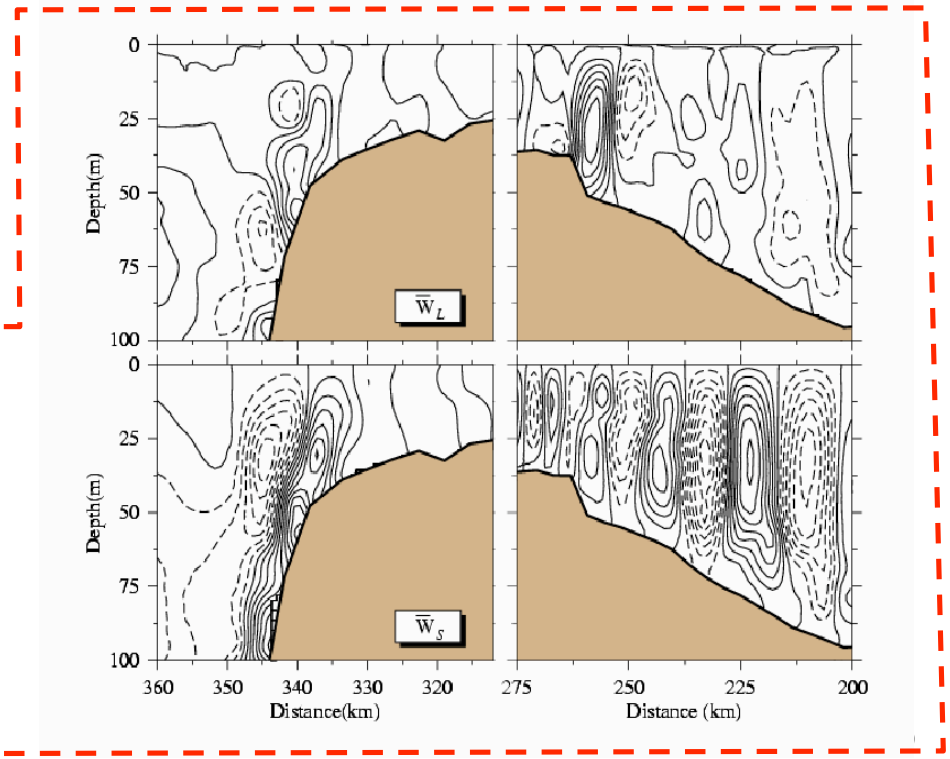
Let $\vec{V}_E$ be the Eulerian velocity (measured at a fix location), the Stokes' velocity is defined as

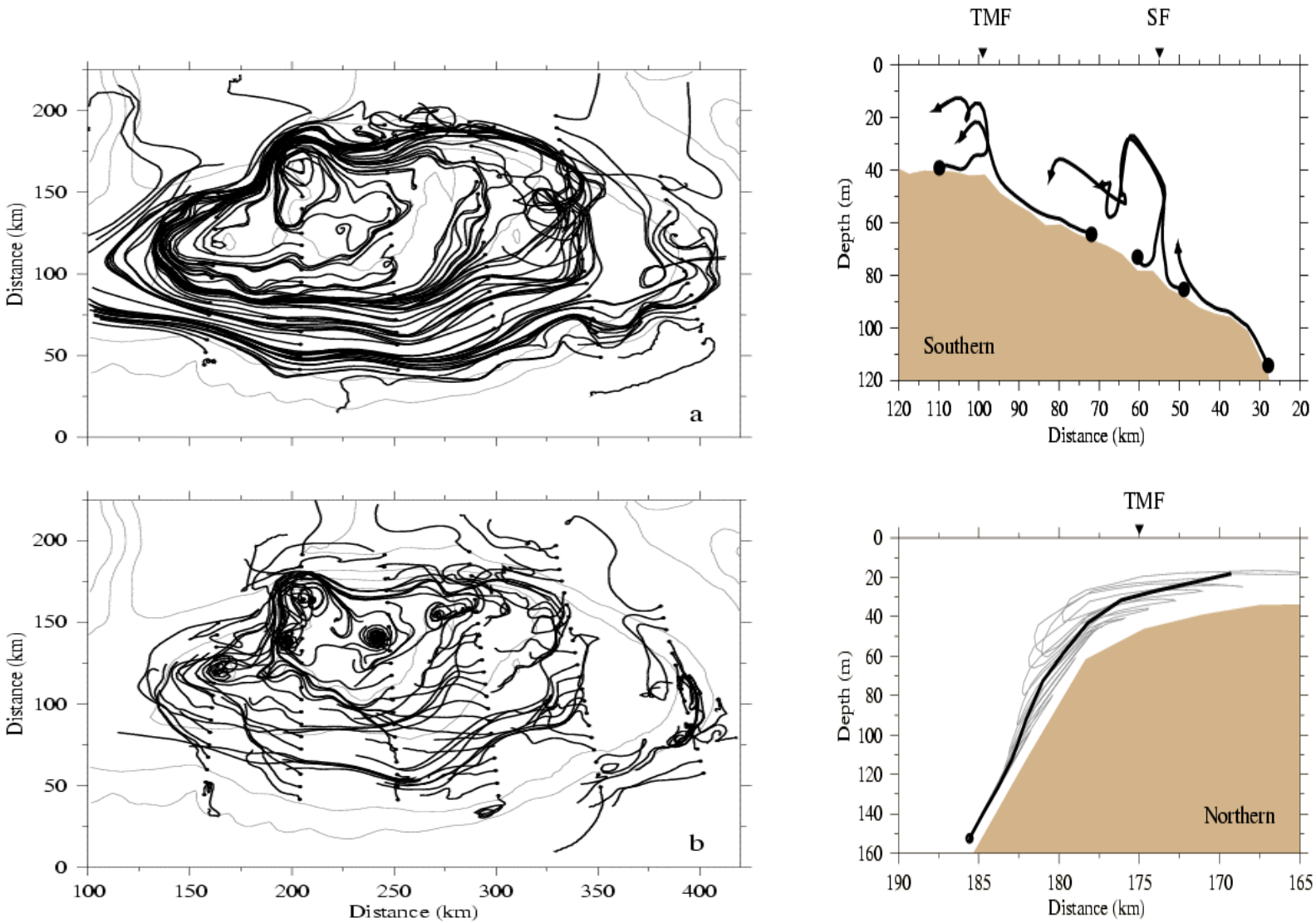
$$\vec{V}_S = \vec{V}_L - \vec{V}_E$$

- If the flow field is linear, the residual flow equal to zero.
- If the flow field is weak nonlinear, the Stokes' velocity should be one order of magnitude smaller than the Eulerian velocity;
- If the flow field is strong nonlinear, the Stokes' velocity could be the same order of magnitude as the Eulerian velocity.

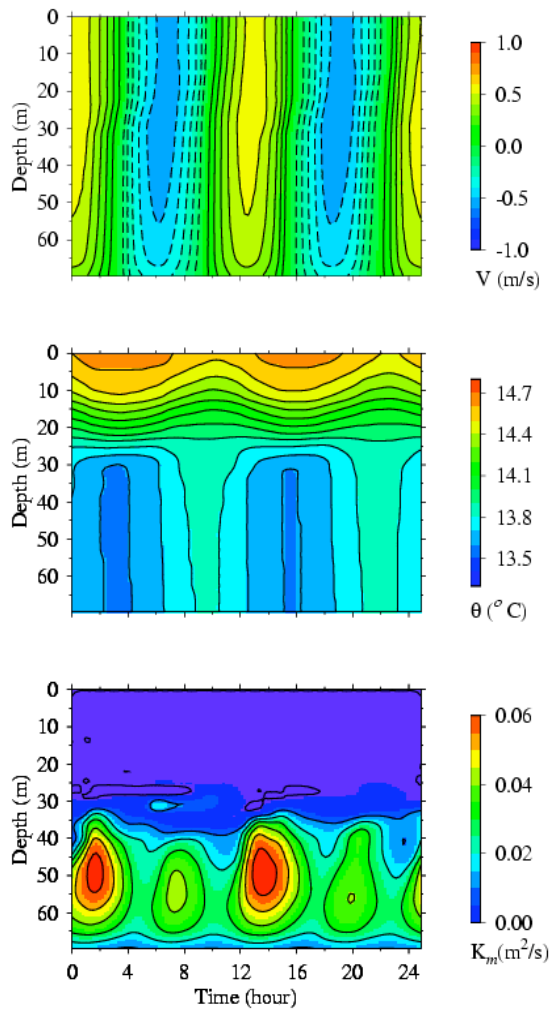


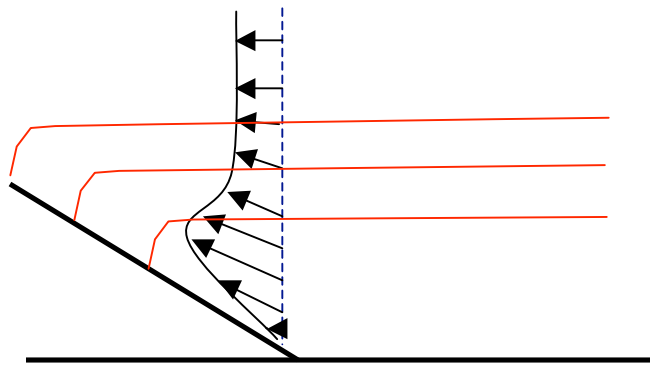
On Georges Bank, the nonlinearity is strong, Lagrangian velocity on the northern flank can be opposite to the Eulerian velocity




TMF
SF
Distance (km)
Depth (m)
Southern
a
b
Northern

3. Asymmetric tidal mixing over tidal cycles





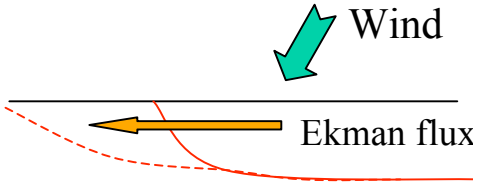
During the flood period:

Mixing is caused by shear instability plus gravitational instability---stronger

During the ebb period:

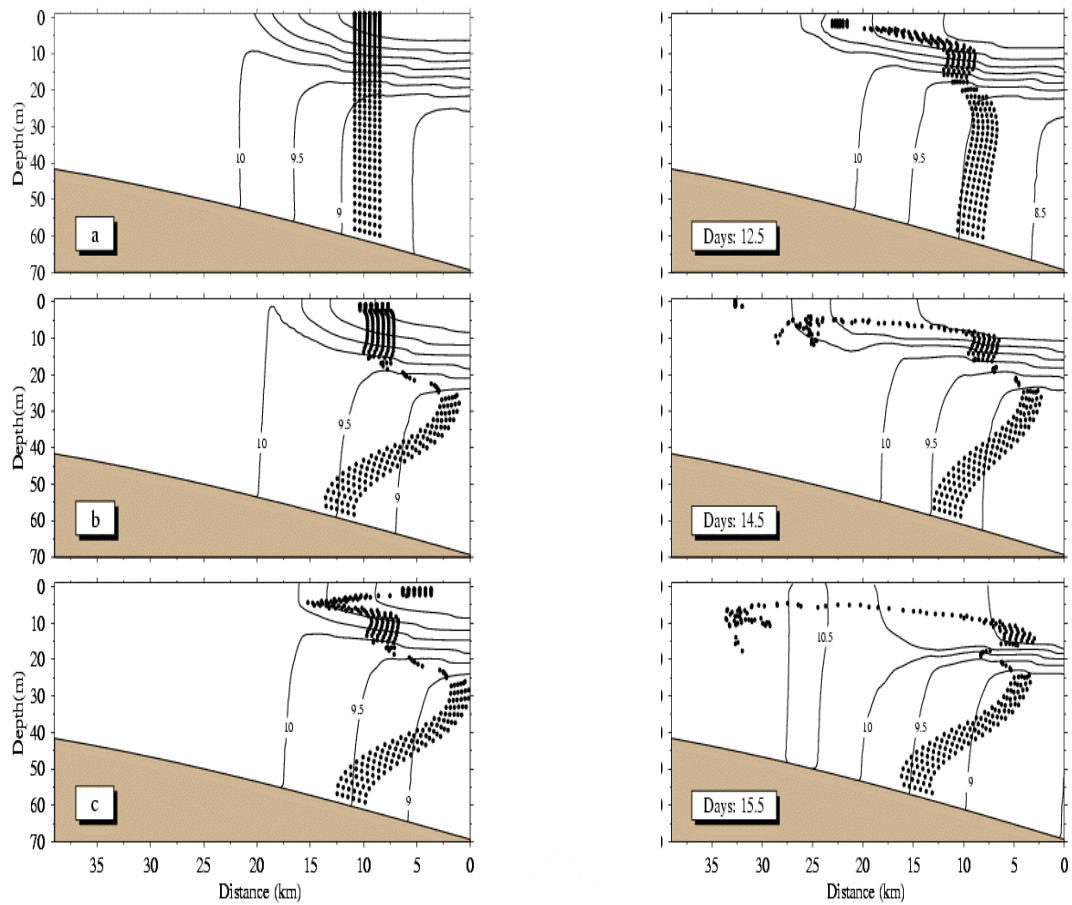
Mixing is caused mainly by shear instability

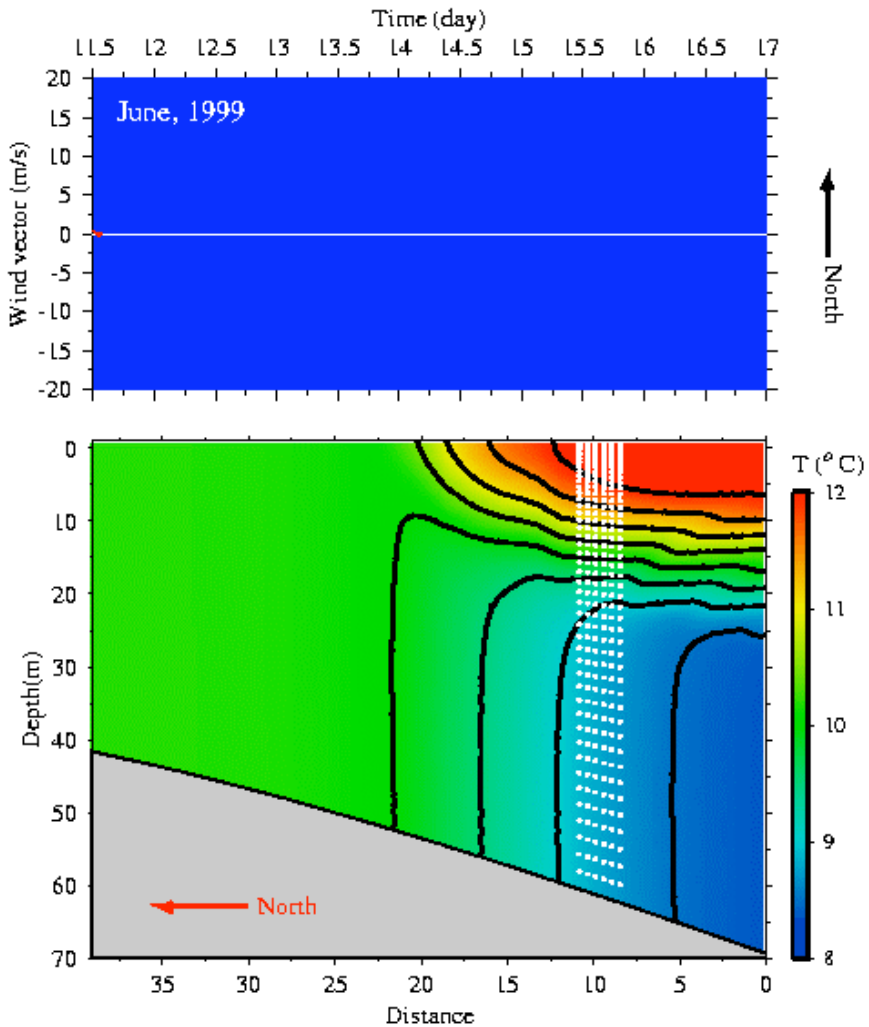
4) Variable winds

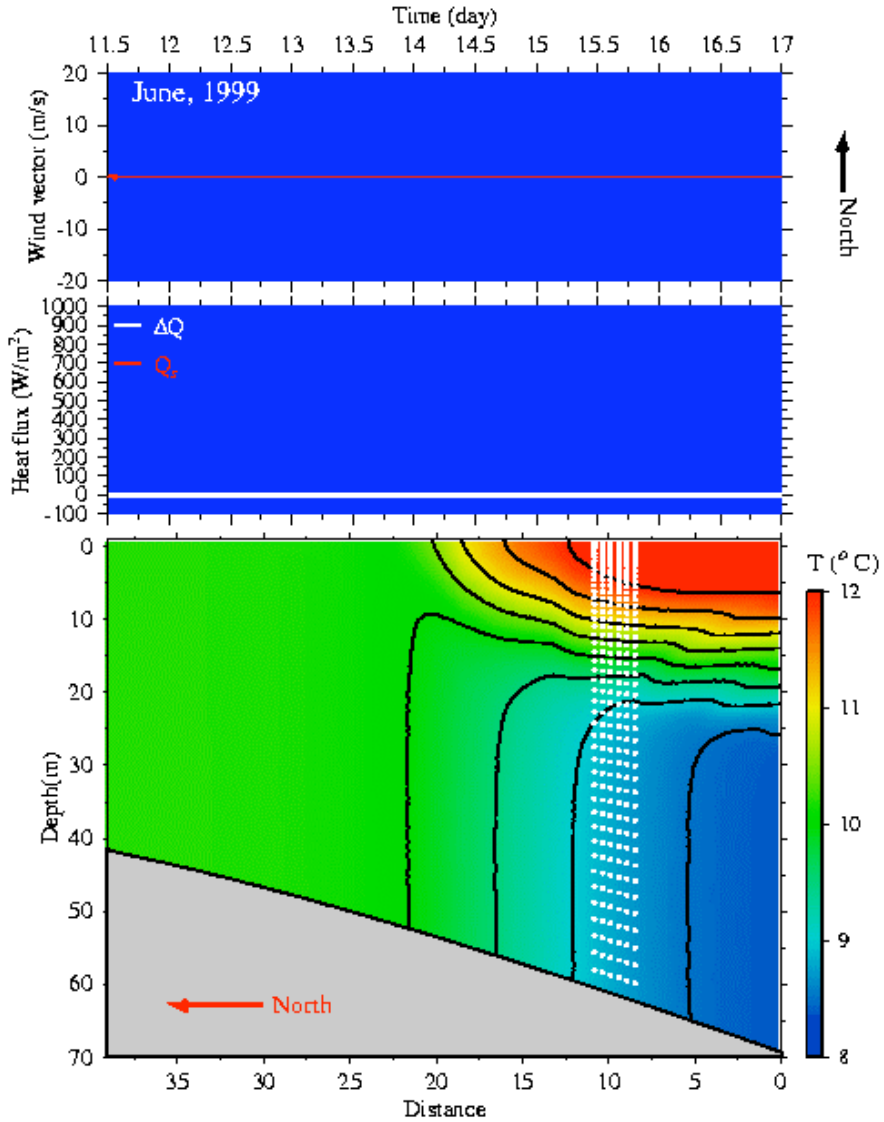


For a constant wind, if no any other forcing exists, the front would move to the direction of the Ekman transport, no cross frontal transport could occur.

However, if the cross-frontal exchange could happen if tidal mixing exist under a variable wind condition.




Time (day)
June, 1999
Wind vector (m/s)
North
Depth(m)
Distance
North
T (°C)


Time (day)
11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 16.5 17
June, 1999
Wind vector (m/s)
20 10 0 -10 -20
North
Heat flux (W/m²)
1000 900 800 700 600 500 400 300 200 100 0 -100
ΔQ
Qs
Depth(m)
0 10 20 30 40 50 60 70
North
35 30 25 20 15 10 5 0
Distance
T (°C)
12 11 10 9 8

5. Chaotic transport