Anomalous circulation in the Pacific sector of the Arctic Ocean in July-December 2008

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Objective: To analyze circulation and interannual variability of the freshwater pathways in the Pacific sector of the Arctic Ocean during the International Polar Year and previous years

Introduction: During the last decade, the Pacific sector of the Arctic Ocean (AO) has experienced a pronounced environmental change. The most well-known events have been tremendous ice retreats in 2007 and 2012. Morison et al. (2012) argued that the observed BG freshening is caused by the increased sea ice melting and changes of the pathways of the Eurasian river runoff. The 4Dvar data assimilation approach (DA) allows accurate reconstruction of the circulation through the assimilation of all available observations. We apply a hybrid SIOM-PIOMAS data assimilation approach and reconstruct the circulation during the 2008, and previous decades (1972-1978, 1989-1996, 1997-2006) and for 2003, 2004, 2005 and 2006. Analysis of the reconstructed circulations will allow to analyze interannual variability of the Fresh Water (FW) content and identify the factors responsible for the observed changes.

Models and approach:

1. *Semi-Implicit Ocean Model (SIOM)* was designed specifically for the implementation of 4D-Var methods into regional models controlled by currents at the open boundaries and by surface fluxes. SIOM is a modification of the Madec *et al.*, [1999] model. The SIOM 4D-Var data assimilation system has been implemented successfully for the reconstruction of the summer circulation in the Chukchi and Bering seas (Panteleev *et al.*,2010, 2016)
2. *Pan-Arctic Ice-Ocean Modeling and Assimilation System (PIOMAS)* was developed at the Polar Science Center, University of Washington. This is a coupled parallel ocean and sea ice model capable of assimilating sea ice concentration and velocity data. PIOMAS is configured to cover the region north of 43°N. The model grid is based on a generalized orthogonal curvilinear coordinate system with the northern grid pole displaced into Greenland.

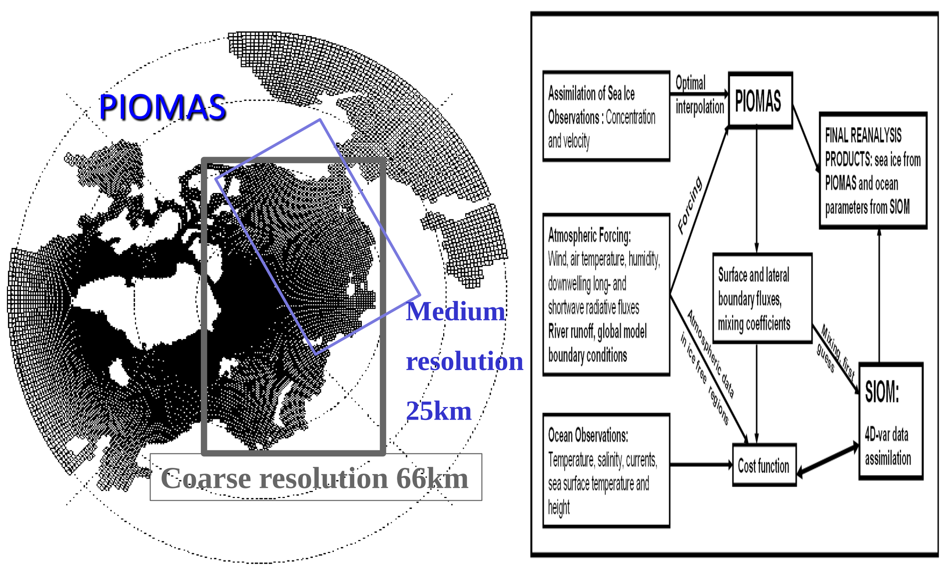


Figure 1. Model configuration and data flow chart for the data assimilation procedure

Data 2008 Jul-2010 Dec

1. Hydrophysical data (IARC, IPY database)

a)T,S –CTD,ITP, POPS

b) Bering Strait Transport (R. Woodgate)

2. Surface fluxes from PIOMAS

3. Ice concentration and velocity

4. Sea Surface Temperature (OSTIA)

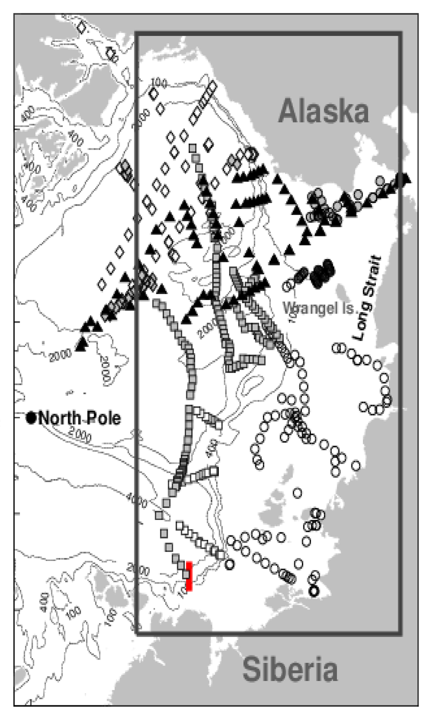


Figure 2. PSAO model domain (solid rectangle) with hydrological stations assimilated into SIOM. during July-December 2008

Observations and reconstructed circulations for 1972-1978, 1989-1996, 1997-2006

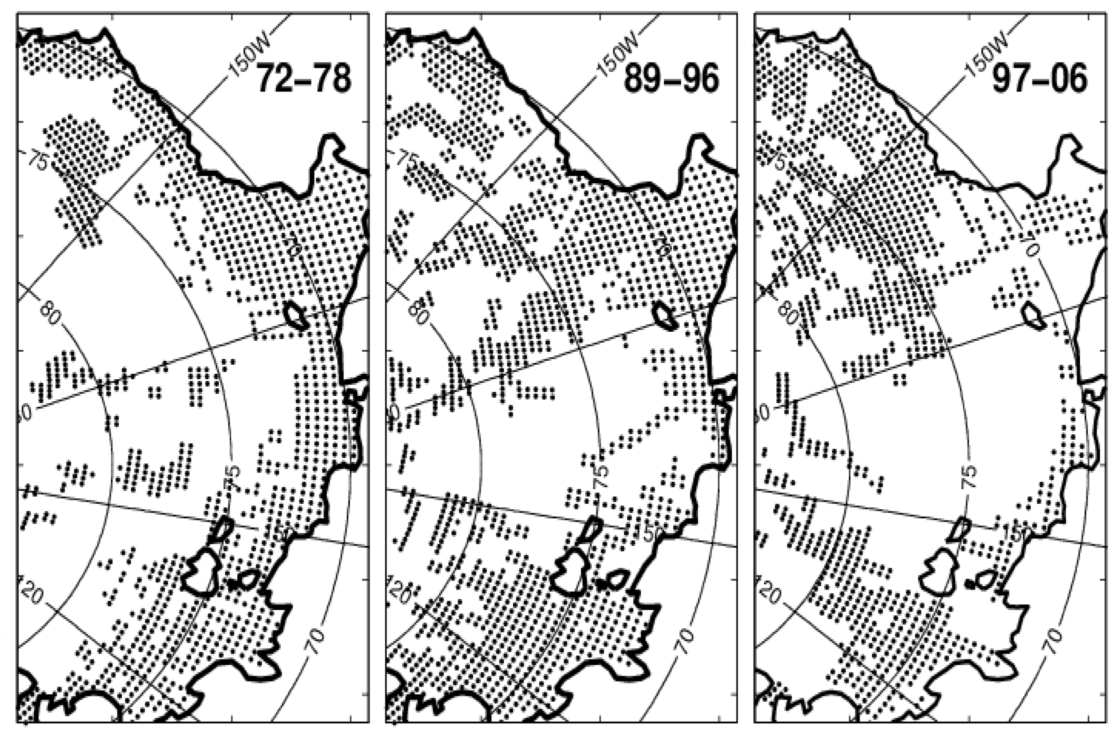


Figure 5. Spatial distribution of the AARI data during three multi-year assimilation periods.

www.whoi.edu/science/PO/arcticgroup//projects/andrey_project2/resultsAP.html

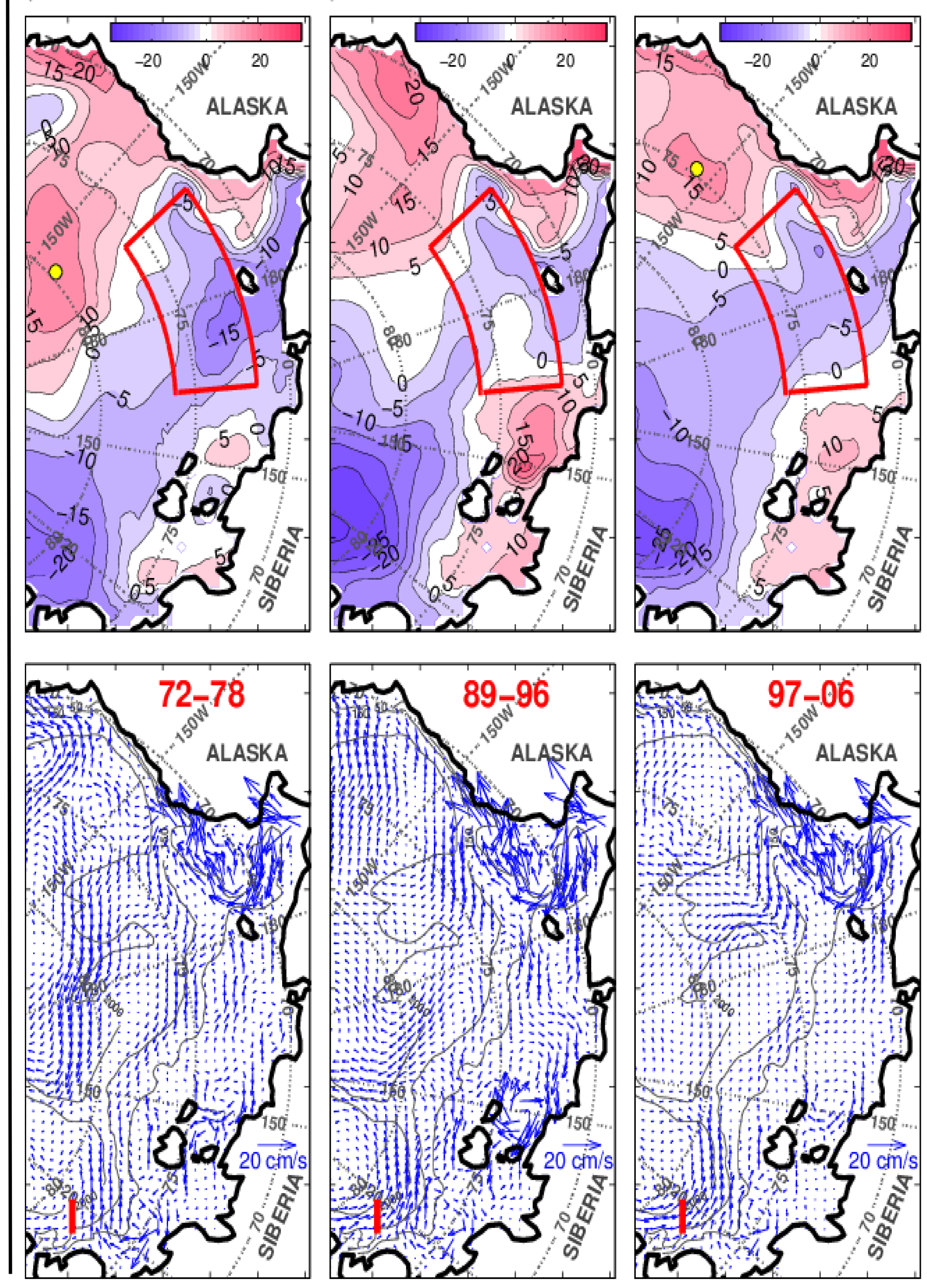


Figure 6. The mean SSH (cm, upper panels) and surface velocity (cm/s, lower panels) fields corresponding to the three phases of the AOO: A1 (1972-1978), C1 (1989-1996) and A2 (1997-2006). The red vertical line near 120°E indicates the section across the continental shelf break where the total transport has been computed. The SSH averaging area is marked by the red rectangular sector. Yellow circles denote the BG center locations.

Basic features of the PSAO 2008 circulation :

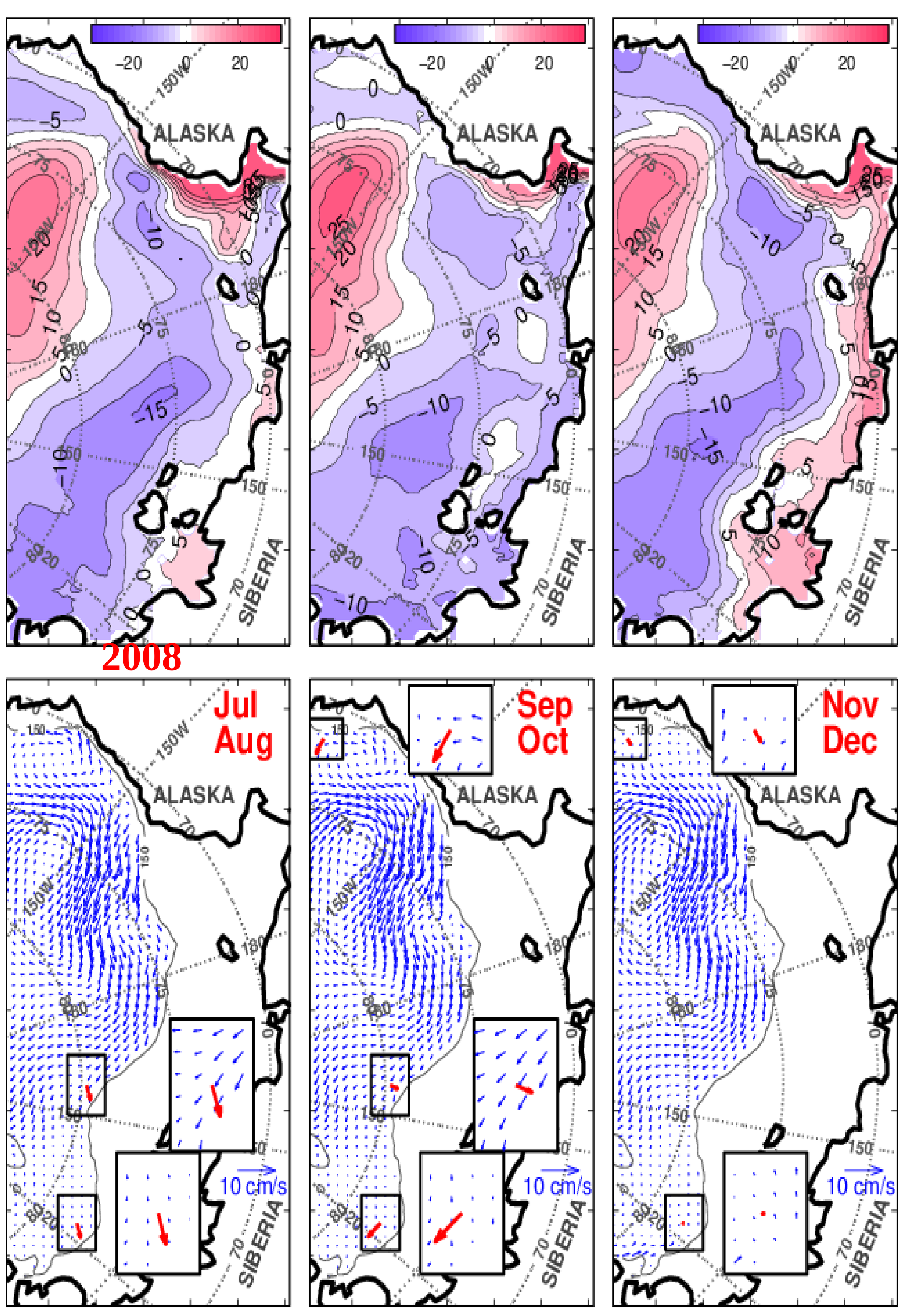
a) Anticyclonic AOO phases (72-78, 97-06 are characterized by a more pronounced BG with maximum SSH values of 18 and 16 cm, respectively.

b) Our results indicate a general increase C3of the total transport in this region from 2.1 Sv (72-78) to 1.5 Sv (C1) to 2.8 Sv during 97-06

c) Anticyclonic AOO phases (72-78, 97-06 are characterized by a more pronounced BG with maximum SSH values of 18 and 16 cm, respectively.
d) It is worth noting that during the 72-78 and 97-07 periods, there is more profound SSH depression than during the 89-96 period.

Observations and reconstructed circulations for 2008

Figure 3. Bi-monthly (Jul-Aug, Sep-Oct, Nov-Dec) averaged PIOMAS SSH (cm, upper panels) and circulation (lower panels) in 2008. Red arrows in boxes show mean velocities measured byNABOS moorings during the respective periods.

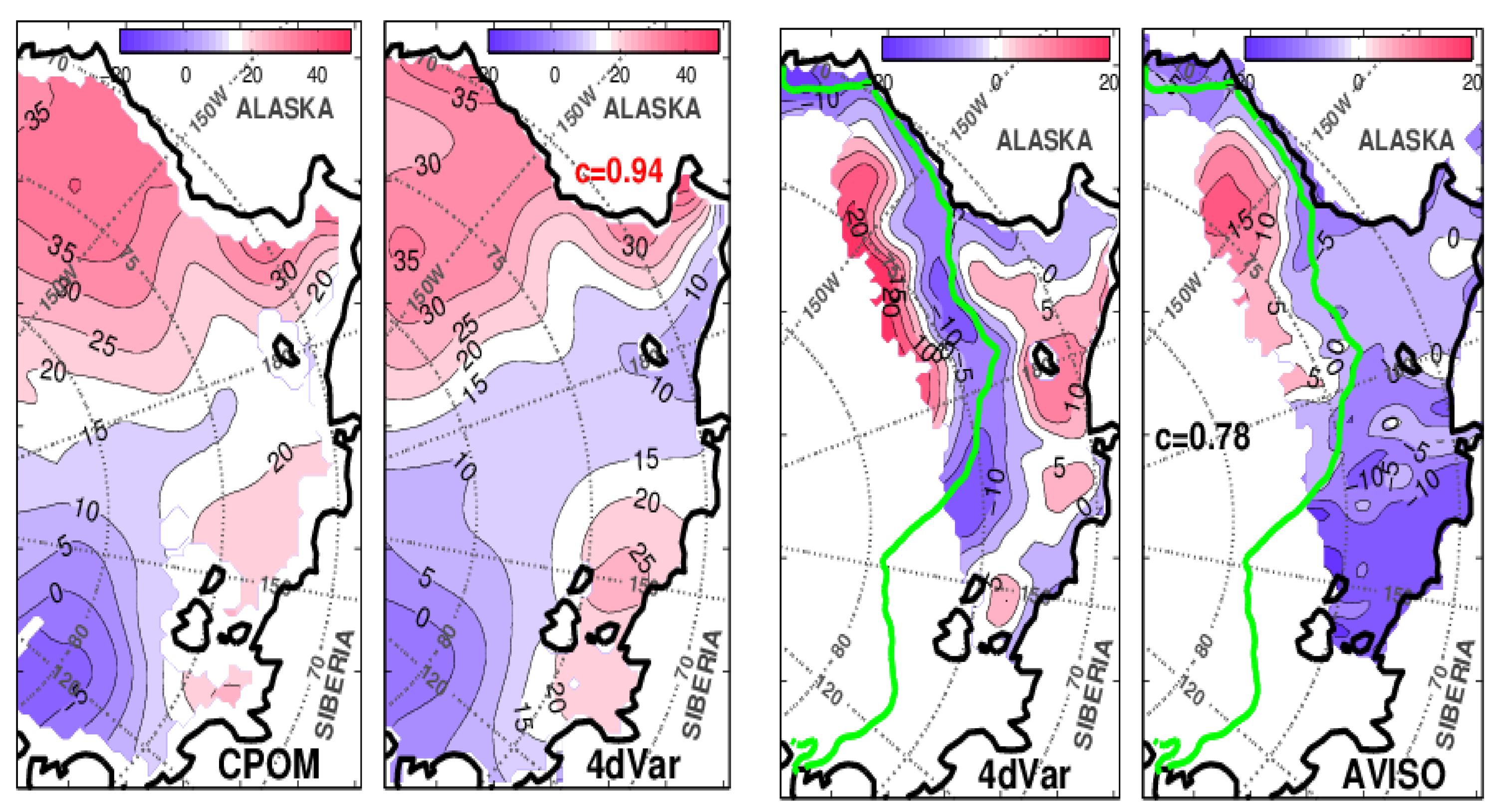


Basic features of the PSAO 2008 circulation :

a) A reversal of the total transport in the AW inflow region of -2.9 Sv in July-August which later relaxed to an eastward transport of 0.8-1 Sv. Agrees with NABOS observations.
b) Formation of a prominent SSH trough extending from the eastern Laptev Sea to the Bering Strait. Correlates with the Bering Strait transport.

Validation SIOM 2003 & 2008 SSH against CPOM-DOT & AVISO SSHA

Figure 7. Bi-monthly average of the CPOM-DOT (left) and the corresponding 4Dvar SSH (right) during September-October 2003.



Freshwater Content

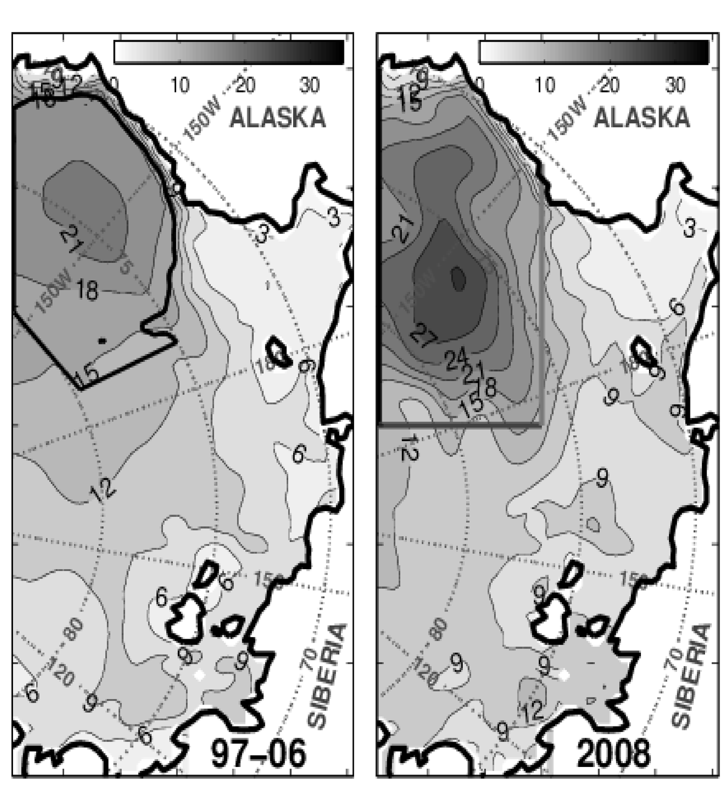
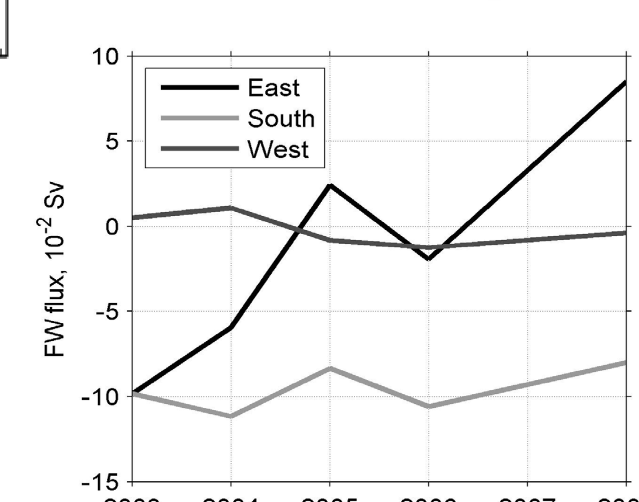


Figure 9. Maps of the average FW content (m) of the 4Dvar reconstruction during September-October 1997-2006 and 2008. The three gray lines in the right panel show the eastern, western and southern sections used for estimating the FW transports

Figure 10. The interannual variation of the mean FW transports during July-December 2003-2008 through the three boundaries of the Beaufort Gyre. Line colors correspond to the coloring in Figure 9.

Interannual variability of Freshwater Transport



Validation (PIOMAS & SIOM)2008 circulation:

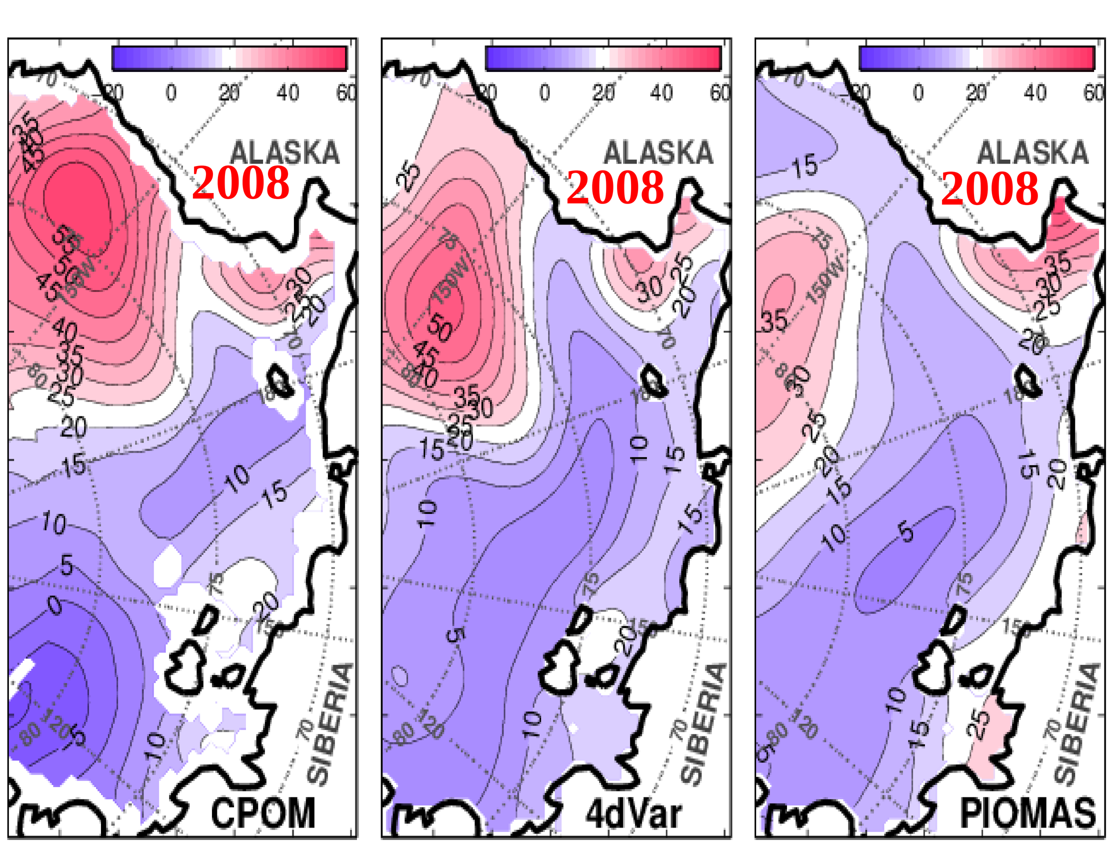


Figure 4. Averages of the CPOM-DOT (left), 4dVar (center) and the PIOMAS SSH during September-October 2008

Lagrangian trajectories in different periods

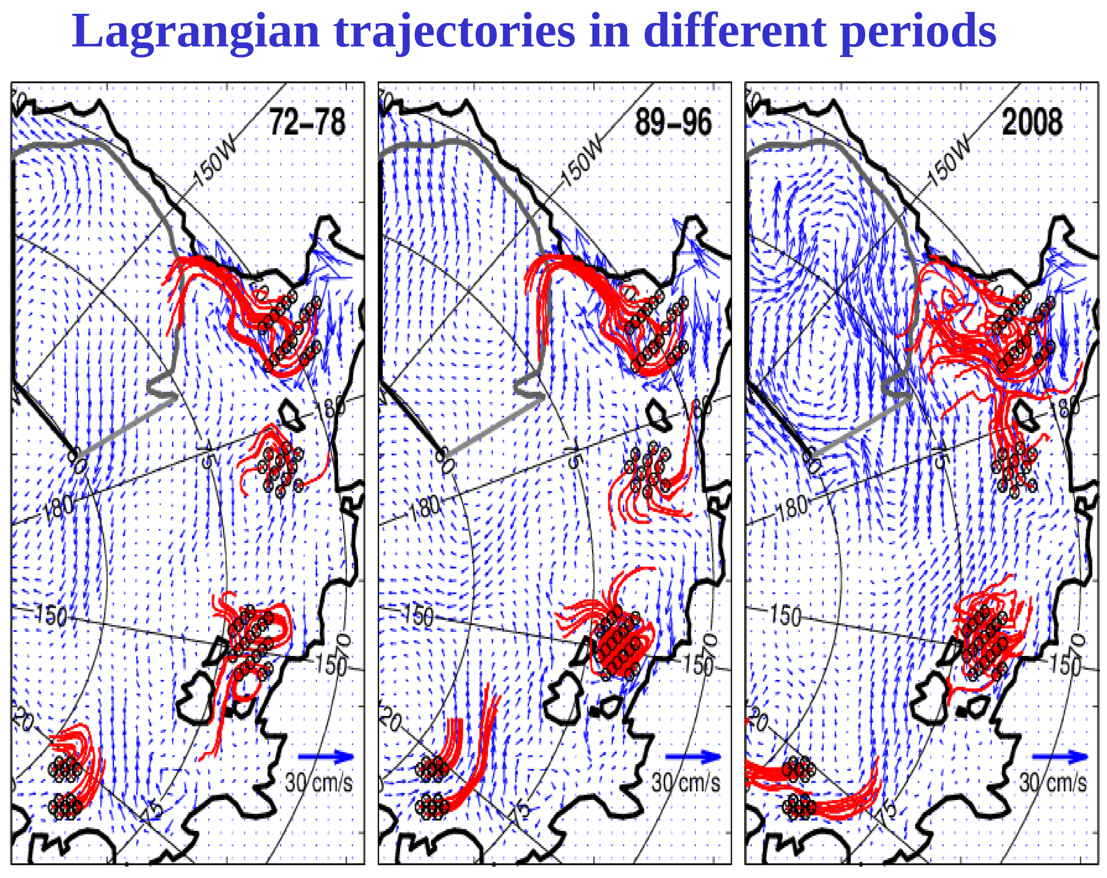


Figure 11. The 6-month trajectory of the water parcels launched on July 1 at a 10m-depth in different years superimposed on the velocity fields averaged over respective periods. The BG integration area is shown.

Conclusions:

1. Validation of the results against independent SSH and velocity observations demonstrated a significantly better consistency with the data compared to the PIOMAS system, whose output was utilized as a first guess solution for subsequent 4dVar analysis.
2. The 4dVar reanalysis for periods of 72-78, 89-96, and 97-06, support and further quantify the concept of Proshutinsky and Johnson (1997). Our results indicate that AOO + phases are characterized by a larger inflow into the PSAO along the continental slope of the Laptev Sea, which brings the AW and tends to increase the total salt content in the Canadian Basin over a long term perspective.
3. We found indications of FW accumulation in the East Siberian Sea during the cyclonic AOO phase (1989-1996) compared to the positive AOO phases (1972-1978, 1997-2006). This process has a prominent SSH signature in the form of a 15-20 cm high dome emerging in the western ESS (central panel in Figure 4). Quantitative estimates show an increase of FW content in the ESS by 10% (500 km^3) during the negative AOO phases.
4. Analysis of the circulation and FW content in BG during 2003-2006, and 2008 indicate:

a) A reversal of the total transport in the AW inflow region of -2.9 Sv in July-August which later relaxed to an eastward transport of 0.8-1 Sv

b) Formation of a prominent SSH trough extending from the eastern Laptev Sea to the Bering Strait. A similar and even stronger structure was obtained in the PIOMAS solution and is indirectly evidenced by two NABOS moorings located on the continental slope of the Laptev Sea. The 2008 SSH depression also agrees with the analysis of the force balance in the Bering Strait, revealing an increased role of the pressure head between the Bering Sea and Arctic Ocean during 2007-2011 (Woodgate et al., 2012).

c) A significant increase of the FW content in the Beaufort Gyre from 16,700 km^3 in 2003 to 21,500 km^3 in 2008. The analysis of the FW transports across the BG boundaries indicate that FW accumulation in 2004-2008 was mainly caused by the anomalous inflow through the eastern section that changed from -0.1 Sv in the beginning of 2003 to 0.8 Sv inflow in 2008.

d) Weak interannual variability of the flow through the southern section suggests that changes of the FW pathways from the ESS as well as a certain increase of the Bering Strait transport provides only a minor contribution to the emergence of the FW anomaly in the Beaufort Gyre in 2008. Furthermore, the Lagrangian analysis and the above mentioned reduction of the FW flux through the southern section in 2008 suggests that the FW transport from the ES and Chukchi Seas into BG in 2008 was less than in 2003-2005.