INFLUENCE OF MELTING GLACIERS ON HYDROCHEMICAL STRUCTURE OF COASTAL EOCOSYSTEM OF WESTERN SPITZBERGEN

Alexander Polukhin, Shirshov Institute of Oceanology, Russia
Evgeniy Yakushev, Norwegian Institute for Water Research, Norway
Petr Makkaveev, Shirshov Institute of Oceanology, Russia
Elizaveta Protsenko, Shirshov Institute of Oceanology, Russia
Shamil Yakubov, Shirshov Institute of Oceanology, Russia
Andre Staalstrøm, Norwegian Institute for Water Research, Norway
Svetlana Stepanova, Shirshov Institute of Oceanology, Russia
Pavel Khlebopashev, Shirshov Institute of Oceanology, Russia
Marit Norli, Norwegian Institute for Water Research, Norway
Hans-Frederik Braaten, Norwegian Institute for Water Research, Norway

polukhin@ocean.ru

The goal of this work was to evaluate a potential influence of the melting glacier on the hydrochemistry of the surrounding coastal waters. The studies were based on 2 expeditions to the Tempelfjord (Western Spitzbergen) performed in winter 2014 and in summer 2015 when there were measured hydrophysical, chemical and biological parameters in the sea water, coastal discharge and the sea ice. Obtained results of the research show that the glacier runoff has a clear impact on the hydrochemical structure of the fjord waters not only in warm season, but in cold seasons as well.

Key words: Arctic Ocean, coastal ecosystem, glacier runoff, water structure, carbonate system, nutrients, Spitzbergen

I. INTRODUCTION

Impact of climate change have already been reported in the Arctic Ocean, such as warming [1] decreasing ice-covered area [2], freshening [3], Arctic rivers discharge increase [4] and increasing surface carbon dioxide (CO_2) concentrations [5] with concomitant ocean acidification [6, 7, 8]. Observations and predictions show that declining summer sea ice cover, and increased river runoff to the Arctic Ocean, will likely modify several processes relevant for the freshwater and carbon budget which in turn also affect the high latitude marine ecosystem. The increase in atmospheric CO_2 and elevated oceanic CO_2 uptake, with the consequence of decreased pH and carbonate ion concentrations are expected to put further stress on marine organisms, in particular, calcifiers [9].

The largest ocean acidification signal (pH decline) in the world oceans is projected to occur in the relatively cold and fresh Arctic surface waters [6, 10]. In addition to direct effects of changes in pH and carbonate ion concentrations on marine organisms and ecosystems, there can also be indirect links, through changes in biogeochemical cycling of substances, especially nutrients and their bioavailability for primary production [11].

An overall goal of this work was to advance the knowledge of contemporary and future coastal ecosystem state in the Arctic Ocean. Throughout the project we aimed:

- To obtain new information on carbonate system parameters in the Arctic based on collaborative, Norwegian and Russian studies;
- To receive new knowledge on the influence of the ice on the biogeochemical and carbonate system parameter distributions on the base of the field studies in Spitzbergen (Templefjord);
- To intercalibrate Russian and Norwegian techniques of the carbonate system parameters determination.

II. MATERIALS AND METHODS

During the studies there were performed measurements of hydrophysical, chemical and biological parameters in the Tempelfjord at Spitzbergen (Fig. 1). The Tempelfjord is situated in the inner part of the enormous Isfjord at the west coast of the island. At the head a calving glacier called Tunabreen run into the Tempelfjord. The bathymetry of the fjord is relatively shallow in the inner part. The depth was 50 m 200 m from the calving glacier, and only 34 m 3 km from the glacier. A basin of depths of more than 100 m is found in the middle of the fjord near the mouth.

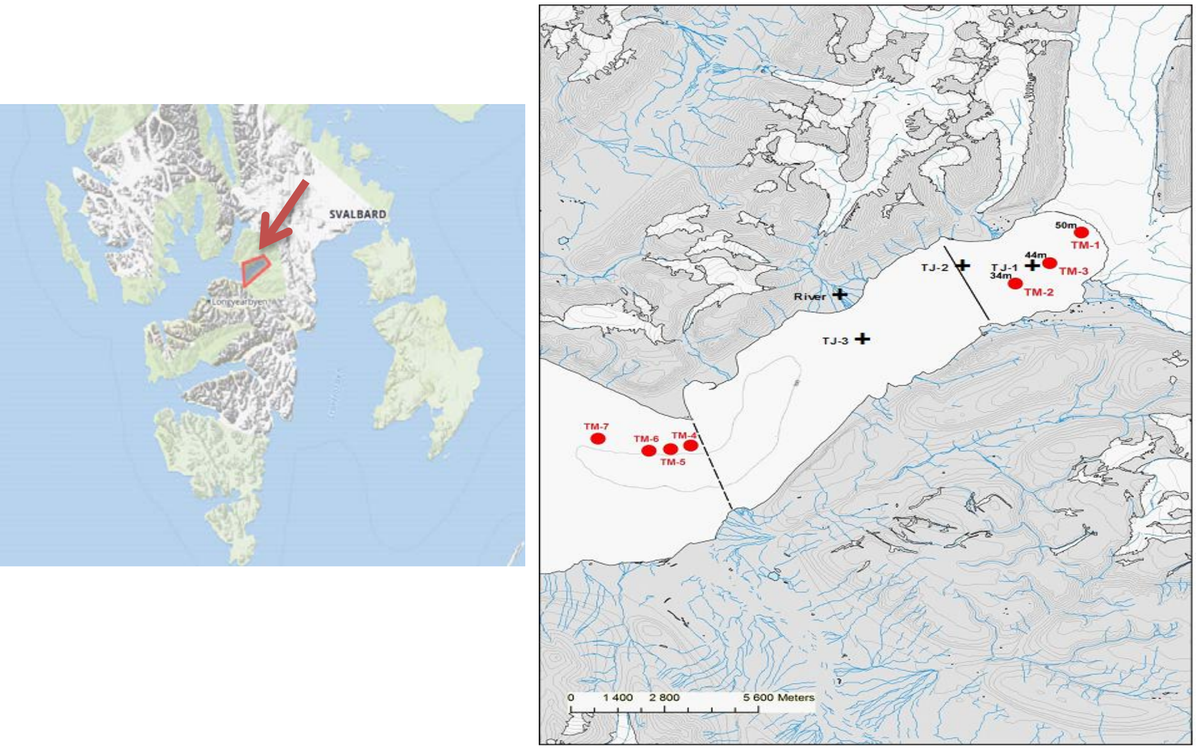

Fig.1 Research area on the map of Spitzbergen (left, red arrow) and position of the sites during expeditions (red for 2014 and black for 2015). The black strait line outside station TM-2 indicates the approximate position of the edge of the solid ice cover 18th March 2014. The dotted strait line just inside the station TM-4 indicate the position of the pancake ice 19th of March 2014

Expeditions have been based in Longyearbyen, from where we used to get to the place of sampling by snowmobiles (in the ice-covered part of the fjord), or by a boat in the open part of the fjord. Sampled water has been analyzed in the laboratory of UNIS (the University Centre in Spitzbergen, Longyearbyen) on the same day; some samples have been preserved and sent for further analysis in the NIVA laboratory. At the sites, located on the glacier, the ice cores were sampled first. Temperature was measured along the ice core with discreteness of 10 cm. Next they have been delivered to the lab, where were divided into several layers (usually three layers: the surface, the middle part and bottom). In the melted ice water samples were conducted the same analysis, as in the sea water.

The dataset of measured parameters in the winter (March 17-19, 2014) and summer (June 16-18 2015) periods included: temperature, salinity, pH, dissolved oxygen (O_2), total alkalinity (Talk), nitrate nitrogen (NO_3), silicate (Si), mineral phosphorus (PO_4), dissolved organic carbon (DOC). Determination of mentioned parameters was performed according to [12, 13, 14]. Total inorganic carbon (TIC), CO_3, HCO_3, pCO_2, Aragonite Saturation has been calculated from direct measurements of pH and Talk according to [15].

III. RESULTS

Winter expedition.

There is high vertical salinity gradient on sites TM-1 and TM-2 (Fig. 2, 3) 2 meters under ice cover. Temperature of the water column on both sites varies between -1.75 and -1.5 °C. Samples show high concentration of nutrients under the ice near the glacier on site TM-1 (Fig.2). 9.4 µM of NO_3, 25 µM of Si and 0.9 µM of PO_4 in the surface layer under the ice are forming good feeding base for ecosystem development, vertical structure of nutrient distribution under the halocline is homogenous. Dissolved oxygen (355µM), high pH (8.43 NBS) and low pCO_2 (200 ppm) on site TM-1 shows active biological processes of phytoplankton just under the ice as well. Carbonate parameters (Talk, TIC, HCO_3) in surface layer on TM-1 are 2339.8, 2200.8 and 2042 µM respectively; they are increasing towards outer part of the fjord. Ω_{ar} is higher under the ice cover near the glacier (see Fig. 2, 3, 4).

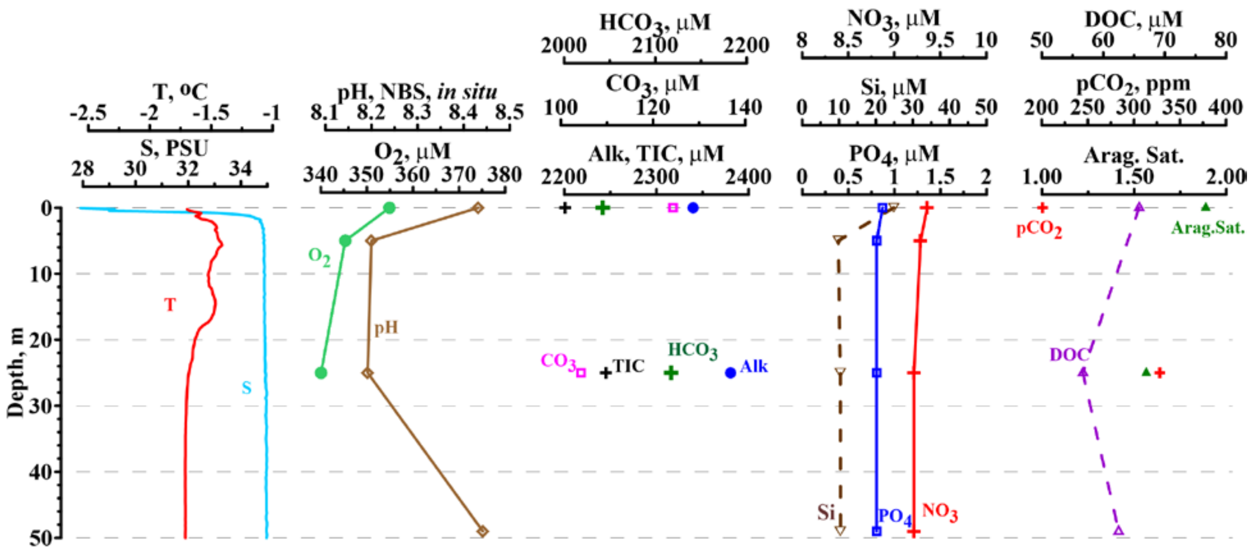

Fig.2 Vertical structure of water column on site TM-1

We can see influence of glacial drainage water on carbonate system state of the surface layer: 2339 µM on site TM-1 near the glacier, 2345 µM on site TM-3 and 2379.5 µM in the open part of the fjord. The same situation is for TIC and HCO_3.

On site TM-3 (Fig. 3) there is the same stratification as on site TM-1. After 2 meters of freshened layer (27 psu) goes homogenous water with salinity 34.8–34.9 psu. Dissolved oxygen concentration is higher on site under the ice (390 µM) though pH becomes lower in comparison with TM-1 (8.21 NBS), pCO_2 increasing (300 ppm). After 20 m concentration of all nutrients increases as well and becomes the highest near the bottom. But we can mark 2 times reducing of Si under the ice in comparison with TM-1. On 5m depth we note minimum of O_2 and maximum of pCO_2 probably due to biological processes.

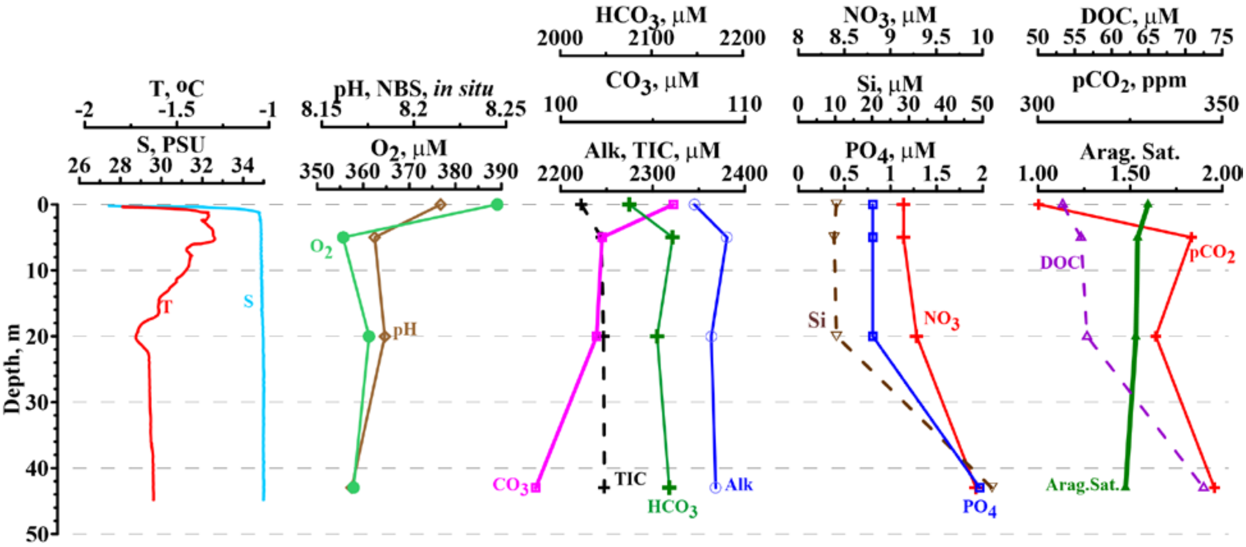

Fig.3 Vertical structure of water column on site TM-3

On site TM-6 (14 km away from the solid ice and 1.5 km from pancake ice) we can see no freshening on the surface in the open part of the fjord. The whole water column on the site is well-mixed, salinity is about 35 psu. Temperature is slightly rising from -1.5 on top to -1 °C near the bottom. O_2 is the lowest in the surface layer (328 µM). Nutrients concentration increasing to the bottom layer, generally water structure is homogenous.

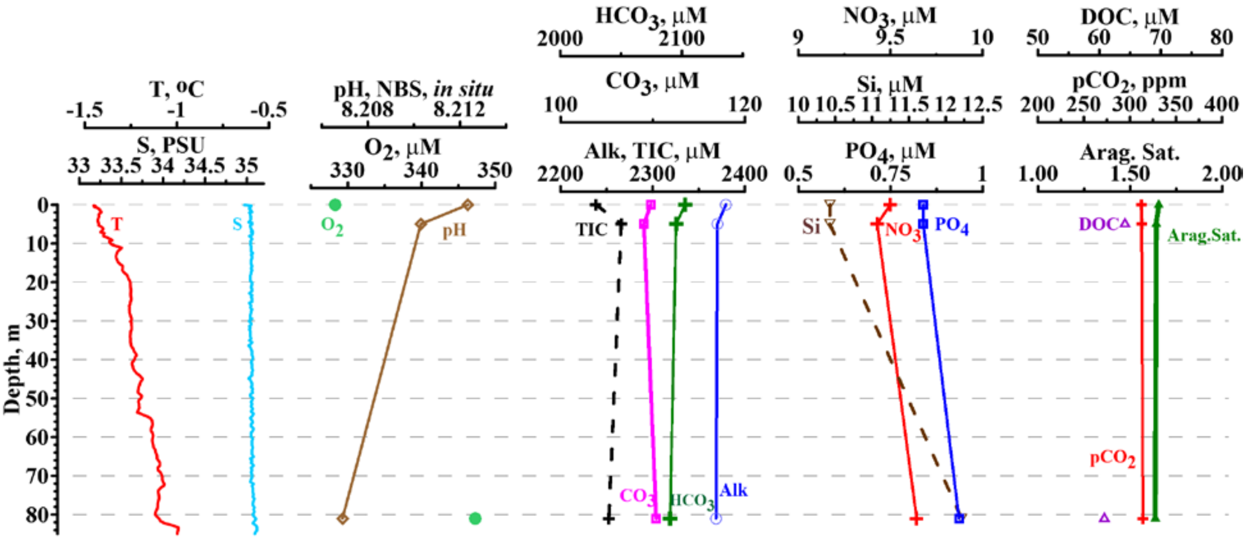

Fig.4 Vertical structure of water column on site TM-6

In the ice cores of station TM1 nutrient concentration is 2-3 times lower than in surface layer under the ice (Table 1). Alkalinity is 4-5 times lower and DOC is a little lower in the ice core as well. In the ice core of station TM-2 all characteristics are approximately 2 times lower than in the ice core on TM-1. It seems that brine flows faster through the ice away from the glacier.

Table 1. Data on vertical structure of the ice cores on sites TM-1 and TM-2

Site #	Layer cm	Temp °C	Alk µM	PO_4 µM	Si µM	NO_3+NO_2 µM	DIC µM	DOC µM	Hg total ng/l	MeHg ng/l
TM-1										
	0-18	-3.23	503.7	0.26	12.5	2.2	383.33	59.17	0.8	0.01
	18-36	-1.67	374.1	0.23	9.7	1.5	286.67	65		
	36-52	-1.24	378.9	0.26	12.2	1.6	280	60.83		
TM-2										
	0-10	-3.85	259.1	0.13	4.4	0.8	154.17	31.67	0.7	0.01
	10-20	-2.11	338.5	0.16	4.6	1.2	234.17	100		
	20-30	-1.96	407.9	0.23	6.9	1.6	316.67	108.33		

Summer expedition.

Freshening of the surface layer was strong during measurements in summer. On site TJ-1 on the surface salinity was 23 psu, then strong vertical gradient on 2 meters turns it to 31 psu, and down to the 40 meters depth it has slight changes about 32 psu (Fig. 5). Oxygen and pH are high on the site (377 µM and 8.41 NBS respectively). Carbonate parameters (Talk, TIC, HCO_3) are much lower on site TJ-1 in comparison with the site TM-3. Alkalinity on the surface was 1710 µM, TIC – 1542 µM, HCO_3– 1472 µM. After 10 meters it becomes practically constant and is close to open seawater values. We note almost complete absence of nutrients that could become a limiting factor of phytoplankton bioactivity in surface layer as well (Fig. 5, 6, 7). Up to 20 meters of water column lack the concentration of nutrients. pCO_2 and Ω_{ar} are growing to the outer part of the fjord in the surface layer. On the whole pCO_2 parameter in the upper 20 meters on all 3 sites is low and in comparison with high oxygen saturation we can confirm high level of biological activity of phytoplankton. The highest value of Ω_{ar} was found on the surface of the site TJ-3 (3 µM/kg, Fig.7) which is comparable with the highest Ω_{ar} in the whole Arctic Ocean [16].

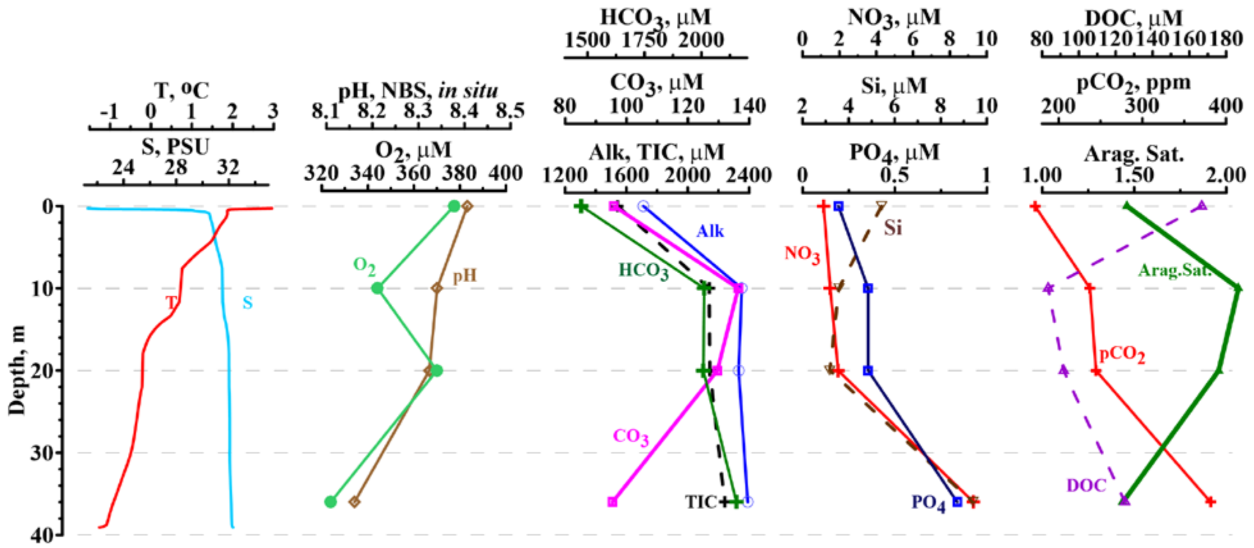

Fig.5 Vertical structure of water column on site TJ-1

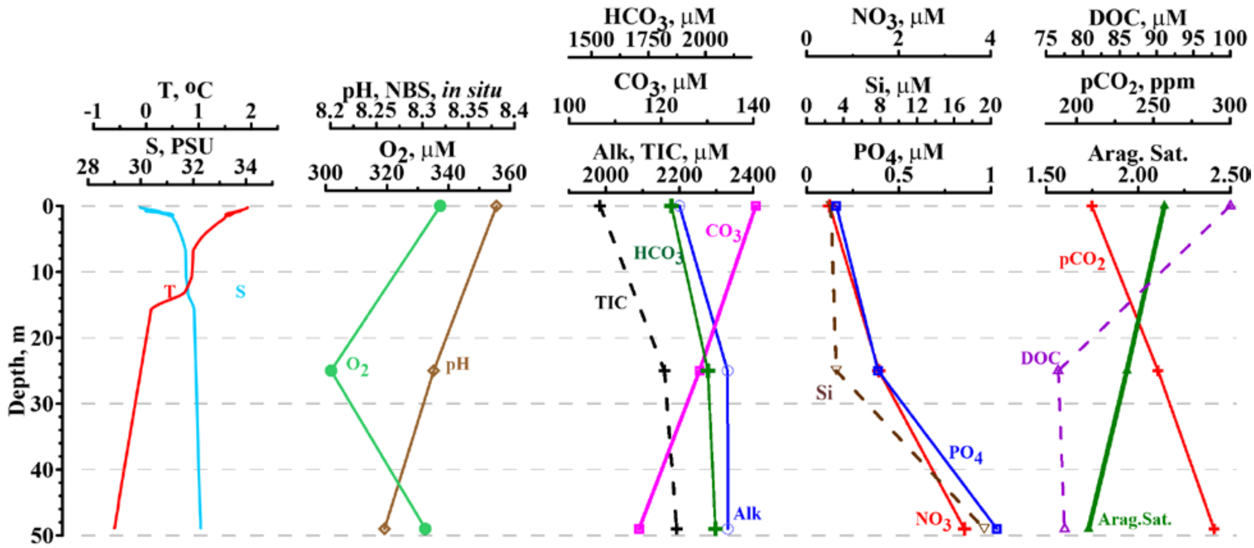

Fig.6 Vertical structure of water column on site TJ-2

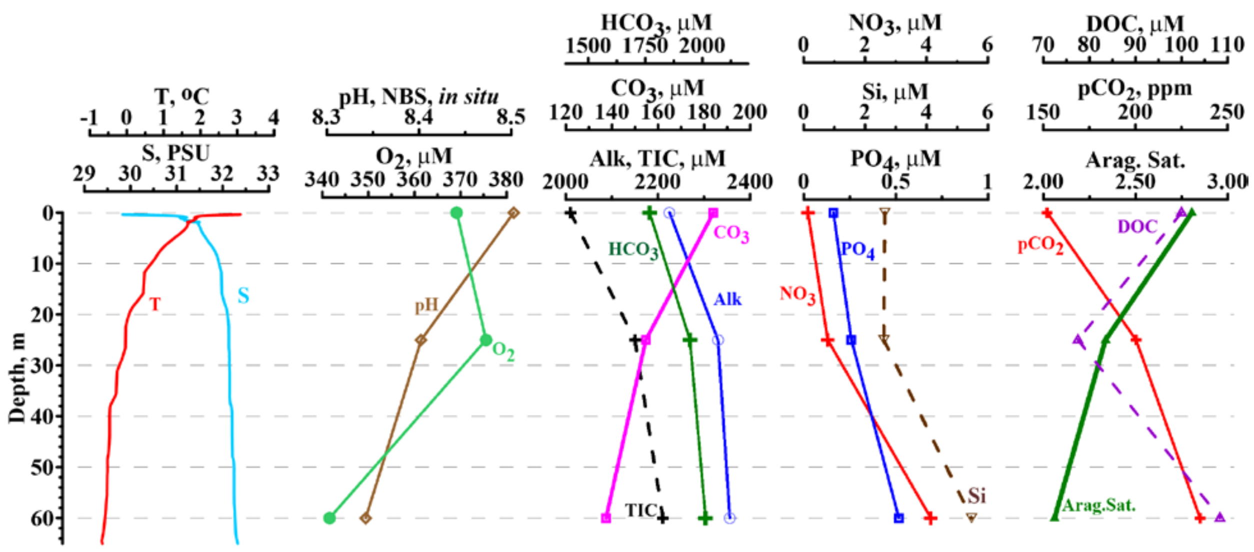

Fig.7 Vertical structure of water column on site TJ-3

A sample of water from a small stream which flows into the fjord in the central part of the northern shore (Fig.2) gave us some interesting results about flow of nutrients to the water of the fjord. Analysis has shown that the water sample contains 57 µM of Si and 8.5 µM of mineral nitrogen (NO_3+NO_2). Such a high concentration of nutrients in water of glacier origin could occur in a case of leaching of salt from the bedrocks forming Spitzbergen mountains and shores. The same effect was described in [17].

We also performed intercalibration of determination of total alkalinity. The method of determination is the same (direct titration) but Norwegian colleagues mark end of titration potentiometrically while Russian scientist use visual end of determination (the Bruevich method) [18]. Samples have been collected in June on site TJ-1 and from a small freshwater stream. Intercalibration has displayed very good results. Correlation of results of determination by different techniques is 0.99.

IV. CONCLUSION

After 2 field expeditions in different seasons we can state the significant influence of melted glacier water on the carbonate system, as well as on the regime of nutrients in the surface layer of the Tempelfjord. In winter-early spring owing to ice desalination cells with brine bring nutrients into the water just beneath the ice cover that causes active bloom of phytoplankton. Concentration of nutrients under the ice could also be increasing owing to glacial drainage water [19]. This leads to changes in the parameters of the carbonate system: increases pCO_2, TIC, DOC, HCO_3. In summer freshening near the edge of the glacier is strong but affects only upper 2 meters layer.

Some of our results are confirmed and partly explained in [19]. Authors are presenting some positive moments of freshening of the surface layer of the Templfjord: e.g. decreasing of Ω_{ar}. But owing to chemical compound of bedrock and glacier drainage water ocean acidification may increase.

The work is based on the studies in only one fjord, but obviously a similar conclusion can be done for many glaciers in the Arctic-North Atlantic region. Given the proximity and interconnection of these regions, the impact of meltwater on the carbonate system and nutrients variability can spread widely, putting a significant pressure on the ecosystem of the Arctic.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] J. E. Overland, M. Wang and S. Salo “The recent arctic warm period”, *Tellus*. Vol.60a, pp.589–597, August 2008

[2] T. Vihma “Effects of Arctic Sea Ice Decline on Weather and Climate: A Review”, *Surv. Geophys.* (2014).Vol. 35. pp.1175–1214

[3] S.-K. Min, X. Zhang, F. Zwiers “Human-Induced Arctic Moistening”, *Science.* 2008. Vol.320, pp.518-520

[4] J. W. McClelland, S. J. Dery, B. J. Peterson, R. M. Holmes and E. F. Wood “A pan-arctic evaluation of changes in river discharge during the latter half of the 20th century”, *Geophys. Res. Lett.* 2006. Vol.33, L06715, 10.1029/2006GL025753

[5] W.-J. Cai et al. “Decrease in the CO_2 uptake capacity in an ice-free Arctic Ocean basin”, *Science*.2010.Vol.329, Issue 5991, pp.556-559.

[6] R. G. J. Bellerby, A. Olsen, T. Furevik and L. Anderson “Response of the surface ocean CO_2 system in the North Atlantic to climate change”, in *The Nordic Seas: An Integrated Perspective* (eds H. Drange, T. Dokken, T. Furevik, R. Gerdes and W. Berger), American Geophysical Union, Washington, D. C.2005. doi: 10.1029/158GM13

[7] M. Yamamoto-Kawai, F. A. McLaughlin, E.C. Carmack, S.Nishino, K.Shimada “Aragonite undersaturation in the Arctic Ocean: effects of ocean acidification and sea ice melt”, *Science.* 2009. Vol.326. pp. 1098–1100, doi:10.1126/science.

[8] M. Yamamoto-Kawai, F. A. McLaughlin and E. C. Carmack “Effects of ocean acidification, warming and melting of sea ice on aragaonite saturation of the Canada Basin surface water”, *Geophysical Research Letters.*2011. Vol.38, L03601 doi:10.1029/2010GL045501.

[9] O. Hoegh-Guldberg, P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi, M. E. Hatziolos “Coral Reefs Under Rapid Climate Change and Ocean Acidification”, *Science.* 14 Dec 2007. Vol. 318. Issue 5857. pp. 1737-1742. DOI: 10.1126/science.1152509

[10] M. Steinacher, F. Joos, T.L. Frölicher, G. -K. Plattner, S. C. Doney “Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model”, *Biogeosciences.*2009. Vol.6. pp. 515-533

[11] R. G. J. Bellerby, K. G. Schulz, U. Riebesell, C. Neill, G. Nondal, E. Heegaard, T. Johannessen, and K. R. Brown “Marine ecosystem community carbon and nutrient uptake stoichiometry under varying ocean acidification during the PeECE III experiment”, *Biogeosciences*.2008. Vol.5. pp.1517–1527

[12] DOE (1994) Handbook of methods for the various parameters of the carbon dioxide system in sea water; version 2/ Eds. Dickson A.G. & Goyet C., ORNL/CDIAC-74.

[13] H.P. Hansen “Determination of oxygen”, in *Methods of Seawater Analysis. 3d, Completely Revised and Extended Edition (*Eds. K. Grashoff et al.), Wiley-VCH, Weinheim, NewYork, Chichester, Brisbane, Singapore, Toronto, 1999. Pp. 75–90.

[14] H.P. Hansen, F. Koroleff “Determination of nutrients”, in *Methods of Seawater Analysis. 3d, Completely Revised and Extended Edition (*Eds. K. Grashoff et al.), Wiley-VCH, Weinheim, New York, Chichester, Brisbane, Singapore, Toronto, 1999. Pp. 149–228.

[15] F.J. Millero “Thermodynamics of the carbon dioxide system in oceans”, *Geochim. et Cosmochim. Acta*. 1995. Vol.59. № 4. pp.661-677.

[16] M. Chierici and A. Fransson “Calcium carbonate saturation in the surface water of the Arctic Ocean: undersaturation in freshwater influenced shelves”, *Biogeosciences*. 2009. Vol6. pp.2421-2431. doi:10.5194/bg-6-2421-2009

[17] P.N. Makkaveev, A.A. Polukhin, P.V. Khlebopashev “The surface runoff of nutrients from the coasts of Blagopoluchiya bay of the Novaya Zemlya Archipelago”, *Oceanology*.2013.Vol.53.№5. pp. 539-546.

[18] G. Yu. Pavlova, P. Ya. Tishchenko, T. I. Volkova, A. Dickson and K. Wallmann "Intercalibration of Bruevich's Method to Determine the Total Alkalinity in Seawater", *Oceanology*.2008.Vol.48.№3. pp. 438–443.
[19] A. Fransson, M. Chierici, D. Nomura, M. Granskog, S. Kristiansen, T. Martma, G. Nehrke "Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years", *J. Geophys. Res. Oceans*.2015. Vol.120. pp.2413-2429. doi:10.1002/2014JC010320