Secondary Upwelling along the shelf break

Vincent Rossi, Yves Morel, Véronique Garçon
Typical summer situation:
Operations during MOUTON2007
Density

Chl a
A « PV thinking » approach of upwelling dynamics
POTENTIAL VORTICITY “thinking”

\( \zeta = \text{rot} (U) \) important quantity

BUT NOT CONSERVED

\[ \text{PV} = (\zeta + f) \cdot \vec{\nabla} \rho \quad (= (\zeta + f)/h) \]

is conserved for each particles if adiabatic motion

PV = TRACER

The velocity/stratification field can be reconstructed from the knowledge of PVA (if geostrophic balance is assumed)

INVERSION PRINCIPLE

\[ a) \]

Layer 1

Layer 2

Layer 3

Creation of PVA

Positive PVA

Negative PVA
Upwelling development

\[ PV = \text{cst} \Rightarrow \zeta = f \frac{h}{H_{\text{rest}}} + \text{geostrophy} \]

\[ \Rightarrow \text{« Kelvin » currents :} \]

\[ U = \sum_k U_k e^{-x/R_k} \]

At the coast \( V_{(x=0)} = 0 \)

\[ \Rightarrow \partial_t U = \tau \]

\[ \Rightarrow U_k = \tau_k t \]

Importance of barotropic mode (Ro ~ 500 km)
O’Brien & Hurlburt (1972)
Reference Numerical experiments
Configuration (2D)
PVA layer 3
Sensitivity studies

Bottom stress
Shelf width
margin slope
3D
Effect of the Bottom stress

\( C_d = 0 \) (ref) \hspace{2cm} \( C_d = 3 \cdot 10^{-3} \)

![Graphs showing the effect of bottom stress with time for different depth levels, comparing \( C_d = 0 \) and \( C_d = 3 \cdot 10^{-3} \).]
Effect of the bottom stress: competition between two processes

Acceleration of cross-shelf circulation

=> Enhances shelf upwelling

Modifies PVA in BBL (layer 3)

=> Diminishes PVA and shelf upwelling

\[
\frac{d\ PV_k}{dt} = \frac{1}{h_k} \text{rot}(\bar{\tau}_k/h_k)
\]

\[
\frac{d\ PV_k}{dt} = -\frac{1}{h_k} \partial_y(\tau_x/\rho h_k)
\]

\[
\approx -\frac{1}{h_k} \partial_y(-C_d\bar{u}\bar{u}/h_k)
\]

\[
= -\frac{1}{h_k} \partial_y(C_d u^2/h_k)
\]

Close to the shelf break, U and 1/h diminishes

=> \[
\frac{d\ PV_k}{dt} > 0
\]
PVA in layer 3

Cd = 3.10^{-3}

Cd = 0 (ref)
Effect of the continental shelf slope
Effect of the shelf width
More « realistic » (2 D) experiment (16 layers)

Observations
Conclusion

There exists shelf break upwellings along portuguese coasts

They can be explained by low PV advection from off-shore by the barotropic circulation developing on an extended shelf

Bottom friction:
- equilibrates the wind stress effect and the barotropic circulation
- accelerates the cross shore circulation (⇒ no steady state)
- diminishes the PVA (diabatic process) and the shelf break upwelling

3-D effects play an important role to limit velocity (not taken Into account here)

These results can be extended to downwelling winds