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

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Chu 2002 (GRL)
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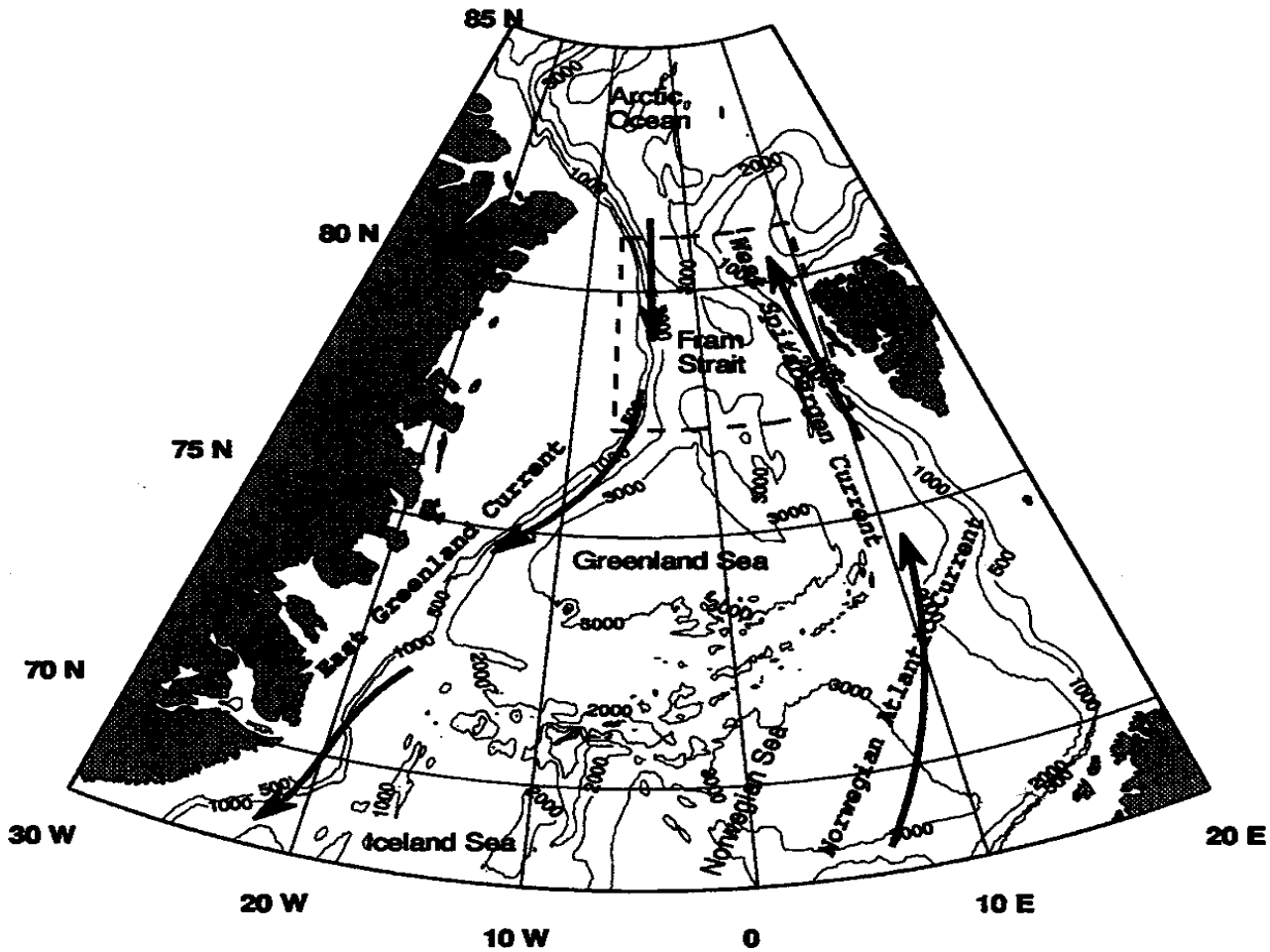
Secondary Circulation

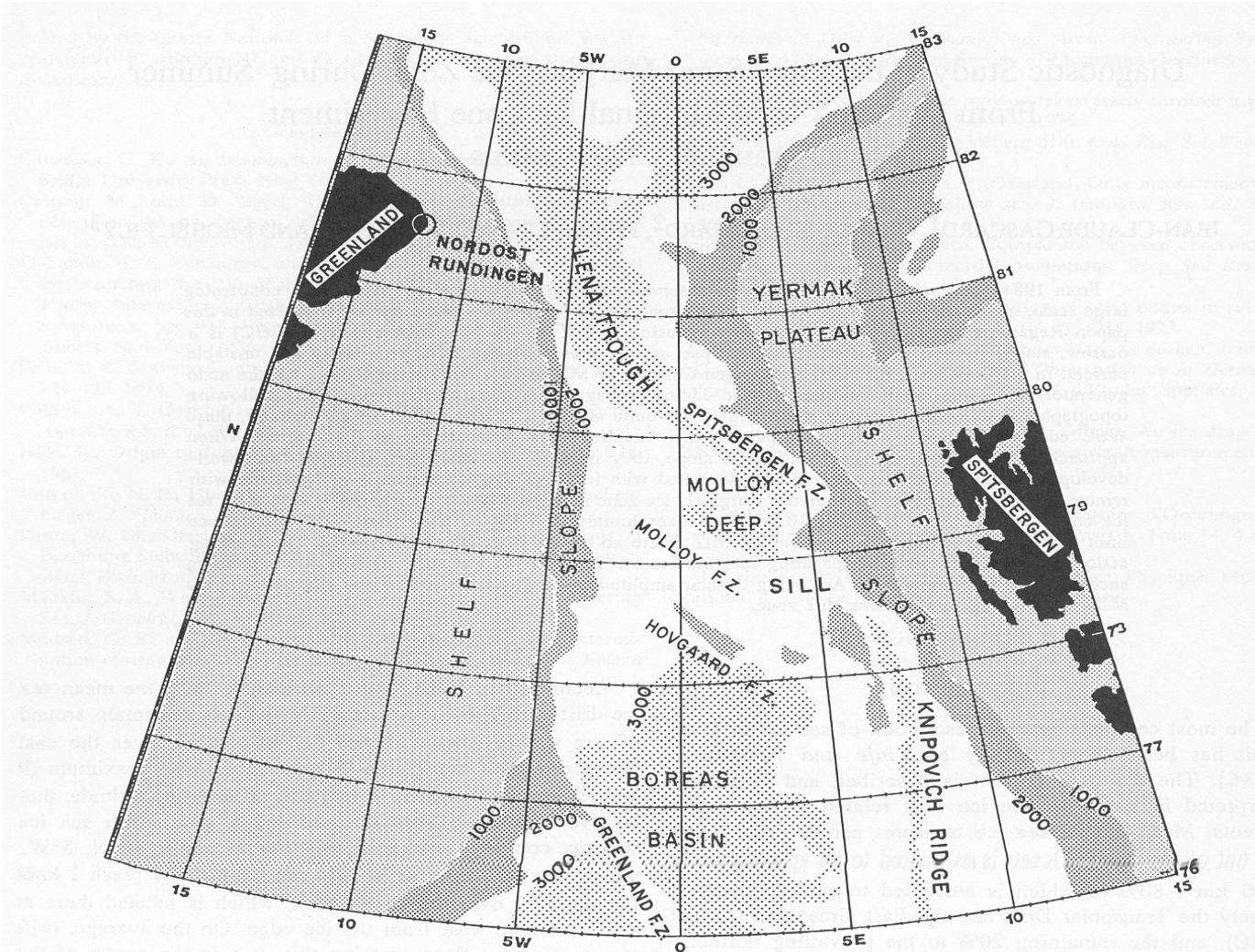
- Ageotrophic
- Impact on Biological Productivity
- Various Scales
- Not Easy to Identify

Can the secondary circulation be identified from routine oceanography observation such as CTD?

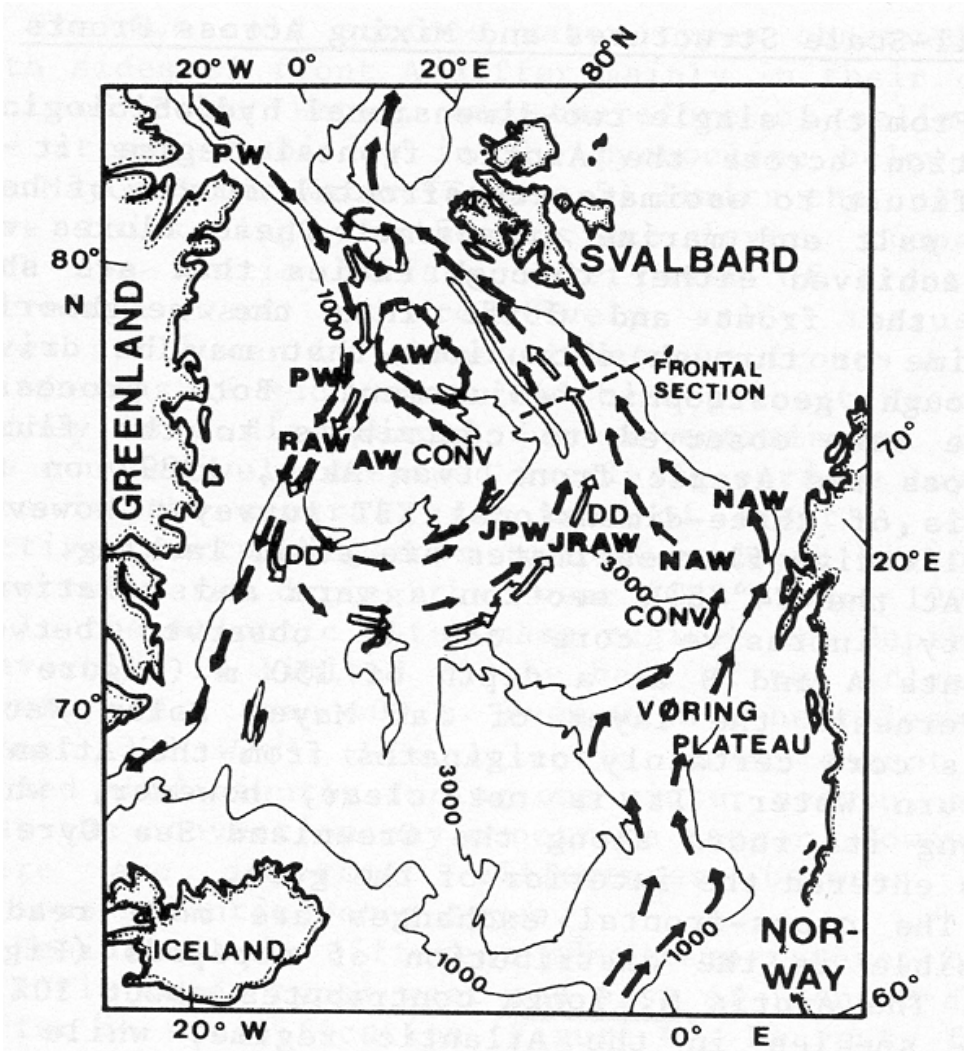
Fram Strait and GIN Seas



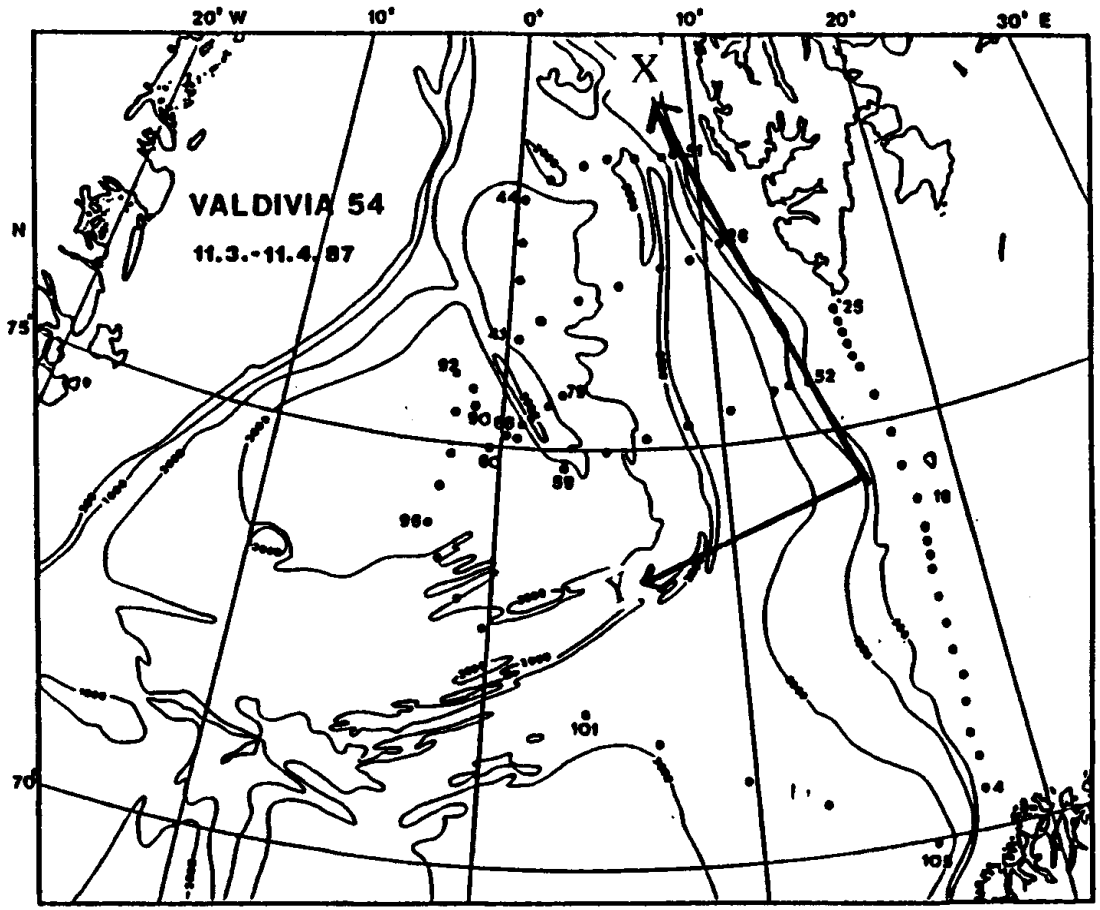
Bottom Topography of Fram Strait and GIN Seas

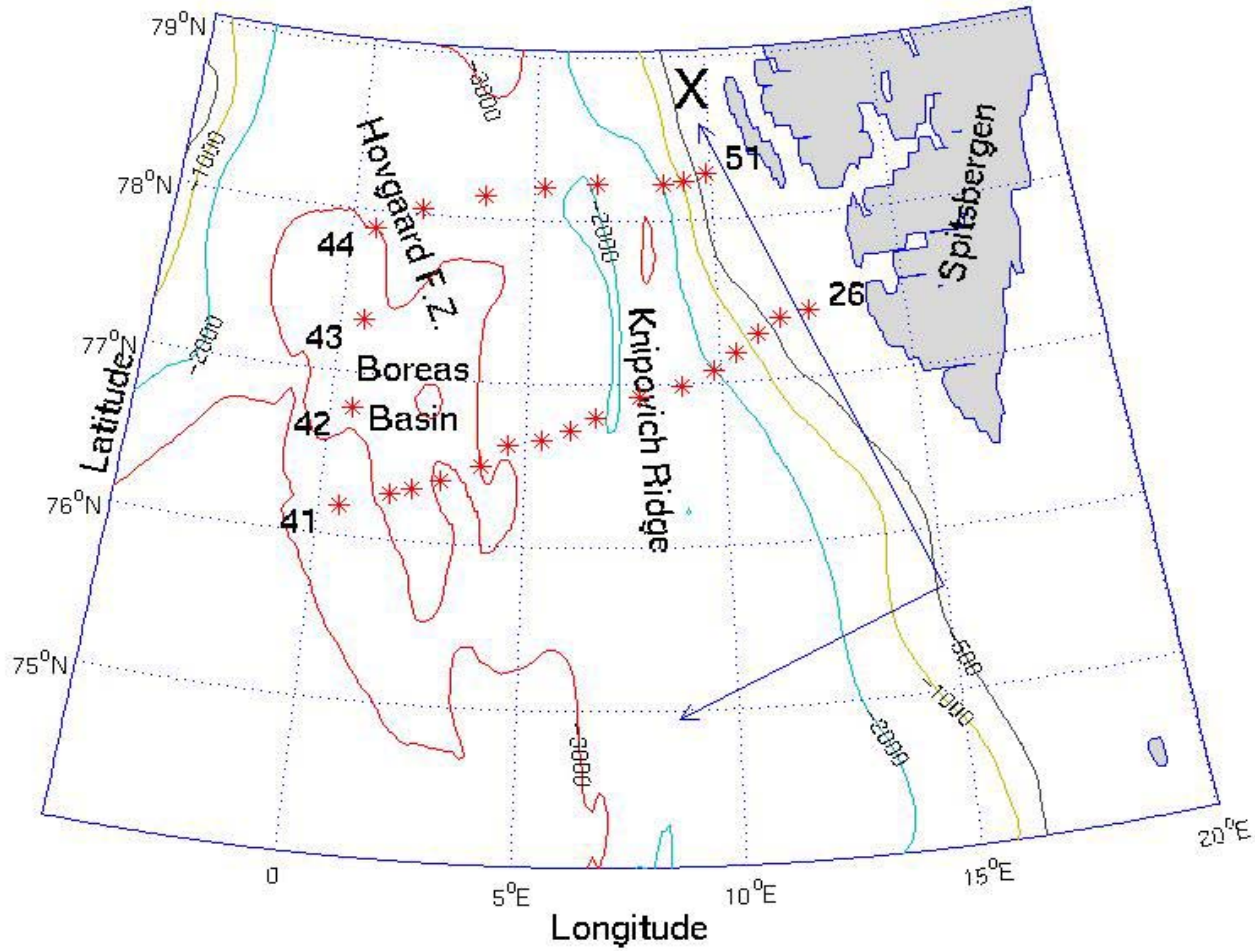


Circulation in Fram Strait and GIN Seas

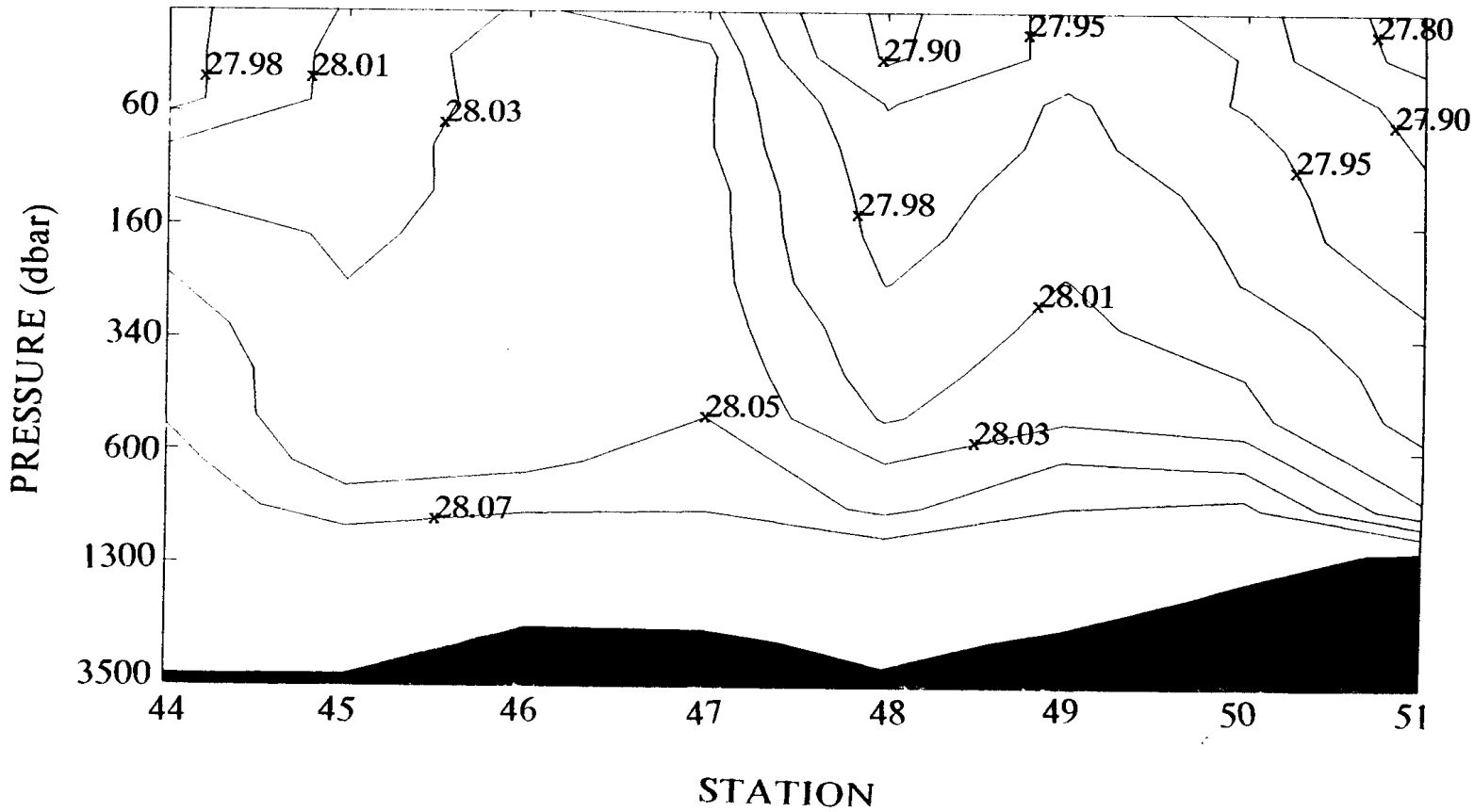


CTD Measurements on R/V Valdivia 54 3/11-4/11, 1987 (Quadfasel and Ungewiss)

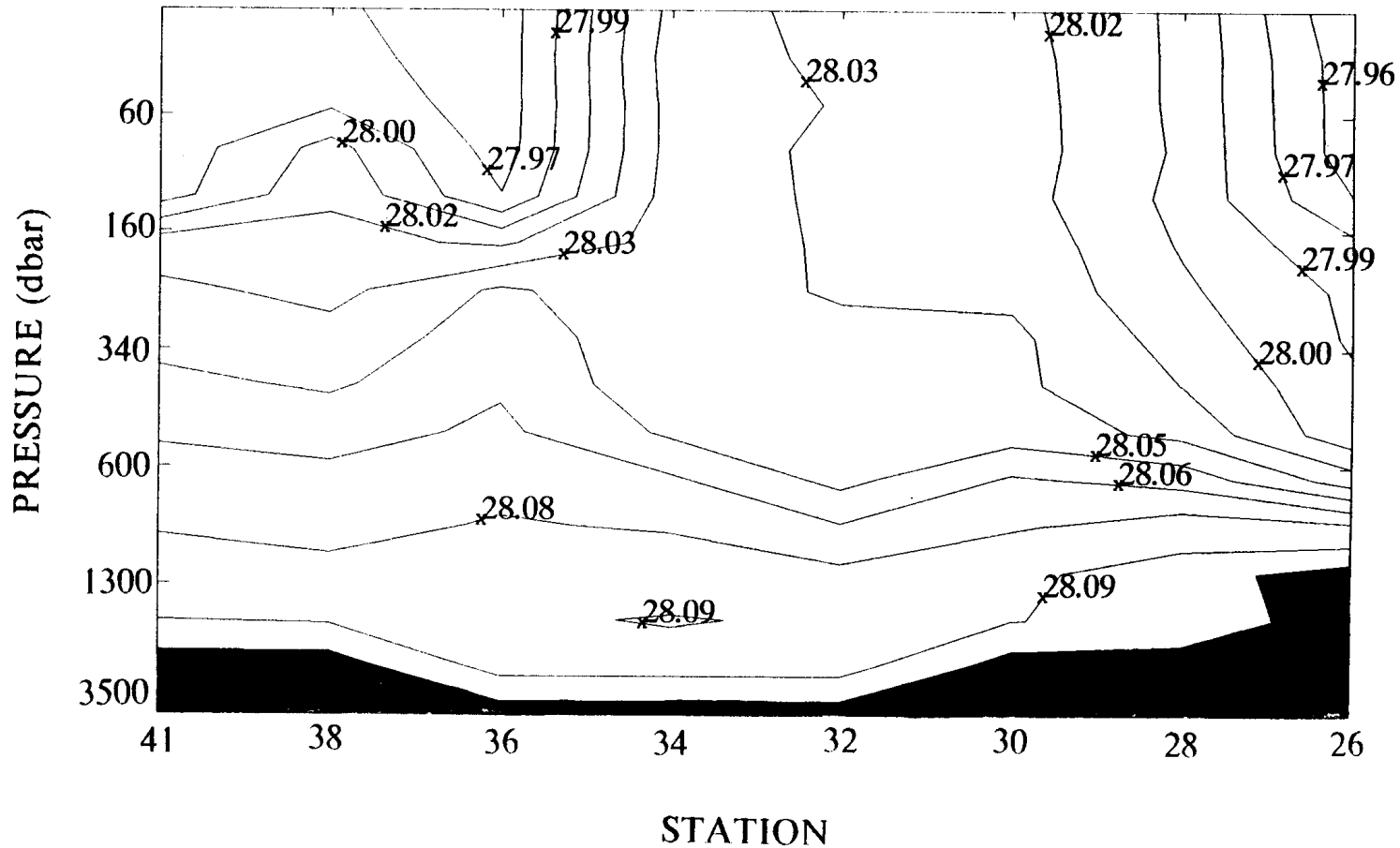



79°N
78°N
77°N
76°N
75°N
Latitude
0
5°E
10°E
15°E
20°E
Longitude
Hovgaard F.Z.
Knipovich Ridge
Boreas
Basin
Spitsbergen
X
51
26
44
43
42
41
-3000
-2000
-1000
-500
-2000
-3000
-2000
-1000
-500

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

$$f\frac{\partial u_g}{\partial z} = -\frac{\partial b}{\partial y}, \qquad f\frac{\partial v_g}{\partial z} = \frac{\partial b}{\partial x}, \qquad b = -g\frac{\hat{\rho}}{\rho_0}$$

Flow Decomposition

- $U = Ug + Uag$
- $V = Vg + Vag$
- $(Uag, Vag) \sim$ Ageostrophic Velocity

Quasi-Geostrophic

$$-fv_{ag} = \frac{1}{\rho_0}\frac{\partial X}{\partial z} - (\frac{\partial}{\partial t} + \mathbf{V}_g \bullet \nabla) u_g ,$$

$$fu_{ag} = \frac{1}{\rho_0}\frac{\partial Y}{\partial z} - (\frac{\partial}{\partial t} + \mathbf{V}_g \bullet \nabla) v_g ,$$

$$N^2 w_{ag} = \frac{\partial B}{\partial z} - (\frac{\partial}{\partial t} + \mathbf{V}_g \bullet \nabla) b ,$$

Pseudo-Vorticity (Xu 1992, JAS)

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

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

$$\frac{\partial}{\partial x}(f^2 v_a) - \frac{\partial}{\partial y}(f^2 u_a) = 2C_z,$$

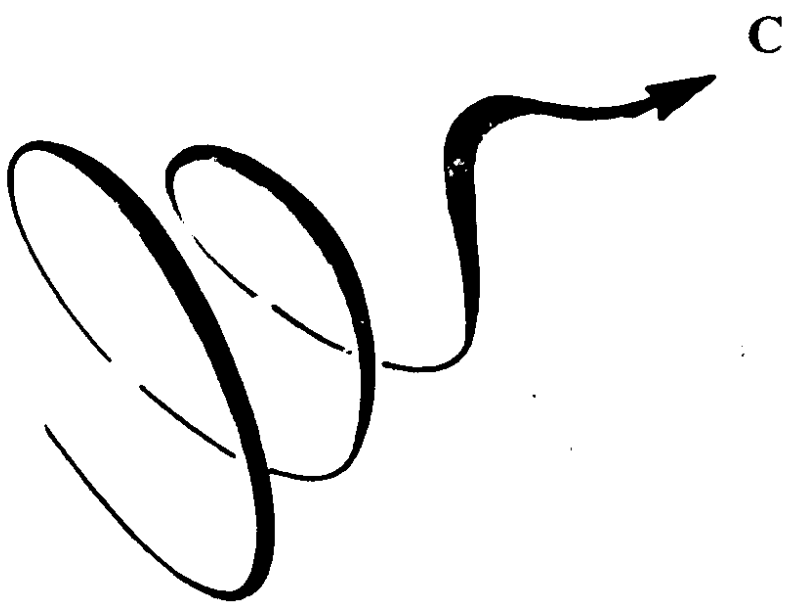
C-Vector

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

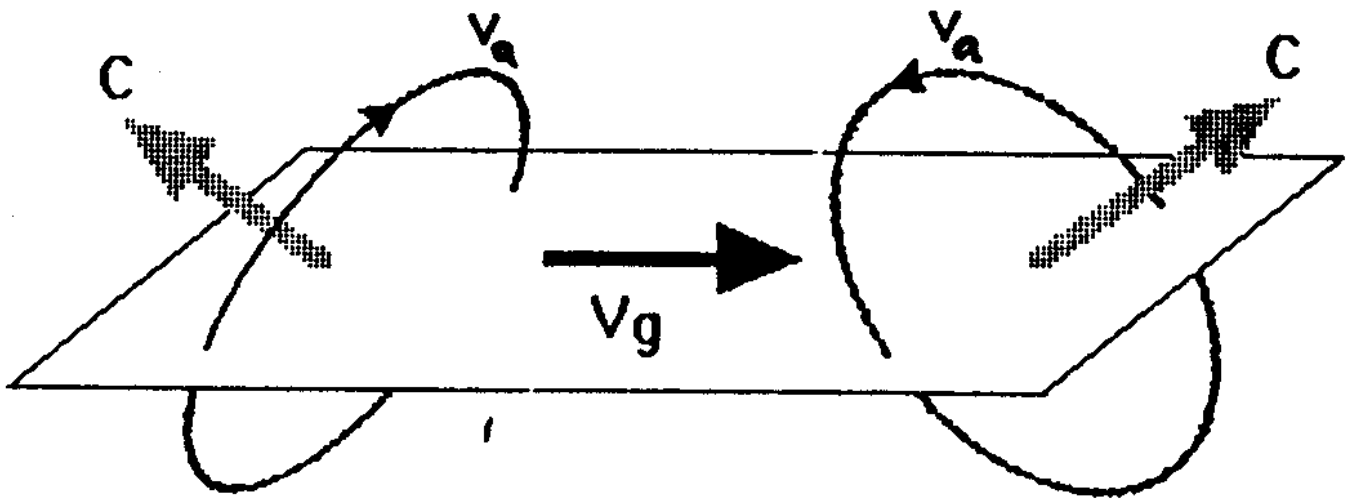
$$C_y = -f\frac{\partial(u_g, v_g)}{\partial(z,x)} + \frac{1}{2}\frac{\partial}{\partial z}\left(f\frac{\partial Y}{\partial z} - \frac{\partial B}{\partial x}\right),$$

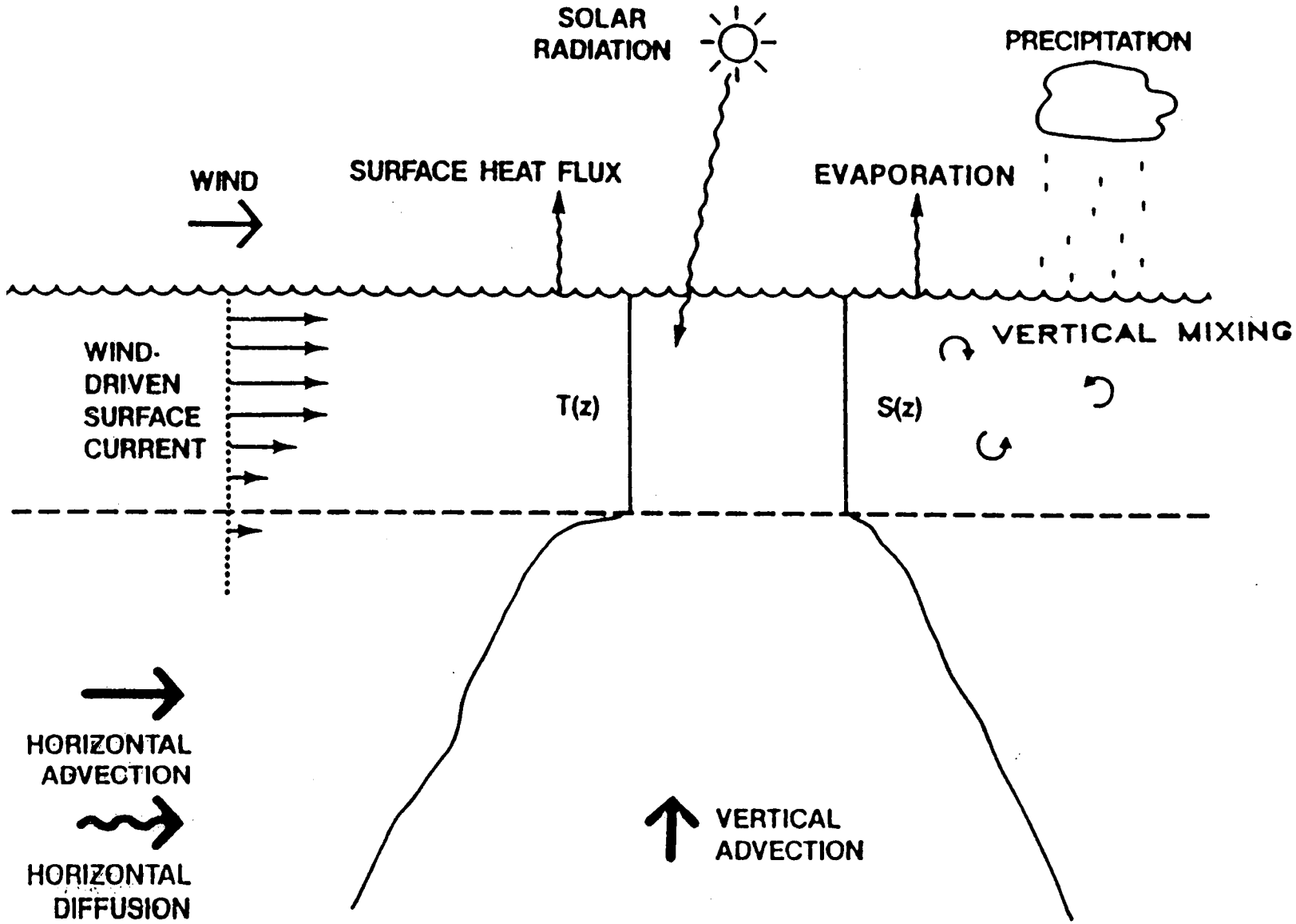
$$C_z = -f\frac{\partial(u_g, v_g)}{\partial(x,y)} - \frac{f}{2}\frac{\partial}{\partial z}\left(\frac{\partial X}{\partial x} + \frac{\partial Y}{\partial y}\right) - \frac{\beta}{2}\frac{\partial Y}{\partial z},$$

C-Vector
Ageostrophic Vortex Line



C –Vector
Ageostrophic Vortex Line




SOLAR
RADIATION
PRECIPITATION
WIND
SURFACE HEAT FLUX
EVAPORATION
VERTICAL MIXING
WIND-
DRIVEN
SURFACE
CURRENT
T(z)
S(z)
HORIZONTAL
ADVECTION
HORIZONTAL
DIFFUSION
VERTICAL
ADVECTION

Turbulent Momentum & Buoyancy Fluxes (Mixed Layer Model)

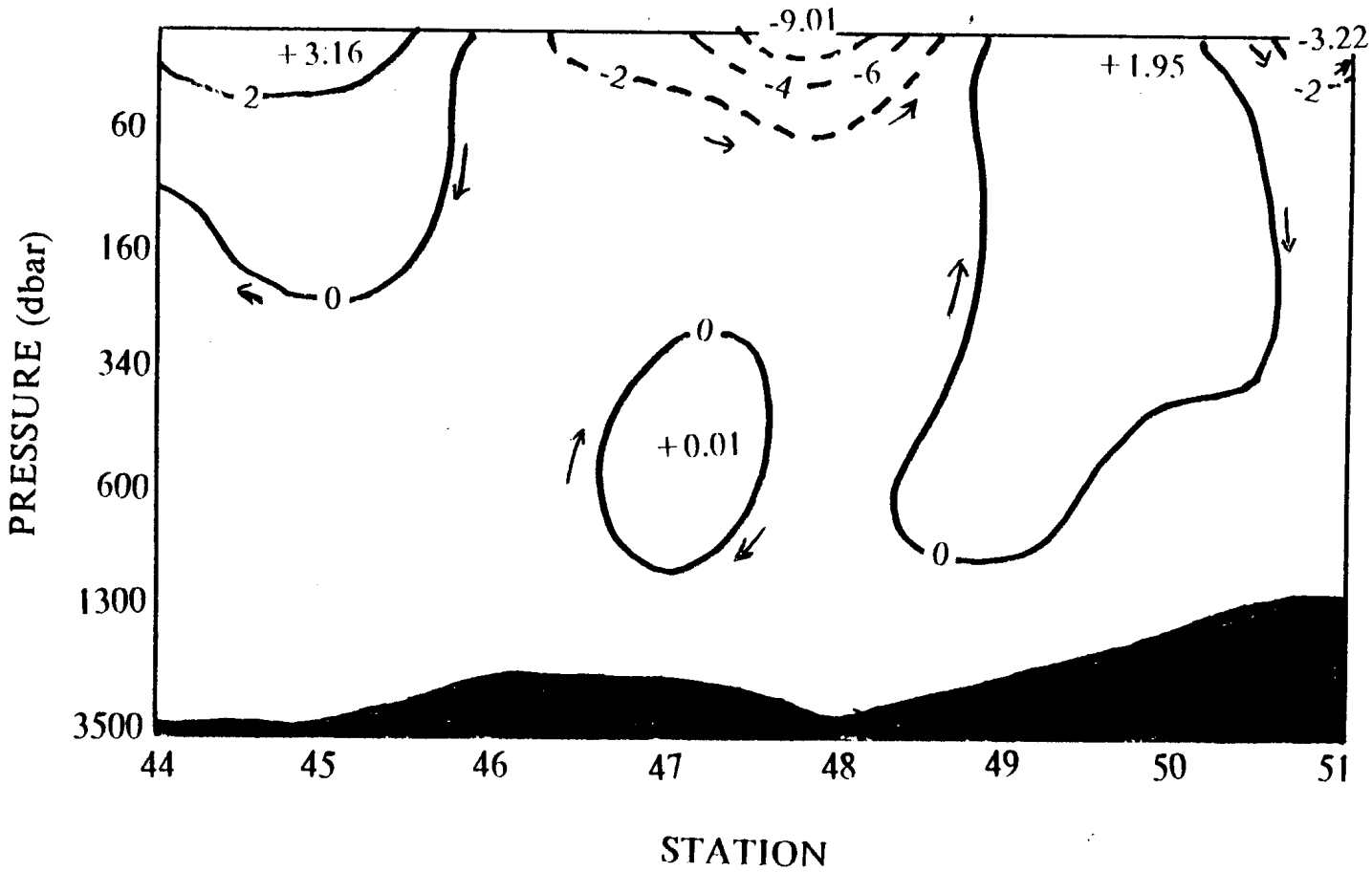
$$(X,Y) = (\tau_x,\tau_y) + [(\tau_x,\tau_y) - (X,Y)_{-h}\frac{z}{h}],$$

$$B = B_0 + (B_0 - B_{-h})\frac{z}{h}, \qquad \text{for } z > -h,$$

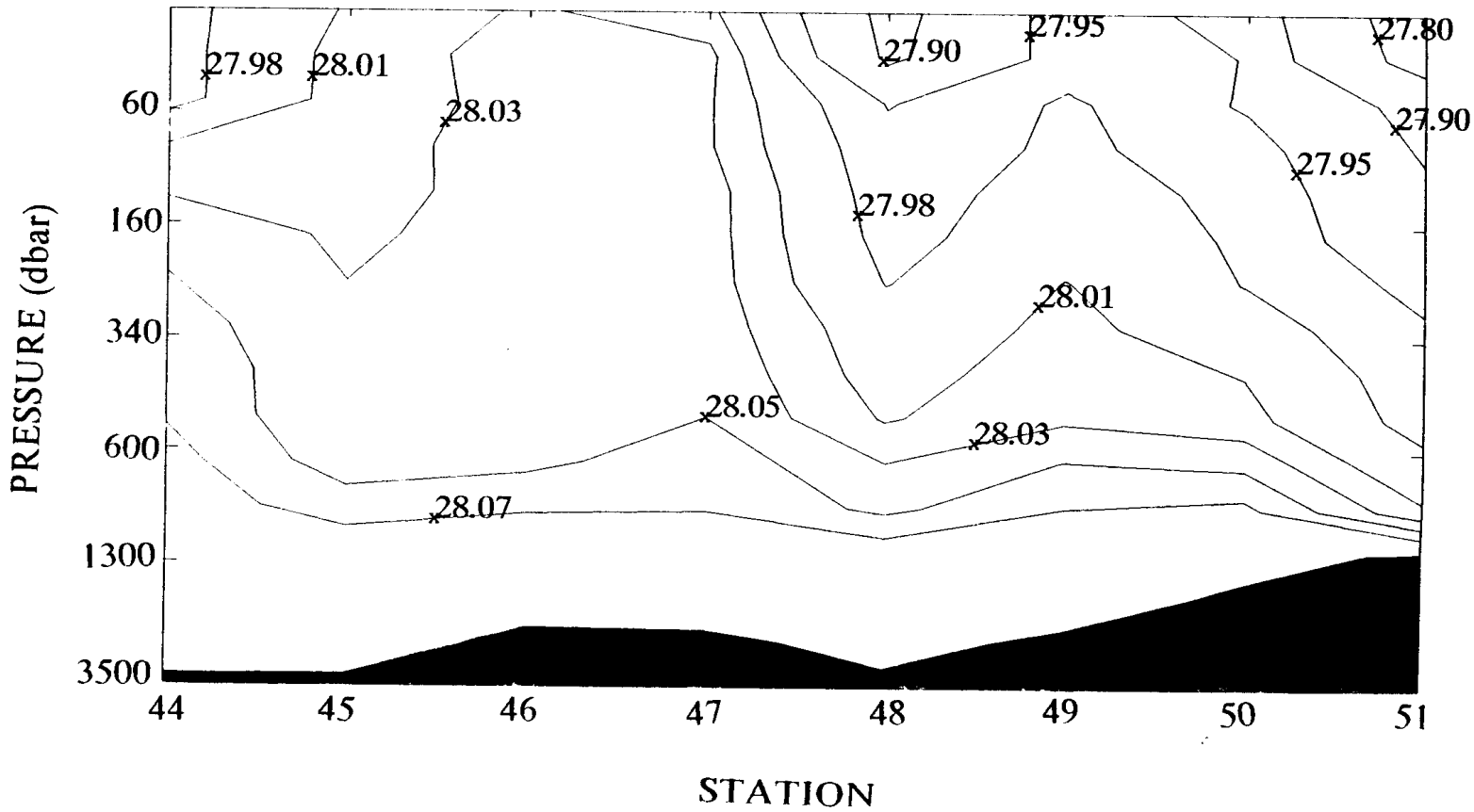
$$(X, Y, B) \simeq 0 \qquad \text{for } z < -h,$$

$$\frac{\partial^2 X}{\partial z^2} = 0, \quad \frac{\partial^2 Y}{\partial z^2} = 0,$$

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

$$\frac{\partial}{\partial z}\left(\frac{\partial B}{\partial y}\right) = 0, \qquad \frac{\partial}{\partial z}\left(\frac{\partial B}{\partial x}\right) = 0,$$

Conveyor Belt

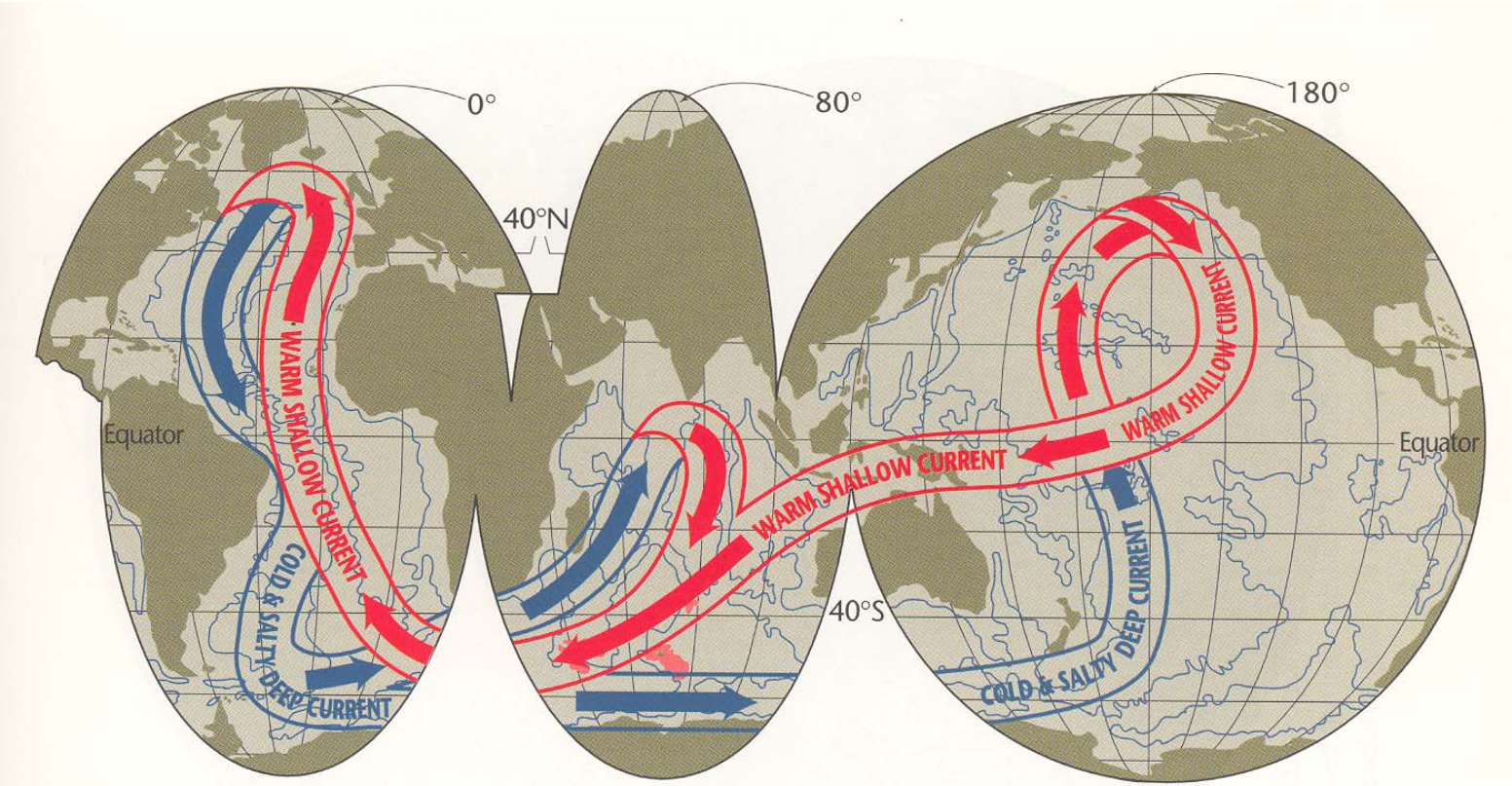
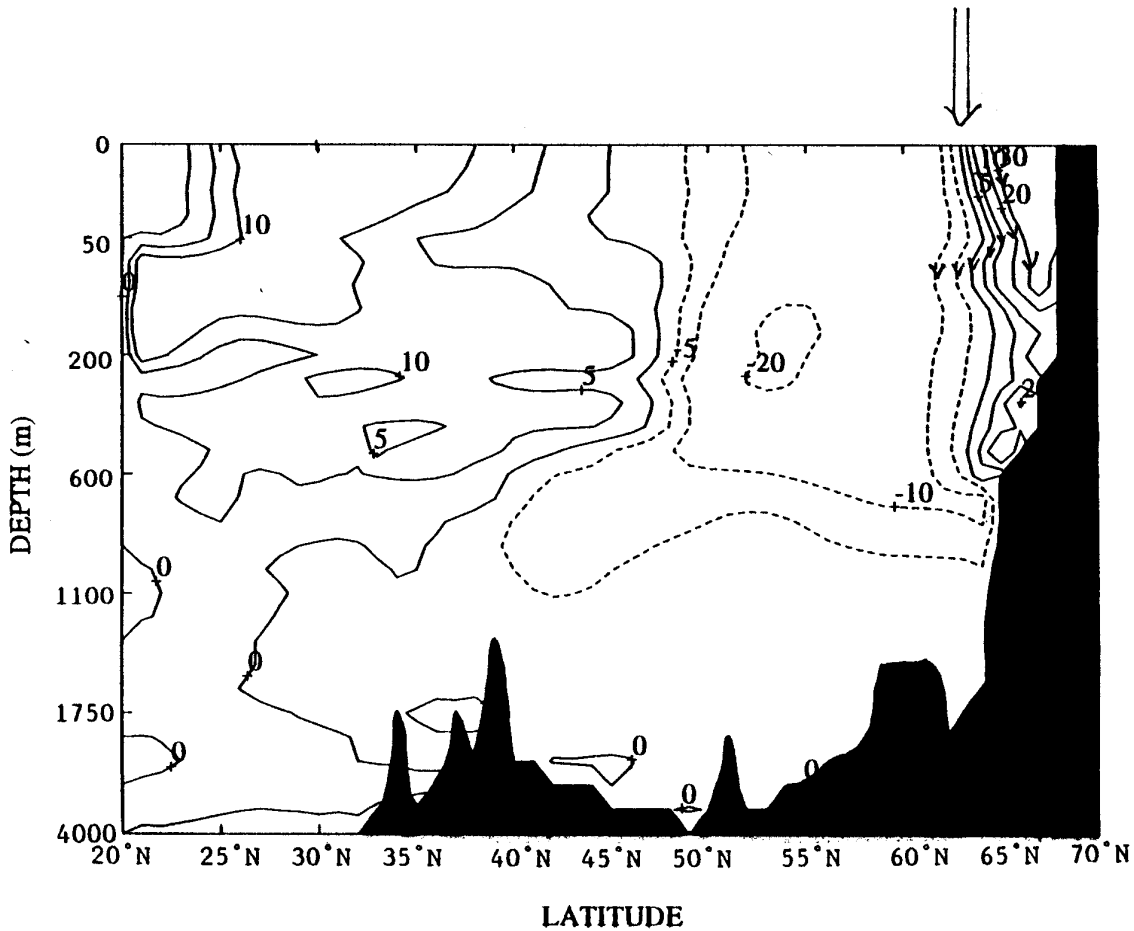


Figure I-8: A two-layer thermohaline conveyor belt summary taken schematically from Broecker (1987, 1991) by Schmitz (1995).

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

Use of NODC T, S Data

(Levitus 1994)



C_x (in 10^{-2}) values in the 30°W meridional cross section.

Conclusion

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