Fronts in shallow seas

Fronts in the ocean can be defined as regions where properties change markedly over a relatively short distance.

Another way of expressing this is that fronts are regions where the **horizontal gradient of a property goes through a maximum**.

Six types of fronts are usually distinguished in oceanography.

- Three of these are found in the coastal ocean.
- Two of these are found in estuaries.
- The sixth type of front is restricted to the deep ocean.

The physics of fronts

• Large regions of small horizontal variations, bounded by narrow regions where horizontal gradients are large >> **Fronts are the narrow high-gradient regions.**

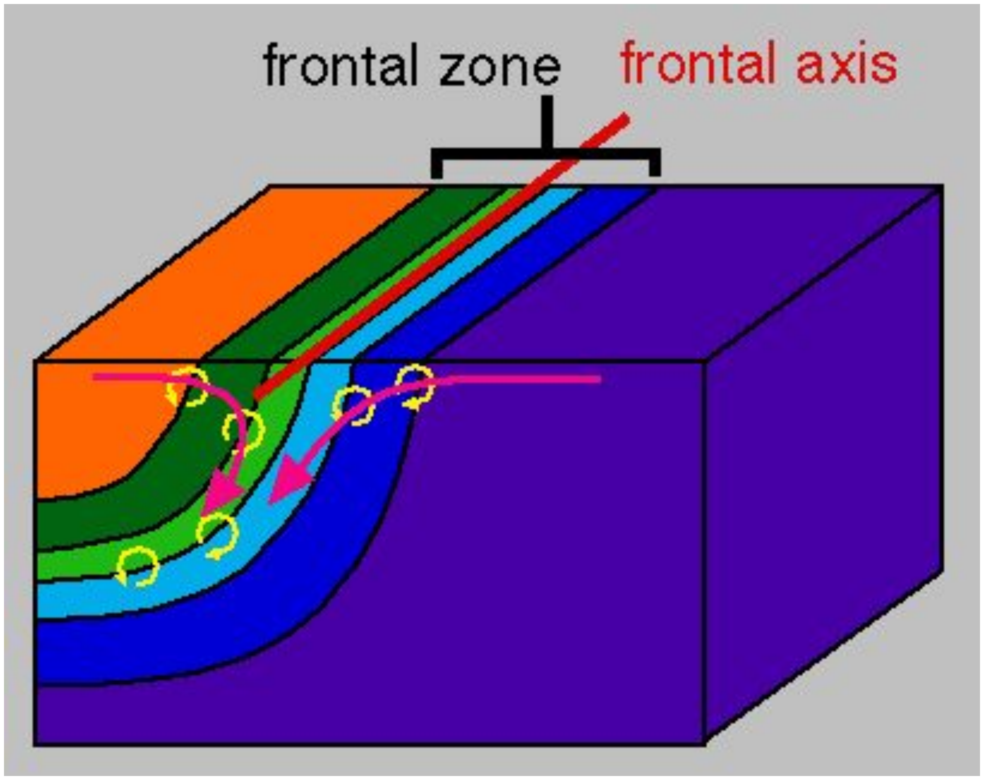
i.e.Front or Frontal zone: sloping interface between two water bodies with different water properties (density, temperature, salinity)

• **Examples:**

Western boundary currents (e.g. Gulf Stream) 1000's of kms; T difference of 10° C over 50 km;

Tidal flow transient fronts typically a few kms, T difference only 1-2°C

Dynamics of ocean fronts



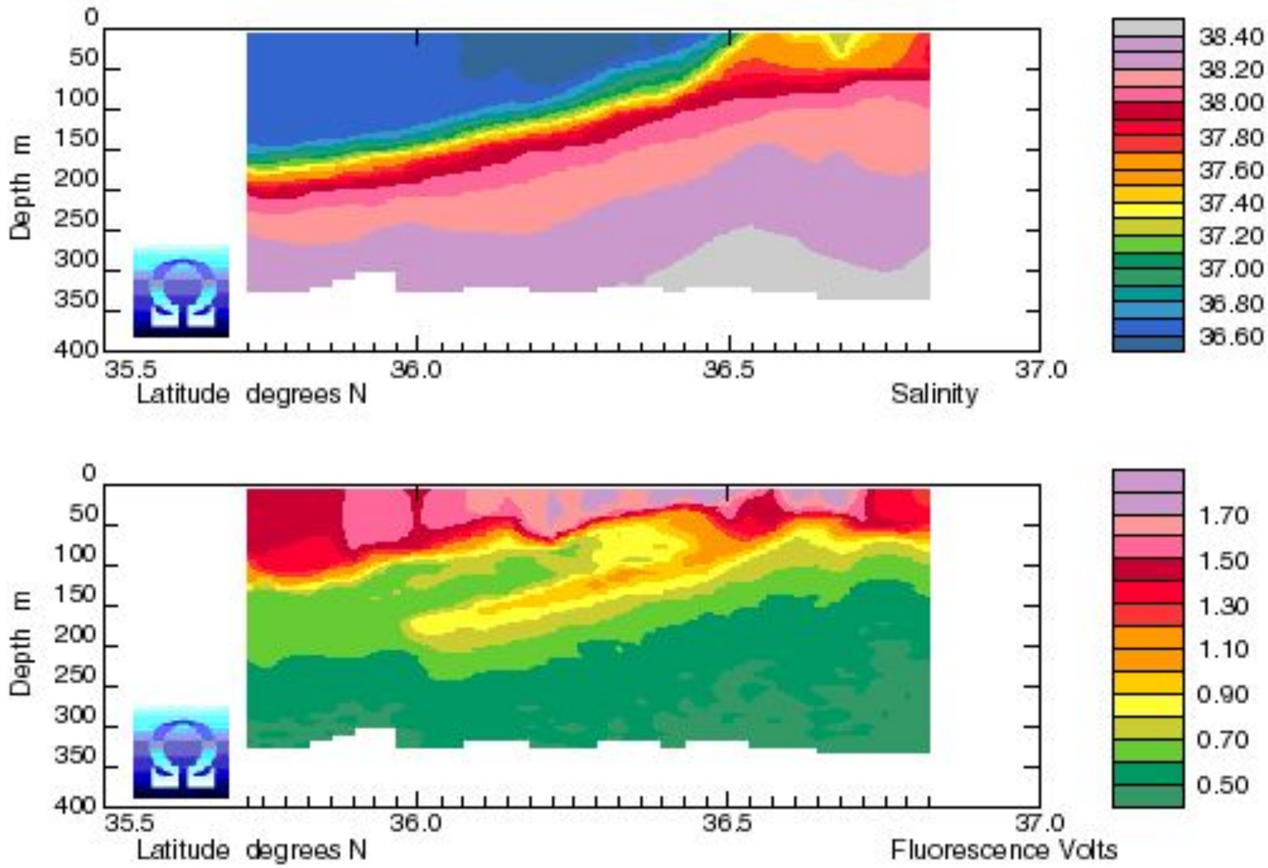
Sketch of the circulation in a front

The black contours indicate surfaces of constant property values; to take an example, in a temperature front the contours would be isotherms, cold would be purple, warm would be gold.

Water movement is towards the front at the surface, producing a convergence into the front. It can be seen that water moves across the contours (eg isotherms), so strong mixing, indicated by yellow arrows, must occur in the front.

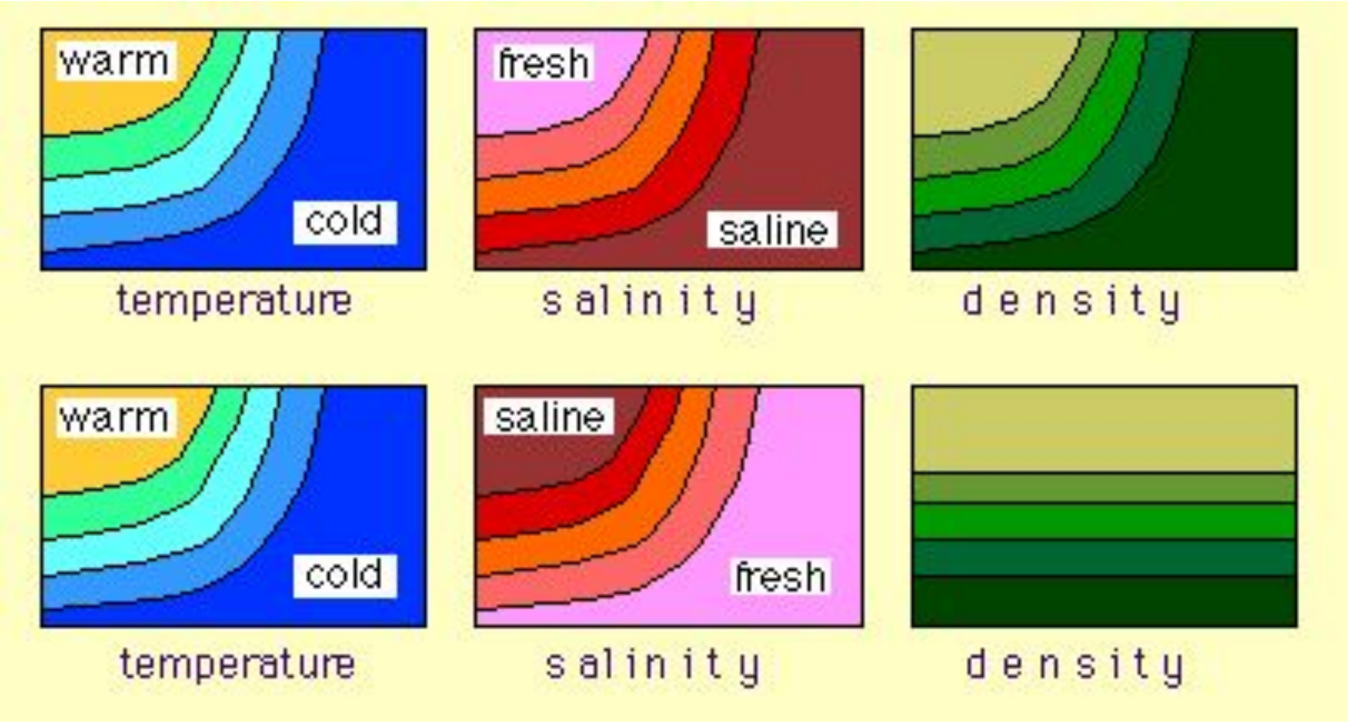
The frontal zone is the region of rapid property (e.g. temperature) change at the surface. The frontal axis is the location of the largest horizontal property (e.g. temperature) gradient.

Where there is convergence there will be a front, and where there is a front there has to be flow convergence.



Interactions between physics and biology at a front in the Alboran Sea.

T and S are not good indicators for vertical water movement because they determine the stability of the water column . Downward movement in the frontal zone is clearly seen in optical properties. Here fluorescence in a frontal region of the western Mediterranean Sea.



The hydrographic structure of a density front (top) and a density-compensated front (bottom).

The stable stratification component in the density-compensated front of this example is temperature; it is compensated by salinity.

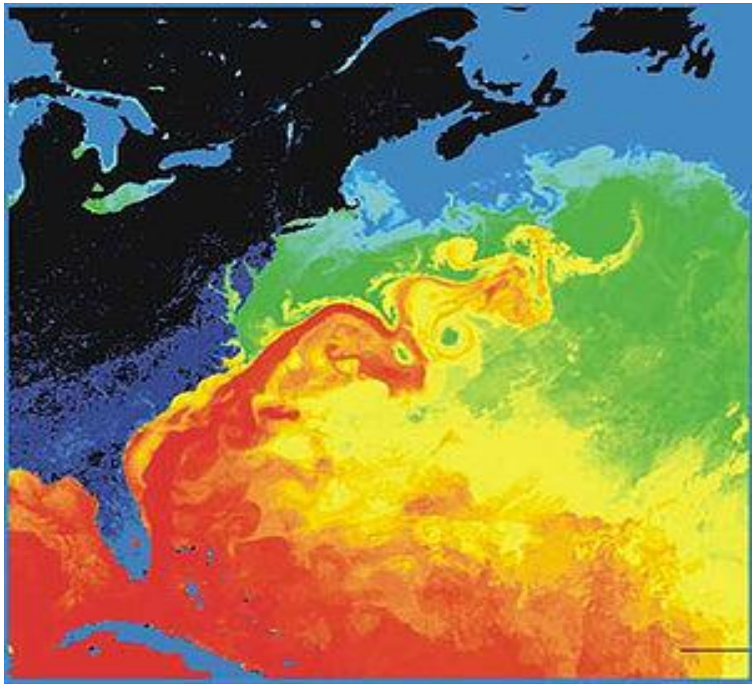
Another possibility would be to have fresh, cold water above saline, warm water.

Fronts of the deep ocean

Planetary fronts

- Found in deep ocean
- They span the width of entire ocean basins
- Associated with features of planetary wind system
- Fronts are found in the Circumpolar Current and between the subtropical and subpolar oceanic gyres of the northern Hemisphere.
- Have great impact on air/sea interaction processes
- Create atmospheric conditions due to T differences across a planetary front.

Planetary fronts

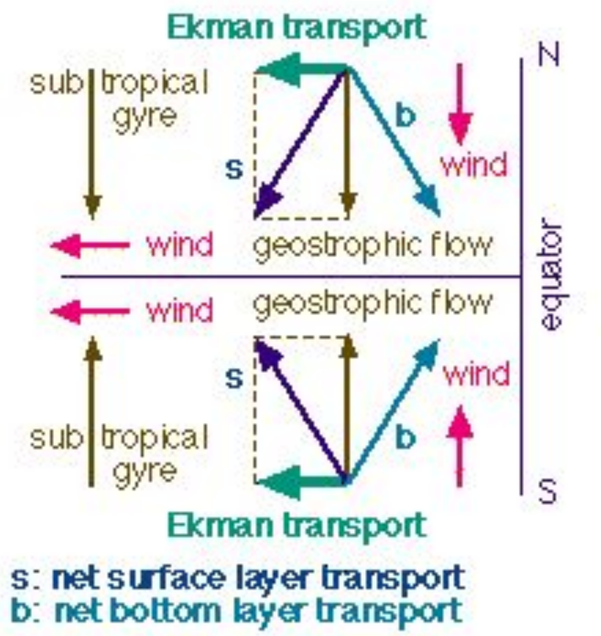


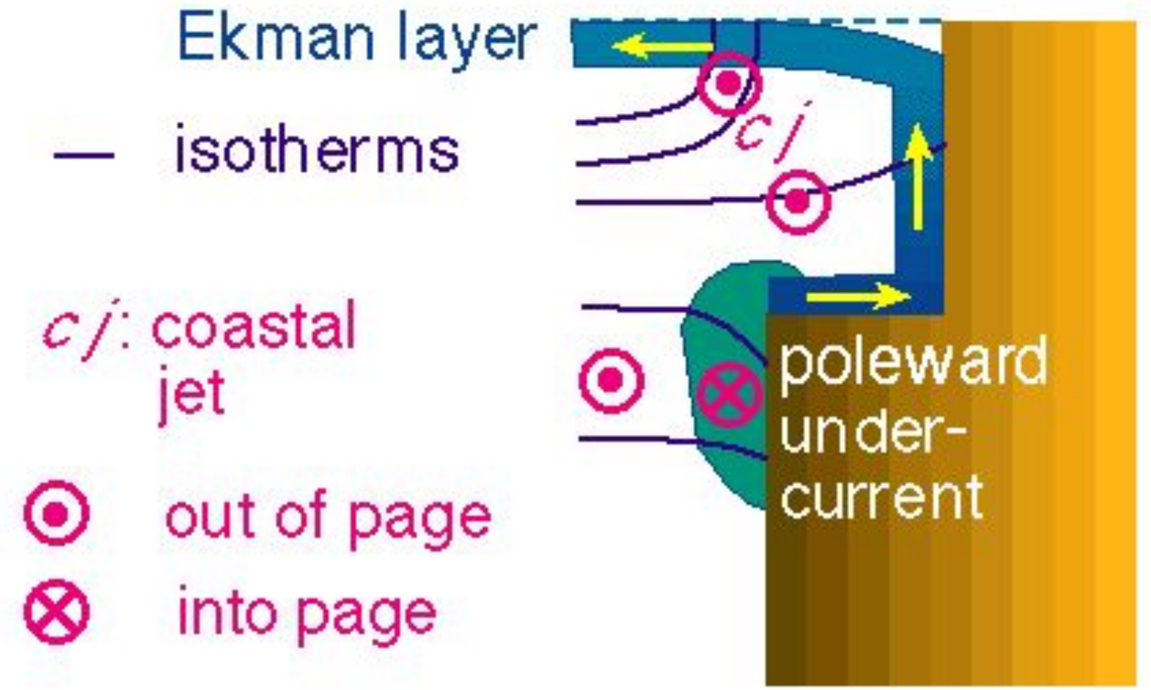
examples

- *Gulf Stream Front*
- *Antarctic Polar Front*
- *Kuroshio front (Pacific coastal area)*

Fronts of the coastal ocean

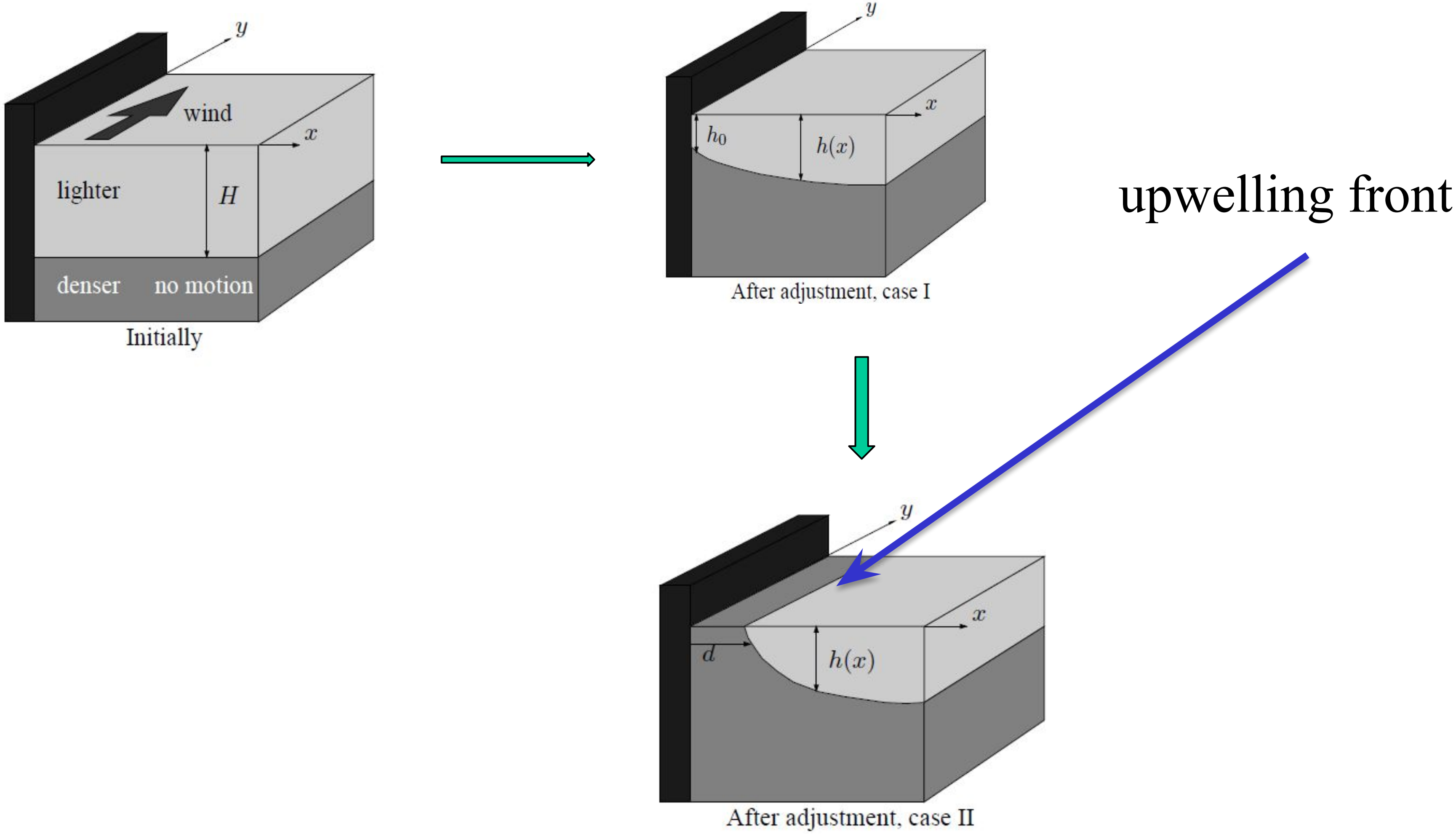
1. Upwelling front

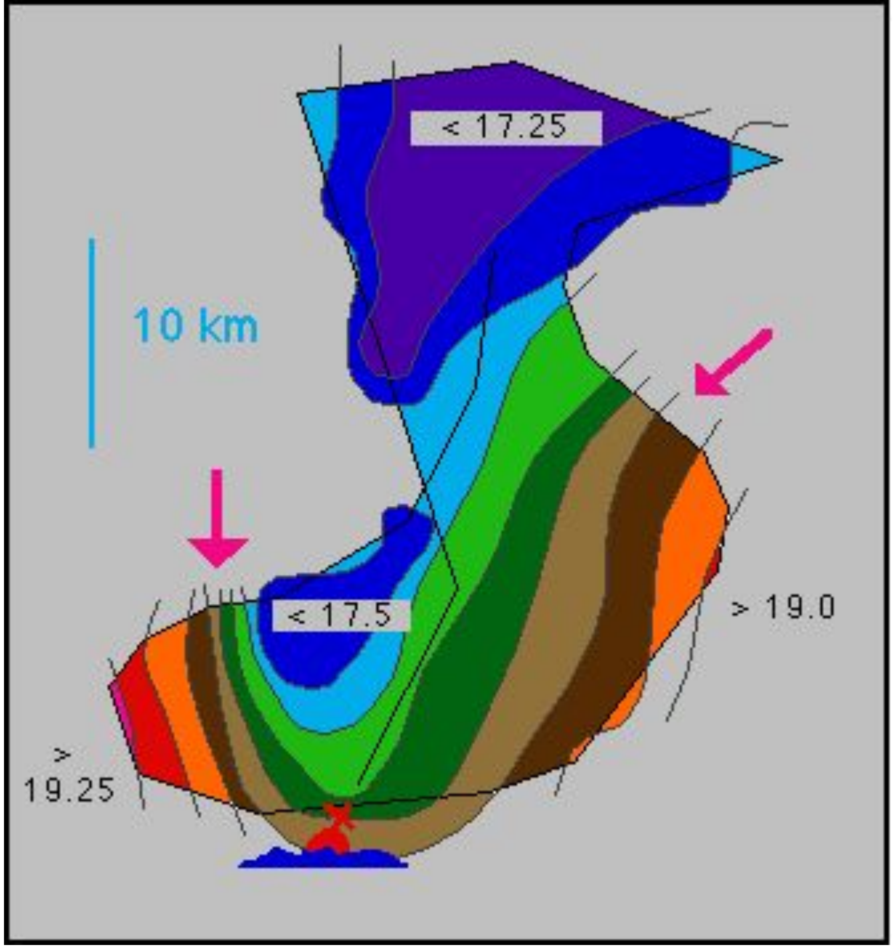




Strength of upwelling is determined by the strength and direction of the wind.
Most important upwelling regions are located in the Trade Wind region where winds are relatively uniform in strength and direction

Wind-driven upwelling





Sea surface temperature in the Canary Current upwelling region off the Mauritanian coast showing the upwelling front and the drift of a buoy deployed to mark freshly upwelled water.

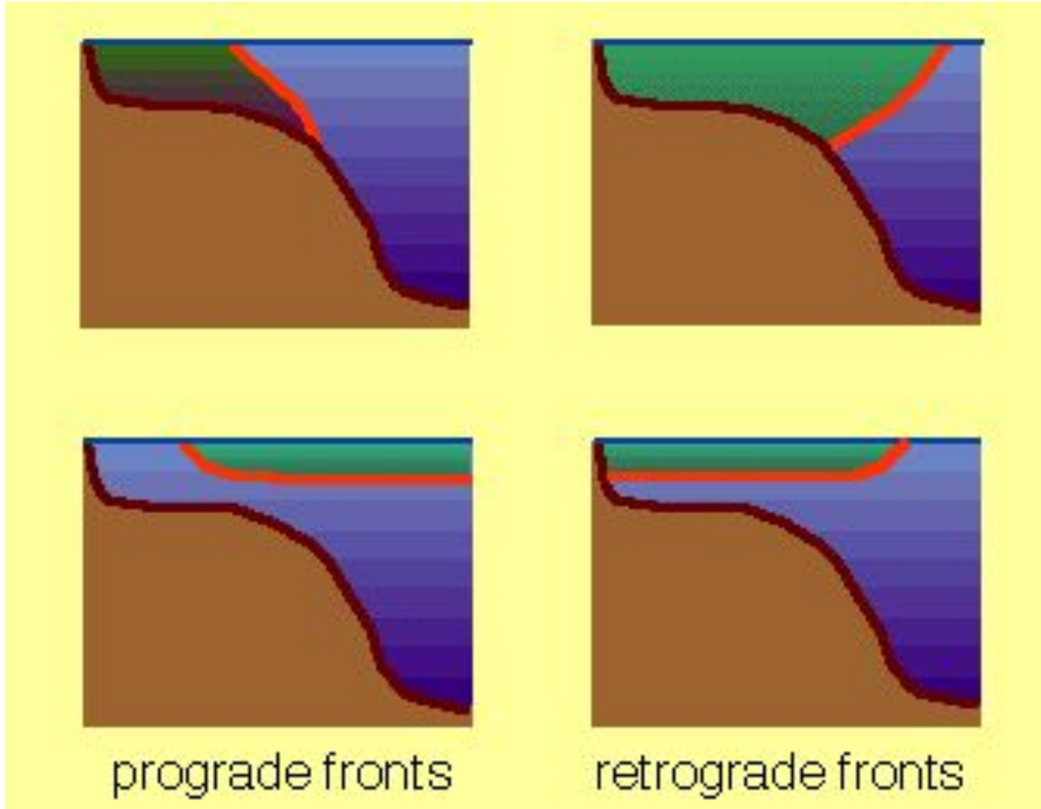
Upwelling front

This figure shows the drift of the buoy. The buoy had a subsurface drogue attached and therefore served as an indicator of water movement for the upper mixed layer.

Black contours and colours indicate water depth, contouring interval is 250 m.

Thick lines indicate buoy drifts. The first drift (cyan) lasted 6 days, until the buoy had reached the upwelling front (at the black dot). It was then recovered and redeployed for a second drift (magenta), which lasted 3 days. By that time the buoy had again reached the front.

Note that the buoy crosses the continental slope at an offshore angle, in agreement with upwelling dynamics.



Examples of prograde and retrograde density fronts.
In the prograde front the bottom slope and the slope of the front are of the same sign, in the retrograde front they have the opposite sign.

2. Shelf break fronts

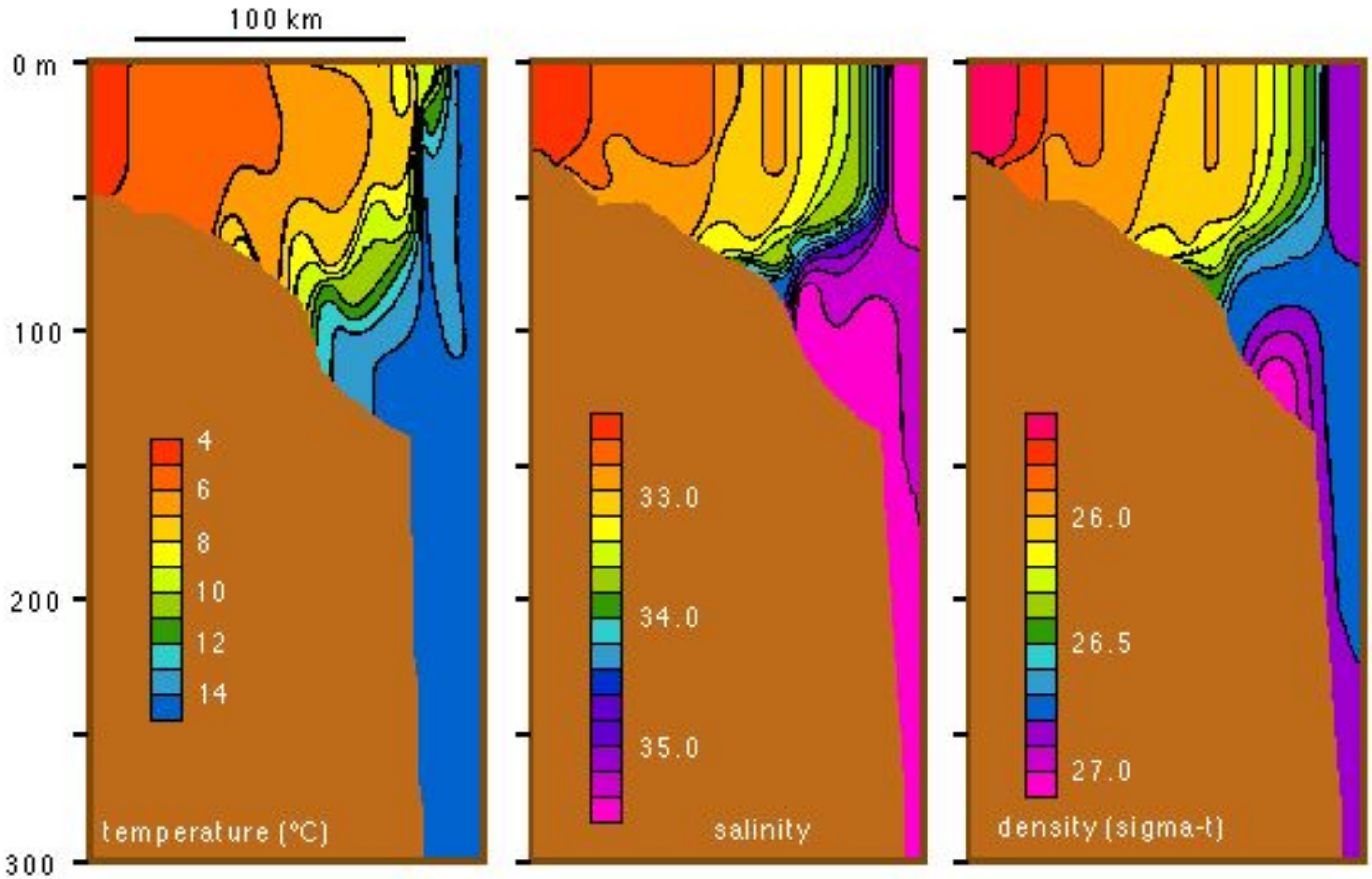
$$Ro = \frac{1}{f}\sqrt{g\frac{\rho_2 - \rho_1}{\rho_2}D_1}$$

Shelf break fronts

- Result of differences in hydrographic properties between the coastal ocean and the open sea.

- In contrast to upwelling fronts and shallow sea fronts, shelf break fronts are more or less stationary.

- Position controlled by the location of the shelf break, departures from this position only through eddy formation.



Shelf break front along the Atlantic coast of USA. Winter situation south of Rhode Island. Stratification on the shelf minimal during winter, T > 4° inshore to 8° near the front. Salinity from 32.5 to 33.5.

3. Shallow sea fronts

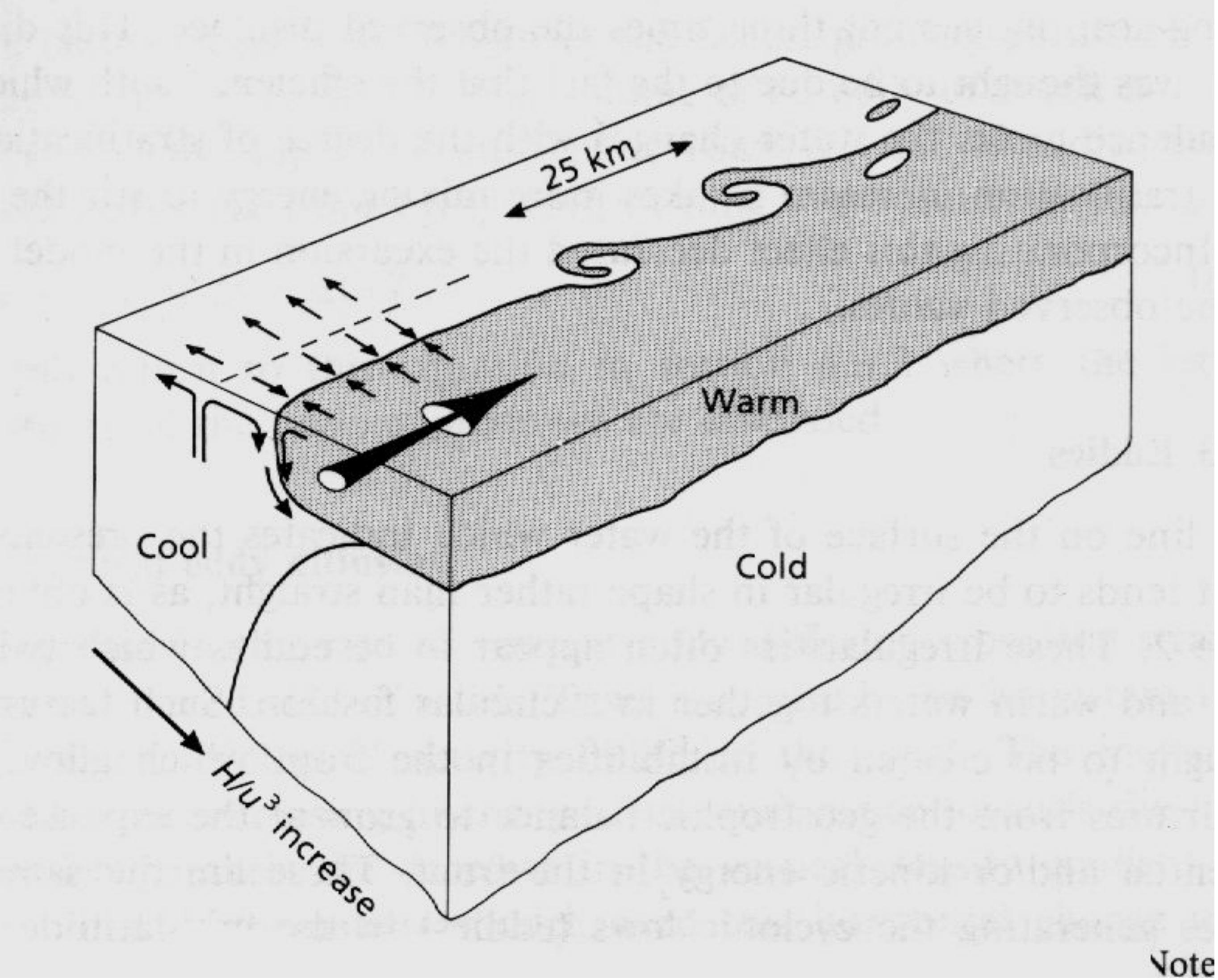
Tidal (shelf sea) fronts

Tidal mixing fronts are maintained by competition between vertical distribution of solar energy (stratifies the water column) and the vertical turbulent mixing generated by tidal stresses at the seabed (acting against the thermal stratification)

Shallow and/or tidally energetic regions of temperate shelf seas remain vertically mixed throughout the year, as the strong tidal stirring is always able to overcome the tendency to stratification caused by surface heating.

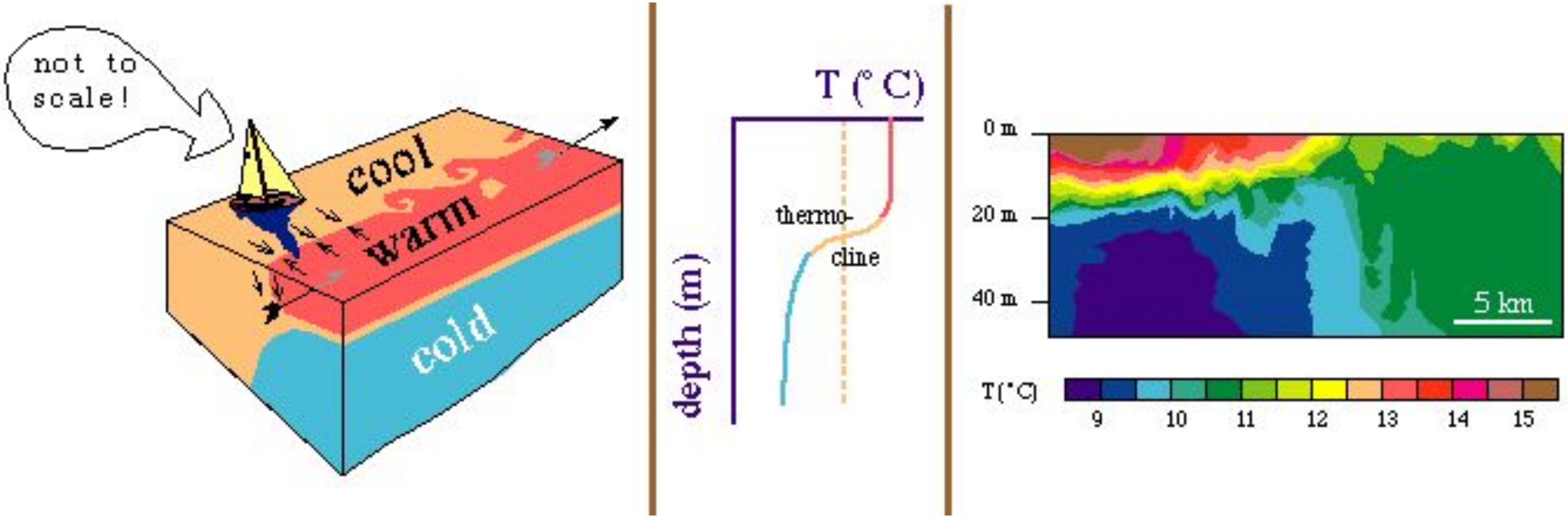
In deeper and/or less tidally energetic regions the tidal stirring is not able to counter the effects of surface heating in summer, ant the water column will stratify.

Tidal mixing fronts mark the boundaries between these different regions.



H/u3. , where H is the water column depth and u the amplitude of tidal currents

Frontal structure and circulation (after Simpson, 1981). Strong along-front mean flow, convergence and downwelling at the front, upwelling the wel-mixed side, and frontal eddies, some of which close on themselves to form isolated patches.

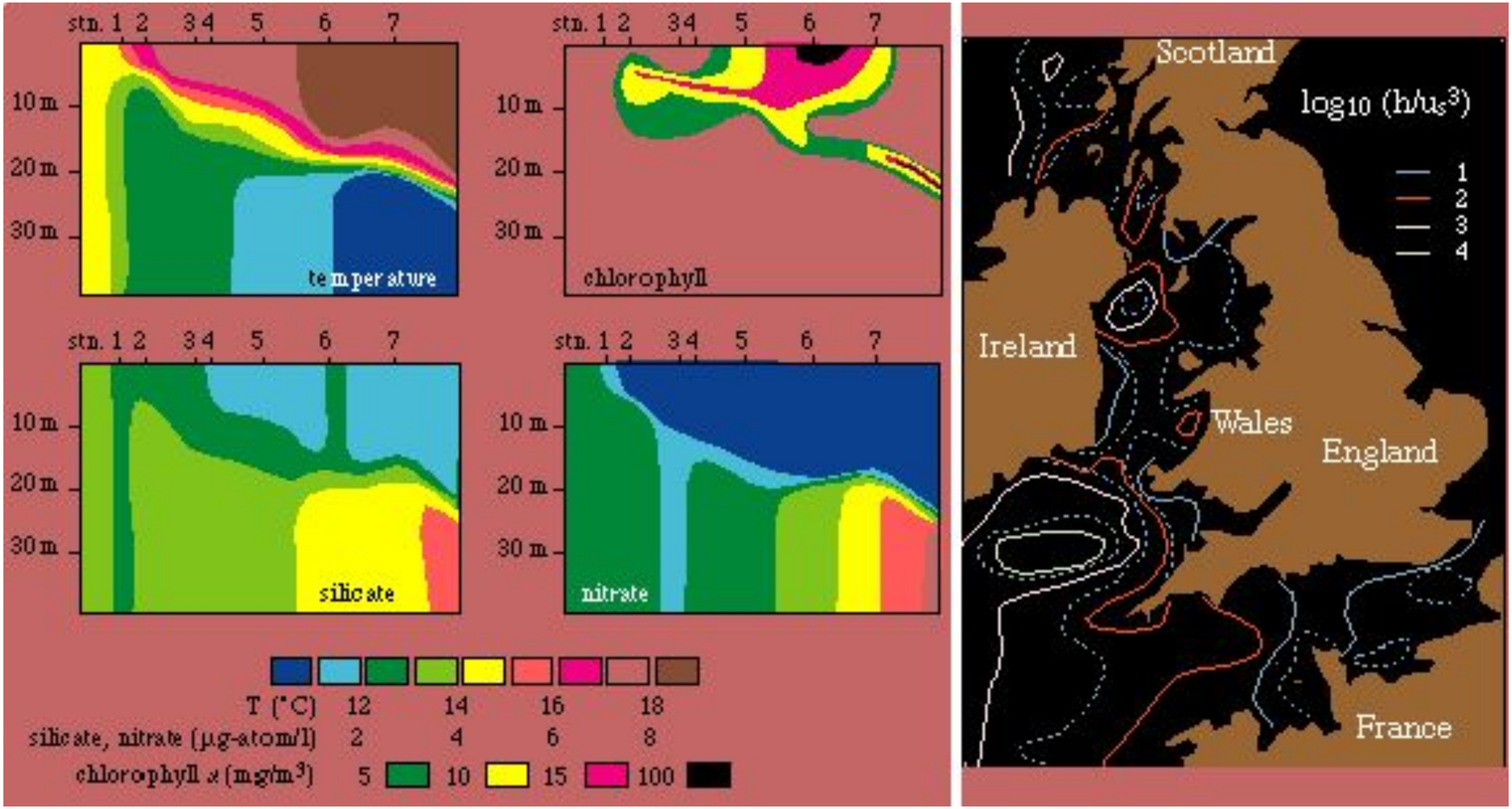


The shallow sea front.

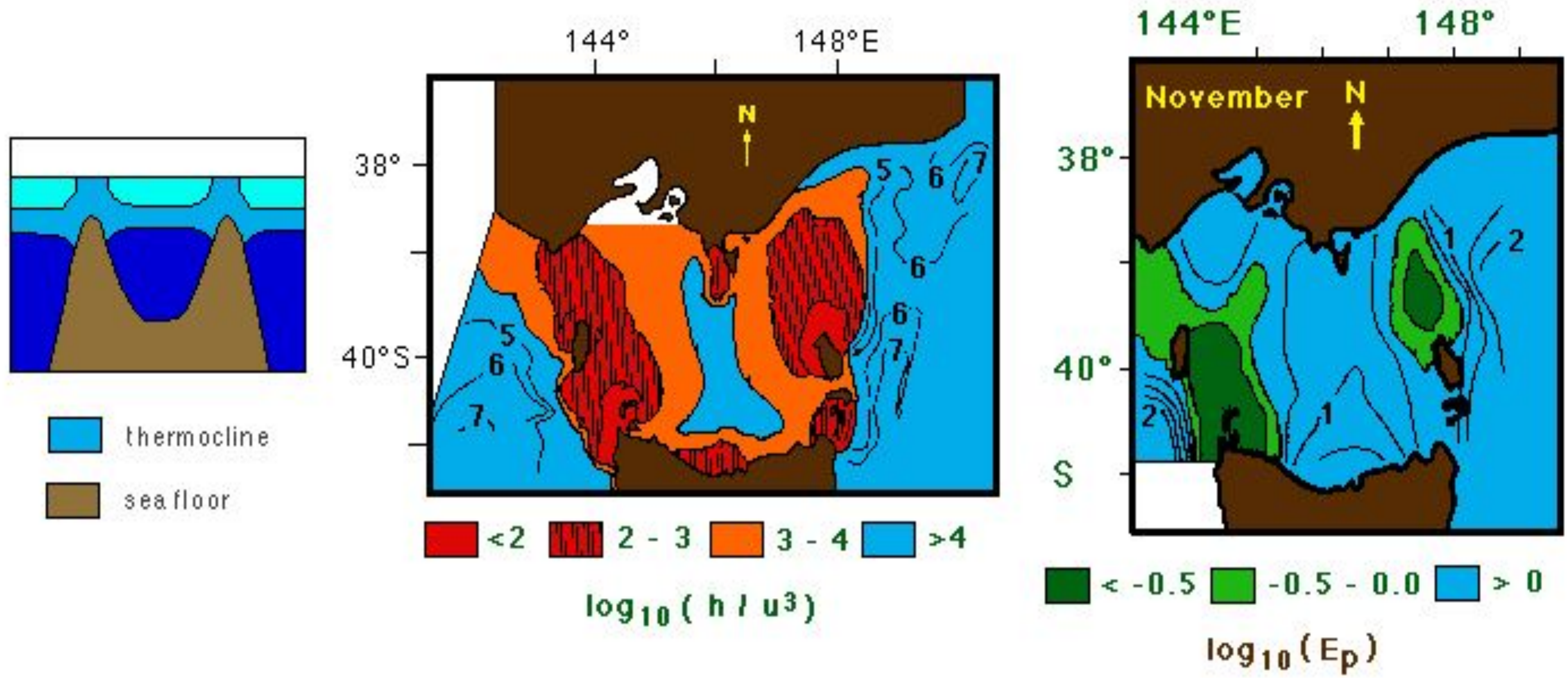
Left: sketch of a shallow sea front, showing the temperature field, the associated current along the front and the surface convergence. The deeper water is to the right.

Centre: temperature in the deeper water as a function of depth, indicating the colour code for the surface mixed layer, thermocline and lower layer.

Right: Observed temperature field in a shallow sea front. The deeper water is on the left. The data are from the front in the Irish Sea.



A section through a shallow sea front, showing temperature, chlorophyll-a, silicate and nitrate.

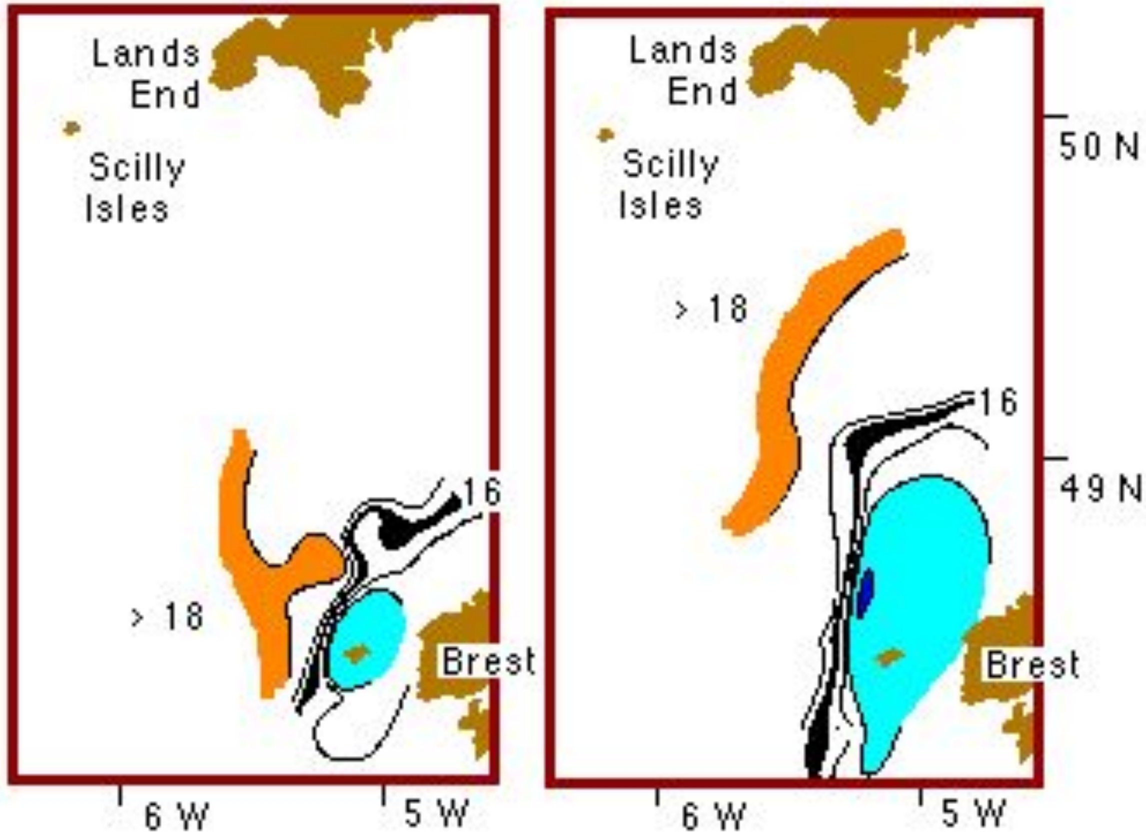


Shallow sea fronts in Bass Strait.

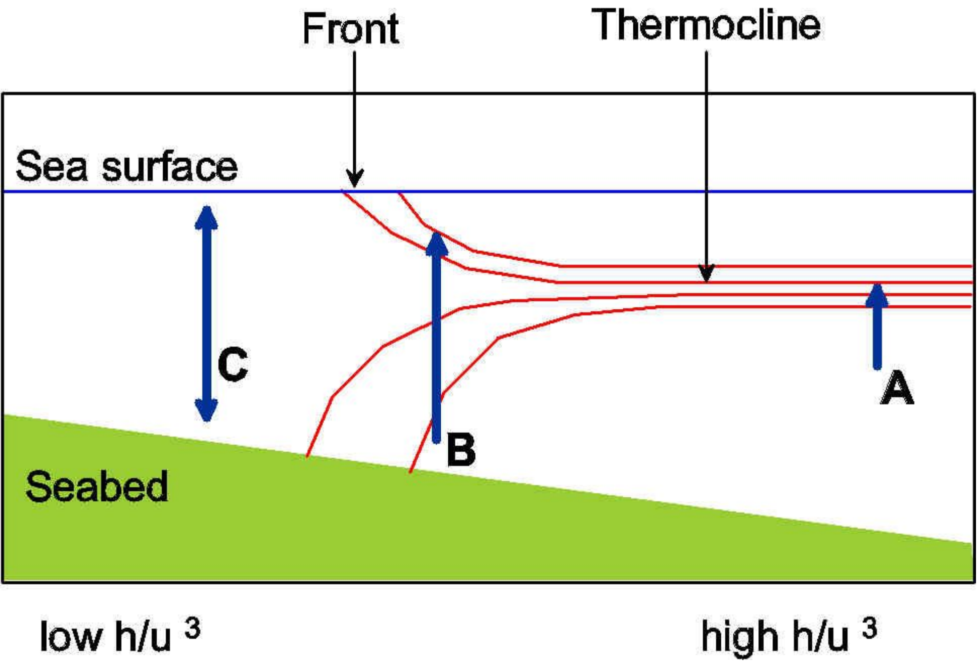
<u>Left:</u> Sketch of the stratification observed during summer; the thermocline splits on both sides of Bass Strait as a result of tidal mixing in shallow water.

<u>Centre</u>: log10(h/u3) calculated from a numerical tidal model.

<u>Right</u>: log10(Ep) calculated from the observed density field. The darkest regions are unstratified.



Sea surface temperature in the region of the Ouessant (Ushant) front along the French coast during neap tide (left) and during spring tide (right).



Schematic of thermal structure through tidal mixing front.

h/u3. , where **h** is the water column depth and **u** the amplitude of tidal currents

A represents the weak nutrient flux into the base of the thermocline on the stratified side of front. This flux supports production within the subsurface maximum, but production in the surface layer is nutrient limited.

Arrow **B** represents increased nutrient flux through the weaker stratification at the front potentially supporting the near-surface productivity at the front.

Arrow **C** represents the strong vertical nutrient exchange within the mixed water column. While this will maintain high nutrient concentrations through the depth, the same mixing continuously removes algae from the photic zone and so production will be light limited.

Tidal fronts

• Speed of tidal currents varies over lunar month (28 days) between spring and neap tides

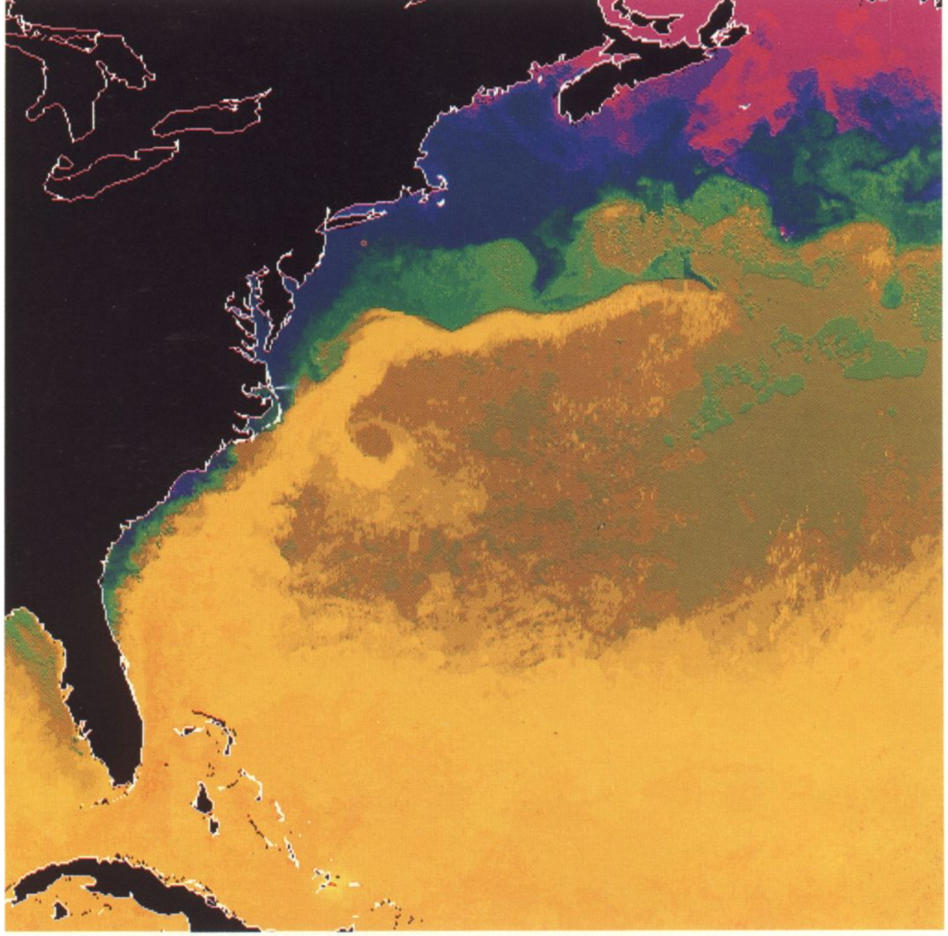
• As current speed increases the energy available for mixing increases, which causes the level of turbulence to increase.

• The depth of water where the turbulence is energetic enough to break down the stratification will increase >> boundary between the mixed and stratified water will move towards deeper water, decreasing the area of stratified water.

• When the tidal currents decrease, the turbulence declines and the front moves towards shallower water, allowing the area of stratified water to increase again.

• The newly stratified water behind the advancing front will contain nutrient levels characteristic of the previously mixed water.

Eddies

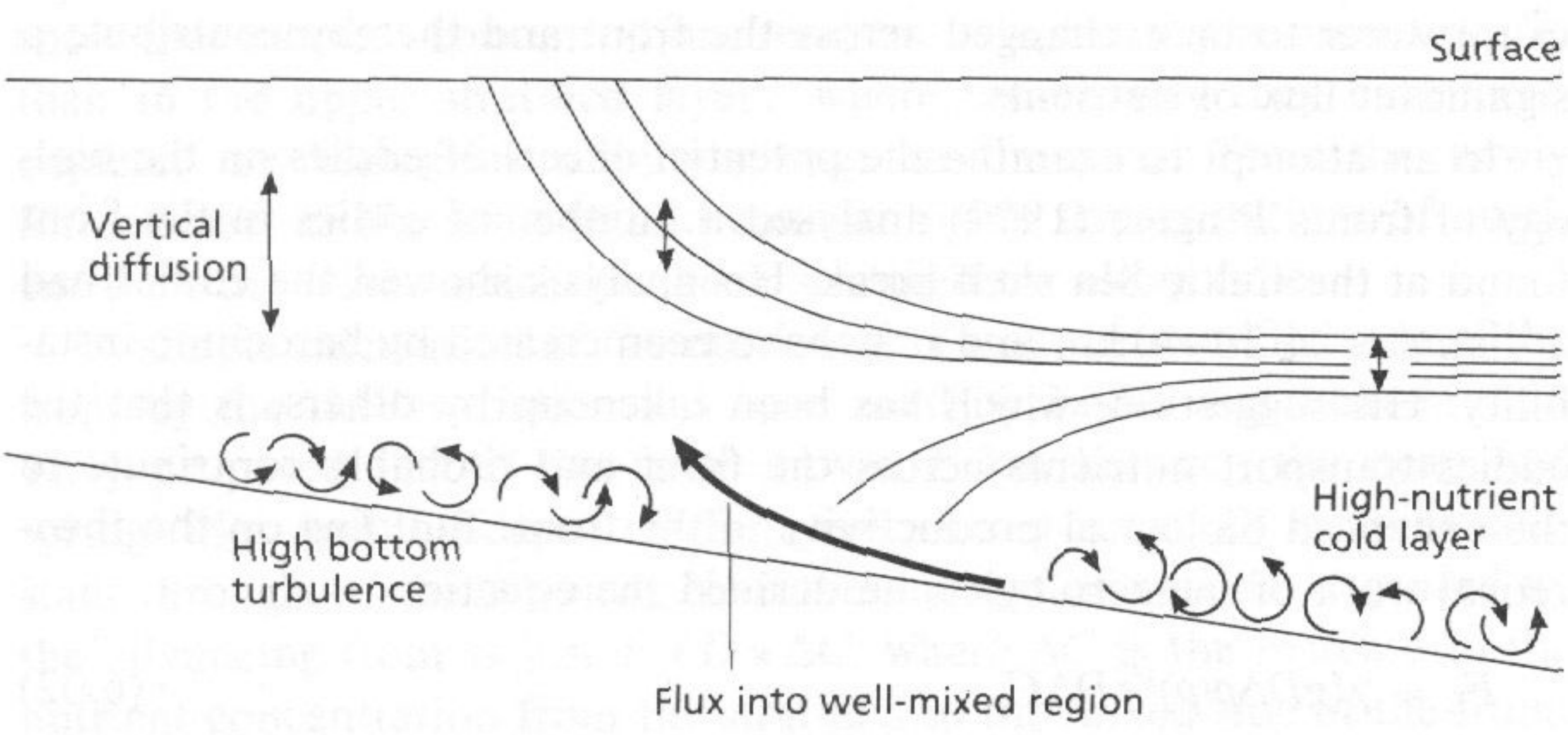


Irregularities often appear to be
eddies, which twist
the cold and warm water
together in a circular fashion.

Created by instabilities of the front, which allow small departures fron the geostrophic balance to grow at the expense of the potential and/or kinetic energy in the front.

Frontal eddies are of interest as it is often suggested that they cause water to be exchanged across the front and thereby contributing a significant flux of nutrients

Vertical eddy diffusion -transfer of dissolved materials-



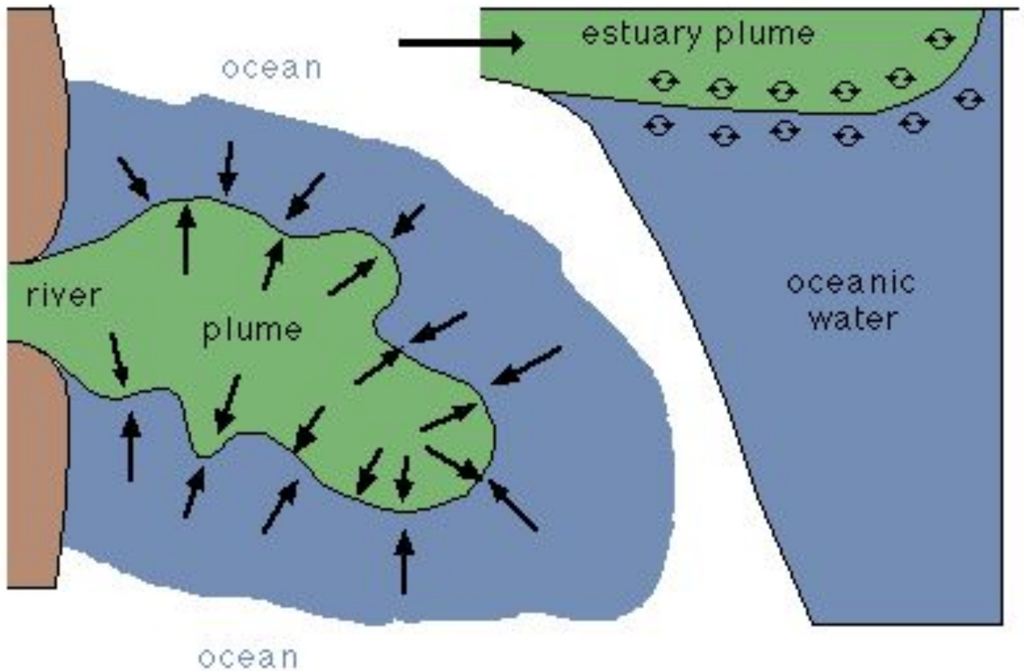
Density section through a tidally mixed front with vertical arrows indicating the increase in the rate of vertical eddy diffusion (low in the stratified side because vertical diffusion through the pycnocline is low and high in the well mixed side caused by tidal stirring) from the stratified side to the mixed cold, high-nutrient layer into the fullymixed
region.

Fronts in estuaries

1. Plume fronts

River and Estuarine-plume fronts

- Plume fronts form where relatively fresh water reaches the mouth region of an estuary and discharges into the oceanic environment.



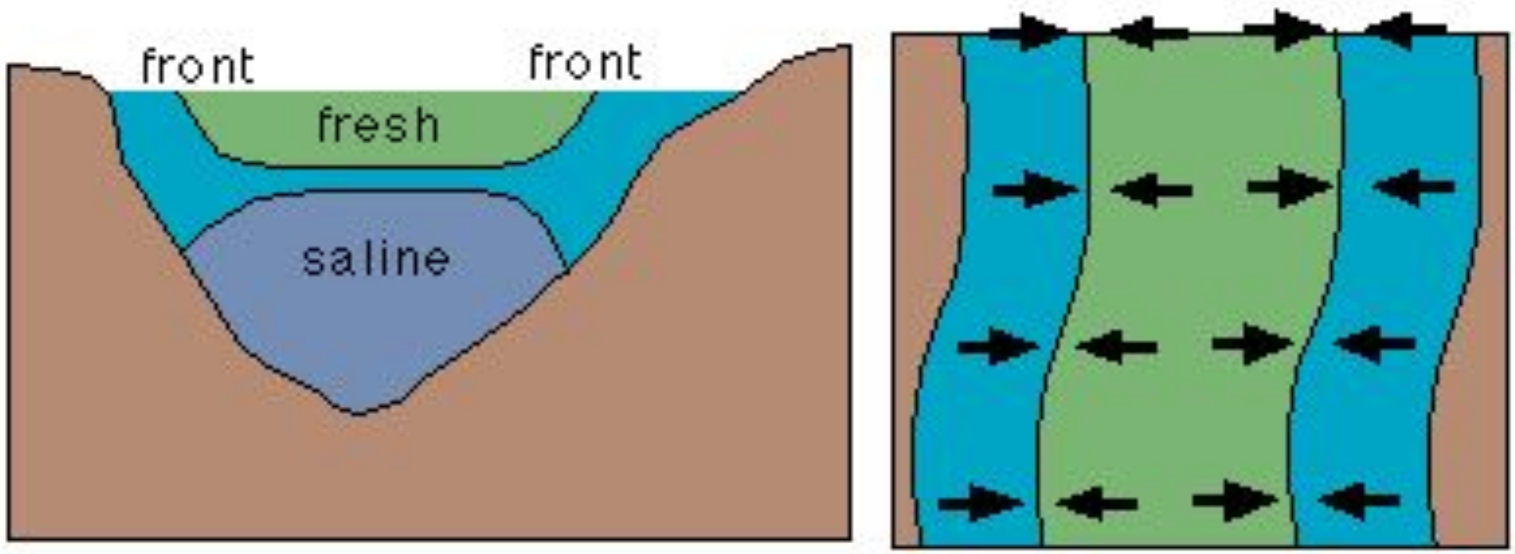
Sketch of a plume front.

Plume front extending beyond the estuary mouth. The front around the plume Is strongly convergent and turbulent. Here fresh water is absorbed into the oceanic environment. Plume fronts are often indicated by an accumulation of drifting material such as leaves or foam.

2. Estuarine fronts

Estuarine plume fronts are not restricted to the mouth of an estuary. They may run parallel to the banks of the estuary at some distance.

Dynamically they are a miniature version of the shallow sea front in the sense that tidal mixing competes against buoyancy generated stability of the water column, the difference being that in an estuary the stability is maintained by salinity rather than temperature.



Sketch of an estuarine front.

The left diagram is a vertical section showing the halocline between the fresh upper layer and the saline lower layer in the central part of the estuary and the front where the upper halocline reaches the surface.

The right diagram is a plan view, showing two fronts on either side of the estuary running parallel to the shore. Water movement is convergent at the fronts.