P1.4 OCEAN CIRCULATION AND SHELF-BASIN EXCHANGES IN THE CANADA BASIN FROM A HIGH RESOLUTION MODEL

Waldemar Walczowski*, Wieslaw Maslowski, Douglas C. Marble, and Albert J. Semtner
Naval Postgraduate School, Monterey, CA 93943.

1. INTRODUCTION

The geographical focus of our study is on the Chukchi/Beaufort shelves and on the deep Canada Basin. Our main scientific goal has been to contribute toward understanding of the governing processes involved in shelf-basin communication. Results from a high-resolution coupled Arctic Ocean and sea ice model are analyzed to describe the water circulation and exchanges in the Canada Basin and the adjacent shelves. The model has been developed and maintained at NPS. Its characteristics are:

- Ocean Model: regional adaptation of Parallel Ocean Program (POP) (Smith et al.,1992);
- Sea Ice Model: parallel version of Hibler (1979) dynamic-thermodynamic model using viscous-plastic rheology (Zhang et al., 1999);
- Model Grid: Pan-Arctic with resolution of 1/6° (~18 km) and 30 layers;
- Forcing: ECMWF 1979-1993 reanalysis, operational products for 1994 – 1998, Levitus monthly mean surface and lateral boundary T&S climatology, and daily averaged annual cycle of river runoffs;
- Integration: a 200-year run forced with 1990-1994 followed by a 20-year integration with the repeated 1979 annual cycle and a 20-year run using interannual forcing for 1979-98 (Maslowski et al., 2000; Maslowski et al., in press). ·

2. CANADA BASIN GENERAL CIRCULATION

Temperature and salinity fields reflect the effects of wind and baroclinicity. Bottom topography considerably modifies structure of the thermohaline fields and currents pattern. A transect across the Canada Basin (see Fig.2 for the location) from the Northwind Ridge (left) to the Banks Island (right) shows (Fig.1) an example of the hydrographic structure and currents of the Canada Basin. Three distinct water layers can be identified:

- A thin, cold and low salinity, mixed surface layer (approximately 0-70 m) is a combination of Pacific Water, meltwater and river runoff;
- A thick, salty and relatively warm intermediate layer (100-1500 m) formed by Atlantic Water and modified by the entrained shelf waters;
- A cold and salty deep and bottom layer waters.

The strong halocline constitutes a boundary between upper and intermediate layer. Despite the temperature inversion, the vertical density gradient is strong: from about σ_θ=24 kg/m^3 at the surface to σ_θ=~27.7 kg/m^3 at depth of 200 m. Intermediate and deep waters are separated at depths 1200 – 1800 m by a weak thermocline.

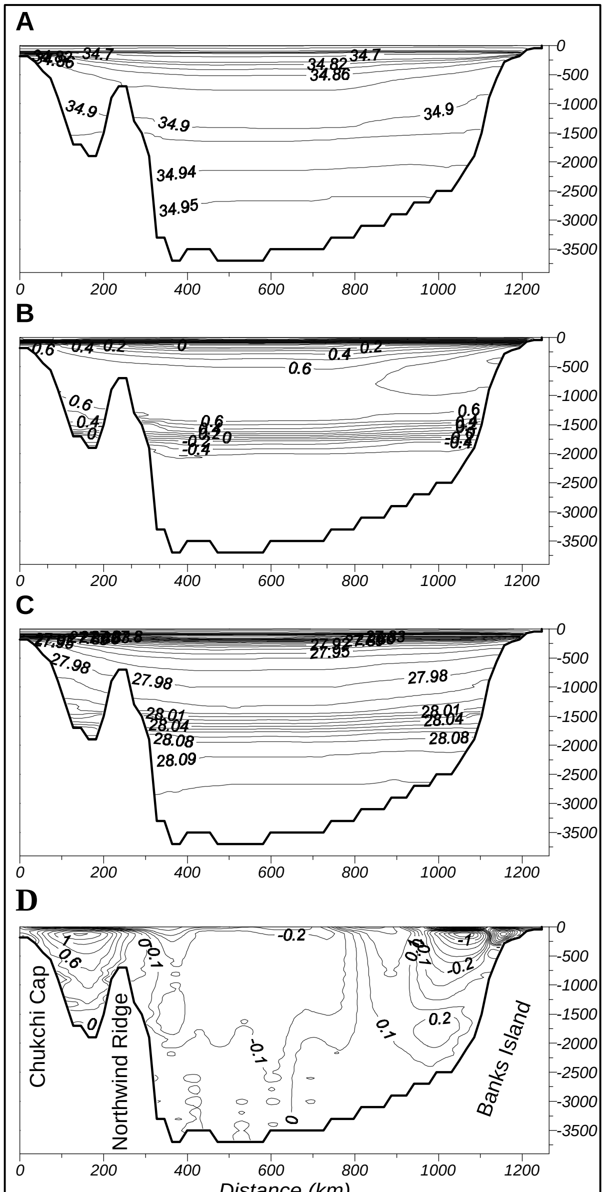

Figure 1. A vertical transect across the Canada Basin in January 1992. (A) Salinity (psu), (B) Temperature (°C), (C) Sigma-è, (D) Velocity fields. Positive velocities indicate currents towards the paper (northeastern direction).

· *Corresponding author address:
Waldemar Walczowski, Naval Postgraduate School, Dept. of Oceanography, Code OC/WA, 833 Dyer Road, Monterey, CA 93943,email waldekw@oc.nps.navy.mil
Also: Institute of Oceanology Polish Academy of Sciences, 81-712 Sopot,
Powstancow Warszawy 55, Poland

A schematic circulation of water masses in the Canada Basin region may be described by a superposition of the three-layer circulation driven by the atmospheric and thermohaline forces. In the deep layer an upward tilt of isopycnals in the mid-basin indicates a cyclonic circulation. At these depths the modeled currents are slow, less than 0.2 cm/s, with local maxima near the deep slope regions. This occurs in particular in the eastern, Canadian part of the transect, at depths 1500-2200 m. The deep circulation is weak, but it extends over a significant portion of the lower water column, so it represents a considerable volume transport. This transport, below 1500 m depth, amounts to around 0.5 Sv in each direction.

The structure of the density field within the intermediate layer indicates an anticyclonic, geostrophically balanced circulation. The uplift of the isohaline surfaces near the continental margins represents a relatively strong anticyclonic boundary current along the basin's boundaries. Velocities of order 5 cm/s or more are present in the boundary current.

The surface layer circulation over the shelves is mostly atmospherically driven and changes synoptically.

3. THE MEAN CIRCULATION

The general model circulation in the Canada Basin is shown in Fig. 2, as the vertically-integrated (from the surface to the bottom) and time-averaged (over the period 1979-1998) flow. It represents the time-mean volume transport per unit width.

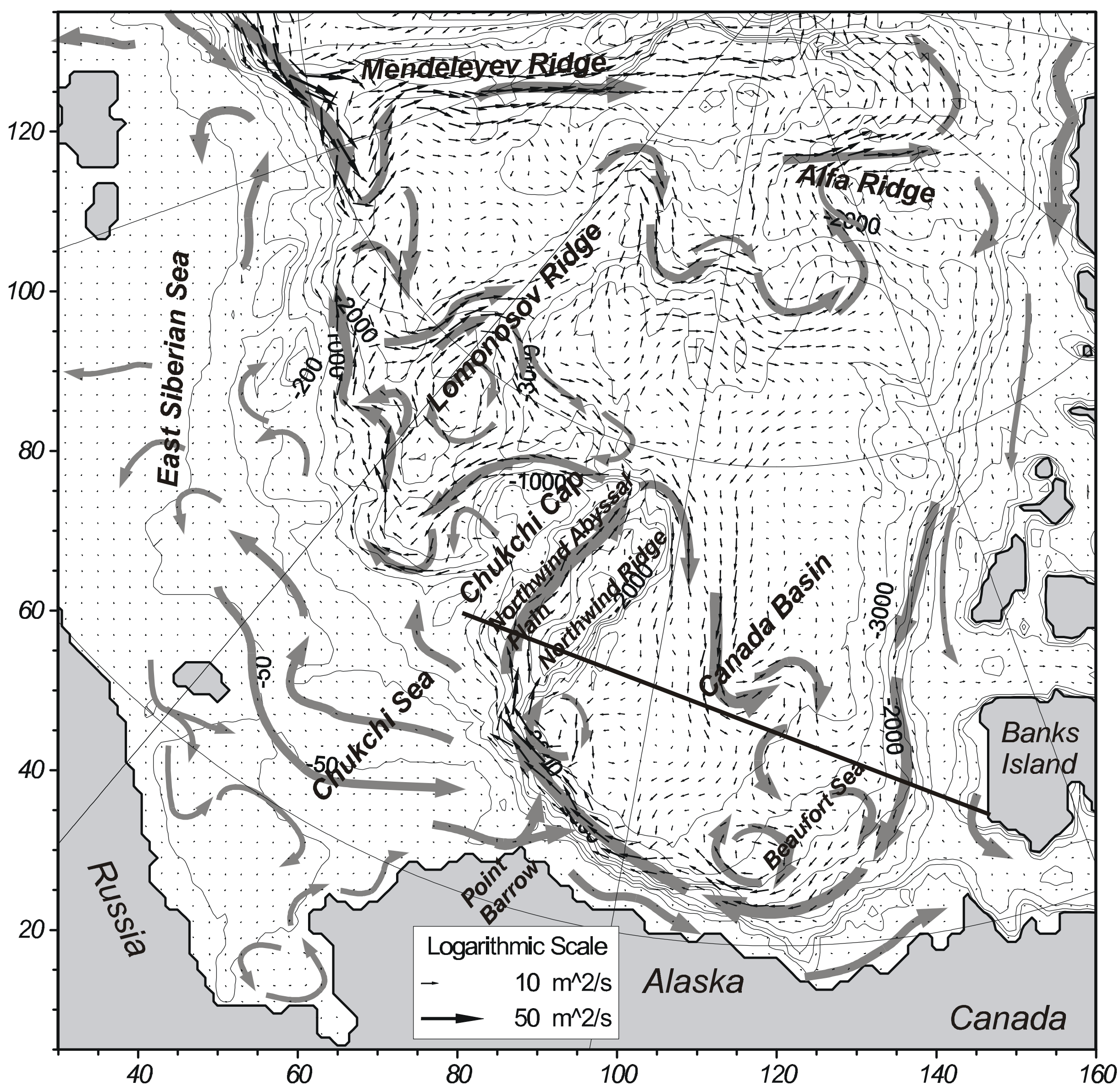

Figure 2. General water mass transport in the Canada Basin. Mean currents from period 1979-1998 are integrated vertically from the surface to the bottom.

The mean volume transport is dominated by the bottom topography steered flows along the slopes of continental shelves and underwater ridges. A large anticyclonic gyre occupies the Canadian Basin. It consists of the boundary currents flowing along the slopes of the northwestern Alpha Ridge, the Canadian Archipelago and the Alaskan margins, towards the Northwind Ridge. There the mean boundary flow enters the Northwind Abyssal Plain and follows between the Chukchi Cap and the Northwind Ridge. Upon reaching the northern end of the Chukchi Cap, the flow bifurcates. One branch rounds the northern and western side of the cap. This water feeds boundary currents that meander along the shelf slope of the East Siberian Sea towards the Lomonosov Ridge, to eventually close the anticyclonic circulation in the area of Alpha Ridge. The second branch of the water, which leaves the Northwind Abyssal Plain turns to the east and then to the south into the Canada Basin. There it merges with the main southward inflow into the deep Canada Basin originating somewhere from the center of the Alpha-Mendeleyev Ridge. The deep Canada Basin is dominated by the S-shaped meander system. Numerous mesoscale eddies persist in the southern part of the Canada Basin.

On the Chukchi shelves water of the Pacific origin is transported northward from the Bering Strait region, along the Alaskan coast by the Alaska Coastal Current. This mean transport splits into three branches in the vicinity of Barrow Point. One branch contributes towards an eastward advection of surface waters over the Beaufort shelf. The northward branch carries waters along the Barrow Canyon directly into the deep basin. The last branch turns westward along the upper slopes of the Chukchi Sea. In the central Chukchi Sea, to the south of this latter branch, an eastward flow exists. The vertically integrated volume transport over the shelves is much smaller than over the deep basin.

4. TEMPORAL VARIABILITY

The large-scale currents change significantly during the 20-year time period of simulation. The cyclonic and anticyclonic modes of circulation are identified. A shift from the anticyclonic to cyclonic mode of circulation is observed between the 1980s and the early 1990s. During this period the Arctic Oscillation index has increased significantly. The decrease of this index in the late 1990s results in a clear reversal of the large-scale circulation pattern back towards the anticyclonic regime (Maslowski at al., in press).

During the period of the anticyclonic mode the main inflow into the Canada Basin originates in the central Alpha-Mendeleyev Ridge region, along the Canadian Archipelago. The anticyclonic circulation along the deep slope of the Beaufort Sea is strong and wide. The main outflow occurs between the Northwind Ridge and the Chukchi Cap. The anticyclonic circulation exists both in the surface and intermediate layer, which results in higher (relative to the cyclonic mode of circulation) water transport within the Canada Basin.

During the period of the cyclonic mode of circulation major inflow into the Canada Basin takes place at both layers along the shelf slopes of the Laptev and East Siberian Sea, Chukchi Cap, and Northwind Ridge. In the Beaufort Sea, significant differences exist between the circulation at the surface and intermediate layers. The surface layer circulation over the shelf and upper slope is cyclonic. An increased outflow into the Canadian Archipelago is evident. The mean intermediate layer flow over the Beaufort slope is still anticyclonic but weak and includes many mesoscale eddies and meanders.

The volume transport along the Alaskan shelf-break changes over that time significantly. The net volume transport across the section perpendicular to the slope roughly to the north of Prudhoe Bay varies from 1.8 Sv to the west in 1980 (anticyclonic mode) to –0.2 Sv in 1992 (cyclonic mode). Even in the 1990s, the anticyclonic (westward) component of the flow exists within the boundary current and it transports more than 0.4 Sv of water in the intermediate layer. The absolute magnitude of the eastward component of the transport reaches maximum of ~0.8 Sv during the year 1993.

5. SHELF BASIN EXCHANGES

Pacific Water entering to the Arctic Ocean through the Bering Strait is modified on the Chukchi, East Siberian and Laptev shelves and maintains the upper halocline. The lower halocline is derived from the modified Atlantic Water [Smethie at al., 2000]. Modified pacific waters enter the Canada Basin mostly through the Barrow Canyon [Münchow and Carmack, 1997].

There is a strong seasonal variability of the modeled water exchanges. The northeastward volume transport through the Barrow Canyon reaches maximum of 0.15 Sv every winter, in January-February. The maximum on-shelf transport reaches 0.15 Sv and occurs almost every fall. In addition, an interannual variability of the volume transport through the Barrow Canyon exists. The maximum offshore transport occurs during the cyclonic mode of circulation.

An increased eddy activity is observed over the Chukchi/Beaufort slopes. Particularly, an intensification of this mesoscale activity occurs during the cyclonic mode of circulation, in the early 1990s. Meanders with a diameter of 100 -150 km originate in the Barrow Canyon region and slowly propagate eastward along the Beaufort slope, upstream of the anticyclonic circulation. Cyclonic meanders are baroclinic in nature and they represent a significant upward displacement of the Atlantic Water. Modeled perturbations are long lasting and they exist at least few years. Some of the meanders evolve into eddies. They break off the mean current and move toward the central Canada Basin. These mesoscale features appear to be an important mechanism of shelf-basin interaction.

Results from the experiment with numerical tracers of river runoff and Pacific Water also show that the cyclonic mode of circulation promotes increased shelf-basin exchanges between the Chukchi/Beaufort Seas and the Canada Basin. The influx of Pacific Water into the Canada Basin in 1992 (Fig.3) provides a clear example of these type of activities. Transport through

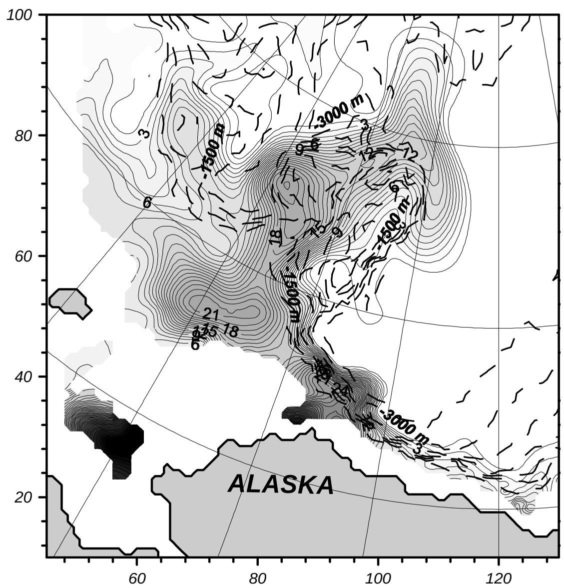

Figure 3. Horizontal distribution of the Pacific Water tracer at depth 45 - 70 m. September 1992.

the Barrow Canyon increases during that time. The outflow from the canyon bifurcates as it enters the deep basin. As represented by the tracer shown in Fig. 3, part of this water circulates cyclonically along the Beaufort Sea slope. However, in spite of the cyclonic regime, most of the shelf water entering through the Barrow Canyon advects westward. It passes across the deep gap between the Northwind Ridge and the Chukchi shelf and moves along the Northwind Abyssal Plain. Then it turns to the east and flows towards the central Canada Basin.

CONCLUSIONS

Results from the 18-km model show complex hydrographic and dynamic structures with high spatial and temporal variability in water properties, currents, and volume transports. The circulation pattern in the Canada Basin strongly depends of the atmospheric mode of circulation, but it is predominately anticyclonic. The cyclonic mode of circulation promotes increased shelf-basin exchanges and transport of the shelf water into the deep basin. The Barrow Canyon plays an important role in the shelf-basin communication. It influences the circulation in several ways. First, it is the main advection pathway of water of Pacific origin. Second, this bottom topography combined with the buoyancy fluxes from the Chukchi shelf, contribute to mesoscale eddy formation.

REFERENCES

Aagaard, K., and E.C. Carmack, *The Arctic Ocean and Climate: A Perspective,* in *The Polar Oceans and Their Role in Shaping the Global Environment*, O.M. Johannessen, R.D. Muench, J.E. Overland, Eds, pp 4-20 Gephys. Monogr. 85 AGU, 1994.

Aagaard, K., and A.T. Roach, *Arctic Ocean-Shelf Exchange: Measurements in Barrow Canyon*, J. Geophys. Res. Vol. 95, 18,163-18,175, 1990.

Häkkinen, S., C.A. Geiger, *Simulated low-frequency modes of circulation in the Arctic Ocean*. J. Geophys. Res.,105, 6549-6564, 2000.

Maslowski, W., D.C. Marble, W. Walczowski, A.J. Semtner, *On Large Scale Shift in the Arctic Ocean and Sea Ice Conditions during 1979-1998*, Annals of Glaciology, in press.

Maslowski, W., B. Newton, P. Schloser, A.J. Semtner, and D.G. Marrison, *Modeling Recent Climate Variability in the Arctic Ocean*, Geophys. Res. Lett. Vol.27, No.22, pp.3743-3746, 2000.

McLaughlin, F.A., E.C. Carmack, R.W. Macdonald, and J.K.B. Bishop, *Physical and geochemical properties across the Atlantic/Pacific water mass front in the southern Canadian Basin*, J. Geophys. Res., 101(C1), 1183-1197, 1996.

Münchow, A., and E.C. Carmack, *Synoptic flow and density observations near an Arctic Shelf Break*. J. Geophys. Res., 27, 1402-1419, 1997.

Rudels B., E.P. Jones, L.G. Anderson and G. Kattner, *On the Intermediate Depth Waters of the Arctic Ocean,* in *The Polar Oceans and Their Role in Shaping the Global Environment*, O.M. Johannessen, R.D. Muench, J.E. Overland, Eds, pp 4-20 Gephys. Monogr. 85 AGU, 1994.

Smethie, W.M. Jr., P. Schlosser, G. Bönisch, *Renewal and circulation of intermediate waters in the Canadian Basin observed on the SCICEX 96 cruise*. J. Geophys. Res., *105*, 1105-1121, 2000.

Smith, R.D., J.K. Dukowicz, and R.C. Malone, Parallel ocean general circulation modeling, Physica D, 60, 38-61, 1992.

Thompson, D.W.J. and J.M. Wallace, *Arctic Oscillation signature in the wintertime geopotential height and temperature fields*. Geophys. Res. Letters, 25(9), 1297-1300, 1998.

Proshutinsky, A.Y., M.A. Johnson, *Two circulation regimes of the wind-driven Arctic Ocean.* J. Geophys. Res., *102*, 12493-12514, 1997.

Weingartner T.J., D.J. Cavalieri, K. Aagaard, Y. Sasaki, 1998: *Circulation, dense water formation, and outflow on the northeast Chukchi shelf*., J. Geophys. Res., *103*, 7647-7661.

Zhang, Y., W. Maslowski, and A.J. Semtner, Impact of mesoscale ocean currents on sea ice in high resolution Arctic ice and ocean simulations, J. Geophys. Res., 104(C8), 18,409-18,430, 1999.