AOMIP - Arctic Ocean Intercomparison Project.

FORCING

- Realistic daily atmosphere pressure and temperature for 1948-2002 period - NCEP\NCAR Reanalysis.
- Prescribed parameterizations for shortwave and net longwave radiation.
- PHC 2.0 monthly mean ocean temperature and salinity.
- Prescribed monthly mean precipitation.
- Prescribed monthly mean cloudiness.
- Constant 90% realtive humidity.
- 13 rivers with monthly mean discharges.

OUTPUT

- Comparison with all the available observations.
- Uniform data presentation

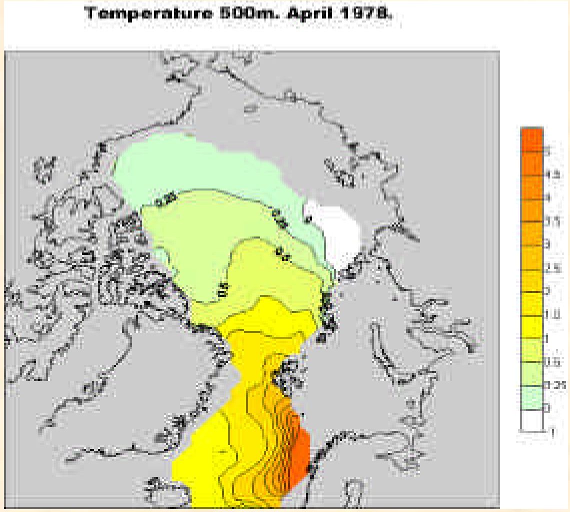
Participating Models

Home Institute	Alfred Wegener Institute	Goddard Space Flight Center	Internat. Arctic Research Center	Institute of Ocean Sciences	Naval Postraguate School	New York University	Russian Academy of Sciences	University of Washington
AOMIP Model ID	AWI	GSFC	IARC	IOS	NPS	NYU	RAS	UW
Ocean Model Pedigree	MOM	MOM	POM	MOM	MOM	MICOM	FE	MOM
Coupled Sea-Ice Model	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

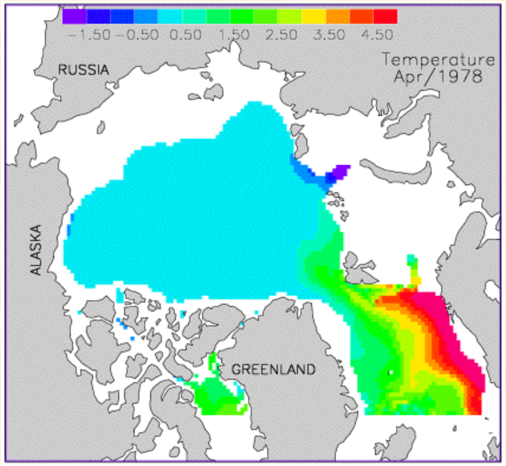
MOM - Bryan, 1969
POM - Blumberg and Mellor, 1987
MICOM - Bleck and Boudra, 1981
FE - Finite Element - Yakovlev, 2002

Very Different Results for the Atlantic Water Inflow

http://members.shaw.ca/planetwater/research/AOMIP.html

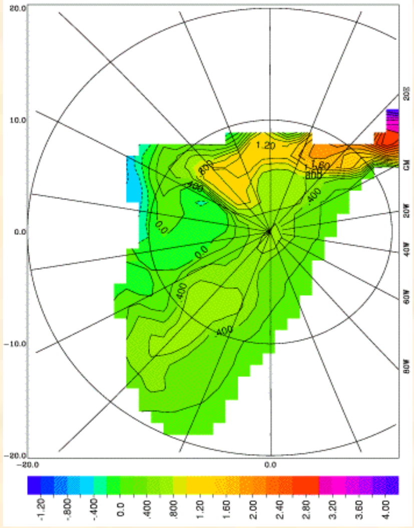


INM RAS

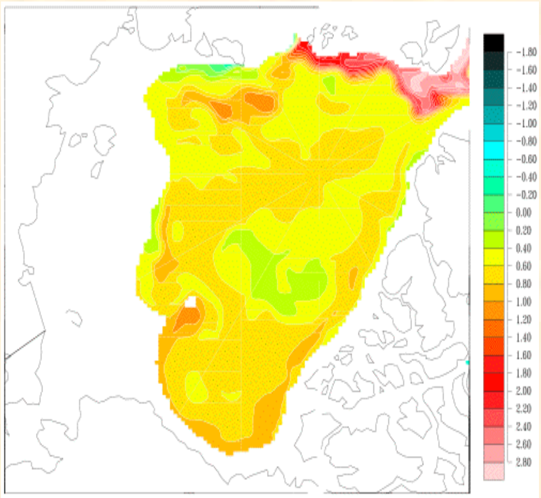


UW – 40 km

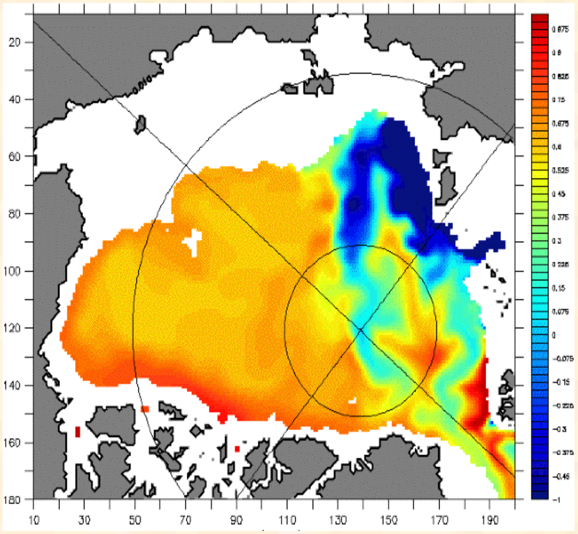
AWI2 – 100 km



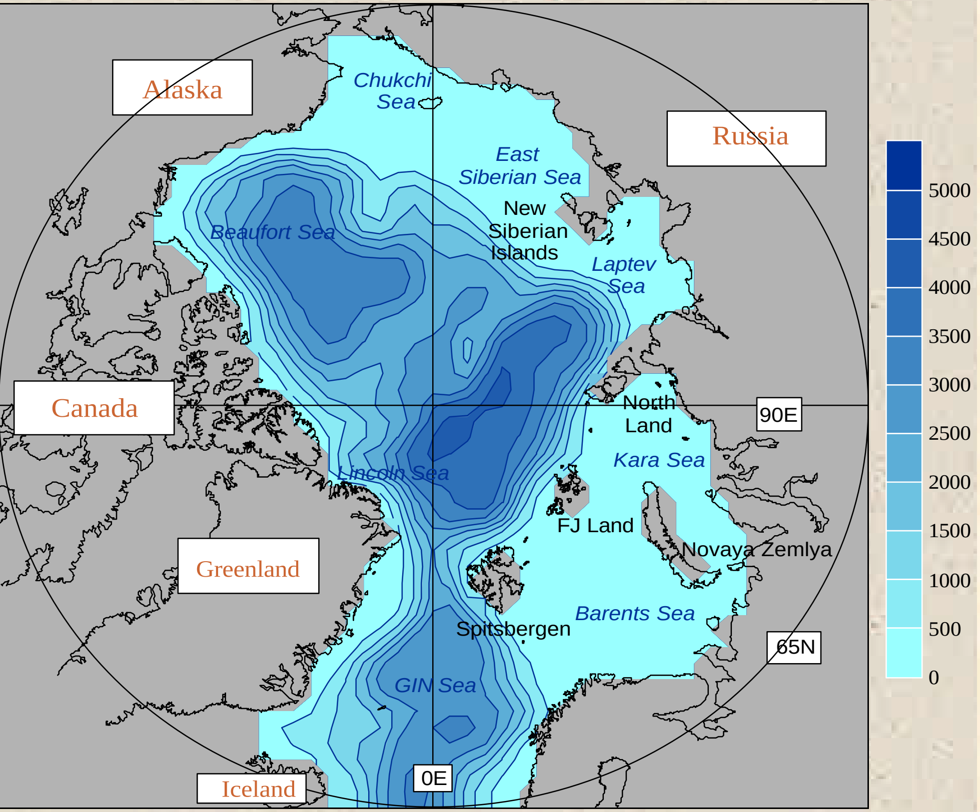
AWI1 – 20 km



NPS – 9 km



General Layout



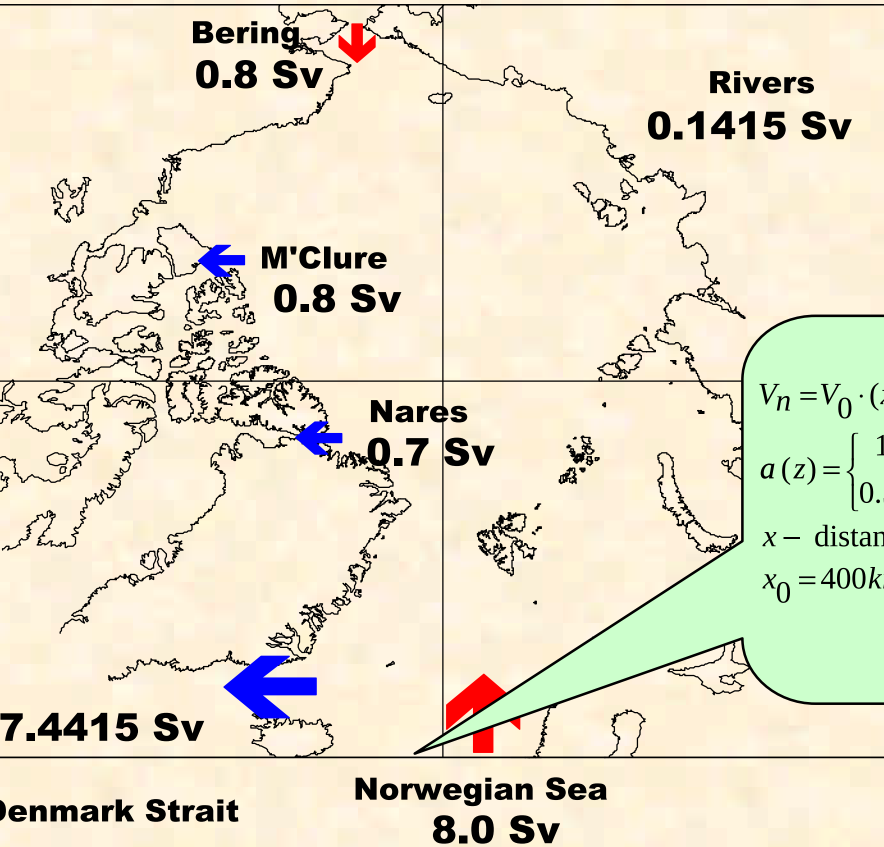
- Area of the Arctic Ocean north to 65N.
- North Pole shifted to the point 0N, 180E.
- 1 degree (~111.2 km) spatial resolution in the new coordinate frames.
- Z-coordinate vertical approximation, 16 levels.
- 5 islands.
- Five passages with the specified mass transports.
- Eight main rivers (both mass and salinity fluxes).

Ocean Model

- **Primitive equations** with ordinary Boussinesque, hydrostatics and incompressibility approximations.
- **Linearized kinematics condition** at the ocean upper surface.
- **Sea level elevation** as an integral function of the model. This equation is derived on the **finite-dimensional level** thus providing mass conservation. Free slip boundary conditions at solid boundaries. Linear or quadratic friction at bottom.
- No heat and salinity fluxes at solid boundaries.
- **Specified mass transports** at open boundaries and at river estuaries . V_n
- Momentum fluxes with the quadratic ice drift drag at the upper surface.
- Heat and salinity fluxes at upper surface caused by snow\ice melting or freezing.
- **Heat and salinity fluxes** $Q_{S,b} = -S_{obs} \cdot V$ at inflow side boundaries and $Q_{S,b} = S \cdot V_n$ at outflow ones. Sobs is a specified salinity. The same is for T.
- **Vertical turbulence** parametrized by **Monin-Obukhov theory**.

Passages

Linear
Velocity Profile
Max at Alaska



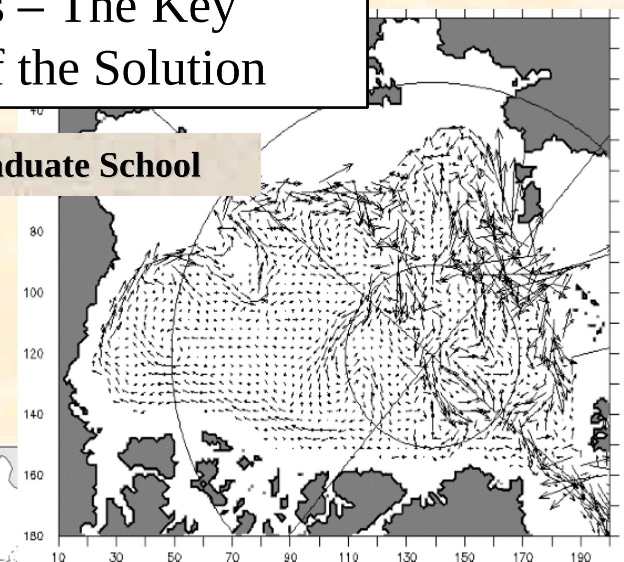
$$V_n = V_0 \cdot (x - x_0) \cdot a(z)$$

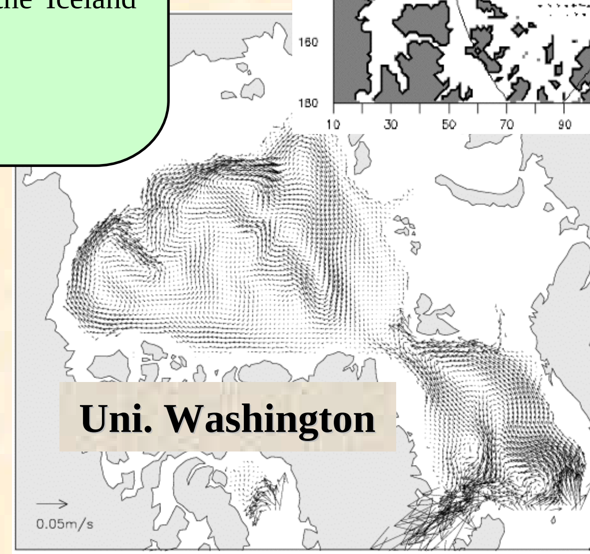
$$a(z) = \begin{cases} 1, & z \le 100m \\ 0.5, & z > 100m \end{cases}$$

x – distance from the Iceland

$x_0 = 400km$

Mass Transports – The Key
to the Control of the Solution





Rivers

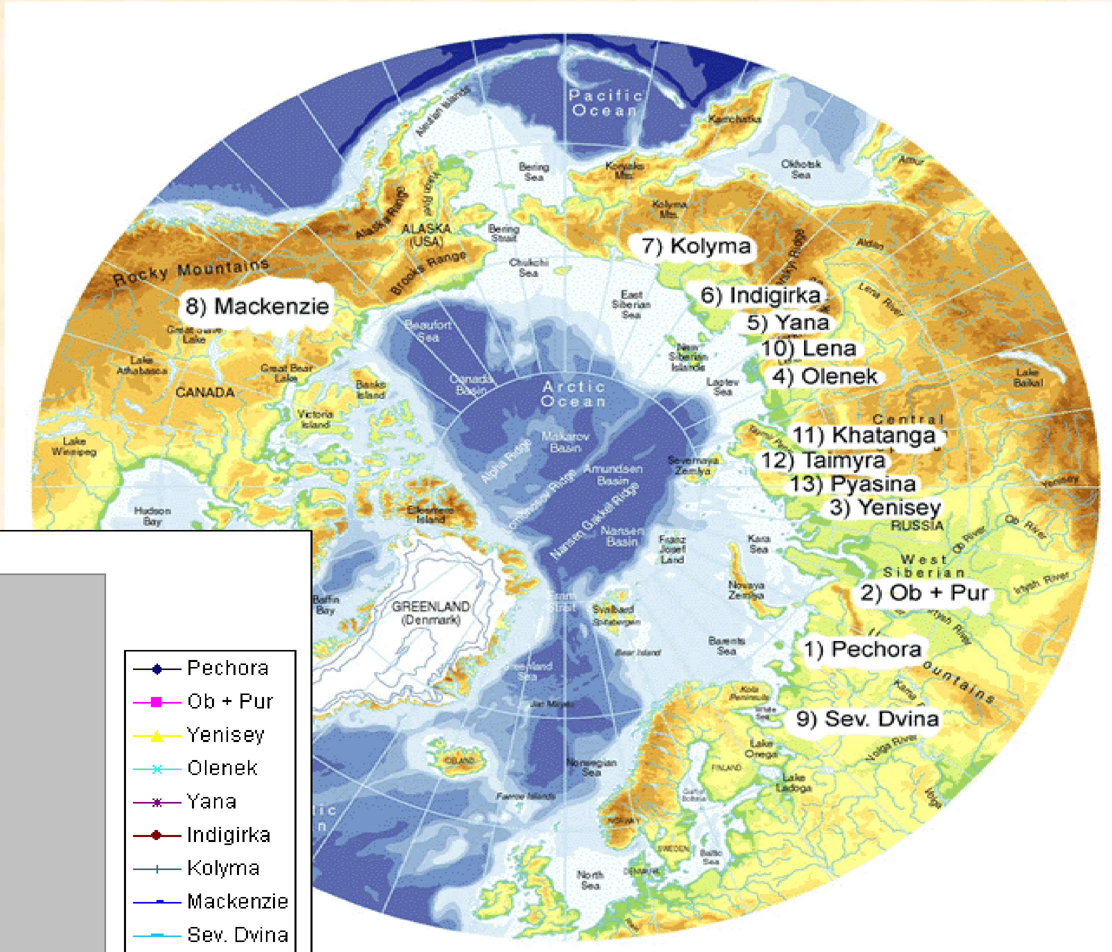
Prange, M., 2002

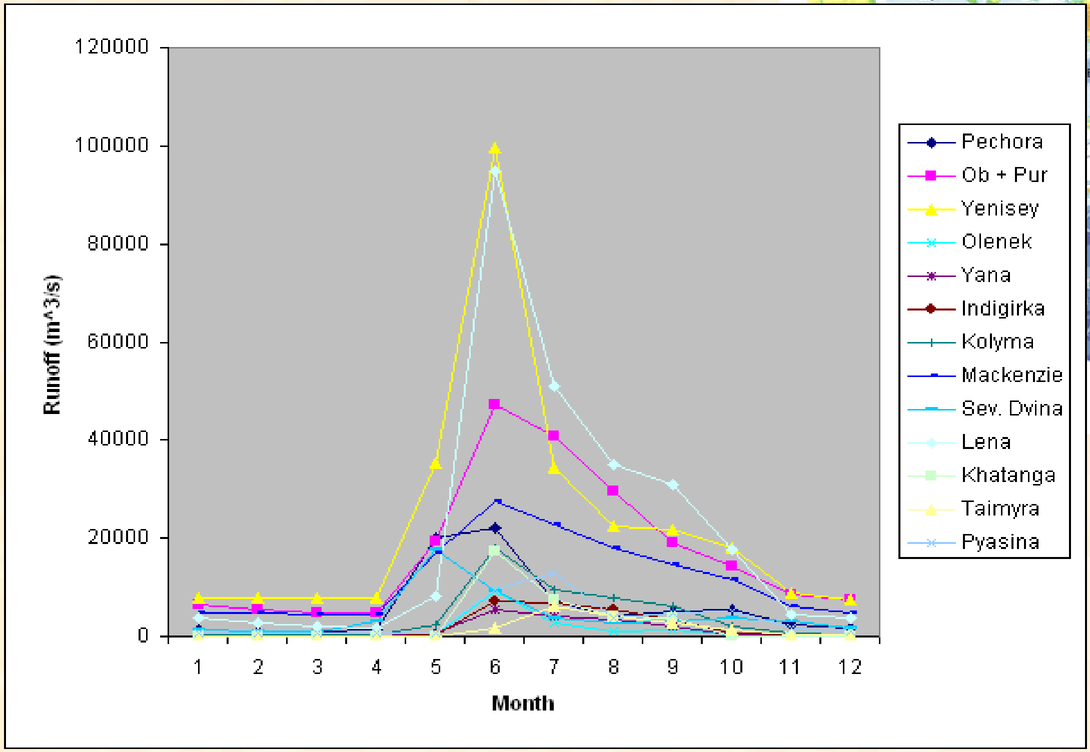
Prange, M., and G. Lohmann, 2001

Salinity flux

$$Q_{S,r} = -V_r \cdot (S - S_r)$$

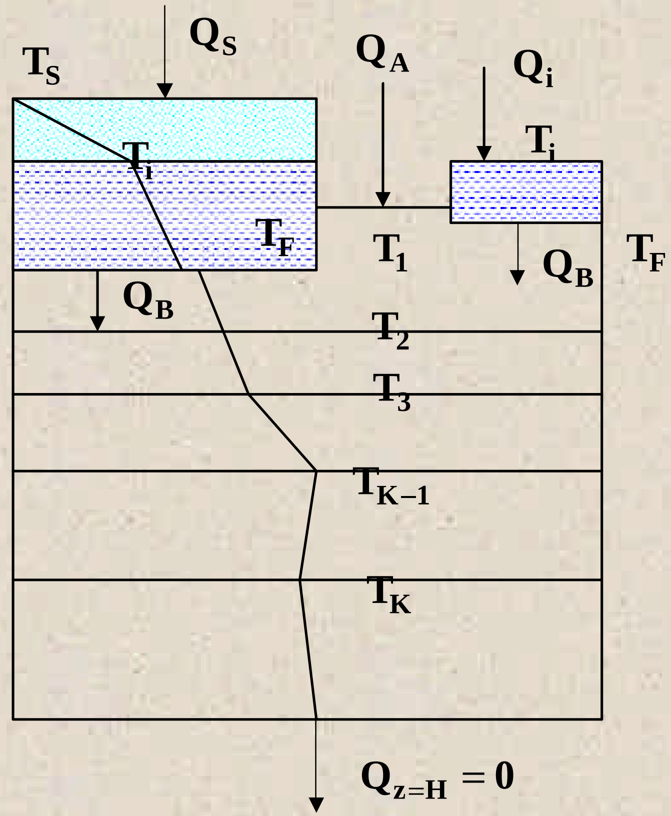
$$S_r = 10\ ppt$$





All the river discharge assumed to outflow from the Denmark Strait with the constant rate

Ice Thermodynamics



- Similar to *Parkinson and Washington (1979)* model. Linear profiles of temperature in snow and ice, thermodynamic equilibrium at the upper surface.
- Several gradations of ice thickness.
- Solution of the 1D thermodynamics problem for the whole snow-ice-water vertical column.

1. Ocean water temperature profile from the surface to the bottom. Implicit time scheme.
2. Snow-ice thermodynamic evolution.
3. Total salinity flux at the ocean surface. Snow-ice melt and freezing, precipitation.
4. Ocean water salinity profile from the surface to the bottom. Implicit time scheme.

Ice Dynamics

1. Governing equations

$$m\frac{\partial \vec{u}_i}{\partial t} + ml\vec{k}\times\vec{u}_i = -mg\vec{\nabla} z + \vec{t}_a + \vec{t}_w + \vec{\mathbf{F}}$$

$$m = \sum_{k=1}^{N} m_k$$

$\mathbf{F}$ - rheology

$$\vec{\tau}_w = \rho_w C_w \left|\Delta\vec{u}_{iw}\right|(\Delta\vec{u}_{iw}\cos\varphi + \vec{k}\times\Delta\vec{u}_{iw}\sin\varphi)$$

Rheology

$$\mathbf{F} = \nabla\cdot s$$

$$\begin{pmatrix} F_l \\ F_q \end{pmatrix} = \frac{1}{R\sin q}\begin{pmatrix} \frac{\partial}{\partial l}s_{11} + \frac{\partial}{\partial q}(s_{12}\sin q) + s_{12}\cos q \\ \frac{\partial}{\partial l}s_{12} + \frac{\partial}{\partial q}(s_{22}\sin q) - s_{11}\cos q \end{pmatrix}$$

2. Ice mass and compactness transport

$$\frac{\partial m_k}{\partial t} + div\left(m_k\vec{u}_i\right) = R_m(m_k, m_1, m_2, ..., m_N),$$

$$\frac{\partial A_k}{\partial t} + div\left(A_k\vec{u}_i\right) = R_A(A_k, A_1, A_2, ..., A_N),$$

$$A = \sum_{k=1}^{N} A_k \leq 1$$

3. Ice thickness redistribution

Deformation Rates Tensor

$$\dot{e}_{11} = \frac{1}{R\sin q}\left(\frac{\partial u}{\partial l} + v\cos q\right) \qquad \dot{e}_{22} = \frac{1}{R}\frac{\partial v}{\partial q}$$

$$\dot{e}_{12} = \frac{1}{2R}\left(\sin q\frac{\partial}{\partial q}\left(\frac{u}{\sin q}\right) + \frac{1}{\sin q}\frac{\partial v}{\partial l}\right)$$

Stress Tensor

$$s = zD_I\mathbf{I} + 2h\mathbf{D}' - \frac{1}{2}P\mathbf{I} \qquad D_I = tr\mathbf{D} \qquad D_{II}^2 = tr\mathbf{D}'\mathbf{D}'$$

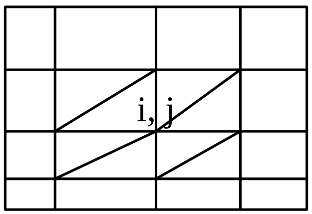
$$\mathbf{D}' = \mathbf{D} - \frac{1}{2}D_I\mathbf{I} \qquad z = \frac{P}{2\Delta} \qquad h = z/e^2 \qquad \Delta^2 = D_I^2 + \left(D_{II}/e^2\right)^2$$

$$s_{11} = (z - h)D_I + \frac{2h}{R\sin q}\left(\frac{\partial u}{\partial l} + v\cos q\right) - \frac{P}{2}$$

$$s_{12} = \frac{h}{R}\left(\sin q\frac{\partial}{\partial q}\left(\frac{u}{\sin q}\right) + \frac{1}{\sin q}\frac{\partial v}{\partial l}\right)$$

$$s_{22} = (z - h)D_I + \frac{2h}{R}\frac{\partial v}{\partial q} - \frac{P}{2}$$

Spatial Discretization



1. **Horizontal approximation** of model area - triangles derived from the rectangular discretization

2. **Vertical approximation** of model area - z-coordinate, bottom topography by stepwise function

3. Ocean **horizontal velocities, temperature, salinity, pressure** approximated by tensor products of 2D linear piecewise finite functions to 1D linear piecewise finite functions:

$$\Phi^h = \sum_{i,k} \Phi_{i,k} j_i y_k$$

4. **Vertical velocity** is approximated by tensor products of 2D linear piecewise functions to 1D finite constant piecewise functions:

$$w^h = \sum_{i,k} w_{i,k} j_i (x, y) \Pi_k (z) \qquad \Pi_k(z) = \begin{cases} 1, & z \in [z_k, z_{k+1}] \\ 0, & z \notin [z_k, z_{k+1}] \end{cases}$$

5. Some special approximation for **ice deformation rate tensor components** in spherical coordinates.

Transport Scheme

Transport scheme for temperature, salinity and momentum

(Hughes and Brooks 1979).

Additional artificial diffusion

$$\vec{\nabla}\cdot(\mathbf{A}\vec{\nabla}\mathbf{q}) \approx \frac{1}{R^2\sin^2?}\frac{\partial}{\partial ?}A_{11}\frac{\partial q}{\partial ?} + \frac{1}{R^2\sin ?}\left(\frac{\partial}{\partial ?}A_{12}\frac{\partial q}{\partial ?} + \frac{\partial}{\partial ?}A_{12}\frac{\partial q}{\partial ?}\right) +$$

$$+\frac{1}{R^2\sin ?}\frac{\partial}{\partial ?}A_{22}\sin ?\frac{\partial q}{\partial ?}$$

$$A_{11} = C\frac{u^2}{|\vec{u}|^2},\ A_{12} = C\frac{u\cdot v}{|\vec{u}|^2},\ A_{22} = C\frac{v^2}{|\vec{u}|^2} \qquad C \approx \frac{1}{2}|\vec{u}|h$$

$$|\vec{u}|^2 = u^2 + v^2$$

Time Scheme. General Structure

1.Turbulence
Turbulent diffusion coefficients for momentum, heat and salt.

2. Transport and Horizontal Diffusion
Explicit Matsuno time scheme. Modified transport scheme.

3. Ice mass and compactness transport
Explicit Euler time scheme. Upwind transport scheme.

4. Vertical diffusion of heat and salt, Ice thermodynamics.
Implicit time scheme.
Vertical momentum exchange (ice and water).
Implicit predictor-corrector time scheme. Wind, ice-water drag, bottom friction.

5. Ice thickness distribution
The simplest distributor - thinner ice to the next thicker gradation.

6. Rheology I
Explicit Euler scheme with small time steps ~ 1-2 min.

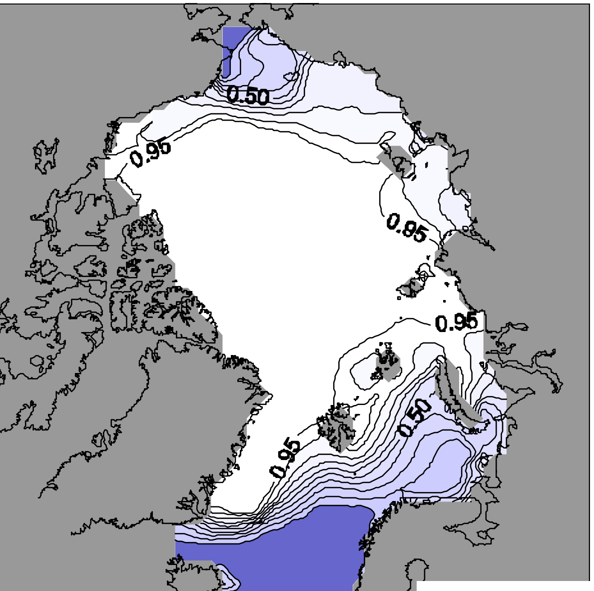
7. Velocity-Pressure Adjustment
Implicit time scheme. GMRES for Level Elevation Solution.

8. Ice velocity caused by sea level slopes

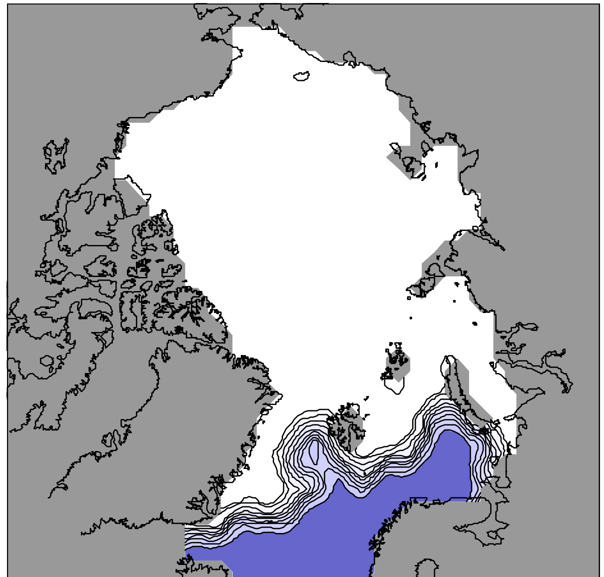
9. Ice Pheology II
Explicit Euler scheme with small time steps 1-2 min.

10. Vertical Velocity

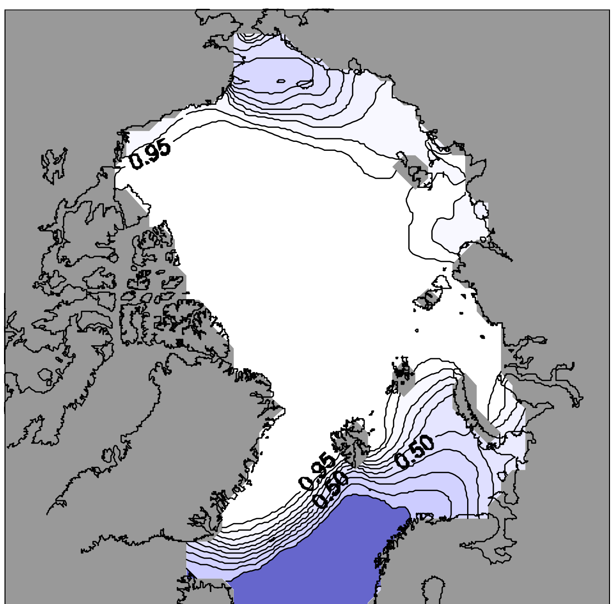
Model Ice Compactness
1978 February



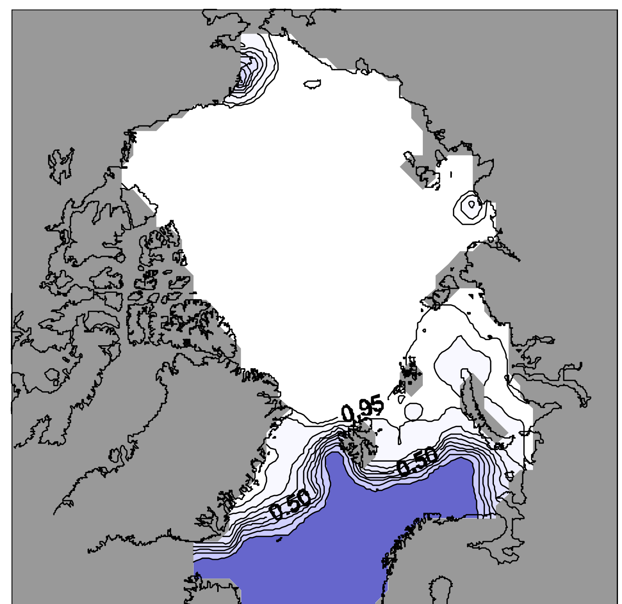
Observed Ice Compactness
1978 February



Model Ice Compactness
1978 May

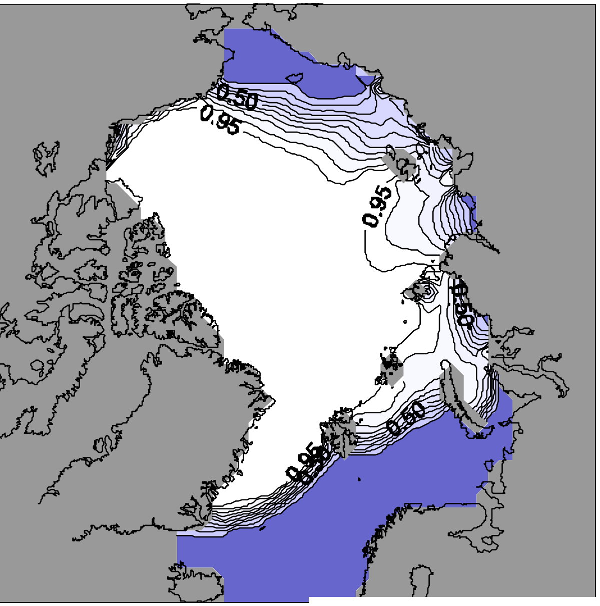


Observed Ice Compactness
1978 May



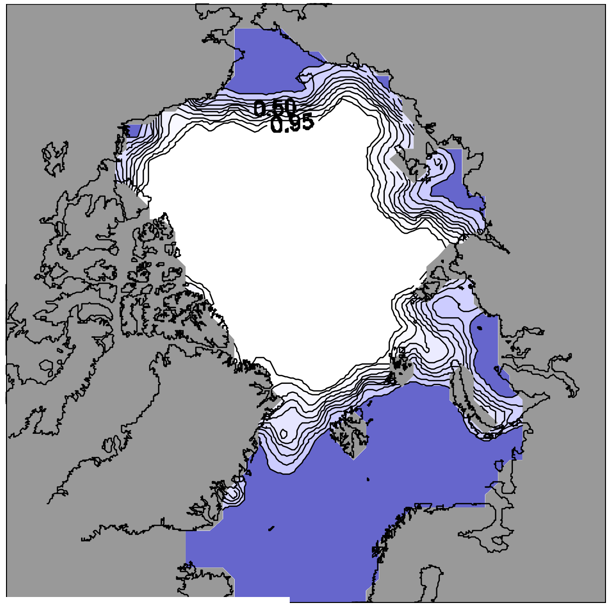
Model Ice Compactness

1978 August



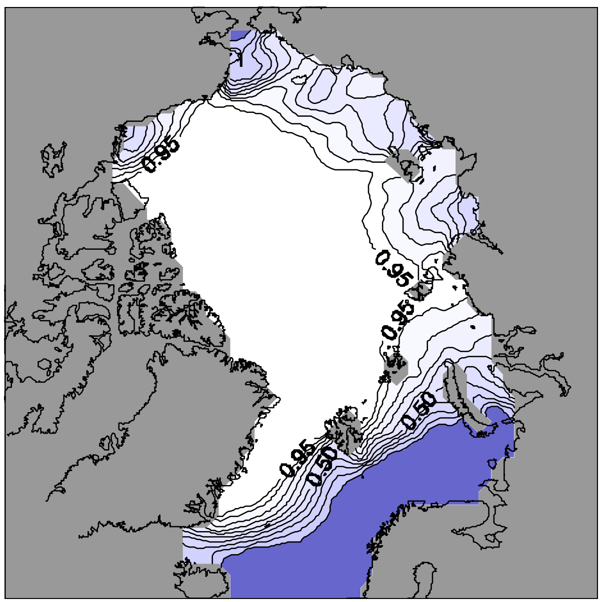
Observed Ice Compactness

1978 August



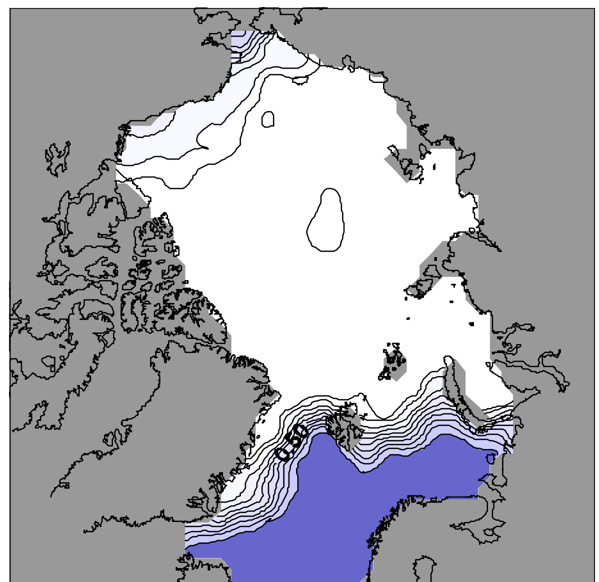
Model Ice Compactness

1978 November

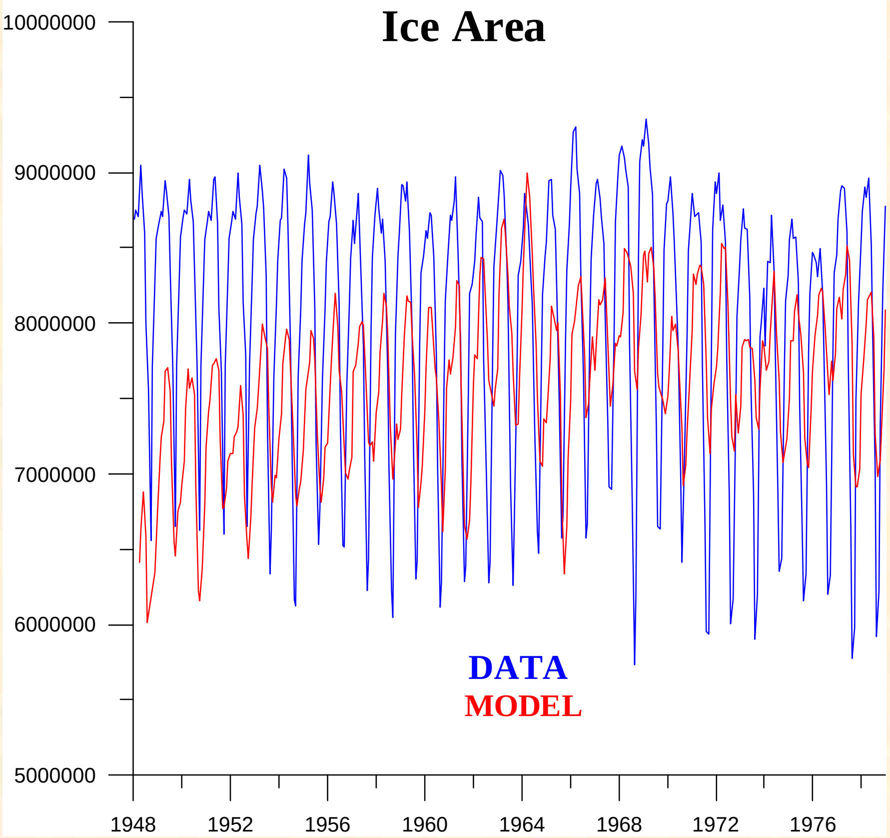


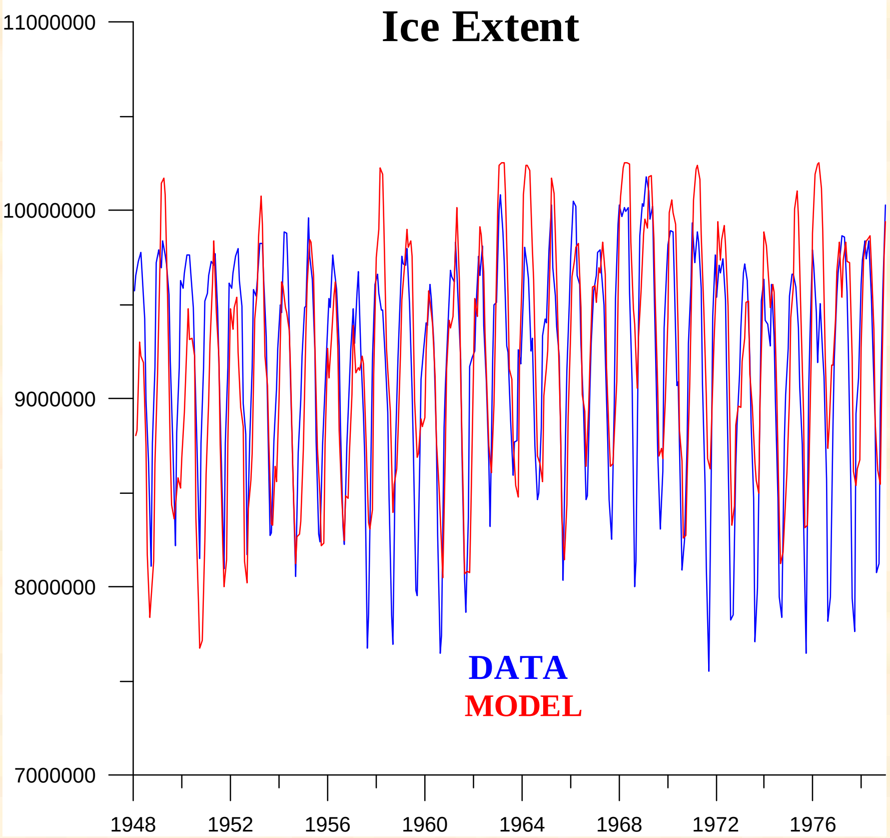
Observed Ice Compactness

1978 November

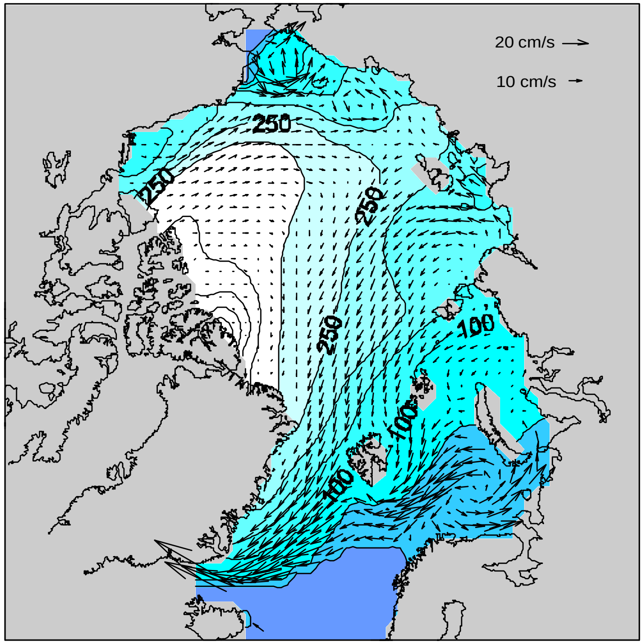


Ice Extent and Area: Model and Data

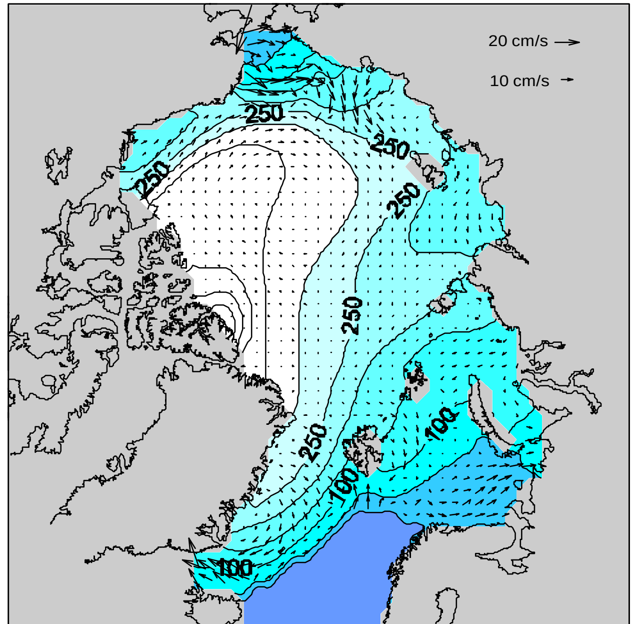




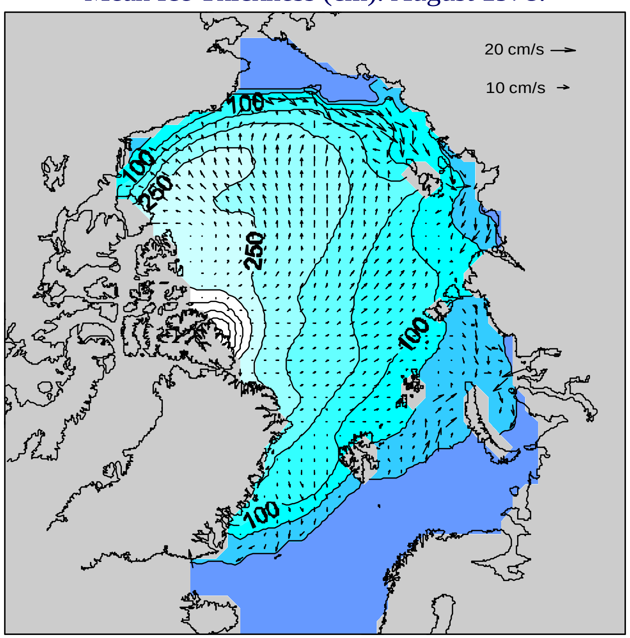
Mean Ice Thickness (cm). February 1978.



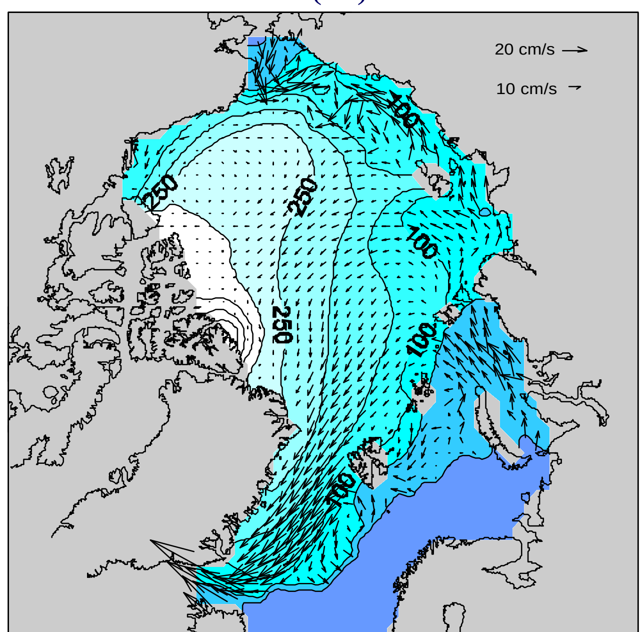
Mean Ice Thickness (cm). May 1978.



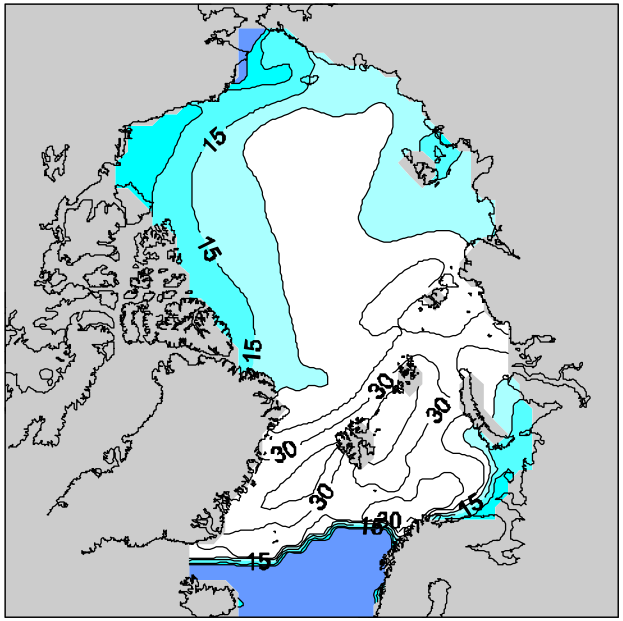
Mean Ice Thickness (cm). August 1978.



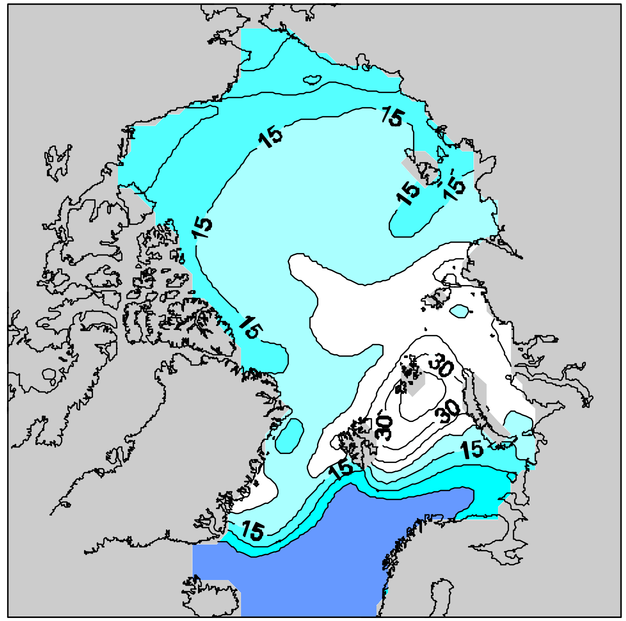
Mean Ice Thickness (cm). November 1978.



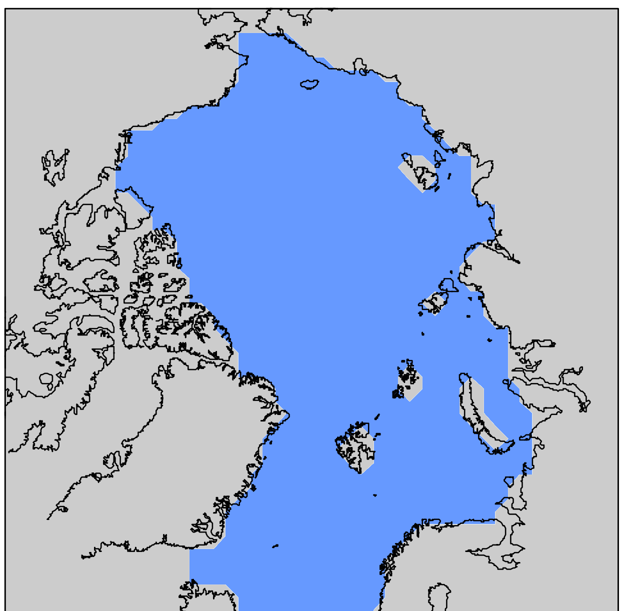
Snow Thickness (cm). February 1978.



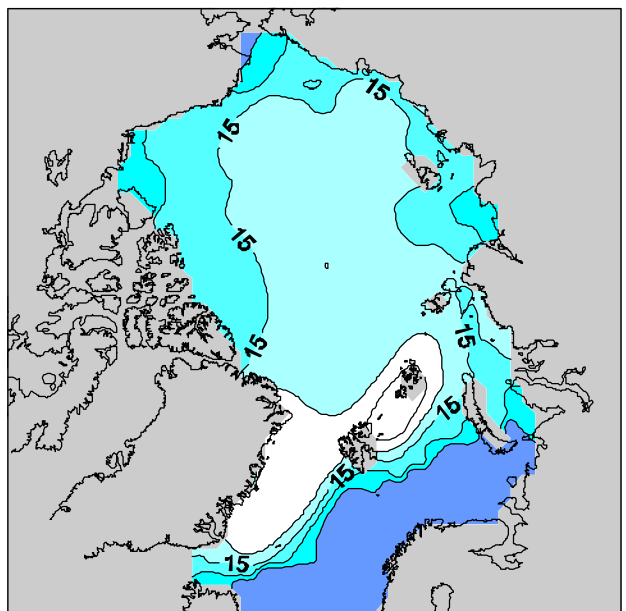
Snow Thickness (cm). May 1978.



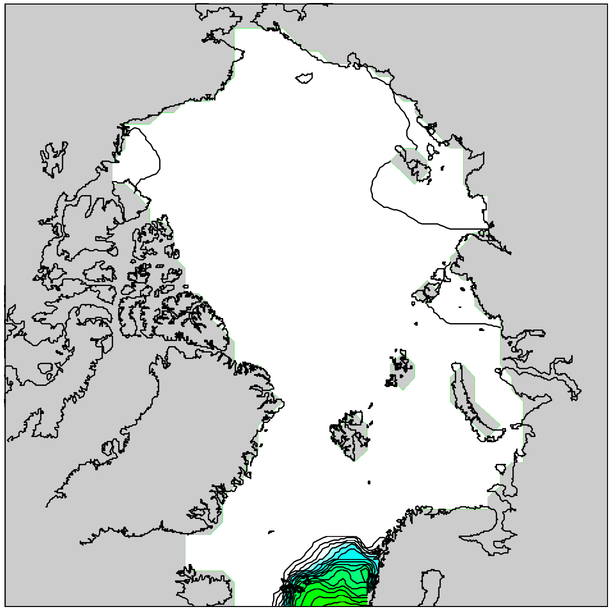
Snow Thickness (cm). August 1978.



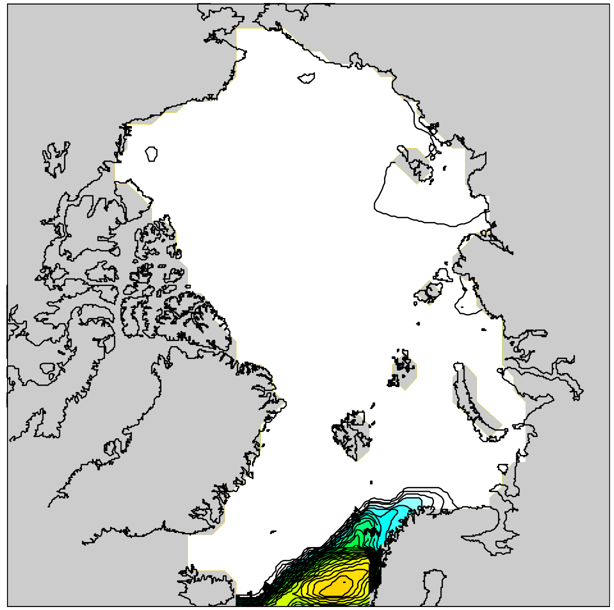
Snow Thickness (cm). November 1978.



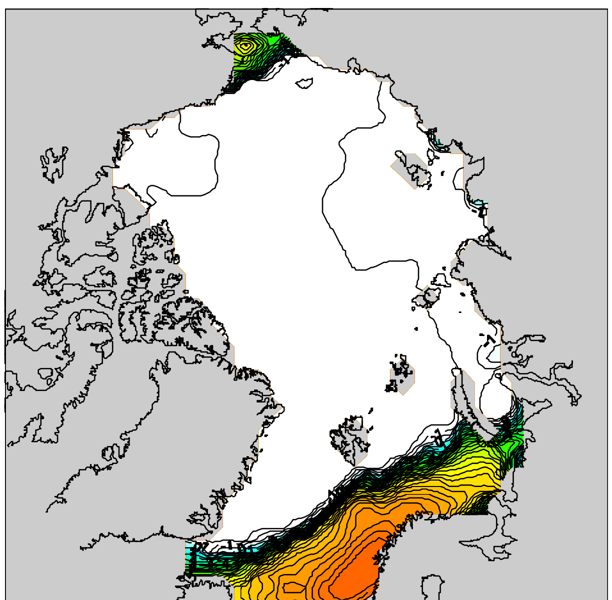
Temperature z=0 February 1978



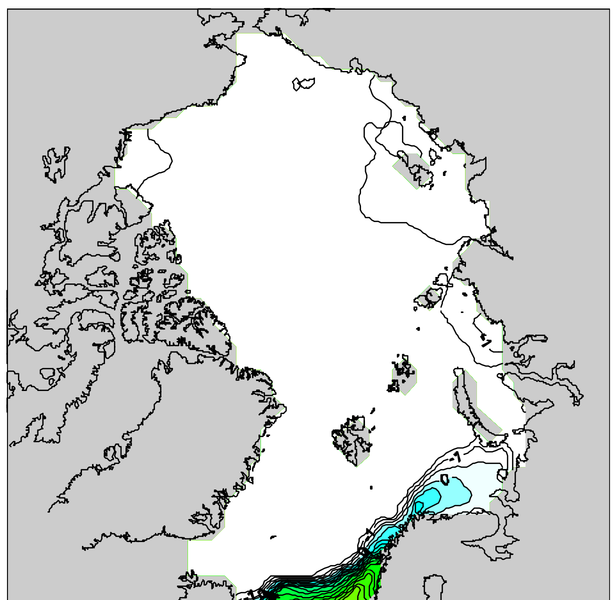
Temperature z=0 May 1978



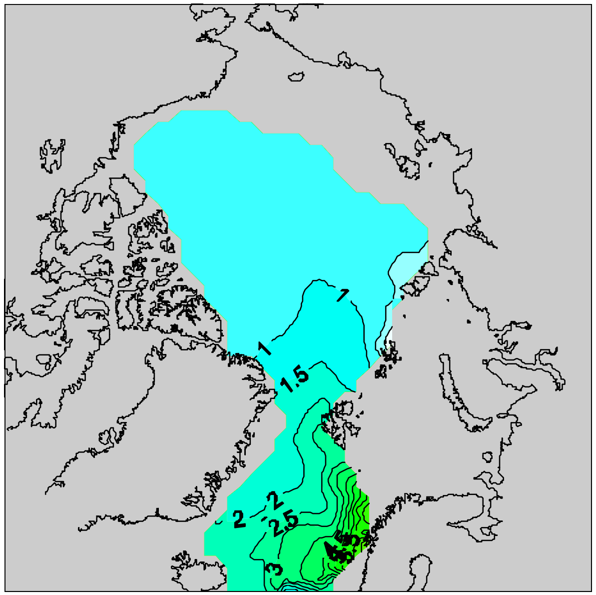
Temperature z=0 August 1978



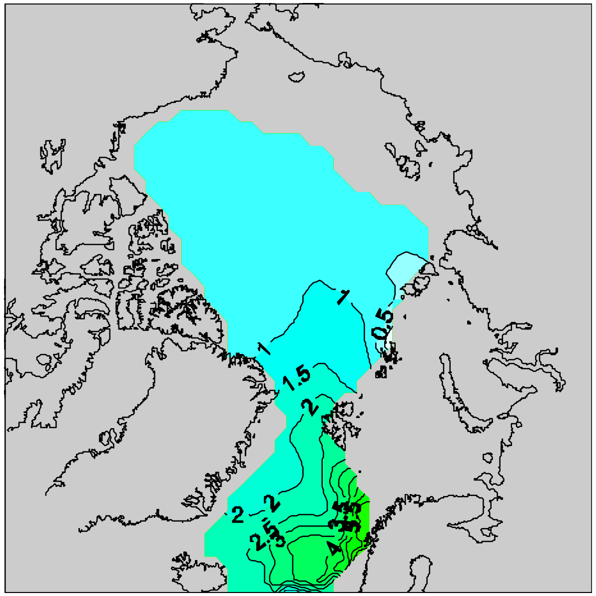
Temperature z=0 November 1978



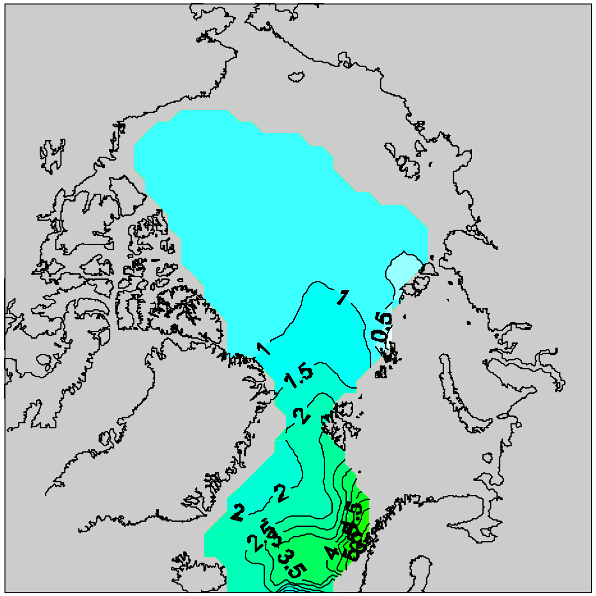
Temperature z=500 February 1978



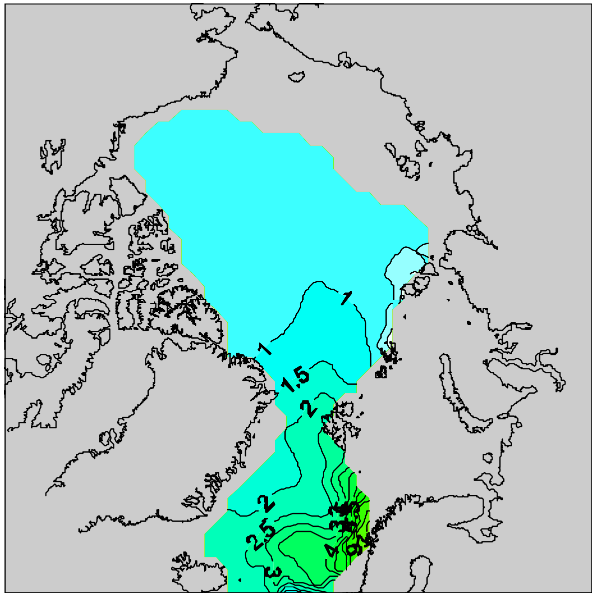
Temperature z=500 May 1978



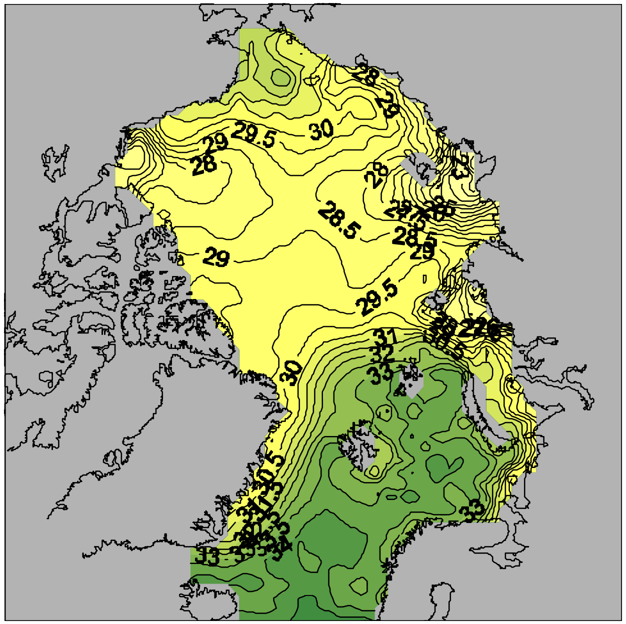
Temperature z=500 August 1978



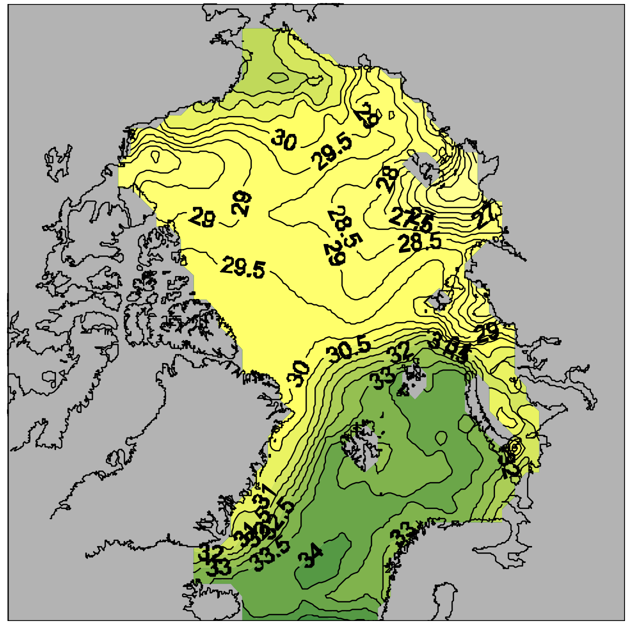
Temperature z=500 November 1978



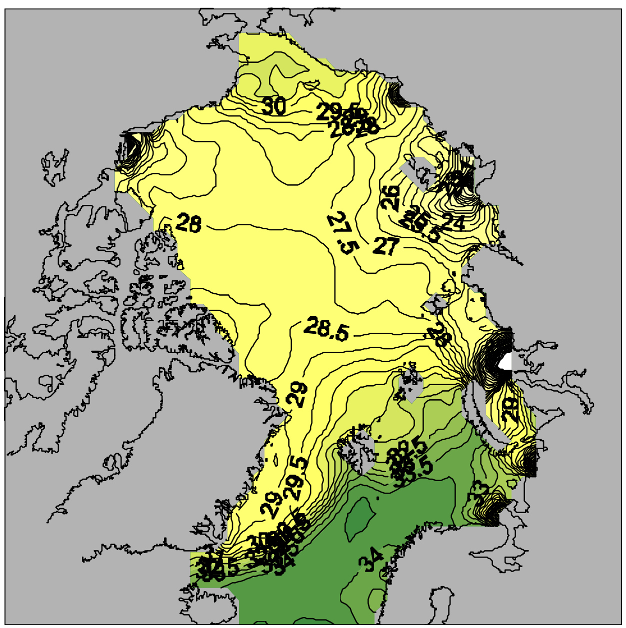
Salinity 0m. February 1978.



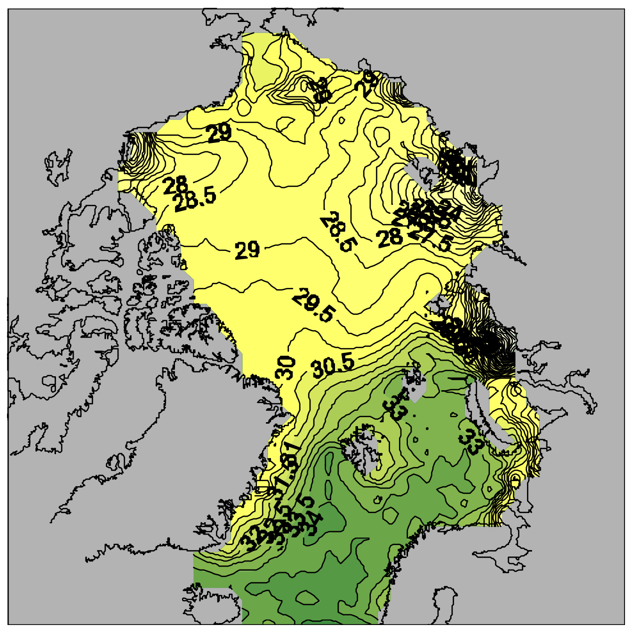
Salinity 0m. May 1978.



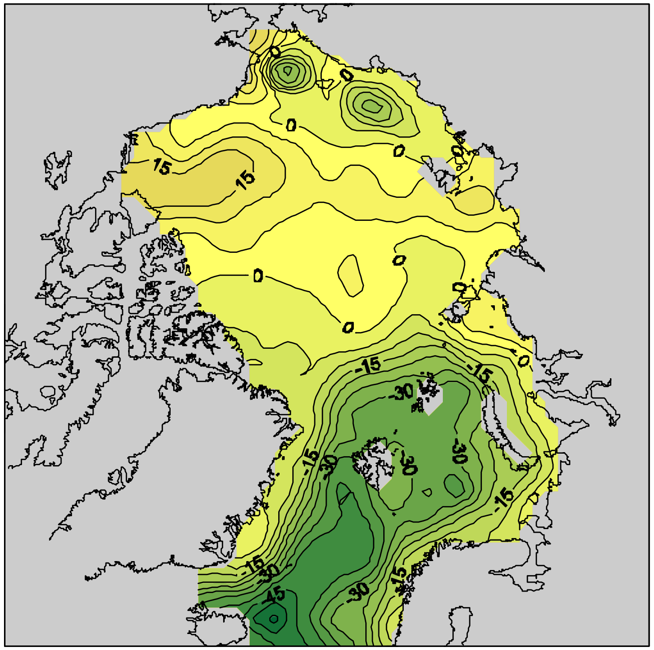
Salinity 0m. August 1978.



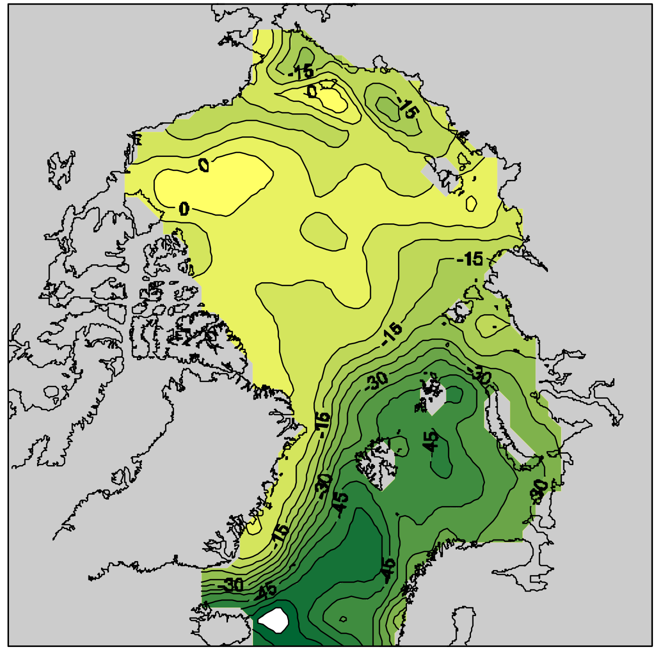
Salinity 0m. November 1978.



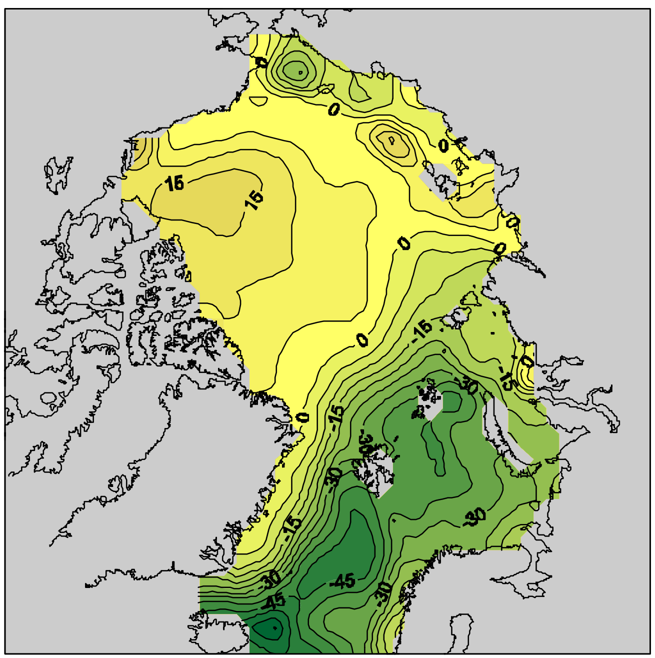
Sea Level (cm). February 1978.



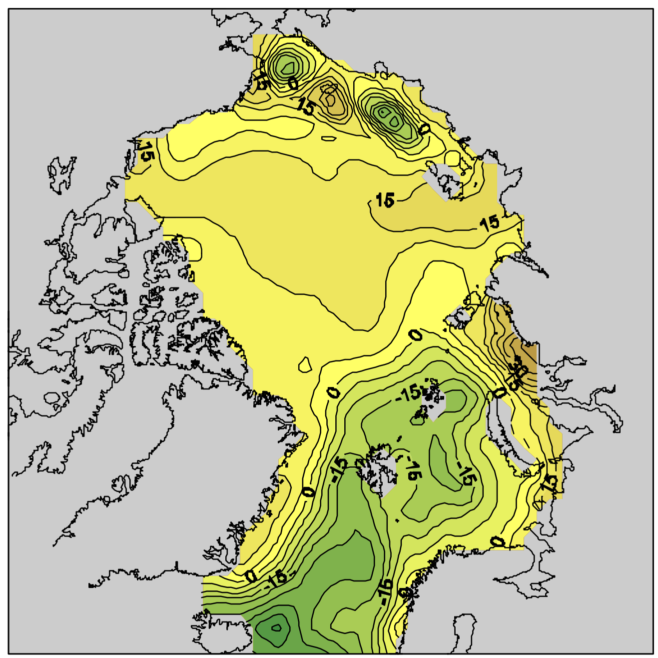
Sea Level (cm). May 1978.



Sea Level (cm). August 1978.



Sea Level (cm). November 1978.



Neptune effect

Holloway G. Representing topographic stress for large-scale ocean models. *J. Phys. Oceanogr.*, **22**, 1033-1046, 1992.

$$\psi^* = -fL^2 H$$

$L = 3 \div 12$?? . (Eby, M., and G. Holloway, 1994). $D_H u \rightarrow D_H (u - u^*)$

E. Kazantsev, J. Sommeria, J. Verron. Subgrid-Scale Eddy Parametrization by Statistical Mechanics in a Barotropic Ocean Model. *J. Phys. Oceanogr.*, 28, 1017-1042, 1998.

$$\frac{\partial \overline{\omega}}{\partial t} + J(\overline{\psi}, \overline{q}) = A_E \nabla^2 \overline{\omega} + \frac{A_E}{\mu}(\omega^* - \omega)$$

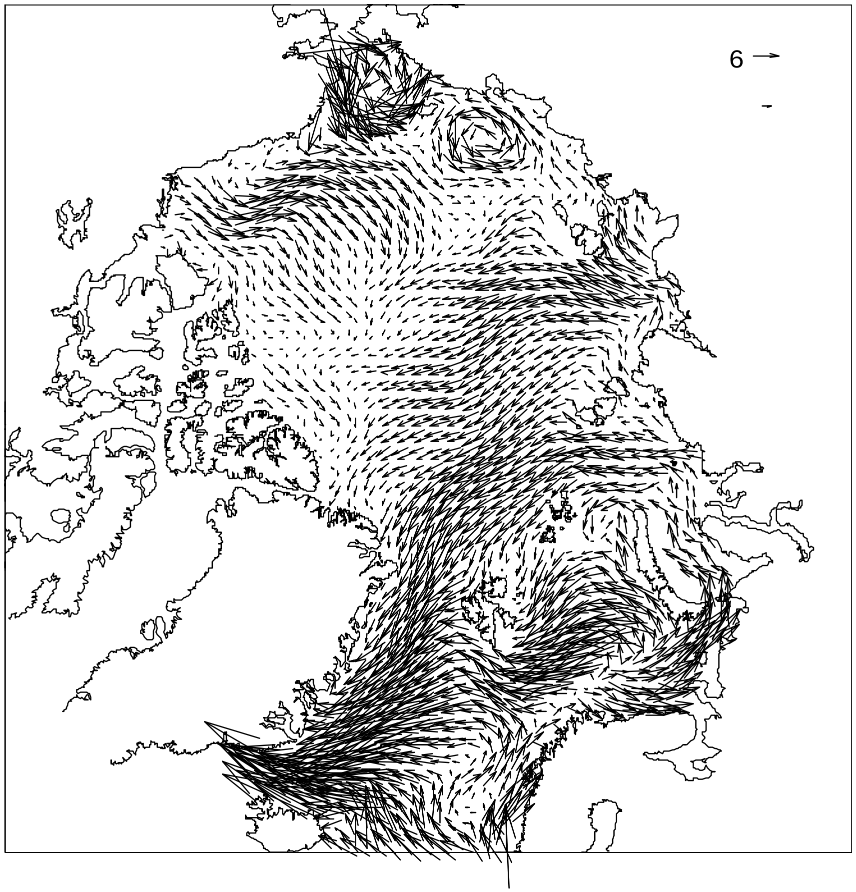
I. Polyakov. An Eddy Parameterization Based on Maximum Entropy Production with Application To Modeling of the Arctic Ocean Circulation. J. Phys. Oceanogr., 31, 2255-2270, 2001.

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv = -g\frac{\partial z}{\partial x} + \nabla A \nabla u + F_u + AfD^{-1}\frac{\partial D}{\partial y} + \frac{1}{2} gAb(t)D^2\overline{q}^2 f^{-1}\frac{\partial z}{\partial y}$$

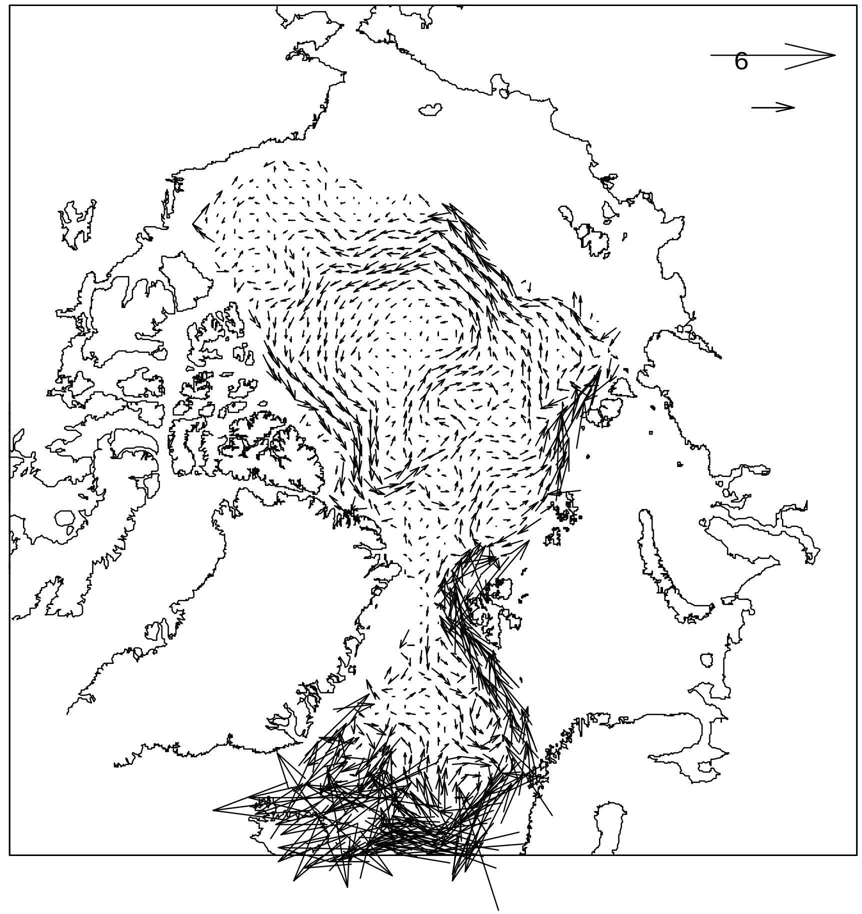
$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + fu = -g\frac{\partial z}{\partial y} + \nabla A \nabla v + F_v - AfD^{-1}\frac{\partial D}{\partial x} - \frac{1}{2} gAb(t)D^2\overline{q}^2 f^{-1}\frac{\partial z}{\partial x}$$

D – total depth, $A \propto h\langle u \rangle \langle D \rangle$

Velocity 0m. February 1978.



Velocity 500m. August 1978.



SUMMARY