1. Tidal Mixing Front (Tidal Front)

- Solar radiation
- Warm
- Cold
- Current shear
- Mixing
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

\[ \frac{H}{U^3} \]  \textbf{(Simpson and Hunter, 1974)}

\begin{align*}
H & : \text{Water depth} \\
U & : \text{Mean tidal current velocity}
\end{align*}

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

\[
\log_{10} \frac{H}{D_t} = 1.9
\]
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.
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 $16L_R$ 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

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

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

$$Q_E = \gamma \Delta C \sqrt{gD\frac{\Delta P}{\rho}} = \gamma \Delta C \sqrt{gD}$$

where $\Delta C$ is the cross-frontal difference of nutrient concentration.
2. Nonlinear interaction between tidal currents

Lagrangian velocity: \( \vec{V}_L = \frac{\vec{X}_T - \vec{X}_o}{T} \)

\( T \): 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.
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.
5. Chaotic transport