C-Vector for Identification of Oceanic Secondary Circulation Across Arctic Fronts in Fram Strait

Peter C Chu
Naval Postgraduate School
Monterey, California

Chu 2002 (GRL)
http://www.oc.nps.navy.mil/~chu
Secondary Circulation

• Ageotrophic

• Impact on Biological Productivity

• Various Scales

• Not Easy to Identify
Can the secondary circulation be identified from routine oceanography observation such as CTD?
Fram Strait and GIN Seas
Bottom Topography of Fram Strait and GIN Seas
Circulation in Fram Strait and GIN Seas
CTD Measurements on R/V Valdivia 54 3/11-4/11, 1987 (Quadfasel and Ungewiss)
Potential Density Excess Along the North Lag (~78.2°N) Cross-Section
Potential Density Excess Along the South Lag (~76.1-77.3°N) Cross-Section
What is the secondary circulation around the density fronts?
Geostrophic Balance

\[ f \frac{\partial u_g}{\partial z} = -\frac{\partial b}{\partial y}, \quad f \frac{\partial v_g}{\partial z} = \frac{\partial b}{\partial x}, \quad b = -g \frac{\hat{\rho}}{\rho_0} \]
Flow Decomposition

- $U = U_g + U_{ag}$
- $V = V_g + V_{ag}$
- $(U_{ag}, V_{ag}) \sim \text{Ageostrophic Velocity}$
Quasi-Geostrophic

\[-f v_{ag} = \frac{1}{\rho_0} \frac{\partial X}{\partial z} - \left( \frac{\partial}{\partial t} + V_g \cdot \nabla \right) u_g ,\]

\[f u_{ag} = \frac{1}{\rho_0} \frac{\partial Y}{\partial z} - \left( \frac{\partial}{\partial t} + V_g \cdot \nabla \right) v_g ,\]

\[N^2 w_{ag} = \frac{\partial B}{\partial z} - \left( \frac{\partial}{\partial t} + V_g \cdot \nabla \right) b ,\]
Pseudo-Vorticity (Xu 1992, JAS)

\[ \frac{\partial}{\partial y} (N^2 w_a) - \frac{\partial}{\partial z} (f^2 v_a) = 2C_x, \]

\[ \frac{\partial}{\partial z} (f^2 u_a) - \frac{\partial}{\partial x} (N^2 w_a) = 2C_y, \]

\[ \frac{\partial}{\partial x} (f^2 v_a) - \frac{\partial}{\partial y} (f^2 u_a) = 2C_z, \]
C-Vector

\[ C_x = -f \frac{\partial (u_g, v_g)}{\partial (y, z)} + \frac{1}{2} \frac{\partial}{\partial z} \left( f \frac{\partial X}{\partial z} + \frac{\partial B}{\partial y} \right), \]

\[ C_y = -f \frac{\partial (u_g, v_g)}{\partial (z, x)} + \frac{1}{2} \frac{\partial}{\partial z} \left( f \frac{\partial Y}{\partial z} - \frac{\partial B}{\partial x} \right), \]

\[ C_z = -f \frac{\partial (u_g, v_g)}{\partial (x, y)} - \frac{f}{2} \frac{\partial}{\partial z} \left( \frac{\partial X}{\partial x} + \frac{\partial Y}{\partial y} \right) - \frac{\beta}{2} \frac{\partial Y}{\partial z}, \]
C-Vector
Ageostrophic Vortex Line
C – Vector
Ageostrophic Vortex Line

![Diagram of C-vector and ageostrophic vortex line](image-url)
Turbulent Momentum & Buoyancy Fluxes (Mixed Layer Model)

\[(X,Y) = (\tau_x, \tau_y) + [(\tau_x, \tau_y) - (X,Y)_{-h}\frac{z}{h}]\]

\[B = B_0 + (B_0 - B_{-h})\frac{z}{h},\quad \text{for } z > -h,\]

\[(X, Y, B) \approx 0 \quad \text{for } z < -h,\]

\[
\frac{\partial^2 X}{\partial z^2} = 0, \quad \frac{\partial^2 Y}{\partial z^2} = 0,
\]
$C_x / f^2$ Along the North Cross-Section in Fram Strait
Potential Density Excess Along the North Lag (~78.2°N) Cross-Section
C-Vector for Large-Scale Secondary Circulations (Thermohaline Circulation)

\[ C_x = -f \frac{\partial (u_g, v_g)}{\partial (y, z)} + \frac{1}{2} \frac{\partial}{\partial z} \left( \frac{\partial B}{\partial y} \right), \]

\[ C_y = -f \frac{\partial (u_g, v_g)}{\partial (z, x)} - \frac{1}{2} \frac{\partial}{\partial z} \left( \frac{\partial B}{\partial x} \right), \]
Turbulent Buoyancy Flux Neglected

\[ \frac{\partial}{\partial z} \left( \frac{\partial B}{\partial y} \right) = 0, \quad \frac{\partial}{\partial z} \left( \frac{\partial B}{\partial x} \right) = 0, \]
Conveyor Belt

Figure I-8: A two-layer thermohaline conveyor belt summary taken schematically from Broecker (1987, 1991) by Schmitz (1995).
Use of NODC T, S Data

(Levitus 1994)

This downward motion is the major sinking of the "great ocean conveyor belt".

$C_x$ (in $10^{-2}$) values in the $30^\circ W$ meridional cross section.
Conclusion

• C-Vector - an effective method to identify vertical circulation such as secondary circulation and thermohaline circulation.