P-Vector Method for Determining Arctic Ocean Circulation from the Joint US-Russian Hydrographic Data

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References

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Motivation

- Improving the weakness of diagnostic initialization

- Numerical model is usually integrated from
  (T, S) field (climatology or …)
  $u = v = w = 0$

Diagnostic Initialization

Basic Equations for OGCM

$$\frac{\partial \mathbf{V}}{\partial t} = -\mathbf{V} \bullet \nabla \mathbf{V} - w\frac{\partial \mathbf{V}}{\partial z} - \mathbf{k} \times f\mathbf{V} - \frac{1}{\rho}\nabla p + \frac{\partial}{\partial z}(K_M \frac{\partial \mathbf{V}}{\partial z}) + \mathbf{H}_\mathbf{V}$$

$$\frac{\partial T}{\partial t} = -\mathbf{V} \bullet \nabla T - w\frac{\partial T}{\partial z} + \frac{\partial}{\partial z}(K_H \frac{\partial T}{\partial z}) + H_T\,,$$

$$\frac{\partial S}{\partial t} = -\mathbf{V} \bullet \nabla S - w\frac{\partial S}{\partial z} + \frac{\partial}{\partial z}(K_H \frac{\partial S}{\partial z}) + H_S\,,$$

Diagnostic Initialization

$$\frac{\partial T}{\partial t} = -\mathbf{V} \bullet \nabla T - w\frac{\partial T}{\partial z} + \frac{\partial}{\partial z}(K_H \frac{\partial T}{\partial z}) + H_T + F_T ,$$

- Keep (T, S) constai

$$\frac{\partial S}{\partial t} = -\mathbf{V} \bullet \nabla S - w\frac{\partial S}{\partial z} + \frac{\partial}{\partial z}(K_H \frac{\partial S}{\partial z}) + H_S + F_S ,$$

- Generate (u, v, w) fields

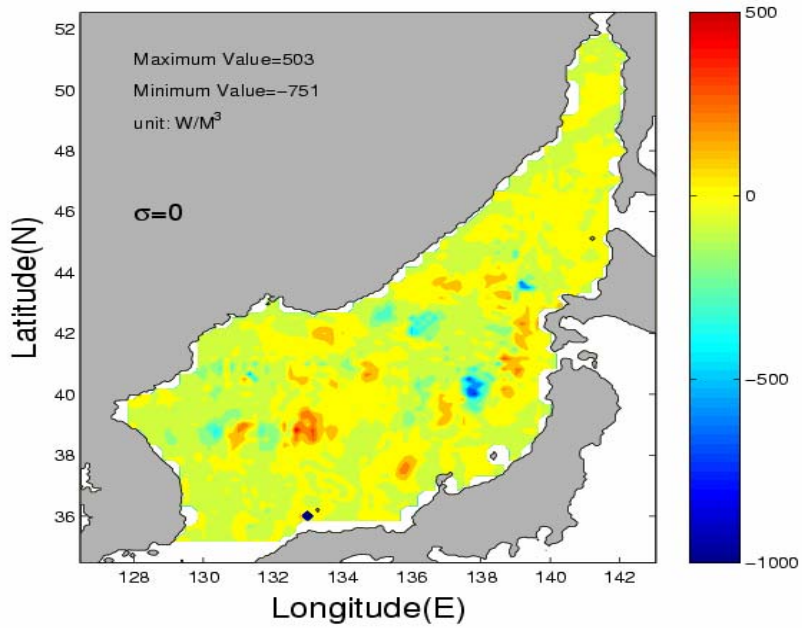
$$\frac{\partial T}{\partial t} = 0, \quad \frac{\partial S}{\partial t} = 0$$

Extremely Strong Thermohaline Source/Sink Terms (Non-Physical)

$$F_T \equiv \mathbf{V} \bullet \nabla T + w\frac{\partial T}{\partial z} - \frac{\partial}{\partial z}(K_H \frac{\partial T}{\partial z}) - H_T,$$

$$F_S \equiv \mathbf{V} \bullet \nabla S + w\frac{\partial S}{\partial z} - \frac{\partial}{\partial z}(K_H \frac{\partial S}{\partial z}) - H_S.$$

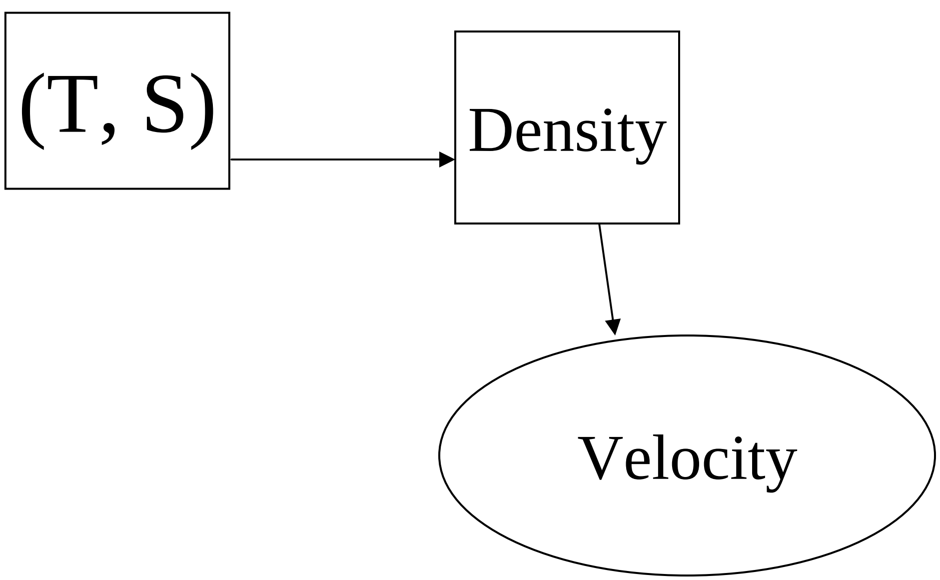
Chu, P.C., and J. Lan, 2003: Extremely strong thermohaline source/sinks generated by diagnostic initialization. Geophysical Research Letters, 30 (6), doi: 10.1029/2002GL016525



Maximum Value=503
Minimum Value=−751
unit: W/M3
σ=0
Latitude(N)
Longitude(E)
52
50
48
46
44
42
40
38
36
128
130
132
134
136
138
140
142
500
0
−500
−1000

Geostrophic Initialization

- Absolute geostrophic velocity computed from hydrographic data



First Thought - Thermal Wind Relation

$$u = u_0 + \frac{g}{f\rho_0}\int_{z_0}^{z} \frac{\partial \rho}{\partial y}\, dz'$$

$$v = v_0 - \frac{g}{f\rho_0}\int_{z_0}^{z} \frac{\partial \rho}{\partial x}\, dz'$$

How to determine (u_0, v_0) ?

Conservation of Mass and Potential Vorticity

$$\mathbf{V} \cdot \nabla\rho = 0$$

$$\boxed{\vec{V} \bullet \nabla q = 0, \qquad q \equiv f\frac{\partial \rho}{\partial z}}$$

Relationship Among Three Vectors

$$\vec{V} \perp \nabla \rho \qquad \vec{V} \perp \nabla q$$

$$\vec{V} \sim \nabla q \times \nabla \rho$$

P-Vector

$$\vec{P} = \frac{\nabla q \times \nabla \rho}{|\nabla q \times \nabla \rho|}$$

$$\vec{P} \quad // \quad \vec{V}$$

$$\vec{V} = r(\lambda, \phi, z)\vec{P}$$

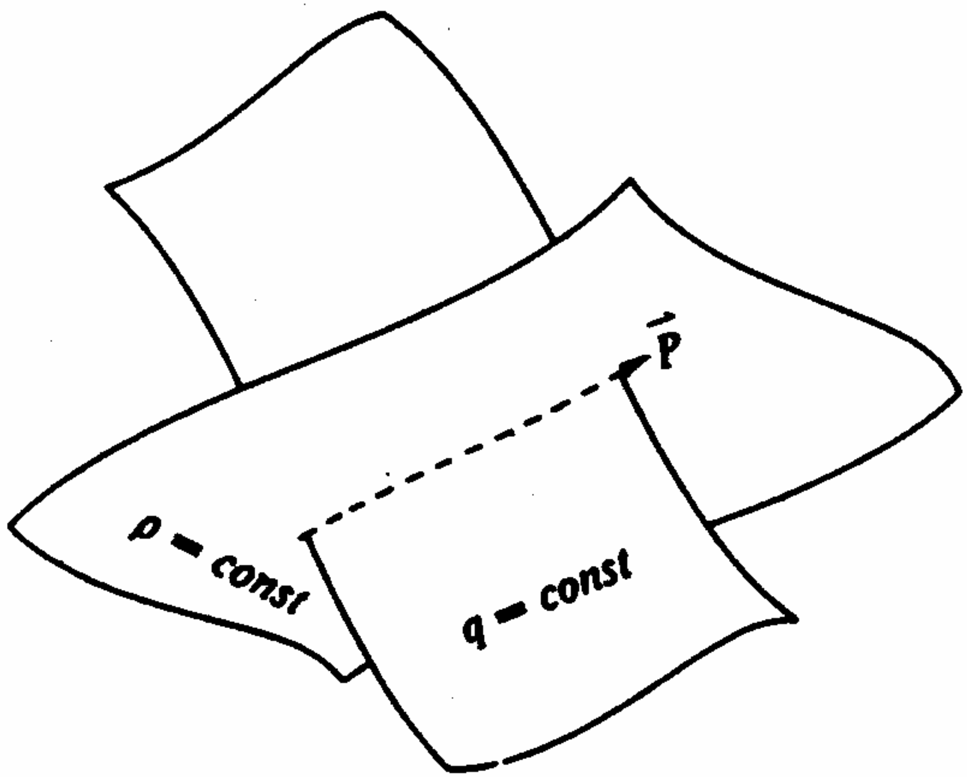
Two-Step Inverse Method

(1) Density determines the P-vector.

(2) Thermal wind relation determines γ.

P-Vector

Intersection of density and potential vorticity surfaces



Thermal Wind Relation Determines γ

$$r^{(k)} P_x^{(k)} - r^{(m)} P_x^{(m)} = \Delta u_{km}$$

$$r^{(k)} P_y^{(k)} - r^{(m)} P_y^{(m)} = \Delta v_{km}$$

$$\Delta u_{km} \equiv \frac{g}{f\rho_0} \int_{z_m}^{z_k} \frac{\partial \rho}{\partial y} \, dz'$$

$$\Delta v_{km} \equiv -\frac{g}{f\rho_0} \int_{z_m}^{z_k} \frac{\partial \rho}{\partial x} \, dz'$$

Solution of γ

$$r^{(k)} = \frac{\begin{vmatrix} \Delta u_{km} & P_x^{(m)} \\ \Delta v_{km} & P_y^{(m)} \end{vmatrix}}{\sin(\alpha_{km})}$$

$$\begin{vmatrix} P_x^{(k)} & P_x^{(m)} \\ P_y^{(k)} & P_y^{(m)} \end{vmatrix} = \sin(\alpha_{km})$$

$$\alpha_{km} \neq 0$$

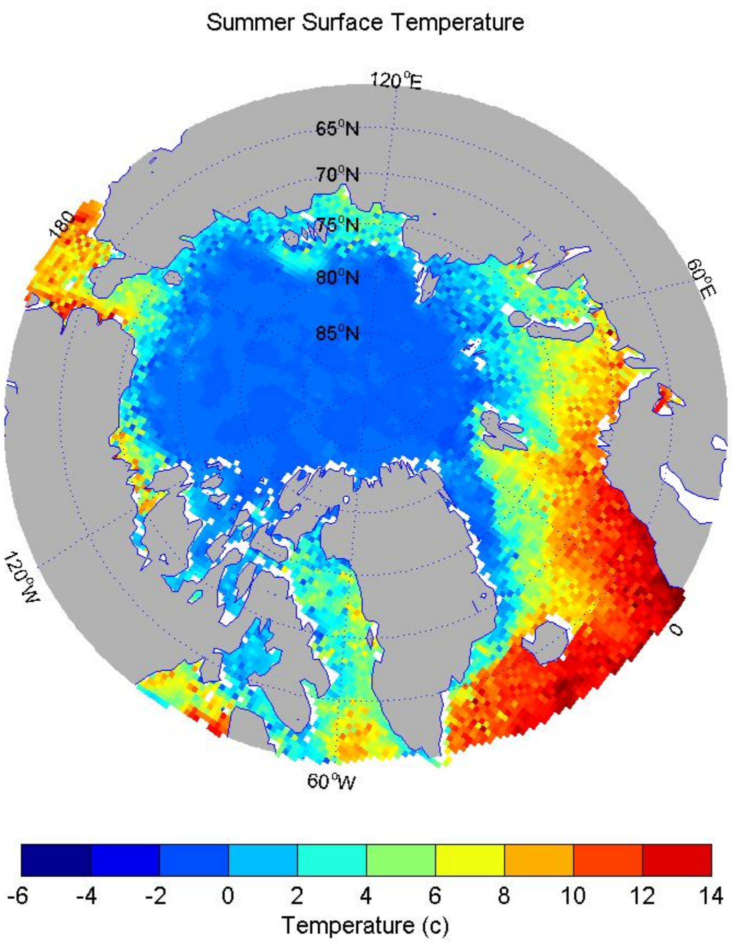
US-Russian Arctic Hydrographic Data

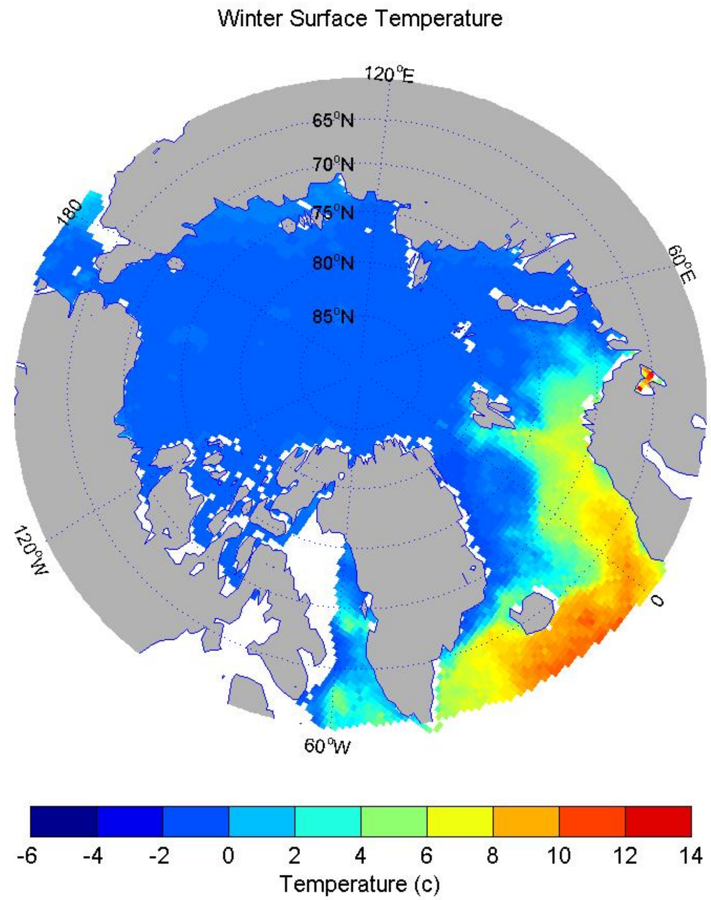
National Snow and Ice Data Center

SUPPORTING CRYOSPHERIC RESEARCH SINCE 1976

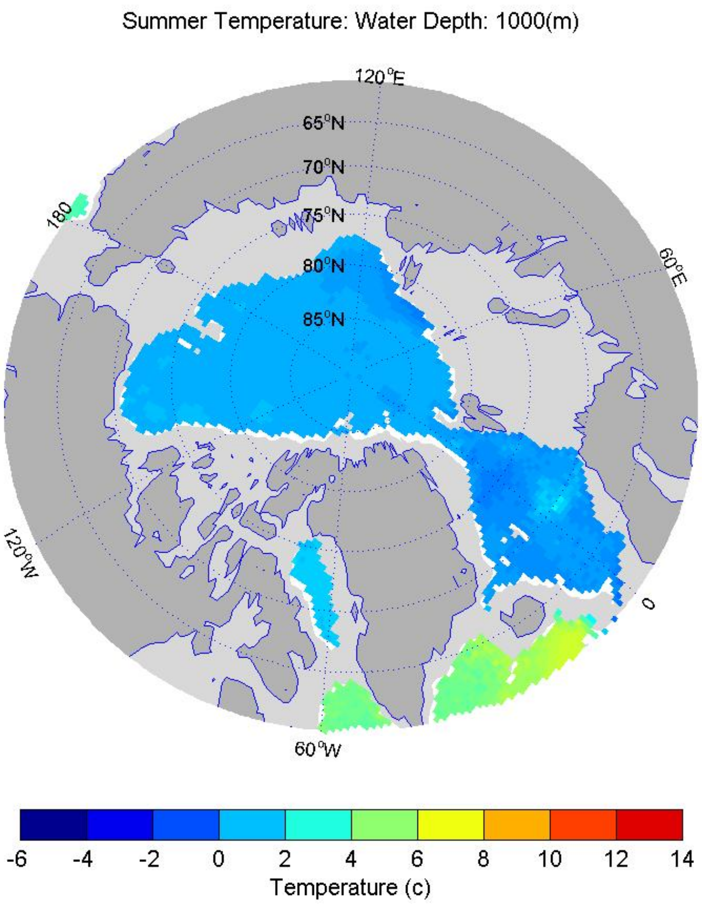
http://nsidc.org/

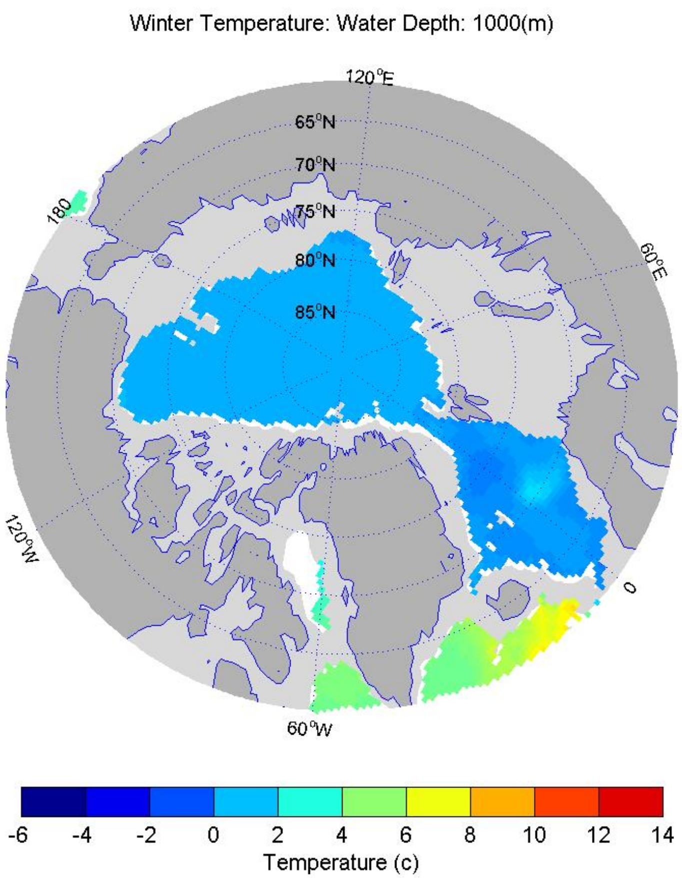
Temperature (z = 0)



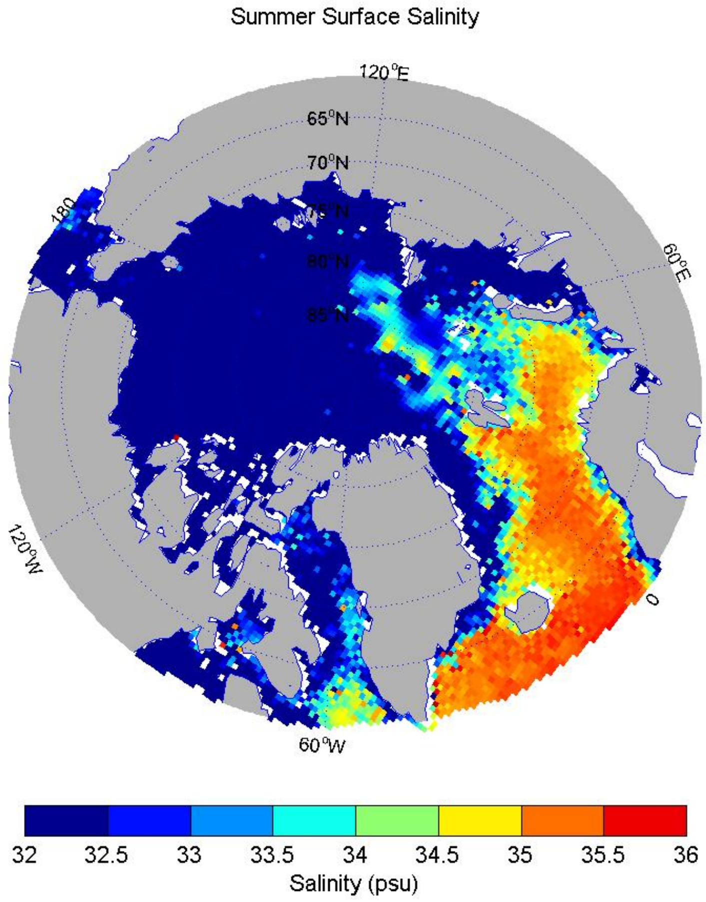


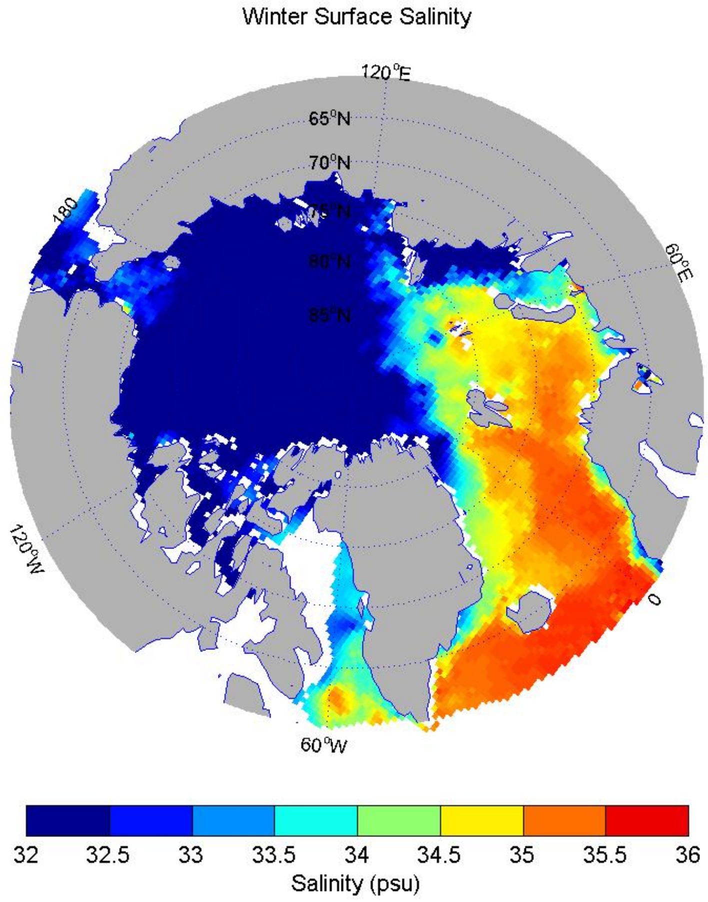
Temperature (z = -1000 m)



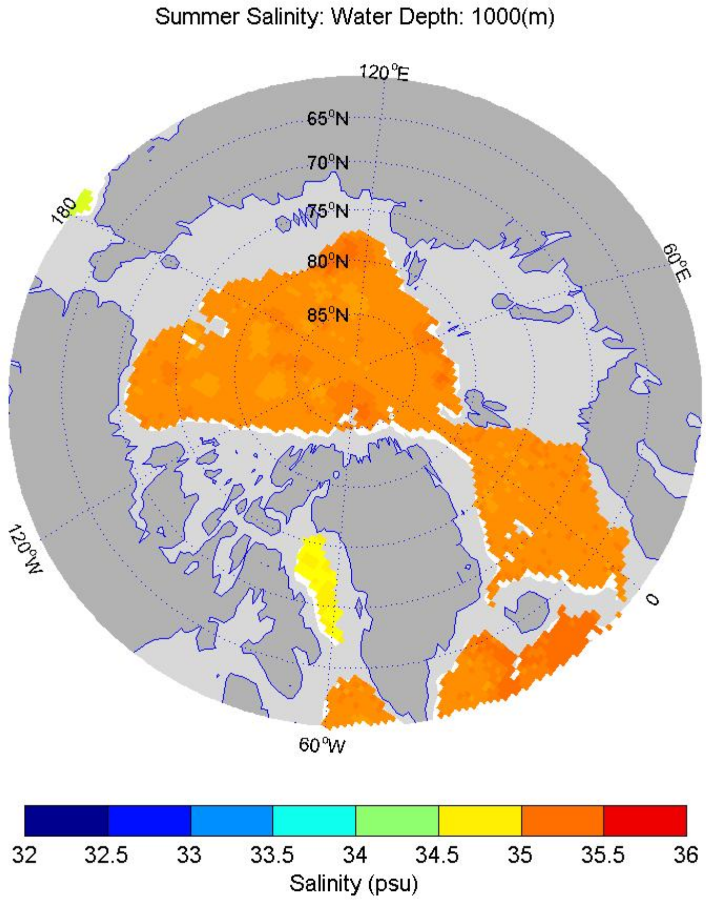


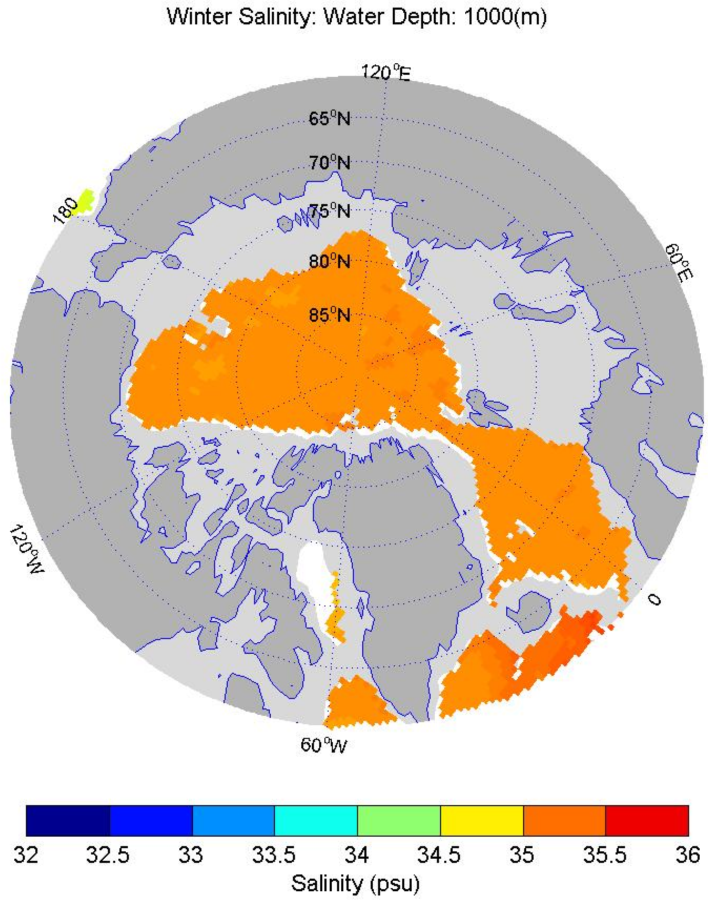
Salinity (z = 0)


Summer Surface Salinity
120°E
65°N
70°N
75°N
80°N
85°N
180
60°E
120°W
0
60°W
32
32.5
33
33.5
34
34.5
35
35.5
36
Salinity (psu)


Winter Surface Salinity
120°E
65°N
70°N
75°N
80°N
85°N
180
60°E
120°W
0
60°W
32
32.5
33
33.5
34
34.5
35
35.5
36
Salinity (psu)

Salinity (z = -1000 m)

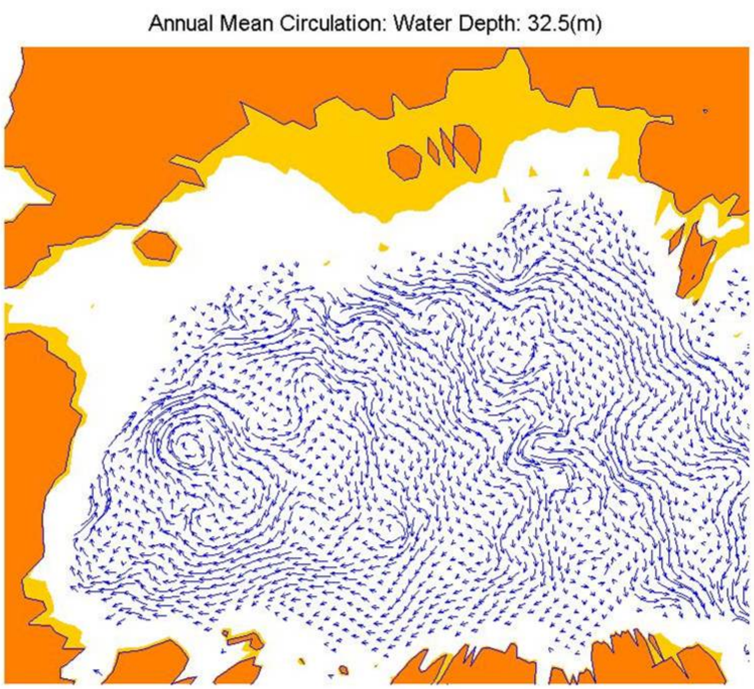


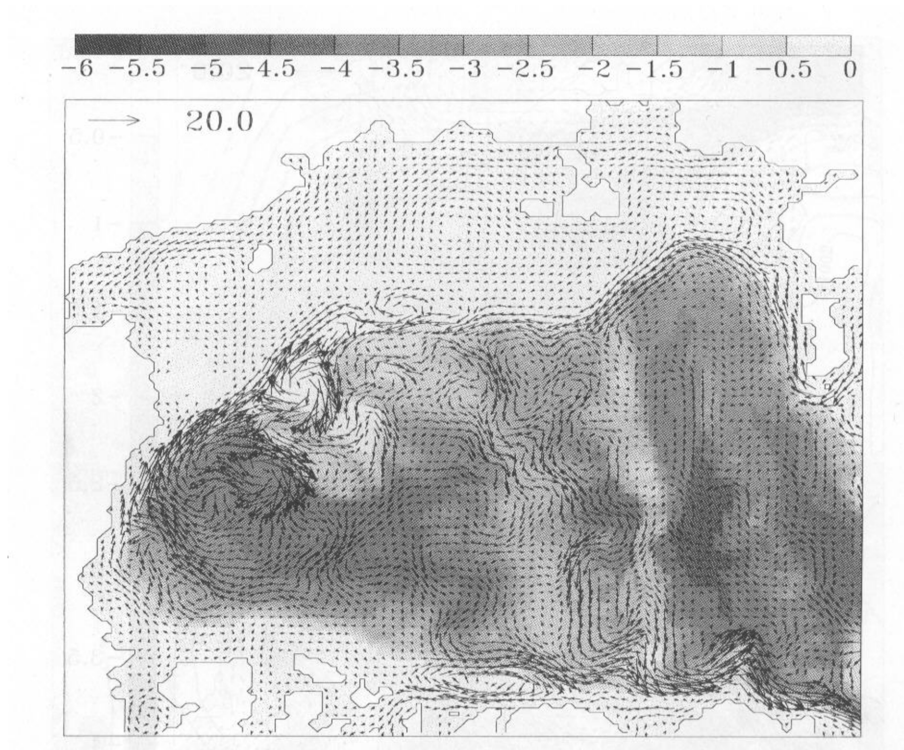


Mean Circulations (z = -32 m)

P-vector

7 years mean of POPS model results (Zhang, Maslowski, Semtner, 1999, JGR)





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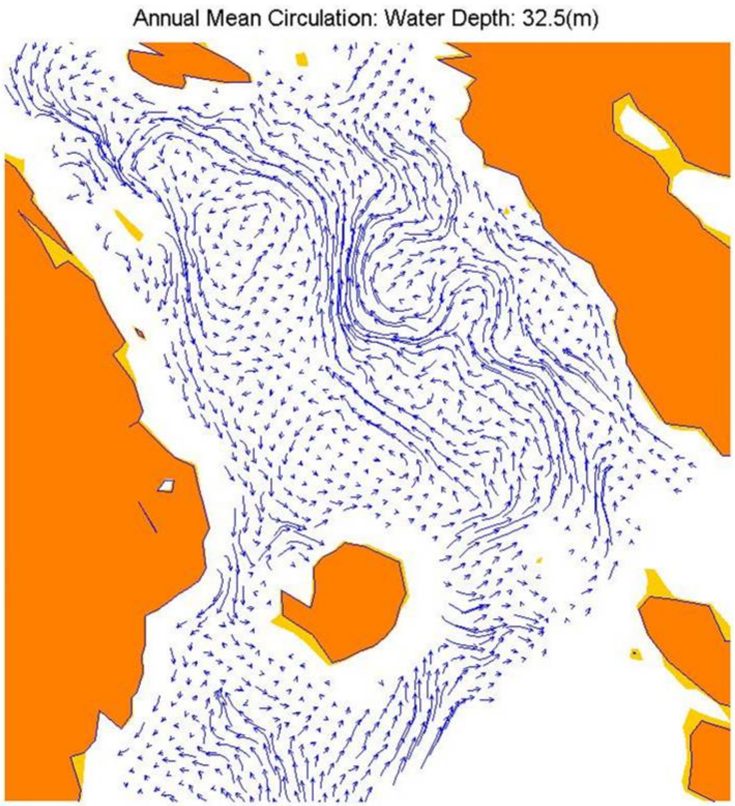

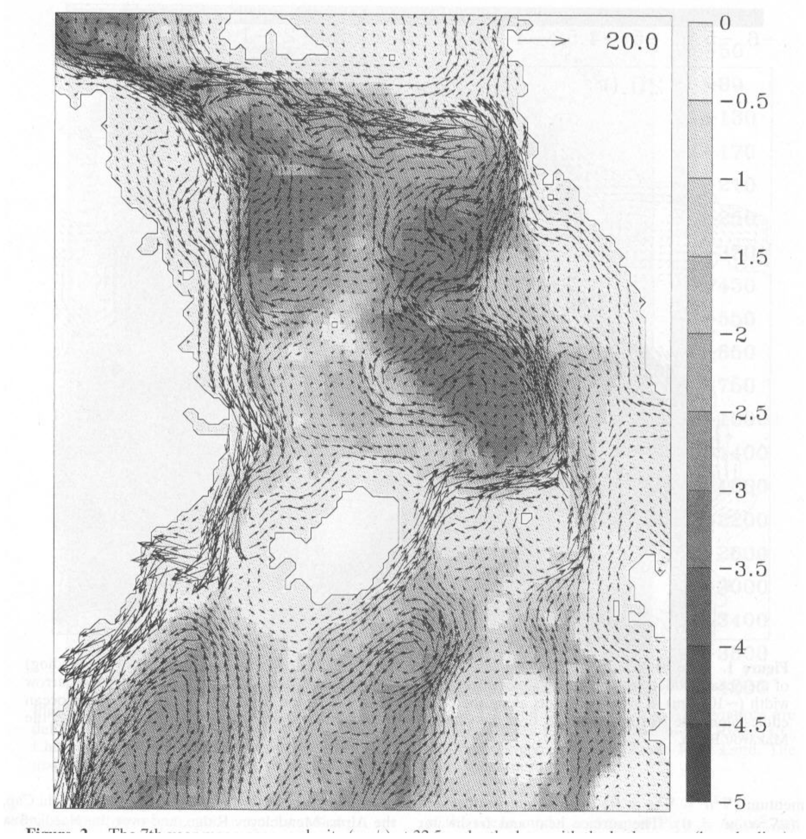

Conclusions

- (1) P-Vector method is effective to calculate the absolute velocity from hydrographic data.
- (2) The initial velocity filed can be calculated using the P-vector method (Geostrophic Initialization).