Arctic Coastal Dynamics

Report of the 4th International Workshop

VNIIOkeangeologia, St. Petersburg (Russia), 10-13 November 2003

Edited by Volker Rachold and Georgy Cherkashov

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Preface

Arctic Coastal Dynamics (ACD) is a joint project of the International Arctic Sciences Committee (IASC) and the International Permafrost Association (IPA) and a regional project of IGBP-LOICZ (International Geosphere-Biosphere Programme – Land-Ocean Interactions in the Coastal Zone). Its overall objective is to improve our understanding of circum-Arctic coastal dynamics as a function of environmental forcing, coastal geology and cryology and morphodynamic behavior.

The fourth IASC-sponsored ACD workshop was held in St. Petersburg, Russia, on November 10-13, 2003. Participants from Canada (7), Germany (7), Great Britain (2), the Netherlands (1), Norway (1), Russia (32), Ukraine (1) and the United States (8) attended.

During the first part of the workshop, 63 papers dealing with regional and/or circum-Arctic coastal dynamics were presented. Based on the material presented, five thematic working groups were identified: (1) GIS working group to develop of a circum-Arctic coastal GIS system, (2) coastal permafrost working group to discuss processes involved in the transition of onshore to offshore permafrost, (3) biogeochemistry working group with the focus on transport and fate of eroded material (4) biodiversity working group to initiate planning of an Arctic Coastal Biodiversity research agenda, (5) environmental data working group to discuss coastal dynamics as a function of environmental forcing. Finally, the results of the workshop and the next steps were discussed in the ACD Steering Committee meeting. The present report summarizes the program of the workshop and the main results.

Financial support from the International Arctic Sciences Committee (IASC) is highly appreciated and was essential for conducting the workshop. Additional support of ACD activities is provided by the International Permafrost Association (IPA), INTAS (International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union), the International Arctic Research Center (IARC), and the Canadian Department of Foreign Affairs and International Trade (DFAIT).

IASC

International Permafrost Association

Participants of the 4th International Workshop on Arctic Coastal Dynamics (ACD), St. Petersburg (Russia), 10-13 November 2003
(photo by Hugues Lantuit)

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1 INTRODUCTION

1.1 Background and Rationale

The coastal zone is the interface through which land-ocean exchanges in the Arctic are mediated and it is the site of most of the human activity that occurs at high latitudes. The Arctic coastlines are highly variable and their dynamics are a function of environmental forcing (wind, waves, sea-level changes, sea-ice etc.), geology, permafrost and its ground-ice content and morphodynamic behavior of the coast. Environmental forcing initiates coastal processes, such as the sediment transport by waves, currents and sea-ice and the degradation of coastal permafrost. The coastal response (erosion or accretion) results in land and habitat loss or gain and thus affects biological and human systems. Figure 1 schematically illustrates the major processes involved in Arctic coastal dynamics. Coastal processes in the Arctic are strongly controlled by Arctic-specific phenomena, i.e. the sea-ice cover and the existence of onshore and offshore permafrost. During the winter season comprising 7-8 months a thick and extensive sea-ice cover protects the coastline from hydrodynamic forcing. During the open water season, mainly after break-up in spring, the sea-ice is an important transport agent for coastal sediments.

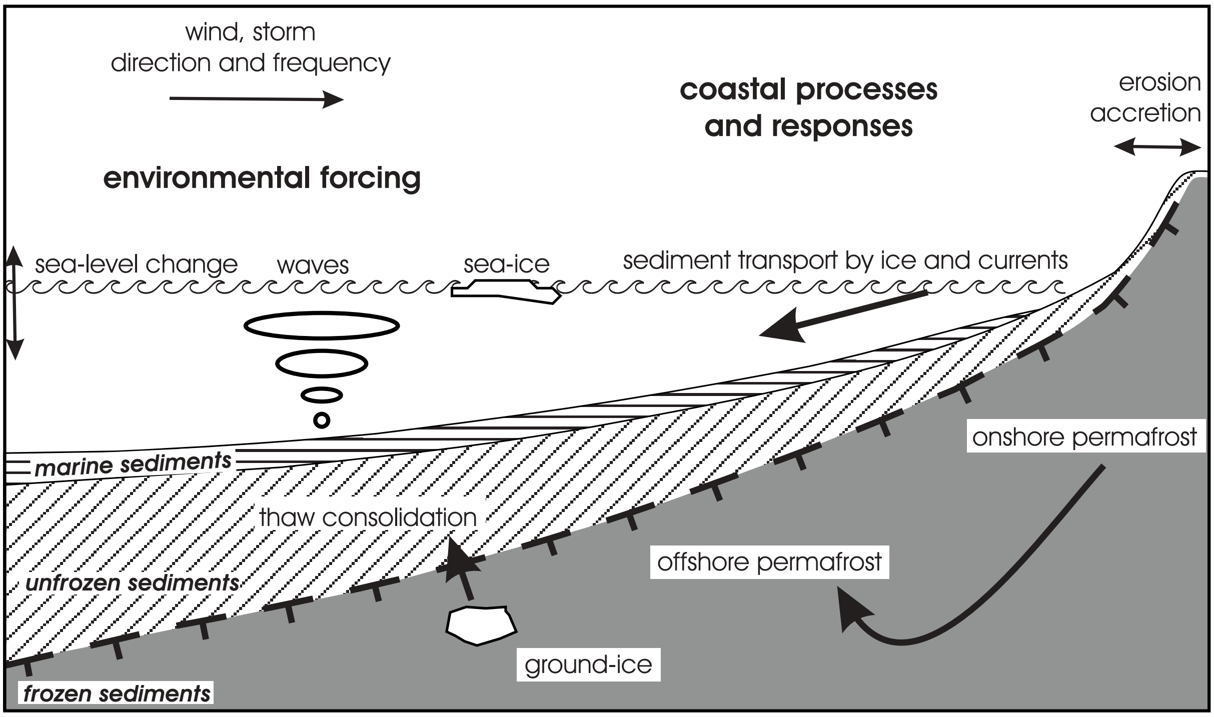

Figure 1. Arctic coastal processes and responses to environmental forcing.

The Arctic coastal region is the transition zone between onshore and offshore permafrost and the degradation of permafrost, which can be connected with the release of permafrost-bond greenhouse gases (GHG), is concentrated in the coastal zone. During the short ice-free period, the unlithified ice-rich, permafrost-dominated coastlines are rapidly eroded (at rates of several meters per year) and it is assumed that the resulting coastal sediment, organic carbon, and nutrient fluxes play an important role in the material budget of the Arctic Ocean.

Global and regional climate changes will significantly affect physical processes, biodiversity and socio-economic development in the Arctic coastal areas. Additionally, Arctic coastal changes are likely to play a role in global systems via feedbacks through the material flux generated by eroding coasts and the GHG emission from degrading coastal permafrost (Figure 2). Thus, the overall scientific goals of Arctic coastal research are: (1) to identify and to understand the key processes controlling Arctic coastal dynamics and its impact on human systems, biology and ecosystems, (2) to decipher and quantitatively assess the recent role of the coasts in the global system of the Arctic concerning estimates of coastal retreat, material flux, GHG emission from permafrost degradation and (3) to establish models to predict the future behavior of the Arctic coastal region in response to climate and sea-level changes.

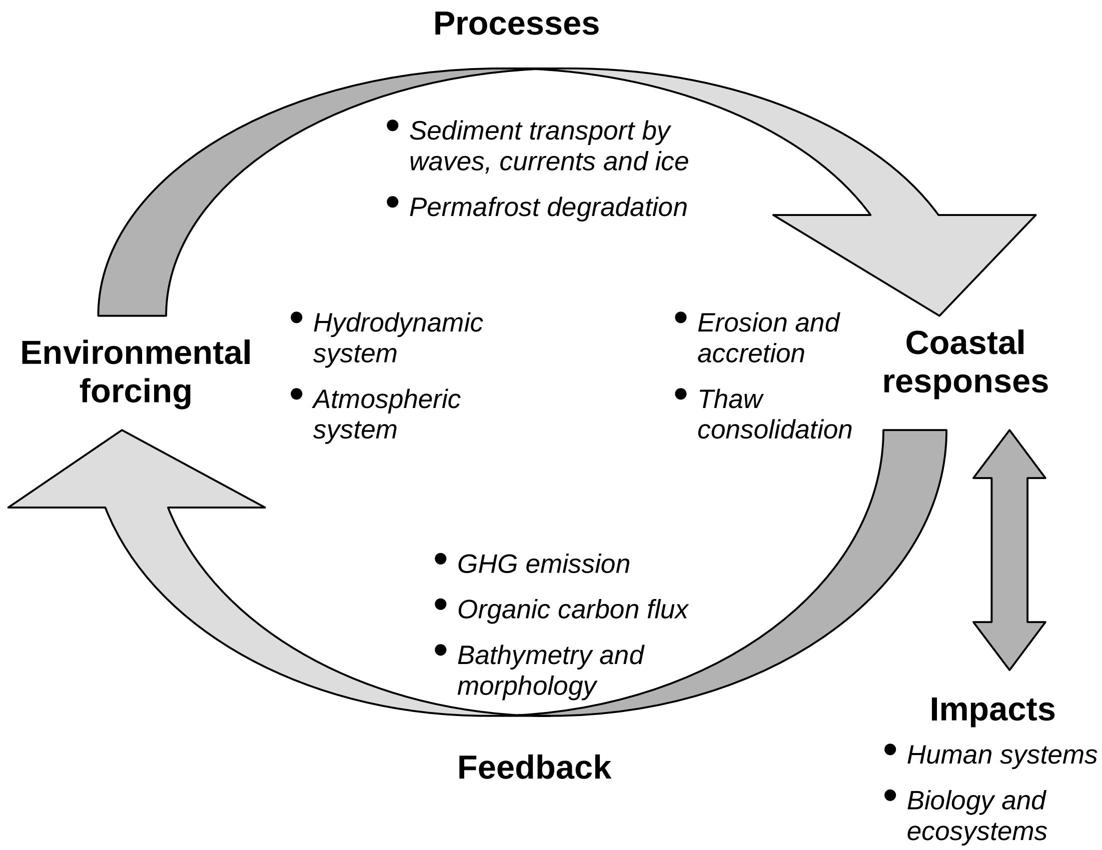

Figure 2. Environmental forcing, coastal processes and responses, impacts and feedback.

1.2 History and Development of Arctic Coastal Dynamics (ACD)

Arctic Coastal Dynamics (ACD) is a multi-disciplinary, multi-national project of the International Arctic Science Committee (IASC) and the International Permafrost Association (IPA) and a regional project of IGBP-LOICZ (International Geosphere-Biosphere Programme – Land-Ocean Interactions in the Coastal Zone). The overall objective is to improve our understanding of circum-Arctic coastal dynamics as a function of environmental forcing, coastal geology and permafrost and morphodynamic behavior. In particular, ACD aims to:

- establish the rates and magnitudes of erosion and accumulation of Arctic coasts and to estimate the amount of sediments and organic carbon derived from coastal erosion;

- develop a network of long-term monitoring sites including local community-based observational sites;
- refine and apply an Arctic coastal classification (includes ground-ice, permafrost, geology, etc.) in digital form (GIS format) and produce a series of thematic and derived maps (e.g. coastal classification, ground-ice, sensitivity etc.);
- compile, analyze and apply existing information on relevant environmental forcing parameters (e.g. wind speed, sea-level, fetch, sea ice etc.);
- identify and undertake focused research on critical processes;
- develop empirical models to assess the sensitivity of Arctic coasts to environmental variability and human impacts.

The project elements for Arctic Coastal Dynamics (ACD) were formulated at a workshop in Woods Hole, Massachusetts, in November 1999 funded by the U.S. National Science Foundation (NSF) and organized under the auspices of the International Permafrost Association (IPA), through its working group on Coastal and Offshore Permafrost and its Coastal Erosion subgroup. As a result of the workshop a metadata form for the selection and establishment of key monitoring sites was developed. A consistent and generalized coastal classification scheme was established based on morphology and materials. Consensus was reached on direct and indirect methodologies for estimating ground-ice volumes and presentations of data on maps. Finally, a suite of standard tools and techniques for development of long-term coastal monitoring sites was recommended (Brown and Solomon, 2000). During the Arctic Science Summit Week in April 2000 in Cambridge, UK, and at the request of the IPA, the Council of the International Arctic Science Committee (IASC) approved funding for a follow up workshop to develop a Science and Implementation Plan for ACD. The resulting international workshop, held in Potsdam (Germany) in October 2000, produced a phased, five-year Science and Implementation Plan (2001-2005). The ACD project office was established at the Research Department Potsdam of the Alfred Wegener Institute with a secretariat to maintain international communications including the web site (http://www.awi-potsdam.de/www-pot/geo/acd.html) and an electronic newsletter. The secretariat is assisted by the International Steering Committee (ISC) consisting of

- Felix Are, St. Petersburg State University of Means and Communication (Russia)
- Jerry Brown, International Permafrost Association, Woods Hole (USA)
- George Cherkashov, VNIIOkeangeologia, St. Petersburg (Russia)
- Mikhail Grigoriev, Permafrost Institute, Yakutsk (Russia)
- Hans Hubberten, AWI, Potsdam (Germany)
- Volker Rachold, AWI, Potsdam (Germany) (Project Leader)
- Johan Ludvig Sollid, Oslo University (Norway)
- Steven Solomon, Geological Survey of Canada, Dartmouth (Canada)
- Frits Steenhuisen, Arctic Centre at Groningen University (The Netherlands)

The Science and Implementation Plan (IASC Arctic Coastal Dynamics, 2001) was made available on the ACD web page and submitted to the IASC Council for review, approval and advice on future directions. At the Council Meeting during the Arctic Science Summit Week in Iqaluit, Canada (April 2001), IASC officially accepted the ACD project.

In the following years, annual IASC-sponsored ACD workshops were held in Potsdam (Germany), 26-30 November 2001 and in Oslo (Norway), 2-5 December 2002. Workshop Proceedings including extended abstract were published in the journal *Reports on Polar and Marine Research* (Rachold et al., 2002, 2003 [a]). Currently, ca. 25 institutions from Austria, Canada, Germany, Norway, The Netherlands, Russia, Switzerland, UK and USA are contributing to the ACD project. The ACD secretariat maintains communication with the following international programs/projects:

- International Arctic Science Committee (IASC) and its projects
  - Arctic Climate Impact Assessment (ACIA)
  - Land Ocean Interactions in the Russian Arctic (LOIRA)
  - Circum-Arctic Terrestrial Biodiversity (CAT-B)
- Arctic Ocean Science Board (AOSB) and its program
  - Arctic Paleo River Discharge (APARD)
- International Permafrost Association (IPA) and its program
  - Global Terrestrial Network Permafrost (GTNP)
- Circum-Arctic Environmental Observatories Network (CEON)
- Conservation of Arctic Flora and Fauna (CAFF)
- Study of Environmental Arctic Change (SEARCH)
- US Land-Shelf Interactions (LSI)
- World Climate Research Program - Arctic Climate System Study / Climate and Cryosphere (WCRP - ACSYS/CliC)

1.3 Current Focus and Objectives of the 4th ACD Workshop

The first phase of the ACD project has been directed towards the assessment and synthesis of existing information on Arctic coastal properties and dynamics. A bibliography of Russian literature on Arctic coastal processes comprising ca. 800 entries and a circum-Arctic collection of ca 120 coastal photographs have been compiled and made available through the ACD web page and the second version of the IPA CAPS-CD (Circumpolar Active-Layer Permafrost System) prepared by the National Snow and Ice Data Center, Boulder, Colorado. A network of long-term monitoring sites has been established. Some of these sites have been studied for ca. 20 year and most of them are re-visited each year (see Figure 3). The metadata information for these ca. 20 ACD key sites (Appendix 1) is available on the ACD web site.

In addition to the ACD workshop reports several ACD relevant papers and extended abstracts have been published in the Proceedings Volume of the 8th International Conference on Permafrost held in Zurich (Switzerland), July 2003. A series of 16 papers on Arctic coastal processes and dynamics to be published in a special issue of the journal *GeoMarine Letters* is currently under review and will be available by mid 2004.

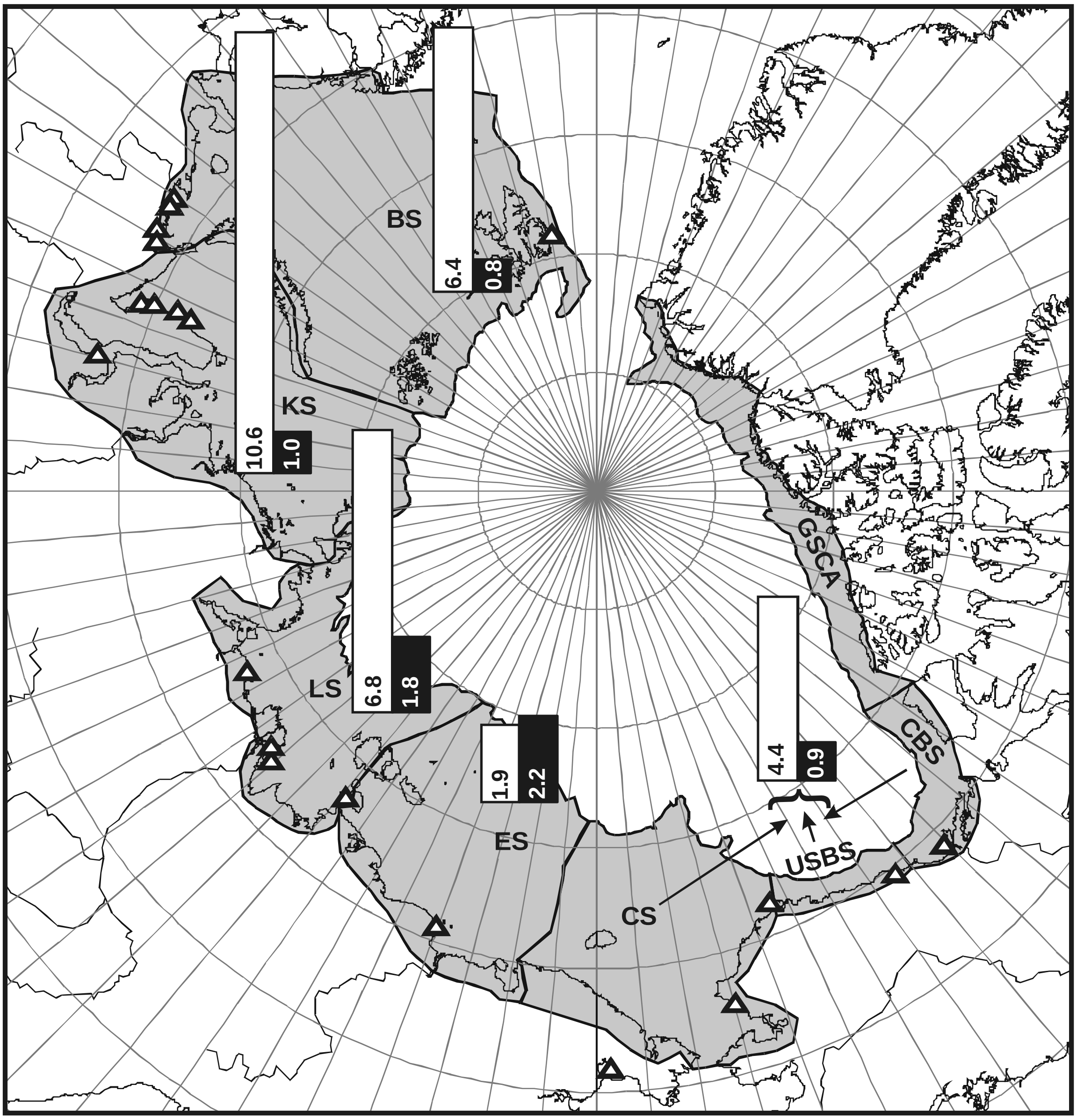

Figure 3. ACD subdivision of the Arctic coastline by major seas (BS = Barents Sea, KS = Kara Sea, LS = Laptev Sea, ES = East Siberian Sea, CS = Chukchi Sea, USBS = US Beaufort Sea, CBS = Canadian Beaufort Sea, GSCA = Greenland Sea / Canadian Archipelago) and ACD key sites (Appendix 1) marked by triangles. Bars represent the riverine and coastal TOC input (10^6 t C yr^{-1}) to the Arctic Ocean (data taken from Rachold et al. 2003 [c]). White bars refer to river input and black bars to coastal input. Note that the sum is shown for Beaufort and Chukchi Sea and that Barents Sea input data include White Sea.

Emphasis is currently on developing a circum-Arctic estimate of sediment and organic input from coastal erosion to the inner shelves. In the past, the contribution of coastal erosion to the material budget of the Arctic seas has been underestimated, but recent investigations have underlined its importance. Reimnitz et al. (1988) presented calculations for 344 km of Alaskan coast in the Colville River area and found that coastal erosion here supplied seven times more sediments to the Alaskan Beaufort Sea than rivers. Are (1999) suggested that the amount of sediment supplied to the Laptev Sea by rivers and shores is at least of the same order and that the coastal erosion input is probably even larger than the input of the rivers. This finding was supported by Rachold et al. (2000), who concluded that the sediment input to the Laptev Sea through coastal erosion is twice as large as the river input. In the Canadian Beaufort Sea on the other hand, the Mackenzie River input is the dominant source of sediments and coastal erosion contributes much less important (MacDonald et al. 1998). These pronounced regional differences in the riverine and coastal erosion sediment input have to be considered in any research related to the fluxes and budgets of the Arctic seas. Several papers on this topic have recently been published under the ACD framework (Brown et al., 2003; Grigoriev and Rachold, 2003; Jorgenson et al., 2003; Rachold et al., 2003 [b]). These studies indicate that coastal erosion forms a major source not only of the sediment input but also of the total organic carbon (TOC) input to the Arctic seas. The comparison between riverine and coastal TOC input, based upon a combination of detailed field studies carried out in the Laptev and East Siberian Seas during the last several years (Grigoriev and Rachold, 2003) and on a review of the existing literature, is shown in Figure 3 (Rachold et al., 2003 [c]). It has to be noted that the data given the figure are the best currently available estimates, but may include errors ranging from ca. 30 % for the Laptev and East Siberian Sea (Grigoriev and Rachold, 2003) to one order of magnitude for the other seas.

The development of a reliable assessment of the sediment and organic input through coastal erosion involves segmenting the entire circum-Arctic coastline into homogenous elements based primarily on morphology, composition and erosion rates. Each segment is to be classified according to a coastal classification template (Rachold et al., 2003 [a], see appendix 2). Geographical information of the segments and physical and geomorphologic attribute tables are stored and managed in GIS format for visualization and analyses. The final data set (incl. Metadata) will be stored in the PANGAEA system (http://www.pangaea.de). Regional expert teams are currently completing the segmentation procedure *(► 2. Program and Main Results of the Workshop: GIS Working Group).*

Available data for various parameters, summarized under the term “environmental forcing”, such as winds, waves, currents, sea-level, water and air temperatures, sea ice, etc., have been analyzed. The subsets relevant to the ACD project are currently being extracted from weather observatories and global reanalysis products and formatted for inclusion in the circum-Arctic GIS (Atkinson, in review). Methodologies for correction of wind data from the reanalysis products and analyses of storms and storminess are by-products of this ACD effort and form an important contribution in their own right to the study of the Arctic coastal environment. The information will be available as GIS layers (shapefiles), which can be overlain and compared with the coastal characteristics *(► 2. Program and Main Results of the Workshop: Environmental Forcing Working Group).*

During the second phase of ACD research, until 2005, emphasis will be on critical processes. This includes to concentrate on the transport and fate of eroded organic material and the most critical and poorly understood transition between onshore and offshore permafrost.

The knowledge of the type of organic carbon (dissolved or particulate), and its fate and availability for bio-productivity is essential in order to understand the role of coastal erosion in the carbon budget of the Arctic *(► 2. Program and Main Results of the Workshop: Biogeochemistry Working Group).*

The future degradation of the permafrost both on shore and on the Arctic shelf is of worldwide importance because GHG bound within and beneath the permafrost may be released (Romanovskii et al., in review). In this context the coastal areas are of specific interest because they are the site of the transition between onshore and offshore permafrost.

Along the Arctic coastlines permafrost is exposed to the influence of relatively warm and saline sea-water, which potentially accelerates permafrost degradation. Changes occurring within the coastal zone control the characteristics of offshore permafrost and the associated geotechnical properties of the offshore materials. A better understanding of this zone is also required for safe and efficient development of offshore Arctic hydrocarbon resources. To decipher the processes acting during the transformation of onshore to offshore permafrost and to improve mathematical models of the permafrost distribution and coastal morphodynamics, coastal permafrost drilling transects are required *(► 2. Program and Main Results of the Workshop: Coastal Permafrost Working Group).*

An additional objective of the last ACD workshop held in St. Petersburg was to initiate planning of an Arctic Coastal Biodiversity research agenda (ACB). The primary goal was to provide an international forum for discussion of research that will be relevant to biodiversity assessment in the coastal zone. Biodiversity assessment is considered a critical prerequisite to improving coastal zone management and design of terrestrial and marine protected areas. Incorporating information on species composition, habitat structure, and ecological function, biodiversity assessment is an emerging interdisciplinary research topic, of critical importance for coastal management. The Arctic coastal zone is especially suitable for biodiversity assessment due to its relative lack of human disturbance and its high sensitivity to ecosystem change through global warming *(► 2. Program and Main Results of the Workshop: Arctic Coastal Biodiversity Working Group).*

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2 PROGRAM AND MAIN RESULTS OF THE WORKSHOP[1]

The fourth IASC-sponsored ACD workshop was held in St. Petersburg, Russia, on November 10-13, 2003. Participants from Canada (7), Germany (7), Great Britain (2), the Netherlands (1), Norway (1), Russia (32), Ukraine (1) and the United States (8) attended. Of these four were young scientists supported by IASC. Two current INTAS projects provided additional support for Russian, German and Norwegian participants. VNIIOkeangeologia (Institute for Geology and Mineral Resources of the Ocean) organized the local logistics for the workshop.

During the first day of the workshop (Monday, November 10) 63 papers dealing with regional and/or circum-Arctic aspects of coastal dynamics were presented. Due to the large number of contributions, most papers were presented in a poster session. The main focus of the workshop was on working group meetings, which were identified according to the workshop objectives and based on the presentations. Five thematic working groups were organized and met from Tuesday, November 11 to Thursday, November 13. Plenary meetings were held twice per day in order to discuss general questions and to exchange information on the progress of the working groups.

Working group summaries and extended abstracts of the presentations assigned to the respective working group are presented in Chapter 3:

GIS Working Group (14 presentations) ►*Chapter 3.1 (page 14)*

Chairs: Rune Odegard and Frits Steenhuisen
Participants: Jerry Brown, Dmitry Drozhdov, Yuri Firsov, Allison Graves, Mikhail Grigoriev, Hugues Lantuit, Sergey Nikiforov, Rune Odegard, Volker Rachold, Feliks Rivkin, Elena Rys'kova, Shawn Serbin, Frits Steenhuisen

Coastal Permafrost Working Group (12 presentations) ►*Chapter 3.2 (page 59)*

Chairs: Michel Allard and Hans-W. Hubberten
Participants: Michel Allard, Feliks Are, Nicole Couture, Don Forbes, Mikhail Grigoriev, Jens Hölemann, Hans-Wolfgang Hubberten, Alexander Kizyakov, Olga Medkova, Volker Rachold, Pavel Rekant, Vladimir Romanvsky, Steven Solomon, N.A. Spolyanskaya, Irina Streletskaya, Vladimir Tumskoy

Biogeochemistry Working Group (14 presentations) ►*Chapter 3.3 (page 97)*

Chairs: Sathy Naidu and Vladimir Ostroumov
Participants: Georgy Cherkashov, Nicole Couture, Olga Gruzdeva, Birgit Heim, Anne Hickey, Nina Kasyankova, Alexander Kholodov, Elena Miroluhova, Sathy Naidu, Vladimir Nikulin, Vladimir Ostroumov, Vera I. Petrova, Boris Vanshtein

Arctic Coastal Biodiversity Working Group (14 presentations) ►*Chapter 3.4 (page 157)*

Chair: Christopher B. Cogan

[1] The complete program and the list of participants are given in Appendices 3 and 4.

Participants: Christian Buschbaum, Natalia Chernova, Christopher B. Cogan, Nina V. Denisenko, Michael Jennings, Vladislav V. Khlebovich, Katja Metfies, Thomas Noji*, John C. Roff, Boris I. Sirenko, Vassily A. Spiridonov, Mark A. Zacharias, Christoph Zöckler

*contribution to workshop report, but not present in St. Petersburg

Environmental Forcing Working Group (9 presentations) ►*Chapter 3.5 (page 183)*

Chair: David E. Atkinson[2]
Participants: David Atkinson, A.A. Yermolov, Don Forbes, A.M. Kamalov, Stanislav Ogorodov, F.A. Romanenko, Steven Solomon, Alexander Vasiliev, David Viner, G.K. Zubakin

Based on the presentations and on the results of the WGs discussions, the following next steps were identified in the Steering Committee meeting:

Development of the Circum-Arctic Coastal GIS

The segmentation and classification of the circum-Arctic coastline has been almost completed during the workshop and remaining gaps will be closed during spring 2004. A first version of the GIS, which will be available on CD-ROM, is anticipated by mid 2004. This will include the coastal classification and the relevant environmental and climate forcing data as individual GIS layers *(see GIS Working Group Report, chapter 3.1.1, page 15 and Environmental Forcing Working Group Report, chapter 3.5.1, page 184).*

Field Work

Several ACD relevant field studies in the Laptev, Kara, Barents, East Siberian and Beaufort Seas and at Svalbard, and annual measurements at the key sites will continue.

The field activities in the Laptev Sea will focus on the transition of onshore to offshore permafrost in the coastal zone *(see Coastal Permafrost Working Group Report, chapter 3.2.1, page 60).* The expedition target is a coastal section in the western Laptev Sea, which will be visited in spring 2004. Starting at the cliff and perpendicular to the shoreline, a transect consisting of 5-6 permafrost boreholes with depths of up to 100 m will be drilled. Geochemical and sedimentological studies on the transport and fate of eroded material will be continued *(see Biochemistry Working Group Report, chapter 3.3.1, page 98).*

Beaufort Sea activities will focus on geophysical studies of the on-offshore transition *(see Coastal Permafrost Working Group Report, chapter 3.2.1, page 60)* and validation of techniques for mapping of bottom-fast ice in that zone. The establishment of GPS monitoring sites in support of sea level change and vertical motion studies is also continuing.

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[2] David Atkinson, the leader of the Environmental WG, is financed through the IARC grant "Analysis of Coastal Meteorological and Oceanographic Forcing in the Arctic Basin".

New ACD-related Projects and Proposals

- The European Science Foundation (ESF) has recently approved funding for the ESF-Network SEDIFLUX (Sedimentary Source-to-Sink Fluxes in Cold Environments), which has an ACD component. The first workshop and Steering Committee meeting will be held in Iceland, June 2004.

- INTAS approved the application for the Young Scientist Grant of Stanislav Ogorodov (Moscow State University) who will stay at AWI Potsdam as a guest scientist for 3 months in 2004 and 2005.

- A new INTAS proposal will be developed, deadline for submission is June 2004.

- A US-coordinated proposal will be submitted to the National Science Foundation ("Study of the Northern Alaska Coastal System" - SNACS)

- As an ACD initiative and thanks to financial support provided by IASC a working group on Arctic Coastal Biodiversity was convened during the workshop *(see Arctic Coastal Biodiversity Working Group Report, chapter 3.4.1, page 158).* After the initial steps, which were coordinated under the umbrella of ACD, the biodiversity group will develop its own research program as a separate project (linked to ACD), a proposal will be presented to the IASC Council at the Arctic Science Summit Week in Reykjavik (Iceland), 21 - 28 April 2004.

- ACD-related Canadian activities are expected to accelerate through involvement in the Canadian Program “ArcticNet (National Network of Centers of Excellence)”.

Publications

A special issue of the journal “Geo-Marine Letters” (Springer) will be available by the end of 2004. The special issue will comprise ca. 15 papers on Arctic coastal dynamics, which are currently under review.

Conference Presentations will be given at:

- Arctic Science Summit Week, Reykjavik (Iceland), 21 - 28 April 2004 (Report to the Arctic Ocean Science Board AOSB),

- Annual conference of the Russian permafrost community, Tyumen (Russia), 22-29 May 2004 (special session on Arctic land ocean interactions, coastal and offshore permafrost and coastal dynamics),

- 32nd International Geological Congress, Florence (Italy), 20-28 August 2004,

- Arctic Climate Impact Assessment ACIA Meeting, Reykjavik (Island), November 2004,

- XXI International Coastal Conference, Svetlogorsk (Russia), 7-11 September 2004,

- AGU Fall Meeting in San Francisco (USA), 13-17 December 2004 (a special session on Arctic coastal dynamics focusing on coastal and offshore permafrost is planned, co-chaired by Volker Rachold and Vladimir Romanovsky).
- A Coastal Working Group theme will be developed for the 2nd International Conference on Arctic Planning (ICARP II) which will be held in autumn 2005 (Working Group Chair: Volker Rachold).

Next ACD Workshop

The next ACD workshop scheduled for late autumn 2004 will be held in Montreal (Canada) hosted by the Department of Geography at McGill University (Wayne Pollard).

Acknowledgements

The success of the workshop would not have been possible without the financial and logistic support through the International Arctic Sciences Committee (IASC), in particular, we would like to express our appreciation to Odd Rogne. VNIIOkeangeologia provided excellent logistics, special thanks go to Boris Vanshtein, Nina Kosyankova, Lena Rys'kova and Anna Kursheva.

Additional financial support by the following organizations is highly appreciated:

- International Permafrost Association (IPA)
- Canadian Department of Foreign Affairs and International Trade (DFAIT) - Canada-Germany agreement
- INTAS (International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union): project numbers INTAS Open Call 2001-2329 and INTAS Open Call 2001-2332
- International Arctic Research Center (IARC): grant "Analysis of Coastal Meteorological and Oceanographic Forcing in the Arctic Basin"
- In addition to IASC funding the young scientists received financial support from the Barrow Arctic Science Consortium (Allison Graves), the University of Colorado (Anne Hickey), Michigan State University (Shawn Serbin) and by McGill University (Hugues Lantuit).

3 Extended Abstracts and Working Group Reports

3.1 GIS WORKING GROUP

Working Group Chairs: **Rune Odegard and Frits Steenhuisen**

Participants

Jerry Brown, Dmitry Drozhdov, Yuri Firsov, Allison Graves, Mikhail Grigoriev, Hugues Lantuit, Sergey Nikiforov, Rune Odegard, Volker Rachold, Feliks Rivkin, Elena Rys'kova, Shawn Serbin, Frits Steenhuisen

3.1.1 GIS - Working Group Summary

Rune Odegard[1] and Frits Steenhuisen[2]

[1]*University of Gjovik, Gjovik, Norway (rune.oedegaard@hig.no)*

[2]*Arctic Centre at Groningen University, The Netherlands (f.steenhuisen@let.rug.nl)*

The main objectives of the GIS working group at the ACD workshop were:

1. To make the final decisions on how to do the coastal segmentation, in particular in areas of numerous small islands, estuaries and other types complicated coasts.
2. To get an overview of the coastal segmentation made by the regional experts.
3. To get an overview of the status of the data that will be linked to each individual coastal segment in the ACD database.
4. To decide on a schedule to finish the data collection work.

Segmentation based on polygons

It was decided during the plenary session and the opening discussion of the GIS working group to do the segmentation based on polygons and to include islands in the ACD segmentation. The main advantage of this approach is that it will secure a consistent segmentation in areas of complicated coasts. On the other hand polygon segmentation will not cause problems in areas of simple coasts (Figure 1).

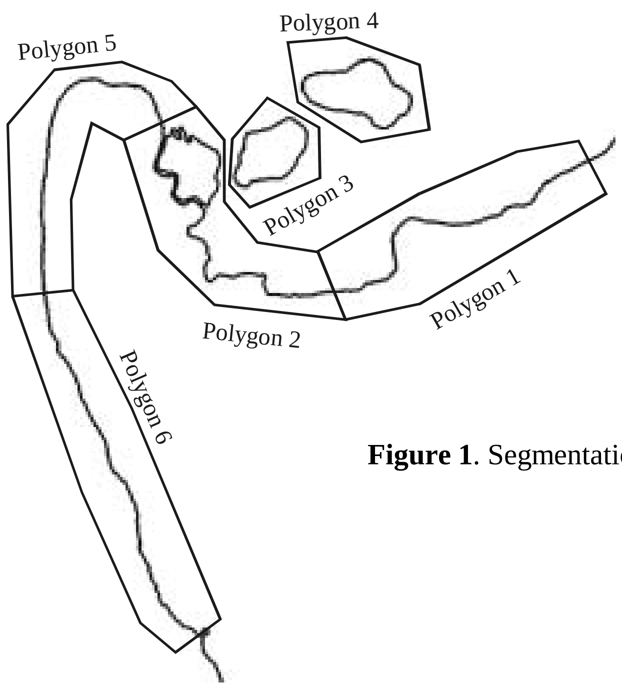

Figure 1. Segmentation of the coast based on polygons.

The polygon layer, which will define the coastal segmentation, will be overlaid with the World Vector shoreline to define the line segments. Another advantage of this approach is that the polygon layer could be used for segmentation of other digital maps for comparison with the World Vector shore line. It is particularly important to compare length estimates from coast lines at different map scales. Also, future updates and changes of the World vector shoreline can be easily implemented by overlaying the polygon layer with the new WVS data.

During the working group meetings the participants mainly worked on the polygon based coastal segmentation using the intersection data from the local experts. The polygons were edited in standard GIS software, (ArcView and ArcGIS). Most of this work could be finished during the workshop. Additional work will be needed from the local experts to decide on the final segmentation in areas of complicated coasts. Some of these areas were solved during the workshop, in the cases where the local experts were available for discussions. Figure 2 illustrate the current status of the ACD prototype GIS compiled during the workshop. Most sectors have been segmented and for some regions the classification is available in the GIS.

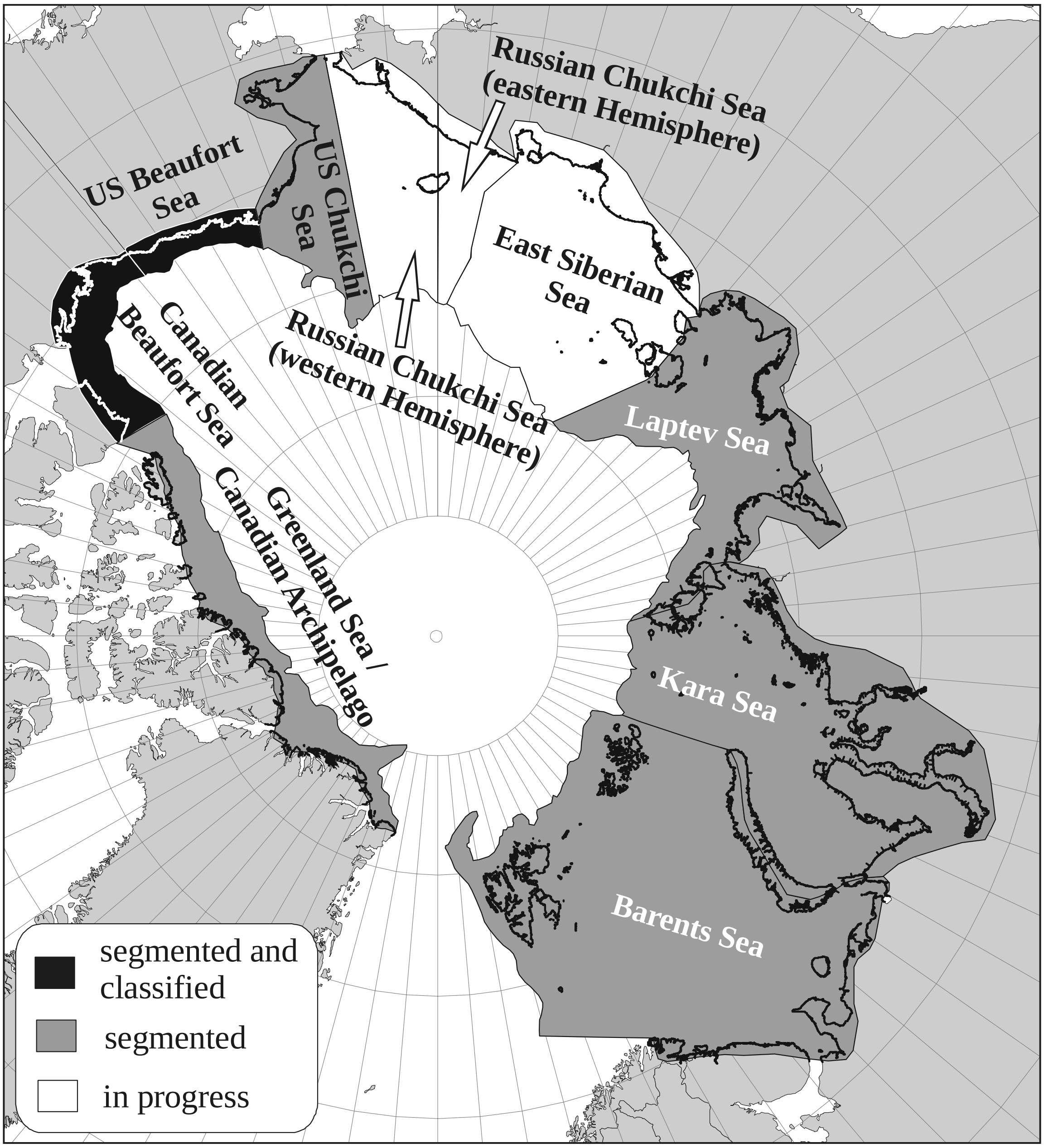

Figure 2: Current status of the ACD prototype GIS.

All segments are eventually coded with a numbering system. These unique segment (polygon) ID's will be used as a key field to link the actual datafile, i.e. the ACD classification data (see appendix 2) to the geometric data. Table 1 shows the coding system for the sectors given in Figure 2 and the level of completeness.

Table 1: Alpha-numerical coding of Arctic shelf seas used in the ACD segmentation and classification.

Sector name	Alpha code	Numerical code	Country + description	Level of completeness*
Chukchi Sea	CS	10	Russia, eastern hemisphere	0
Chukchi Sea	CS	11	Russia, western hemisphere	1
Chukchi Sea	CS	12	US	1
US Beaufort Sea	USBS	20	US	2
Canadian Beaufort Sea	CBS	30	Canada	2
Greenland Sea / Canadian Archipelago	GSCA	40	Greenland Sea	1
Greenland Sea / Canadian Archipelago	GSCA	41	Canadian Archipelago	1
Barents Sea	BS	50	Russia	1
Barents Sea	BS	51	Spitsbergen	1
Kara Sea	KS	60	Russia	1
Laptev Sea	LS	70	Russia	1
East Siberian Sea	ES	80	Russia	0

* 0 = segmentation in progress
1 = segmentation completed (classification in progress)
2 = segmentation and classification completed

Segment coding (numbering): 6 digits: xxnnnn

xx : sector (numerical code)

nnnn: segment number, 0010, 0020, 0030, … numbering starts from E to W.

The workshop showed that the segmentation of the coasts for the different seas (Figure 2) is almost finished. There are, however, still several gaps in the table data. There are numerous empty fields, and in some cases the standard classification has not been followed. It was decided on a final deadline at the end of May to have these problems solved by the local experts for the different seas. The first complete version of the GIS is anticipated for the next ACD workshop (October 2004). By the end of 2004 the GIS will be available on CD-ROM and on the internet. A WWW-based GIS interface using ArcIMS software will be used to provide access to the polygon data. The prototype developed by Christopher Cogan was presented during the plenary session of the workshop.

The final version of the georeferenced information (polygons and corresponding classification) will be archived in the PANGAEA database (www.pangaea.de) together with the metadata information. Due to limited geographical data functionality in PANGAEA the pre-processing and quality checks of the baseline data have to be done in standard GIS software before. Once the data are archived in PANGAEA there will be no possibility to change the segmentation until a new major revision.

3.1.2 GIS – Extended Abstracts

CREATION OF ESTIMATED NATURAL RISK MAPS OF CRYOLOGICAL HAZARDS ON THE VARANDEI PENINSULA COAST

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The intense technological impacts of industrial engineering on the Russian Arctic coast result in and intensify cryological processes, including coastal ones.

To estimate the intensity of cryological processes on the Varandei Peninsula coast, we carry out complex engineering and geocryological studies, from which an electronic database is created.

Geoinformation systems (GIS), together with the created database, have allowed mapping of natural risks and the assessment of the potential for cryological processes and their intensity on the Varandei Peninsula coast.

Results of the engineering geocryological studies performed on the Varandei Peninsula coast were used as a basis for the estimation of the intensity of cryological processes.

Natural risks of such cryological hazards as frost heaving, soil settlement upon thawing, thermal erosion, landslides, and cryogenic manifestations were evaluated based on the compiled database. The ice content and salinity of soils were also estimated in order to assess the complexity of the area.

A map of the intensity of exogenic cryological processes at the key site on the Varandei Peninsula was created as a result of the performed studies.

Further, depending on the type of the technological impact (above-ground pipeline; underground pipework; highways; rectangular objects), an evaluation map of technological impact hazards on the Varandei Peninsula coast will exploit these studies.

This work is supported by Russian Coast Protection Program and INTAS grant 2332.

COASTAL DYNAMICS OF THE NOVOSIBIRSKIE ISLANDS: COMPARISON OF REMOTE SENSING RESULTS OBTAINED AT DIFFERENT TIMES

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**** Faculty of Geology, Moscow State University*
**** *Industrial and Research Institute for Engineering of Construction (IRIEC), Moscow*

Information on coastal dynamics (and particularly on arctic coastlines) is sparse and is based, as a rule, on above-ground data. Thus, we use remote sensing data obtained at different times to study multiyear coastal dynamics.

We began studying the coastal dynamics of the Laptev and Vostochno-Sibirskoe seas within the framework of the "Sea shore protection from dangerous natural phenomena" project of the Production Scientific-Research Institute for Engineering Surveys and Construction (PNIIIS) under the supervision of Dr.Sc. V.V. Baulin. Here we present preliminary results obtained from several key areas on the Novosibirskie Islands (above-ground studies were performed by V.E. Tumskoy).

We used the 1951-1952 aerial photos from Industrial and Research Institute for Engineering of Construction (IRIEC) funds and 2001-2002 ETM Landsat and Modis Terra satellite images with resolutions of 30 and 500 m/pixel, respectively. Thus the time span between first and last images is 50 years.

Using the Modis Terra satellite images, we estimated sea ice conditions (in different seasons) that determine the periods of active coastal dynamics. Coastline changes were estimated through comparison of their positions in aerial and Landsat images.

Methodological aspects of this study are now in progress. To compare aerial and satellite images, we use special software developed in the ScanEx center and the laboratory of remote sensing (Faculty of Soil sciences, Moscow State University) under the supervision of D.V. Dobrynin.

A special program, Timan 7.02, performs geometric transformation and topographic overloading of bit-mapped and vector cartographic and remote sensing data. We use an oversampling algorithm that preserves image brightness, permitting later high-grade decoding.

In this study, the technique of mutual orientation of images uses the following sequence of operations:

1. Transformation of ETM-Landsat data into the 1942 coordinates;
2. Scanning and preliminary registration of aerial photography data;
3. Creation of a "tie-in points" system of paired aerial and satellite images. Here we used points no more than 300 m from the coastline, where maximum preciseness of transformation is necessary;
4. Oversampling of aerial photo data and its transformation into 1942 coordinates;
5. Data export into GIS (MapInfo);
6. Topographic overloading of different images;
7. Vectorization (digitization) of coastlines of both imaged periods;
8. Morphometric studies (distance measurement) of coastal retreat;

The capabilities of the Timan 7.02 program grew out of problem solving of geometric correction and transformation in certain projections of remote sensing bitmap data. Algorithms for the thematic processing of images, combined with technological cycles, form its base:

1. To classify brightness and texture features for decoding, Kohonen neural nets (SOM) and GTM algorithms are used;
2. To distinguish reference objects and extrapolate resolution, the Marcov random fields (MRF) and Gauss-Markov fields are used;
3. Structural analysis, and distinction and classification of lineaments are performed by hybrid technology including wavelet-transforms and neural net algorithms;

At the present time, test studies were performed on three key localities of the Novosibirskie Islands. Two areas are located on Novaya Sibir Island near Cape Pestsovyi (in the southeastern part of the island), in Myra Bay (northwestern part of the island) and on the northern coast of Faddeevskiy Island. Apart from remote sensing methods, fieldwork results obtained by V.E. Tumskoy during the 2000-2003 field seasons are used in this study.

The Pestsovyi and Faddeevskyi localities are similar in geological structure. At the base of the profiles, frozen clayey marine deposits with similar cryogenic structure occur. They are overlapped with thin ice-complex deposits. The heights of the cliffs are 25-40 m. According to the remote sensing studies, the coastal dynamics of the two sites differ. Thermal abrasion is the dominant process defining coastal dynamics, but the 50-year shoreline retreat is 30-120 m (or 0,6-2,4 m/year) on Faddeevskyi Island, and 70-220 m (or 1,4-4,4 m/year) on Cape Pestsovyi (twice as much as on Faddeevskyi Island). We suggest that the disparity depend on differences in coastal exposition (northern on Faddeevskyi and southern on Cape Pestsovyi) and sea ice regime.

Mira Bay is geologically different. High cliffs (30-35 m) are composed of marine deposits with thick massive ground ice strata of 20-30 m thickness and several kilometers length. They occur between -15 and 40 m a.s.l. The rate of coastal retreat is similar to that in the Faddeevskyi area and is 0-150 m over the 50-year period (0 - 3 m/year). Results of direct measurements of retreat rate during the 2000-2003 field seasons showed 4-5 m. Similar retreat rates of key areas with different geological structures could be explained by compensatory effects of the sea ice regime and wave action. Thermal denudation, together with thermoabrasion, also plays an important role in coastal erosion. For example, new thermo-cirques of 300 m diameter were formed during the last 50 years.

The presented results show that remote sensing methods deliver highly representative data on arctic coastal dynamics. We can use such results to arrange different types of shorelines according to their resistance to external action, to map shoreline changes and as a basis for analyzing the interactions between coastal dynamics and geotectonic, engineering and geological conditions. These are the goals of further research.

THE SEGMENTATION OF THE RUSSIAN NORTHERN COAST-LINE OF THE COASTLINE FOR THE PURPOSES OF THE ARCTIC COASTAL DYNAMICS PROJECT

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The Arctic Coastal Dynamics (ACD) international project seeks to reveal and investigate the complex parameters and features of sea-continent interactions in the Arctic sector of the Globe. Geographical, marine, geological, biological and environmental aspects are taken into consideration. Specialists and various scientific divisions and organisations are involved in the ACD program (Rachold et al. 2002). Many parties have carried out a variety of research at diverse and numerous sites along the Arctic coastline.

Detailed examination of every mile of coastline is, of course, not a realistic task. Specific tasks, such as an account of erosion and accumulation rate, the estimation of the amount of sediments and organic carbon derived from the continent, and the assessment of dangerous exogenic processes and human impact, all require some segmentation of the coastline and the classification of these segments. The current ACD classification template sets a framework for detailed and particular descriptions of each segment. Each segment should be relatively homogenous. The available information can be found on various maps (geological, geocryological, topographic, landscape, and bathymetric), or in archives and the literature. The spatial limits of homogeneous segments can be designated based on geosystem principles. A useful technique for Arctic coastal classification, and in particular for application to ACD problems, is Geographic Information Systems (GIS) technology.

GIS technology can be used to handle a multi-disciplinary database correlated with particular polygons or lines on the map and to create digital maps. GIS technology also supports monitoring needs, especially in the case of significant human activity. If some forecasting algorithm is accepted based on designed scripts of natural dynamics and economic activity, the GIS and monitoring system are able to not only represent modern data but also create prognostic information on environmental parameters (natural and human influenced).

So the main algorithm of the segmentation of the Arctic Russian coastline based on GIS technology and geosystem principles includes the following steps:

- refine geological and landscape onshore maps and databases of the coastline (Ganeschin et al., 1976; Gudilin et al., 1980; Circum-Arctic map, 1997; Melnikov et al., 1999);
- collect the available data on the elevations and morphology of the coastal zone;
- examine the curvature of the coastline and the presence of various islands along the coast;
- make an overlay of appropriate electronic layers to classify the coastal zone;

According to this algorithm, the segmentation of the coastal zone is executed separately for several large parts of the northern Russian coast in cooperation with collaborators of different scientific divisions participating in ACD projects and in several ITAS grants. The segmentation of the European part of the Russian coast was performed in part together with S.Ogorodov (MSU), Western Siberia, together with A.Vasiljev (ECI SB RAS, ITAS grant 01-2329), Chukotka and with M.Grigoriev (PIY SB RAS, ITAS grant 01-2332).

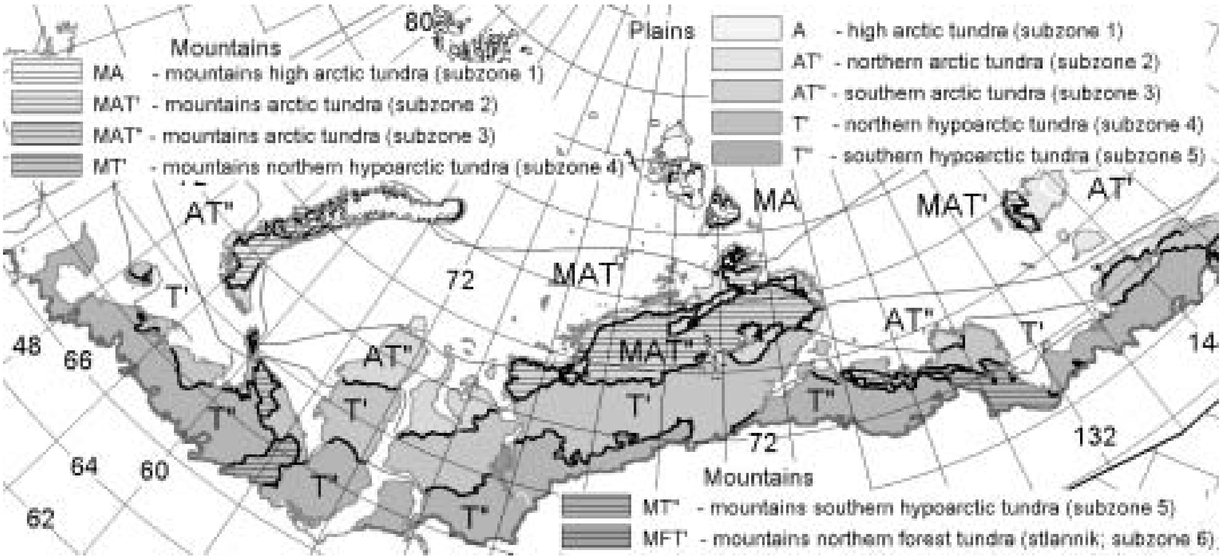


Fig.1. A landscape map of the Russian Arctic coastal zone: Climatic zonal, subzonal and altitudal-longtitudal landscape units.

The quaternary (surface) geology and landscape maps present the Russian Arctic coastal zone from its Norwegian boundary up to Chukotka. For the needs of ACD and INTAS, the width of the maps was expanded to reach 200 km (Fig.1). The **surface geology** map shows geological strata of Quaternary sediments and covers: terrains of different genesis (marine sediments, ice-marine sediments, fluviomarine sediments, fluvial sediments, lacustro-fluvial sediments, lacustro-fluvial ice-rich and thawed sediments, lacustrine sediments, lacustro-till sediments); terrains & covers of different genesis (glacial sediments, glaciofluvial sediments); thin quarternary sediments atop bedrock (residual sediments – e, deluvial sediments – d, solifluctional sediments – s, colluvial sediments – c; and different combinations). The map presents 113 types of quaternary sediments. Both bedrock without quaternary soil and debris cover are shown. The class “lacustro-fluvial ice-rich and thawed sediments” is of special relevance to coastal research. The landscape map displays longitude and altitude zonation, morphology, lithology and vegetation (Drozdov, 2001; Drozdov, 2003).

The Barents sea coast (the **European part** of the Russian coast) can be divided preliminarily into 4 coarse segments before the detailed segmentation (Fig.2). The first segment is the Kola peninsula, which is represented mainly by rocky slopes with many fiords. Few sites with low marine terraces or glacial plain can be found near the shore. The second segment is the Wight seacoast. It has the appearance of altered low marine terraces or glacial plain along the sea. All coastal material is unfrozen. The third segment, up to the Yugorsky Peninsula, is represented mainly by frozen soils of various quaternary geological origins and ages. At Vaigach and Novaya Zemlia, frozen rocks and debris prevail (Drozdov et al., 2003; Ogorodov, 2001).
The Kara sea coast (**Western Siberia** and **Taymyr;** Fig.5): Novaya Zemlia has mainly marine sediments (clay, sand, debris) along the coast of its southern island , glaciers and marine beaches on the northern island, and debris-covered marine coasts in the extreme north.

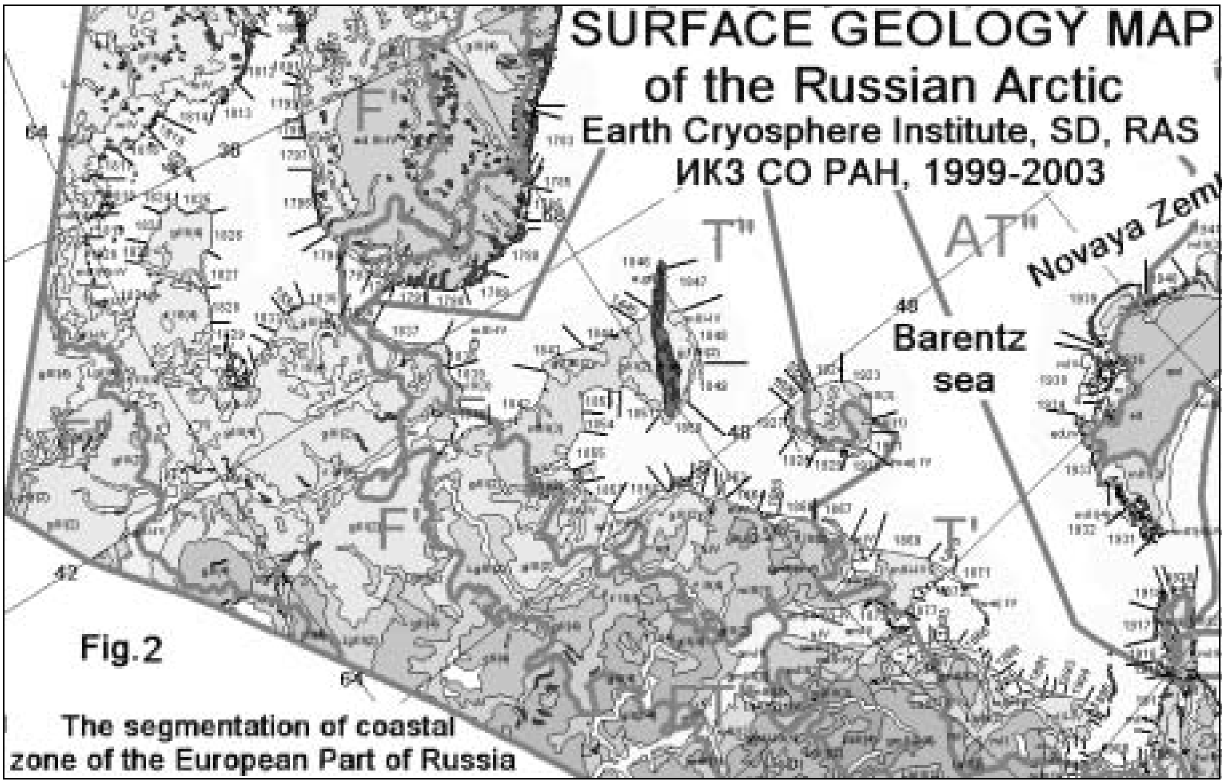


Fig.2

The segmentation of coastal zone of the European Part of Russia

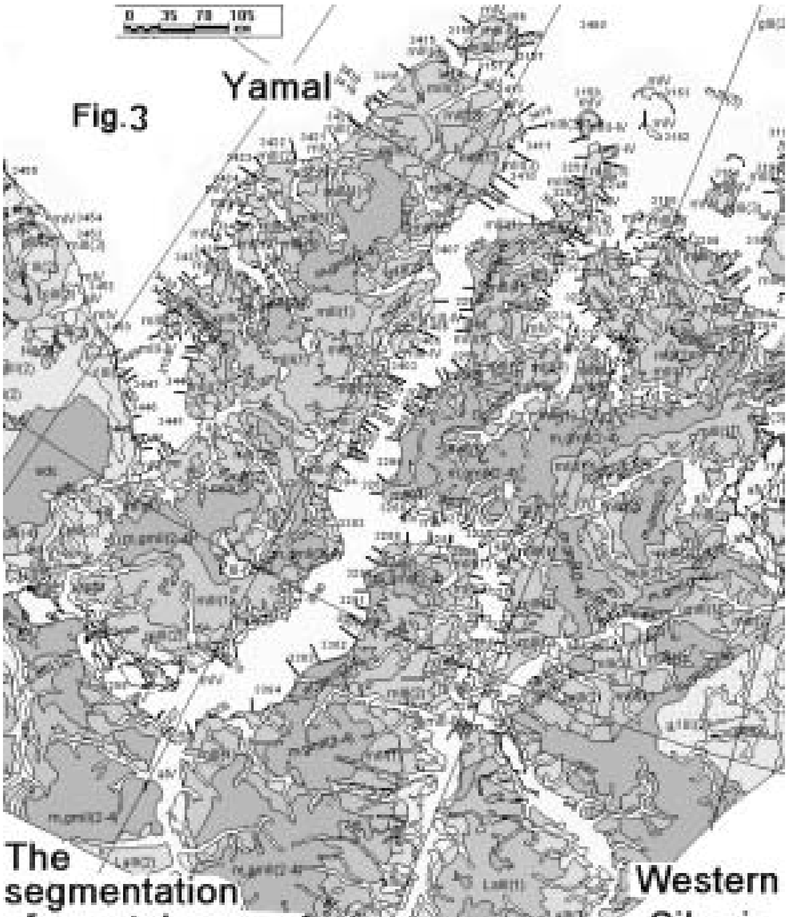


Fig.3

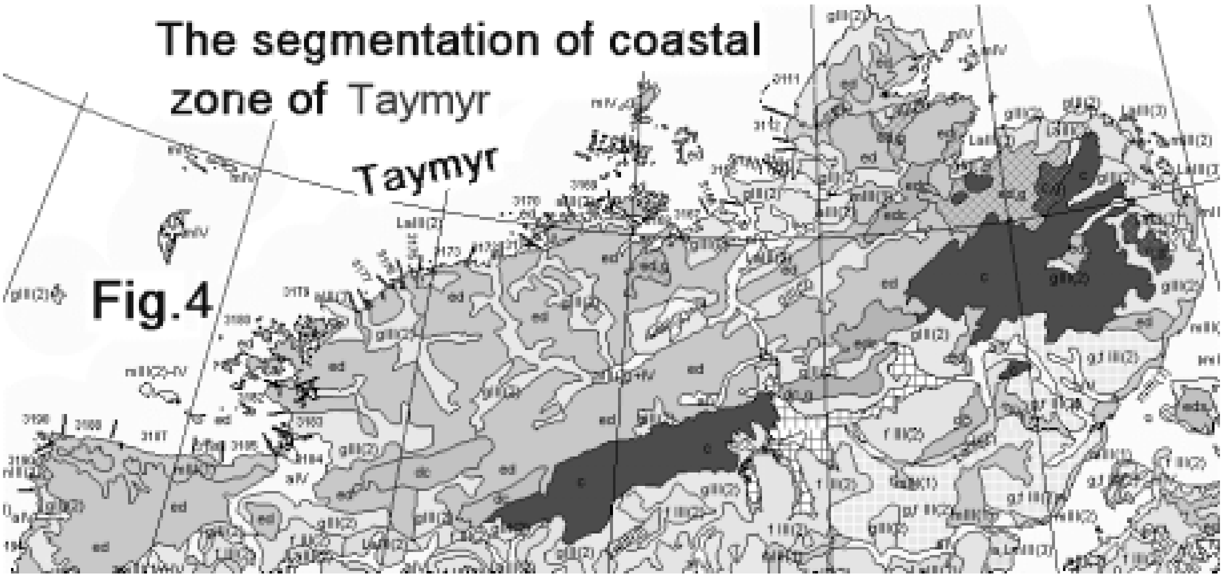
The segmentation of coastal zone of Western Siberia

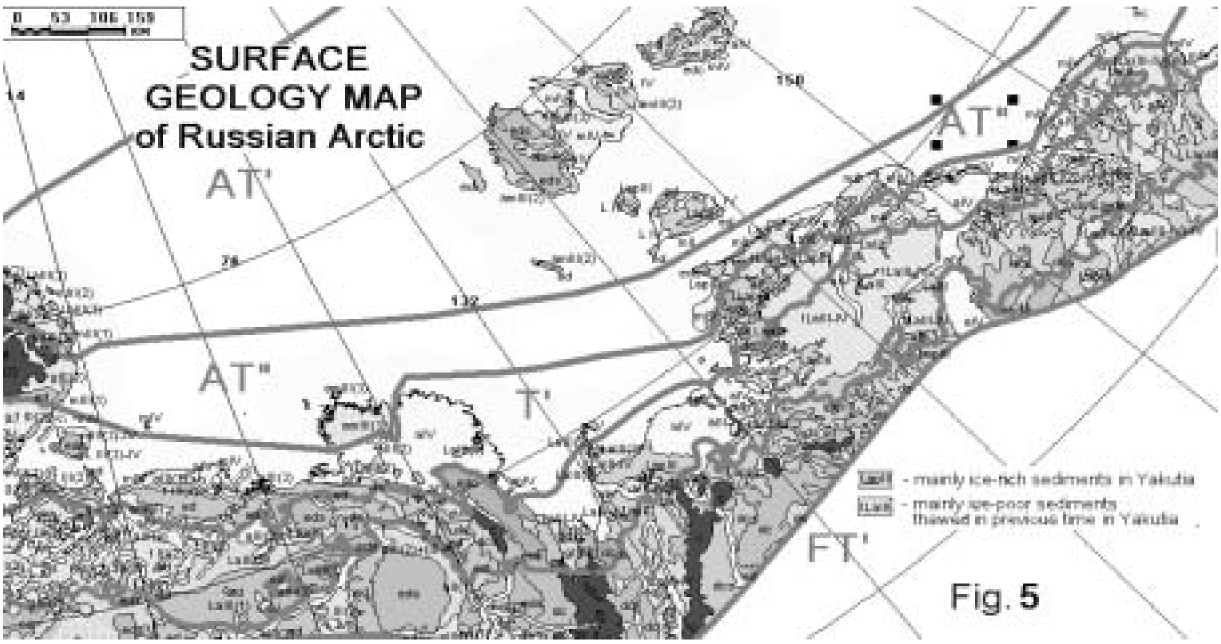
Western Siberia is a rather homogenous region considering its coastal conditions. Along the coastline, marine terraces of various lithologies and sometimes sandy-clay river plains are found (Fig.6). Marine terraces are mainly frozen, while alluvial ones may be frozen or thawed.

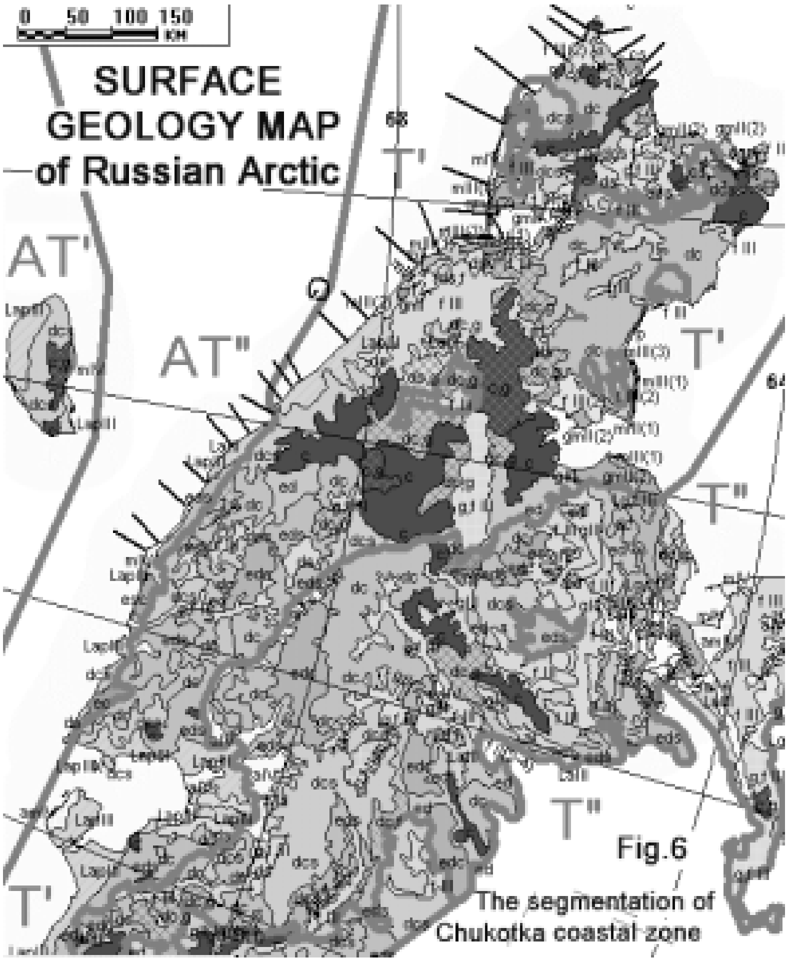
The Taymyr coastline (Fig.7) can be divided preliminarily into 4 coarse segments, all of which are frozen. The western coastline segment stretches from the Yenisey Gulf to the mouth of the Piasina. It is formed mainly of marine terraces. Sometimes rocky peninsulas, such as Dikson, can be found. The second segment (from the Piasina to the Taymyra rivers) resembles an alteration of rocky coasts, debris slopes and till-filled valleys. Further on in a northeasterly direction, up to the Cheluskin Peninsula, till slopes prevail in the coastal zone.

The Severnaya Zemlia Islands have mainly marine sediment coasts (clay, sand, debris) and glaciers.

The common table according to the ACD classification for the entire **Kara Sea** is already completed for Western Siberia (Vasiljev, Tab. 2) and is now being processed for Taymyr.







	A	B	C	D	E	F	G
1	**ACD Coastal Classification of the Kara Sea**						
2	*field*	entry options					
3	**primary_contact_person**	provide name and email: Alexander Vasiliev,					
4	regional_sea	Chukchi Sea=CS, East Siberian Sea=ESS, Laptev Sea=LS, Kara Sea=KS, Barents Sea=BS, Greenland	KS	KS	KS	[illegible]	KS
5	**segment (length, km)**		21,1	24,4	31,6	12,2	35,5
6	segment_name	text field	Tazovskaye	Tazovskaye	Obskaya gu	Obskaya gu	Obskaya gu
7	segment_no	number	86+87	86+87	88	89	90
8			3286	3287	3288	3289	3290
9	segment_start_lat	decimal degrees (4 decimals)	68,9264	68,8861	68,8086	68,6368	68,5299
10	segment_start_long	decimal degrees (4 decimals)	75,8617	75,4047	74,9133	74,4510	74,4756
11	segment_end_lat	decimal degrees (4 decimals)	68,8861	68,8086	68,6368	68,5299	68,2724
12	segment_end_long	decimal degrees (4 decimals)	75,4047	74,9133	74,4510	74,4756	74,5443
13	segment_comment	yes=y or no=n (to be added if islands are included in the	L+FP	L+FP	4 mer.ter	FP	4 mer.ter
14	**onshore** (direction landward from the sea)						
15	onshore_form	delta=d, lowland(<10m)=l, upland(10-300m)=u,	d	d	s	w	u
16	**backshore** (upper part of the active beach above the normal reach of the tides (high						
17	backshore_form	cliff=c, slope=s, flat=f, ridged/terraced=r,	f	f	c	f	c
18	backshore_elevation	in meters	2.5	2.5	40	2.5	40
19	backshore_material_1	lithified=l, unlithified=u	u	s	s	u	u
20	backshore_material_2	mud-dominated=m, sand-dominated=s, gravel-dominated=g, diamict=d, organic=o, mixture= e.g.mg, sg	s	s	ms	s	ms
21	backshore_comment	text to be added if backshore_form=r or					
22	**shore** (strip of ground bordering the sea which is alternately exposed, or covered by						
23	shore_form	beach=b, shore terrace*=t, cliff=c, complicated=x	b	b	b	b	b
24	beach_form	fringing=f, barrier=b, spit=s (to be filled if					
25	shore_material_1	lithified=l, unlithified=u	u	s	s	u	u
26	shore_material_2	mud-dominated=m, sand-dominated=s, gravel-dominated=g, diamict=d, organic=o, mixture= e.g.mg, sg	s	s	ms	s	ms
27	shore_comment	text to be added if shore_form = x					
35	**general**						
36	ground_ice_1	low(2-20)=l, medium(20-30)=m, high(>30)=h	l	l	m	l	m
37	ground_ice_2	in % total volume of shoreline (best guess!)	20	20	34-42	20	34-42
38	ground_ice_comment	text to be added if ground ice template was filled out					
39	change_rate	in meter/year (erosion=minus, accumulation=plus)	no data	no data	-0.3	no data	-0.4
40	change_rate_interval	in years (years of observation, e.g. 1956-1999)					
41	dynamic_process	erosive=e, stable=s, accumulative=a (interpretation, only to be filled out if change rate is not available)	s	s	e	s	e
42	dry_bulk_density	in t/m3 (if no data available use: clay=1.3, silt=1.5,					
43	organic_C	in weight % (best guess!)					
44	soil_organic_C	in kg/m2 (if available)					

Conclusions

This investigation has segmented the northern coastline based on on-shore data. The integration of on-shore and off-shore data creates the potential for a formalized description of the coastal zone.

The table of data on the designated coastal zone segments (following the ACD classification template) is the most uniform presentation of co-ordinates, morphology, topography, bathymetry, geology, and soils.

Acknowledgements

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GEOMATICS IN RUSSIAN ARCTIC COASTAL DYNAMICS INVESTIGATIONS

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Coastal evolution is controlled by the interaction between hydrodynamic forcing (waves, currents and water levels) and a combination of shoreface and subaerial coastal material properties and morphology. Along high latitude coasts, limits to our understanding of coastal and shoreface dynamics depend upon a lack of information on coastline topography and the characteristics of the shoreface. Therefore, precise geodetic and bathymetric measurements for the evaluation of coastal retreat are very important for studying coastal dynamics. Following the International Arctic Coastal Dynamics Program strategy, field investigations should be implemented at specific key sites, which are characteristic for the entire coastline. During three expeditions (2001- 2003), scientists from VNIIOkeangeologia carried out investigations at key sites in the western Russian Arctic using modern survey equipment and technologies. A suite of standard and original geomatic tools and techniques was implemented for the development of long-term coastal monitoring sites.

An onshore topographic survey was carried out using an electronic total station (Nikon DTM-350). For position determination during offshore surveys, the DGPS equipment GeoExplorer (Trimble) was used. Soundings were carried out with the addition of complex equipment, V2600P (JMC), which includes a digital single beam echo sounder, GPS and video plotter. Survey lines were input to V2600P and sailed using video-plotter presentation. For V2600P data acquisition, a special digital logging device was developed (data logger).

As real time GPS differential corrections are currently inaccessible in western regions of the Russian Arctic, high accuracy positioning was conducted with the addition of DGPS post-processing software. The Trimble program package "PathFinder Office" was used. For the final processing of offshore survey data, the hydrographic software "NabatEdit" was used. This software provides the following functions: input of automatic depths and time logging from data logger into the NabatEdit sounding database; logging of differentially corrected coordinates files from PathFinder Office software into the NabatEdit sounding database with simultaneous association in UTC time of corrected coordinates and measured depths; graphical editing of coordinates and measured depths; reduction of soundings using sound velocity, tide and transducer-offset corrections; data export from the NabatEdit sounding database to an ASCII file. The resulting onshore survey data was exported from the total station to a PC computer. While surveying special features and attributes, geo-coding was implemented. After exporting, the topographic data was processed by the program "Convert". This software is used for coordinate conversion and feature detection. The resulting files from “Convert” represent all kinds of observed topographic features (location of the cliff edge, cliff base, waterline, driftwood line), and describe underwater and onshore relief in a common coordinate system. All information is then exported into ARC VIEW shape-file format, which enables production of digital maps. ARC VIEW software is used for visualization, further analysis, storage and for creating TIN surfaces for studying coastal dynamics, volume calculations and other tasks. An additional advantage of GIS is its ability to load geo-referenced historical maps as background raster images for shoreline retreat comparison. For example, the large-scale topographic survey at the Marresale key site (western Yamal) was carried out in 1941. We successfully located the 1:1000 scale map in the archives. After careful investigation of coordinate transformation problems, this map was scanned, geo-referenced and loaded to the Marresale GIS project. According to project data, the coastline retreat at the Marresale site between 1941 and 2003 is about 153 m. The average annual sediment input volumes at the Marresale site were also estimated.

Thus the first step is made towards GIS-based quantification of Arctic coastal erosion. Further efforts in the field of geomatic-based ACD investigations are closely linked with remote sensing and high-resolution satellite imagery.

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SPATIAL DATA INFRASTRUCTURE SUPPORTS LONG TERM MEASUREMENTS TO DETECT ARCTIC CHANGE

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On a global scale, the "Establishment of Spatial Data Infrastructures (SDI) is emerging as a major endeavor. The SDI encompasses the policies, organizational remits, data, technologies, standards, delivery mechanisms and financial and human resources necessary to ensure the availability and access to spatial data."

Global Spatial Data Infrastructure web site: www.gsdi.org

The Barrow Arctic Science Consortium's Digital Working Group (BASC-DWG) is striving to contribute to the global SDI effort through creation of a regional framework focused on the area surrounding Arctic research at Pt. Barrow, Alaska. The Barrow Area SDI is an essential framework to aid research efforts in detecting change over time. The tools of this framework are being developed and made available for the Barrow, Alaska area, but are applicable to other regions within the arctic system faced with the challenge of monitoring coastal dynamics.

Many research efforts are spatial in nature and often involve establishing and monitoring transects, referencing remotely sensed imagery or performing analysis with Geographic Information System (GIS) technology. Unfortunately, much of the data is dispersed, sets of measurements on the ground are not standardized and imagery exists in varying formats. The BASC-DWG is tackling these issues with the implementation of SDI resources and standards to promote the collection of consistent measurements for long-term monitoring programs. Components of the Barrow Area SDI include physical infrastructure, data and spatial data policy. The Barrow Area SDI provides tools such as a survey grade Differential Global Positioning System (DGPS), geospatial data (remotely sensed imagery, GIS themes, ground control points), standards (software, hardware, map projection, datum, metadata, use of ground survey markers), associated attributable databases plus a means for archiving and distributing this information. Through the Barrow Area SDI, user protocols will be stressed in an effort to ensure consistency for long-term monitoring.

A key component of the Barrow Area SDI is the Barrow Area Information Data – Internet Map Server (BAID-IMS). The Barrow Area Information Database began as a relational database in Microsoft Access. Through the efforts of the BASC-DWG, this tool was developed to include a web-based interface with mapping capability. The resulting Barrow Area Information Database – Internet Map Server (BAID-IMS) provides a means for tracking historic and current research activities, a logistic planning tool, an aid for permitting new study sites, plus a means for connecting researchers working in the Barrow area and a tool for public outreach. Research efforts focused on tracking coastal erosion can use this tool to locate erosion markers, ground control points, a time series of coastline delineations, plus historic and current imagery (air photos and satellite images.)

Web address: http://ims.arcticscience.org

Standard data formats (ESRI shape files, ArcGIS GRID format, GeoTiffs, map projection and datum) and metadata have been compiled to meet the Federal Geographic Data Committee standard (FGDC). Metadata ensures that geospatial data is used appropriately while it preserves and passes on institutional knowledge to new users. FGDC formatted metadata is a requirement for publishing geospatial data on a federally recognized clearinghouse nodes such as the National Science Foundation's Arctic System Science (ARCSS) Data Coordination Center (ADCC) at the National Snow and Ice Data Center, Boulder, Colorado.

The Barrow Area SDI framework would not be possible without the foresight of a dedicated team of professionals who are actively involved in research that requires geospatial technology. The Barrow Area SDI is a prototype that may be modeled by other research hubs throughout the Arctic.

For more information on the emerging Barrow Area Spatial Data Infrastructure resources and tools, please visit our web site: www.arcticscience.org

Acknowledgements:

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SEGMENTATION OF THE U.S. CHUKCHI SEA COASTLINE

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A regional classification of the U.S. (Alaska) coast of the Chuckhi Sea was developed according to protocols established by the Arctic Coastal Dynamics program. This sector of coast extends from Cape Prince of Wales on Bering Strait, northeast to Kotzebue Sound, northwest to Point Hope, and northeast to Barrow. Segmentation was based on 1:63,360-scale topographic map data, aerial and satellite imagery, and fieldwork. A total of 47 segments were delineated, spanning a total of about 1350 km. Six general coastal geomorphic classes were identified: unlithified bluffs; lithified bluffs / headlands; strand plains / capes; barrier island / lagoon systems; bays / inlets; and deltas. Most segments can be considered transgressive (erosion rates ranging between 0.3 and 1.5 m yr^{-1}), while local progradation occurs at the down drift ends of some coastal compartments, especially in the southern half of the sector. Ground ice content and mean annual erosion rate tend to increase to the north. Overall, the Alaskan Chukchi coast is characterized by varied substrates (silt, sand, gravel, bedrock, both glaciated and unglaciated) and sedimentary responses to atmospheric and marine climate during the late Holocene.

CLASSIFICATION OF THE ALASKAN BEAUFORT SEA COAST AND ESTIMATES OF SEDIMENT AND CARBON INPUTS FROM COASTAL EROSION

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A regional classification of shoreline segments along the Alaskan Beaufort Sea Coast was developed as the basis for regional quantification of coastal morphology, lithology, and sediment characteristics. Segmentation of the coast, based on the 1:250,000-scale World Vector Shoreline, delineated 48 segments along the mainland coast totaling 1957 km, as well as 1334 km of spits and islands. Mainland coasts were grouped into five broad classes, exposed bluffs (313 km), bays and inlets (235 km), lagoons with barrier islands (546 km), tapped basins (171 km) and deltas (691 km). Sediments of the various segments were classified as silts (mostly marine), silt and sands (deltaic), sands (eolian and marine), pebbly silty sands (genesis uncertain), and uncommonly gravel (fluvial). Bank heights generally range from 2–4 m high for most erosional areas and are usually <1 m in depositional areas such as deltas. Mean annual erosion rates (MAER) by coastline type varied from 0.7 m/yr (maximum 10.4 m/yr at Elson Lagoon) for lagoons to 2.4 m/yr for segments along exposed bluffs (maximum 16.7 m/yr at Cape Halkett North Coast). When considering dominant soil texture, MAER was much higher in silty soils (3.2/yr) than in sandy (1.2 m/yr) to gravelly (-0.3 m/yr)soils. Soil organic carbon along eroding shorelines (excluding 14 delta segments) are estimated to range from 50 to 159 kg C/m^2 of bank surface. When accounting for segregated and wedge ice, the annual carbon flux for eroding shorelines (1265 km in 34 segments) is highly variable, ranging from 16 to 818 Mg (metric tons) C/km of shoreline. Deltas are assumed to be sediment sinks and not contributing sediments and carbon from erosion. Across the entire Alaskan Beaufort Sea coast, carbon input from eroding shorelines is estimated to average 149 Mg C/km of shoreline and total 168,506 Mg (tons) C/yr. Annual mineral input from eroding shorelines (deltas excluded) is estimated to average 2743 Mg/km of shoreline and total 3,119897 Mg/yr.

A VOLUMETRIC ANALYSIS OF LONG-TERM COASTAL EROSION ON HERSCHEL ISLAND, YUKON TERRITORY : PRELIMINARY RESULTS

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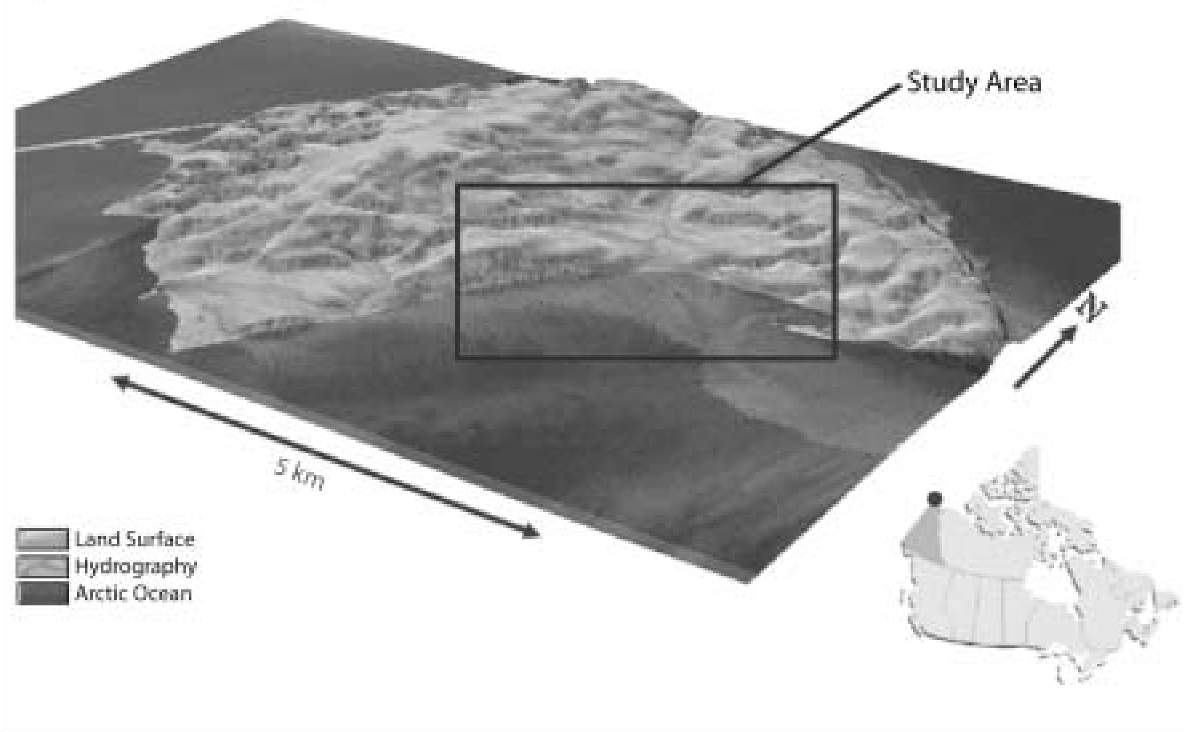
Study Area

Herschel Island, also known as Qikiqtaruk, is located in the Beaufort Sea at 69°36'N, 139°O4'W on the northern coast of the Yukon Territory, Canada. The island lies approximately 60 km east of the border between Yukon and Alaska and 3 km north of the continental coast (Fig. 1). It is a moraine resulting from the late fluctuations of the Pleistocene ice sheets and is composed of marine, non-marine and mixed origin sediments (Bouchard, 1974).

Fig.1 Location map of Herschel Island



The tremendous coastal retreat occurring in the area, which is assumed to be the most ice-rich area of the Canadian Arctic (Pollard and French, 1980) has been recently emphasized in the scientific community. Coastal processes have been investigated through detailed field studies (Are, 1988; Solomon et al., 1994) and experimental numerical modelling (Kobayashi et al., 1999; Makhloufi et al., 1999). Harper (1991) documented average coastal retreat rates for the southern Canadian Beaufort Sea of 1.0 m/yr for the 1944-1970 period, with some peak rates of 18.2 m/yr. For the 1970-2000 period Solomon (2003) documented average coastal retreat rates of 1 to 5 m/yr using the locations referenced by Harper (1991) in his study.

Previous studies

Horizontal coastal retreat rates have been documented on Herschel Island for two different periods. MacDonald and Lewis (1973) investigated coastal evolution on the Yukon Coastal Plain for the period 1954-1970 and reported an average horizontal coastal retreat rate of 0.68 m/yr. For the 1970-2000 period, Lantuit and Pollard (2003) documented coastal retreat rates reaching 1.03 m/yr (Fig. 2). This 50% general increase is moderated by the high local variability of erosional hot spots (Fig. 3). Global warming is believed to be responsible for the enhancement of erosional processes. McGillivray et al. (1993) showed that a longer open-water season, warmer sea temperatures and a reduced sea-ice extent would lead to greater storm frequency, and hence, greater erosion.

Fig. 2 Horizontal coastal retreat rates: 1954-2000 evolution

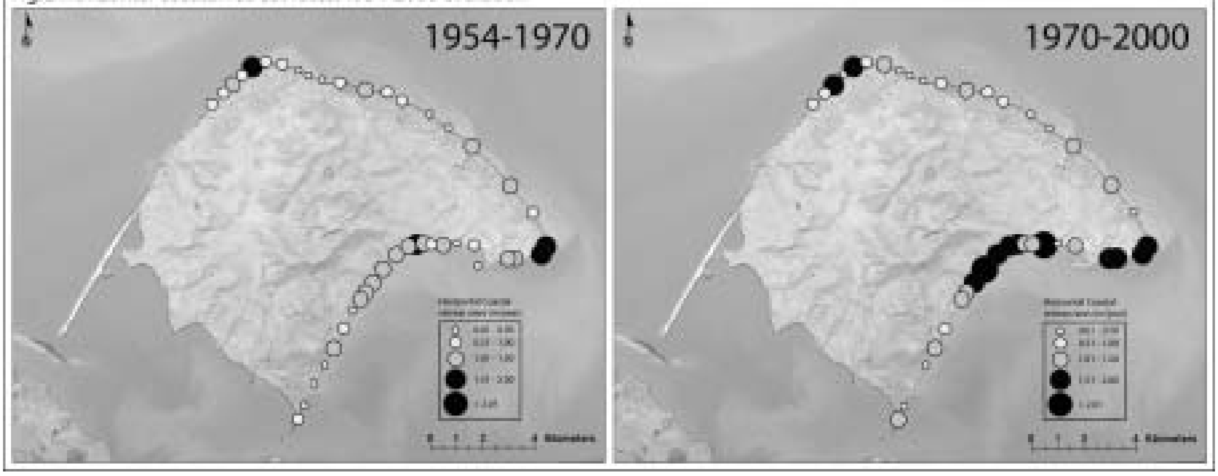
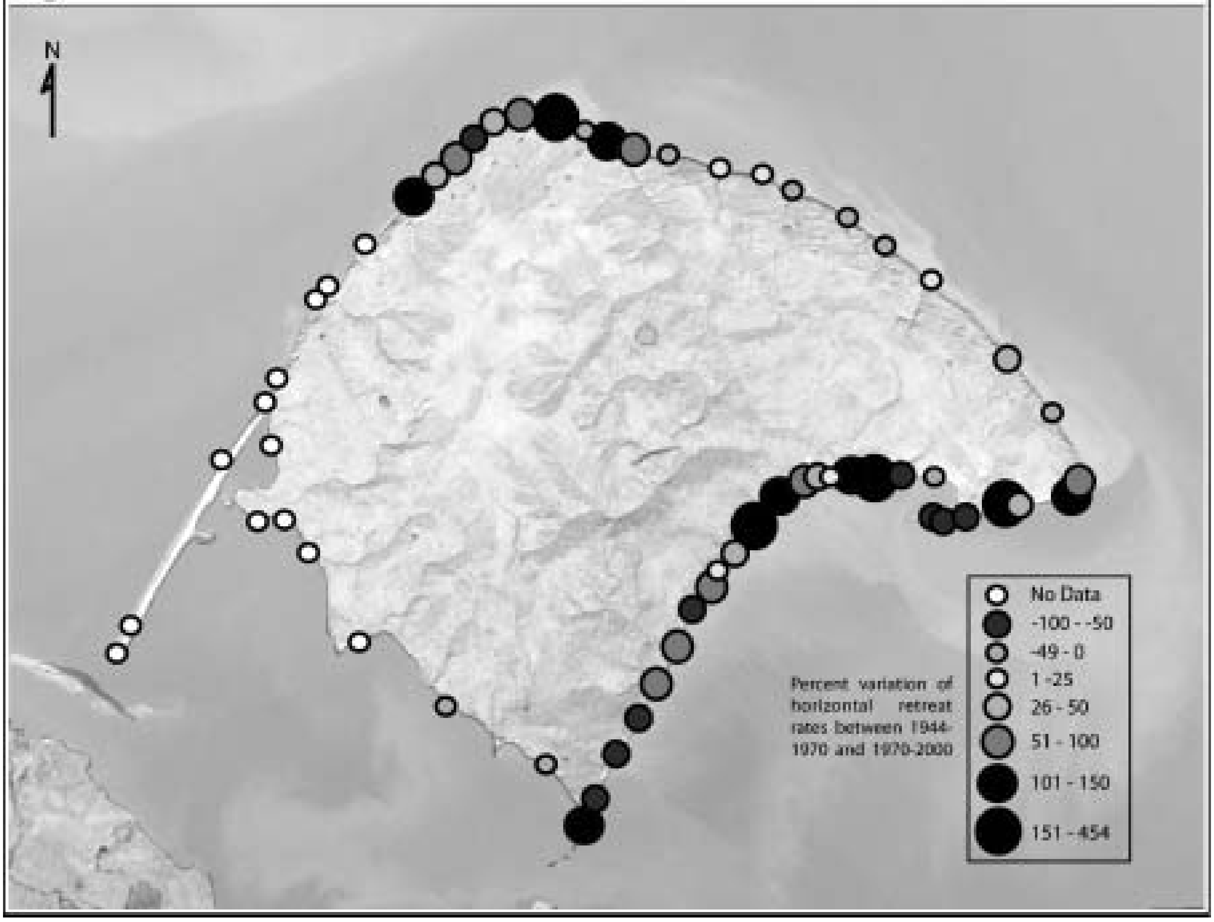


Fig. 3 Identification of enhanced erosion zones



Coastal erosion was shown to be important (>1m/yr) in the vicinity of large retrogressive thaw slumps (Lantuit and Pollard, 2003), in other words, where the shoreface exhibited high ice contents. Although horizontal retreat rates provide valuable information about the amount of sediment released by coastal erosion, Hequette and Barnes (1990) have shown that there can be a discrepancy between horizontal and volumetric rates. The goal of this study is therefore to compare horizontal and volumetric coastal retreat rates, and to highlight the parallel evolution of these two datasets during the last half of the twentieth century.

Methods

Softcopy photogrammetric tools were used to compile airphoto archives of Herschel Island from 1954 and 1970. The PCI Geomatics stereophotogrammetric workstation Orthoengine was chosen to process the airphoto data sets. Orthoengine allows for the generation of high precision digital elevation models (DEMs). The accuracy of the elevation measurements is estimated at 0.10 to 0.20% of the flying height. For airphotos at the 1:12,000 scale, it yields an estimated accuracy of 20 cm.

Georeferencing of digital images of Herschel Island used to rely on aerotriangulated coordinates from the 1970's and on topographic maps at the 1:50,000 scale. Inaccuracies in absolute georeferencing appeared to be greater than 40 m in certain locations, and points regularly shifted by tens of metres. Therefore, post-processed kinematic GPS points were collected in the field during September 2003 using a Trimble 4700 differential GPS device in order to provide accurate absolute georeferencing. The horizontal and vertical accuracy of the Trimble GPS is between 3 and 10 cm, 95% of the time. Such error is negligible when compared with the expected accuracy of stereophotogrammetric results. An arbitrary error value of 0.50 m was however assigned to these GPS survey points in order to account for the resolution of the available imagery.

Airphoto blocks were georeferenced according to those surveyed points and DEMs for years of interest were produced using the stereomatching algorithm of the PCI Geomatics Orthoengine software. The DEM spatial resolution was correlated with airphoto scale. 1:60,000 images were scanned at 1600 dpi and produced 1.1 m theoretical resolution images. 1:13,000 images were scanned at 800 dpi and produced 0.3 m theoretical resolution images.

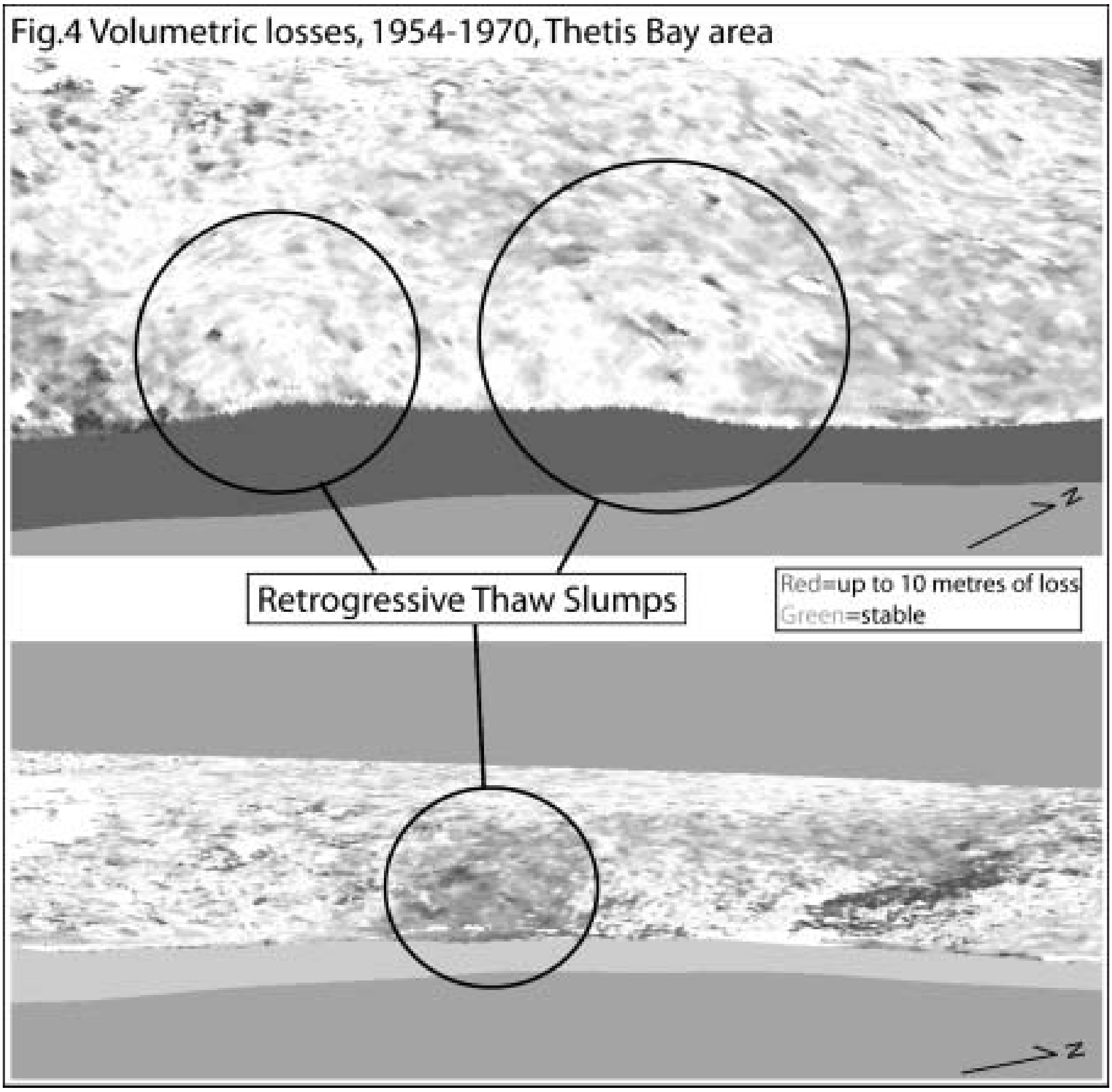
Arithmetical and vizualisation operations on outputs were processed in ArcGIS. Both DEMs were resampled to the same spatial resolution (1.1 m) and then the 1970 DEM was subtracted from the 1954 one to produce a map of volumetric erosion.

Preliminary Results

DEMs were first produced for a sample area (Fig. 1) characterized by shore sections known to be susceptible to intense erosion (Lantuit and Pollard, 2003). The chosen section of coast is approximately 4 km long and consists of a succession of steep cliffs and retrogressive thaw slumps. The objective was to produce DEMs with comprehensive coverage of the area, but the DEMs lacked some detail in areas of flat topography. The coastal sections, however, had enough definition to make a first estimation of volumetric erosional losses.

The resulting dataset exhibited numerous artifacts, probably due to the coarse resolution of the 1954 images and to the lack of ground control points, but nevertheless gave us a first tentative GIS layer for differential volumetric erosion over the 1954-1970 period. Two major processes were outlined by this layer. First, a direct observation of the coastal delineation confirmed a general correlation between volumetric and horizontal coastal retreat. Although statistical analyses have not yet been conducted on the dataset, it is not surprising that these two variables are linked. Second, the sections of the coast characterized by the greatest rates of volumetric erosion during the period corresponded to newly activated retrogressive thaw slumps. Retrogressive thaw slumps are landforms associated with the meltout of bodies of massive ground ice. They are commonly found along ice-rich coasts (Wolfe et al., 2001). These slumps were easily idenditified by their bowl-shaped signature on the GIS layer (Fig. 4).

Pixel values on the GIS layer represented vertical variations in metres between the 1954 and the 1970 land surfaces. Within the areas identified as slumps, the difference in land surface was up to 10 metres.



Conclusion

As noted in our previous study for the area (Lantuit and Pollard, 2003), the greatest rates of horizontal erosion seem to be correlated with the activation or re-activation of ground-ice related features. The current study confirms that the greatest volumetric losses are also associated with these features and pinpoints that these losses were almost always located at the end of the lobes of the newly activated retrogressive thaw slumps.

Retrogressive thaw slumps can be essentially characterized by thermally-triggered mechanisms and should be occurring as frequently inland as near the shore; however most of them are primarily located along the coast. Accurate volumetric erosion data can give us more detail about the link between the volumetric expansion of retrogressive thaw slumps and the intensity of coastal erosion.

Future processing of the entire island's coast topography for the years 1954 to 1975 (range of available airphoto archive), coupled with an Ikonos panchromatic stereo image for the year 2004 will give us an accurate basis for the compilation of volumetric erosional losses on

Herschel Island for the last 50 years. A detailed statistical analysis of the evolution of the rate, parallel to the activation/reactivation of ground-ice related landforms will provide us with a better understanding of the role of ground ice in coastal erosional processes in the Arctic

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PHOTOGRAMMETRIC ANALYSIS OF COASTAL EROSION ALONG THE CHUKCHI COAST AT BARROW, ALASKA

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A variety of empirical and modeling approaches are being taken to assess the history and risk of erosion and flooding along the Chukchi Sea coast near Barrow, Alaska. Part of a broad assessment of climate impacts for the North Slope (nome.colorado.edu/HARC), this study utilizes softcopy photogrammetry and GIS to quantify coastal erosion over the last five decades. Barrow was also established as a key site with the Arctic Coastal Dynamics (ACD) program, http://www.awi-potsdam.de/www-pot/geo/acd.html.

We conducted a preliminary analysis of aerial photography for 1948 and 1997 (Fig. 1). The scanned photos were orthorectified (1997) and co-registered (1948) with PCI Geomatics to 0.5 m pixel resolution. The 1997 photos were orthorectified using Ground Control Points (GCP's) previously acquired for this project with Differential GPS (instaar.colorado.edu/QGISL/barrow_gcp) and a Digital Elevation Model (DEM) created from 1997 topographic lines. Bluff bottom line (Fig 1a) and shoreline (Fig 1b) positions were then digitized and overlaid. A graph was created showing alongshore-coastal changes between 1948 and 1997. Locational accuracy is about 1.9 m for shorelines and 2.1 m for bluff bottom lines, considering errors due to 1948 co-registration, digitizing, and transient waterline shifts from tides and wave setup. Accuracy for corresponding erosion rates, averaged over the 49-year period, is thus 0.04 m/yr.

Coastal erosion is spatially variable, with virtually no erosion on the bluffs south of the gravel pit (the southern third of the photo in Fig. 1a), and high erosion on the bluffs near Barrow. Over the 49-year period, the bluff bottom has retreated only 0.2 m for the area south of the gravel pit, compared to an average of 17.6 m near Barrow. Immediately southwest of Barrow, bluff-bottom retreat due to erosion reaches a maximum of 34 m. Corresponding time-averaged erosion rates are <0.01 m/yr for the area south of the gravel pit, and 0.36 ± 0.04 m/yr on average for the bluff near Barrow, reaching a maximum rate of 0.69 m/yr southwest of Barrow. It must be noted that time-averaged coastal change rates are not reflective of the true nature of coastal change on the Chukchi coast, where change is primarily determined by extreme storm events (Walker, 1991, Harper, 1978).

Similarly, beach erosion is spatially variable, with substantial retreat near Barrow, and growth of the beaches near Browerville (Fig. 1b). The shoreline at Barrow has retreated on average 22 m (0.45 m/yr) over the intervening five decades, reaching a maximum retreat of 40 m (0.82 m/yr). Net progradation averaged 17 m (0.34 m/yr) for part of the Browerville shoreline, with maximum progradation reaching 40 m (0.82 m/yr). Some Browerville shoreline areas eroded an average of 4.8 m (0.1 m/yr). The erosion rates are approximately half those calculated for the ice-rich, peaty shorelines along Elson Lagoon, east of Barrow (Brown et al., 2003). They nonetheless are representative of the high rates of coastline erosion threatening many arctic settlements (cf. Hopkins and Hartz, 1978; Reimnitz et al., 1988; Jorgenson et al., 2002; Smith, 2002).

This analysis documents a significant hazard for the Barrow community. We plan to extend the analysis in space and time (SW of Barrow to Point Barrow, with additional photography for 1955, 1962, 1964, 1979, 1984, and 2002) to address such questions as: Which environmental factors control spatial variability in erosion? Is erosion accelerating due to climate change? Is coastal change gradual, or is it controlled by low-frequency, high-magnitude storms? Have mitigation efforts during the 1990's been effective at slowing erosion? Are the low-gradient gravel beaches northeast of Browerville experiencing progradation due to longshore drift of eroded materials? And with continued mitigation efforts, can we expect significant damage to buildings and infrastructure within the coming few decades?

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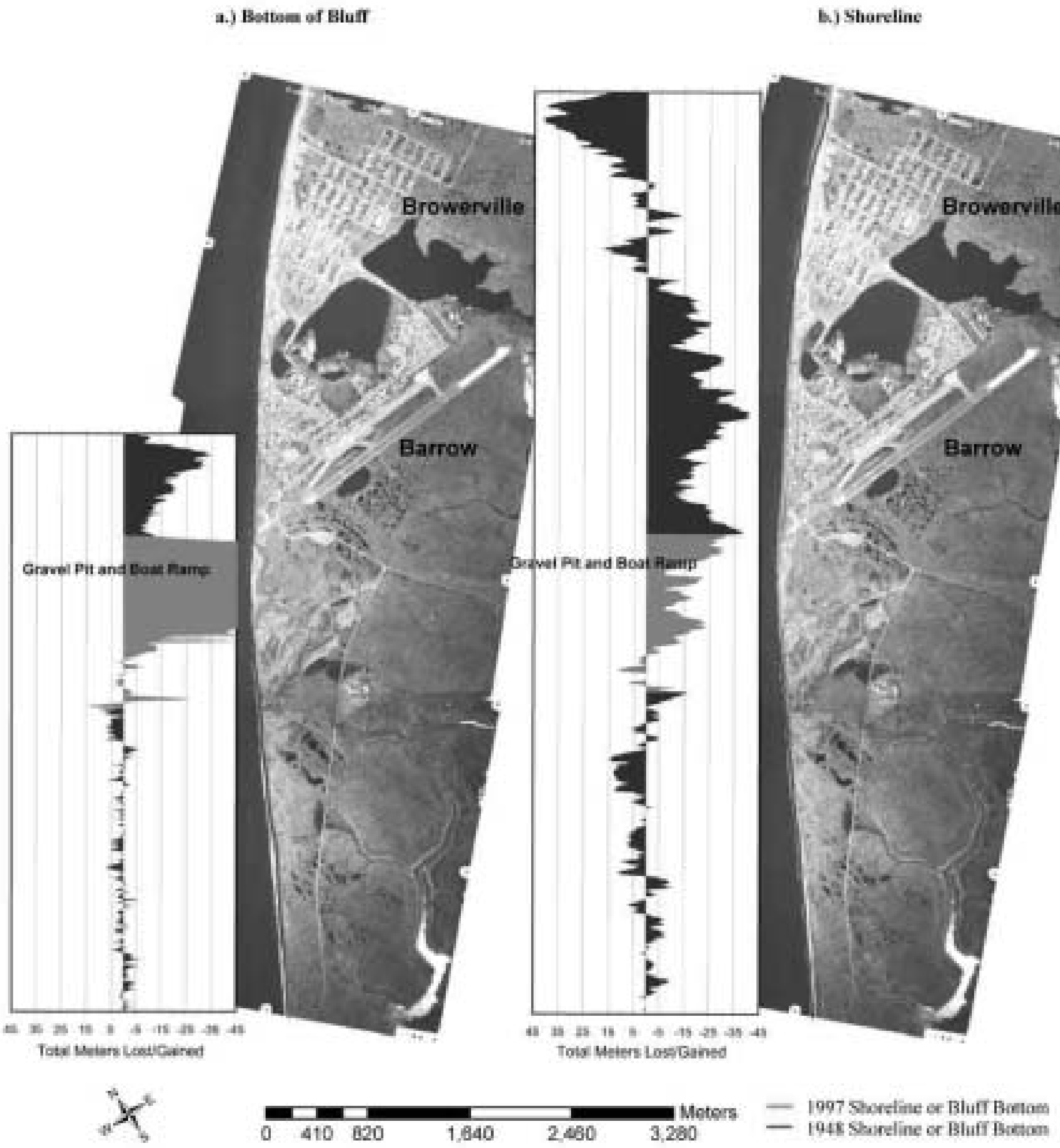

Figure 1. Coastal Retreat (Negative Values) or Aggradation (Positive Values) Between 1948 and 1997, Barrow, Alaska. Orthorectified 1997 aerial photography of Barrow and Browerville, showing the a.) bluff bottom positions in 1948 (red) and 1997 (green) and the b.) shoreline positions in 1948 (red) and 1997 (green). Portions of the graphs in gray depict the location of the gravel pit and boat ramp. Bluff and beach erosion in the study area is highest immediately southwest of downtown Barrow.

BATHYMETRIC SEABED MAPPING BASED ON GIS-TECHNOLOGY

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Evolution of arctic coastal zones differs significantly from other areas of the World Ocean caused by the interaction of modern wave and ice factors and including the influence of numerous glaciations and large-scale sea-level fluctuations. Glaciations have left coastal traces on the western part of the Russian Arctic only, whereas its eastern part was almost completely drained during glacial epochs. At present, a relatively large collection of data is available concerning the bathymetry, modern processes, geology and geomorphology of the Arctic coasts and seabed including the conditions of predominant cryogenic processes. Our investigations are based on the results of long-term research with the application of modern equipment, including narrow-beam and multi-beam echo sounders, the "Parasound" acoustic profiling complex, side-looking radars, bathymetric (navigation) maps and sediment samplers.

Although bathymetric digital mapping is now well-developed, depths are mechanically interpolated on regular (and sometimes irregular) grids and available geophysical, geological, morphological, etc. data are neither involved nor is their complex analysis carried out. Available electronic maps usually have a base scale of 1:1 000 000 and higher but such small-scale charts cannot reflect the heterogeneity of seabed relief. At the same time, the definition of relief origin has basic value even in its preliminary stages. Without an understanding of the genetic features of the mapped forms, their objectively proven image is impossible. Thus, despite the large database that has accumulated over the years, a uniform technique for bathymetric and geomorphological mapping has not been developed until now.

Our bathymetric mapping technique includes: (1) joint analysis of structural, modern and paleogeographic peculiarities and determination of relief origin, (2) manual map processing at a base scale of 1:200 000, and (3) image digitization using large-format scanners and licensed software such as ArcView. Map sheets are usually scanned with a resolution of 200 or 300 dpi. The volume of information after scanning maps in A1 format is about 50 MB. After the scanned data is processed, vectoring is performed. For further processing AutoCad Map or ArcView software is generally employed (Fig.1 and 2). On the basis of digital bathymetric maps, 3-D images can also be constructed (Fig 3).

The same ideas may also be applied to geomorphological mapping, but, except for bathymetric images, it is necessary to create additional "layer by layer" files: (1) a map of the structural basement; (2) a paleographic map and (3) a map of modern relief. It is possible to use various graphic depictions for display. For example, the structural basis is allocated with color, relic relief forms with various lines, and modern relief with shading. As a result of their overlapping with bathymetry, a geomorphological map is produced.

This study is support by INTAS (grant no.2332).

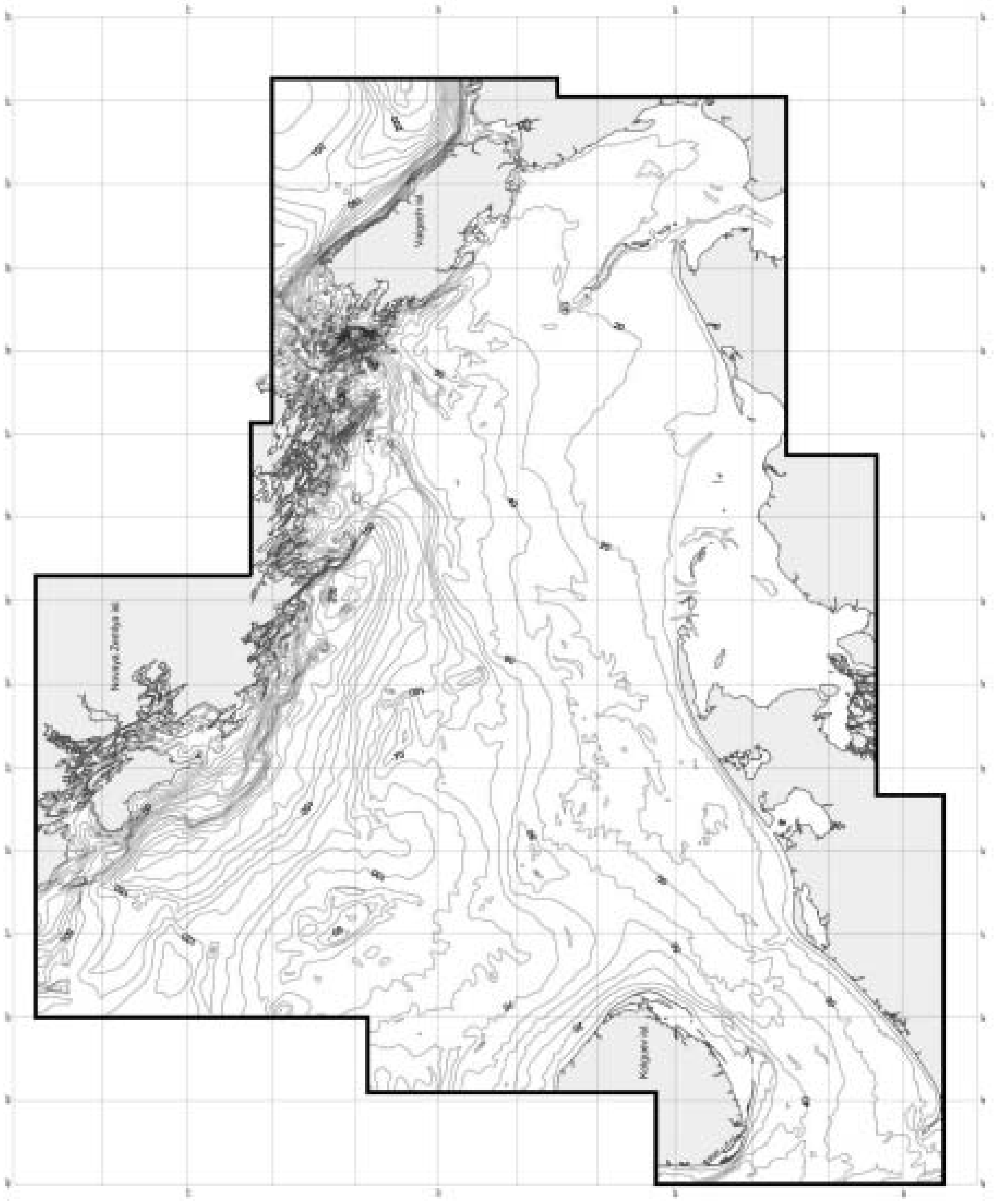

Fig 1. Bathymetric map of the Pechora Sea (isobath step 10 meter).

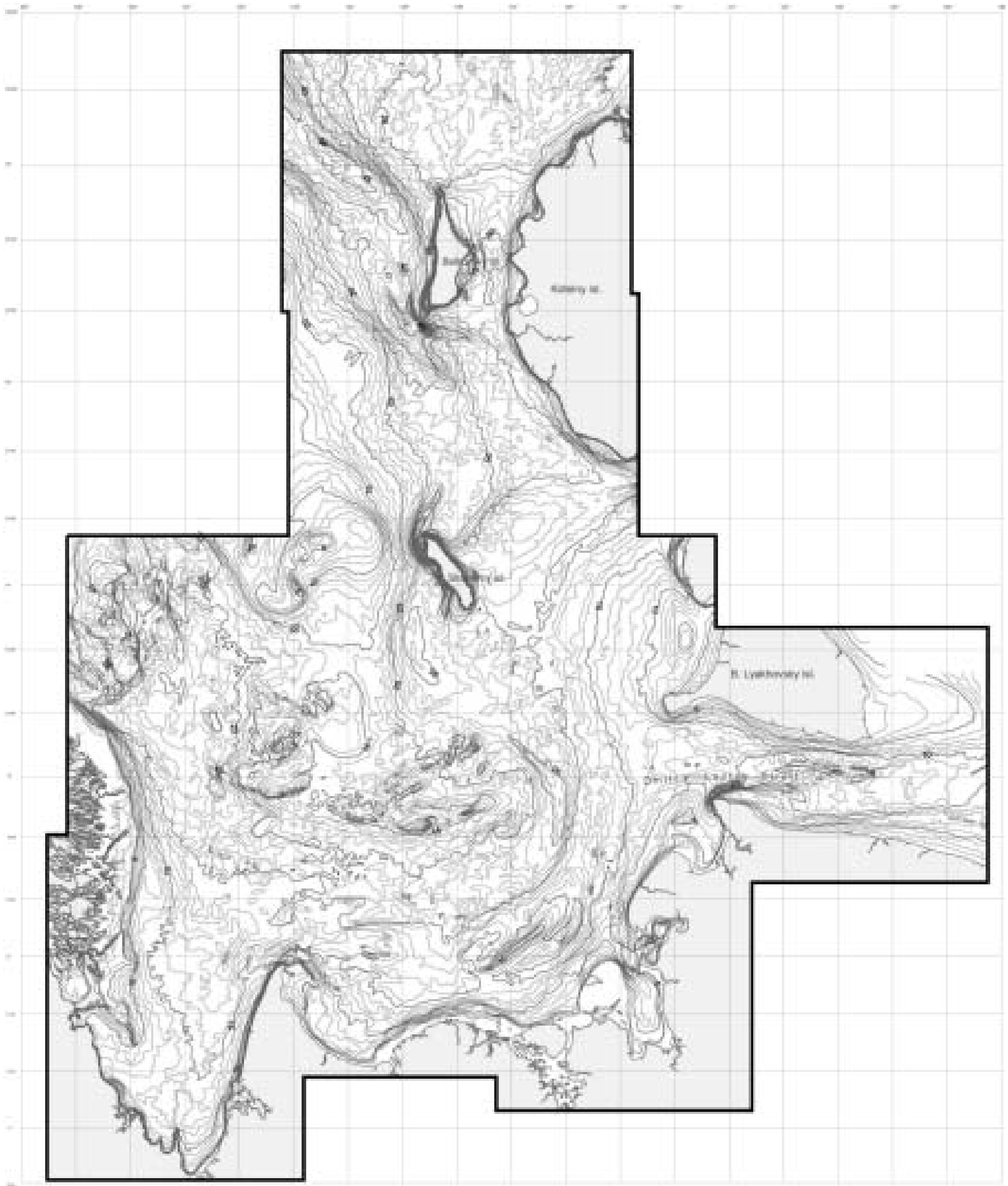

Fig 2. Bathymetric map of Laptev Sea (eastern sector, isobath step 1 meter).

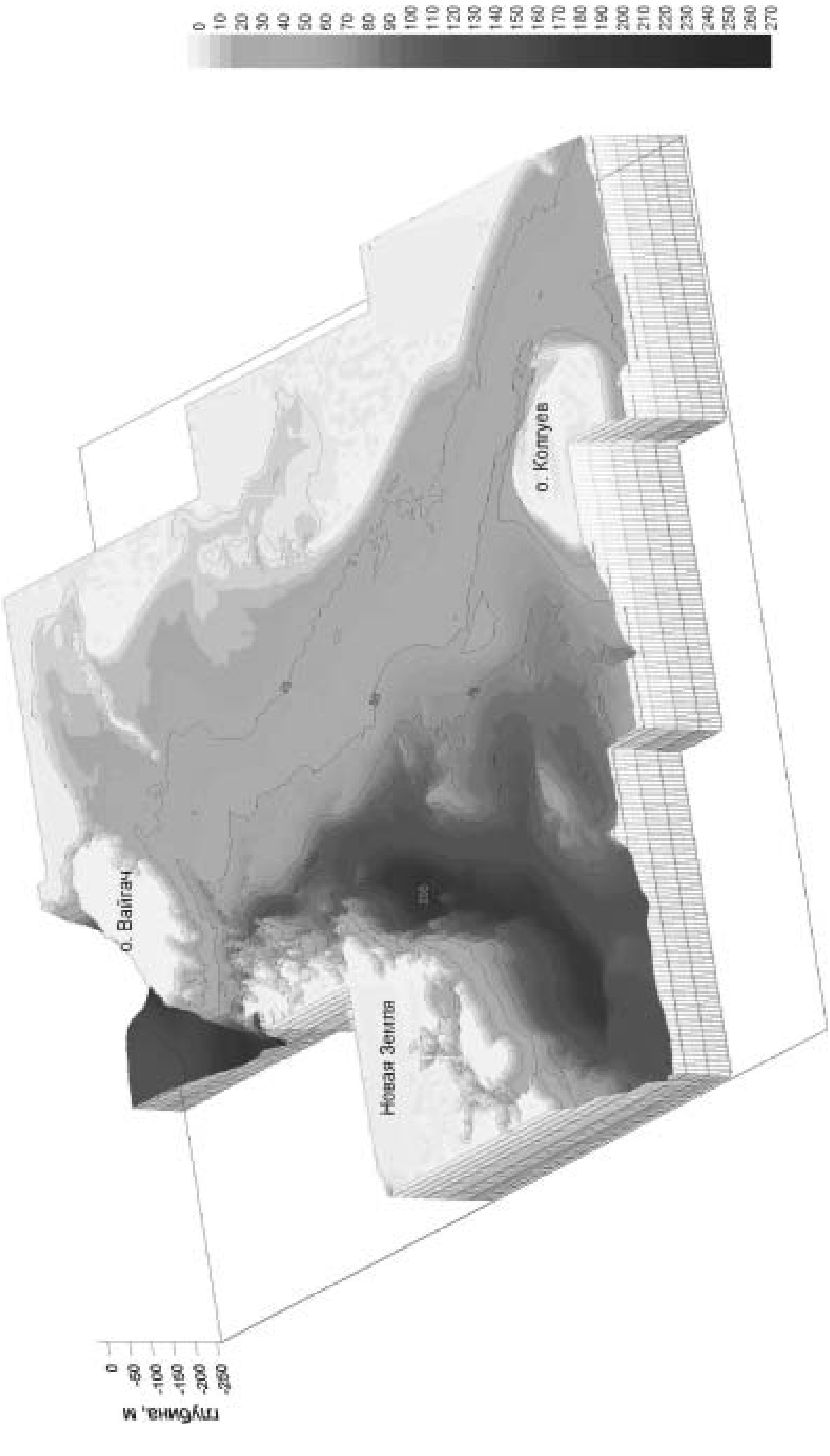

Fig 3. 3-D image of the Pechora Sea (view from the west).

ENGINEERING-GEOCRYOLOGICAL ZONING OF THE ARCTIC COAST OF THE RUSSIAN EUROPEAN NORTH

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Engineering-geocryological zoning of the coastal zone of the central and eastern parts of the Russian European North is being carried out to estimate the intensity of exogenous geological processes and technogenic hazards.

The work presented here is the continuation of an earlier engineering-geological zoning of the Arctic coast of Russia (scale of the map 1:8 000 000). Impacts of industrial activity on the Arctic coast were estimated on the basis of this map.

During this project, we plan to create a map (scale 1:1000000) of theengineering-geocryological zones of the coastal zone of central and eastern parts of the Russian European North.

The area of investigation covers a 10 km wide territory along the Arctic coast from the Mezen in the west to the Korotaikha in the east (Figure 1).

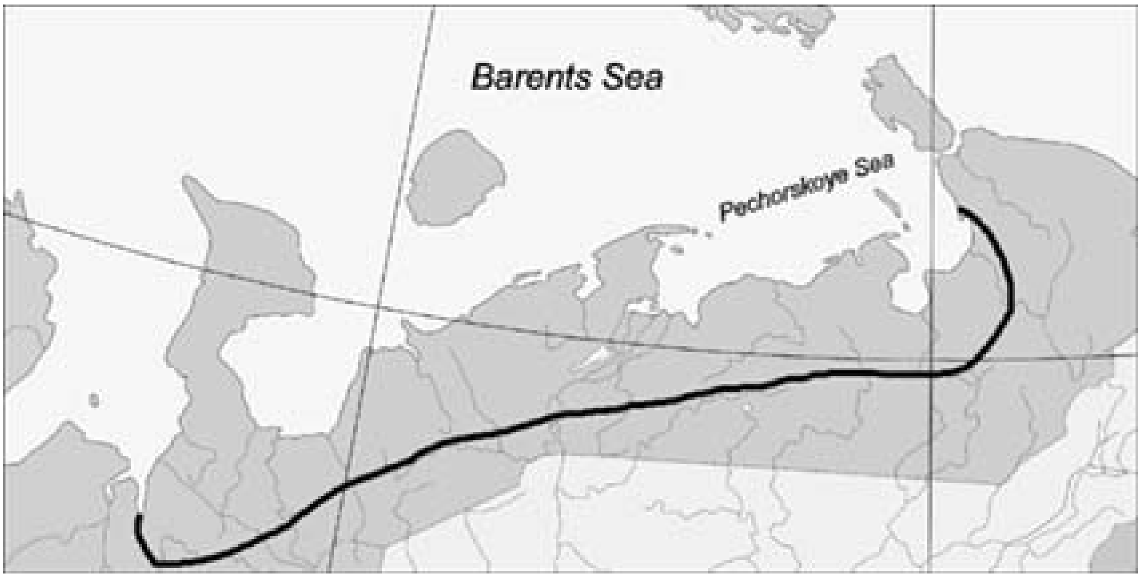

Figure 1. Key site the area of investigation.( contour area of investigation)

The coast under investigation is of great interest since many oil fields are located here and the territory is currently being intensively developed. This development is connected with prospecting, and with the logistics and exploitation of oil fields.

The main peculiarity of the coast under investigation is the presence of permafrost and cold rocks. Geocryological conditions at the investigated site are heterogeneous and complex and generally more severe in the east than in the west.

Permafrost distribution on the coast ranges from rare-insular to continuous. In the western part of the territory, rare-insular and massive island distributions of frozen masses prevail. In the eastern part, a continuous distribution predominates. Thawed regions are found in the valleys of the Mezen and the Pechiora.

The temperature and thickness of permafrost cover a wide range. In the western portion of the territory, rock temperatures vary from 2 to –2ºC. The thickness of frozen ground lies between

0 and 50 m. In the eastern area, the temperature reaches -5 to -7ºC. The thickness of permafrost exceeds 100 m.

At present, a central principle by which the engineering-geocryological zones of the coast under investigation are defined has been developed and the legend for the zoning map is completed. The legend is compiled in matrix form (Table 1), allowing the combination of engineering-geological complexes of rocks and their geocryological characteristics.

Table 1. Legend for the Map of the engineering-geocryological zoning for the coastal zone of central and eastern parts of the Russian European North .

Frozen and thawed grounds	Permafrost distribution	Ground temperature , °C	Thickness of permafrost, m	Iciness of permafrost		Engineering-geological complexes of rocks: Holocene marine sediments of a layda. mIV	Late Pleistocene marine sediments of 1-st terrace. mIII-IV	Late Pleistocene marine sediments of 2-st terrace. mIII(3)	Late Pleistocene marine sediments of 4-st terrace (kazantsevskaya). mIII(1)	Middle Pleistocene ice-marine sediments of 5 and 6 terrace. gmII(2-4)	Holocene Fluviomarine sediments of a river-plain both layda. amIV	Holocene both late Pleistocene Fluvial and lagoon-marine sediments of 2 terrace. amIII(3)	Holocene Fluvial sediments of a river-plain. aIV	Holocene both late Pleistocene Lacustro-fluvial sediments of 1 terrace. laIII-IV	Late Pleistocene Lacustro-fluvial sediments of 4 terrace (plain). laIII(1)	Middle Pleistocene Lacustro-fluvial sediments of 4 terrace (plain). laII(4)	Middle Pleistocene Lacustro-fluvial sediments of 4 terrace (plain). laII(4)	Late Pleistocene glacial sediments. gIII(2)	Midd Pleistocene glacial sediments. gII(4)	Late Pleistocene glaciofluvial sediments of 3 terrace. fIII(2)	Late Pleistocene glaciofluvial sediments of 5 terrace. fII(4)	Residual-Deluvial sediments. ed	Bedrocks
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Thawed grounds		>0			a								8a				12a	13a					
Frozen grounds	Rare-insular	2,0 : -0,5	0-25	low icy	b		2b				6b	7b					12b	13b		15b	16b		
				icy low icy	c																		
	Massive Island	1,0 : -1,0	0-25	low icy	d	1d	2d		4d		6d	7d						13d	14d	15d	16d	17d	
				icy low icy	e			3e				7e											
	Discontinues	0,5 : -2,0	0-50	low icy	f	1f	2f		4f		6f	7f						13f		15f		17f	18f
				icy low icy	g										10g								
			50-200	low icy	h		2h	3h															
				icy low icy	i										10i								
	Continuous	-0,5 : -2,0	0-50	low icy	k													13k					18k
				icy low icy	l											11l							
			50-200	low icy	m				4m	5m		7m											
				icy low icy	n										10n								
		-1,0 : -3,0	>100	low icy	o				4o	5o													
				icy low icy	p									9p	10p	11p							
		-2,0 : -4,0	>100	low icy	q			3q		5q													
				icy low icy	r									9r		11r							
		-3,0 : -5,0	>100	low icy	s			3s		5s													
				icy low icy	t									9t		11t							

Eighteen engineering-geological rock complexes were defined along the investigated section of coast. In the legend, short characteristic descriptions of the deposits are given (for the upper horizon to 10-15 m depth). On the map, the engineering-geological complexes of rocks are represented in color.

Each zone exhibits a definite set of geocryological conditions. On the map, the following main geocryological characteristics will be shown: distribution, temperature, thickness, and ice content of permafrost. These features are given in the legend and represented on the map by hatching. The map is intended to show the exogenous geological processes and soil salinization for each zone.

Eight types of coasts were defined: abrasion, thermal abrasion, thermal-denudation, accumulative, lagoon and liman-lagoon, laida, deltas and stable coast (fiard, fiord and ckerry). Their definition is based on the morphogenetic classification developed within the framework of the grant. Coastal types will be indicated on the map by special color lines along the coast.

Thus, the developed legend will facilitate cartographic representation of the engineering-geocryological conditions of the coastal zone of the Russian European North. The investigated coastline will be shown on the basis of the borders given by ACD. We plan to create the map using the GIS program ArcView.

In the future, this map will be used for the estimation of the intensity of exogenous geological processes and technogenic hazards. Six types of coastal zones with different intensities of exogenous geological processes were defined (Tab. 2). Expert input will be used for their confirmation. As a result, we expect to compile a map on the intensity of exogenous geological processes for the coastal zone of the central and eastern parts of the Russian European North.

Table 2. Types of zones with different intensity of exogenous geological processes

	Low intensity
	Insignificant intensity
	Moderate intensity
	Considerable intensity
	High intensity
	Very high intensity

In addition, four types of industrial impact on the coast were defined (Tab. 3), which will be shown on the map of the technogenic hazard estimation.

During the course of this work, previously published materials and maps for the given territory, materials from PNIIIS' long-term investigations, and ACD publications were used.

Table 3. Schema of the industrial impact Schematic assessment

# in the legend	***Degree of danger***	**The characteristic of activation of exogenous geological processes as a result of industrial influence**
1	non-hazardous	Available exogenous geological processes are not intensified, and new processes are not originated;
2	slightly hazardous	The origination or intensification of exogenous geological processes are hardly probable, and the disturbance of geocryological and surface conditions is reversible; conditions close to initial are recovered after the termination of an industrial impact;
3	hazardous	The origination or intensification of exogenous geological processes are probable; processes develop intensely but decay;
4	very hazardous	Available processes are intensified, and new exogenous geological processes are originated; the development of processes is accelerated and cause irreversible changes in the natural environment.

The work is executed with the support of INTAS, grant # 2002-5-2332.

AN ENGINEERING GEOCRYOLOGICAL ZONING OF VARANDEI PENINSULA AND THE ADJOINING SHALLOW SHELF ZONE

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This work reports on the progress of small-scale engineer-geological zoning of the Russian Arctic coast for estimating industrially-caused hazards (scale 1:8 000 000).

With a view to further understanding Arctic coastal dynamics, the Varandei Peninsula region has been zoned and mapped at a scale of 1:200 000 on the basis on engineering and geological parameters. The Varandei Peninsula (Fig.1) has been selected as a key site in the Arctic coastal dynamics program as one of the most active regions for oil and gas field development.

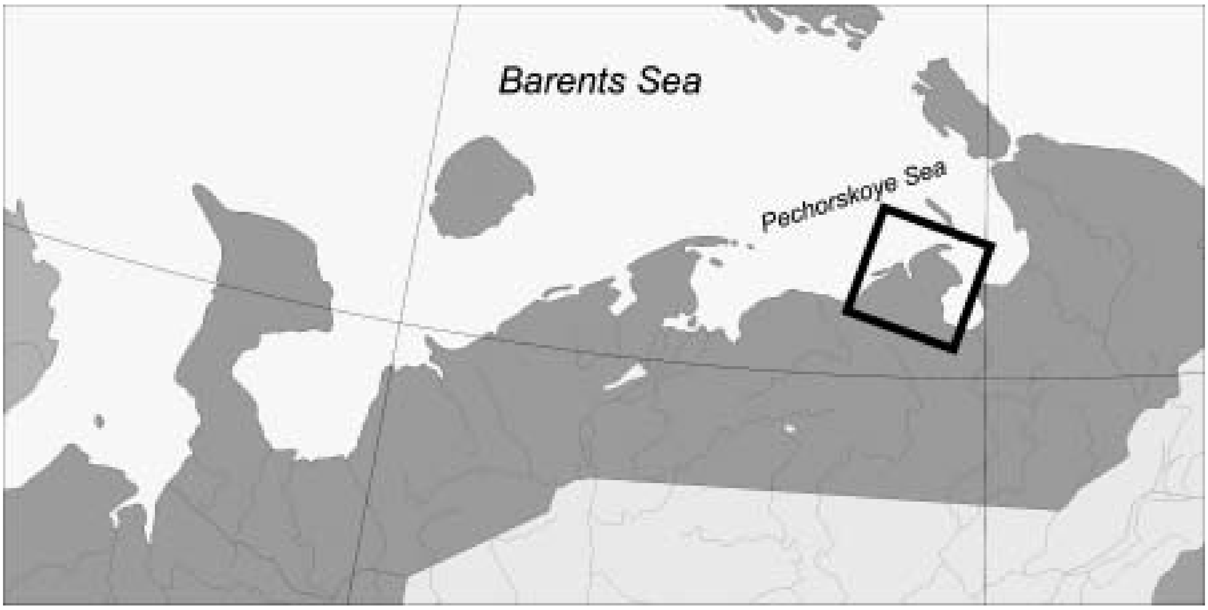

Fig.1. Key site Varandei Peninsula.

In 2000-2003, the Production Scientific-Research Institute for Engineering Surveys and Construction (PNIIIS) carried out detailed field engineer-geological research on a North European expedition to the Varandei Peninsula. Extensive material on the peninsula's lithology, temperature, ice content, and on the salinity of subsurface sediments, the properties of perennially frozen ground, and on exogenous geological processes, both in an internal part of the peninsula and at the coast was assembled. The preliminary results of this work (including a map fragment of the Peninsula; Fig. 2) have already been submitted to a working group meeting in Zurich.

The map of the engineer-geological zoning of the Varandei Peninsula will include all of its territory and also the adjoining shallow shelf zone. Moscow State University's study of coastal processes on the Peninsula and ACD publications will also be incorporated into the map.

Zoning is performed on a geological and geomorphological basis. The genesis of deposits, surface microrelief, the degree of drainage, and vegetative associations are determined for each area. Detailed areas are characterised on the basis of lithology, ice content, the salinity of subsurface sediments, the temperature, thickness, and occurrence of frozen, thawed and cold saline ground, and on hazardous exogenous geological processes.

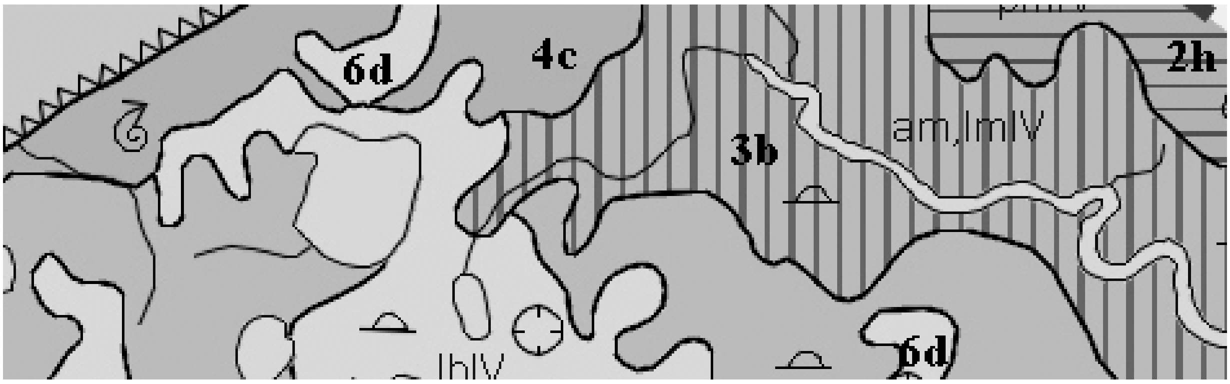

Fig. 2. Fragment of a map of the engineering geocryological zoning of the Varandei Peninsula.

The engineering-geocryological zoning scheme has been tabulated (Tab. 1) and shows the relationship between the geomorphological level, genesis, lithology, landscape and average ground temperature. The color shows ground temperature, while shading indicates different distributions of salinity. Conventional signs designate exogenous geological processes and formations. Coastal types are allocated on the basis of this small-scale engineering geocryological zoning of the Russian Arctic coast for estimating hazard of the industrial impact.

For the adjoining shallow shelf zone of the Pechora sea, the occurrence of perennially frozen ground, seasonally frozen ground, cold saline ground, and thawed ground is hypothesized. The bathymetry is given by the P. P. Shirshov Institute of Oceanology, RAS. The coastline of the Varandei Peninsula will be shown on the basis of borders given by ACD.

The engineering-geocryological zoning map will be the basis for compiling maps of exogenous geological process hazard intensity and for estimating industrial impact hazards in view of previously erected engineering objects on the Varandei Peninsula. Estimation methods use both expert opinions and analytical formulae, allowing quantitative parameters of the current processes in natural and industrial conditions to be produced.

Table 1. The scheme of engineering geocryological zoning.

Geomorphological level	River floodplains	Laida		First sea terrace		
Genesis	alluvial	coastal	alluvial-marine, lagoon-marine	marine		lacustrine-boggy
Lithology	a IV	pm IV	am, lm IV	m III		lb IV
Landscape	sand	sand	silt, sand, clay	sand	clay	peat
	1	**2**	**3**	**4**	**5**	**6**
a. Flat surface of low laida with rills; motley grass; poorly drained surface	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**
b. Flat surface of high laida with oxbow lakes; alternating motley grass and lowbush tundra; rained surface	**1b**	**2b**	**3b**	**4b**	**5b**	**6b**
c. Convex-plane surface; lowbush-moss-lichen vegetation; drained surface	**1c**	**2c**	**3c**	**4c**	**5c**	**6c**
d. Thermokarst depressions (khasyreyas); sedge-moss vegetation; different degree of watering (drainage conditions)	**1d**	**2d**	**3d**	**4d**	**5d**	**6d**
e. Flat hillocky peatbog; lowbush-moss-lichen vegetation; relatively drained surface	**1e**	**2e**	**3e**	**4e**	**5e**	**6e**
f. Polygonal-roll bogs; lowbush-sedge-moss vegetation; poorly drained surface	**1f**	**2f**	**3f**	**4f**	**5f**	**6f**
g. Flat surfaces of river floodplains; willow with a height of up to 60 cm, motley grass, and sedge; uniformly drained surface	**1g**	**2g**	**3g**	**4g**	**5g**	**6g**
h. Coastal ridges and sand beaches; motley grass, somewhere without vegetation	**1h**	**2h**	**3h**	**4h**	**5h**	**6h**

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THE UTILITY OF SURVEY GRADE DIFFERENTIAL GLOBAL POSITIONING SYSTEMS (DGPS) TECHNOLOGY FOR MONITORING COASTAL EROSION

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On-going research has documented the coastal dynamics within the Barrow area, using a combination of GIS and remotely sensed imagery interpretation to estimate coastal loss and accretion (Brown et al. 2003). The objective of the current project was to demonstrate the viability of Differential Global Positioning System (DGPS) technology in monitoring coastal position and changes. The result is a high-resolution outline of the entire coastline of the Elson Lagoon ACD key site located on the eastern boundary of the Barrow Environmental Observatory. The development of this baseline data set is intended to help confirm prior conclusions of erosion, update the estimated rates for the four contiguous segments of the key site coastline, and develop a protocol to track future shoreline changes. This methodology may also contribute applicable standards to other studies of erosion in coastal regions in the Arctic.

Methods

The project employed advanced industry hardware and software including survey grade DGPS equipment (Trimble Navigation 5700 dual-frequency, 24 channel, base station and rover receiver), GIS software from the Environmental Systems Research Institute (ArcGIS 8.3 and ArcIMS 4.0.1), image processing software from Leica-Geosystems (ERDAS Imagine 8.6), and Trimble's Geomatics Office (TGO) version 1.6 for GPS data processing.

During the summer of 2003, the 11-km coast was carefully walked along the top of the bluff edge to obtain continuous positioning and elevation. The rover receiver was installed in a standard equipment backpack configuration, which allowed for easy modification of antenna placement and radio equipment. The Zephyr survey grade antenna was consistently mounted on the bluff side of the backpack to accurately represent the edge. To process the field survey data, two industry standard survey methods were used. The first approach, known as Real Time Kinematic (RTK) surveying, required a radio link to a base station and allowed for instant processing of sub-meter data. The second method utilized the Post-Processed Kinematic (PPK) survey style, which did not require a radio link, but instead relied on an unobstructed On-the-Fly (OTF) initialization period to acquire enough satellite empheris data to provide accurate processing. Both methods had the rover receiver set to log data in one-second intervals to compensate for slight velocity changes and to allow for more locational data in the case of point outliers. The surveys acquired elevation measurements at these one-second intervals, allowing the survey to obtain high precision data in the XY and Z planes. This data provides a means to monitor changes in elevation and allows further investigation and insight into how bluff elevation is related to morphology.

To further demonstrate the value of DGPS for accurately monitoring and confirming shoreline retreat, the existing 14 permanent transects located within the four segments of the coastline were surveyed. The DGPS equipment was used to obtain position of the permanent markers with the antenna consistently centered on the top of the marker for increased accuracy and comparison. It was important to supply exact (X, Y, Z) locations of these permanent benchmarks in order to provide an assessment with annual ground measurements using taped or traditional survey methods. The data also allows comparison of erosion rates based on previously photo-interpreted coastline.

All field data were imported into GIS applications to develop a dataset for the study. Using tools within ArcMap, the raw coastline point data was converted to a polyline, then to polygon to be used as a base map for further evaluation. This base map was then compared with previously digitized coastlines and overlaid onto imagery of the key sites to develop detailed erosion estimates (mean width lost) and compare with prior results. The DGPS and taped positions from the 14 transects were imported as well into the database. The accuracy of the GPS surveyed coastline was determined by tools within TGO during the post-process and field quality assessment step. When exporting the data from TGO, fields were added to the attribute table to document information for each point including: the horizontal and vertical errors; Position Dilution of Precision (PDOP); and minimum satellites tracked. This information was based on a network adjustment report set to a 95% confidence limit within TGO. The results show that average horizontal error was lower than 10 cm with a maximum of 20 cm and average vertical error was less than 30 cm with a maximum of 50 cm. The overall error for the static permanent marker locations was < 2.5 cm due to the stationary survey method and the ability to be selective on the results, using more than one observation per location if necessary.

The final data consists of a series of ArcGIS shapefiles with associated metadata stored in the U.S. Federal Geographic Data Committee standard. This information is published online and can be viewed via the Barrow Arctic Science Consortium Internet Map Server at ims.arcticscience.org. In addition, the data files will be submitted to the ACD archive (http://www.pangaea.de/Projects/) and to the National Snow and Ice Data Center.

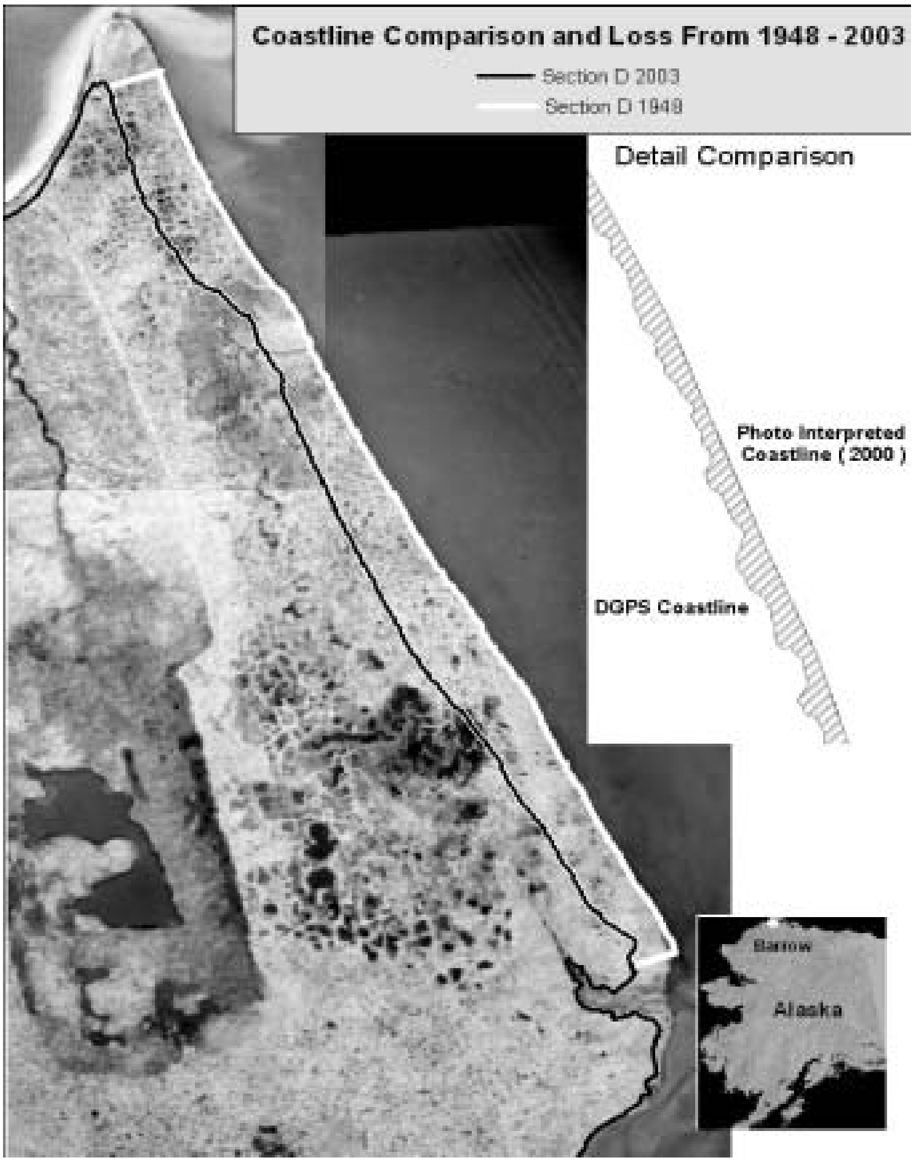
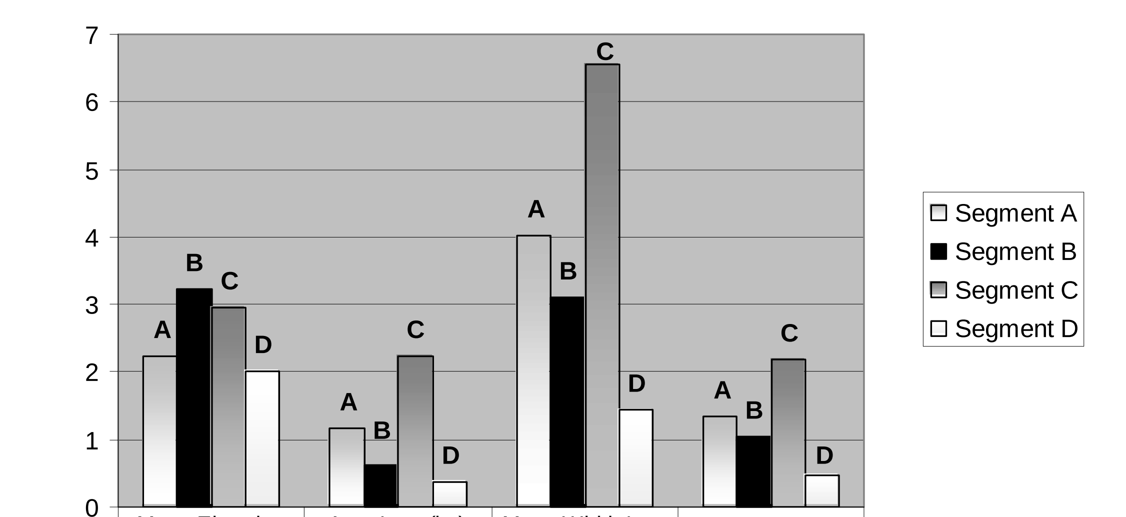


Fig. 1: Comparison of coastline data and detail at zoomed scale, derived from photogrammetric interpretation and DGPS method.

Results and Discussion

The objective of this project was to demonstrate a new method to help track coastline changes and at the same time provide a comparison with previously employed methods. In order to accurately compare these data sets, we modeled the data analysis after a recent study in the Barrow key site that was also the source of the photo-interpreted coastlines (Brown et al. 2003). The investigation utilized the four segments that are considered characteristic of the Arctic Coastal Plain topography.



	Mean Elevation DGPS_masl	Area Lost (ha) 2000-2003	Mean Width Lost (m)	Loss (m/yr)
Segment A	2.24	1.165	4.02	1.34
Segment B	3.22	0.62	3.11	1.04
Segment C	2.96	2.23	6.56	2.19
Segment D	2.00	0.36	1.43	0.48

Fig. 2: Quantified changes for the period 2000-2003 in coastlines due to erosion, Barrow, Alaska.

For the period 2000-2003 high spatial variations in erosion rates exist between the four segments of the study area, ranging from a minimum of 0.48 m/yr to a maximum of 2.2 m/yr, with an overall rate of 1.26 m/yr. Prior to 2000, in the period 1979-2000 the overall rate for the segments was 1.27 m/yr, suggesting a steady yearly rate of loss for the area. The total loss for the 11-km long study site for the period 2000-2003 reveals a loss of 4.4 ha of coastline. Consistent with earlier reports, the results show these changes are highly dependent on storm activity and the resulting wave energy. Although, in contrast to earlier time periods, between 2000 and 2003 section D experienced the least amount of erosion suggesting a shift in storm directions and energy. This shift in increased erosion relative to Segment D warrants further observations. Additionally, many of the linear transects produced slightly high rates of erosion, providing further evidence of the high spatial variability of the site.

Loss of Land and Sediment				
Segment	1979-2000 Area Lost **(ha)**	2000-2003 Area Lost **(ha)**	1979-2000 **Annual Sediment Loss** (10^3x m^3/km)*	2000-2003 (10^3x m^3/km)*
A (2.9 km)	4.4	1.2	0.9	4.6
B (2.0 km)	2.8	0.62	1.1	5
C (3.4 km)	6.4	2.2	1.3	9.7
D (2.5 km)	14.6	0.36	2.5	1.43

* assumed 50% of mean bluff height is ground ice (Brown et al. 2003)

Fig. 3: Metadata, Input of sediment due to changes in coastlines, Barrow, Alaska

The methods used demonstrate that DGPS is a viable method and can lower costs and time allocated by forgoing the need to acquire annual or repeat imagery. Instead of digitizing a coastline from new imagery, highly detailed mapping can be used to conduct annual surveys and derive annual rates of change of bluff position. It also eliminates the need to locate control points for ground truthing and rectification of imagery sets. Furthermore, the accuracy increases as does the amount of usable data because of the ability to map every detail of the bluff line, including individual polygons and troughs. Lastly, errors can occur such as mistaking highly turbid water for coast when interpreting black and white or infrared imagery, along with other classification difficulties. Conversely, at the present time this research tool is only feasible on the smaller scale, researching short sections of coastline at one time. The DGPS method can be combined with remote sensing techniques to represent larger areas. Once calibrated, this extrapolation can prove to be a powerful way to develop large-scale models to estimate change.

Acknowledgements

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BOTTOM RELIEF OF THE PECHORA SEA AS A RESULT OF LAND-OCEAN INTERACTIONS

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Exploitation of oil and gas in the Pechora sea shelf area implies construction of new ports, navigation channels, artificial islands, drill platforms, terminals, above-ground and submarine pipelines. Therefore, it is necessary to consider the bottom morphology in order to find the optimal positioning of hydrotechnical constructions in terms of safeness and the minimization of their negative impact upon shelf geosystems.

The aim of the current investigation is to analyze the previously compiled Geomorphological sketch-map of the Pechora Sea floor (1: 1 000 000) and Geomorphological sketch-map of the Pechora Sea floor near Varandei Island (1: 200 000). The sketch-maps are based on the bathymetric maps plotted with the use of official navigation maps 1: 500 000, 1: 200 000, 1: 100 000; 1: 50 000 and 1: 25 000. The sketch-maps are highly informative and give a detailed image of the bottom morphology, structure, geomorphology and evolution of the Pechora Sea shelf. To plot geomorphological data, we worked out key symbols suitable for the applied scale that correspond to all types of relief and landforms. To clarify the genesis of certain landforms, we used archival and published materials on the geology and geomorphology of the area. Detailed analysis of the shelf bathymetry allowed us to distinguish between elements of marine and subaerial relief. The latter include channels, and slopes of ancient erosional forms, flooded beach ridges, lagoon depressions. Also, elements of structural and gravitational relief (scarps, troughs) were mapped. Taking into account the evolution history and modern lithodynamic conditions, four main types of bottom relief have been distinguished within the Pechora Sea.

The Pechora Sea bottom relief is a result of land-ocean interactions. The Arctic Ocean experienced significant sea-level oscillations during the Pleistocene and Holocene. Geological and geomorphological indicators evidence that the Pechora Sea bottom relief consists of two generations: relatively young landforms and older landforms. The conventional boundary between these generations corresponds to water depths of 50-55 m. The younger landforms appeared during the Late Pleistocene regression when the present inner shelf was subjected to subaerial erosion. The erosional network includes paleovalleys of the Pechora, Korotaikha and More-Yu rivers. Later, the subaerial relief underwent transformation by wave activity and tides during the course of postglacial transgression. Inundated old beach ridges found at depths of 12-13, 17-18 and 22-23 m evidence stabilization of the sea level during postglacial transgression.

3.2 Coastal Permafrost Working Group

Working Group Chairs: **Michel Allard and Hans-W. Hubberten**

Participants

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3.2.1 Coastal Permafrost – Working Group Summary

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Introduction: problem statement

The working group identified the need for a better comprehension of the geomorphological, cryological and thermal changes that take place in the ground during the transition from onshore (terrestrial) to offshore (sub-littoral) conditions. This change of state of the soil and of the sediments occurs in different conditions that are defined by coastal dynamics. Some coasts are undergoing a rise in relative sea level due to the general eustatic uplift that is presently affecting parts of the world coastlines and new submarine surfaces are formed due to continuing coastal erosion. Other coasts are undergoing a fall of relative sea level, in regions that are subjected to post-glacial isostatic uplift since the withdrawal of the Pleistocene ice sheets. In the first case, the ground evolves from terrestrial conditions exposed to cold climates and underlain by permafrost to warmer submarine conditions. In the second case, the shallow offshore sediments evolve from the non-frozen state below sea level to exposure to cold climate conditions and are subjected to permafrost aggradation. Regional tectonic influences can also play a role in relative sea level changes. When the coastline of the whole Arctic Ocean is considered, these major environmental changes take place under a large variety of climate and ecological conditions (e.g. from continuous to discontinuous permafrost regions, from arctic desert to forest tundra), under different geological and sedimentary conditions and under a variety of marine conditions defined by wave environment, tidal regime and sea and shore ice extent and duration.

Despite a reasonable number of existing studies on Arctic Coastal Processes along permafrost affected coast, the working group realized that important basic information is still needed about the processes that occur in this transition zone. Some of these processes take place in the permafrost itself and affect thermal regime, salinity and gas concentration or entrapment. Other processes involve the complex role of the ice-foot and bottom fast ice in the transitional thermal regime of the ground during the evolution from terrestrial to marine environments along receding coastlines or in the course of the inverse transition from marine to terrestrial conditions along prograding shorelines. During the XXIst Century, in the context of very probable climate warming, the chain of processes that lead to retreat or progradation of Arctic coastlines is very likely to be affected by projected changes that include a decrease in sea ice duration and an increase in storminess, precipitation and air temperature. An understanding of the basic processes at work is a pre-requisite for predicting the imapcts of the changes to come. It is also of paramount importance that a circumpolar vision and understanding of coastal changes be developed, encompassing the regional variations in processes and measuring the rates of change in order to be able to make a quantitative assessment of climate change-induced transformations and in order to connect those physical changes with biodiversity changes and carbon balance of the Arctic Seas. This latter need lies in the central core of the Arctic Coastal Dynamics program.

Objectives

The main objective of the coastal permafrost research program within ACD is *to characterize processes, rates and transformation of landscapes and permafrost along the arctic coastlines*. Developing a profound understanding of how the arctic coastlines evolve and providing a comprehensive picture of the geographical variability in processes and dynamical conditions around the Arctic will require a methodology and a set of techniques to acquire data and develop models. Some technological development to that effect needs to be designed. The impetus is to be placed on cooperative international fieldwork requiring investments and resources from multilateral sources.

The question of assessing the amount and the quality of existing data and information on subsea permafrost (depth to top of permafrost, temperature profiles, stratigraphy and ice contents, geophysical data, etc.) from data sources that are possibly available was also raised. This information will surely become essential when the time to produce a comprehensive view on arctic coasts comes. This useful endeavour, however, probably needs to be done first on a preliminary basis to assess the potential amount and quality of data before major resources are invested in that direction.

Methodology

A methodology for the detailed study of several transects shall be applied at a number of sites. The sites will be selected in order to represent the different coastal settings found around the Arctic Ocean based of the classification criteria of ACD. For instances, the array of selected sites shall encompass emerging, submerging and relatively stable coasts, sedimentary and rocky shorelines, ice-rich permafrost, shallow offshore permafrost, retreating shorelines in areas in erosion and prograding shorelines in areas of sediment accretion and forming intertidal permafrost.

A standardized methodology will be adopted that will include, at each transect site, the following activities:

Reconnaissance and characterization of terrain and permafrost conditions.

Precise site selection at the local scale will be made through consideration of the GIS-based ACD coastal classification in order to ensure proper representation of coastal variability at the circum-arctic scale. The first step in a transect site study shall be to characterize the terrain conditions by analyzing:

- landforms, vegetation and permafrost on land,
- the erosional/accretionnal state of the shoreline and coastal type, and
- shallow submarine morpho-sedimentological conditions.

Terrestrial component characterization shall make use of air photo analysis or high resolution remote sensing and field observations in order to map landforms, soils, and vegetation. 2D or 3D representation of the permafrost and ground ice bodies (e.g. massive ice, ice wedges, etc.) can also be made with the help of geophysical methods such as ground penetrating radar (GPR), electro-magnetic sounding (EM), electrical resistivity (ER) or reflection seismic profiling.

At this preliminary step, coastline dynamics can be assessed through observation of processes and interpretation of air photographs from different epochs. Processes to be considered include, for example, cliff recession, active layer slides, retrogressive thaw slides, platform cutting, invasion of thermokarst lakes by saline water and the creation of lagoons, the submergence of ice bodies such as pingo cores, and the formation of deltas, spits, barrier beaches and tidal flats.

Submarine morphology and sedimentology shall take advantage of precision imaging methods such as side scan sonar, multibeam bathymetry and chirp sonar profiling.

This reconnaissance and characterization phase of the transect study will provide the framework for planning a drilling and sampling program. It will also provide the geological and dynamical context for final interpretation of the results later during the study.

Permafrost drilling and sampling

At least one core shall be drilled in the permafrost in the terrestrial environment. The depth of the borehole shall be deeper than sea level and, for submerging coastlines, will be deep enough to sample and characterize the permafrost layers that will become submarine after a marine transgression. On emerging coastlines, the boreholes should be deep enough to characterize the predictable permafrost facies and composition that will develop in raised marine sediments. A series of cores shall be drilled in the littoral zone and the shallow submarine zone along the transect. The exact location of the boreholes should reflect the different transient situations of the shoreline migration, i.e., under the shorefast ice zone, further outwards and so on.

Core samples shall be submitted to analysis of cryofacies and properties such as ice and unfrozen water content, salt, carbon, and gas contents.

Eventually the succession of cores along the transect shall reflect the metamorphic transformation of the permafrost that takes place through coastal recession or progradation.

Observe and measure the oceanographic parameters and the fate of sediments

Waves, tides, and surges are important agents that drive erosion and sedimentation processes as well as sediment transfers in the shore zone. The transect areas shall therefore be either instrumented for monitoring, for example tidal gauges or pressure gauge-equipped dataloggers, or be sufficiently documented from existing gauging facilities in nearby ports or communities.

Observe and measure the thermal and mechanical impact of shore ice

Shore ice is a key factor in the chain of processes that take place when the shoreline retreats inland or prograde seaward. At the foot of cliffs and on shore platforms where it freezes to the bottom the sediments underneath are still submitted to atmospheric driven temperature variations and freeze-thaw cycles. In deeper water where the ice cover floats the sea floor is subjected only to sea water temperature fluctuations.

Shore ice and sea ice also exert important impacts on the erosion processes either by providing protection against waves during some periods in the year, or becoming agents of active geomorphological activity by scouring, mobilizing (rafting), and depositing sediments.

Therefore, monitoring the ice regime along the coastlines is also a necessary component of the methodology. Probably the safest way to obtain continuous observations of shore ice dynamics will be to integrate automatic cameras or videos in the instrumental setup with the automatic meteorological stations. Some technological development may be necessary in order to adapt existing instrumentation for the harsh and remote environment.

Monitor local climate and permafrost thermal regime

In order to measure, describe and understand the role of climate factors and thermal regime that are at play in the transient changes of arctic shorelines, it is necessary to measure and log climatic parameters. Therefore the methodology calls for the installation of automatic meteorological stations at the study sites (unless a fully manned station is available already). Atmospheric temperatures regulate the ice formation and the ground thermal regime, wind speed and direction generate waves and surges and regulate the redistribution of snow cover. Snow cover affects ground thermal regime. Precipitation affects geomorphological processes and regulate the total amount of snowfall that can affect the soil thermal regime.

Permafrost temperatures need to be known both in the terrestrial component and the marine component of the transects as they are a function of climate conditions as well as of environmental changes induced by thermokarst, slope processes, submergence, surface erosion, sedimentation, sea bottom temperatures and saline water intrusions. Therefore thermistor cables shall be installed in boreholes and readings shall be recorded with dataloggers. This procedure is currently in common use, however, new technical designs will almost certainly be necessary in order to properly protect thermistor cables, dataloggers and connections to shore stations for the shallow subsea permafrost. Ad-freezing of shorefast ice in the tidal zone and sea-floor scouring by drifting ice floes pose a real threat and a difficult challenge to equipment integrity.

When archived into the ACD information system, the acquired climate data from the network of transects around the Arctic Ocean will also constitute a very valuable data base to monitor climate changes and support the other components of the program, for instances the biodiversity and the carbon budget components of ACD.

Expected outcome of the project

The gathered data and observations along each transect will facilitate explanation of how the observed differences in ice content, salinity, gas content, and cryostructure that exist between terrestrial and offshore permafrost are generated during the transition from onshore to offshore. With proper geological and thermal data, the support of the visual monitoring data on processes, and contextual knowledge, a thorough understanding and knowledge of processes, rates and transformation of landscapes and permafrost along the arctic coastlines shall be obtained. This will in turn enable elaboratation of conceptual, graphic and numerical models.

The assembly of the results from all the proposed transects around the Arctic will provide the basis for a synthesis on coastal changes and permafrost evolution. This will be a necessary input for forecasting the impacts of climate warming and their consequences.

3.2.2 Coastal Permafrost – Extended Abstracts

THE NORTHERN RISCC PROJECT. AN OVERVIEW, AND OPPORTUNITIES FOR INTERNATIONAL COLLABORATION

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The environmental, socio-economic and strategic consequences of climate change, including temperature rise, a reduction of sea ice cover in the Arctic Ocean, and the degradation of the permafrost over vast areas in Canada and elsewhere in the circumpolar region, are likely to be substantial. Impacts will be felt first and most severely in the High Arctic before spreading to the south. To help to face the ecosystem-level challenges raised by climate change, Arctic Net aims to build synergy among the existing arctic centres of excellence in the natural, medical and social sciences.

Northern RiSCC (Regional Impacts and Sensitivity to Climate Change) is a cooperative undertaking coordinated through the Canadian Network of Centres of Excellence (NCE) program Arctic Net, which is composed of three integrated regional study themes: on the coastal marine Canadian High Arctic (Theme 1); on the North-South gradient of terrestrial ecosystems in the Eastern Arctic (Theme 2; Northern RiSCC, linked to the international Antarctic program RiSCC), and on the land-ocean interaction zone in Hudson Bay (Theme 3). Each of these studies will contribute the knowledge needed to formulate policies and adaptation strategies to adjust to climate change in the Canadian coastal Arctic (Theme 4).

The network is built around deployment of the Canadian Foundation for Innovation-funded icebreaker CCGS Amundsen, with research cruises that will address current gaps in knowledge about climate change and impacts in the coastal Arctic. The cruises for Northern RiSCC are planned for the period 2005-2010. The geographic focus of Northern RiSCC is on the coastal lands and freshwaters within eastern Canada, over 30 degrees of latitude (53 to 83 ^{o}N). The study sector lies across the boreal, subarctic and arctic ecoclimatic provinces, with vegetation zones ranging from forest to shrub tundra to high arctic polar desert. It spans a broad range of temperature regimes, from a mean annual temperature of –2 ^{o}C at the southern end (James Bay) to –20 ^{o}C at Ward Hunt Island, in Quttinirpaaq National Park, northern Ellesmere.

Using the research icebreaker as a moving field station, Northern RiSCC will compare the response to climate change of coastal terrestrial ecosystems and impacts on communities along the North-South gradient of the eastern Arctic. This will be coupled to land-based observations and experiments throughout the duration of Arctic Net (2004-2010).

Northern RiSCC is also a network of expertise still in construction. Permafrost, hydrology, vegetation dynamics, microbiology, aquatic ecology and wildlife ecology are at the core of its natural science component.

Opportunities for permafrost research in the coastal zone under RiSCC are numerous and open to both international and interdisciplinary collaboration. Some specific topics and possibilities are, for instance:

- measuring and monitoring ground temperatures at deep and shallow sites along the latitudinal transect

- observing and measuring landforms, thermokarst processes, and active layer dynamics across the latitudinal transect
- map and measure coastal changes
- delineate and measure permafrost temperature and aggradation in intertidal zones in areas still undergoing post-glacial isostatic uplift
- delineate and measure subbottom and submerging permafrost in the coastal zone in areas that are affected by eustatic submergence
- sample cores and sections at syngenetic permafrost sites for stratigraphic studies and paleoecological reconstruction
- assess suspended and dissolved organic carbon stored in permafrost and likely to be released in the ecosystem in the eventuality of thermokarst
- assess greenhouse gas contents in permafrost and their potential release in the atmosphere in the eventuality of thermokarst.

THE IMPACT OF CLIMATE CHANGES ON AN EMERGING COASTLINE AFFECTED BY DISCONTINUOUS PERMAFROST: MANITOUNUK STRAIT, NORTHERN QUÉBEC.

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A comparative analysis of air photos and a field survey show that permafrost affected sectors of coastline along Manitounuk Strait receded at an increasing rate between 1950 and 1995. Those sectors are in bays where clays of the post-glacial Tyrrell Sea outcrop. During the same period, rock and till shorelines on headlands as well as sand beaches at the mouth of streams prograded at the pace of isostatic uplift. Permafrost that had aggraded and formed lithalsas and plateaus during the XIXth century, i.e. during the Little Ice Age, had expanded over the tidal marsh and had locally provoked accelerated coastal emergence. Climate warming during the XXth century, particularly during summers, generated a chain of impacts involving forest growth, snow cover, ground warming and permafrost degradation. Waves and tidal currents apparently were mainly responsible for evacuation of the silts and clays produced by thermokarst from the shore into the marine basin.

OIL DISTRIBUTION IN THE ACTIVE LAYER AT THE COASTAL KEY-SITE "CAPE BOLVANSKY": TWO YEARS AFTER CONTAMINATION

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An experimental oil pollution site at key-site "Cape Bolvansky" (Pechora gulf, Nenets district, 120 km to the north from Naryan-Mar town, European Russia) is situated 500 m back from the cliff on the top of lightly sloping hill (fig.1).

Fig.1. Oil pollution site location

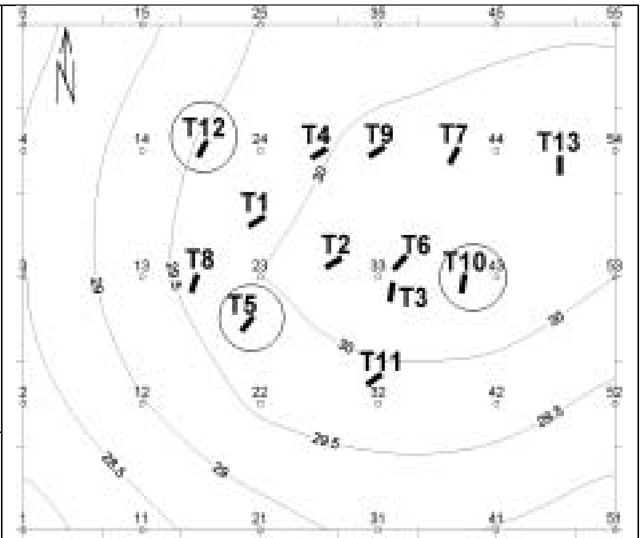


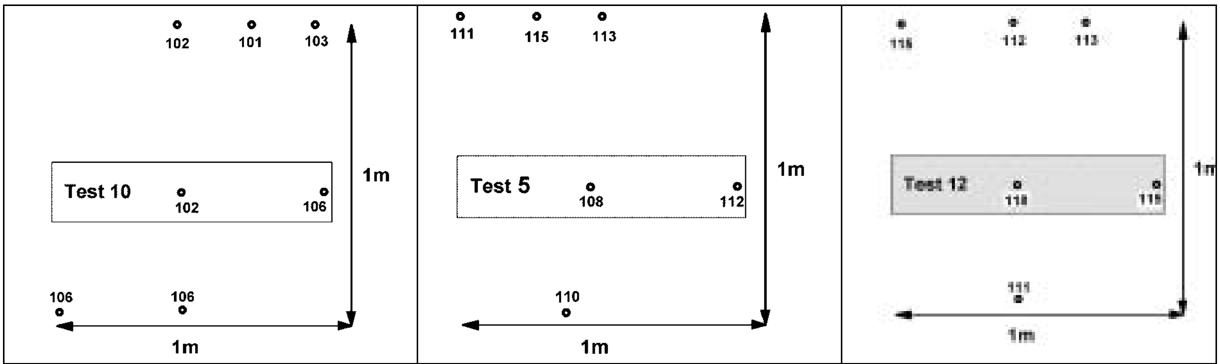
Fig.2. Oil pollution site map (area 60x75 m)

The active layer is underlain by continuous permafrost at this key site. Varandy oil, with temperature of hardening of –27°C, was used for the field experiment. The experiment was initiated in July, 2000 in 13 testes according to the technique prescribed by N.Solnceva (1998). The rectangular tanks (1 x 0.2 m^2) (bottom removed) are recessed slightly into surface and were filled with oil. The oil proceeded to saturate the ground of the active layer and migrate downward and in lateral direction. The amount of oil in different tests varied from 5 to 20 liters. The location of tests is presented at figure 2.

The sampling and measurements of oil concentration were made at several intervals following contamination: at 5 days (July, 2000), 2,5 months (September, 2000), 15 months (September, 2001), 27 months (September, 2002) and 39 months (September, 2003).

The measurements of 2003 have not been processed, so this article discusses data from the years 2000-2002. Two complete freezing and thawing cycles have occurred in the active layer during this time. The results from the measurements acquired in 2002 are indicative of data gathered in the previous two years and are focused on here.

The depth of the active layer at the polluted site was not significantly different from that at at unpolluted sites. Similarly, thawing depth measurements at the pollution sites and in the surrounding area (1 m in radius) indicate that the presence of oil pollution does not seem to influence thawing depth. (fig.3). The thaw depth within polluted sites ranged from from 102 to 118 cm in 2002, averages 110 cm (measurements in 6 points). In undisturbed sites the thaw depth shifts from 102 to 115 cm, averages 108 cm (in 13 points). Statistical analysis (not presented) indicates the depth measurements do not differ between the sites.



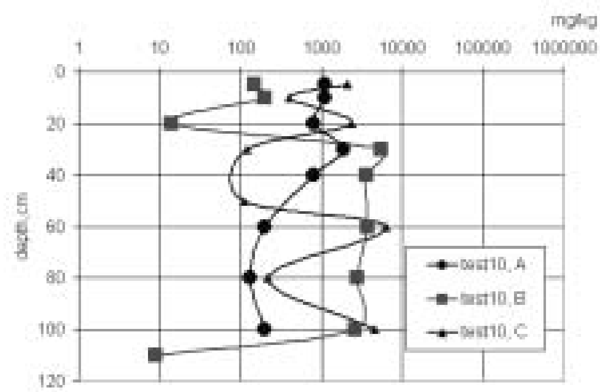
test10, 20 liters of oil	test 5, 10 liters of oil	test 12, 5 liters of oil

Fig.3. Thaw depth, cm

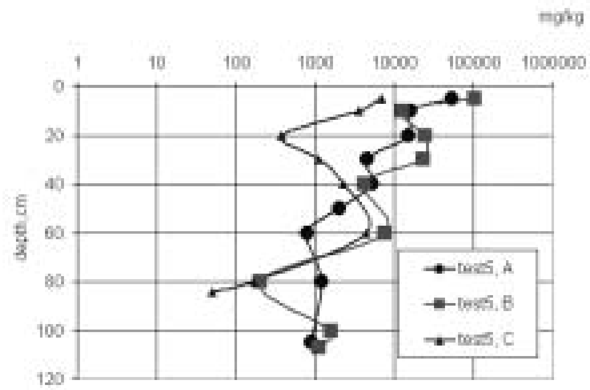
The range that is observed in the thaw depth measurements is caused, by micro relief features and vegetation cover within key-sites, and is not associated with the variability of soil thermal conductivity, which could be caused by different factors.

We surveyed three tests: test **12,** 5 liters of oil, test **5,** 10 liters of oil and test **10,** 20 liters of oil. At each test-site, at three points –"A – the center", "B – the edge" and "C – at the distance of 1m", there were drilled screw-gauge boreholes to enable sampling at certain depths. For sampling purposes the active layer was divided into 9 sections of equal interval over the entire depth of the active layer, with the last sample being selected from the frozen horizon. The chart of oil content at the test sites is shown at fig.4, 5, 6.

Test 10 (20 liter of oil)



Test 5 (10 liter of oil)



Test 12 (5 liter of oil)

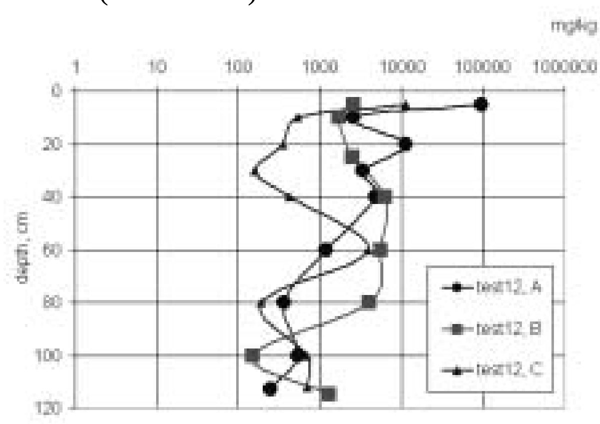


Fig.4. Oil products content in cross-sections of test sites, mg/g

All examined cross-sections have shown significant amount of oil present in the ground. The maximum oil content (up to 97g per 1kg of soil) is found in upper peat horizons; oil concentration gradually decreases downwards. The oil content at the active layer bottom is less then 1 g per kg. In comparison to measurements from previous years of the investigation there has occurred a significant increase of oil concentration in the lowest active layer horizons, caused by gravitational penetration of oil from above.

The oil concentration in the upper layers of permafrost increased in comparison to 2001. The, increase, on the order of 10-fold, is most likely explained by the fact that, in the previous year, thawing depth was slightly more than it was in 2002 (the previous season, 2001, was warmer and maximum thawing depth reached 118-120 cm at the key-site). Thus the frozen samples obtained in 2002 at 107, 110, 112 and 113 cm depths represent the bottom of the active layer, whereas the ground at that depth was thawed in 2001. A decrease of oil concentrations in subsurface horizons have been found in two cross-sections (vertical profiles). This fact can indicate biodegradation of oil started in the soil.

To investigate the lateral dispersion of oil two bore pits were dug and examined at test-sites 5 and 12. The visual observations of the polluted active layer horizons in the pit walls are summarized and interpreted below. A vertical heterogeneity in the rate of oil front movement in the active layer, which was observed in previous years, was maintained. Severe polluted intra layers, ‘pockets’, lenses or bands located in peaty or sandy horizons were in evidence (as they had been in previous years). It shows that the lithological and geochemical heterogeneity of the cross-section exerts a controlling influence upon the redistribution of oil in the active layer. The laboratory data support the field observations and suggest a similar delimitation of horizons (fig.5). Oil was also observed to accumulate in pockets under large boulders, which were noted in abundance throughout the active layer.

Freeze-thaw processes also influence oil distribution throughout the active layer. In the pit wall of test site 12 were observed oily horizons that had been divided into lenses by cryoturbation. That may be explained by extrusion and penetration of oil polluted soil during frost coursed movement of soils in the active layer. The oil content in the center of test site can differ within one horizon from 2500 to 15300 mg/kg. At a distance of 1 m from the center of oil pollution test site a virtual absence of oil components was noted (oil products content is 160-350 mg/kg). However, slightly farther out (1,2 m from the center of oil pollution test site) an increase in oil content (up to 4040 mg/kg) was observed in spots along the vertical profile (cross-section) –. This is a result of oil migration along cracks and surfaces formed by cryoturbations, especially if peat or some vegetation (grass, moss, bushes, etc.) is spread along these surfaces.

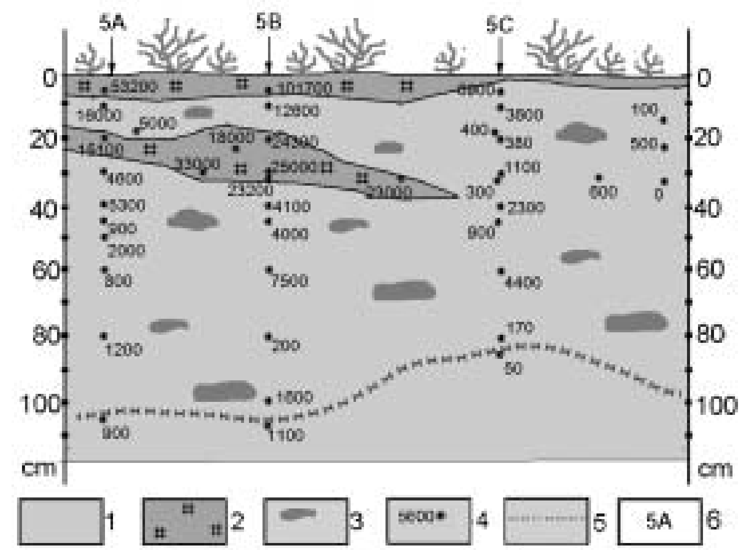


Fig. 5. Vertical cross-section

1 – loam and sandy loam;

2 – peat loam;

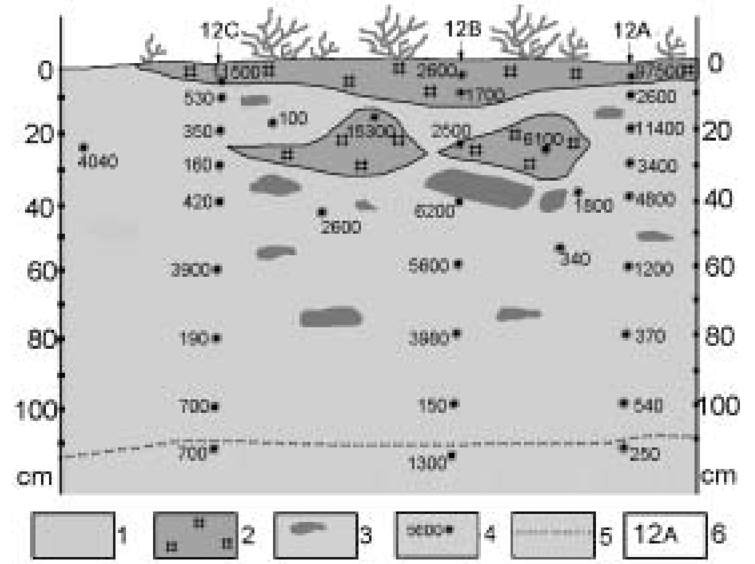
3 – debris;

4 – laboratory sample and oil product content, mg/kg;

5 – base of active layer;

6 – section and its number (5A – center of test, 5B – edge of test; 5C – moving off from the center)

Test 5 (10 liter of oil)



Test 12 (5 liter of oil)

Conclusions

- A significant amount of oil is observed in the cross-sections at all test sites. The concentration of oil gradually decreases downwards, but an even gradient is disturbed by vertical heterogeneity in the soil structure. Oil concentration does not exceed 1g/kg at the active layer bottom.
- Maximum concentrations (up to 97 g of oil per 1 kg of ground) are found in the top-most, peat-rich horizons.
- From year to year is observed an increase of oil concentration in bottom horizons of the active layer.
- Spot locations of relatively high oil concentrations at distances of approximately one meter from test sites indicates significant lateral oil movement, especially along some disturbed zones in active layer.
- Freeze –thaw processes influence redistribution of oil pollution in the active layer because of cryoturbation of ground.

- o The depth of seasonal thawing at the polluted test sites practically was not observed to differ from that at undisturbed sites.

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THE INFLUENCE OF PERMAFROST DEGRADATION IN NORTH RIVER BASINS ON MARINE AND ESTUARY COASTAL DYNAMICS IN THE MIDDLE SIBERIAN NORTH

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Introduction

Global climate fluctuations and local technogenic impacts influence cryolithozone state. Coastal dynamics of the Arctic seas and huge rivers of the Eurasian North are especially sensitive. Massive ice complexes, widespread in northern river valleys, melt due to thermal and chemical impacts; this leads to river flow enlargement, changes in the salinity of estuaries and offshore sea waters, and triggers landslide development on terrace slopes. This leads both to infrastructure destruction at northern ports and to increased runoff of sediments and salts. A larger sediment runoff may alter the depth of a sea. The coastal dynamics of northern river estuaries and mouths can be used to indicate regional climate change and local technogenic impacts.

Results

Multiple field investigations have demonstrated the fact that permafrost degrades in areas experiencing climate warming and in areas where industrial activity disrupts the cryolithozone. There are four main geocryological risks associated with permafrost degradation [Grebenets, Kraev, 2003]:

1. World ocean transgression [in part] due to ground ice and glaciers melting;
2. the activation of dangerous cryogenic processes (thermokarst, thermoerosion etc.);
3. the release of millions of tons of pollutants (frozen at the moment) to river systems and then to the world oceans as well as to the atmosphere;
4. the destruction of northern towns and tribal settlements.

In 1999-2002 field investigations of the modern coastlines of rivers, seas, lakes, and reservoirs were conducted in middle northern Siberian region. Sediments with high ice contents showed the fastest reaction to environmental changes and it was revealed that the action of water has the most destructive influence. For example, observation of several thermodenudation cirques on the Noril'skaya River (Pyasino lake basin) east coast revealed mean diameter growth from 60 to 80 m. Noril'sk meteorological data analysis did not show any tendency to climate warming. Instead, increasing thermodenudation along the river coasts is associated [Grebenets, 2003] with the local technogenic impact of large, metal producing factories of the Noril'sk industrial region. The mechanism by which

Fig. 1. Thermodenudation cirque is on Norilskaya river shore. July, 2002

industrial emissions can induce a ground-thermal response is outlined below.

First, modification to the forest tundra landscapes occurs, leading to an increase in the thickness of the seasonally thawed layer. This allows an increase in ground runoff to the river after an overflow event. The near shore area comes under mechanical and thermal influence of the river. Hydrological data for 1938-78 from the Noril'skaya River [Hydrological data…, 1978] indicate that mean water level reaches approximately 3.2 m during a debacle and 3.7 m during an overflow. These levels both reach the base of massive ice sheets. Physical impact due to floating ice causes mechanical destruction of shore ice massifs; thermial destruction is caused by relatively warm river waters. As a result of a single hydrological year the additional river runoff, formed by melting ice, enters the stream. The shore slope angle is reduced in cirques due to the thermal effect of the melt water, and the shore slopes between the cirques are destroyed mainly by mechanical action until the massive ice is exposed. Additional runoff increases the base water level in the river. The exposed shores undergo rapid melt due to solar radiation and warm summer temperatures.

Fig. 2. Interblock depression reasoned by ice-wedges thawing. Micro terrace relief formed of slimy sediments. Mouth of Yenisei, July 2003

Second, accompanying emission of gasses by the Noril'sk industrial region (for example, sulfur dioxide emissions reach up to 2 M tons a year) causes acid rain, increasing the salinity of seasonally thawing layer waters. They transport dissolved chemicals both to the permafrost table and the top of massive ground ice sheets. The chemicals undergo various reactions both with mineral and organic components of the ground (also with other chemicals) or deposit when the bottom of the active layer is reached. The chemical reactions may be classified as exothermic and endothermic; both types of reactions have associated effects. Exothermic reactions introduce the heat to the permafrost table. Endothermic reactions increase ground salinity, which increases frozen ground strength thus resistance to slope cryogenic processes and destruction by river ice. The salinization of runoff waters (along with contamination by heavy metals) also results.

Noril'skaya river flows into Pyasino lake where is situated the headwaters of the Pyasina River. Water runoff increase in the upper reaches of the watershed will cause an attendant increase in the lower reaches of the watershed. The Pyasina River crosses North-Siberian plain, which is characterized by various structures of perennially frozen ground, including multiple ice wedges, massive ground ice sheets and buried ice delfs [Popov, Tumel', 1989]. The Pyasina River basin is 10 times larger than the Noril'skaya River basin. The shores of the Pyasina River and its tributaries have been undergoing active mechanical and thermal erosion over the last several decades.

A phenomena noted in the estuary of the Yenisei River is almost the same. Research conducted in the Ust'-Port settlement and surrounding area have revealed intensive ice-wedge melting in the near shore zone for last 30 years. This has led to the generation of block relief (fig. 2). Thermoerosion also destroys massive grounds sheets of up to 6-8 m thickness, widespread in this region, fig. 3. An onbserved increase of fine- fraction sediments in the runoff composition may be attributed to thermodenudation of sediments in the region of the Sanchugovskaya River (a Yenisei tributary). Yenisei pebble beaches are covered with fine-fraction sediments from the thermodenudation of cirques and tributary shores. This material flows to Kara Sea in suspension, especially during overflows and heavy storms. The Dudinka River (another Yenisei tributary) adds pollutants from the Noril'sk industrial region as dissolved salts and suspended sediments.

The increase in fresh water runoff in the Yenisei and Pyasina River basins will ultimately contribute to a reduction in Kara Sea salinity levels in offshore areas. The freezing point of water is increased towards 0° C as salinity drops [Zubov, 1944]. The net result will be a southward migration of the mean edge of the sea ice, at least in the eastern part of the Kara Sea. This border coincides with the climatologically axis of western summer cyclones moving into the eastern regions of the cryolithozone.

CONCLUSION

Accounting only last circumstance, with modern temps of global climate warming there is no risk of western cyclones move axis replacement from continental part of Eurasia. However, a more precise assessment of the potential impact posed by increasing runoff of the northern rivers due to cryolithozone ice melting caused by climate warming or local technogenic impact will only be obtained with additional research. The salinity decrease in shelf zone sea waters is balanced by thermal runoff of submeridional flowing huge rivers of cryolithozone. Dissolved salts and suspended sediments runoff from thawing pulp depositories are also compensating salinity reduce.

Fig. 3. Massive sheet ground ice in Yenisei valley. July, 2002

To determine coastal dynamics of seas, estuaries and mouths in order to further possible global climate warming it's necessary to monitor extra river sediments formed by shores destruction. It allows defining the temps of sedimentation in Arctic seas near mouth parts. Asian shelf beneath Arctic seas has a gentle slope in this area. Sea may shallow due to additional sedimentation in a short time. Both squares of landflow fields and shelf cryolithozone growth are expected. Sea coasts thermoabrasion temps decrease reasoned in marine waves speed drop on shallow areas.

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COASTAL PERMAFROST DRILLING IN THE LAPTEV SEA

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There have been only a few drilling transects within the shoreface of the Asian Arctic Seas. These transects have been drilled from spring sea ice or small drilling platforms. Generally, on thermal abrasion coasts within the shallow Laptev Sea shelf, the sub-sea permafrost table is found at 5-60 meters depth. Unfortunately, deeper boreholes do not exist in the studied near-shore area. New sub-sea permafrost formations have been found in the shallows within accumulative bottom deposits.

Our previous studies of coastal permafrost degradation along the Ice Complex coast showed that the sub-sea permafrost table slowly descends from the shoreline to greater water depth. The inclination of the table depends on many parameters, but mainly on coastal retreat rates, water temperature and salinity. Drilling transects from Muostakh Island and Bykovsky Peninsula gave us some preliminary information on the permafrost degradation on rapidly retreating coasts. The average sub-sea permafrost table inclinations at the two locations are 0.007 and 0.013 (with average coastal erosion retreat rates 13 and 3 m/year), respectively.

In spring 2003, sub-sea permafrost drilling was conducted from the sea ice at Mammoth Tusk Cape (Western Laptev Sea coast). The average retreat rate of the ice-rich coast at the selected site (the beginning of the drilling profile) is 5.8 m/year, and the average retreat rate for the whole coastal segment is about 4-4.5 m/year. Drilling reached 32.5 meters and gave us unexpected results. Despite the high erosion rate and very low water temperature, the inclination of the permafrost table up to 1.3 km from the shore was very steep (0.015) and from 1.3 to 1.4 km extremely steep (more than 0.3). This anomaly is probably explained by ancient thermokarst processes under subaerial conditions. The rate of permafrost table degradation along the studied transect is estimated to be at least 8 cm/year.

In order to study sub-sea permafrost evolution within the whole shoreface near Mammoth Tusk Cape, relatively deep drilling (up to 300 m depth) is planned for spring 2004. The main objectives are:

- to drill a longitudinal transect of boreholes using a professional drilling machine;
- to determine sub-sea permafrost table depths up to 10-15 km from the shore;
- to discover sedimentological features of the deposits;
- to analyze the temperature and salinity distribution in the bore-holes;
- to understand the interactions between freshwater permafrost and saline seawater in the onshore/offshore transition zone based on pore-water geochemical studies
- to estimate rates of permafrost degradation depending on coastal erosion activity and other factors

THE COASTAL OCEAN ALONG THE SIBERIAN ARCTIC: NEW PROCESS-ORIENTED STUDIES OF THE PHYSICAL ENVIRONMENT OF THE SOUTHEASTERN LAPTEV SEA SHELF

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On the basis of previous results obtained from Russian-German expeditions to the Laptev Sea, it became evident that ice-bearing permafrost is common in large areas of the Laptev Sea shelf. The submarine permafrost was formed under subaerial conditions during the last glacial and subsequently underwent submersion due to postglacial sea-level rise and, more recently, shoreline erosion. Therefore its present state is highly transient. Heat and mass transport processes in the water column and the sediment largely determine the response rate of the submarine permafrost to the new warm and saline boundary conditions. Even though the submarine permafrost is of importance for the global climate system, knowledge of its recent dynamics remains limited.

During the past decade a large-scale change in the arctic atmospheric circulation took place causing a shift in various oceanographic boundary conditions, e.g., decrease in sea-ice coverage, increase in riverine input and in air temperatures and increased inflow of Atlantic water masses into the Arctic Ocean and the Laptev Sea. These changing boundary conditions probably also influence the marine environment (including the submarine permafrost) and the coastal zones of the Siberian Arctic shelf seas.

Within the framework of the new German-Russian research program "Process Studies on Permafrost Dynamics in the Laptev Sea" a first marine expedition (TRANSDRIFT IX) was carried out aboard RV "IVAN KIREYEV" from August 28 to September 4, 2003. The overall scientific aim of the process-oriented studies was the investigation of the complex interaction between the atmosphere, water column, and seafloor/submarine permafrost on the inner- and mid-shelf area of the Laptev Sea. During the expedition two oceanographic bottom-mooring stations were successfully deployed to study the seasonal variability in temperature and salinity distribution within the water column and the interacting processes in the transition zone between the water column and sediment, and to monitor the current system and the transport processes for the period of one year. One of the bottom-mooring stations was deployed in the nearshore area north of the Lena Delta to characterize processes in an onshore/offshore environment. To study changes in the hydrodynamic system and its interaction with the seafloor, the second bottom-mooring station was deployed in the mid-shelf area.

Further information is available at: www.geomar.de/~tmueller/Laptevpage/Start/

MULTI-YEAR MONITORING OF COASTAL EROSION AT THE KHARASAVEI KEY SITE, WEST YAMAL

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The West Coast of Yamal Peninsula is situated in the sphere of strategic economic interests of Russia. The Kharasavei Gas Condensate Field, located here, has been developed since the middle of the 1970s.

We have systematically observed the coastal dynamics in the region of the Kharasavei key site since June of 1981 at 33 control profiles on the shore slopes undergoing thermal abrasion installed along the 11-km zone from the settlement of Pionerskii to Kharasavei Cape. Control profiles have been installed in the most representative coastal areas. Observations are being made using a standardized procedure, which includes geomorphological description, identification of cryolithologic characteristics, repeated shore leveling, sea bottom profile surveys by attached profiles, etc.

The Kharasavei key site is one of the most investigated on the west coast of Yamal Peninsula. The coast is composed of perennially frozen soil of varying ice contents and is undergoing degradation due to thermal abrasion, retreating an average of about 1.0 m/year. The highest coastal retreat rates are found on Cape Kharasavei and are most likely associated with the serious technogenic destruction of the environment that has been identified in this area.

We have identified four typical coastal areas, differentiated on the bases of cryolithological structure and the level of resistance to thermal, hydrodynamic and technogenic exposures.

The shore in the region of the Kara Expedition Settlement is one of the four representative areas, where over a 20-year period the shore has retreated in all places between 1 and 10 m, which represents an average retreat rate of 0.1-0.7 m/year. The washed out shore area is represented here by a 5-11 m high sea terrace composed of aleurites, sands and loam with 15-20 % ice content. Currently, the minimum distance from the coast slope edge to the first building lines of the Kara Expedition Settlement has been reduced to 40 m.

Further to the south we have identified a 6-8 m high shore area of 1.2 km total length, which has remained stable over a 13-year period of observation. Sands and clayey sands with an average 10-15 % ice content predominate here in the lithological coast structure. Recently thermoabrasion processes have accelerated slightly on the south flank of the area, causing shore deterioration and a resulting average retreat rate of 0.05-0.15 m/year.

Along the adjacent 1-km section the shore bluff (8-9 m height) possesses greater ice contents (30-40%) and grey clayey-sands with reticulate structure. Here the coastal retreat rate is greater, averaging up to 1.35 m/year.

In the 2.5-km length of coast bordering Cape Kharasavei on the north the average coastal retreat rates range from 1.7-2.4 m/year and are the highest on the coast observed. Here the shore slope (8-10 m height) is composed of various granulated frozen layers with an ice content of 35-45 %. The Cape Kharasavei shore is the least stable, with coastal retreat rates reaching 2.4 m/year over the 20-year period of observation. The retreat rate obtained from field observations of the coastal profile is supported by results obtained from topographic interpretation, which suggests an average coastal retreat rate of 2.73 m/yr over the last 48 years.

The main kinds of human impacts on the Kara sea coast under study are: destruction of vegetation and top-soil, formation of ravines as a result of industrial and domestic water evacuation, environment pollution with oil products and unsupervised dumps of scrap metals over the tundra and coasts.

Analysis of study data suggests a cyclic recurrence of thermoabrasion processes. The coastal retreat rate has changed over the 20-year period of study. An overall reduction in the intensity of coastal retreat has been identified over the last 5 years. Among the causes of this is a decrease in the total magnitude of wind-wave energy, a reduction in or a complete cessation of man-made influences, and especially a withdrawal of sediments from the bottom and beaches.

MAPPING OF THE COASTS OF YUGORSKY PENINSULA, KARA SEA

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Field studies at the ACD monitoring sites on the Yugorsky coast were performed in August, 2003. Development of thermocirques and coastal retreat were observed. Enroute geomorphologic mapping was undertaken aimed at describing the coastal topography and subdividing the coast along a 44,5 km stretch from the Hubtyakha river mouth in the east up to the town of Amderma in the west (Fig.1). This work is an extension of studies ongoing since 1999.

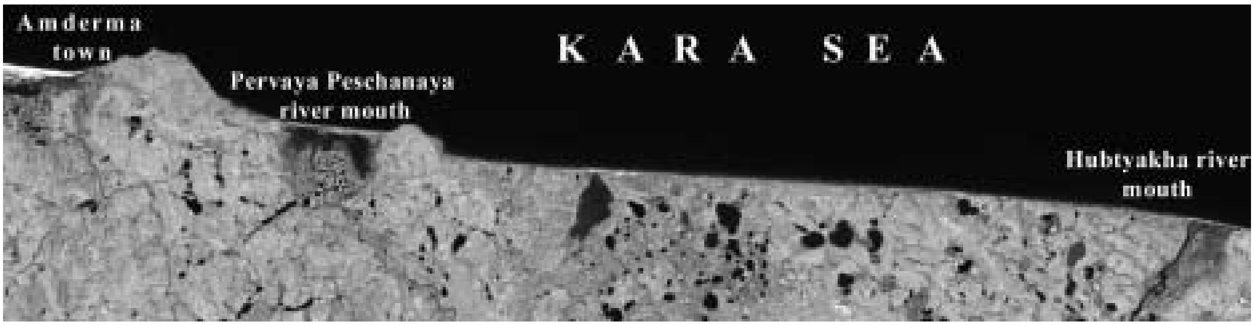

Fig.1. Study area of Yugorsky peninsula

Overall, the coast may be subdivided into two main zones based on geological structure. In the eastern portion the sea interacts with the undulating plain built of Quaternary sandy-clayey frozen deposits. The coasts are undergoing active degradation by coastal thermoerosion. In the western portion, which covers 15,2 km from the town of Amderma eastward, bedrock occurring at the base of the section is overlain with Quaternary sandy-clayey frozen deposits. The entire coast along this section is mostly erosional, with only small fragmentary patches of pebbly beaches occupying concave areas between the rocks.

Field surveys and interpretation of aerial and satellite images formed the bases for the compilation of a geomorphological map along a 2-3 km strip paralleling the shoreline (Fig.2).

In the coastal zone terrace-like surfaces are subdivided with steps 8-12, 15-25, 25-35 m high, and ridges with heights 35-45 m, oriented along west to east and north-west to south-east directions, and also interfluve complexes of ridges and hills with heights of 45-70 m. Surfaces with heights of 15-25 and 25-35 m are the most widespread along the coastal zone. These surfaces, affected by the sea, are dissected by thermoerosion gullies inheriting structure from the polygonal ice network. They are 2 to 30-40 m long and appear every 15-50 m. Thus, the edge of a coastal bluff in projection is festoon-like. Gullies near the bluff edge frequently form concave, cup-shaped depressions. Thermocirques formed over the tabular ground ice bodies are widespread. In a number of cases, for the coastal sections with tabular ground ice, a high bluff (18-25 m high) is separated from the sea by a lowered bench 8-15 m high, dissected by gullies and scours (thermoterrace). The total length of the shoreline with thermocirques is 1500 m, which comprises about 3% of the study shoreline. Sediment yield though is concentrated in the channels with average width about 10 m.

There are khasyrei (alas), which are well expressed in relief and interpretable on satellite images. Some of these former lakes are lowered due to retrogressive gully erosion linked to coastal bluff edge.

Gully mouths and active thermocirques form detrital fans on the beach. These fans, 6-15 m wide, can be completely superimposed on the beach and advance up to 15-20 m into the sea, changing the shape of a coastal line. In cases where massive ground ice gets exposed in a retreating flat bluff, mass-wasting events are observed in which thawed wet deposits slip as a uniform block. Such events were observed on coastal bluff 18-20 m in height: over a period of several seconds there was a dissection and sliding of clay material from the middle of the slope. The landslide totally superimposed the beach and measured 25x25 m in size and about 1,5 m thick.

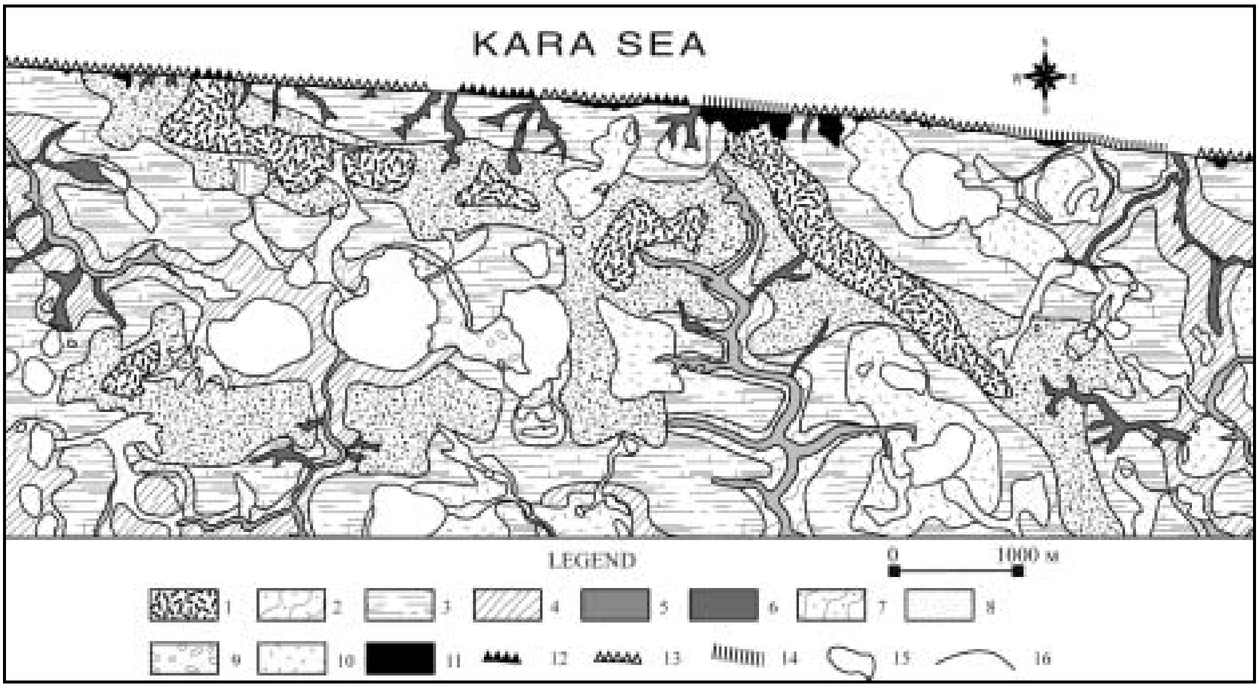

Fig. 2. Fragment of geomorphic map for the study site at Yugorsky peninsula coast.

Accumulation relief: 1 - terrace-like marine surface 35-45 m high, 2 - terrace-like marine surface 25-35 m high, 3 - terrace-like marine surface 15-25 m high, 4 - terrace-like marine surface 8-12 m high. Erosion relief: 5 - river flood plains, 6 - ravines and hollows, 7 - erosion slopes. Thermokarst and thermodenudation relief: 8 - erosion-thermokarst scours, 9 - lake terraces, 10 – hasyreys, 11 – thermocirques. Retreating coastal types: 12 - thermoerosion bluffs, 13 - thermoerosion-thermodenudation bluffs, 14 - thermodenudation bluffs. Other: 15 – lakes, 16 - geomorphic boundaries.

In coastal typing work performed by V.A.Sovershaev (1992) were identified three coastal types, undergoing retreat, consisting of frozen Quaternary deposits. These have been classified according to the relative influence of thermal erosion and thermal denudation processes as: 1, thermoerosion bluffs; 2, thermoerosion-thermodenudation bluffs; and 3, thermodenudation bluffs. These three types characterize various mechanisms of coastal destruction, however the subdivision is rather provisional and is utilized primarily for the purpose of mapping of the coastal zone in more detail. Thermoerosion coasts are characterized by pronounced morphological forms, wave-cut niches in this case, which are associated with wave action. These coastal types are subjected to wave action only during surges and autumnal storms. At locations where waves do not produce a niche and are not the leading agent of coastal destruction, a prominent degradational role can be played by thermodenudation. Such coasts are considered to be of combined thermoerosion-thermodenudation origin. Thermodenudation coasts develop mainly due to thermodenudation on slopes. At these locations waves attack only material that has fallen on a beach and do not directly impact the bluff. The most prominent morphogenetic feature in the study area, occupying 25% of the shoreline, are coasts with thermoerosion-thermodenudation bluffs. Thermodenudation coasts cover approximately 6% of the shoreline (Table 1).

Aggradational coasts, as a rule, are linked to river mouths. Low sandy marine terraces up to 2,5 high are observed in the mouths of Pervaya, Peschanaya, and Hubtyakha rivers. There are small lakes and marshes on the surface of these landscape types. They are separated from the sea by broad, sandy banks with pebbly "riprap" on top of a beach that are up to 160 m wide.

Table 1. Coastal retreat and sediment yield from different coastal types of 44,5-km long portion of Yugorsky Peninsula shoreline east of Amderma town

	Bedrock coasts	Coasts built of Quaternary sandy-clayey frozen deposits			Thermocirque mouths and river estuaries
Coastal types	Erosion cliffs	Thermoerosion bluffs	Thermoerosion-thermodenudation bluffs	Thermodenudation bluffs	Aggradational coasts
Total shoreline length	9500 m	9600 m	13700 m	2700 m	9000 m
		26000 m			
Coastal retreat in 1947-2001	no data	from 30 to 63 m, average 35-55 m	from 20 to 92 m, average 35-60 m	from 35 to 53 m, average 40-45 m	30-60 m
Average retreat rate	no data	0,6 – 1,1 m/year	0,6 – 1,1 m/year, max. 1,7 m/year	0,7 – 0,8 m/year	0,6 – 1,1 m/year, 0,6-4,2 m/year**
Shoreline length for different topography	no data	h=5-15 m – 320 m h=15-25 m – 5450 m h=25-35 m – 2350 m h=35-45 m – 680 m	h=5-15 m – 420 m h=15-25 m – 10400 m h=25-35 m – 2880 m	h=15-25 m – 1720 m h=25-35 m – 580 m h=35-45 m – 400 m	no data
Specific yield from 1 m of a shoreline per year*	no data	14,2-26,1 m^3	13,1-24 m^3	17,58-20,1 m^3	180 m^3 **
Total annual sediment yield*	no data	137000-251000 m^3	180000-328000 m^3	47500-54200 m^3	27000 m^3 **
		364500-633200 m^3			

* The volume of yield is calculated as multiplication of shoreline length by bluff/scarp height and average retreat rate. ** The volume of yield from thermocirque mouthes.

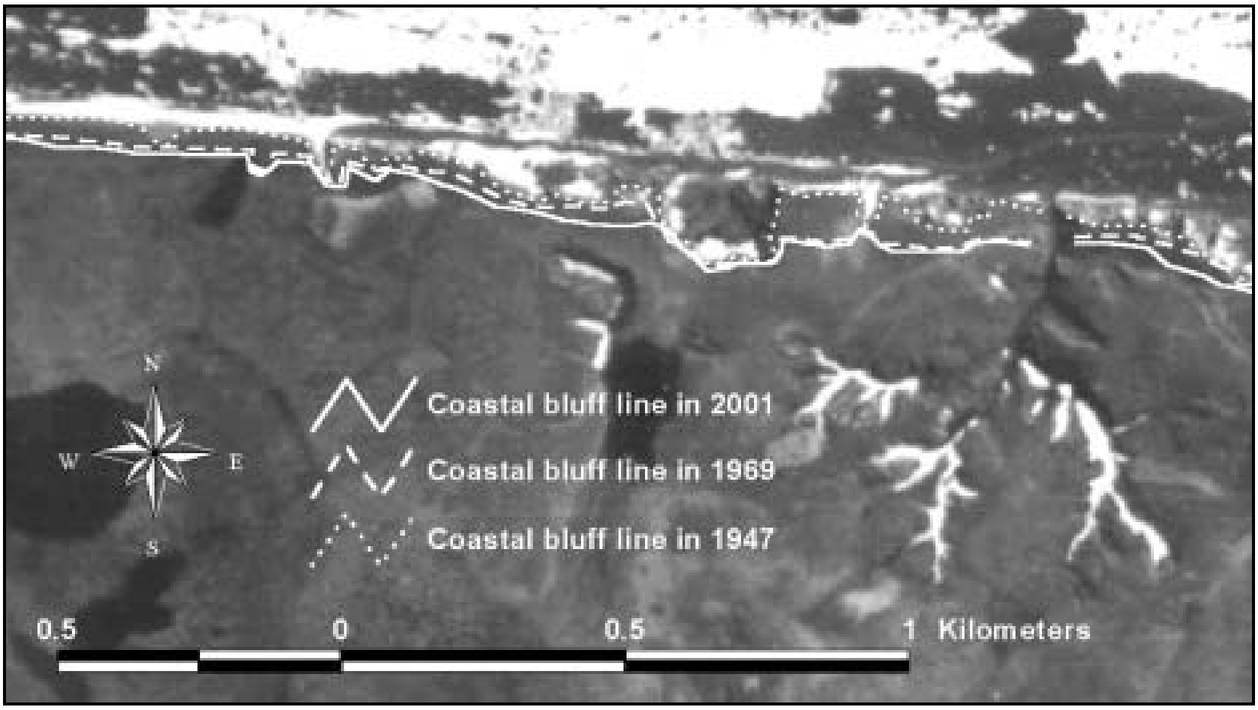

Fig. 3. Edge of the coastal bluff as in 1947, 1969 and 2001, fragment of the sketch - coastal bluff line.

An estimate of the coastal retreat rates along the Yugorsky Peninsula is based on a comparative analysis of the bluff edge position at different years, using aerial photos (1947), topographic maps (1969), and satellite imagery (2001). These three sources were superimposed using ERDAS Imagine software. Most visible on the images was the bluff edge, which was considered to reflect the coastal retreat, given that the slope angle was stable. ArcView GIS was used to measure the distances between the shoreline of various years along a 15800m stretch of coast westward from the Hubtyakha River mouth (Fig. 2).

Shoreline positional accuracy in 2001 depended on the satellite image resolution and was equal to ±7,5 m. Average rates of retreat for the coasts of various types was not measurably different at this resolution, and was within 0,6 to 1,1 m/yr for the period 1947 to 2001. The data obtained for the 16 km length of shoreline was applied to the rest of the coastal bluffs (total of 26 km) according to the type of the coast.

Table 1 shows the amount of material delivered to the coastal zone due to retreat for the 26 km-long shoreline. Total annual sediment yield due to thermal erosion and slope processes (excluding transport by rivers and thermocirques) is 364500-633200 m^3.

About 15 active thermocirques were mapped in the study area. Based on a comparison between the topographic survey of 2001 and aerial photography from 1947, we calculated the sediment yield from one key-site thermocirque. The average yield without accounting for the ice volume was about 1800 m^3 per year for this period. This demonstrates that specific transport of material from 1 m of the shoreline of the thermocirque mouth may be 5 to 6 times higher than that from 1 m of flat coastal bluff.

Thus 1,5 km shoreline out of 26 km of Quaternary coasts provides up to 5-10% of sediment yield.The work was made possible due to the support of INTAS, grants 01-2211 and 01-2329.

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THE MODERN AND THE BURIED CRYOGENIC STRUCTURES: THE KEY TO RECONSTRUCTION OF THE COASTAL DYNAMIC PROCESSES

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Relic cryogenic submarine structures were identified at Spindler and Marresale key sites as the result of extensive onshore and offshore field operations conducted by VNIIO and MSU in 2001. The onshore work revealed two different types of coastal degradation: at Marresale site was found a “linear” coastline recession with the rate ~1,9 m/year, whereas at Spindler site a “voluminous” type of degradation with rate ~3 m/year was observed (Leibman, 2001).

Based on results from high resolution offshore seismic profiling, two seismic units have been defined. The upper unit is interpreted as melted permafrost and unfrozen Holocene sediments, whereas the low one is likely the frozen permafrost complex of the Late Pleistocene-Holocene. The strong reflector dividing the units is interpreted as the upper permafrost surface.

Based on these data a 3-d model of the modern position of the permafrost surface was constructed. It shows several depressions at the surface of the permafrost measuring up to 2 km in width. The edges of these depressions are very abrupt, with relative heights up to 10-15 m. Most of these structures are covered by a veneer of sediments and are not expressed in the modern topography. Each of these large depressions includes a few local isometric depressions. The latter are interpreted as buried thermocirque or paragenetical with thermocirques which occurred in the coastal zone. The complexes of the buried thermocirques themselves mark the location of the ancient shoreline. There are two spatially separated complexes of such buried structures. The most distinguished thermocirque is respresented as a terrace 18 meters high. According to Danilov’s curve of sea level change (Klige et al., 1998) the age of this elevation could be approximately 6 Ka.

Based on preliminary assessment average retreat rate at this site was 0.2-0.5 m/year over the last 6000 years.

This study was supported by INTAS grant 2329.

LENSES OF MINERALIZED CONFINED GROUNDWATER (CRYOPEGS) IN THE COASTAL AREA OF WEST YAMAL PENINSULA, RUSSIA

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Mineralized groundwater lenses existing at below 0°C temperatures (cryopegs) are widespread in the coastal area of west Yamal. They occur at different depths as isolated lenses, are not connected with each other or to ground or surface waters, and have different pressure heads (depending on the depth of location). An examination of a cross-sectional profile shows that cryopeg lenses occur in multiple layers. In some cases boreholes drilled through cryopegs resulted in the emission of a gas. Cryopeg water has a relatively constant chloride-sodium composition, however concentrations of SO_4^{-2}, Mg^{+2}, Ca^{+2} ions can differ among occurrences, as can salinity.

The presence of cryopegs in the ground poses several challenges to infrastructure: they considerably reduce the bearing capacity of the ground and the brine solution aggressively attacks concrete and is corrosive to metals, which also renders surface water unusable for water supply.

The goal of the investigation is to determine specific features associated with the occurrence and formation of cryopegs, focussing primarily on those shallowly lying in the coastal zone of west Yamal. Cryopegs in this region have been drilled through by boreholes on several occasions, to different geomorphological levels at depths ranging from 2-3 m to 10-12 m during explorations in the oil- and gas fields of this region (Kharasavej, Kruzenshtern, Bovanenkovo, central Yamal and others), along the lines of trenches planned for gas utilities and railways (Fig.1). The deep parametric boreholes drilled in the areas of Kharasavej and Bovanenkovo have detected cryopeg lenses at depths ranging from 30-50 m to 200-250 m (Kondakov, et al, 2001).

The analysis of the data concerning the conditions of the occurrence and the chemical composition of cryopegs, obtained during these investigations and taken from the literature, enabled us to identify landscape indicators of the cryopegs that are situated near the surface (Kritsuk, 1990; Streletskaya, 1991), as well as to classify the cryopegs of the Yamal Peninsula into four types according to conditions of occurrence and genetic features.

Laida type. On the laida in the Kara Sea and Baidarats Bay (as well as those areas near the mouths of the rivers discharging into them) cryopegs are very prevalent at depths of 0.5-3 m to 8-10 m. The cryopeg lenses are related there to interbed zones amongst organogenic silts and silted sands, and sandy loam of up to 1.5 m thick. The cryopegs have a slightly cryogenic head or have no head at all, and are identical to sea water in chemical composition, although currently no direct links to the ocean were in evidence, and the salinity is considerably higher (80-112 g per liter).

Flood-plain type. Cryopegs are widespread on the floodplains of the medium-sized rivers, both on beaches and spits, and also in the central and rear parts of the floodplain where they are associated with the bottoms of ancient lakes as well as exposed parts of modern lakes. Electrical soundings of the floodplain lake bottoms within the talik zone have revealed lenses of low resistance as well as pillar-like areas (Pugach and Timofeyev, 1987). Isolated cryopeg lenses were detected under the Se-Yakha and Yuribej Rivers beds at depths varying from 3-5 m to 10-20 m (and within the river beds up to about 30 m). The water has cryogenic head, with a chemical composition dominated by chloride ions (to 97-100 %). Sulphate in the flood-plain cryopegs (unlike in the cryopegs of laida type) are either absent or present in minor proportions, whereas the Na^+ content varies over a wide range (from 34 to 87 %-equiv.) due to a sharp increase (to 42 %-equiv.) of Mg^{+2} ions. The mineralization of the analyzed flood-plain cryopegs changes from 6.0 to 91.9 g per liter.

Terrace type. In the river valleys within terraces, the near- surface cryopegs are associated chiefly with the bottoms of modern and ancient drained lakes (hasyreys), as well as in the under-lake and under-bed taliks. At the same time, in the areas with widespread deposits of thick ground ice, the cryopeg lenses were often striped on the gently sloping hills overgrown with high willow. The water has cryogenic head, is sulphate-free, and of differing salinity than cryopegs characteristic of other zones (from 6.2 to 43.5 g per liter).

Watershed type. On plain IV the cryopegs were striped exclusively in the bottoms of deep bogs and in the valleys of small rivers where low-resistance layer lies at a depth of 10-20 m (according to vertical electrical sounding data), whereas within the flat plain its depth is over 100 m, reaching 250 m. The cryopegs there have high head, are sulphate-free, and possess salinities of 10-20 to 30-33 g per liter.

The conditions of occurrence and different chemical compositions of the cryopegs point to the different genesis of their water. This is confirmed by isotopic investigations. In eight tested cryopeg samples, $\delta^{18}0$ changes from -5,9‰ to -18,6‰, δD - from -69‰ to -99‰ (Kritsuk & Polyakov, 1993).

Sea water is associated with the formation of those cryopegs, which possess a salinity greater than 35 g per liter (the normal salinity of sea water) and an oxygen-isotope composition close to that of sea water (> -10‰ SMOW). Such cryopegs include all the cryopegs of the *laida* type and a number of the *flood-plain* type. The formation of these cryopeg lenses is associated with the freezing of Holocene marine sediments where, due to tidal fluctuations of the river water level, the water flow has a reciprocating character. At the same time, a part of the flood-plain cryopegs were being formed, obviously, at the early phases of sediments' freezing (at once after going out from the sea level). Some cryopegs are formed as a result of salt redistribution in the seasonally thawed layer during activation of slope processes.

The origin of those cryopegs which possess both a salinity that is considerably lower than that of the sea water and a chemical composition that is devoid of sulphates but has increased magnesium ion content, cannot be considered to be fully understood. Association of the cryopegs with hasyreys and riverbeds suggests that their formation is connected with cryogenic metamorphosis during deep freezing of the lake (surface) and under-lake (under-riverbed) groundwater in very severe climatic conditions (about 20 000-18 000 years ago). In this case, the depth of cryopegs of this type is determined by the depth of the paleo-lake. A promising direction for ongoing investigations of cryopegs is the greater application of isotopic methods.

The analysis of conditions of occurrence, character of distribution, and chemical composition of the cryopegs under consideration carried out by the authors enabled a classification of the western coast of the Yamal Peninsula into zones according to the most distinctive types of cryopegs, and to map their extent in the surrounding regions.

This work was supported by INTAS (grant 01-2329) and by the Russian Foundation for Basic Research (projects no. 02-05-64263, 01-05–64635), grants Russian Science Schools – 2067.2003.5T and "Russian Universities".

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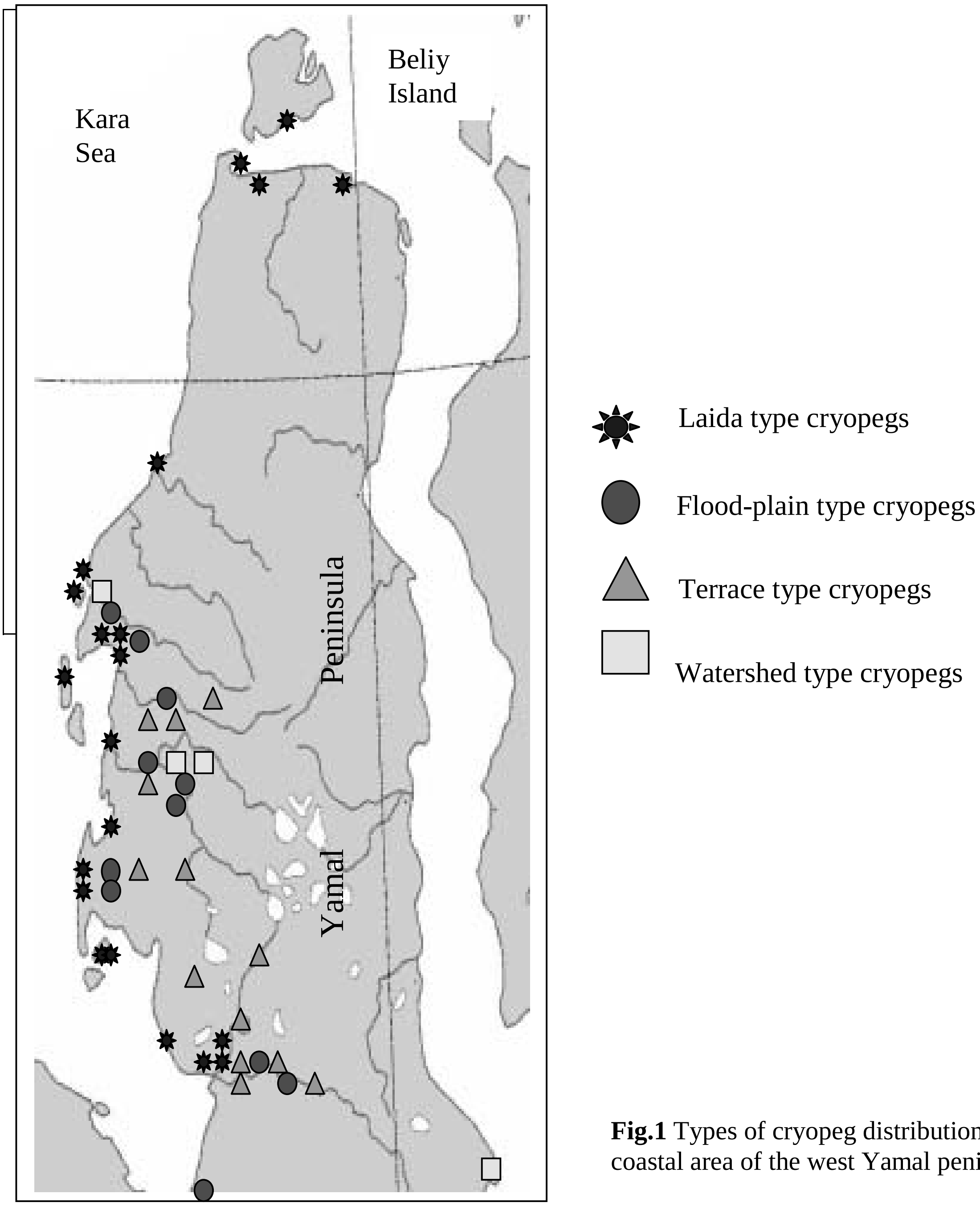

Fig.1 Types of cryopeg distribution in the coastal area of the west Yamal peninsula

COAST FORMATION IN THE EASTERN SECTOR OF THE RUSSIAN ARCTIC REGION DURING THE PLEISTOCENE-HOLOCENE

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The dynamics of the coastline in the eastern sector of the Russian Arctic region has been reconstructed for the last approximately 250 000 years. This work continues our earlier study devoted to the development of the western Arctic coasts (Shpolyanskaya et al., 2003). A series of maps illustrating the character of the coasts and the rocks that composed these coasts at different stages of the Pleistocene-Holocene evolution has been constructed.

The coastline in the eastern Arctic sector and the frozen ground composing the coasts were formed in the Quaternary, mostly under continental conditions, against a background of permanently severe climate. In this region the Pleistocene transgressions affected mainly islands, narrow coastal regions, and deltas of large river valleys on the mainland.

The seas were permanently ice-covered during almost the entire Pleistocene, and woody plants made only sporadic appearances on the coasts, even within interglacial periods. During the cold periods glaciation developed only in mountain regions and glaciers did not appear on the coasts and so did not affect them. Fossil ice veins were formed on coastal plains (Rozenbaum and Shpolyanskaya, 2000).

These conditions were not favorable for development of various coastal processes. Coasts developed mostly under the action of local exogenous processes, whose intensity depended on the specific cryolithology of a particular coastal region.

The marine transgression began to penetrate farther inland at the end of the Late Pliocene–Early Pleistocene, and the Val'karai lowland in the north and the Anadyr lowland in the east, within which sea terraces are distinguished, were flooded by the Middle Pleistocene. Deltas of large rivers were flooded in northern Yakutia. The coastline between the Lena and Anabar river mouths and in the lower reaches of the Indigirka and Kolyma rivers was located slightly southward of the modern coastline (Kaplin and Selivanov, 1999).

The climatic conditions in the Middle Pleistocene (II_{2-4}) are reconstructed as cold and continental over the majority of the region and as more humid in the easternmost parts of this region. The average annual temperatures were –10°, -15°, and even –20°C and lower in cold epochs of the Middle Pleistocene (Velishko, A.A. 1999). Ground temperatures were low, and the cryolithozone thickness possibly exceeded 2000 m in mountain regions. The submarine relic cryolithozone existed in flooded areas of the Val'karai and Anadyr lowlands and in the island zones flooded as a result of sea transgressions.

As a result of a short summer period and a wide sea area covered with ice, coastal processes were not active and the coastal material was carried small distances by fast ice under the conditions of a shallow sea. The coastal geomorphological types of this time were mainly abrasion-accumulative, thermoabrasion-accumulative, and accumulative (Fig. 1).

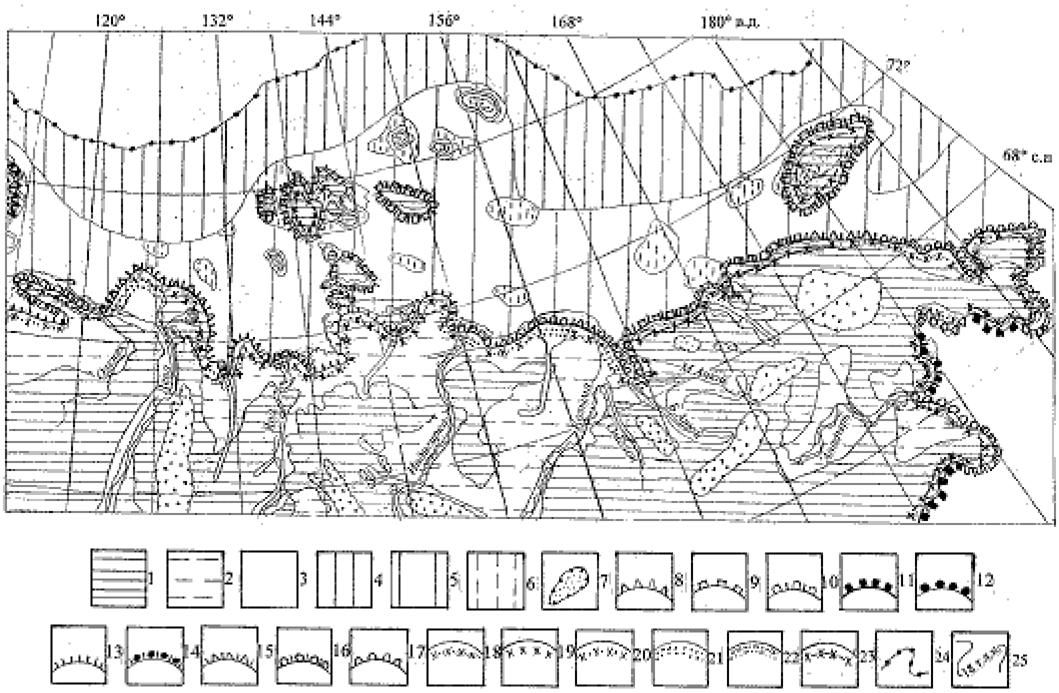

Figure 1. The East Arctic Ocean coastline position in the Middle Pleistocene. Maximal glaciating and sea transgression (II_{2-4}).

1 - The subaeral cryolithozone in the mountains and uplands.

2 - The subaeral cryolithozone in the fluvio-lacustrine and marine lowlands.

3 - The subaeral cryolithozone in the river valleys.

4 - The frost penetration shelf deposits.

5 - The submarine cryolithozone in the shallow shelf.

6 - The relict submarine cryolithozone.

7 - The sheet glaciations and caps.

8-17 - The types of coasts:

8 -the thermo-abrasion glacial shores, 9 - glacial trough shores, 10 diastrophic-denudation-eroded shores, 11 – abrasion-denudation shores, 12 - abrasion shores, 13 - thermo-abrasion shores, 14 - abrasion-accumulative shores, 15 - thermo-abrasion and accumulative shores, 16 - thermo-erosion and accumulative shores, 17- accumulative shores.

18 - 23 - The types of deposits:

18 – clayey sandy loam aleurite (Yeadomian periglacial formation in Yakutia), 19 - sandy loam clay, 20 - sand, sandy loam and loam, 21 - sandy loam and sand (deltaic deposits), 22 – sand land waste pebbly, 23 - before Quaternary crystalline and metamorphic deposits.

24-25 - The boundaries:

24 – shelf, 25 – relict coast boundaries of last marine transgression (by Lozhkin, 2002

At the beginning of the Late Pleistocene, the regime was still marine on the shelf of the Eastern Arctic region and the coastlines approximated their modern positions. The climate was warmer than modern between 135 and 90 ka. During the climatic optimum (Kazantsevo interglacial (III_1), 125 ka ago), perennial ice was absent and only seasonal ice predominated in the Arctic Ocean. Sea level was +6 m. The shelf was completely flooded, and the lowlands were partially flooded. All straits were open, which promoted a free water exchange between Arctic seas. The conditions favored the development of dynamically active morphological sedimentation processes. Clearly defined terrace-like surfaces testify to the occurrence of two pre-Holocene coastal complexes in the region. The coastal processes were predominantly abrasion and abrasion-accumulative, and thermoabrasion-accumulative in the areas with thawed ice complex. Accumulative coasts with beach barriers, bars, and spits were formed in shallow straits and in the coastal parts of river mouths.

The Kazantsevo interglacial, a warm stage about 70 ka ago, was followed by a very cool period, the Zyryanka Glacial phase (III_2), which was accompanied by intensive development of permafrost on the exposed shelf, where typical periglacial conditions were initiated. The sea-levels decreased to -80 m and coastlines shifted northward.

Between approximately 50 and 40-25 ka ago, the climate was slightly warmer and sea level increased to -40 -35 m. The shelves of the Siberian seas were still mainly exposed, but the coastline moved toward the modern coast; the land-fast sea-ice zone also shifted. The sedimentation below ice, started as long ago as the cold Zyryanka Glacial phase, continued. Ancient coastal complexes with elevations of 5-12 m on the coasts of the Chaun and Nol'd Bays, as well as terrace-like surfaces with elevations of 20-30, 8-12, and 2-5 m on the Van'kina Bay coast, were formed at that time.

The Late Pleistocene regression and the following Pleistocene-Holocene transgression played an important role in the development of the onshore shelf.

The sea-level in the most recent glacial period, the Sartan Glacial epoch (III_4), decreased to -110 m (Pavlidis et al., 1998). The Arctic Ocean was isolated from other oceans, and the Bering land bridge existed. A large proportion of the shelves were exposed, and the straits between seas were sealed off. An ancient coastline was only roughly established at the margin between the shelf and eastern Siberian seas, which is most probably explained by the preservation of the coastline by stiff fast ice. Coastal processes were absent. Sediments accumulated both below and above ice. In the northern regions of Central and Northeastern Siberia, glaciations were local (mountain-valley) and remained inside the modern coastline, even within eastern Chukotka (Fig. 2).

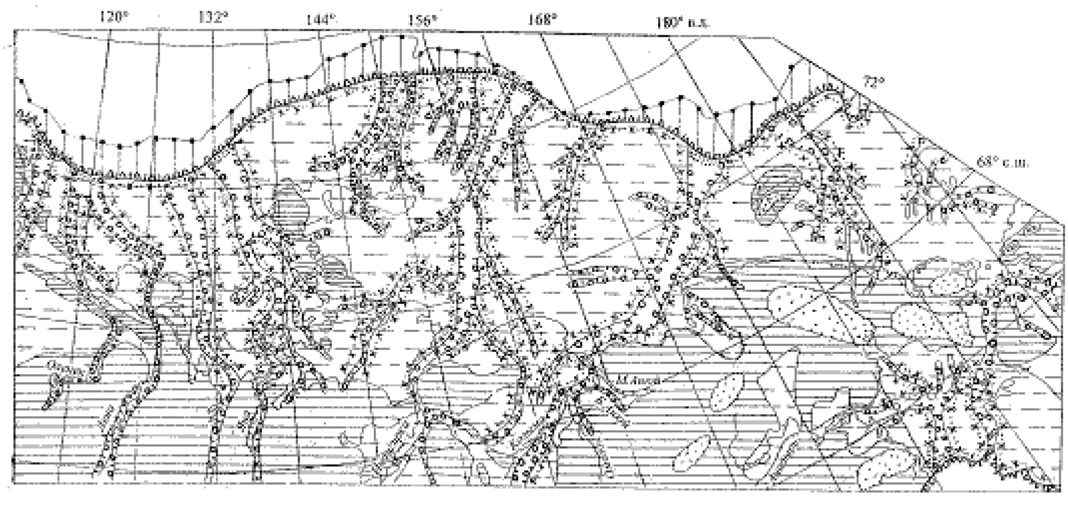

Figure 2. The East Arctic Ocean coastline position in the Late Pleistocene. Sartan epoch (III_4).

A change in natural conditions on the shelves of eastern Arctic seas at the boundary between the Sartan Glacial epoch and Holocene (IV) differed from a change that occurred at the same time on the shelves of the western Arctic seas. Marine transgression, rather than global climate warming, was the main active factor (Pavlidis et al., 1998).

The modern coastline formed at approximately 6 ka. Coastlines and topographic features, now clearly defined on the shelf, were formed in the course of this transgression when the transgression was repeatedly terminated. Ancient coasts at depths of up to 50-55 m are pronounced on the shelves of the Laptev and East Siberian seas, where the ancient deltas of the Lena, Yana, Indigirka, Kolyma, and other rivers are located. Ancient coastal complexes at depths of 40-45, 30-36, 21-25, 15-16, 8-12, and 4-5 are also clearly defined (Lozhkin, 2002). The flooding of the continent by seawater in the Holocene resulted in a rapid thawing of ice in the Pleistocene sediments and in a thermal abrasion of coasts composed of the ice complex. Abrasion and thermal abrasion processes predominated within ancient coastlines under conditions of marine transgression and gradual climate warming (Fig. 3). Coasts, with elevations of 5-6 m above sea level and composed of Holocene sediments, were sporadically situated, mostly at the heads of bays, and were represented by exposed zones, beach barriers, and adjacent terraces.

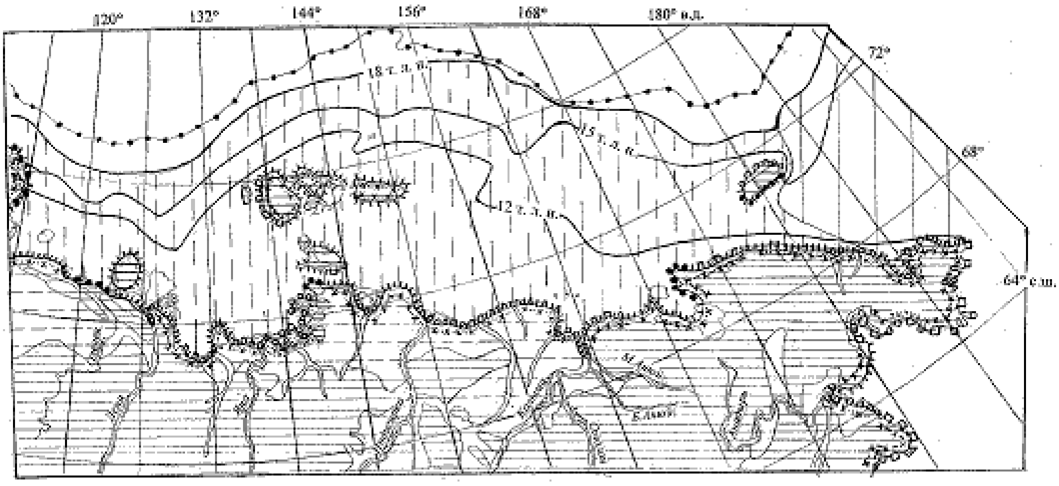

Figure 3. The East Arctic Ocean coastline position in the Holocene (IV). The warm interglacial period (6 ka ago).

Recent coastal processes in the eastern sector of the Russian Arctic region are very diverse. Such diversity is most typical of Chukotka. The coast is mainly represented by denudation formations of hard bedrock slightly changed by the action of the sea (Wrangel Island, coasts of the Chukchi and Bering seas). The ground of the ice complex contains thick, reformed ice wedges that are strongly affected by the processes of thermal abrasion and denudation. Wave-cut notches (with a depth of 5-10 m) are formed, and frozen sediment blocks are subsequently separated from the coast and are eroded. The coastal unevenness is insignificant.

In the eastern and southeastern Chukotka thermal abrasion mostly affects tabular ice in glacial-marine sediments. The process is episodic and catastrophic and is related to short-period climate fluctuations (Kotov and Tregubov, 2003). The abrasion of coasts composed of glacial sediments with low ice content (moraine) and without large inclusions of underground ice proceeds due to wave notching and subsequent collapse of the sediment block. Large accumulative formations occur on the Eastern Chukotka coast. These are numerous areas with wide beaches (where boulders, gravel, and pebble are accumulated), bars, and bay barriers. They are confined to the coastal areas subject to the direct action of waves.

This work was supported by INTAS (grant 01 - 2329), grant Science Schools – 2067.2003.5 and by the Russian Foundation for Basic Research (project no. 02-05-64263) and grant “Russian Universities”.

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FORMATION OF THERMODENUDATION RELIEF IN THE COASTAL ZONE IN CONNECTION WITH TECTONICS, YUGORSKY PENINSULA, KARA SEA

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The southwestern part of the Kara Sea and its coast is known for the wide distribution of tabular ground ice. The ice bodies, when thawing, determine the nature of coastal process activity via the formation of thermocirques. It is likely that relic thermocirques can be found on the sea floor where they were flooded by the most recent transgression. Both onshore and offshore thermocirques may have connections to the geological and tectonic structure of the area. To examine this, the geological map of the region (with thermocirques) of the Yugorsky Peninsula, Shpindler Urochishche (Fig.1), as well as the Tectonic Scheme applied to a State Geological Map of scale 1:1 000 000 (R-40-42), were analyzed (Fig.2).

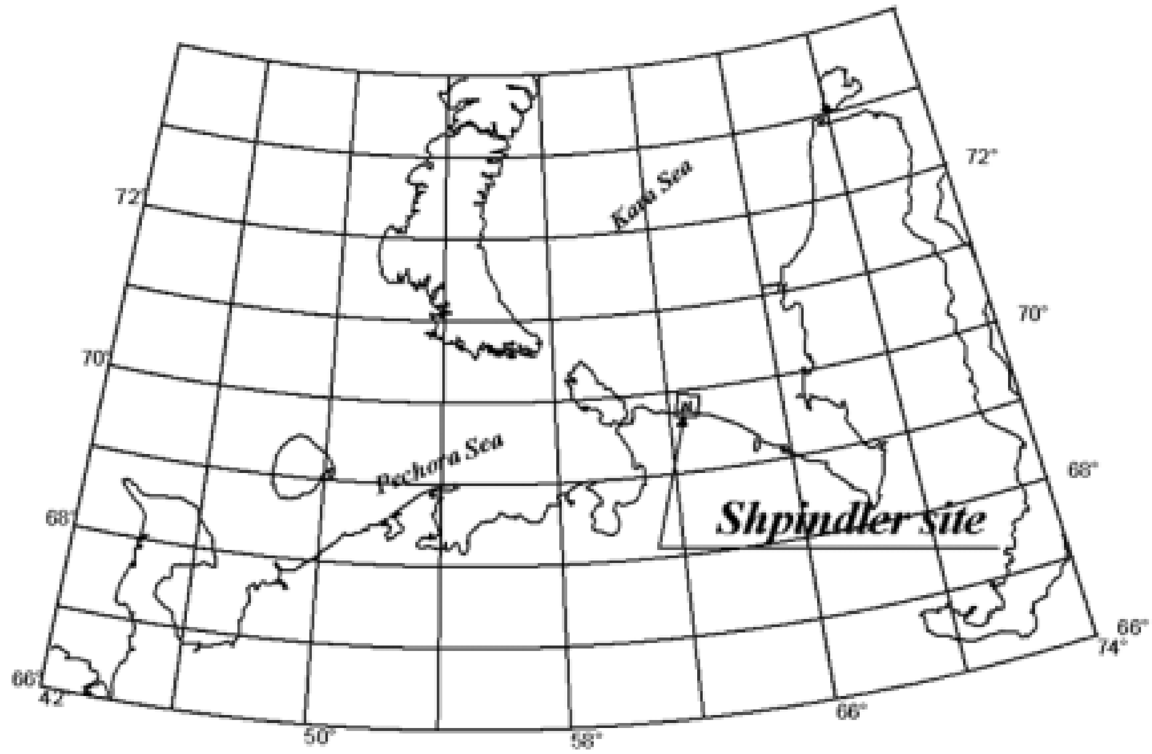

Fig.1. Location of Shpindler Urochishche.

Three thermocirques at the main observation site (Eastern, Central and Western) are located on a northwest extension of a tectonic fault. The main lineaments in patterns of thermocirque occurrence are inherited from the prevailing system of faults, which possess a directional maxima at 300-320^{o} (Fig. 3). Thus, it is possible to speak about tectonic controls of thermocirque formation in relation to the position of the retreating scarp. The concentration of linear elements with a strike 300-320^{o} 8-10 km westward of the main observation site is marked by a system of thermocirques with tabular ground ice exposures as well, which emphasizes the influence of tectonics in coastal dynamics.

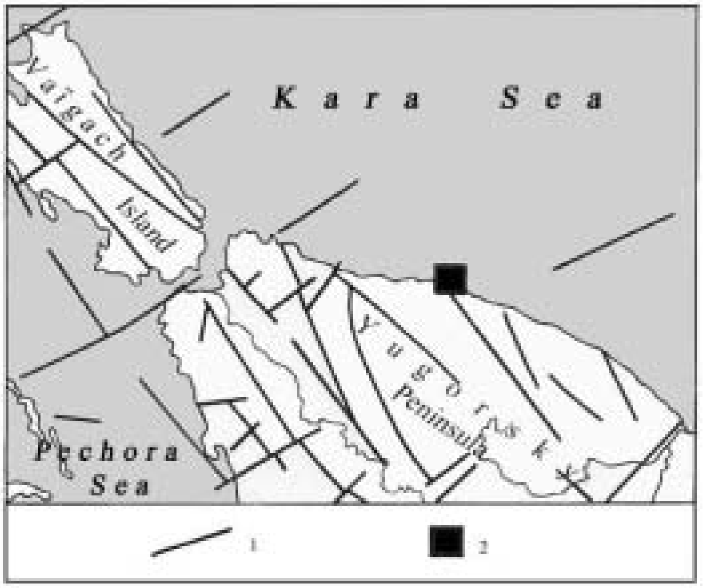

Fig. 2. Main faults in Yugorsky Peninsula and adjacent areas, based Tectonic Scheme: 1, faults; 2, main observation site

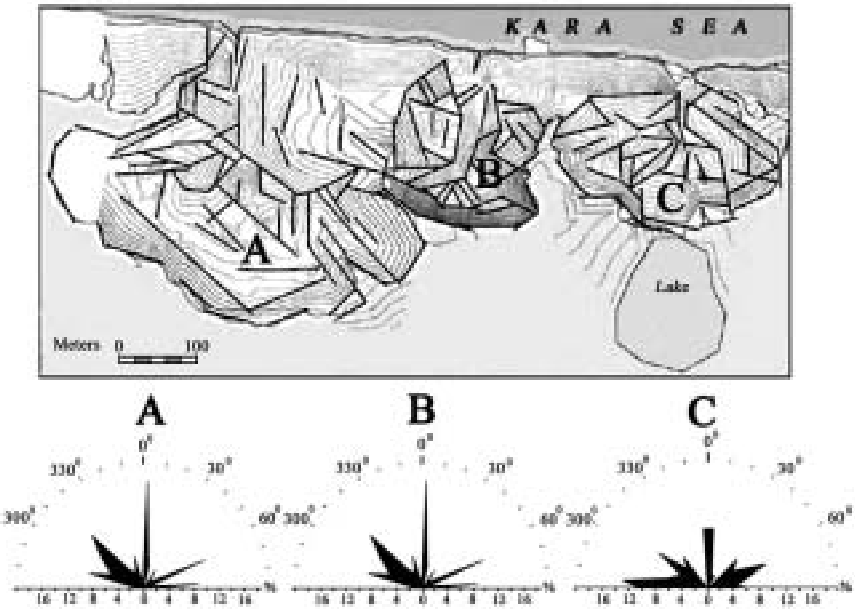

Fig. 3. Three thermocirques at the main observation site: morpholineaments and rose diagrams.

A subsea topographic survey conducted near the main observation site has shown that traces of thermocirques are found on the sea floor (Fig. 3,4). Possible «relict» thermocirques, in the form of elongated depressions at depths of 6,5-7,5 m, appears limited by a wall possessing a northwest strike (315-320^{o}) and shows a clear morphological similarity with the modern thermocirques on the western shore. Evidently the system of hills containing ice domes and dissected by thermocirques, which are currently observed onshore, had larger extent seaward (Fig. 3). It is possible, then, that the subsea depression is linked to one of the ice domes situated closer to the former shoreline. It cannot be ruled out, however, that a closed hollow in the central part of the subsea depression is a result of thermokarst of the submerged ice body.

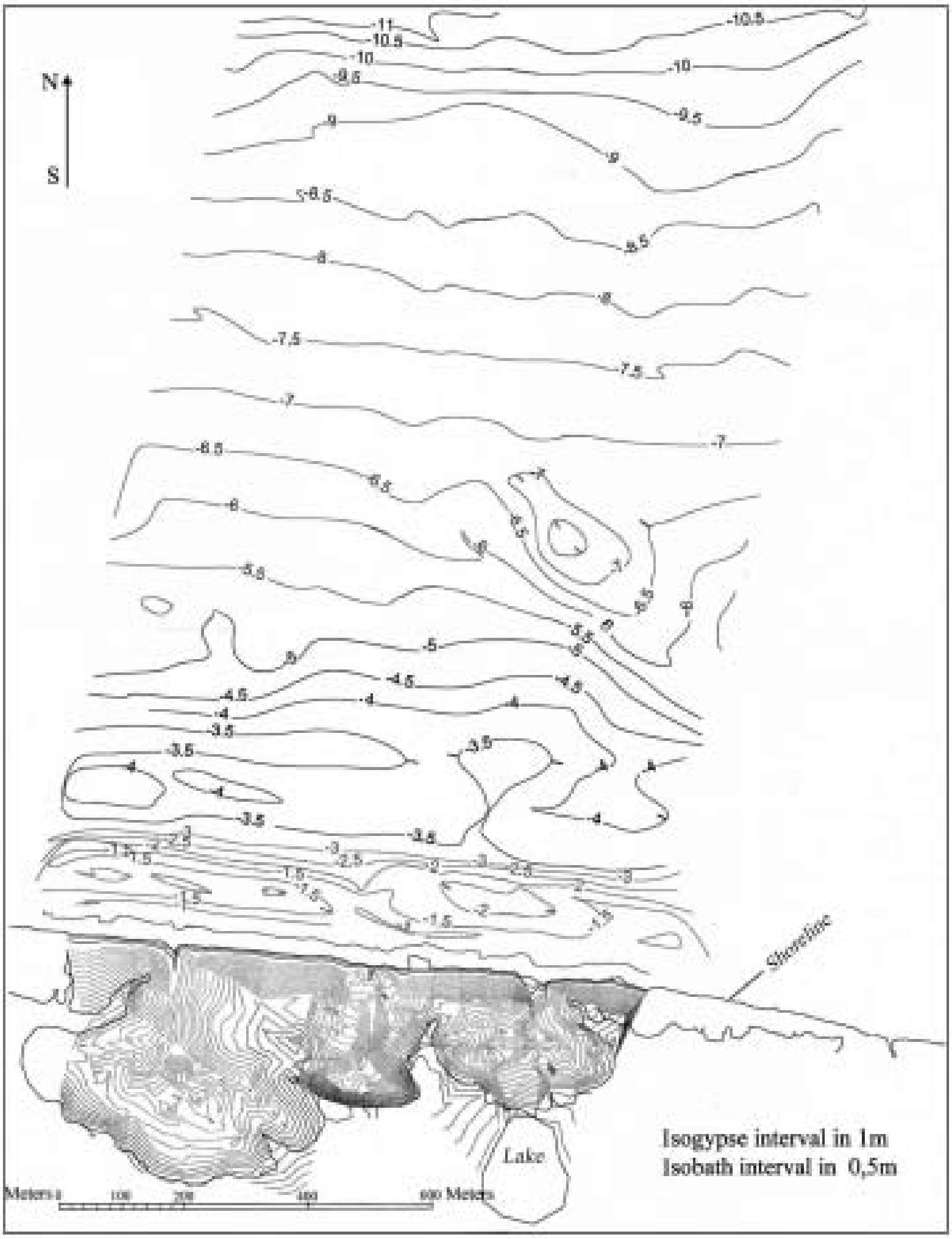

Fig. 4. Smooth sheet of geodetic and bathymetric measurement (Yu.G.Firsov, M.V.Ivanov, expedition 2001).

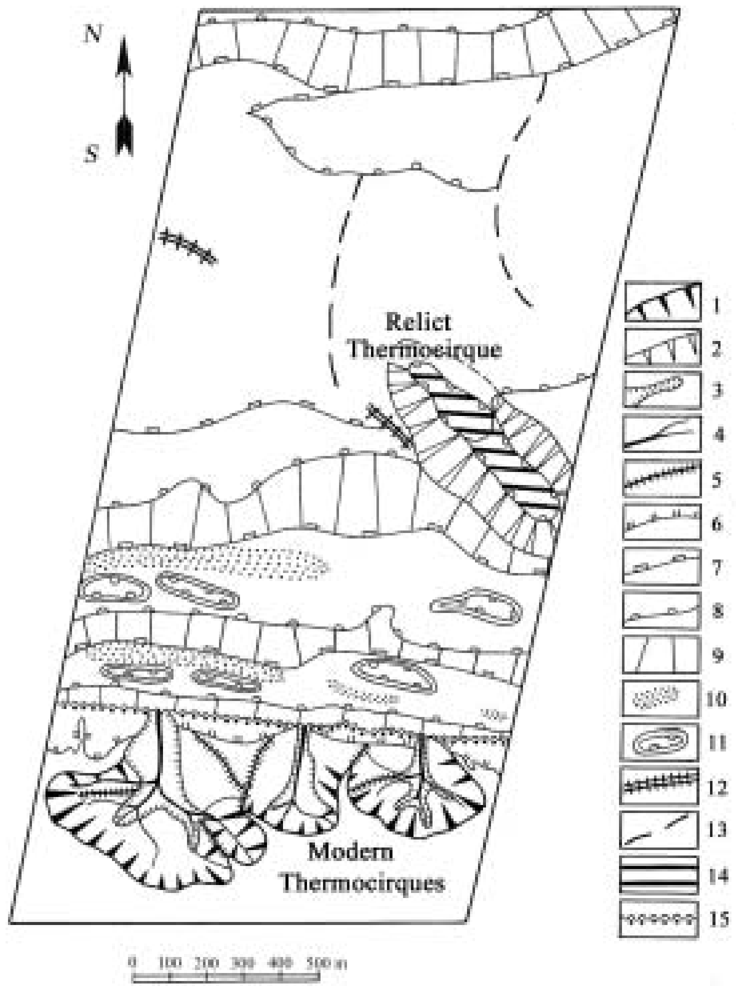

Fig. 5. Geomorphological scheme of the main observation site. Key: 1, scarps of thermocirques onshore; 2, scarps of probable thermocirque at the sea-floor. 3-6, *Relief onshore,* gullies: 3 – breaks, 4 – thalwegs, 5 – divides, 6 – breaks of the coastal slopes. 7-14, *Relief of the sea-floor:* 7, lines of the convex fracture; 8, lines of the concave fracture; 9, sloping surfaces; 10, breakpoint bars; 11, intrabar rills; 12, small ridges; 13, gentle relict drowned gullies; 14, floor of probable thermocirque; 15, shoreline.

If the sea level at a depth 6,5-7,5 m, as far as 650 m from a modern coast, was a shoreline 3-3,5 thousands of years ago, the average rate of coastal retreat for this period would equal roughly 20 cm per year if the contribution of thermocirque-induced scarp retreat were not accounted for. Given that the scarps are 300-500 m farther than the shoreline, the retreat rate must be adjusted upwards by more than 1,5 times, to 35 cm per year.

The activation of coastal retreat for the ice-rich and massive ice coasts possesses a cyclical character that is connected to climatic fluctuations. The modern retreat rate, measured at the active edges, equals 1 to 5 m per year. This means that thermocirque scarp retreat of 950-1100 m would be expected during a 200- to 1000-year period. Therefore, the period of active destruction for the last 3,5 thousand years covers approximately 6 to 30 % of the total time of thermodenudation coast development. In remaining time the coast, probably, was in a stage of preservation.

The work was done due to support of INTAS, grants 01-2211 and 01-2329.

Reference

State Geological Map of scale 1:1 000 000 (R-40-42). 2000. St-Petersburg. VSEGEI. 357p

3.3 Biogeochemistry Working Group

Working Group Chairs: **Sathy Naidu and Vladimir Ostroumov**

Participants

Georgy Cherkashov, Nicole Couture, Olga Gruzdeva, Birgit Heim, Anne Hickey, Nina Kasyankova, Alexander Kholodov, Elena Miroluhova, Sathy Naidu, Vladimir Nikulin, Vladimir Ostroumov, Vera I. Petrova, Boris Vanshtein

3.3.1 Biogeochemistry - Working Group Summary

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Issues of Relevance to ACD

The initial discussions focused on identifying the biogeochemical issues that would be of high priority to the Arctic Coastal Dynamics (ACD) program.. Two major issues emerged for further deliberations. One relating to the "Mass Balance of Particulate Organic Carbon, POC (sources, fluxes, accumulation, export, and post-depositional fate of POC) in the circum-arctic". The Group felt that this issue will have bearing in the understanding of some wider biogeochemical problems relating to the Arctic margin and basin (e.g. source of the high ΣCO2 associated with the Arctic Basin halocline, and the fate of the CO2 subsequent to global warming). The second issue identified pertained to the "Concentrations, partitioning and geochemical cycles of metals in sediment, water, ice and biota", with relevance to collecting baselines for contaminant monitoring.

Current Status of Database

The Group felt that there is a wide published database available on the concentrations of POC/POM and their sources (based on δ13C, δ15N, and selected biomarkers) for the major estuaries and margin of the Laptev-East Siberian-Chukchi-North Bering-Beaufort Sea region (Stein and Macdonald, 2003 and references therein). It was also recognized that mass balance estimates of POC were also available on a site-specific basis for the shallow margin areas of the Barents, Kara, Laptev, East Siberain, Chukchi and Beaufort Sea Stein and Macdonald, 2003). The Group, however, was not aware of the extent of the above database available for the Nordic and adjacent margins.

The Group also recognized that extensive published data exist on several heavy metals in sediments of the major estuaries and shelves of the circum-arctic (Naidu et al., 1997; AMAP, 2002 and references therein).

Recommendations

1. Make available all published and unpublished data on the ACD format and into the PANGEA website. This information will be important for model development.
2. Refine the calculation of the mass balances on organic carbon for the circum-arctic coastal region, particularly taking into account the relative importance of the epontic (sea ice held) algal production on the overall Arctic carbon budget.
3. Assess the lability of the terrigenous organic carbon/matter to get an insight into the remineralization rate of this component and extent of its contribution to the total pool of CO_2 in the arctic, with reference to the Arctic Basin halocline ΣCO_2.
4. Determine the composition, concentrations and distribution of biomarkers in circum-arctic coastal sediments, and distribution of DIC/DOC in waters.
5. Establish protocols for monitoring heavy metals and organic contaminants (including gross sediments versus mud fraction, phases, partitioning patterns, bioavailability) in waters, ice, and sediments and its interstitial fluids. Modify, if necessary, the protocols established by the USEPA and AMAP to suit the arctic environmental conditions.
6. All laboratories involved in the ACD programme should be encouraged to participate in the round robin interlaboratory calibration exercises such as the one conducted by

the National Research Council of Canada (NRCC), for maintaining QA/QC, and comparing regional data base on heavy metals.

7. The Group recognized and recommends the development of the scope and use of remotely-sensed techniques (satellite imaginary) for mapping, for example, the distribution of sediment plumes, POC, sea ice and water masses, in the coastal and shallow marine regions of the arctic.

3.3.2 Biogeochemistry – Extended Abstracts

ENVIRONMENTAL PROBLEMS OF THE EUROASIATIC ARCTIC COASTAL ZONES AND MANAGEMENT STRATEGY FOR SUSTAINABLE DEVELOPMENT

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A range of natural and anthropogenic impact factors influence the stability of the coastal zone. In turn, the coastal zone state directly affects marine biota biodiversity and functioning.

The branch of oceanography that studies abiotic components of a salt water ecosystem (lithosphere, hydrosphere and marine atmosphere), as well as its transformation induced by natural and anthropogenic factors and their influence on biota and human beings, is an integral part of geoecology.

Analysis of biocenosis structure and its functioning in natural and human-modified conditions is important for more thorough understanding of abiotic impact on the biotic situation.

Hence, several tasks of the Euroasiatic Arctic coastal zones study follow from this concept of geoecology.

1. Estimating the correlation of natural and anthropogenic factors with Euroasiatic Arctic coastal zone dynamics.

2. Analysis of physical impact on the coastal zone that result from human economic activities in the 21st century.

3. Analysis of water chemical pollution of the Euroasiatic Arctic coastal zones.

4. Analysis of transboundary transfer of pollutants in the Euroasiatic Arctic seas and in the contiguous oceans (the Atlantic and the Pacific oceans).

5. Studying the influence of physical and chemical dynamics on the coastal zone, focusing on biota and on human health.

6. Elaboration of coastal zone stability criteria and management strategies for sustainable development.

The global ecological crisis is being manifested in the Euroasiatic Arctic seas.

The impact of human economic activity on the Arctic coastal zone has reached such a level that it makes sense to discuss the beginnings of a radical change in the structural and functional organization of the biosphere and to consider its transition to a new state – the noosphere. Now is the time to study the correlation between natural and anthropogenic factors and the changes going on in the coastal zone. The natural component is predominant, however anthropogenic components may be dominant at local scales. The largest deposits of oil, gas and solid minerals are concentrated in the Arctic coastal zones. The construction of seaports, defense complexes and petrochemical infrastructure is expanding in connection with the development of the North Sea route. Together with natural processes, these anthropogenic factors have a cumulative negative influence on the coastal zone state. The problem of deriving the specific influence of the anthropogenic component and its vector is an important and difficult task.

There can be distinguished two types of coastal zone impact: physical and chemical. The physical impact is more or less understood, but the chemical impact needs work on trends and a delineation of scale. Coastal water purity has not been taken into consideration until recently in the analysis of the coastal zone dynamics, yet this characteristic, in our opinion, is part of the "coastal zone stability" concept.

What pollutants can be found in the Euroasiatic Arctic seas coastal zones?

1. Hydrocarbons;

2. Pesticides;

3. Heavy metals;

4. Technogenous radionuclides;

5. Poison-bearing chemicals and ammunition.

The task of our research includes the analysis of the current state of physical and chemical pollution in the specified region, the classification of a coastal zone in accordance with these attributes, and the forecast of its development on the basis of GIS-technologies for the 21st century.

One of the most important problems of geoecological research in the Euroasiatic Arctic coastal zones is the extent of interstate pollution and the sheer size of the potential accumulation area for pollutants. The agents of the interstate pollution in the Arctic seas are runoff from rivers and streams, as well as ice, the atmosphere, biota and human beings. A main purpose of the research includes the analysis of the mechanisms and directions of pollutant transfer as one of the sediment components. The applied task of the research consists of arriving at an estimate of the chemical pollution of the coastal zone, and includes answering the question about whether the frontier countries affect the environment of the neighboring states via pollution of the marine environment. If they do, then the question arises as to how to minimize this impact. The "precautionary principle" is fixed basically in Principle 15 of the Declaration at Rio, 1992, as follows: "In case of a serious or irreparable damage or danger the lack of full scientific information should not serve as a reason for a delay of efficient measures on prevention of natural environment destruction". Reduction of these shortcomings is also one of the purposes of the geoecological research.

The working hypotheses and premises in conducting the geoecological research are the following:

- In view of the fact that the Euroasiatic Arctic seas are polluted, and interstate pollution as such exists, pollution of the sovereign states' coastal zone is possible. The expansion of civil and defense activity of the Arctic states in the seas at the beginning of the 21st century will lead to an increase of pollution levels and of ecological risk for the seas of the frontier states.
- In connection with the expected warming of the Arctic an activation of ice drift, with entrained pollutants, is supposed.
- The horizontal circulation of waters of the Arctic seas of Eurasia encourages transboundary transfer of pollutants in the seas of the frontier countries as well as into the waters of the Atlantic and Pacific oceans.

Determination of the present geoecological state of the Euroasiatic Arctic coastal zone and forecast of its evolution allow an estimate to be made of the influence of physical and chemical pollution on biota and human health, to classify the coastal zones of Eurasia, and to develop stability criteria and management strategies for sustained development.

Finally, in Russian scientific literature the term "coastal zone" means a zone: a coast, including the upper part of a shelf where waves impact on a bottom, is understood by this. We interpret a coastal zone as a shelf, a coast and a part of the land where Holocene sea deposits are distributed. In our opinion, the authors of the project need to agree upon definitions and terminology for delimitation of an object of study.

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ARCTIC SHOREFACE PROFILES

F. Are

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Shoreface profile investigations are not included in the ACD Science and Implementation Plan in an explicit form, however, these investigations are important for understanding coastal dynamics.

The shoreface is the underwater slope of the coastal zone. The essential component of coastal erosion may be considered to be just the erosion of the shoreface. The destruction of the sub-aerial part of the coastal zone is only a consequence of shoreface erosion. Without shoreface erosion the coast is stable.

A considerable part of the total sediment and organic carbon amount supplied by coastal erosion to the sea is eroded from the shoreface. Along the low coasts, it is the major part.

The coastal contribution to the marine sediment balance depends on the kind of change the shoreface profile undergoes during erosion. The shoreface, retreating equally with the shoreline and preserving its shape during retreat (Fig. 1,A), supplies twice as much sediment to the sea as does the shoreface preserving only its outer boundary during retreat (Fig. 1,B).

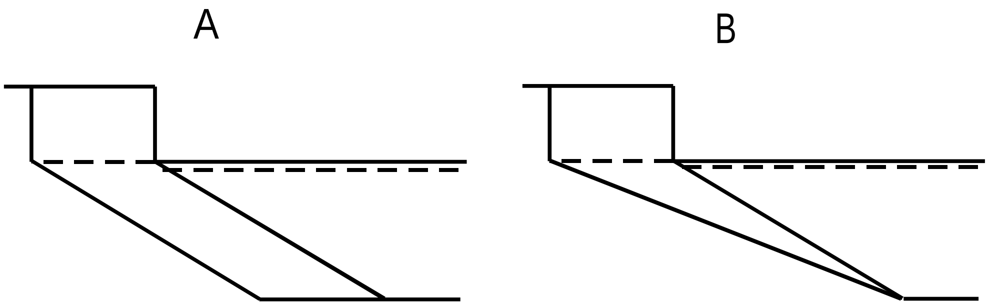

Figure 1. Two kinds of the shoreface retreat.

The notion of shoreface profile equilibrium is widely used in predictive models of coastal change. The mathematical description of the shoreface profile shape is directly used in some models.

The sandy shoreface profile shape in the mid- and low latitudes is well studied, however almost nothing was known about Arctic shorefaces until recent times. Two main features may cause considerable distinctions between shoreface shape in the Arctic and outside of the Arctic. (1) The Arctic shoreface is exposed to a strong impact of sea-ice, and (2) the sediments of Arctic coastal lowlands are characterized by a high silt content, which usually equals 60-80 % by volume, ranging up to 90 % in places.

Investigations directed at understanding Arctic shoreface morphology were started in 1999 under the auspices of the Russian-German project “Laptev Sea system”. The project goal was to study the shape of the shoreface profile in the Arctic and compare it with the shape observed outside the Arctic. The field studies included bathymetry measurements and bottom sediment sampling. During 4 field seasons 35 profiles were measured in the Laptev Sea.

In addition, other researchers contributed data from other regions. Steve Solomon provided over 20 measured profiles from the Canadian Beaufort Sea, Erk Reimnitz added several profiles from Alaskan Beaufort Sea. Bathymetry charts of Chukchi, Beaufort, Laptev and Kara Seas were also used to obtain shoreface profiles. In all, about 70 profiles were available from sites around the Arctic basin.

The shoreface profile shape is usually described by a power function as suggested by Bruun (1954)

$$h = -A \cdot x^{m}, \quad (1)$$

where ***h*** is water depth, ***x*** is offshore distance from the shoreline , ***A*** is a sediment scale parameter, which depends on sediment grain size, and ***m*** is a profile shape factor, reflecting the wave energy dissipation on the shoreface.

According to Bodge (1992), the following exponential function gives better fits

$$h = -B(1 - e^{-kx}), \quad (2)$$

In equation (2) ***B*** is an asymptotic depth at a great offshore distance, and ***k*** is a decay constant, related to the sediment grain size.

These two functions were used to describe the shape of the Arctic shoreface profiles using "Tablecurve 3.0" software. The values of ***A*** and ***m*** for different sections of the coasts are presented in Table 1 for comparison with the same parameters for coasts in the mid- and low latitudes. The ***m*** values in Table 2 do not show any striking difference between Arctic and non-Arctic shoreface profiles. This may indicate that the hydrodynamic forcing in the Arctic and in the mid- and low latitudes result in similar shoreface shape, and that the impact of sea-ice does not influence it. Generally, results of this study do not show any evident impact of cryogenic factors on the shape of the shoreface profile in the Arctic.

Table 1

Coastal section	Number of profiles	***A***			***m***		
		Min.	Average	Max.	Min.	Average	Max.
Laptev Sea, all	19	0.002	0.264	1.383	0.268	0.563	0.890
Laptev Sea, ice complex coasts	9	0.002	0.124	0.661	0.337	0.656	0.890
Laptev Sea, sand coasts	9	0.054	0.273	0.772	0.341	0.510	0.659
Chukchi Sea	11	0.031	0.274	0.708	0.340	0.514	0.772
Beaufort Sea, Alaska	17	0.007	0.325	0.781	0.219	0.504	0.847
Beaufort Sea, Canada	25	0.017	0.377	0.881	0.255	0.432	1.002
Arctic Seas, all	72	0.002		1.383	0.219	0.51	0.890
U.S Atlantic and Gulf coasts after Dean (1977)	504	0.0025	-	6.31	0.1	0.67	1.4
Bass Strait, Australia after Wright et al. (1982)						0.4	
Inman et al. (1993)						0.4	
Caribbean beaches after Boon & Green (1988)						0.5	

A big divergence between maximum ***A*** values in the Arctic and outside of the Arctic most likely reflects the difference in sediment composition.

Our data do not support the statement by Bodge that the exponential function fits shoreface profiles better than the Bruun power function. Coefficients of determination, presented in Table 2, show that the power function describes Arctic shoreface profiles in general as well as profiles in particular seas a little better.

Table 2

Location	R^2	
	$h = -A \cdot x^m$	$h = -B(1 - e^{-kx})$
All profiles	0.95706	0.93204
Laptev Sea	0.96780	0.96387
Canada Beaufort Sea	0.92857	0.88583
Alaska Beaufort Sea	0.96613	0.95120
Chukchi Sea	0.98309	0.97588

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LAND-SHELF INTERACTIONS: AN UPDATE ON SCIENCE PLANNING FOR U.S. PROGRAM ON ARCTIC NEAR-SHORE AND COASTAL ZONE RESEARCH

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The Land-Shelf Interactions (LSI) science plan was developed with broad research community involvement over a three-year period with the goal of formally identifying critical research topics in Arctic coastal regions (both nearshore and onshore) that need to be addressed in order to predict and respond to environmental change that is, or will be, significantly impacting human and biological communities. This science planning effort, sponsored by the U.S. National Science Foundation's Arctic System Science Program, has been largely completed, following a series of open workshops, on-line forums, comments on draft iterations of the science plan, and a collective editorial process that generated a "virtual" science plan that is available at http://arctic.bio.utk.edu/RAISE/index.html

Among the key research topics that have been identified as needing emphasis include such unresolved issues as the impacts of dynamic changes on Arctic coasts, including erosion, and the intermediate and ultimate fates of biogeochemical constituents provided to the coastal zone by rivers and as a result of shoreline retreat. The human dimensions of environmental change have also been recognized as having importance, including changes in subsistence gathering activities that are likely with changes in climate, sea ice regimes, and biological communities.

Within the context of Arctic Coastal Dynamics and its internationally coordinated research efforts, the LSI initiative will also strive to incorporate international information sharing and coordination. LSI is an outgrowth of the Russian-American Initiative for Land-Shelf Environments (RAISE) research framework, which is the only binational science program jointly supported by both the U.S. National Science Foundation (NSF) and the Russian Foundation for Basic Research. Information about the potential

research topics that could be supported through LSI and linked to internationally coordinated efforts have also been shared with research programs such as Land-Ocean Interactions in the Russian Arctic (LOIRA), as well as international coordinating groups such as the International Arctic Science Committee (IASC) through its International Science Initiative in the Russian Arctic (ISIRA) and the International Geosphere-Biosphere Programme (IGBP) through its Land-Ocean Interactions in the Coastal Zone (LOICZ) program.

Following presentations at science advisory committees for NSF in October 2002, and March 2003, the LSI science priorities are being formally considered as components of a new science announcement of opportunity that is expected to be recommended to the Office of Polar Programs at NSF by the Arctic System Science Committee, which functions in an advisory role to NSF.

SEDIMENT GRAIN SIZE DISTRIBUTION ALONG THE EROSIONAL SHOREFACE PROFILE OF THE LAPTEV SEA COASTS

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Field investigations of sediment grain size distribution along erosional shoreface profiles were carried out during 1999-2002 at several key sections of the Laptev Sea coast to understand sediment dynamics in the coastal zone of the Arctic erosional shores. Bottom sediments for sedimentological analyses were sampled along 22 shoreface profiles of coasts composed of ice complex (7), ice complex lying on bedrock at about the sea level (5), sand (7), and bedrock (3) at every meter of water depth. A light grab sampler was used to obtain between 2 and 18 samples from every shoreface profile. Samples of beach material also were taken on some profiles. Altogether l51 samples were analyzed using a laser-granulometry device and results are presented in tables which contain volumetric percentages of sediments by size fraction as well as various grain size statistical moments, including average, median, mode, skewness, and kurtosis.

A generalized dependence of sediment grain size on water depth for the four types of coasts under consideration is presented in Fig. 1. The diagrams in Fig. 1 show weak dependence of the coasts containing ice complexes; the relationship is characterized by a low coefficient of determination. The dependence relationship is stronger for shorefaces composed of sandy coasts, and stronger still for coasts containing ice complexes lying on bedrock as well as for rocky coasts. The coefficient of determination values increase in the same sequence up to 0,97.

The ice complex sediments consist mainly of silt (40-90%), but sand generally prevails on the shoreface of coasts containing ice complexes. For example, on Shirokostan Peninsula, Cape Terpyay-Tumsa, and Cape Mamontov Klyk, sand content ranges between 70 and 90 % down to 10-m depth.

The sediments on the sandy coast shorefaces contain over 90% sand down to the 5-6 m depth. Farther down slope a more or less regular decrease in sand content occurs until 40-50% is observed.

The shoreface sediments of the coasts containing ice complexes lying on bedrock contain mainly 80-90% sand down to 10-m water depth. The decrease of sand content with the depth is very slow.

The sediments on the rocky coast shoreface are absent in places but generally also consist mainly of sand and silt. Pebbles were observed in some samples.

The clay content in bottom sediments of all types of coast is low and usually does not exceed 5-6%.

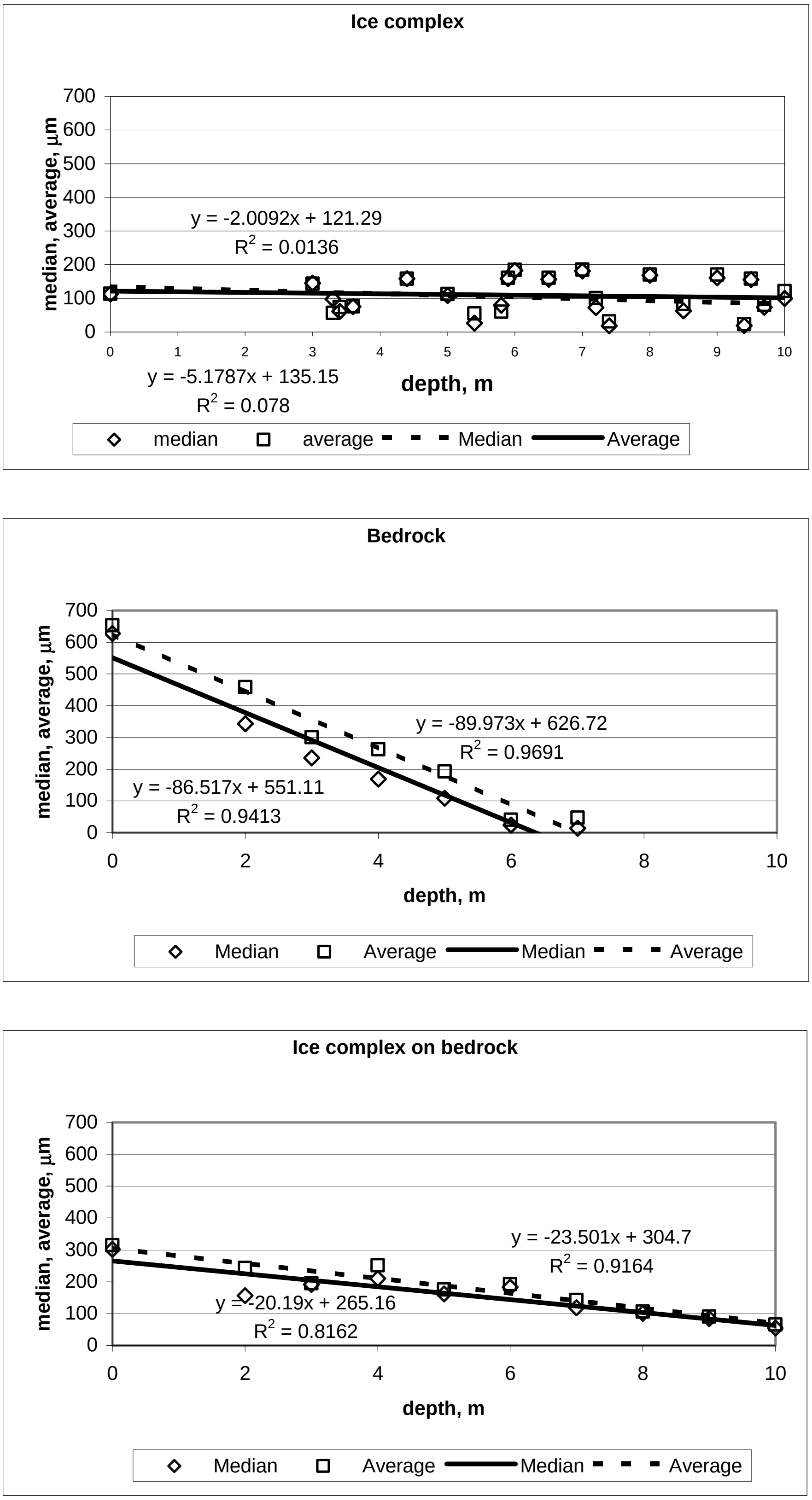

Fig. 1. Dependence of the sediment grain size on water depth.

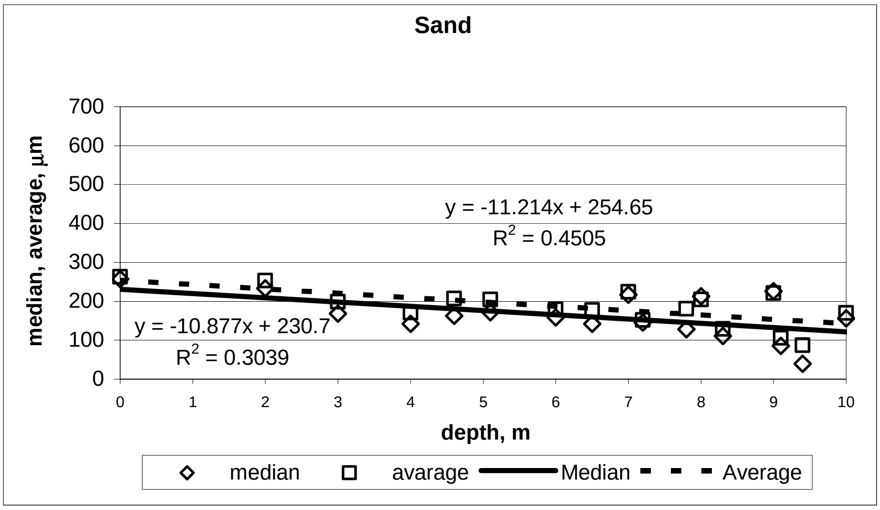

Fig. 1. continued.

ANALYSIS OF ORGANIC MATTER INPUT ALONG THE SIBERIAN COAST USING OCEAN COLOUR DATA

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Abstract

Fluvial and coastal delivery of terrestrial organic matter into the marine environment represents the largest land-to-ocean carbon flux, and constitutes an important component of the global carbon cycle. Organic-matter input is expected to greatly increase along the Siberian coast due to enhanced coastal erosion and the thawing of permafrost resulting from global warming. This increased supply of organic matter will severely affect biogeochemical carbon cycling and ecosystems on Arctic shelves. The objective of the proposed study, referring to the work and results of the Arctic Coastal Dynamics (ACD) Project (Rachold et al., 2003), is to monitor and further clarify the spatial and seasonal patterns of organic matter input by rivers and coastal erosion along the Siberian coast using Ocean Colour data.

Introduction

Remote-sensing studies of the arctic coast have long been undertaken with airborne and spaceborne photography and multispectral scanner data. The multispectral sensors, such as the Multispectral Scanner (MSS), the Thematic Mapper (TM) and the Enhanced Thematic Mapper (ETM+), provide information at high spatial resolutions that is used to monitor sedimentary transport and coastal sedimentary features.

Radiometric and spectral interpretation of airborne hyperspectral and spaceborne Ocean Colour (OC) sensors also provide the basis for qualitative and quantitative studies of water constituents. OC data are derived from medium-resolution (1 km^2) satellite missions with a high spectral and radiometric resolution in the visible wavelength range. The first OC Sensor, the Coastal Zone Scanner (CZCS), was launched in 1987 by NASA and successfully provided long-term data of the marine biosphere. More recently, several high-performance OC satellites, such as SeaWiFS (NASA), two MODIS instruments (NASA), and MERIS (ESA), monitor the globe with a high-temporal resolution (repeat cycle 1–3 days). In the future, the POLDER (CNES) and OSMI (KAI) satellite instruments will provide further OC data.

The atmospheric correction of OC data has been identified since the beginning as the most important and complex of the tasks associated with OC imagery recovery and interpretation. Normally, in case of water-body targets, 95% to 99% of the radiometric signal that is scanned by the satellite sensor originates solely from the atmospheric contribution. The study of OC data is still a broad field of research, and OC investigations have been predominantly undertaken in marine pelagic waters. Recently, optical measurement and OC data processing methods have been developed for coastal waters (e.g. Ruddick et al., 2000). As an example, the coastal waters of the Baltic Sea are of an organic-rich water type, and have been investigated by Schwarz et al. (2003), and Schwarz (2004), as a test site to develop OC-algorithms for Dissolved Organic Carbon (DOC) quantification. The first OC studies on arctic coastal to pelagic waters have recently been undertaken by Pozdnyakov et al. (2003), with a remote-sensing SeaWiFS study of the White Sea.

Bio-optical modeling in coastal arctic waters

The combined processes of absorption and scattering by the group of major optically visible water constituents (H_2O, phytoplankton, coloured dissolved and particulate organic matter and suspended matter) determine the underwater light field. The water-exit signal is an expression of the type and concentration of the respective water constituents.

Suspended matter (SPM) and DOC algorithms are complex and must be adapted to local conditions. Within the DOC pool, humic, fulvic and hydrophilic acids are representative of the main part of the coloured agents. Still, the bio-optical properties of dissolved and particulate organic matter in the natural aquatic environment are not well understood, and the term ‘yellow substance’ or coloured dissolved organic matter (cDOM) is applied to a variable mixture of different groups of absorbing and fluorescing water constituents.

The protein-pigment complex of the main photosynthetic pigment of phytoplankton, chlorophyll-a, is generally estimated from optical satellite data by its absorption maximum in the blue wavelength region at around 440nm. The best known and globally used chlorophyll algorithm, the OC4 (O'Reilly et al., 1998), is established by linear regression analyses of the relationship between the logarithm of chlorophyll concentration (sea-truth data) and the logarithm of the ratio of two bands in the blue-green spectral range. This OC4 switching-band ratio achieves in good conditions an accuracy of ±35% (O'Reilly et al., 2000). Good conditions are clear pelagic waters, so called 'case 1 waters', where the phytoplankton is the main optical component, and other water constituents, such as detritus and organic matter, are low in concentration and directly correlated with the chlorophyll concentration.

Recent OC investigations (e.g. Koponen et al. 2001, Heim et al. 2003) focused on more optically complex waters, referred as ‘case 2 waters’, in which the optically important water constituents may not be correlated, such as in coastal waters and inland water bodies. There are several limitations on the validity of chlorophyll algorithms if used for the coastal arctic water type. Coastal arctic waters are definitely non-case 1 waters, and their optical properties vary in the offshore direction to the pelagic waters.

The quality of chlorophyll algorithms (which have been developed predominantly for application in lower latitudes) will be lower in higher latitudes due to the presence of more accessory pigments (carotinoids, biliproteins) of phytoplankton. As a result, the specific absorption coefficient of phytoplankton at higher latitudes is three to four times less than that of phytoplankton adapted to higher irradiation levels/lower latitudes (Mitchell et al., 1988). Therefore, the OC4 algorithm is reported to underestimate the chlorophyll concentrations at lower irradiation levels/higher latitudes.

On the other hand, in the case of organic-rich fluvial and coastal terrigenous input, the absorption in the blue to green spectral wavelength range is caused by organic matter and by phytoplankton. Because the standard OC-algorithms do not have the capability to distinguish between cDOM and phytoplankton absorption, they overestimate considerably chlorophyll concentrations in these coastal waters.

Conclusion and outlook

The strong inverse dependence of the water-exit signal on the inherent optical properties of the specific water body provides the physical basis for all OC algorithms. Therefore, the optical properties of coastal arctic waters can be assessed through building up an in-situ data set of the specific water constituents and their spectral properties. Qualification and quantification (semi- and/or absolute quantification) of the optically visible water constituents will be possible and will enable the different types of coastal arctic waters to be identified (Fig.1).

The challenge is (i) to provide and extract the correct bio-optical parameters for the Siberian coastal environment from a ground truth data set, which has yet to be built up, and (ii) to adapt the marine OC standard processing methods and algorithms to a mixed marine/continental atmosphere and to a high-latitude water body dominated by terrestrial input. Additionally, this coastal arctic study will be an excellent opportunity to further investigate the bio-optical problem of organic matter compounds. OC satellite remote sensing monitoring will therefore become an appropriate tool for observing the fate and transport of organic matter in the arctic coastal waters.

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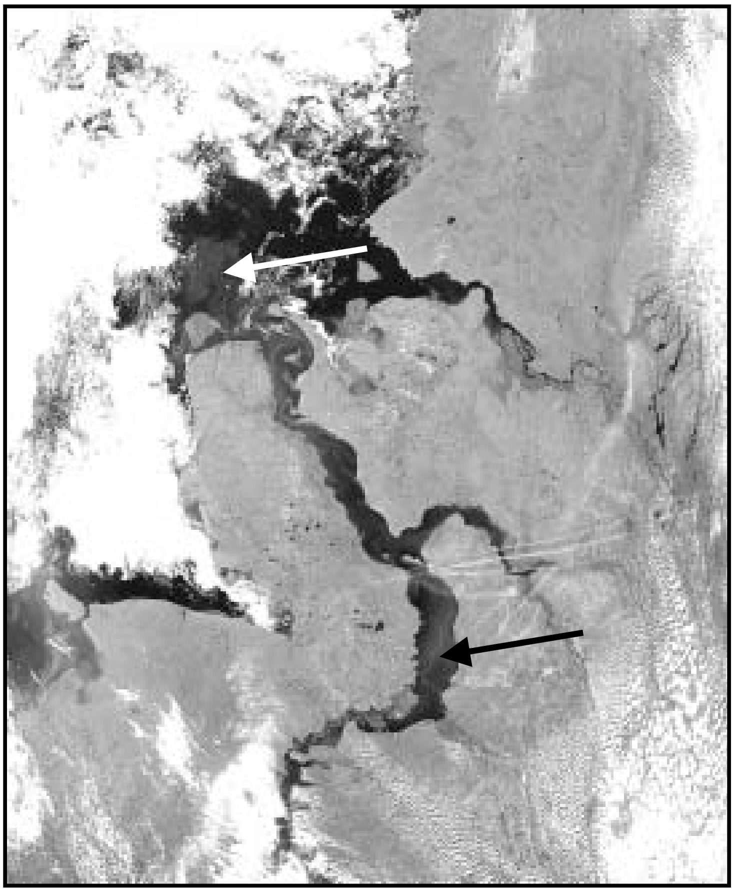

Fig.1. SeaWiFS quasi-true colour RGB 642; image date 08-07-1999 (NASA); Obskaya Gulf in the Tyumen region of Arctic Russia. Features to note are the organic-rich surface waters of the river Ob (black arrow) and the phytoplankton-rich shelf waters (white arrow).

EVALUATING NEAR-SHORE PROCESSES USING LANDSAT SATELLITE DATA: A CASE STUDY IN THE BARROW, ALASKA REGION

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The Arctic near-shore system may be particularly susceptible to environmental changes brought about by warming temperatures and land use change because it is an area where oceanic, atmospheric, and terrestrial processes converge. Therefore, alterations in any one of these processes are likely to have an effect on the near-shore. For example, changes in atmospheric circulation may increase the frequency and intensity of storms, causing greater coastal erosion. Additionally, anthropogenic activities such as industrialization and summer overland vehicle use may increase sediment, nutrient and dissolved organic matter fluxes to the near-shore zone from rivers. It is therefore important to establish near-shore baseline conditions, identify potentially vulnerable areas, and evaluate pathways for change. Remotely sensed data offers an ideal way to address this problem because it provides a synoptic view of remote Arctic areas. Theoretically, water temperature, suspended materials and optically active components (OAC's), such as chromophoric dissolved organic material (CDOM) and phytoplankton, can be analyzed with visible and infrared satellite data.

This study is an initial effort to evaluate the feasibility of using remotely-sensed data to analyze near-shore waters on the Alaskan North Slope and to identify the processes that have a significant influence on near-shore areas in the Barrow, Alaska region (Figure 1) so that the near-shore impacts of environmental change can be evaluated and predicted. The analysis was accomplished by evaluating near-shore patterns of water temperature, suspended materials, and OAC's from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data acquired on August 5, 1985 and July 20, 2002, respectively. ENVI was used for data preprocessing and the analysis. Both data files were calibrated to produce reflectance values with the standard ENVI Landsat calibration tool. Dark object subtraction using minimum band values was then applied to both data sets to correct for atmospheric effects.

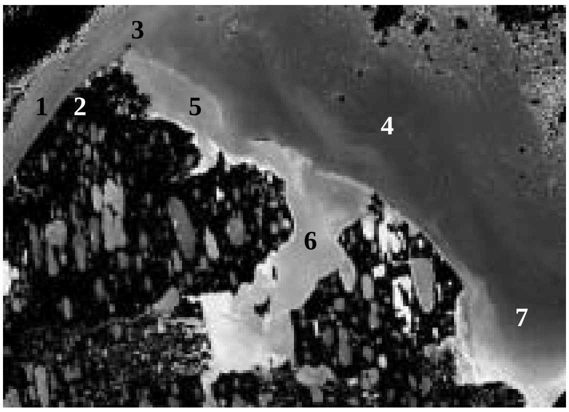

Fig. 1: Map of the Study Area

1= Chukchi Sea

2= Barrow, AK

3= Point Barrow

4= Beaufort Sea

5= Elson Lagoon

6= Admirality Bay/Dease Inlet

7= Smith Bay

Suspended sediment can be derived from coastal erosion, delivered to the near-shore by rivers, or re-suspended by wind. Differentiating between which of these processes controls suspended sediment in an area can assist in identifying areas that may be affected by different types of environmental change. Suspended sediment patterns were identified using near-infrared data (Band 4) and the extent that surface runoff in rivers influences near-shore waters was evaluated using thermal data (Band 6). The sources of suspended materials (i.e. erosion, riverine, resuspension) were inferred based on a comparison of the near-infrared and thermal data with wind data, coastal erosion studies, and flow patterns. Patterns of the thermal data illustrated that near-shore temperatures similar to the inland lakes occurred only in the immediate vicinity of river outflow, indicating a limited influence from surface runoff during the time periods evaluated. However, warmer lagoon waters were transported further offshore in currents from Smith Bay and through deeper areas between the barrier islands in Elson Lagoon.

Suspended sediment pattern differences between the 1985 and 2002 images (Figures 2a and 2b) are likely attributable to stronger winds re-suspending sediment before and during the time of acquisition in 1985. In both images suspended sediment is concentrated along the coast, indicating it is likely the result of coastal erosion, corroborating results from Brown et al (2003) and Lestak et al (2004). Suspended materials in the 1985 image cover a larger extent offshore and likely result from a combination of resuspension due to wind and coastal erosion processes, as winds were stronger before and during the time the 1985 data was acquired. Suspended sediment delivered to the near-shore from rivers does not appear to be transported beyond the immediate vicinity of river outflow. Data in the near-infrared region showed that during late July in 2002 and early August in 1985 the extent of suspended sediment from rivers is confined to the immediate vicinity of river outflow in Admirality Bay and Smith Bay.

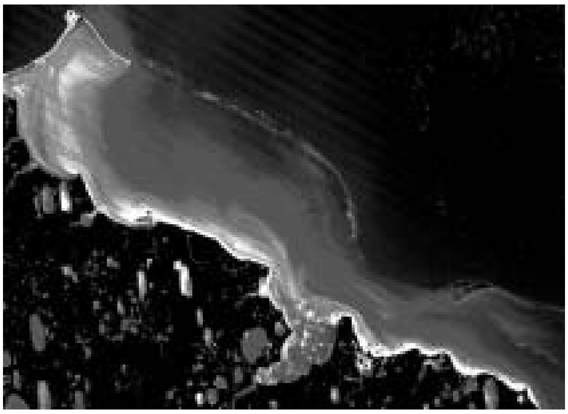

Fig. 2a: 1985 Band 4 Reflectance Values

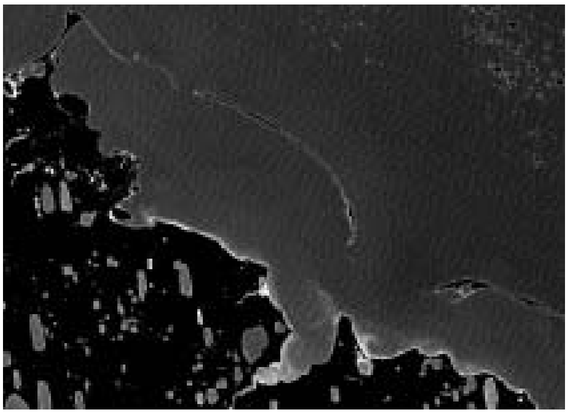

Fig. 2b: 2002 Band 4 Reflectance Values

The analysis of OAC’s with satellite data represents a unique challenge in the coastal environment because coastal waters are optically complex relative to the open ocean due to terrestrial influence. In this study, analysis of OAC's was hindered by the spectral resolution of the TM and ETM+ sensors. Variations in water color were detected upon analysis of different band combinations and band ratios, but specific OAC's could not be positively identified. Sensors with higher spectral resolution, such as MODIS, would likely prove more effective in the analysis of OAC's. However, a principal components analysis performed on the TM/ETM+ data was able to identify those waters that are more optically complex and therefore probably influenced by terrestrial processes to a greater degree (Figure 3). As would be expected based on relative degree of land-ocean interactions, Elson Lagoon waters were the most optically complex, followed by Chukchi Sea near-shore waters. Beaufort Sea waters beyond the barrier islands were the least optically complex.

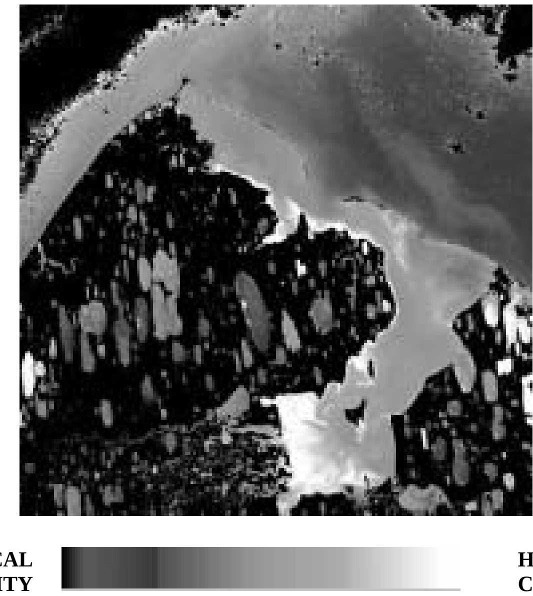

Fig. 3: 2002 First Principal Component

This study demonstrates the feasibility and limitations of using Landsat data to evaluate certain Arctic near-shore processes and identify near-shore waters that are influenced by terrestrial and coastal processes. Further research will analyze OAC signals in data with higher spectral resolution, investigate specific terrestrial processes contributing to near-shore sediment and OAC patterns, evaluate near-shore changes under different warming and land use scenarios, and evaluate the feasibility of using satellite data with moderate spatial resolution, such as MODIS, to extrapolate the study across the entire Alaskan North Slope.

Acknowledgments

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Special thanks to Liz Cassano for providing meteorological data.

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INPUT OF HEAVY METALS INTO COASTAL ZONE OF NOVAYA ZEMLYA ARCHIPELAGO

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Each year a large quantity of suspended and dissolved material (including toxic elements and heavy metals) enters the Barents and Kara seas. The Novaya Zemlya Archipelago is among the most important source regions on the West Arctic shelf. Geological mapping carried out in the NZ during last 20 years has facilitated identification and delineation of numerous ore occurrences of various genesis and scale. Deposits containing such elements as Pb, Zn, Cu, Mn, U, Au, and Ag as well as accompanying elements Hg and As may be considered among the most important, yet most toxic of these. Among the largest is the Pavlovskoye Pb-Zn deposit (POF), which is located at a lower stream of the Bezymyannaya River, 18 km from the Barents Sea. The ore unit represents sulfide polymetals ores of pyrite-galenite-sphalerite series with lead-zinc summary content up to 30%, averaging for ores from 8-10%, with a metal resource valuation estimated at 40 Mtons (Gramberg et al., 2002). The main ore bodies are located on the left shore of the Bezymyannaya River and are cut by deeply incised tributaries that flow year-round. Seasonal streams and areas of swamp/stagnant-water are also present within the area. Seasonal and climatic changes cause erosion of ore bodies which increases the amount of heavy metals entering the environment of the Novaya Zemlya Shelf. The studies carried out within the littoral zone in 1991-2002 revealed abnormally high concentrations of toxic elements in the water, suspended matter, and bottom sediments (more than 700 samples were obtained). In light of this, detailed geochemical investigations have been initiated in order to assess the impact of this natural exogenic source.

Basic statistical summaries readily show that all the samples have anomalously high contents of Zn. This fact indicates a high mobility of Zn in the zone of hyper genesis of the ore bodies. In the middle current of Rusty Brook (where outlets of the ore body reach the surface) the Zn concentrations in the water reach extreme levels (up to 1013 µg/L). Moreover, concentrations of Zn sharply increases to 42 g/l within stagnant-water sites situated directly on ore bodies, with pH=2.36, in what may be categorized as “metalliferous solutions”. High concentrations of Cu (up to 7,0 µg/L) and Cd (0,55 µg/L) are typical of sub- and superpermafrost waters in this region.

Bezymyannaya Inlet receives on the order of 29, 8,7, 1,9 and ~0,1 tons of Zn, Pb, Cu and Cd, respectively, per annum, suggesting the profound importance of geochemical factors in the Barents Sea ecosystem. It may be stated that the volume of HM supplied from natural sources is incommensurable with that introduced into the marine environment from industrial technogenic sources. The POF is a significant source of HM supplied to the Bezymyannaya River ecosystem. No abrupt change in concentrations of toxic elements has been recorded at the river-sea barrier, meaning the frontier of this barrier zone is most likely located west of Lebed’ Island.

FROZEN QUATERNARY DEPOSITS OF LAPTEV SEA COAST AS A SOURCE OF ORGANIC MATTER AND BIOGENIC GASES.

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One of the main peculiarities of frozen quaternary deposits (especialy syncryogenic deposits) is the large amount of buried organic matter they entrain. This organic matter is stored during the sedimentation process and then preserved indefinitely in a frozen state. This preserved organic matter is re-introduced into the biogeochemical cycle when permafrost is thawed as a result of subsequent environmental processes, chief among them being thermal abrasion of the marine coast.

Sources of organic matter in coastal landscapes include organic carbon from modern vegetation, modern soil, and organics that are buried in frozen deposits.

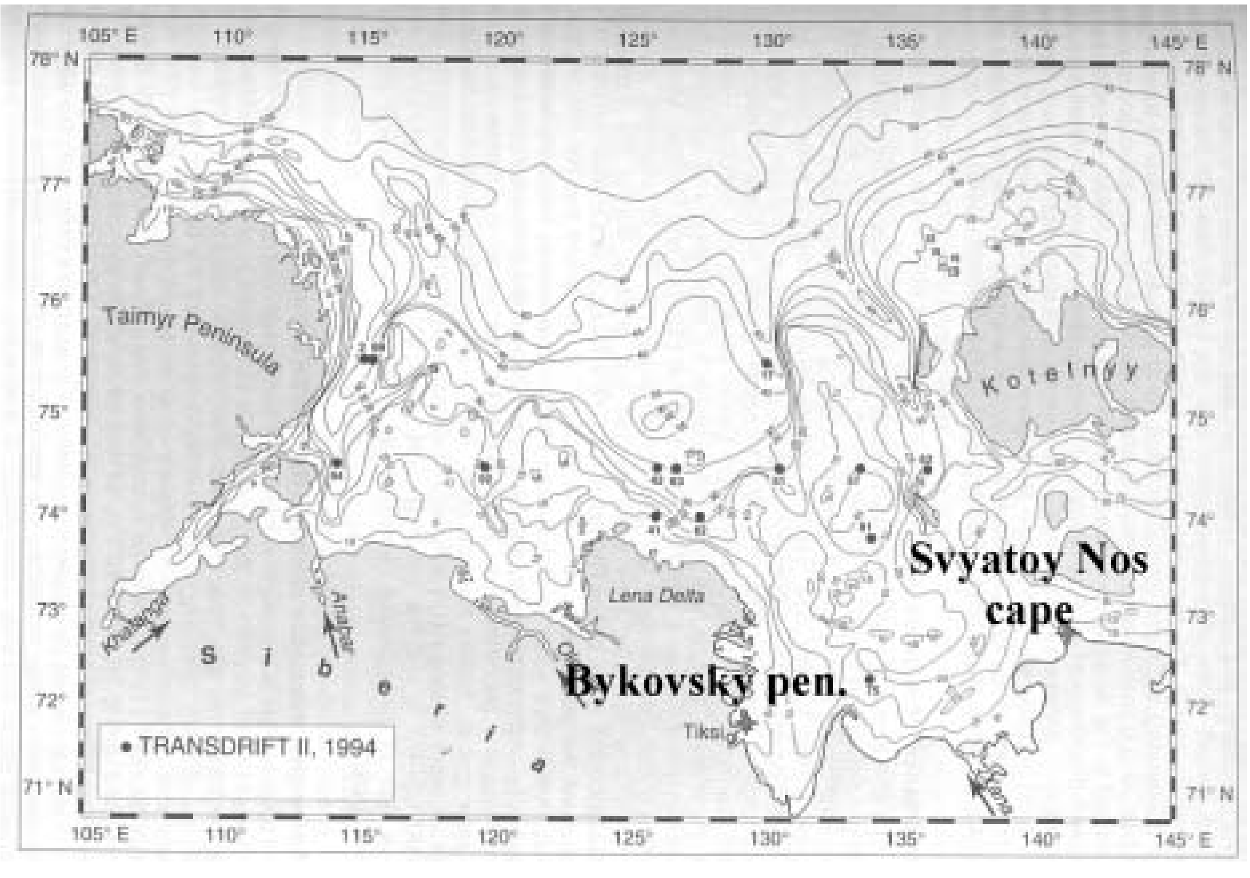

Fig.1 Map of investigated area.

Investigations were carried out at two key sites: Bykovsky Peninsula (129°30'E, 71°40'N.) and Cape Svyatoi Nos (140°0'E 72°55'N) in 2001 and 2003 (Fig. 1).

There are two main types of landscapes associated with the deposits. First is the late Pleistocene (l-alQ_{III}) accumulative plain ("Edoma" formation or Ice Complex) composed of syncryogenic, ice-rich sediments (volumetric ice content of such deposits can reach 80-90%, including 40-50% of pore ice and 40-50% ice in ice wedges) (Fig. 2a). Mean annual ground temperatures within this landscape are -11 to -14ºC. Heights of shore cliffs are 20 to 40 m (Fig 2a). The second type of landscape is alas depressions resulting from the thawing of the ice-complex under thermokarst lakes. The alas complex includes layers of Holocene lake-boggy deposits (l-bQ_{IV}); layers of taberal deposits (thawed and redeposit Ice Complex) (tbQ_{III-IV}), and the rest of Ice Complex (Fig. 2a). Mean annual ground temperature is -9ºC and the height of the Laptev shore cliff is less then 10 m (Fig. 2a).

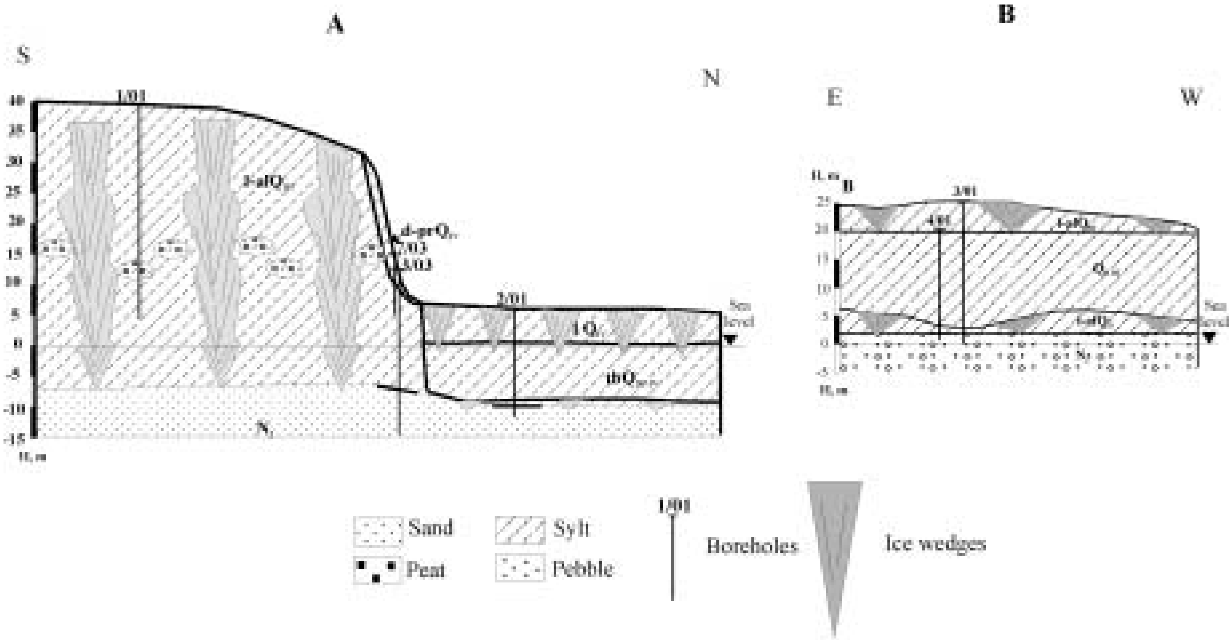

Fig. 2. Scheme of permafrost-geological condition of key sites:
A – Bykovsky peninsula; B – Svyatoy Nos cape.

Outcrops of quaternary deposits also occur along the shore in the eastern part of the Laptev Sea Middle Pleistocene deposits. Two types of such deposits were investigated at the Cape Svyatoy Nos drilling site (Fig. 2b): a Middle Pleistocene Ice Complex (l-alQ_{II}) and deposits of “kutchuguy” suite (Q_{II-III}). Genesis of the latter is still under discussion. (Nikol’sky et al., 1999)

Total organic carbon contents in different types of quaternary deposits and in modern soil were determined, and an estimate of total organic supply for the above mentioned landscapes was made.

Data about the content of organic carbon in different types of quaternary deposits and modern soil are presented in Tables 1 - 3 and Figure 3.

Table 1. TOC content in different types of tundra soils.

Type of soil	Active layer thickness, m	Average TOC, kg/m^3	Supply of C_{org} in active layer, kg/m^2
Cryosoil	0.51	22.11	11.39
Gleic soil	0.42	21.02	8.83
Peaty soil	0.51	40.37	20.59

Table 2. Total organic carbon content in different types of frozen Quaternary deposits on the Laptev Sea Coast.

Ice complex (l-alQ_{III})				
	Number of samples	Average	Modal value	**Deviation**
Bykovsky pen. and Svyatoy Nos cape	23	2.55	2.28	0.81
Alas complex				
Alas deposits. (Bykovsky p-a) lQ_{IV}	4	2.92	-	-
Taberal deposits (Bykovsky peninsula) tbQ_{III-IV}	6	0.99	1.22	0.21
Kutchuguy suite Q_{II}				
Svyatoy Nos cape	17	0.99	1.36	0.32

It was determined that 1 m^3 of ice-complex contains 5-12 kg of C_{org}. Our data, and data obtained in the context of the Russian-German project "Laptev Sea System" shows that on the Bykovsky Peninsula a significant supply of C_{org} in IC deposits is situated in horizons of buried soil, formed during Kargan thermochron or MIS 3 (Fig 4). Deposits of alas complex are characterised by a similar total C_{org} content (8-12 kg/m^3). The main part of the organic content (75%) in these deposits is concentrated in the upper part of the section that is composed of lake-bogy sediments. Taberal deposits have less organic matter relative to the initial ice-complex. The average organic content in a 50-m thick section of massive ice-complex on the Bykovsky Peninsula is 22 kg/m^3, but a 10 m section of taberal deposits contains 3 to 10 kg/m^3. Thus, due to thawing of the ice-complex during development of the thermokarst lake up to 50% of the organic matter can be removed.

Taking into account thickness and cryogenic structure of quaternary deposits, it was determined that 1m^2 of alas can contain ***200 kg*** of C_{org} (***190 kg/m²*** in a frozen quaternary deposits and ***10 kg/m²*** in a modern soil). Organic supply in Ice Complex is ***500 kg/m²*** (***480*** and ***20 kg/m²*** correspondingly) (Table 3). The amount of organic carbon in modern vegetation is insignificant in comparison with that stored modern soil and permafrost.

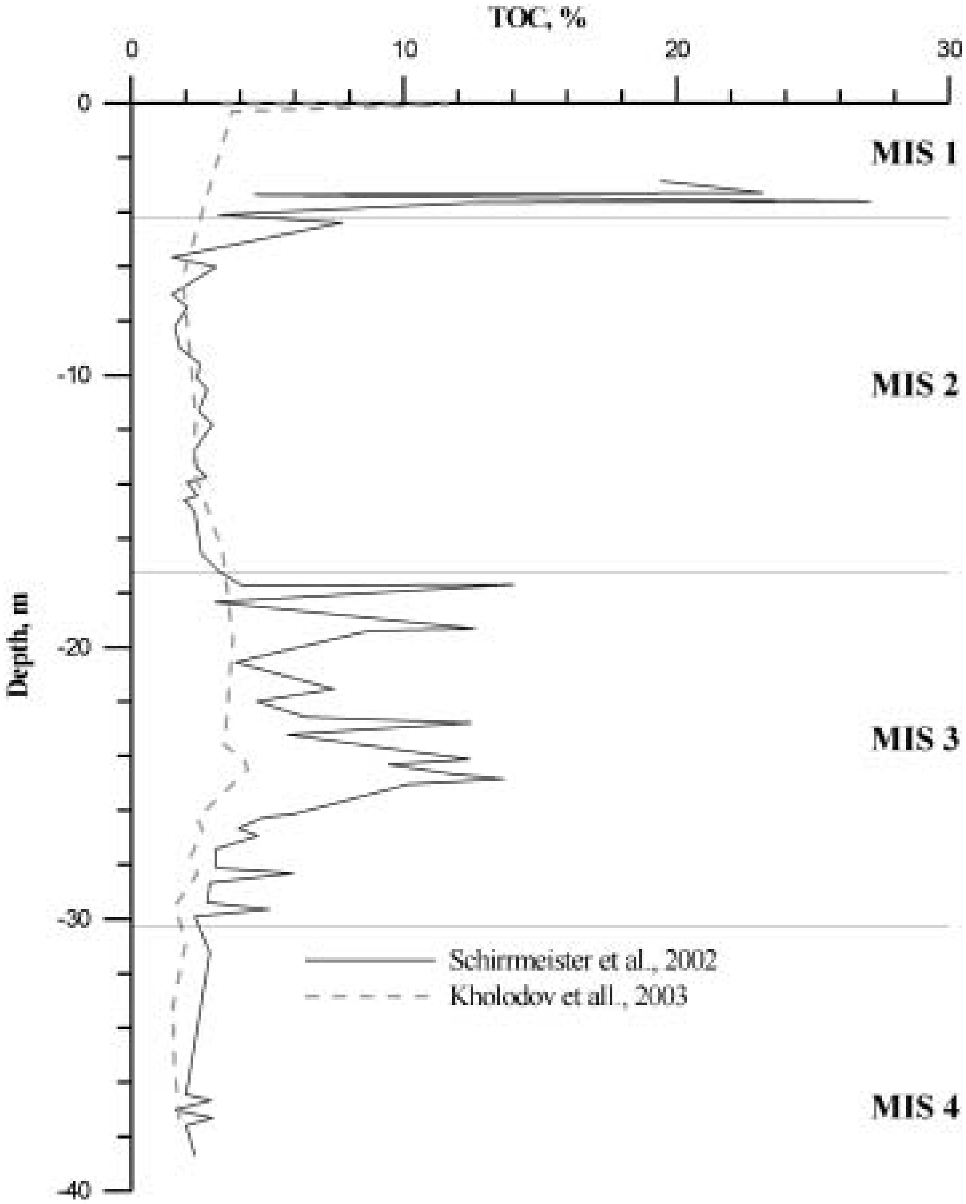

Fig. 3. Organic carbon content in the boreholes on the Bykovsky Peninsula (1/01 and 2/01) and Cape Svyatoy Nos (3/01 and 4/01). Boreholes locations on Fig 2.

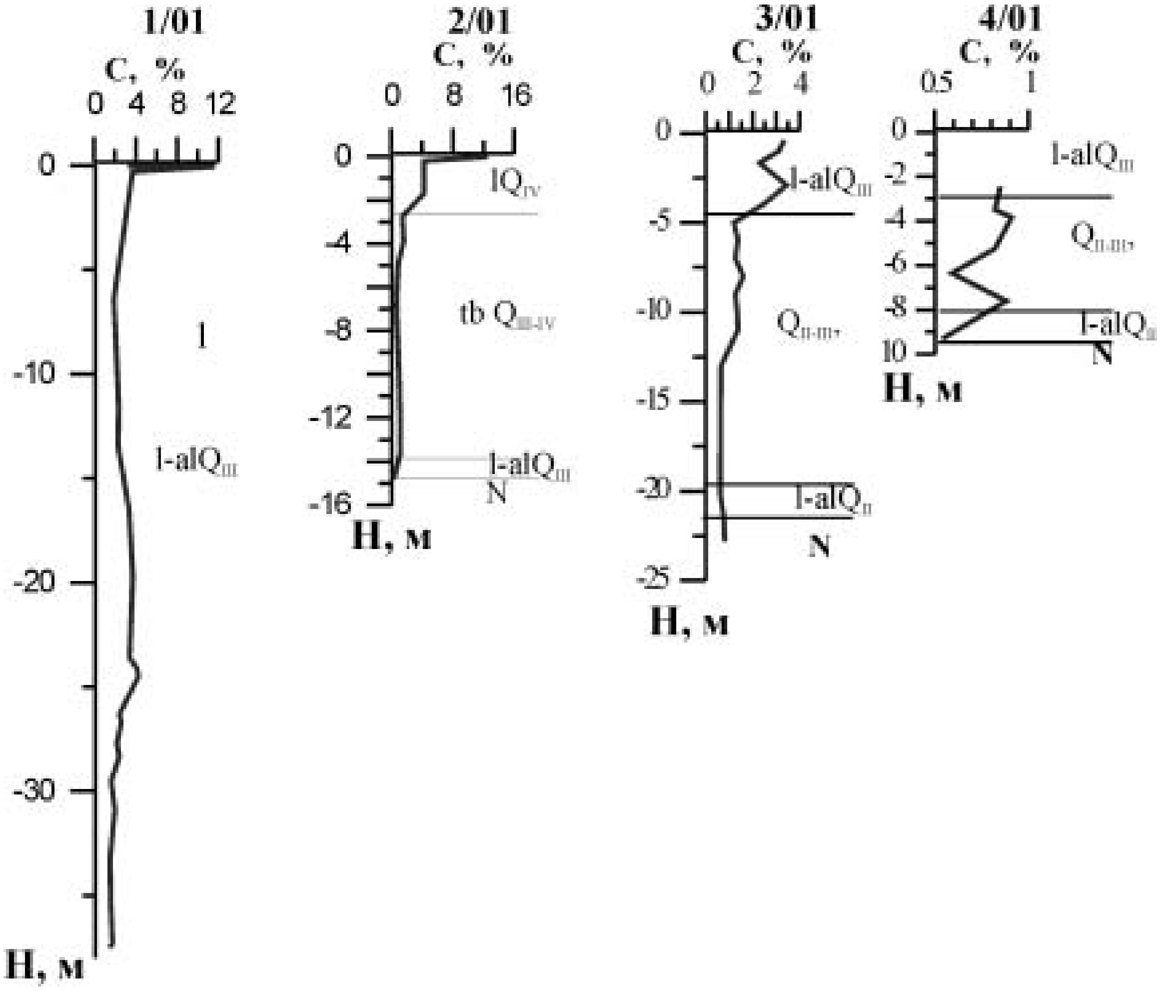

Fig. 4. Comparison of data about TOC in Ice Complex on the Mamontovy Khayata due to boreholes (dashed line) and from outcrop (solid line).

Table 3. Content of organic carbon in frozen deposits and modern soil of Laptev Sea coastal zone.

Borehole	Deposits	Average TOC, kg/m^3
Bykovsky peninsula		
1-01	l-alQ$_{III}$	11.2
2-01	N-l-bQ$_{III-IV}$	12.2
Svyatoy Nos cape		
3-01	l-alQ$_{II-III}$	5.5
4-01	Q$_{II-III}$	3.4
Modern soil (Chukochyi cape)		
Edoma	Hummock	19.6
	Spot medallion	14.8
	Hummock slope	24.5
	Crack	5.6
Alas	Hummock	21.7
	Spot medallion	25.3
	Hummock slope	23.1

Another important component of frozen deposits are biogenic gases (mainly CH_4). Concentrations of methane were determined in syncryogenic deposits of ice complex, alas and taberal deposits. Average concentrations of CH_4 in an Ice Complex is ***0.1 ml/kg***. In alas and taberal deposits, where organic decay under the unaerobic condition took place during the period from 11 to 6 kyr B.P. (Romanovskii et al., 2000), methane concentrations can reach ***10 - 15 ml/kg*** (Fig. 5).

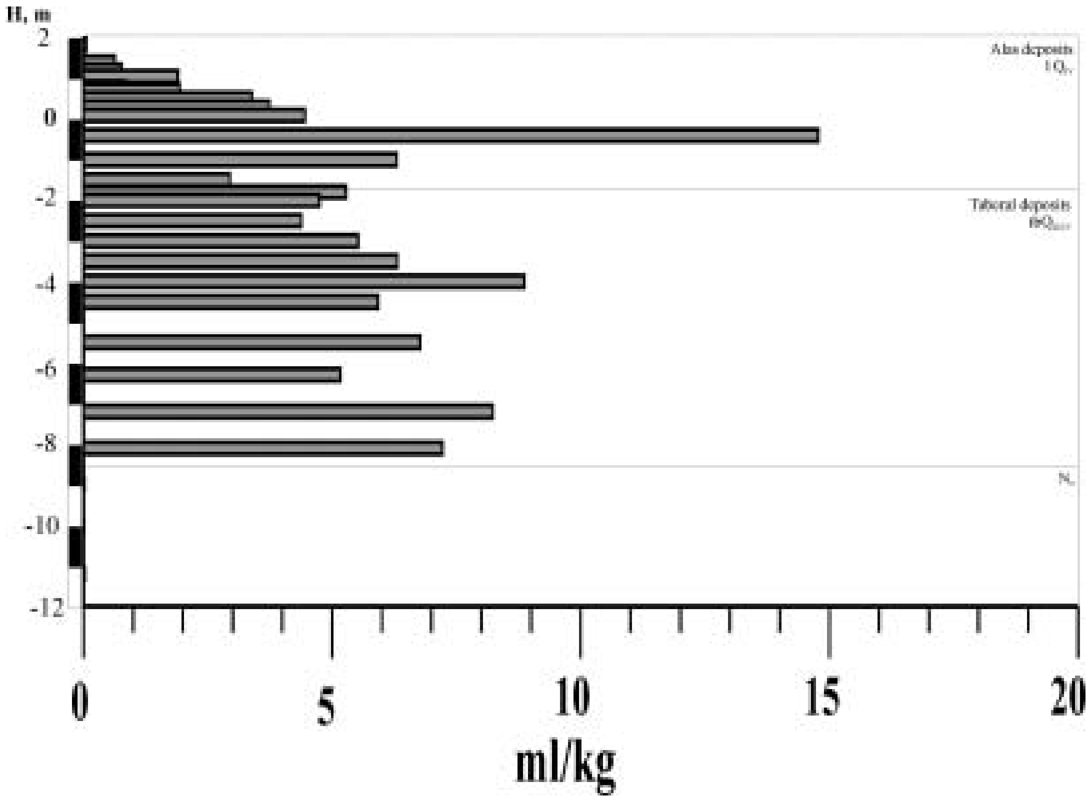

Fig. 5. Concentration of methane in the deposits of alas complex. Borehole 12-13/03, Ivashkina lagoon coast, Bykovsky Peninsula.

Assuming the length of eroded coast equals 1300 km (Are 1998, 1999) and an average rate of coastal retreat (2m/year) and knowing the C_{org} supply for different types of landscapes, the annual input of C_{org} into the Arctic basin due to shore erosion can be estimated at $\boldsymbol{0.91 \cdot 10^6}$ ***ton/year***. This value corresponds well with other estimations (Danyushevskaya et al., 1990; Romankevich and Vetrov, 2001)

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MULTIDISCIPLINARY STUDIES IN THE WHITE SEA IN THE FRAME OF THE LOIRA PROJECT

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Introduction

Land-Ocean Interactions in the Russian Arctic (LOIRA) is an IASC (International Arctic Science Committee) project (LOIRA, 2000). The LOIRA Science Plan originally adapted plans from the LOICZ (Land Ocean Interactions in the Coastal Zone, an IGBP Core Project) and ELOISE (European Land Ocean Interaction Studies) projects to the Russian Arctic. The primary objective of LOIRA is to obtain an understanding of the fundamental science concerning physical, chemical, geological and biological processes under the influence of global change and anthropogenic impact in the Russian Arctic, in order to develop a scientific and socio-economic basis for integrated management of the coastal environment. Coastal dynamics of the Russian Arctic are studied in close cooperation with Arctic Coastal Dynamics (ACD), another IASC project. Initially, the Pechora Sea area was studied by a number of subprojects within the framework of the LOIRA project. The results of these studies are summarized in a monograph (Romankevich et al. 2003). A White Sea System subproject is ongoing.

The White Sea is a shelf water body situated in the subpolar physico-geographical zone of the northern European part of Russia. It is connected to the Arctic Ocean via the Barents Sea. In spite of the large extent of this water body, which lies to the south of the Arctic Circle, the White Sea belongs to the arctic-boreal category of seas due to peculiarities of its climate, hydrology, flora and fauna (Berger et al. 2001).

It is expected that the recovery of diamonds, oil production and the timber industry in the watershed, natural gas transport through the White Sea from the Shtockman gas-field located in the Barents Sea, and some other industrial activity could significantly alter the environmental conditions in the White Sea region in the near future. To understand these changes we need to assess the present state of the White Sea system. Studies began here in the second half of the 19th century. Much data has been collected and many papers have been published. A system studies approach has only now, however, begun.

System Approach

A system approach is necessary for the comprehensive study of the White Sea ecosystem and its functions (Lisitzin 2002, 2003), i.e. studies of the entire system of oceanology (physics, chemistry, biology and geology) and its dynamics and the interactions of its parts in space and time (four-dimensional approach). In particular:

1. the distribution of natural and anthropogenic components is considered in fluxes from the atmosphere, with ice, sea and river waters, and vertical particle fluxes in the water column.
2. quantitative studies using several independent methods of particle flux determination: sediment traps, isotopic methods, ecosystem models, etc.; a nanotechnology approach (study of nanoparticles in different geospheres – atmosphere, hydrosphere, cryosphere, biosphere, lithosphere).
3. determination of chlorophyll-a, suspended matter, dissolved organic matter concentrations for the whole sea using satellite data and verification in expeditions; use of hydro-optical vertical profiling for precise sampling in the water column.

Partners

Many Russian and foreign institutes and organizations take part in the White Sea System subproject. These include but are not limited to:

- P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences, Moscow and it's branches in Kaliningrad and St. Petersburg;
- M.V. Lomonosov Moscow State University;
- SEVMORGEO, St. Petersburg;
- Zoological Institute of the Russian Academy of Sciences, St. Petersburg;
- VNIRO, Moscow;
- Sevgidromet, Arkhangelsk;
- Water Problems Institute of the Russian Academy of Sciences, Moscow;
- Northern Water Problems Institute of Karelian Scientific Center of the Russian Academy of Sciences, Petrozavodsk;
- Institute of Ecological Problems of the North of the Ural Branch of the Russian Academy of Sciences, Archangelsk;
- SEVPINRO, Arkhangelsk
- Institute of Microbiology of the Russian Academy of Sciences, Moscow;
- VNIIOkeangeologia, St. Petersburg;
- Murmansk Marine Biological Institute of the Russian Academy of Sciences, Murmansk;
- VSEGEI, St. Petersburg;
- Institute of Chemical Kinetics and Combustion of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk;
- Trofimuk United Institute of Geology, Geophysics and Mineralogy of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk;
- Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences, Tomsk;
- Nansen International Environmental and Remote Sensing Centre, St. Petersburg;
- St. Petersburg State University;
- Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany;
- Nansen Environmental and Remote Sensing Centre, Bergen, Norway;
- University of Plymouth, U.K.;
- Plymouth Marine Laboratory, U.K;
- Institute for Marine Research, Vigo, Spain;
- School of Ocean Sciences, University of Wales-Bangor, U.K.;
- Akvaplan-niva, Tromso, Norway;
- Abo Akademi University, Turku, Finland;
- Goeteborg University, Sweden.

Results

In 2000-2003, multidisciplinary studies were carried out in the White Sea on more than 20 expeditions (Dolotov et al. 2002; Lisitzin et al. 2003; Lukashin et al. 2003; Kosobokova et al. 2004; Shevchenko et al. this volume). In 2003, much work was done on the expedition onboard the RV “Sergey Kravkov” (18-25 April), on the 57th expedition of the RV “Ivan

Petrov" (11-21 June), on the expedition onboard the RV "Ekolog" (26 July – 8 August) and on the 55th expedition of the RV "Professor Shtokman" (20-30 August). The positions of stations in these expeditions are shown in Figure 1. From May 31 to June 10, studies of processes in the marginal filter of the Northern Dvina were carried out onboard the RV "Akvanavt-2" (Fig. 2).

The strong seasonalities of meteorological, hydrological, hydrochemical, biological and geochemical processes were revealed (Rachor 2000; Berger et al. 2001) and are reflected in the seasonality of sediment supply and of vertical particle fluxes (Lisitzin et al. 2003; Shevchenko et al. this volume). Studies of vertical particle fluxes were continued in 2003 using sediment traps (Fig. 3).

In the river-sea barrier zone (in the marginal zone), more than 90 % of riverine suspended matter (including pollutants) is deposited. There are many similarities between the functions of marginal filters of the White Sea and other Arctic Seas, but there are some peculiarities (Lisitsyn 1995; Lisitzin et al. 2000, 2003; Dolotov et al. 2002; Lukashin et al. 2003).

Simultaneous remote sensing observations (SeaWiFS and other satellites), suspended matter sampling, chlorophyll sampling, hydro-optical studies and sediment trap measurements make 4-D research of material fluxes possible (Lisitzin 2002, 2003; Lisitzin et al. 2003; Pozdnyakov et al. 2003). The development of new algorithms for the interpretation of satellite data permits the simultaneous determination of chlorophyll-a concentration, and, after verification, of phytoplankton primary production, suspended matter and dissolved organic matter (yellow matter) for the whole sea. All data were verified during summer and autumn expeditions (Lisitzin et al. 2003; Pozdnyakov et al. 2003).

Results of multidisciplinary studies of the White Sea system were presented and discussed at 4 LOIRA workshops in Moscow in 2000-2003, two of which were held within the framework of the 14th and 15th International Conferences on Marine Geology (Third 2000; Geology 2001, 2003; Fifth 2002).

Conclusions

In 2000-2003, much work was done studying the White Sea system (including climate, hydrophysics, hydrochemistry, biology, geochemistry, and geology) by scientists from many organizations.

Multidisciplinary studies in the White Sea within the framework of the LOIRA project have the potential to lead to the development of a new generation of Arctic environmental monitoring (four-dimensional).

Acknowledgements

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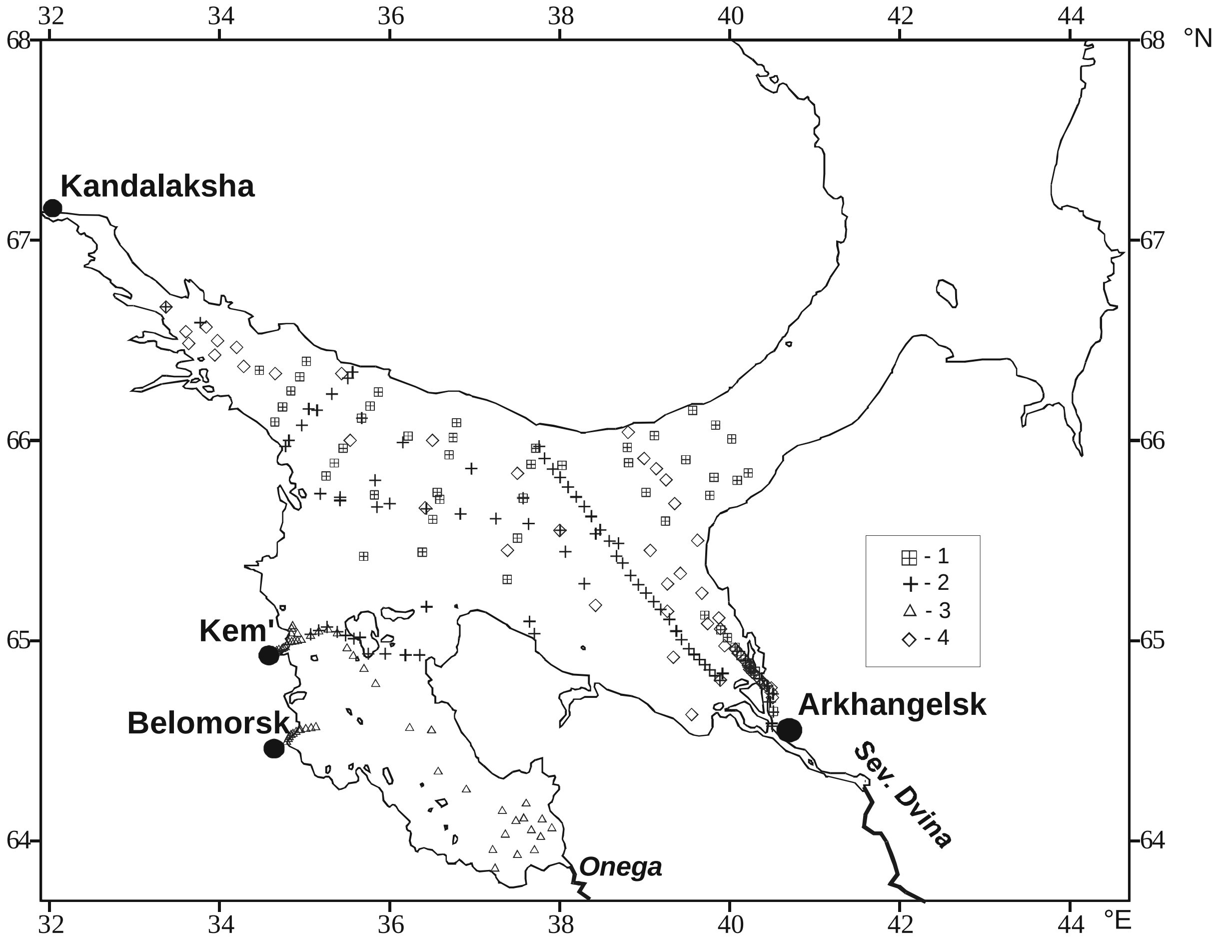

Fig. 1. Positions of stations for the following expeditions: 1 – cruise of the RV "Sergey Kravkov", April 2003; 2 – 57-th cruise of the RV "Ivan Petrov", June 2003; 3 – expedition onboard the RV “Ekolog”, July-August 2003; 4 – 55-th cruise of the RV "Professor Shtokman", August 2003.

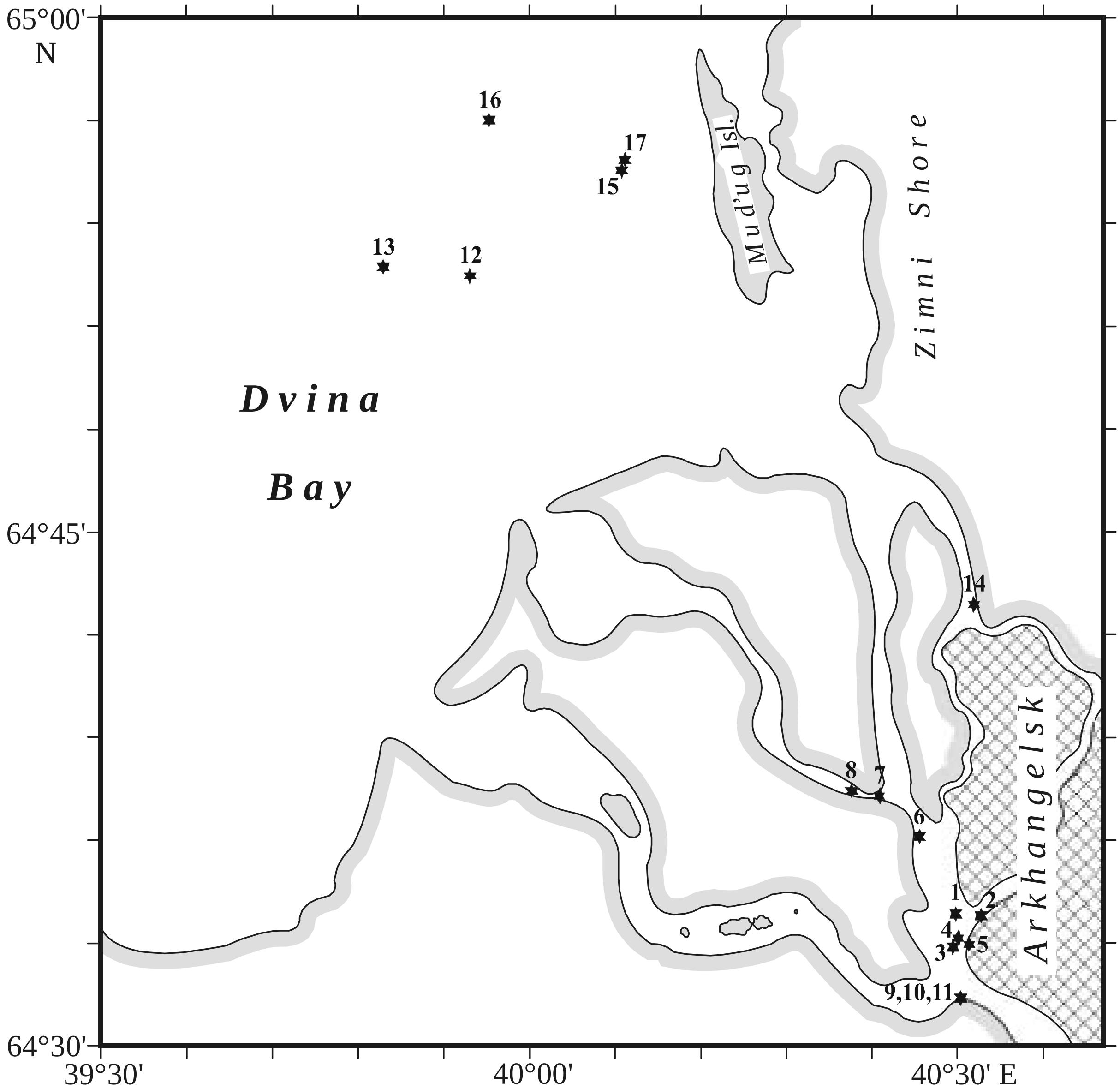

Fig. 2. Positions of expedition stations of the RV "Akvanavt-2" in the marginal filter of the Northern Dvina (31 May – 10 June 2003).

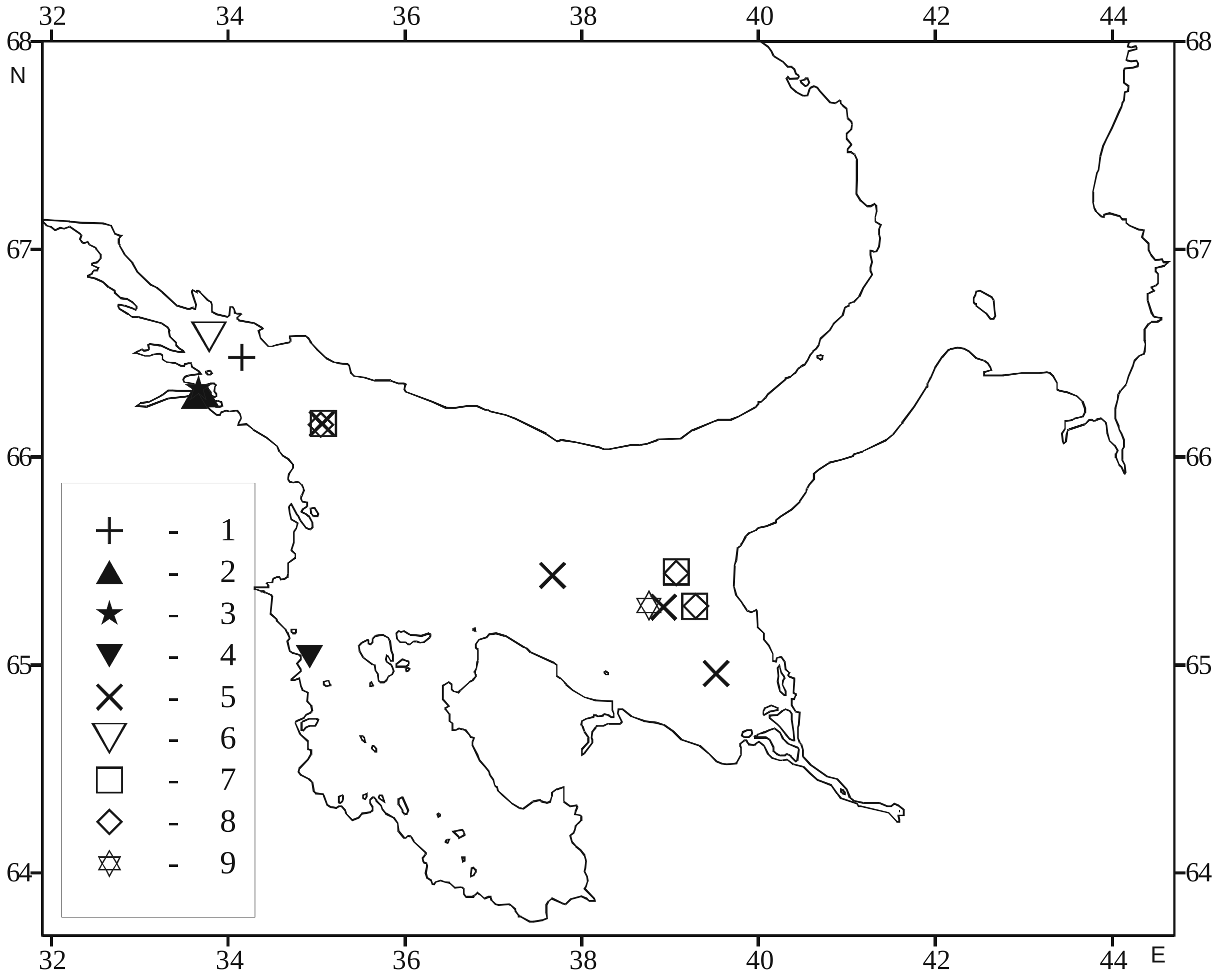

Fig. 3. Sites of sediment trap deployments: 1 – cruise of the RV "Kartesh", June 2000; 2 – cruise of the RV "Kartesh", September 2000; 3 – the biological station "Kartesh"; 4 – cruise of the RV “Ekolog", July 2001, August-September 2002; 5, 6 – 49-th cruise of the RV "Professor Shtokman", August 2001 (6 – large conical sediment trap with multi-cup sampler); 7 – 52-nd cruise of the RV "Ivan Petrov", June-July 2002; 8 – cruise of the RV "Ekolog", September 2002; 9 – 57-th cruise of the RV “Ivan Petrov”, June 2003.

A "WORKING BUDGET" OF POC FOR THE MARINE FACIES OF THE COLVILLE DELTA

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We have calculated a tentative budget of particulate organic carbon (POC) for the 450 x 10^6 km^2 area of the marine facies of the Colville Delta, Alaskan Beaufort Sea coast. This budget is based on data drawn from several publications (Schell, 1983 and references therein; Naidu et al., 1984, 1999, 2000; Parrish, 1987). The deltaic marine facies is the offshore region that derives sediment predominantly from the Colville, the largest river in the North Slope of Alaska (Naidu and Mowatt1975; Naidu et al.1984). In this region the marine primary producers are microalgae (benthic, epontic and pelagic) and the localized kelp beds. The marine primary production rate in the nearshore of the Alaskan Beaufort Sea is 25 g C m^{-2} y^{-1} (Parrish 1987). Additional sources of the POC input are the Colville River runoff and erosion of the peat-enriched shoreline. The average annual output of POC from the Colville River is 170 x 10^6 kg C y^{-1} (Schell 1983). We calculate a net annual mass output of POC, from erosion of the 72 km coast of the Colville Delta, to be about 90 x 10^3 g C y^{-1}, based on a mean rate of 1.4 m y^{-1} of coastal erosion (Naidu et al. 1984), an average height of 3 m of the permafrost dominated (75% ice) coastal bluff, an average thickness of 1.82 m of peat (Schell 1983) and 1.18 m non-peaty deposits in the bluffs, and an assumed 60 % OC in peat and 1.5 % OC in non-peat sediments. If the POC derived annually from the Colville outflow and coastal erosion were to be spread and deposited evenly over the entire area of the Colville Delta marine facies, the amount of POC thus accumulated from the fluvial source would be 378 g C m^{-2} y^{-1} and 202 g C m^{-2} y^{-1} from the shoreline degradation. An addition of the POC derived from marine primary production (25 g C m^{-2} y^{-1}) would add up to a potential pool of 605 g C m^{-2} y^{-1} for deposition within the above area. However, the average mass of POC currently accumulating within the delta is 160 g C m^{-2} y^{-1}, as calculated from an average mass sediment accumulation rate of 1 g cm^{-2} y^{-1} (Naidu et al. 1999) and a mean POC content of 0.016 g/g in the Colville deltaic sediments (Rob: please cite the Table with the POC concentrations in Alaskan sediments sent earlier to you). Thus, it is suggested that about 72 % of the pool of POC available for potential deposition must be lost by advection, remineralization or biological consumption. As discussed below, we contend that the loss is chiefly by advection by ice.

Arnborg et al (1963) noted that 43 % of the annual discharge and 73 % of the total inorganic suspended load (5.8 x 10^6 tons) are discharged from the Colville River during a three-week period at spring breakup (late May-mid June). This discharge extends as an turbid overflow wedge over sea ice to about 10 km offshore, resulting eventually in thick deposition on the ice of the entrained suspended sediments and POC (Walker 1974). With the subsequent breakup of the sea ice most of the fluvial sediment and POC deposit is transported to the shelf by ice rafting. Consequently, deposition of a large proportion of the Colville-derived sediment and associated POC is bypassed at the delta-front platform located off the river mouth and, thus, lost to the shelf (Naidu et al.1975). Considering the $\delta^{13}C$ mean value of –26.2 o/oo of the sediment of the marine facies of the Colville delta, the $\delta^{13}C$ values of the terrestrial and marine end-members, -27 o/oo and –23.5 o/oo respectively (Naidu et al. 2000), and using a mixing equation (Shultz and Calder 1976) we estimate that about 77 % of the POC deposited in the Colville Delta marine facies is terrestrial and the rest is marine-derived.

Our estimation of the relative importance of the mass of POC supplied from the two terrestrial sources, fluvial versus coastal erosion, to the marine deltaic environment of the Alaskan Beaufort Sea is consistent with that for the Mackenzie Delta, Canadian Beaufort Sea

(Macdonald et al. 1998). Both the investigations indicate that the mass of POC derived from fluvial discharge significantly exceeds that from coastal erosion, which is in contrast to the estimate for the Lena Delta of Laptev Sea, Russia (Rachold et al. 2000). Presumably, the regional disparity can be explained to the presence of relatively higher coastal cliffs and a magnitude higher shoreline erosion rates in the Lena Delta (Rachold et al. 2000).

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THE FATE AND TYPE OF ORGANIC CARBON SUPPLIED TO THE ARCTIC SHELVES THROUGH COASTAL EROSION

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Organic carbon is supplied to the Arctic shelves and basins by rivers and rapid erosion of unlithified coastal materials. The knowledge of the type of organic carbon (dissolved or particulate etc.) and its fate is essential to understand the role of coastal erosion in the carbon budget of the Arctic.

Three coastal key transects, located in the Kara, Laptev and East Siberian Seas, have been sampled with regard to performing detailed organic carbon studies during the summer activities in 2003 as a first step.

This poster presents our first estimates of the amount of organic carbon supplied to the Arctic Shelves through coastal erosion and an outlook on the results obtained from detailed organic geochemical studies.

We wish to thank Georgy Cherkashov (VNIIO), Vladimir Ostroumov (Pushchino), Lutz Schirrmeister (AWI), Waldemar Schneider (AWI), Irina Streletskaya (MGU) and Alexander Vasiliev (Earth Cryosphere Institute) for sampling the coastal transects in the Kara, Laptev and East Siberian Seas.

SUSPENDED SEDIMENT DISTRIBUTION AND VERTICAL PARTICLE FLUXES IN WESTERN BAYS OF THE NOVAYA ZEMLYA ARCHIPELAGO AND VAIGACH ISLAND

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Abstract

In this paper a comparative analysis of suspended particulate matter (SPM) distribution and composition and vertical particle fluxes in Russkaya Gavan' Bay (Northern Island of the Novaya Zemlya), Bezymyannaya Bay (Southern Island of the Novaya Zemlya) and Dolgaya Bay (northwestern part of the Vaigach Island) is presented. Field studies were carried out during the 9th expedition of the RV "Professor Logachev" in September 1994 and during the 11th expedition of the RV "Akademik Sergey Vavilov" in September-October 1997.

In general, on Novaya Zemlya and Vaigach, most SPM settles out of suspension in the bays (fjords) and only a small part of it reaches the Barents Sea. This is due to the hydrodynamic conditions in the bays, the large size of the particles, and morphological barriers in the relief at the bay entrances. It is important for ecological purposes to map out migrational pathways of the SPM with pollutants from bays to the open sea. Results of these investigations indicate that the bays of the Novaya Zemlya Archipelago act as traps for suspended matter derived from glaciers and coastal abrasion.

Introduction

The study of suspended particulate matter (SPM) in the ocean is necessary for understanding modern sedimentation processes and for assessing the ecological state of the environment (Aibulatov 1990; Lisitzin 1996). Currently, SPM in the Arctic is insufficiently studied (Lisitsin et al. 2000; Aibulatov 2001).

The fjords of the western coast of the Novaya Zemlya Archipelago (Fig. 1) are one of the sediment sources for the Barents Sea (Elverhoi et al., 1989). On Novaya Zemlya intensive glacial meltwater discharge occurs from the Northern Island and riverine run-off occurs on the Southern Island (Medvedev and Potekhina 1990; Matishov 1995). Studies in fjords receiving glacial meltwater show a variety of biogeochemical and sedimentological processes taking place there (Syvitski and Murray 1981; Lewis and Syvitski 1983). SPM in glacier-fed fjords along the western coast of the Northern Island was studied by Medvedev and Potekhina (1990) using filtration through the old type filters. In 1996 SPM in fjords of northern Novaya Zemlya was studied using more modern methods (Korsun 1996; Shevchenko et al. 1996; Korsun and Hald 1998).

In this paper results from comparative analyses of SPM distribution and composition and vertical particle fluxes in Russkaya Gavan' Bay (a fjord influenced by glacier meltwater), Northern Island of Novaya Zemlya, Bezymyannaya Bay (river run-off influenced), Southern Island of Novaya Zemlya and Dolgaya Bay, and Vaigach Island are presented.

Materials and methods

Suspended particulate matter and vertical particle fluxes in Bezymyannaya Bay (Southern Island of Novaya Zemlya) and the adjacent Barents Sea were studied during the 9th expedition of the RV "Professor Logachev" in September 1994 (Fig. 2) (Ivanov et al. 1997; Shevchenko et al. 1999 a, b) and in Russkaya Gavan' Bay (Northern Island of the Novaya Zemlya), in Dolgaya Bay (north-western part of the Vaigach Island) and the adjacent Barents Sea during the 11th expedition of the RV "Akademik Sergey Vavilov" in September 1997 (Fig. 3, 4) (Aibulatov et al., 1999; Politova et al. 2000; Romankevich et al. 2000; Shevchenko et al. 2000). For SPM studies the filtration of water samples was carried out using Nuclepore filters (47 mm in diameter, pore size 0.45 µm). For vertical particle flux studies we used small cylindrical sediment traps (vinyl plastic cylinders, 118 mm in diameter, with a 490 mm high working part and baffles installed in the upper part). Prior to sediment trap deployment we poured into the flasks 5 ml of 40% formaline solution to eliminate bacterial activity and to prevent the settled particles from being eaten by zooplankton (Gardner et al. 1983). To study SPM distribution and to establish the correlation between SPM concentration and the attenuation coefficient we used a "Del'fin" transparency probe. Its measurement range is 0.01-8.00 m^{-1} with an absolute accuracy of 0.005 m^{-1} at a wavelength of 555 nm. To obtain plankton samples we used the method of reverse filtration through a nuclear filter (pore size 0.45 µm), followed by sample re-concentration up to a volume of 5-6 cm^3. The counting and determination of algae and microzooplankton levels were carried out with a counting camera, using a sample volume of 0.05 cm^3, and an MBI-3 microscope with magnification ranging between 210-420x.

Results and discussion

Bezymynnaya Bay

On September 26-27, SPM concentration 1994 in the inner part of Bezymyannaya Bay (Fig. 2) was > 3 mg/l, decreasing towards the open sea, where the concentration was < 1 mg/l (Shevchenko et al. 1999b). It was assumed that suspended matter mostly settles out in the outer part of the bay. Values of vertical particle fluxes in the adjacent area of the Barents Sea were relatively high. At the station PL-9-6 (73º01.2'N, 52º53.9'E, water depth 40 m) particle flux at 15 m depth was equal to 314 mg m^{-2} d^{-1} and organic carbon content in the sedimentary matter was 11.1% (Shevchenko et al., 1999a, 2000). Mineral particles are the main component of the particulate matter, collected by sediment traps at this station. Both high values of fluxes and the composition of particulate matter show that re-suspension of material is taking place.

Russkaya Gavan' Bay

In Russkaya Gavan' Bay the SPM concentration in the surface layer in the inner part of the bay was > 10 mg/l, reaching a value of 265 mg/l near the edge of Shokalsky Glacier (Fig. 3). In the outer part of the bay SPM concentration in the surface layer ranged from 2 to 10 mg/l and in the adjacent Barents Sea it was < 2 mg/l (Aibulatov et al. 1999). The concentration of SPM decreases under the picnocline. Surface phytoplankton in the bay was very low (average count was 365 cells/l and biomass 4.2 mg/m^3) and it had proceeded to the autumnal stage of development (Zernova et al. 2001). Dynoflagellates were the most numerous group (46%), followed by diatoms (18%). Only some cells had chromatophores (*Chaetoceros decipiens, Pterosperma undulata, Protoperidinium bipes, P. brevipes*). The number of diatom cells with chromatophores ("living cells") was equal to the number of empty valves (65-50 cells/l). Particle flux at the station ASV-5 (76°16'N, 62°27.1'E, water depth 104 m) at 70 m was 346 mg m^{-2} d^{-1}, organic carbon content in the sedimentary material was 2.47%. Particle flux at 85 m depth (19 m above the sea bottom) at this station was 7660 mg m^{-2} d^{-1}. Sedimentary matter here consisted mainly of mineral grains. Few empty diatom valves were found here. Conditions for algal life are poor at this location due to high suspended mineral matter concentrations coming from glaciers.

Dolgaya Bay

Near Vaigach Island the SPM concentration was relatively low (0.15-2.58 mg/l). The decrease in SPM concentration occurs as a gradient from the inner part of the bay to the open sea (Fig.

4). The proportion of biogenic constituents increases in this direction. Two maxima were typically observed in SPM vertical distribution: one near the surface and a second at near-bottom (nepheloid) layers.

Conclusions

In general, on Novaya Zemlya SPM mostly settles out in bays (fjords) and only a small part of it reaches the Barents Sea due to the hydrodynamic conditions in the bays, the large size of the particles, and morphological barriers in the relief at the bay entrances. It is important for ecological purposes to map out migrational pathways of the SPM with pollutants from bays to the open sea. Our investigations allowed us to say that a) the bays of the Novaya Zemlya Archipelago act as traps for the suspended matter derived from glaciers and coastal abrasion, and b) pollutants emanating from Novaya Zemlya will remain in the bays.

Acknowledgments

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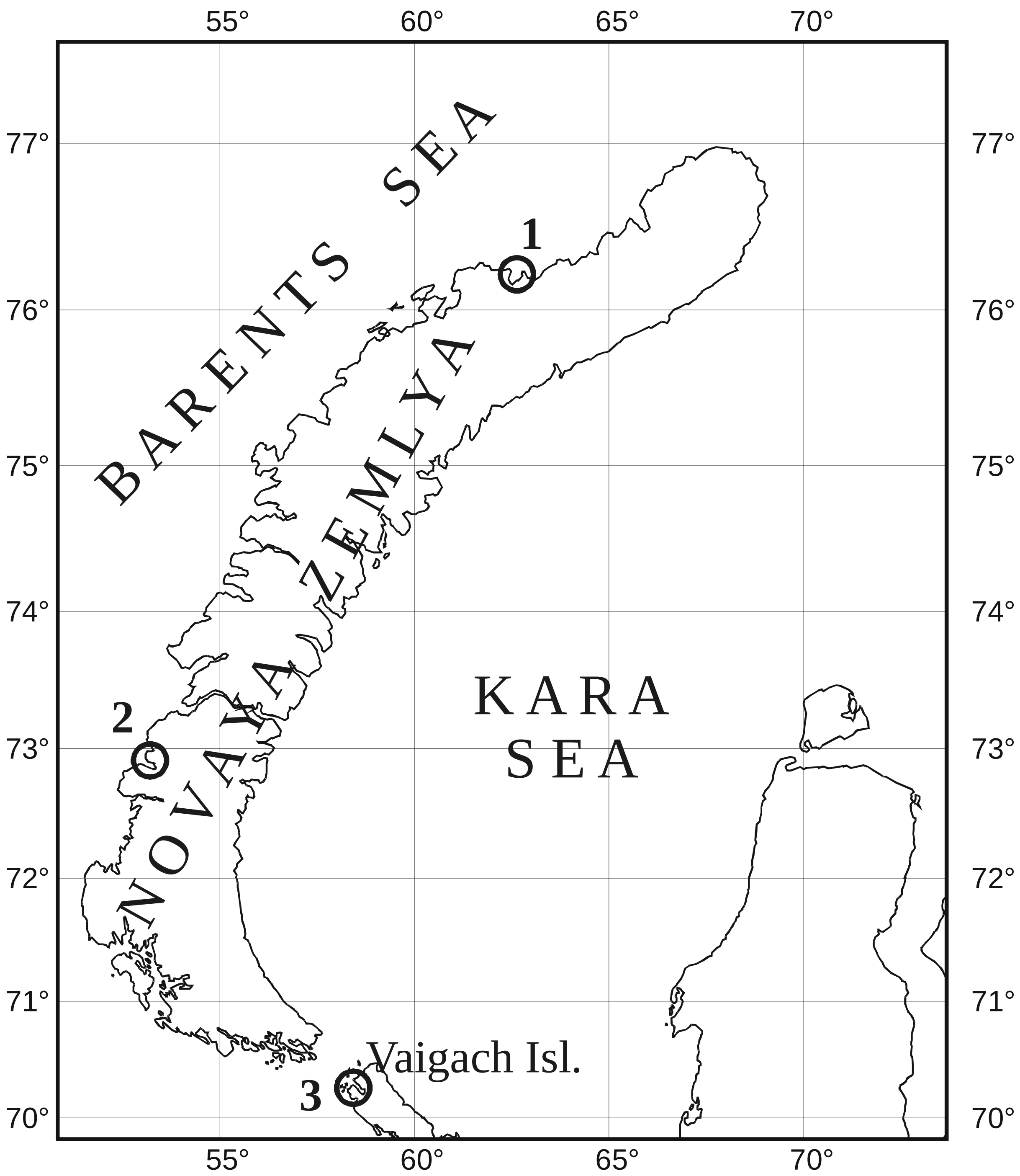

Fig. 1. Position of studied areas: 1 – Russkaya Gavan' Bay; 2 – Bezymyannaya Bay; 3 – Dolgaya Bay.

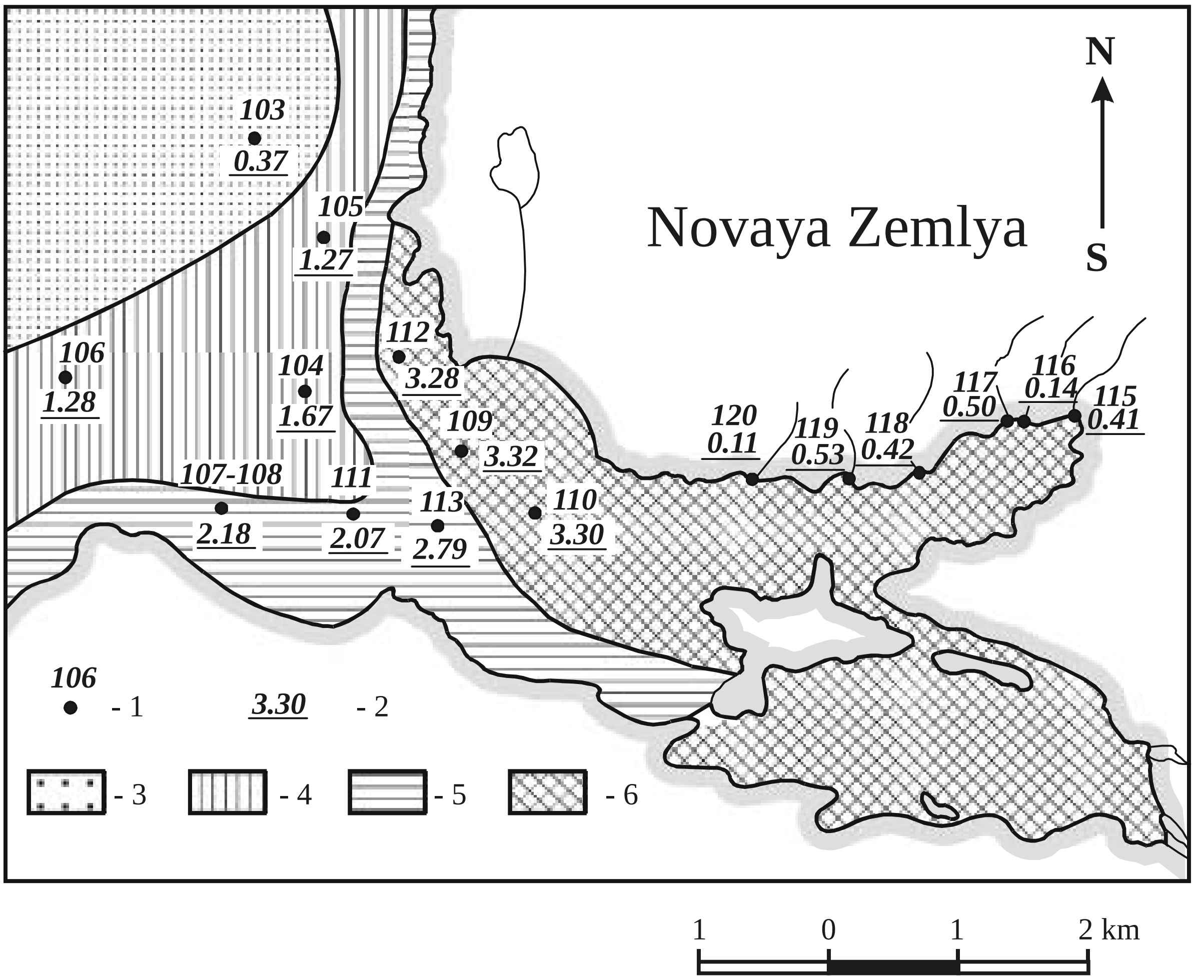

Fig. 2. Distribution of suspended particulate matter (SPM) in the surface layer (0-1 m) of the Bezymyannaya Bay, Novaya Zemlya Archipelago, in September 1994: 1 – station number; 2 – concentration of SPM: 3 – < 1 mg/l; 4 – 1-2 mg/l; 5 – 2-3 mg/l; 6 – > 3 mg/l (Shevchenko et al. 1999b).

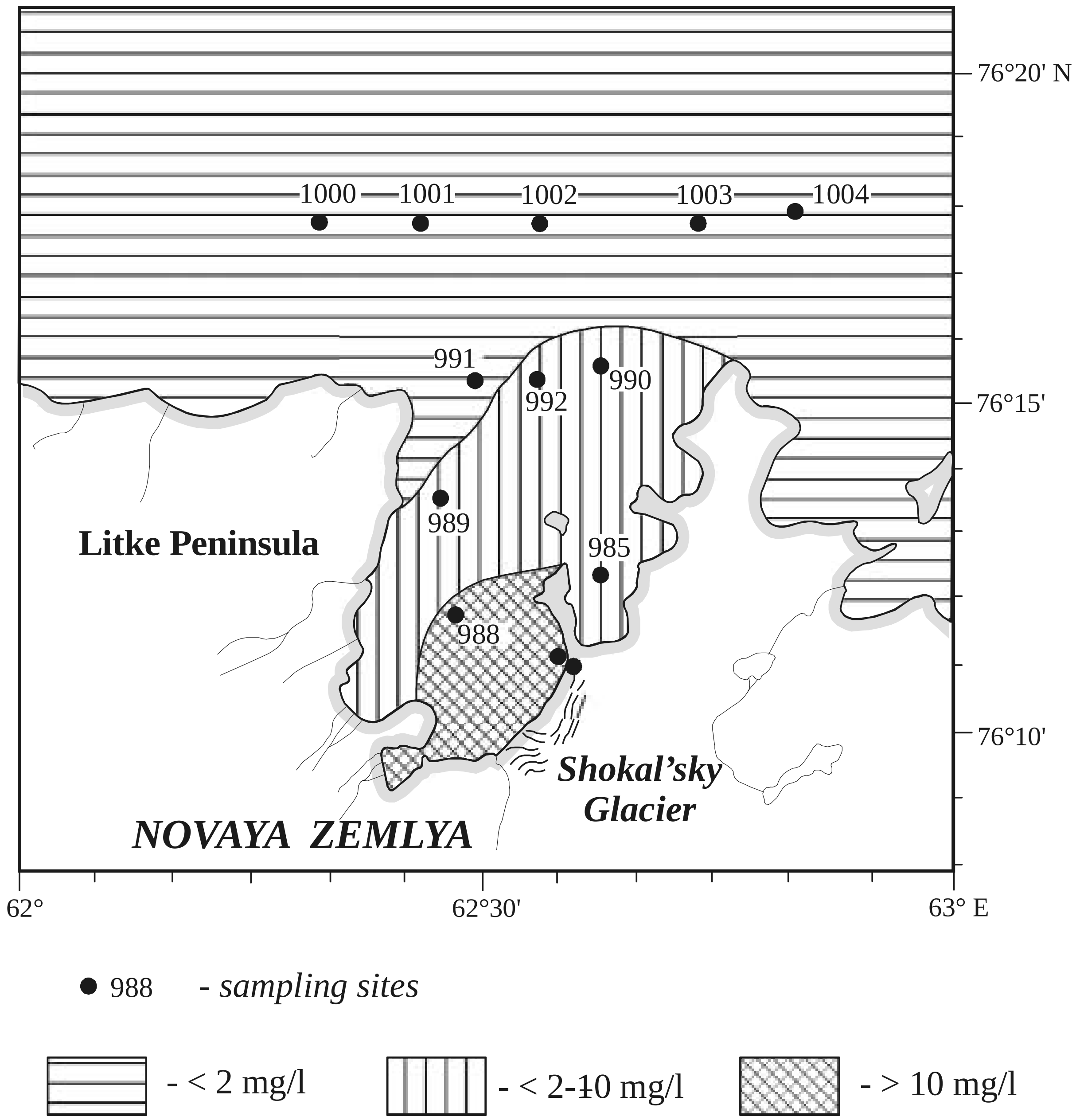

Fig. 3. Distribution of SPM (mg/l) in the surface layer of Russkaya Gavan' Bay, Novaya Zemlya on 22.09 - 24.09.97 (Aibulatov et al., 1999).

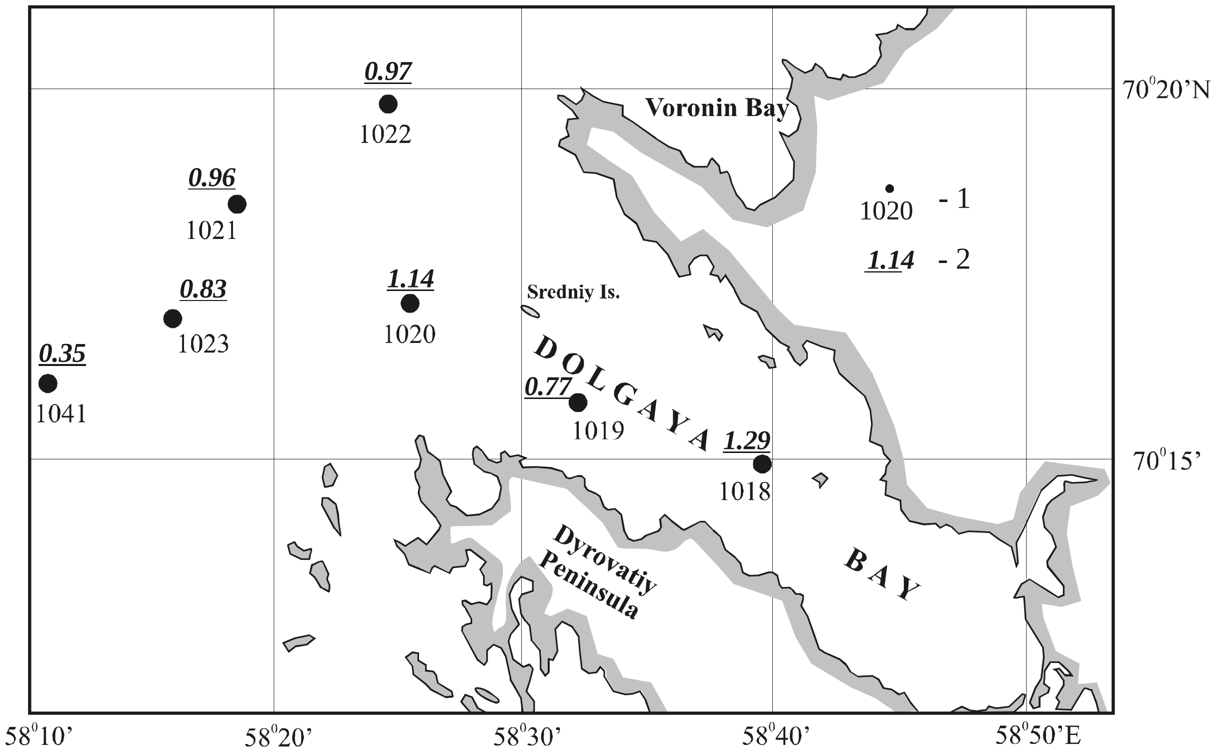

Fig. 4. Distribution of SPM in the surface layer of Dolgaya Bay, Vaigach Island: 1 – station number; 2 – concentration of SPM (mg/l).

SEASONALITY OF SUSPENDED PARTICULATE MATTER DISTRIBUTION IN THE WHITE SEA

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Abstract

Suspended particulate matter (SPM) distribution and composition in the White Sea was studied in 2000-2003 over the course of 17 expeditions. More than 1700 samples were collected by filtration through the Nuclepore filters (pore size 0.45 µm). Along with SPM research hydrooptical, hydrophysical, planktonological, and hydrochemical studies were carried out. These studies were conducted from March to October. Strong seasonal variability in SPM concentration was identified. The highest SPM concentrations were registered during the spring flood (from the middle May to middle June). A second SPM concentration peak was detected during the phytoplankton bloom in summer. Weather conditions, processes in marginal filters, and biological activity strongly influence the distribution and composition of SPM.

Introduction

The study of suspended particulate matter (SPM) in the Ocean (both in remote areas and in the coastal zone) is necessary for understanding modern sedimentation processes and for conducting ecological assessments of the state of the environment (Lisitzin 1996).

In near future the White Sea could become one of the most heavily polluted Arctic seas due to oil production, the timber industry, and diamond mining on the land and in the sea. Previously in the White Sea, SPM distribution was studied by Medvedev and Krivonosova (1968) using membrane filters, which distort the results of suspended matter concentration measurements. The current suite of SPM studies in the White Sea was started in 2000 under the auspices of the "White Sea System" project (Lisitzin 2002). In 2000-2003 over the course of 17 expeditions onboard different research vessels multidisciplinary research, including SPM studies, were carried out in the White Sea (Dolotov et al. 2002; Lisitzin 2002; Lisitzin 2003; Lisitzin et al. 2003; Lukashin et al. 2003 etc.).

Methods

More than 1700 samples of suspended particulate matter were collected in the White Sea in 2000-2003. Water samples were obtained from the water column by Niskin bottles and from the surface by plastic bucket. The filtration of water samples was carried out using pre-weighed Nuclepore filters 47 mm in diameter (pore size 0.45 µm). After filtration, filter papers were washed with distilled water, dried at 50-55 °C, packed in plastic Petry diches, and then sealed in plastic envelopes for later analysis at the institute laboratory. A more complete procedures write-up is found elsewhere (Lisitzin et al. 2003; Lukashin et al. 2003).

Seasonal variations of vertical particle fluxes were measured in the central part of Kandalaksha Bay at buoy station B-16a (66º34.67’ N, 33º47.06’ E, глубина моря 236 м) using a large conical sediment trap (diameter of collecting area is 80 cm, working part height 150 cm with baffle installed) over the period August 20, 2001 to June 30, 2002 (Lisitzin et al. 2003).

Results and discussion

The Northern Dvina is the main source of riverine SPM to the White Sea (Gordeev et al. 1996). SPM distribution in the Northern Dvina mouth was studied during several expeditions. The highest concentrations of SPM in the Maimaksa Branch of the Northern Dvina were registered during flood stage. For example, on 11.06.03 during the 57th expedition of the RV "Ivan Petrov", the average concentration of SPM was 13.2 mg/l. The average SPM concentration in April 2003, during the expedition onboard the RV "Sergey Kravkov", was 2.48 mg/l, and on 20.08.03 during the 55th expedition of the RV "Professor Shtokman", 6.14 mg/l (Fig. 2).

The distribution of total suspended matter (TSM) in the axial part of Dvina Bay (Fig. 1) at the beginning of July 2002 is presented in Fig. 3, and in August 2001, in Fig. 4. The highest concentrations of TSM were registered near the mouth of the Northern Dvina. Concentrations decrease sharply towards the sea and the majority of particles are sedimented in the marginal filter (Lisitsyn 1995). The vertical section is characterized by a pronounced three-layer structure with two maxima of suspended matter concentration: one over the picnocline and a second near the bottom (nepheloid layer). The similar type of SPM distribution was described in the seas of the Russian Arctic earlier (Lisitzin et al. 2000). In general, the concentration of SPM in August (in time of low water and after the phytoplankton bloom) is lower then in beginning of July.

In the central part of the Basin (monitoring site in Fig. 1) the highest concentrations of SPM were also registered in June, at the end of the flood season (Fig.5). The concentrations of SPM in April 2003 and August 2003 were lower.

The seasonality of SPM distribution is reflected in the seasonality of vertical particle fluxes (Lisitzin 1996; Lisitzin et al. 2003). Results of vertical particle flux studies in the central part of Kandalaksha Bay at station B-16a show distinct seasonality (Fig. 6). Flux values increased at the end of December and beginning of January, possibly due to activation of the near-bottom nepheloid layer. In spring the increase of flux is connected with the increase of biological productivity and is typical for this season (Berger et al. 2001).

Conclusion

The strong seasonality of suspended matter distribution and composition in the White Sea has been identified. The highest concentrations of SPM are registered during the spring flood; terrigenous material dominates the composition of SPM at this time. In summer SPM concentration decreases due to the phytoplankton bloom. The lowest concentrations of both terrigenous and biogenic SPM are observed in winter. The seasonality of SPM concentrations is reflected in the seasonality of vertical particle fluxes.

Acknowledgments

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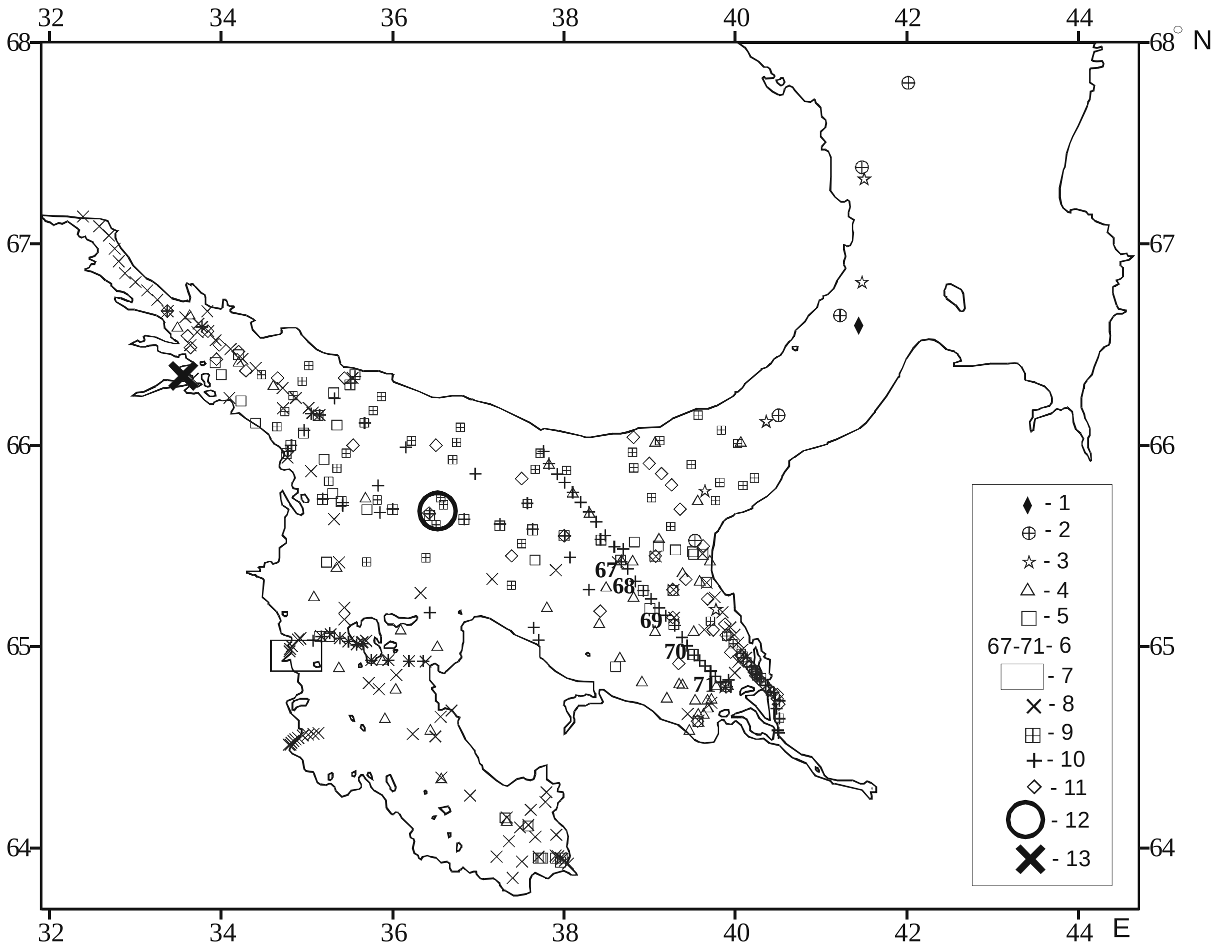

Fig. 1. Position of suspended particulate matter (SPM) studies in the following expeditions: 1 – 11-th cruise of the RV "Akademik Sergey Vavilov", 10.1997; 2 – 13-th cruise of the RV "Akademik Sergey Vavilov", 08.1998; 3 – 14-th cruise of the RV "Akademik Sergey Vavilov", 09.1998; 4 – 49-th cruise of the RV "Professor Shtokman", 08.2001; 5-6 – 52-nd cruise of the RV "Ivan Petrov", 06-07.2002 (6 – stations in axial part of the Dvina Bay); 7 – cruise of the RV "Ecolog", 07.2001 and 08.2002; 8 – cruise of the RV "Ecolog", 09.2002; 9 – cruise of the RV "Sergey Kravkov", 04.2003; 10 – 57-th cruise of the RV "Ivan Petrov", 06-07.2003; 11 – 55-th cruise of the RV "Professor Shtokman", 08.2003; 12 – monitoring site in the Basin; 13 – the biological station "Kartesh".

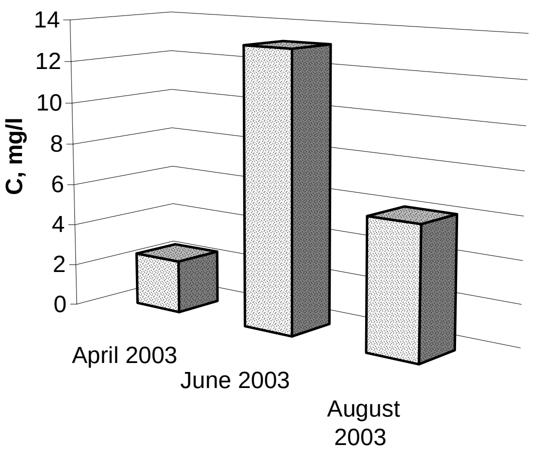

Fig. 2. Average concentration of SPM (mg/l) in the surface layer of Maimaksa Brunch of the Northern Dvina delta in April, June and August 2003.

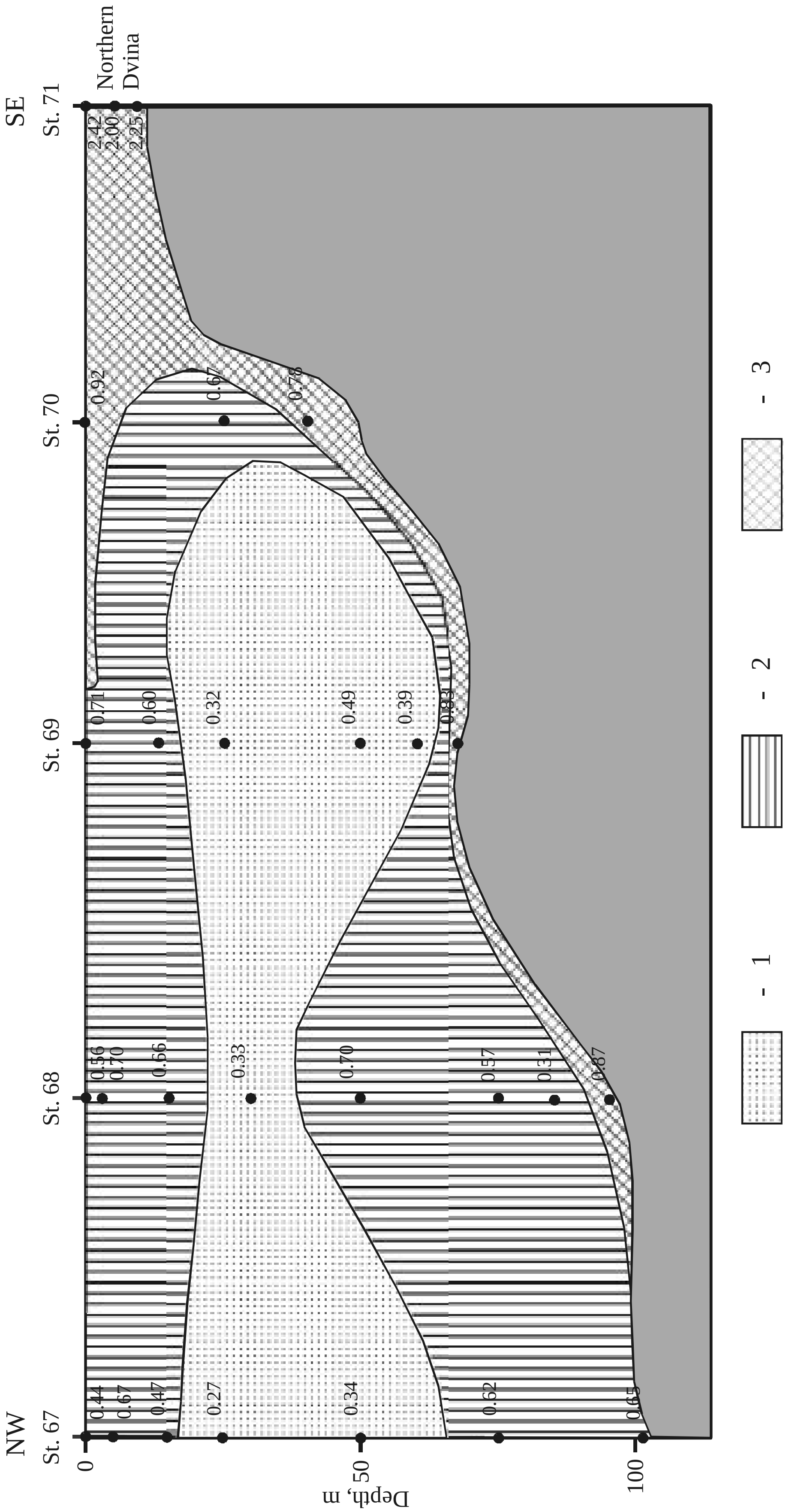

Fig. 3. Quantitative distribution of TSM in the axial part of the Dvina Bay on 4-5 July, 2002 (position of stations is shown on the Fig. 1): 1 – < 0.5 mg/l; 2 – 0.5-0.75 mg/l; 3 – > 0.75 mg/l (Lisitzin et al. 2003).

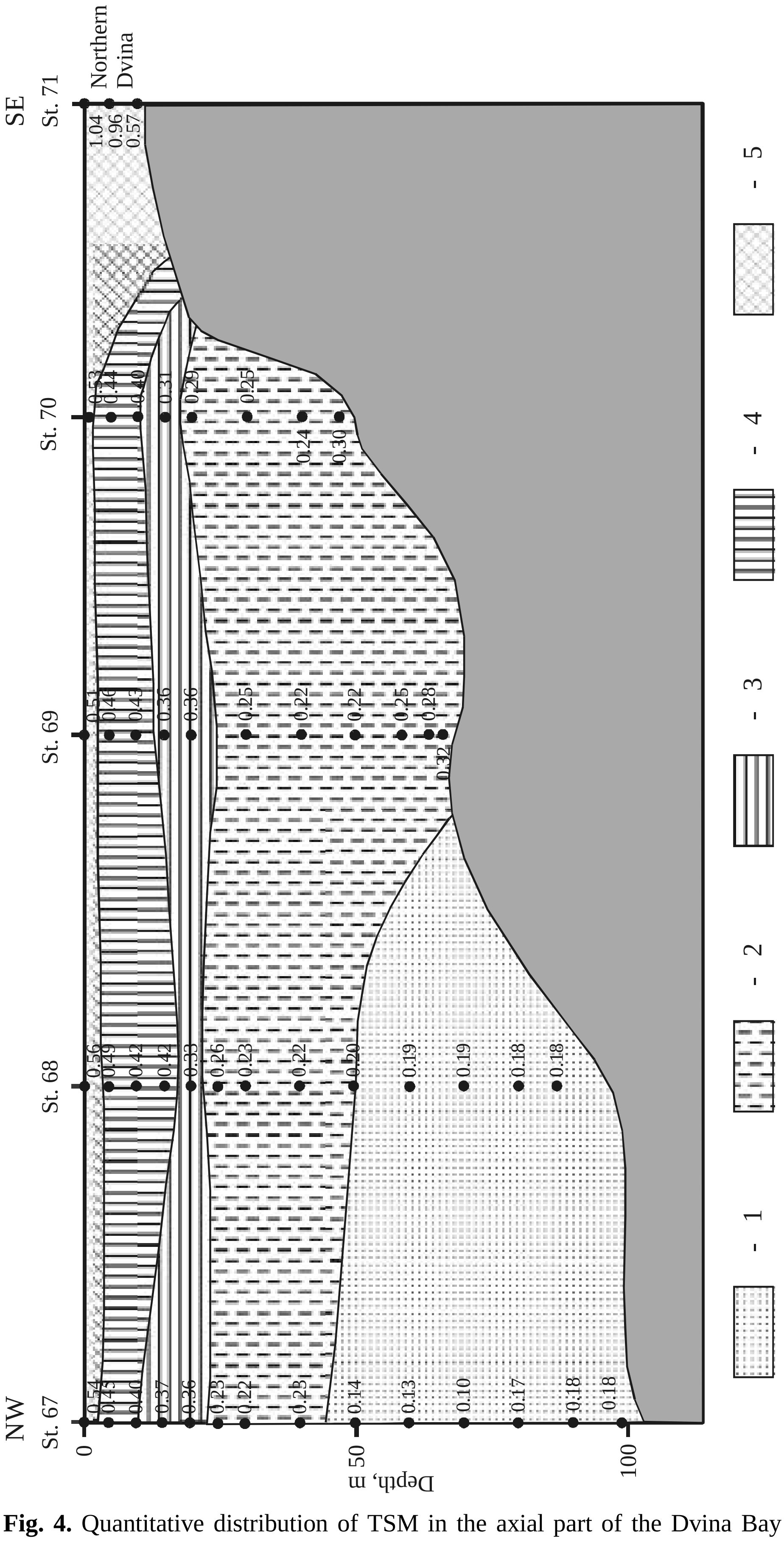

Fig. 4. Quantitative distribution of TSM in the axial part of the Dvina Bay on 11-14 August, 2001 (position of stations is shown on the Fig. 1): 1 – < 0.2 mg/l; 2 – 0.2-0.3 mg/l; 3 – 0.3-0.4 mg/l; 4 – 0.4-0.5 mg/l; 5 – > 0.5 mg/l (Lisitzin et al. 2003).

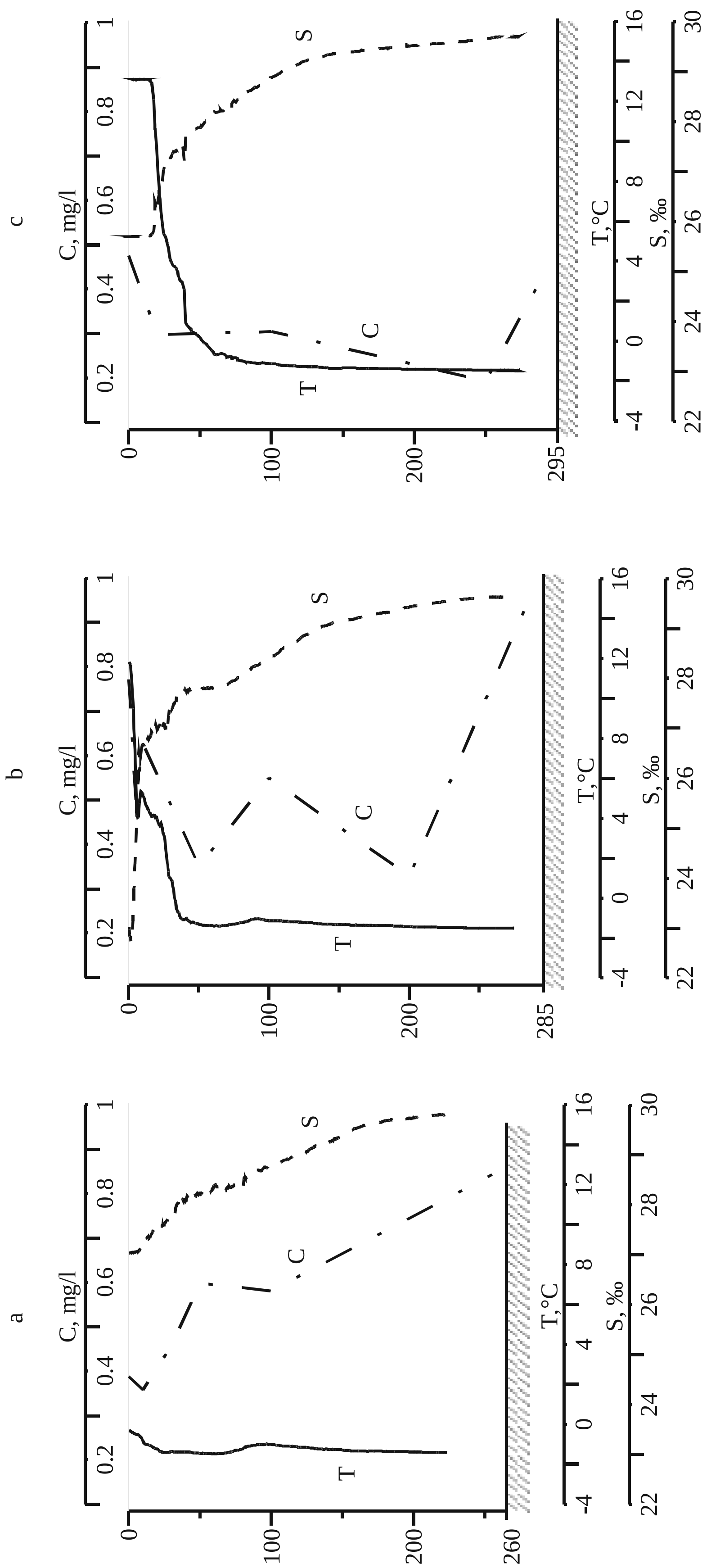

Fig. 5. Seasonal variations of temperature (T), salinity (S) and SPM concentration (C) in the central part of the Basin: a – April 2003, expedition onboard the RV "Sergey Kravkov"; b – June 2003, the 57th expedition of the RV "Ivan Petrov", c – August 2003, 55th expedition of the RV "Professor Shtokman".

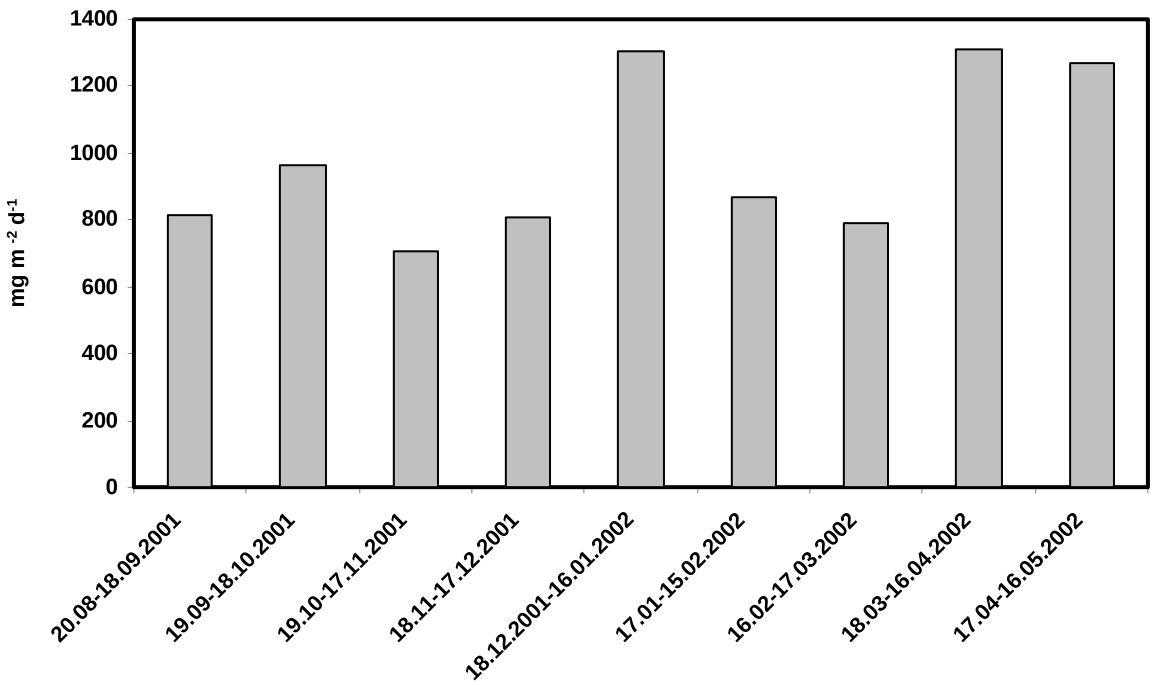

Fig. 6. Seasonal variability of particle fluxes (mg m^{-2} d^{-1}) at the Station B-16a in central part of the Kandalaksha Bay in 10 m above the bottom, depth 236 m (Lisitzin et al. 2003).

RUSSIA-US MARINE CARBON STUDIES IN THE ARCTIC EAST-SIBERIAN COASTAL ZONE - A BRIEF REVIEW OF COLLOBORATIVE STUDIES BETWEEN THE PACIFIC OCEANOLOGIOCAL INSTITUTE AND THE UNIVERSITY ALASKA FAIRBANKS

Semiletov I.P

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Scientific justification

Any attempt to understand the effects of the Arctic Ocean on global change or the effects of global change on the Arctic Ocean requires a thorough understanding of coastal processes. The major transport of fresh water and dissolved and solid materials into the Arctic Ocean is determined by riverine discharges from Eurasia and North America, and by coastal erosion. Therefore, coastal processes form a critical link between land and ocean processes in the Arctic.

Beneath the Arctic Ocean lies the broadest continental shelf area in the world. The continental shelves occupy about 36% of the Arctic oceanic area. The East Siberian Region, ESR (defined as the land-shelf system running from east of the Lena River to the Bering Strait), is the widest and shallowest continental shelf in the world, yet it is the least explored. The ESR has a unique sea-ice regime and some of the highest rates of coastal erosion, sea level rise, and river discharge. Notable as well, the ESR has a strong gradient of biological rates from Long Strait/Wrangell Island to the Lena delta. Thus biological processes, and how they may respond to change, are of critical concern.

The shallow shelf is an important region for processing carbon and nitrogen, with the largest gradients in dissolved oxygen and pCO_2, and nutrients anywhere in Arctic. Following recent definition of the "Pacific Arctic" geographical zone (IASC, 2003), we can consider the ESR as constituting the bulk of the Pacific Arctic zone. It is in this zone where the direct influence of Pacific Ocean water is most pronounced. The coastal zone in this area plays a significant role in the regional budget of carbon transport, accumulation, transformation and seaward export of particulate and dissolved materials to offshore shelf/slopes regions. Riverine input and connections to the Laptev, East-Siberian, and Chukchi Seas are influenced directly by atmospheric forcing. The ESR is influenced by water exchange from the eastern Laptev Sea (warm, low salinity) and Pacific waters from the Chukchi Sea (cold, higher salinity), both of which are under the influence of similar patterns of atmospheric forcing at synoptic scales. The role of the coastal zone in the transport and fate of terrestrial organic carbon has not been adequately considered in the literature, given that it has been stated that coastal erosion plays an important role in the dynamics of coastal permafrost, bathymetry, and transport of terrestrial material.

One of the key questions of biogeochemistry is how the flux of carbon and nutrients will be altered by long-range and interannual variability in the Arctic atmosphere-land-shelf system. We consider the Laptev Sea and the Chukchi Sea as two seminal areas of the Pacific sector of the Arctic: ecosystem of the Laptev Sea is mostly influenced by old, terrestrial carbon introduced via fluvial and erosional means, whereas the ecosystem of the Chukchi Sea is mostly under the influence of Pacific water. The East-Siberian Sea can be considered a transition zone between the Laptev and Chukchi seas

In order to address this question, we are investigating present conditions and the processes that govern near-shore fluxes and movement, as well as interactions of materials in the ESR using a combination of historical data and field studies using modern techniques. Most complex biogeochemical data were obtained in the near-shore zone during the First Russia-US cruise-2003 in the East-Siberian Sea

Further justification for this project can be found at the IARC/UAF web site: http://www.iarc.uaf.edu/east_siberian_cruise.html

The overall goal of the project is to establish the carbon budget in the ESR.

Objectives of an ESR carbon study (Carbon Cycling and ecosystem response) were defined at the IARC/UAF East-Siberian Workshop (Malaga, 11-17 October, 2003) as the following:

a. Determine the magnitude of particulate and dissolved fluxes of old (terrestrial) organic carbon from land (e.g., via riverine input, ocean/turbidity currents, sea ice transport, air mass deposition, clathrate deposits, etc) and its role in food web dynamics.

b. Determine the magnitude of particulate and dissolved fluxes of new organic carbon (marine) influenced by Pacific-derived source water, Laptev Sea source water, sea ice extent, and its role in food web dynamics.

c. Determine the CO_2 and CH_4 fluxes between the air-water-bottom sediments.

d. Determine the role of sea ice in carbon production (ice algae) and carbon flux (horizontal and vertical transport) on food web dynamics.

Another goal is to define connections between atmospheric forcing, river runoff, water circulation, and the health of the marine ecosystem.

Accomplishment

To establish the carbon budget in ESR we conducted 14 ocean expeditions (including the First Russian Trans-Arctic Expedition 2000, and the First Russia-USA cruise in the East-Siberian Sea), 3 river expeditions (along the Lena, including expedition-2003 from Ust'-Kut to the Laptev Sea), and coastal (including the fast ice studies at Barrow and Laptev Sea) (Fig.1). Since the 1999 cruise our field studies have been focused on the transport and fate of old, terrestrial carbon in the land-shelf system. The East-Siberian Region has extremely large gradients of biological activity rates and sediment geochemical properties along both East-West and onshore-offshore directions, although these observations are currently based largely on the concentration gradients in hydrochemical variables. These gradients (Fig.2) are, in turn, modulated by atmospheric forcing, riverine inputs, and variations in advective transports from the nutrient-rich Pacific and the nutrient-poor Laptev Sea and Atlantic waters (AW). The direct influence of AW is deemed to be insignificant over the ESR shelf because available data indicate only occasional penetration of AW up to the 100m horizon (e.g. in the Barrow Canyon, S. Auckley, personal communication; Pipko et al., 2002). The carbon cycle in the western part of the ESR (bounded by a frontal zone which fluctuates from year-to-year between 160E and 175E) is driven by the transport and fate of terrestrial carbon, both fluvial and erosional sources, whereas the eastern part is driven by the marine food web and a variable influx of different water masses from the Bering Sea. It has been found that the ESR plays an important role in the regional carbon budget. Major results can be found in the publications listed below. Some results considered very briefly are following:

The transport of old, terrestrial carbon eroded in the near-shore zone is determined by coastal erosion and fluvial input. An anomalously high pCO_2 value through the water column (up to 2,000 ppm and more) was initially found in the SE part of the Laptev Sea (HV DUNAY-1997). It was assumed that the high pCO_2 values were associated with oxidation of eroded carbon (Semiletov 1999ab), because the riverine signal usually possesses an upper limit of about 1,000 ppm). Further field studies (1998-2003) confirmed this hypothesis (Semiletov, 2000; Dudarev et al., 2000; Semiletov, in preparation). Seasonal variations are very high: in winter pCO_2 can be increased up to 4,000ppm, (Fig.3). Incubation experiments conducted in the winter of 2002 (in Tiksi) demonstrated high rates of degradation of old OC that had been replaced from the ice-complex to the Laptev Sea. The role of coastal erosion in the ESR can be illustrated by examining the distribution of particulate material (PM) in the coastal zone of the East-Siberian Sea in September 2000 (Fig.4), which shows the highest PM values in the Dm Laptev Strait where coastal erosion activity is high (and direct fluvial input is small). Much higher PM values were found in the 1999 cruise: PM values reached a few hundred mg/l from top to the bottom (Dudarev et al., 2000). Some data (Semiletov et al., 2003, in preparation) show that about one half of the old eroded organic carbon is oxidized and released directly to the atmosphere before reaching the sea.

CO_2 flux between air and the sea.

Source: The data indicate that the near-shore zone is the source of atmospheric CO_2. The flux study across the sea ice is now underway by our group (Semiletov et al., 2003, submitted)

Sink: Three field investigations were made in the Chukchi Sea during the late summer: Septemer 1996 (“Alpha Helix”), September 2000 (“Nikolay Kolomietsev”) and late August 2002 (“Professor Khromov”). During all cruises surface waters were undersaturated with respect to the atmosphere. But the mean gradient of pCO_2 values (a negative sign indicates an atmospheric CO_2 sink) differed significantly, ranging between -104ppm in 1996 to -161ppm in 2000, and -132ppm in 2003.

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Artricles

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Laodong G., Semiletov I., Gustafsson O., Ingri J., Andersson P., Dudarev O., White D. Characterization of Siberian Arctic estuarine sediments: Implications for terrestrial organic carbon transport, in press, Global Biogeochemical Cycle (2003).

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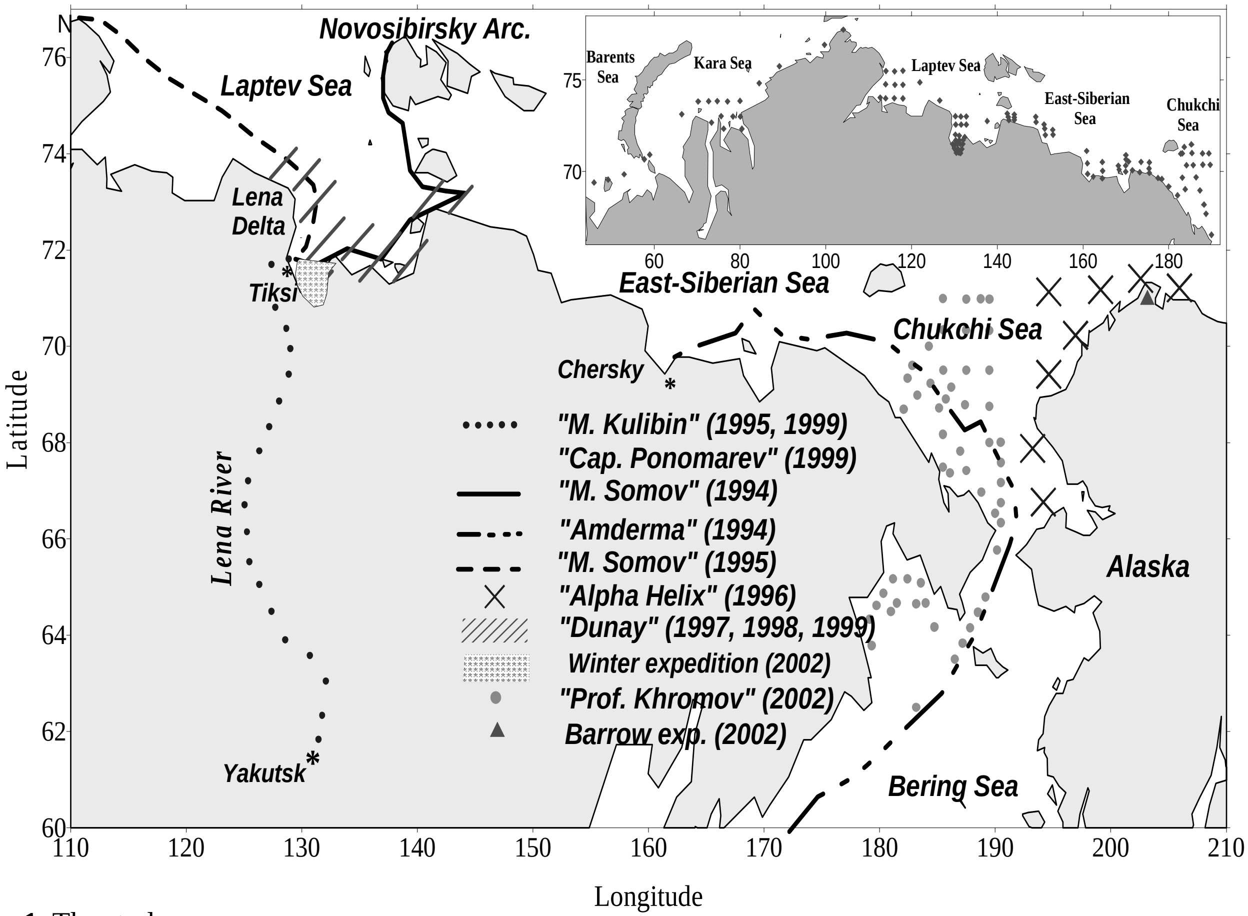

Fig.1. The study area.

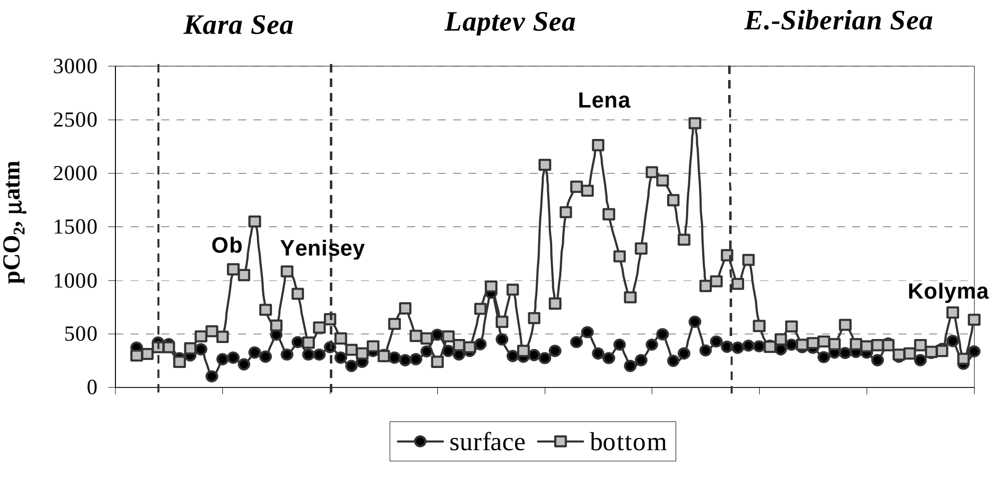

Fig. 2. **Distribution of CO_2 partial pressure (µatm) in the arctic seas in 2000 (Semiletov, 2001)**

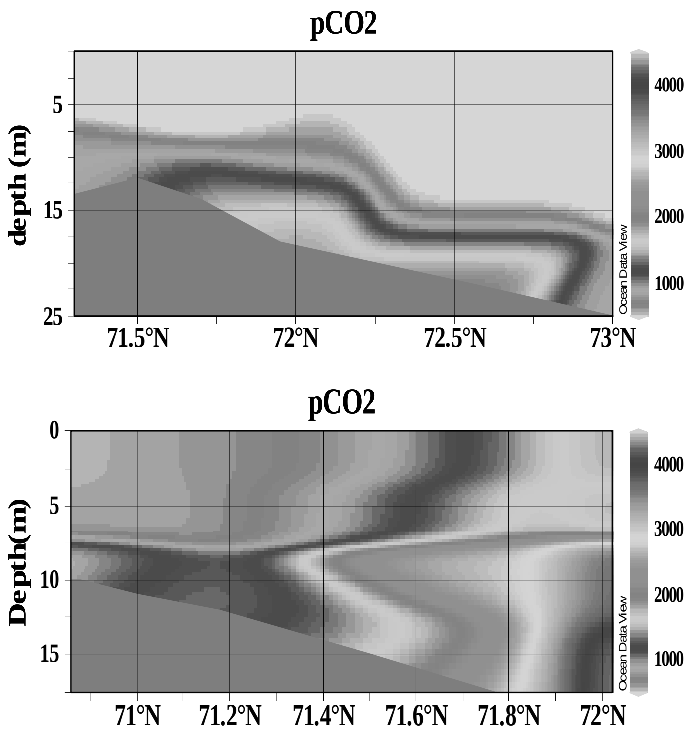

Fig. 3. Vertical distribution of pCO_2, ppm, across the Buor-Khaya Guba (from the south to the north) shows a drastic increase in pCO_2 from summer (September, left) to winter (April, right). Custody of I.Semiletov

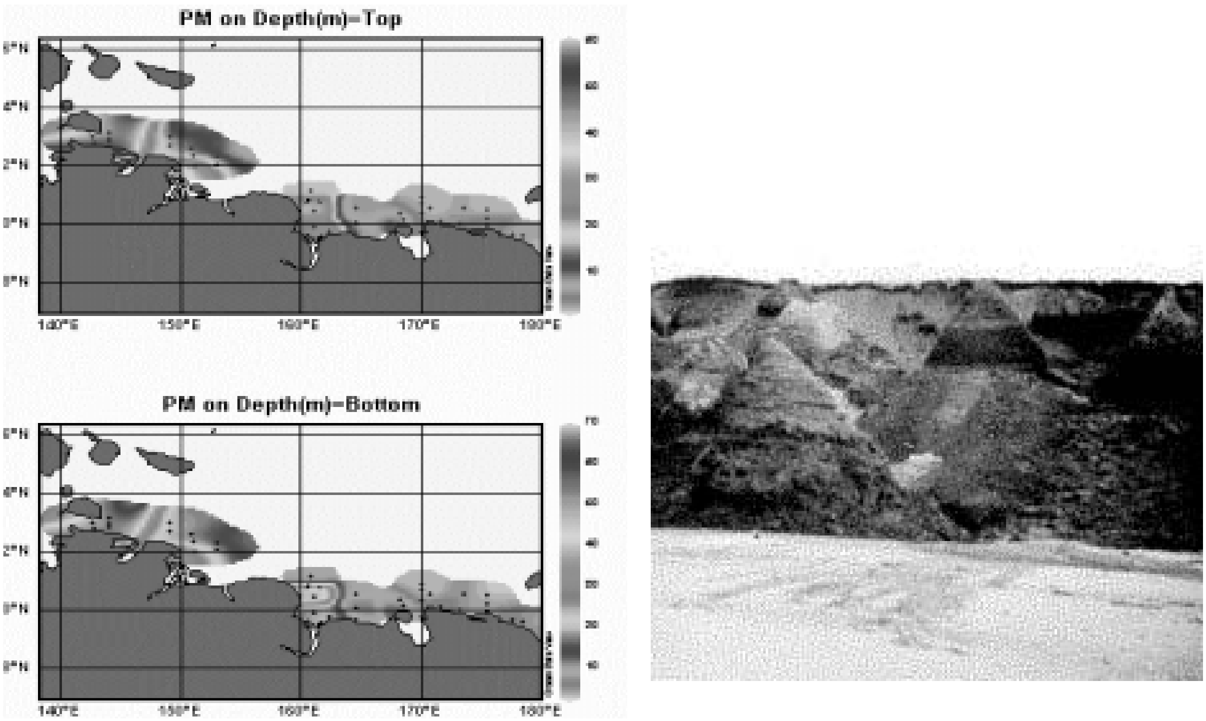

Fig. 4. Left: distribution of PM (custody of O.Dudarev), mg/l, in the East-Siberian Sea (September 2000) in the surface layer (top), and bottom layer (bottom). Right: Coastal erosion near the Cape Buor-Khaya, OC content in the mud near the water edge reached 12%w/w (Semiletov , 1999b).

3.4 ARCTIC COASTAL BIODIVERSITY WORKING GROUP

Working Group Chair: **Christopher B. Cogan**

Participants

Christian Buschbaum, Natalia Chernova, Christopher B. Cogan, Nina V. Denisenko, Michael Jennings, Vladislav V. Khlebovich, Katja Metfies, Thomas Noji*, John C. Roff, Boris I. Sirenko, Vassily A. Spiridonov, Mark A. Zacharias, Christoph Zöckler

*contribution to workshop report, but not present in St. Petersburg

3.4.1 Arctic Coastal Biodiversity – Working Group Summary

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The imperative for Arctic coastal biodiversity assessment

Arctic coastal marine systems are facing unprecedented levels of environmental impact from human civilization. Oil and gas exploration, shipping, mining, tourism, and coastal development activities, as well as regional climate change, have outpaced our abilities to measure, monitor, and manage the region. The mitigation of human environmental impacts that may be possible in balance with economic realities is complicated by a paucity of strategic environmental assessment in terms of basic information, legal frameworks, and consistent international administrative practice. Even with the best of intentions, adequate planning for long-term social, economic, and environmental sustainability will be effective only locally without a formal scientific assessment of biotic structure, composition, and function for the circum-Arctic coastal zone. These multi-scale metrics are all components of biodiversity, as the term is currently used in the scientific literature. In this sense, the quantification of Arctic coastal biodiversity is not only an imperative for the Arctic region and the people who live there, but there is a growing awareness that such measures can provide a vital “strain gauge” for parallel measures in less sensitive coastal zones, providing early warning and technical understanding of related global impacts.

Approaches to address the biodiversity issues

We are approaching an untenable management situation concerning Arctic coastal biodiversity. Decisions are already being made concerning multiple types of regional development without the benefit of adequate environmental assessments that include the integration of multiple spatial, temporal, and thematic scales. Given this imperative, there is a clear need to act quickly, while at the same time maintaining the credibility of good, leading-edge scientific practice. At the invitation of the International Arctic Science Council, a broad based international panel was convened to address this imperative. Functioning as an adjunct working group of the IASC Arctic Coastal Dynamics (ACD) project, we were well situated to capitalize on the existing ACD expertise and data. Our working group approached the biodiversity issues through a series of formal presentations, and facilitated follow-up discussions.

We began in a plenary session with a general overview presentation (C. Cogan), setting the tone of the sessions, and followed up with examples of closely related marine mapping efforts that are currently underway (T. Noji). Following the plenary session, the work group proceeded through a series of topics building up from a solid foundation of conceptual theory and ecological methods towards our primary objective – to reach a consensus on quantitative Arctic coastal biodiversity assessment procedures. This task was initially somewhat handicapped by the varying backgrounds and perspectives of our team, but as the discussions proceeded, we also began to appreciate how these very differences made progress on this interdisciplinary topic achievable. The abstracts for each presentation are included in this volume, following the order of presentation in the workshop. This sequence is important, as it facilitated the buildup of an interdisciplinary approach to Arctic coastal biodiversity assessment through a series of mutually informing presentations that functioned to bridge and capitalize on our individual disciplinary perspectives.

Working group presentations and discussion topics

Our working group began with an introduction to habitat classification systems at the broad conceptual level, drawing on decades of research and recent experiences with their application for biodiversity in national and international conservation programs (M. Jennings). We included terrestrial as well as marine examples to best present the concepts well grounded in science. We brought up questions and issues such as: "How do we define the coastal zone for the purposes of coastal biodiversity analysis?" There are several definitions that are often used, with discipline specific preference, so this was an issue to clarify early on.

From the concepts of habitat classification, we moved to presentations and discussions on existing marine habitat classification systems, including the leading systems from the USA, Canada, and Europe (M. Zacharias).

We also had a series of formal presentations and informal discussions, addressing selected issues and examples of ongoing biodiversity research:

- Comparative studies between the Wadden Sea and Arctic nearshore identifying and describing key habitat types (C. Buschbaum, K. Reise);
- Biodiversity monitoring indicators used by the World Conservation Monitoring Centre including demographics and distributions of indicator species such as Arctic geese, and the modeling of impacts from climate change (C. Zöckler);
- Zoogeography of Arctic fish fauna, describing species richness, distribution, population dynamics, and habitat limitations (N. Chernova);
- Discussion of the Arctic Ocean – Tundra ecotone as an exemplar tying together the structure of coastal topography (marine to tundra), with species composition and ecosystem function (V. Khlebovich).

We concluded our first day's session with an overview presentation and discussion of quantitative biodiversity analysis, drawn from terrestrial ecology concepts that have gained solid acceptance over the last 30 years. We also touched on some of the key differences between terrestrial and marine systems that are important for biodiversity assessment, with the focus of moving from established ecological theory to applied practice (C. Cogan).

In the second day, we addressed several new topics to move us forward towards our focus on Arctic coastal biodiversity assessment. Presentations and discussions included:

- The practical assessment of Arctic Marine Coastal Biodiversity, stressing the importance of representing scale dependant elements and possible surrogates for these elements in a network of marine protected areas (J. Roff).
- Uses of molecular techniques in new ways for biodiversity assessment to assess population structures of protists and microorganisms, as well as the measurement of environmental change via gene expression and protein composition (K. Metfies and L. Medlin);
- Approaches to make the best use of Arctic data collected over the last four decades, and the necessity of including species level information from critical areas (B. Sirenko);
- Elements of zoobenthos diversity, and patterns of variance in the Barents Sea, including temperature variation in water currents and resulting cycles of zoobenthos diversity, emphasizing the need for an integrated environmental and biological approach to biodiversity assessment (N. Denisenko, S. Denisenko, and E. Rachor);

- Threats to Arctic marine and coastal areas, addressing questions such as where and why particular levels of environmental protection are needed, and describing stressor issues such as increasing hydrocarbon development, unsustainable fishing, and coastal development. Socio-political constraints of coastal zone management were also brought forward, reinforcing the concept that biodiversity assessment is strongly linked to human factors outside of typical biological studies (V. Spiridonov).

We concluded the day's session by developing a starting point list of the required elements of Arctic marine coastal biodiversity that will be needed for analysis. In addition to the value of the list itself, this group exercise was seen as a starting point towards building a level of consensus necessary to produce a unified publication on the recommended procedures for biodiversity assessment. In addition to specific biodiversity elements, several key data themes were identified that will allow the most problematic characteristics of the coastal zone to be integrated. Working from the terrestrial coast to the shelf break, we discussed methods to integrate both data and biological concepts to best represent the continuities and discontinuities of these ecotones. Supporting data types include:

- Terrestrial vegetation data such as the CAFF et al. circum-Arctic vegetation map
- Arctic Coastal Dynamics (ACD) coastal segmentation GIS database
- International Arctic estuarine data
- Nearshore and neritic physical and biotic data
- Coastal data, extending to the shelf break.

Most significant, is the ability of this approach to cross the terrestrial-marine boundary in a way that is consistent with structural, compositional, and functional biodiversity elements. This discussion and resultant list met, and exceeded our expectations for goal #1, the development of a list of key biodiversity elements to include in studies of Arctic coastal systems.

The second workshop goal was accomplished in our third day. Drawing from each of the previous presentations and discussions, we outlined a peer-review journal publication, and outlined key sections for further development. The outline calls for a true interdisciplinary approach, international cooperation for a circum-Arctic study area, and a careful blending of well-established science with cutting-edge practice.

Future activities

Our workgroup successfully accomplished the primary goals we set out for – namely to build a consensus on approaches to Arctic coastal biodiversity assessment, the identification of critical parameters, and the initial outline of a manuscript on these issues. Given the many challenges of these goals, we respectively acknowledge the vision and support of the IASC for making this workshop possible. To best harness the momentum of the workshop, we are already planning a sequence of follow-up activities, including the publication mentioned above, a recommendation to the International Conference on Arctic Regional Planning (ICARP II) for a working group theme, and the development of multi-national strategies for a pilot project.

3.4.2 Arctic Coastal Biodiversity – Extended Abstracts

COASTAL MARINE BIODIVERSITY ANALYSIS: CONCEPTS AND ISSUES

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Coastal marine biodiversity assessment is a promising approach to coastal zone management and the design of marine protected areas. In addition, biodiversity research in the coastal zone is also likely to aid a broad span of related marine conservation efforts. In this presentation, I present an overview of our research goals, and the goals of our biodiversity working group. Coastal biodiversity assessment is a logical extension of the Arctic Coastal Dynamics (ACD) project, and I show how such linkages can be useful. I also describe how biodiversity is one component in a sequence of research, how biodiversity fits into an evolving series of conservation targets, and I provide insights to the constituent elements that combine to make up biodiversity. I conclude with a brief list of key issues and questions we will be addressing in the working group.

MARINE HABITAT MAPPING

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There are numerous applications for marine habitat maps in today's society. Marine habitat maps can be important aids to managers with respect to the long-term sustainability of fisheries, the offshore petroleum industry, and the conservation of marine biodiversity. Surveys necessary for the creation of habitat maps employ a suite of technologies working on broad, medium and fine spatial scales. The speed of surveys is generally inversely related to the degree of spatial resolution of the method. The density of measurements will also depend upon the spatial resolution of the technology, whereby broad-scale methods may permit complete coverage, and fine-scale methods may only permit discrete point sampling. Multibeam technology has revolutionized modern mapping of the sea floor, and the introduction of multibeam to oceanographic surveys is akin to the development of aerial photography over land. Multibeam systems differ from conventional echo sounders in having 60-250 beams that simultaneously collect data from a swath of seafloor, rather than from a narrow strip immediately under the ship. The improvement in spatial resolution over single-beam systems is considerable. Aerial technologies also can be useful for the mapping of seabed habitats in shallow areas. Visual techniques such as video and still photographic documentation of the sea floor are an important type of medium-scale groundtruthing. An example of fine-scale groundtruthing is the use of sediment grabs fitted with various cameras. The four basic layers of information needed to produce habitat maps useful for the management of living marine resources are bathymetry, backscatter (which is used to derive sediment type), geology and biology. The most sophisticated high-tech maps today are in the form of animations. Several real-case examples of marine habitat mapping are presented. One such example is the Tampa Bay project, a joint study between NOAA and the US Geological Survey. This project shall help the U.S. to produce map tools to improve hurricane evacuation plans, to better locate habitat restoration projects and to map coastal habitats including associated fauna and flora.

HABITAT CLASSIFICATION FOR BIODIVERSITY ASSESSMENT: LESSONS LEARNED AND OPTIONS FOR COASTAL MARINE ENVIRONMENTS

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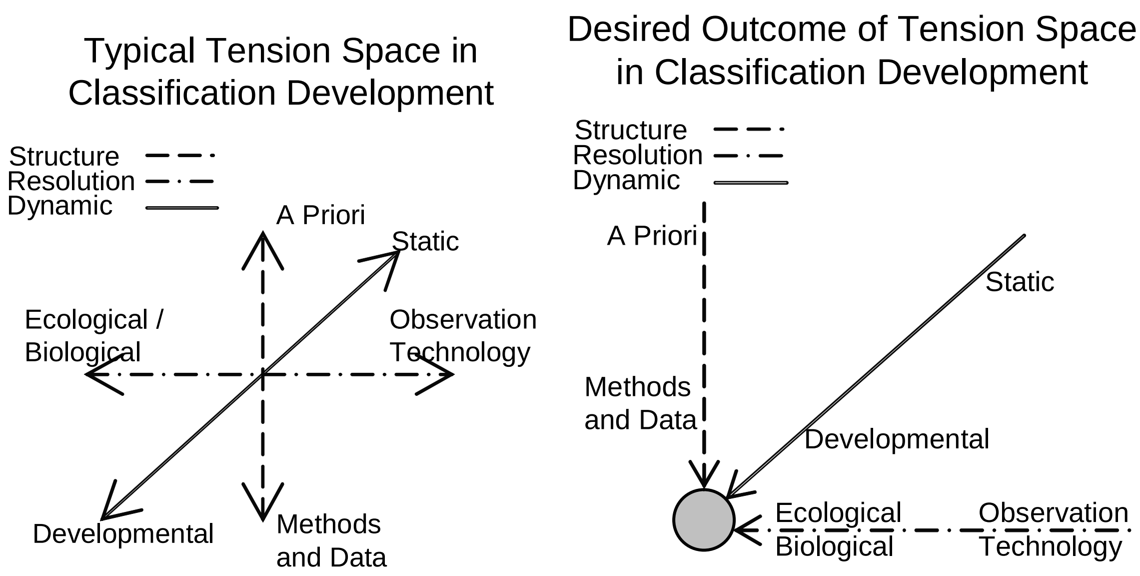
Habitat classification is vitally important to the way high dimensional biophysical information is synthesized and represented quantitatively. It is essential for data reduction, data interpretation, communication, result replication, and comparison among places and times, as well as for the planning and management of land and water resources. In short, habitat classification is foundational to the way biodiversity may be assessed and managed. It summarizes our collective observation and knowledge of patterns in nature as necessary categorical abstractions of a biophysical world that varies in a continuous fashion. Above all, classifications that depict community habitat types (such as a polar subtidal polyhaline upwelling / polychaete dominated bottom) are about species composition (identity and abundance), habitat structure (whether physical or biotic), and habitat function (controls, consequences, and feedback). Habitat classification variables represent environmental conditions across spatial scales, and these combined conditions have an overriding influence on the species assemblages found in a particular habitat. Here habitat classification concepts, and differences between classifications developed for individual versus general applications, are briefly reviewed. Then some of the natural fault lines, or tension zones, commonly encountered when developing a classification are presented and discussed. Should the classification be based on some combination of environmental features, or should it be based only on patterns of species assemblage? What is the appropriate relation between the resolution of ecological themes in a classification and the spatial resolution at which such features may be mapped? I make the argument that a utilitarian habitat classification should be based on ecological units rather than the limits of observational technology, it should be progressively developmental in nature rather than static, and it should use systematic methods driven by field data rather than apriori assumptions (see figure). Examples from the development of a terrestrial habitat classification for North America are used for perspective. Then differences between ecological dynamics of terrestrial and marine systems that could affect habitat classification approaches are pointed out. Finally, options for coastal marine habitat classification based on ordination are discussed.



MARINE HABITAT CLASSIFICATION: POTENTIAL APPLICATIONS IN ARCTIC ENVIRONMENTS

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There is considerable evidence that the terrestrial variables of climate, elevation, and soils have marine analogues with oceanographic and physiographic variables. A number of studies have demonstrated both recurring and persistent associations of marine biological communities with oceanographic and physiographic structures to a degree that the spatial locations of these communities can be mapped with measures of certainty. Unlike the terrestrial realm, however, marine boundaries are ill defined and permeable, marine processes are highly variable and poorly understood, and many marine organisms are highly mobile and patchy over many spatial and temporal scales. Given these constraints, a number of efforts to identify homogenous habitats and communities have been developed in coastal and marine environments. Marine habitat classifications attempt to: a) integrate multiple data sources to infer and predict species, community, and habitat distribution, and b) simplify and abstract numerous and large data sets. Most marine habitat classifications developed over larger areas are based on oceanographic and physiographic information. Biological information, where available, may also be incorporated if biological community structure has not been significantly altered by anthropogenic activities. Regardless of what information is used to develop marine habitat classifications, a good classification exhibits the following characteristics (modified from Emmett & Wainwright 2001):

- The system/method must clearly delineate (using recognizable criteria) repeating community, or habitat types that occur within an environment;
- The system/method must have predictive power, describing the relationships between physical environments and biotic communities;
- The system/method must correspond to species distributions, so that if characteristic species (representative or umbrella species) are protected, biological diversity will also be maintained;
- The system/method should be hierarchical so that description occurs on different spatial scales, allowing for the identification and ultimate protection of lower classification units in the system;
- The system / method should have a global perspective, in which the higher levels of classification are defined by global processes; and
- In a physical or process-driven classification the criteria used must be determinants of biological community structure.

Recent examples of marine habitat classifications applied over larger areas include: the EUropean Nature Information System (EUNIS), the Marine and Estuarine Regions of North America (MEER), and the National Marine Habitat Classification for Britain and Ireland.

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APPROACHES TO ARCTIC NEARSHORE MARINE BIODIVERSITY DERIVED FROM STUDIES ON SEDIMENT SHORES IN THE WADDEN SEA

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Sustainable exploitation of coastal seas requires development of a sound theoretical framework for understanding nearshore marine biodiversity, including genetic, species and habitat components.

In the European Wadden Sea biodiversity research has a long tradition. Fundamental investigations began at the end of the 19th century with the work of Karl August Möbius on subtidal oyster beds in the northern Wadden Sea (Möbius 1877). Based on his research, he defined an ecological community using the term biocoenosis. A term still of scientific validity (Reise 1990). In the first half of the 20th century the initial research was continued by investigations on diversity of benthic organisms in both the intertidal and subtidal zone of the Wadden Sea (e.g. Hagmeier & Kändler 1927, Nienburg 1927, Wohlenberg 1937, Linke 1939, Hagmeier 1941). Since the 1970s the descriptive studies turned to more comprehensive approaches including detailed investigations on species interactions and habitat diversity (e.g. Wolff 1983, Reise 1985, Lozán et al. 1994). Data collected for more than 100 years allow long-term comparisons on biodiversity and their changes due to human impacts. Furthermore, they provide a fundamental knowledge of habitats as well as of species diversity and distribution, and emphasized the Wadden Sea as a unique ecosystem of high international importance. For example, millions of migrant birds use the organisms living on the tidal flats of the Wadden Sea as a food source, enabling long distance flights to their breeding grounds in the Arctic. Thus, migrant birds directly connect both regions.

Comprehensive knowledge of habitat distribution and biodiversity was the basis for protection efforts in the Wadden Sea which mainly started at the end of the 1970s. In 1978 the respective nations (The Netherlands, Germany and Denmark) initiated a trilateral cooperation program to intensify protection strategies. The Wadden Sea ecosystem has been designated a Biosphere Reserve and the German part is a National Park. Experience from this development may help to develop international protection strategies in the Artic.

For example, in a recent large-scale nearshore biodiversity assessment in the northern Wadden Sea, detailed investigations on distribution and abundance of benthic organisms were performed directly in the field and combined with aerial shore surveys. Various key habitats were distinguished and detailed maps were obtained showing habitats and species communities of the area (Fig. 1).

Based on these studies, an approach for Arctic marine biodiversity is suggested. Due to the heterogeneity and huge extent of Arctic shores, it is recommended that a first study selects three pilot sites along the Eurasian coast for relating habitat diversity to species diversity. One of the suggested sites should be close to the Atlantic gate of warm water masses (i.e., White Sea), a second should be close to the Bering gate of Pacific invasions (i.e., East Siberian Sea), and a third should be half way between (i.e., Laptev Sea). In combination with the large data bank on arctic species` distributions collected by Russian expeditions for more than 100 years (Sirenko, Denisenko et al., this volume), the results obtained may give comprehensive insights into biodiversity of Arctic nearshore habitats and, thus, may be essential for sustainable ecosystem development in the Arctic environment. Furthermore, similar to the experiences in Wadden Sea, the study may serve as a baseline for recognizing biodiversity changes caused by human impacts, and for discerning global climate change with rising temperatures expected in the Arctic. We recommend to focus on the transition zone between the land and the sea as the most sensitive and diverse habitat to indicate effects of climate change und human impacts.

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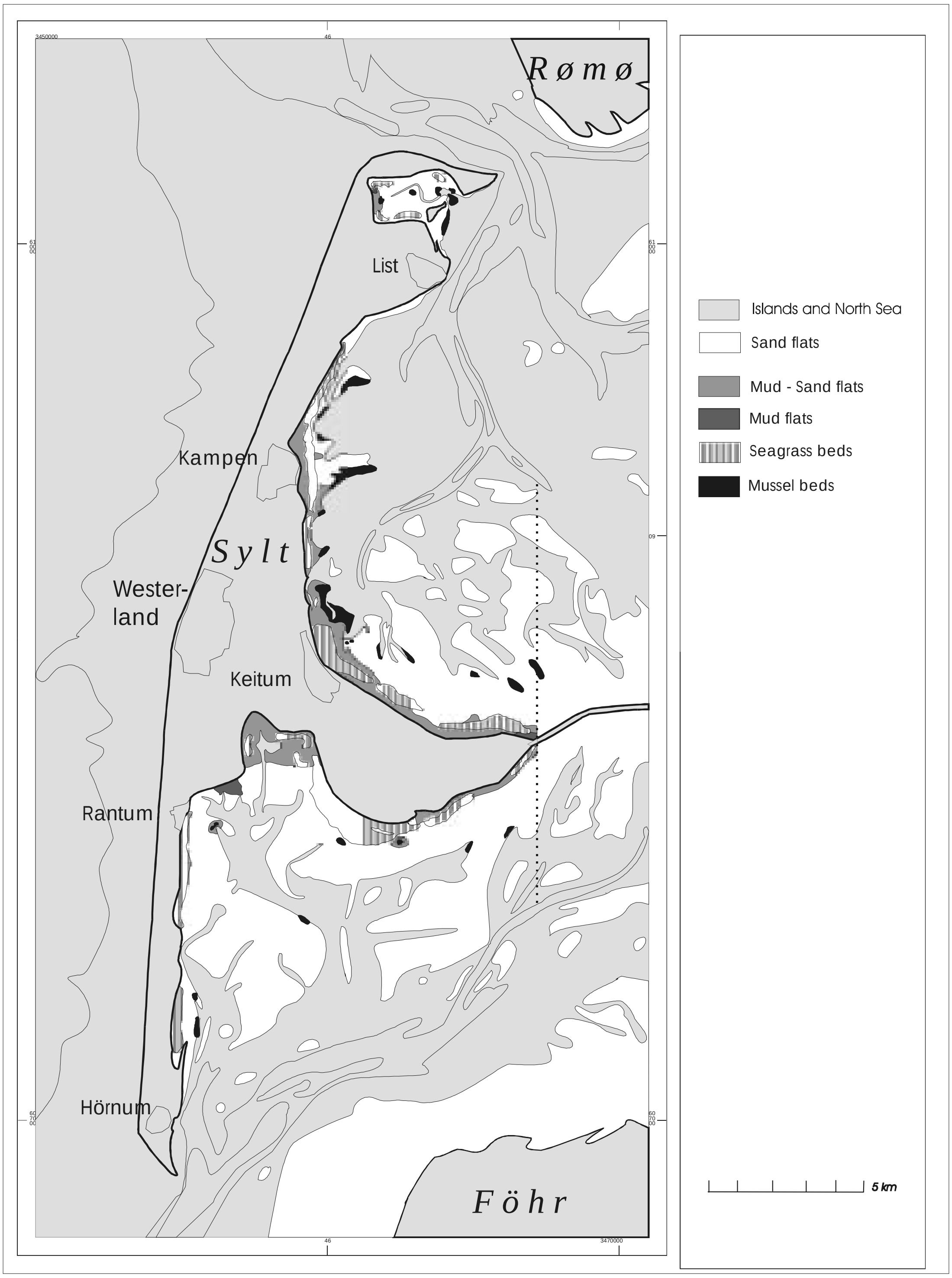

Fig.1. Map of nearshore habitats off the island of Sylt in the Northern Waden Sea as an example for a detailed habitat mapping (German Bight, North Sea; after Lackschewitz et al. 2002). Fundamental knowledge of habitat distribution and biodiversity are the basis for any protection efforts in a coastal environment.

ARCTIC BIODIVERSITY ON THE EDGE: CONSEQUENCES OF ARCTIC COASTAL DYNAMICS AND RELATED IMPACTS ON COASTAL BIODIVERSITY

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The UNEP World Conservation Monitoring Centre (UNEP-WCMC) is compiling, maintaining, and facilitating data on global, regional and national biodiversity with the help of a huge network of stakeholders. For the Arctic region, spatial data on habitat and species distribution is available on a circumpolar scale together with data on protected areas in digital form. They can be displayed, analyzed, and assessed for impact studies, such as those by coastal erosion on biodiversity. Coastal erosion is an impact on vulnerable coastal ecosystems and habitats through a combination of mechanisms, such as sea level rise and increased levels of storminess (Grevemeyer et al. 2000, Atkinson pers. comm.). Whereas the marine aspect of Coastal Biodiversity and its classification has been investigated on a global scale (Zacharias and Roff 2000), little is known for the Arctic Ocean. Data on fisheries and coastal benthos exist for selected regions along the Russian Arctic coast, but are often sparse for other parts of the Arctic. Yet, there has been little focus on the terrestrial biodiversity in the context of coastal erosion. However, Adam (2002) emphasized the vulnerability of salt marshes due to coastal erosion and Pethick & Crooks (2000) even suggested a coastal vulnerability index.

Terrestrial biodiversity data is scarce on a circumpolar scale. A circumpolar vegetation map is available, but does not cover most parts of the European coast, the Bering Sea coast, and most of the Hudson Bay coast (CAVM Team 2003). Birds and mammals have been best investigated and data for water birds and seabird colonies are available on a circumpolar scale. Often the data available only comprise the distribution, rarely good population estimates and even more rarely trend indices over longer periods of several decades. For selected water birds such as geese these data are largely complete for all 12 Arctic species. Likewise, good data exists for many, but not all 70 Arctic breeding wader species. Due to their migratory behavior, Arctic water birds can be assessed outside their remote breeding areas and trend data have been compiled from the various wintering areas around the entire globe. Through long-term bird ringing schemes we now have a better understanding of global flyway patterns and can link populations monitored outside the Arctic to specific Arctic breeding areas (Boere 2003). Other bird species and non-hunted mammals are poorly monitored. Data on seabird colonies are scarce and only complete for the circum-Arctic region for the two guillemot species (*Uria spp.*). Data on coastal breeding gulls and terns are scattered, while information on coastal breeding eider ducks (*Somateria spp*.) and other coastal ducks are better.

Selected water birds breeding in the Arctic have been investigated to assess the potential impacts on terrestrial habitat related to climate change (Zöckler & Lysenko 2000, summary in Rachold et al 2003). The study applies the HadCM2 general circulation model (GCM) of the Hadley Centre to compare the current distribution of 25 avian species with changes in vegetation predicted by two climate scenarios, a moderate one based on rise in temperature of only 1.7^{0}C (HadCM2SUL) and an extreme scenario with a rise of 5^{0}C (UKMO) at the time of CO_2 doubling (2070-2099).

The results of the vegetation models show a large variation in the impact of predicted changes in vegetation on the 25 species. According to the moderate HadCM2Sul, 76% of Tundra Bean Geese (*Anser fabalis rossicus/serrirotris*) will be affected by the alteration of tundra habitats, whilst only 5% of the Sanderlings will be affected. For two of the three water bird species considered globally threatened, namely the Red-breasted Goose (*Branta ruficollis*) and the Spoon-billed Sandpiper (*Eurynorhynchos pygmeus*), 67% and 56% respectively of their current breeding range will change from tundra to forest. The values for the extreme UKMO scenario are even higher, reaching 99% for the Red-breasted Goose. This additional loss of habitat will place these two species at a higher risk of extinction. The Emperor Goose (*Anser canagicus*) is already in decline and with 55% of its small range affected, is highlighted as needing further conservation attention. The study did not take habitat changes on a finer scale into account. However, it can be assumed that southern tundra types will move northwards in the same mode as the forest does and gradually replace the northern tundra vegetation zones northwards to the edge with the High Arctic Desert species which in turn will have little space to retreat.

The results from this study require careful interpretation. As all biological processes these scenarios have to be interpreted in relation to other factors affecting the populations of these birds, such as natural predation, hunting (mainly outside the Arctic) and other effects of climate change (in particular sea-level rise) outside the Arctic.

In the context of Arctic coastal erosion habitats and associated species in the coastal zone are under additional threat from the sea. Increased wave energy (Atkinson in this Vol.) and sea level rise is changing the coastline already. Grigoriev et al. (in this Vol.) estimate the annual loss e.g. on the Laptev Sea coast with 1,5 meter with an increasing trend. Other differently structured coastlines might encounter an even more severe impact. Flat coastlines, salt marshes and estuaries are particular vulnerable. Lagoons and Spits might be under particular threat. On the other hand coastal erosion also might create new habitats in time for many of the species to retreat or adjust. Several of the investigated species under the habitat change scenarios are distributed only locally in the coastal zone. Already affected quite strongly by the perspective of tundra loss due to forest extension these species also face habitat loss by coastal erosion. Among the Geese, the Brent Goose (*Branta bernicla*) with its three subspecies, the Emperor Goose and the Spoonbilled Sandpiper appear to be specifically vulnerable due to their exposed coastal distribution. Both of the latter are not distributed more than five or six kilometers inland. In total, 15 out of the approx. 130 Arctic breeding water birds (Scott 1998, Zöckler 1998) are breeding almost exclusively in coastal habitats and will be severely affected by coastal erosion. This includes the species mentioned above and in particular most gull and tern species, and most of the four Eider species, whereas the King Eider (*Somateria spectabilis*) also penetrates further inland. However, many more bird species breeding further inland favor coastal or near coastal lowland habitats and are similar threatened by coastal erosion. Most of the other seabirds are cliff-breeding birds, less vulnerable to coastal erosion.

Future research will need to refine the existing results, based on improved and updated GIS data on distribution and refined GCM's. Other important components such as sea level rise, coastal erosion and the change in river runoff in the Arctic need to be taken into account in future impact assessments. The strength in future assessments lie in the spatial integration of various GIS data compiled in the ACD context. A vital precondition for any integrative assessment of the impact of coastal erosion is the collaboration of several stakeholder and custodians, all interested in the integration of several large datasets on a circumpolar scale. Arctic Coastal Dynamics (ACD) already established an internet map server (IMS) serving circumpolar data sets on coastal data. UNEP-WCMC similarly established an Arctic IMS and will be in the position to incorporate biodiversity data into an ACD – IMS for data integration and future analyses.

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FISH DIVERSITY IN THE ARCTIC MARINE COASTAL ZONE

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The total number of fishes and fish-like vertebrates in the Arctic is about 416 species, which belong to 227 genera and 96 families (Andriashev and Chernova, 1994). This number includes Arctic fishes living permanently and breeding in cold waters with temperatures close to 0° C as well as warm-water migrants. Most of the migrant species enter for feeding, but do not reproduce in the Arctic waters.

One may classify these Arctic species 1) in terms of salinity: marine, diadromous (anadromous, semi-anadromous, catadromous) and freshwater species, occurring temporarily in brackish waters; 2) in terms of connection with the bottom and mid-water: benthic, near-bottom, bentho-pelagic, nerito-pelagic, cryopelagic, bathypelagic; 3) in terms of geographical distribution, which is related to adaptations for temperature and salinity: Arctic species, mainly Arctic, arcto-boreal, mainly boreal, boreal, south boreal, and widely distributed (see for details: Andriashev, Chernova, 1994); 4) in terms of the origin (Atlantic or Pacific families of fishes).

Discussing the fish diversity in the Arctic marine coastal zone we should consider the fish zoogeography of the Arctic area. Overviews have been published by Andriashev (1985). In the Arctic Ocean and adjacent waters, the following complexes of fish species ("faunas") can be distinguished, based on types of distribution, biology, and historical origins:

1) Arctic circumpolar fish fauna distributed mainly in shelf areas of the Arctic seas, containing many endemic euryhaline species (*Triglops nybelini, Lycodes jugoricus, Artediellus scaber* etc.);

2) Arctic bathy-abyssal (Scandic) fauna living at depth in the central Arctic basin (below 800-1000 meters), in the deep waters off Greenland, and the Norwegian and Baffin seas. This complex is still poorly known (11 species only) and contains mainly stenohaline deep-sea endemic species permanently living at negative temperatures (*Gaidropsarus argentatus, Paraliparis bathybius, Rhodichthys regina, Lycodes frigidus* et al.).

Various Atlantic boreal fauna reach northward to the southern part of the Labrador Peninsula, to southwestern Greenland, Iceland, and to the southeastern waters of the Barents Sea (partly to the White Sea and Spitsbergen). Pacific boreal fish fauna spread northward, mainly to southern areas of the Anadyr Bay and Norton Bay (partly penetrating into the southern Chukchi Sea). Deep-sea (abyssal) ichthyofauna of the Atlantic and the Pacific Oceans do not reach the Arctic Ocean: the Atlantic abyssal fish fauna occur only southward of the Faroe-Iceland underwater ridge, and the Pacific abyssal fauna inhabit the depths southward of the Bering-sea shelf.

Thus, the Arctic marine coastal zone (from the eastern Barents Sea eastward to the Chukchi Sea and along the Canadian Arctic to northern Labrador, Greenland to northern Iceland) is inhabited by Arctic fish fauna consisting mainly of endemic euryhaline species. In the marginal Arctic areas (south-eastern Barents Sea, Labrador coast, southern Chuckchi Sea and others), the Arctic fish fauna are enriched by representatives from the boreal Atlantic and Pacific.

Inside the circumpolar Arctic marine coastal zone, estuaries of numerous large and small rivers must be distinguished as specific ecosystems. Fish complexes inhabiting these zones include about 20 anadromous, and semi-anadromous fishes, as well as those freshwater species which can enter brackish estuarine waters. These fish usually do not occur in the waters of higher salinity (*Acipenser baeri baeri, Coregonus autumnalis, Stenodus leucichthys nelma* and others). On the other hand, some marine fish which have adapted to low salinity (almost to fresh water) also occur there (*Triglopsis quadricornis, Plathichthys flesus* and others).

Other areas of the vast circumpolar Arctic marine shelf are inhabited by ichthyocen, which include about 33 marine euryhaline species, at least 11 of which are distributed circumpolarly (such as *Lycodes pallidus, L. polaris, Artediellus scaber*). Some of these species occur more often in the deeper zone closer to shelf margin, whereas others prefer more shallow coastal waters. The littoral zone in the high Arctic is a harsh environment because of ice presence most of the year.

Benthic species predominate in the Arctic areas. Typical pelagic and bentho-pelagic fish fauna are practically absent in the high Arctic; persisting only to the Arctic marginal waters. Instead, in the high Arctic mid-water so-called cryopelagic fish species are widely distributed (*Boreogadus saida, Arctogadus borisovi*). The life cycles of these species is associated entirely with the pack- and seasonal ice. They are numerous and reach northward to the North-Pole area. These are indigenous species, which have separated to the level of endemic genera (Andriashev, 1970).

Thus, at large scales, fish complexes are generally related to their habitats. The distribution of ichthyocens coincides with the distribution of main water masses in the basin, and these masses are related to some extent with general forms of land and bottom relief. It is also critically important to include historical factors. For example, in the shelf areas of the North Pacific and the North Atlantic that are adjacent to the Arctic, there are numerous fish species with disjunctive (amphiboreal) distributions (which are currently absent from the Arctic seas). These distributions occurred as a result of fish migrations from the Pacific and the Atlantic through the Arctic in former times during the sea transgressions and warmer climate before and after the upper Pliocene glacial period (Berg, 1934). Analysis of the distribution types and the stages of differences between amphiboreal taxa support the current migration route hypothesis (along Siberian coast or along the Canadian Arctic) and estimated time of origination. Of significance is that similar Arctic coastal biotopes (American and Siberian) with similar abiotic conditions can be inhabited by different fish species due to historical reasons.

In conclusion, biodiversity in the marine coastal zone is dependant on zoogeographical conditions. One should clearly understand, for example, where zoogeographical borders (barriers between different faunas) exist; or risk an unreliable hypothesis. As one example, differences in biodiversity between two closely situated coastal areas (e.g. the Murman coast of the western Barents Sea and the western Kara Sea coast) can be much larger than biodiversity differences between two widely separated sites (e.g. the very similar western Kara Sea coast and western Chukchi Sea coast).

At larger scales, species distributions are less clear, and zoogeographical descriptions are more generalized. In the eastern coastal zone of the White Sea, the basin is inhabited by both Arctic and boreal fish species in a mosaic pattern. Spawning and wintering migrations are common, and species presence varies with the seasons of the year.

Biodiversity is an important ecological parameter in the coastal zone. It also may have a large practical application in ecological studies of human impacts on marine coastal ecosystems.

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LAIDA AS ECOTONE BETWEEN THE ARCTIC SEA AND TUNDRA

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The border between the sea and land on the vast space of Russian Arctic exists as the frontier amongst the sea and lake-marsh tundra. In the many places the shores are so low that the slightest oscillation in sea level moves the shoreline great distances in either direction. The tides here are not always expressed, but the atmospheric sleeves and pileups are very usual. Therefore, there is no possibility to establish the longevity of shore line in Russian Arctic as in many localities it is undergoing change. As a great part of the summer season tundra surface is covered by thawed small lakes, the oscillations of sea level result in mixture between marine and fresh waters. This situation was observed by the author in the aircraft expedition of AARI in 1983 the purpose of which was to estimate the distribution of the so called “oil” (carbohydrate) spots” in Arctic waters. It was seen that such kind of film spots were transported to sea under departure of water following intrusion into tundra. Evidently, the formation of this film is related to tundra organic material, i.e. peat. Undoubtedly, there also exists the opposite process of transportation from sea to land and tundra lakes.

The periodic contact of such different biocenoses as marine, freshwater and land is typical of ecotones; the phenomenon characterized by ridge effects with an increase of species biodiversity and general biomass. This phenomenon was observed by us on the shore of Chaun Bay (East-Siberian sea) in the basin of Puchiveyem river. Tundra lakes were referred to as two groups: 1) usual, which are not exposed to seawater, and 2) “ fringe tundra oligohaline lakes”, periodically covered by seawater. In the moment of observation the salinity in the later lakes was near 2 ‰. The mean density of benthos (6270 ind/sq.m) and its biomass (25.0 g/sq.m) in Chaun lakes were on the order of magnitude more than in the other high Arctic lakes studied in this respect by Strelezkaya (1972). The quantitative values of plankton were quite high - the mean density 4360 ind/sq.m, biomass - 1.74 g/sq.m. The high productivity of ecotone shores is apparently connected with the lower bank vegetation and diversity and increase of water-fowl abundance.

On the ecotone ecosystem of this part of Arctic tundra which is periodically flooded by sea water, I propose the local name “laida” so correctly and sonorily described this subject as included into world literature from Russian local words taiga and tundra. From typical salt marshes widely investigated in many countries laida is differing by high-Arctic character both sea and lakes or land, with its bottom permafrost.

It can be assumed that the extreme low volume of knowledge about so widely distributed border ecosystem is connected not with physical difficulties of working in Arctic, but with historical isolation of sciences. The report presented has the purpose to initiate the program of researches of laida with participation of specialists in biology, hydrology, hydrochemistry, hydrology and soil sciences.

QUANTITATIVE BIODIVERSITY ANALYSIS: A CRITICAL STEP FOR COASTAL PLANNING

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Coastal marine biodiversity assessment is an important component of coastal zone management and the design of marine protected areas. Unfortunately, the term “biodiversity” has been popularized and adapted to an increasingly broad range of meanings that obfuscate the term to the limits of usefulness. Here, I outline how biodiversity fits into specific coastal management research goals, as part of a sequence of objectives. Just as biodiversity defies rigid definition, it also resists useful quantification. I outline why this is an inherent property that represents a balancing point between measurement precision and ecological relevance. Understanding such background theory is important to bring forward the concepts of biodiversity to become a pragmatic conservation utility. As a utility, biodiversity assessment is the quantification of ecological elements that span vast spatial, temporal, and thematic scales. I present an overview showing why these scales are important, and give examples of how they can support – rather than degrade – our analysis. Biodiversity assessment incorporating multiple scales requires more than a strong ecological foundation, and I briefly describe the nexus of biodiversity with data structures, data handling tools such as geographic information systems (GIS), and data synthesis. In summary, I propose how our research and management goals can guide a logical sequence of investigation, from habitat classification to the design of marine protected areas. I also propose a set of biodiversity elements that best represent the ecological conditions we are trying to measure and monitor.

Keywords: biodiversity, marine reserves, marine protected areas, geographic information systems (GIS).

ASSESSMENT OF MARINE BIODIVERSITY AT MULTIPLE SPATIAL SCALES

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The components of Marine Biodiversity occupy the spectrum of structures and processes from the genetic to the ecosystem level (Zacharias and Roff 2000). One overall goal for marine conservation (necessary but not alone sufficient) should be to capture as many of these components as possible in regional Networks of Marine Protected Areas (MPAs). This is a complex task, because the various components of biodiversity are strongly scale related. Conservation initiatives may be undertaken at various scales from local to international, inevitably biasing any view of the relative importance of biodiversity components. However, such biases can be substantially evaded if we explore how to combine all possible components of biodiversity into comprehensive frameworks at local, regional, and global scales. In order to achieve the goal of conservation of marine biodiversity, it is necessary to tackle the following issues:

- Define the components of marine biodiversity, using starting points such as those described by Zacharias and Roff (2000);
- Show how these components relate to an overall framework for marine conservation that includes representative (~common) and distinctive (~unique) habitats in a network of connected MPAs;
- Define the scales at which the various components of biodiversity are relevant to planning and assessment;
- Show which components of diversity can and cannot be assessed at various scales of investigation;
- Show how the ‘natural scale’ of biodiversity components can be assessed in terms of size and boundaries, as reviewed by Roff et al. (2003);
- Indicate where surrogate measures of biodiversity components may be useful in planning and assessment. These measures are not just an option in planning for marine conservation; they are a vital concomitant and used extensively. Their use in the Arctic is inevitable where biological data is limited. We should also note that in environments subject to change, habitat analysis (as a surrogate for community type) is more useful and enduring than direct survey of the communities themselves.

MOLECULAR TECHNIQUES IN PLANKTON BIODIVERSITY ASSESSMENT

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In the past three decades molecular techniques have become almost indispensable in many fields of biology. They offer a wide range of possibilities to address biological questions in different ways and from different perspectives than in the pre-molecular era. The study of marine biodiversity involves questions considering e.g. the historical biogeography of organisms, population structure, or responses to environmental changes. In the marine environment Protists and Microorganisms dominate the overall biodiversity. However, it appears to be very difficult to study the biodiversity of these two groups by conventional methods. Due to their small size and the presence of only limited or in some cases uninformative morphological features both groups are taxonomically very challenging. With the introduction of molecular methods into marine biology there are now tools available, which allow addressing questions related to marine biodiversity in respect to compositional, structural, or functional aspects. The assessment of homologous sequences of various species provides new insights into the phylogeny and biodiversity of all marine species, but in particular of Protists and Microorganisms. Homologous gene sequences contain more evolutionary information than morphological features. Molecular phylogenetics makes it possible to directly identify, and quantify species in time and space. Irrespective if the species have only a size of a few microns or a low survival rate for clonal isolations. Due to the problems enumerated before for the study of marine biodiversity, there is currently only little knowledge about population structure in the marine environment. The application of molecular markers like isozymes or various fingerprinting techniques e.g. RAPD (**R**andom **A**mplified **P**olimorphic **D**NA) represents means to study population structures of marine organisms on subspecies level. However, in addition to the previously mentioned advances, molecular techniques can also greatly contribute to the understanding of ecological interactions in the marine environment. The success of a species in any given environment is determined by its ability to recognize and respond to environmental changes. A response to an environmental change goes usually along with a broad change of the gene expression and protein composition of an organism. Thus it is from obvious importance to study these changes at the molecular level in order to understand ecological interactions. Tracing components of the signal-perception and transduction, regulatory molecules or molecules that are only present under certain conditions could do this. Recapitulating molecular biology provides techniques that allow addressing questions related to biodiversity that cannot be addressed by other methods. This reflects a great advance with regard to the assessment of marine biodiversity.

BIOLOGICAL INVESTIGATION IN THE COASTAL ZONE OF THE ARCTIC OCEAN IN RUSSIA

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During the last 40 years the Zoological Institute of the Russian Academy of Sciences has been studying the biodiversity of coastal marine ecosystems. Employing the diving quantitative method that was devised by researchers from the Zoological Institute, shallow waters of different regions of Arctic and Far Eastern seas of Russia were studied. In the Arctic Ocean, several regions were studied in greater detail: Franz Josef Land (1970, 1981-1982), Yarnyshnaya Bay of the Barents Sea (1987-1988), bays of the White Sea (1977-1985), southern coast of the Laptev Sea and New Siberian Shoals (1973), Chauna Bay of the East-Siberian Sea (1986), Vrangel Island, and the De Long Strait and Kolyuchin Bay of the Chukchi Sea (1976, 1989). The materials that were collected during these expeditions include quantitative samples, sediments and irregular observations of temperature and salinity. They are archived in the Zoological Institute. All quantitative samples were preliminary assayed (sorted, weighted, dominated species were identified). The materials of several expeditions were identified to species level and the results were published in the Russian issues "Explorations of the fauna of the seas" in 1977, 1982, 1985a,b, 1988, 1990, 1994a, b, c. Unfortunately, some of the materials have yet to be identified completely. In order to understand some peculiarities of distribution of life along the coasts of Arctic seas it is necessary to study the distribution of marine animals in several other critically important regions including the coast of the Kanin peninsula, coastal Novaya Zemlya, including the Matochkin Strait, and the vicinity of Khatanga Bay.

VARIATION OF ARCTIC ZOOBENTHOS DIVERSITY IN THE TRANSITIONAL BIOGEOGRAPHIC REGIONS AND REFUGE AREAS UNDER CLIMATE FLUCTUATIONS: EXAMPLES FROM THE BARENTS SEA

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Life in the ocean is an interdependent system. For understanding the function of the biological components of the system it is necessary to understand environmental conditions as well as biological patterns of the organisms forming the system. The Barents Sea is one of the most complicated basins among the Arctic seas. There are strong influences on the zoobenthos distribution from the warm water currents entering the Sea from the west and north, and the cold Arctic water coming to the south-eastern areas from the Kara Sea. There are also significant bathymetric channels and fresh water discharge factors – all of which have an important role in formation of biota of the Barents Sea, which is characterized by the richest fauna in the Arctic region (Sirenko, 1998). In this region, zoobenthos is a good indicator and integrator of the multi-year changes in environmental conditions, because many species have longer life cycles, low mobility, and form more stable assemblages than plankton or fish populations.

According to numerous biological studies carried out in the Barents Sea, the transitional zone between the Arctic biogeographic area and the Boreal Atlantic area is located in the southern and western regions. These transitional biogeographic zones are characterized by high environmental variability.

Extensive investigations of bottom fauna and related biogeographic structure, abundance, biomass, and community structure have been performed. These studies provided new insights to the relative production rates and frequency of occurrence for zoobenthic taxa. In addition, there is also data from a five-year study from 11 oceanographic stations in the Kola transect in the south-western part of the Barents Sea, which improved our understanding of the mechanisms of change in the bottom fauna. This data, together with supporting data from archives gathered over the last 100 years shows there is a strong dependence of the marked characteristics of the zoobenthos on water temperature variability. In this area of the Barents Sea, these patterns are likely related to the warm water currents from the Atlantic flowing from the west.

In warm periods, the proportions of boreal species and Atlantic boreal-Arctic species of the bottom fauna increase. At the community level, the roles of boreal and Arctic species are not comparable, and the more abundant wide spread boreal-Arctic species, which have more biomass, predominate in bottom communities. The communities have different dominant species during cooling and warming water mass conditions, thus there is a high correlation between biomass values and water temperature. These temperature driven changes in turn result in alterations of community structure after significant delays. It can take two to five years for this to occur, depending on the duration the dominant species life cycle.

In contrast to the transitional zones, refuge areas such as the Choschkaya Bay of the Barents Sea, with it's associated relict species should be characterized by stable environment. However, analysis of the biogeographic structure of bryozoans collected in different periods demonstrates variations in the fauna. In cold periods (1904, 1964) the Arctic species predominated above boreal forms. In warm years (1994-1995) the boreal species predominated above the Arctic forms. Hence, quantitative characteristics in populations of these bottom fauna should also be variable.

In conclusion, these examples suggest that the system of bottom communities is dynamic, and to estimate their biodiversity and stability in space and time an integrated environmental-biological approach is necessary.

WHY DO WE NEED ASSESSMENT OF THE ARCTIC MARINE BIODIVERSITY?

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Since the 1930's the Arctic Seas are facing the invasion of the human civilization. Use of the maritime Arctic as a transportation and military corridor from the mid-1930's is shifting now towards large-scale offshore hydrocarbon development. Some marginal Arctic areas, i.e. the Barents Sea and the Greenland Sea have been fishing areas of world importance and are now becoming affected by unsustainable fishing practices. Other areas, like the Gulf of Anadyr, where no industrial fishery has been ever started, are now areas of intensive fishery development. Tourism is developing in the most spectacular places and is now a common phenomenon in Greenland, Spitsbergen, over the White Sea coast, in Alaska and Chukotka. Arctic ecosystems are most sensitive to the global climate transformation and the reduction of sea ice cover along with cumulative human impacts already seem to have a profound effect on particular key populations and communities, i.e. polar bear. In contemporary Russia, which occupies more than a third of the circumpolar sea and coast the mitigation of environmental impacts from human economic activity is complicated by the lack of strategic environmental assessment both in the legal framework and practice. The authorities no longer feel themselves responsible for the assessment while the civil society is not developed enough to recognize this as a priority. Thus, in the present situation it falls mainly to the scientific community and environmental NGOs to develop sound, cost effective and clear-cut approaches to conduct biodiversity assessment, especially for such complex realms as the seabed and the pelagial. As a result, the most important, particularly sensitive areas requiring special protection and management regimes should be identified.

The marine biodiversity assessment in the Arctic is complicated by the limited field season, sea ice cover, remoteness and high costs of the field work. The presentation further reviews and discusses some already existing approaches and opportunities for the biodiversity assessment in the Arctic seas.

3.5 ENVIRONMENTAL FORCING WORKING GROUP

Working Group Chair: **David E. Atkinson**

Participants

David Atkinson, A.A. Ermolov, Don Forbes, A.M. Kamalov, Stanislav Ogorodov, F.A. Romanenko, Steven Solomon, Alexander Vasiliev, David Viner, G.K. Zubakin

3.5.1 Environmental Forcing – Working Group Summary

David E. Atkinson

Bedford Institute of Oceanography

Meetings summary

The overall objective of the EWG is to move towards provision of output before summer 2004. To this end, objectives at this meeting were to finalize specific output layers and to prioritize them in terms of delivery time frames.

Discussions were held with various members of the ACD to continue to pursue those aspects of environmental forcing they felt were important. Some members indicated that background wave activity was potentially as important as that caused by extreme events. Given this it was decided that model calculated wave power totals would have to be included. Ogorodov's model is the best candidate for this work; discussions with him secured collaborative use of the model. Long-shore transport of material is an important component as well, and Ogorodov's model also outputs this information. Parameters to be submitted are listed in Table 1. Temporal representation of environmental layers was discussed at length. There is need for both long-term aggregates as well as week-by-week totals, so it was decided that a variety of temporal periods would be provided (Table 1).

Discussions were held with the GIS group concerning the format in which data layers should be provided, as well as the feasibility of providing so many layers (all the temporal permutations for each main parameter layer). It was felt that a point vector file should be provided, in an unprojected format (that is, latitude – longitude). In this manner the final projection and format of the ACD GIS data layers does not matter – the environmental data can be projected and rasterized by AWI staff to suit the requirements of the ACD GIS. In this manner the spatial scale can be determined by the GIS leaders.

There are several blocks of work remaining. First consists of removing the wind speed bias from the NCEP/NCAR Reanalysis data. This has been demonstrated to cause a severe underestimation of the speed of high-magnitude events, which is a major problem for the provision of ACD environmental forcing layers. This effort is underway with a successful initial demonstration. Next consists of applying Ogorodov's model on a large scale. Finally a statistical sea-ice model has yet to be developed.

Other issues attended to at the meeting included modification of the ACD GIS attribute table, to break out some of the environmental components into their own layers.

Table 1: Parameters and temporal periods.

Parameters	**Temporal periods**
Storm counts	Full period mean (1950 – 2000)
Storm mean speed	Series of climatic normals
Storm mean duration	pre-1970 and post-1975 (transition period)
Storm mean direction	five-year means/totals
Wave energy on shore	annual means/totals
wave energy long shore	weekly means/totals
wind statistics: *p* exceed 10 m/s	
wind statistics: number of occurrences	
temperature mean	
temperature range	
thawing degree day totals	
sea ice concentration	
sea ice landfast presence	
sea ice distance from shore (fetch)	

3.5.2 Environmental Forcing – Extended Abstracts

CIRCUM-ARCTIC COASTAL STORMINESS STATISTICS DERIVED FROM OBSERVATIONAL WIND DATA

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Abstract

Given that significant geomorphological impact in the coastal regime occurs during storms, a storm identification algorithm was established and using this, a database of storm events was assembled. From this mean climatologies were assembled for the following parameters, by station by month: mean storm count, mean storm speed, mean storm duration, and mean storm power. These parameters were then aggregated by ACD sector.

Results indicate a difference between those regions proximate to the influence of the mid-latitude oceans (the Atlantic and, to a lesser extent, the Pacific), and those of the north arctic coast. Regions influenced by the oceans show a mid-latitude profile typified by dominant winter-time activity with a minima during summer. Arctic north coast regions, however, show a strong activity peak in the late summer/early fall, coincident with the height of the open water season. Storm potential power, defined as the square of the mean speed multiplied by duration, possesses some of the largest values in the Chukchi Sea zone in late open water season.

Introduction

Coastal regions are particularly sensitive to the impact of high magnitude weather events. Wind energy drives powerful wave action and water level surges, which have a variety of effects. These include significant geomorphological, infrastructure, and ecological impacts, and consist of, for example, wave action causing erosion and sedimentological work (e.g. Solomon et al. 1994, Harper et al. 1988), and surge-induced inland flooding resulting in significant vegetation kill (Reimnitz and Mauer 1979), infrastructure damage due to the strength of positive buoyancy of wooden or hollow objects and structures (Hume and Schalk 1967). The ocean is able to move large quantities of material both to and from the coastal zone, i.e. accretionary and erosional coasts (e.g. Grigoriev et al. 2002; Hume and Schalk 1967), with the net result that a given coastline can undergo significant change on an annual basis. A number of researchers report that most geomorphological work done to a coast occurs during significant events (Reimnitz and Mauer 1979, Solomon et al. 1994).

To provide arctic researchers with more information about storm activity fifty years of storm event occurrences (defined below) were extracted from observational wind data for coastal regions of the circumpolar arctic (Fig. 1). Climatologies, consisting of aggregate totals and means by region, will be presented along with results from trend analyses. Data over the period 1950 – 2000 were utilized.

Method

Station selection and data preparation

Initial station selection was conducted to satisfy the requirements of the Arctic Coastal Dynamics project; for this work observational data from 59 stations were retained and processed (Fig. 1). Data pre-processing was necessary to handle the wide variety of observing regimens noted amongst the stations. All stations were standardized to a 6-hourly observational regime. Where there were insufficient data to adequately represent the 6-hourly regime for each month of the year, a station-year was excluded. This prevented a potential artificial reduction in storm counts.

Storm identification

The identification of a “storm”, in terms of coastal issues, is focussed on the right combination of wind speed, duration, and direction such that the wave-generating and/or surge generation potential is maximized. Depending on the specific application a range of threshold speeds, durations, and form of wind profile (e.g. MacClenahan et al. 2001) must be considered. For this project the interest was in storms that can produce waves and/or surges that are of sufficient magnitude to cause damage to habitats or infrastructure, and/or to perform geomorphological work. Only storms with winds above a certain speed that are maintained for a certain period of time are able to create this sort of impact (e.g. MacClenahan et al. 2001, Solomon et al. 1994). An “event threshold” for wind speed was thus set at 10 m/s. This speed was selected based on precedents that have been set in arctic geomorphology work (e.g. Hudak and Young 2000, Solomon et al. 1994). MacClenahan et al. (2001) set their speed threshold with reference to the more powerful storms to reach the Irish coast. The “duration threshold”, that is, the minimum length for a storm event, for the project described here was set to six hours, as based on various other researchers (e.g. Hudak and Young 2000, Solomon et al. 1994).

For this project the following, multi-stage algorithm for identifying a storm event was utilized. To begin with, any wind speed exceeding event threshold is tagged. The tagged observations are then assessed for grouping into discrete storm events. In performing this task two morphological features in the presentation of a storm event in a wind speed profile are recognized: “lulls” and “shoulder events” (Fig. 2). A lull is a temporary decrease in wind speed during a synoptically contiguous storm event. In this case lulls were defined to be the occurrence of a single wind speed observation that dropped below threshold, with tagged observations immediately previous to and following the lull. A shoulder event was defined as a wind speed occurring before the first, or after the last, tagged observation in a contiguous set of tagged observations, that was just a bit below event threshold, i.e., and most likely associated with the synoptic storm event.

To evaluate lulls and shoulder events a secondary threshold, termed the “continuity threshold”, was defined. This value was arbitrarily set at 0.7 x event threshold. If the lull dropped below this value the tagged events on either side were considered to belong to separate storm events. If a shoulder dropped below this value then the event count tagging was stopped for that event. Without use of lulls the algorithm returned too many storm events that were too short in duration. Without use of shoulder events the synoptic duration of storm events was overly shortened.

After the addition of lulls and shoulder events to the storm events the six-hourly wind speed observations were linearly interpolation to a one-hour frequency. This served to refine estimates of duration and mean speed. Counting began when the hourly wind speed estimate rose above the continuity threshold, and similarly ceased when it dropped below.

This resulted in the generation of a storm event database for each station used in the study. This database served as the basis for the analyses described next.

Analyses

The analyses were based on the aggregation of station results into sector boundaries established by the ACD (Rachold et at. 2003) and modified slightly for this project (Fig. 1). The first set of analyses dealt with the preparation of fifty-year climatologies of selected parameters for each sector, by month. The parameters included, by station: mean event count, mean core wind speed, mean core duration, and mean total power (defined below). The aggregation method varied slightly depending upon the parameter being considered. Determination of a sector mean event count was performed in the following manner. First a mean event count by station, by month was obtained. From station counts the sector mean count was computed. Storm event durations by sector by month were calculated in a manner similar to that used for the frequency count, i.e. a mean duration by station was first determined, then a mean duration by sector was calculated.

From the parameters retained for each storm event a derived parameter, storm wind power, was calculated. This parameter is designed to provide a rough indication of the total power available from a storm event, and is defined as the square of speed multiplied by the duration. Calculations for wind power were based on a subset of storm events selected on the basis of mean direction, that is, if the storm mean direction was from the north sector the event was retained. This is a very rough representation of the fact that many of the coastal observing stations are situated on a coastline oriented east-west and are exposed to water in the north and land in the south. Storm events of interest for derived impacts studies are thus those with a prevailing northerly direction.

The second analysis concerns trends in open-water season storm frequency. This was explored using a mean storm count per station.

Results and discussion

The mean annual counts (Fig. 3) revealed a mid-latitude, northern oceanic influence in zone 1, situated closest to the Atlantic. The low point in July, coupled with the steady rise into the fall, is a typical mid-latitude storm activity cycle. Zone 1 is also situated northeast of the Icelandic Low, a region of strong atmospheric low-pressure system activity in the winter, and is also in an area of strengthened east-west flow that directs weather systems into the region (Wallén 1970 p26-27). The pattern in zone 2 is similar in form to that in zone 1 but in each month the mean annual number of storms is greater, and there is a definite late open-water season peak. This pattern is deemed to be a mixing of two signals, one being a vestige of the mid-latitude signature, and the other being the increase in storminess potential due to temperature differences between the land and the sea. By zone 3 the mid-latitude signature in the storm count pattern is gone. Instead this area sees more activity in the summer with a small drop into the fall. In zones 3, 4, and 5 the storm counts reach a high level in August. Even though open-water has not reached its greatest extent by August, the temperature of the land is at its highest level, thus providing the strongest land-sea thermal gradient of the annual cycle. This is able to compensate for a relative lack of open water, resulting in a storm count peak. Counts in September and October remain high in zones 3, 4, and 5 due to the rapidly increasing open water extents, even though the thermal gradient is dropping. Zone 5 has lower counts in June and July most likely because the storm tracks that develop in the summer channel systems towards zones 2-4 and not 5 (Lydolf 1977). Zone 6 comes under the influence of systems that can move up from the Pacific Ocean either through the Bering Straight or across Alaska. Increasing open water amounts over the five-month period coincide with a general increase in storm activity. Zone 7 is located farther north than the previous 6 zones. It does not have the same open water season, and the northwest edge of the archipelago can have virtually no open water season. Here general storm activity is low compared to other regions. Its peak occurs in July and August as a result of changes in prevailing synoptic pattern; specifically, in the summer, weather from the south can penetrate into this region more readily than at other times of the year.

Zones 1-4 were similar for storm mean speed (Fig. 4), with summer (July and August) representing a speed low point, June representing a secondary peak, and September stronger leading up to October, which possessed the strongest mean winds in all zones for the open water season. In Zone 5 the June secondary peak was reduced to a level below July and August. Zone 6 had low speeds in general, especially for June and July. Zone 7 had consistently strong winds.

Storm durations (Fig. 5) in zones 1 through 4 exhibit the mid-latitude signature. Storms in zone 2 exhibited the longest durations of any sector for each month. The pattern breaks down in zone 5 because June storm durations are significantly lower relative to the other months. The pattern is apparent again in zone 6, although durations are short compared to other zones. Zone 7 does not have as strong an increase into September and October as other zones, and durations are generally short here as well.

Storm potential power (Fig. 6) was calculated as described. A rise in mean power values from a low point in July (zones 1,2,3,5,6) or August (zones 4,7) leading up to October was apparent in all zones, as was a large variability in June. Overall, zones 1,2,3 and 4 exhibited consistently high mean power values, zone 5, a large relative difference between June and October, and zones 6 and 7, consistently lower power values.

Conclusion

The general climatological patterns of storm frequency, duration, wind speed, and power vary by region over the circum-Arctic domain, and reflect the influence of the oceans in regions near the oceans, with an increasingly important Arctic coastal signal appearing for regions far from the oceans. Specific observations include:

- The greatest power values were observed not in the Atlantic zone but in zone 5, the Chukchi zone, late in the open water season.
- The Kara Sea zone (2) is a very active region, having many storms with long durations.
- a strong storm count peak that appeared in June in the Kara Sea zone (2) and the Laptev Sea zone (3) was noted and is possibly linked to the frequent occurrence of early open water off the mouths of the Ob and Yenesei Rivers in the Kara and the Lena River in the Laptev, caused by voluminous June discharges from these rivers (Lammers and Shiklomanov 2000) and/or polynyas in both of these Seas.

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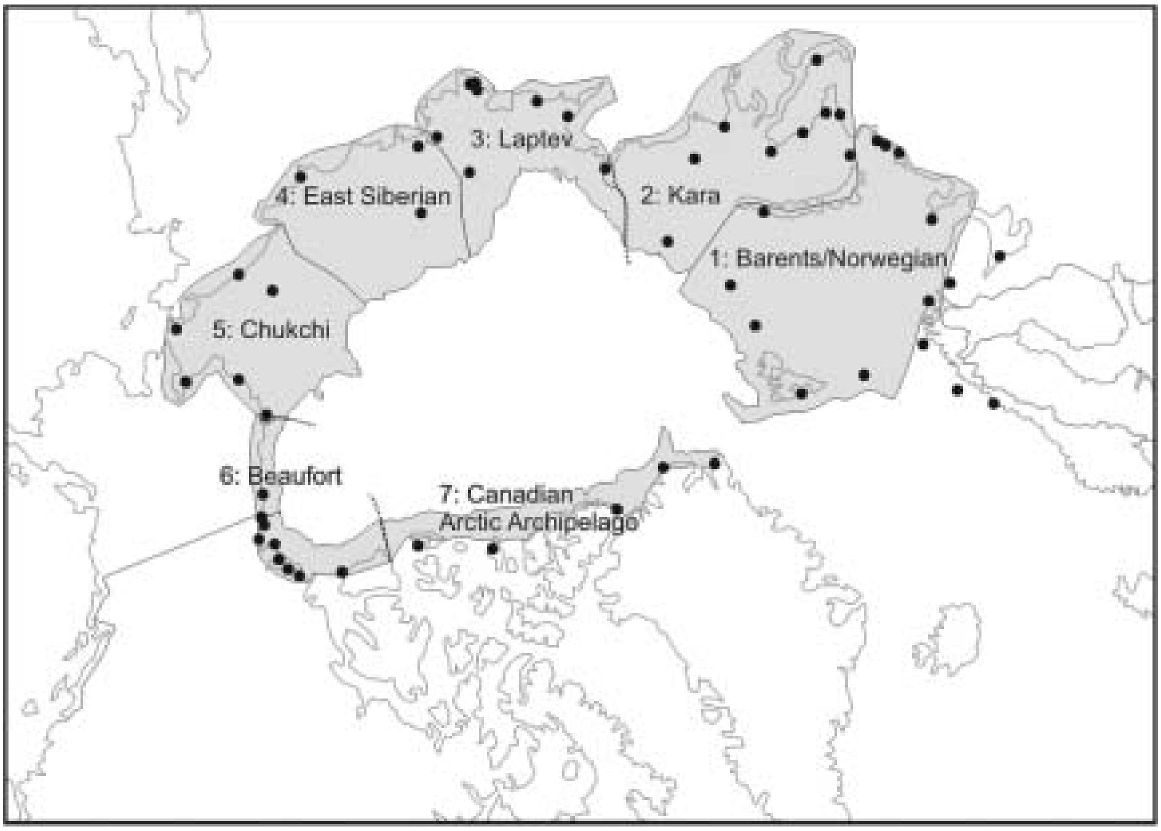

Figure 1: The circum-polar region. Sectors identified by the Arctic Coastal Dynamics project are identified as grey zones. Minor modifications adopted in this paper are indicated with heavier dashed lines. Station locations are indicated by black dots. In some cases two stations are located very close together and appear as one dot.

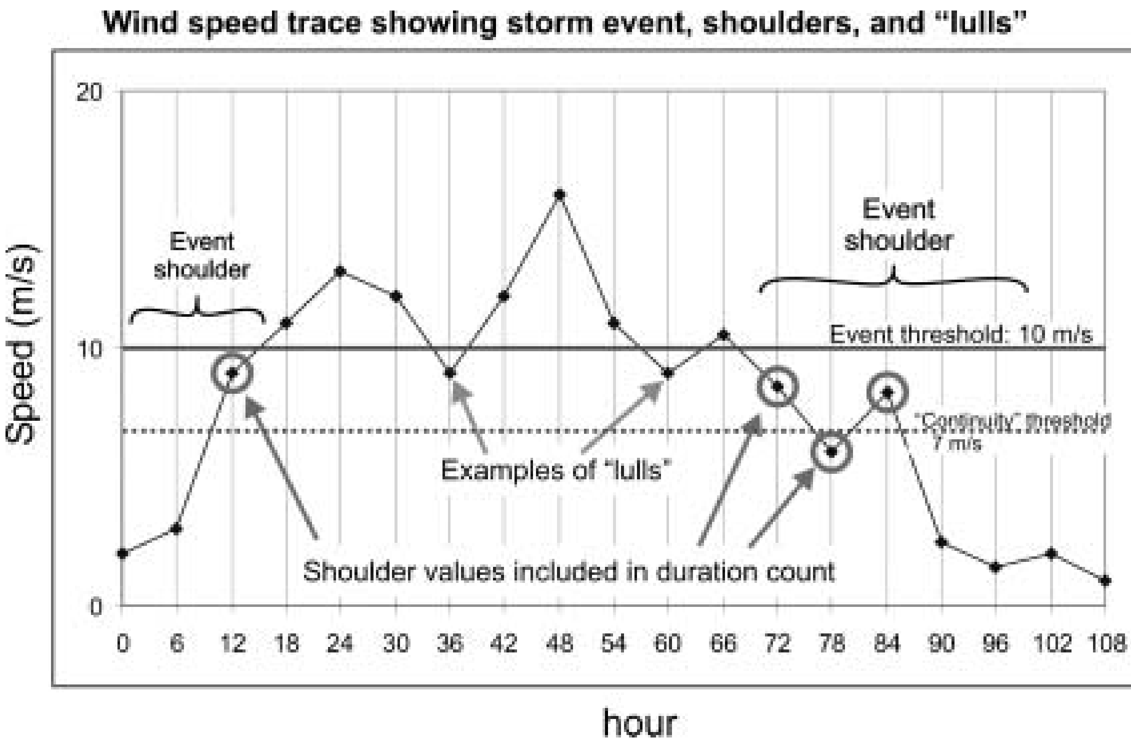

Figure 2: Schematic representation of storm representation in the wind speed profile with various components indicated.

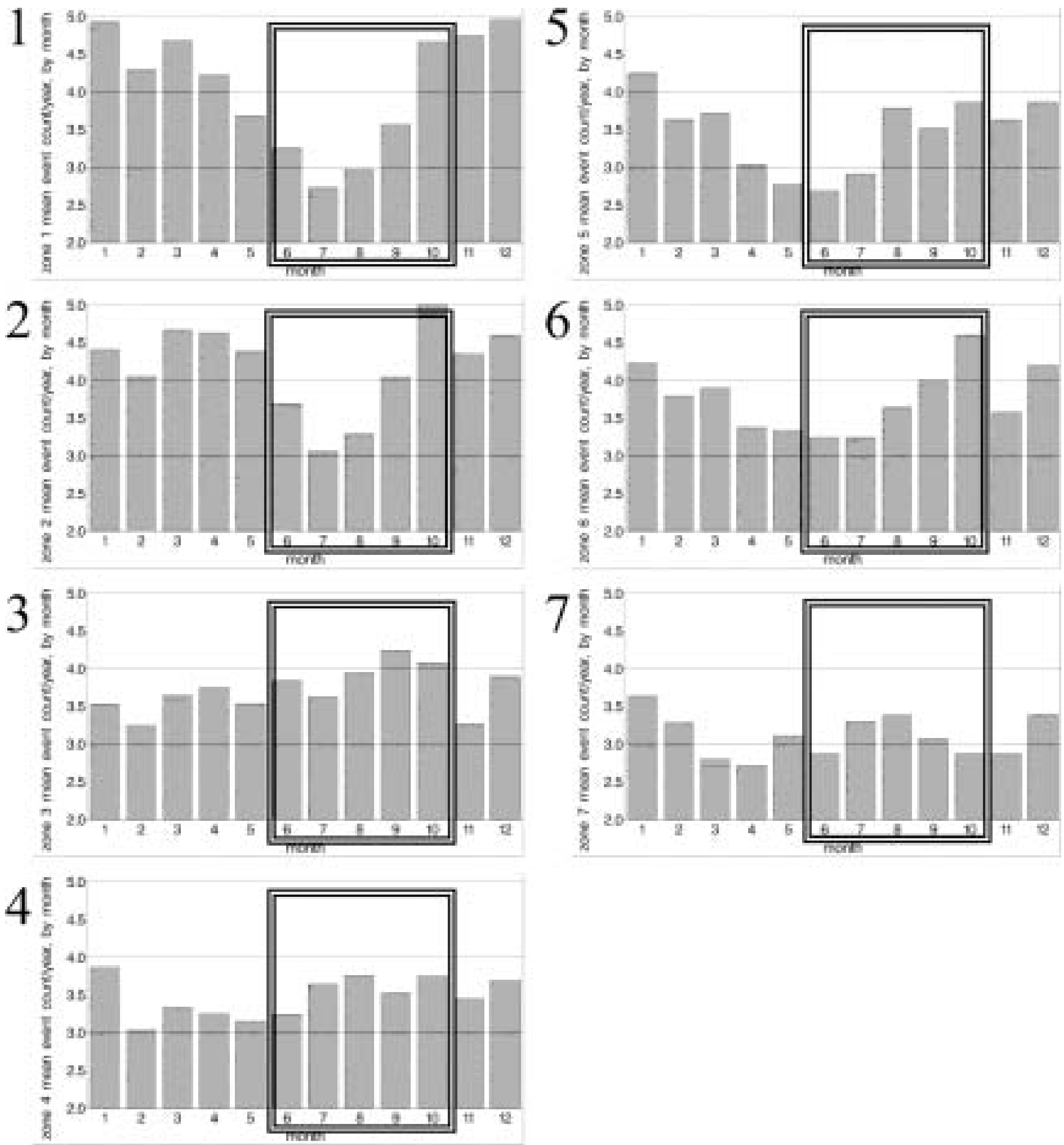

Figure 3: Mean annual storm event counts by station by month, aggregated by sector. The box represents a rough open-water season.

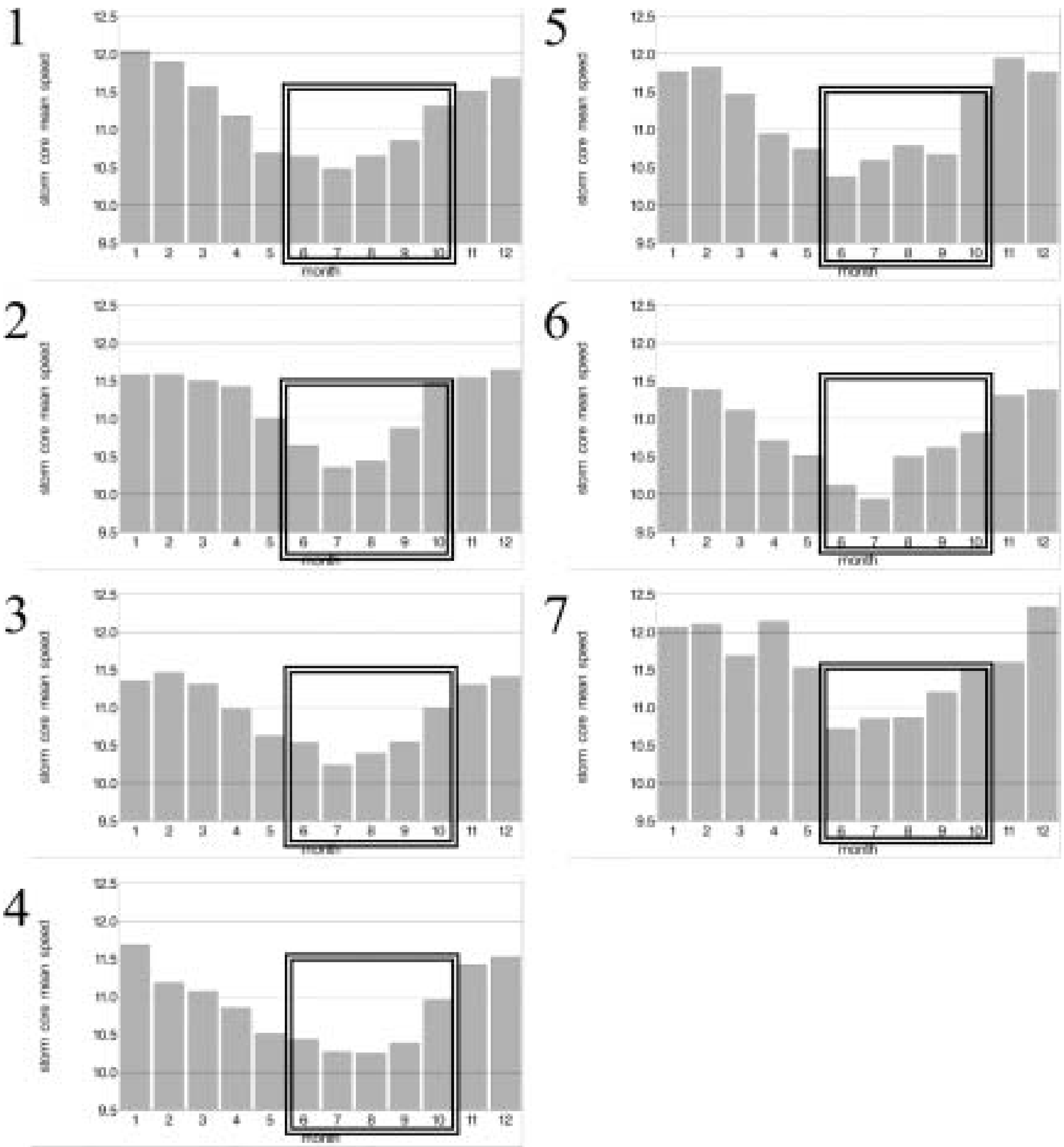

Figure 4: Mean storm core speed (m/s) by month, aggregated by sector. The box represents a rough open-water season.

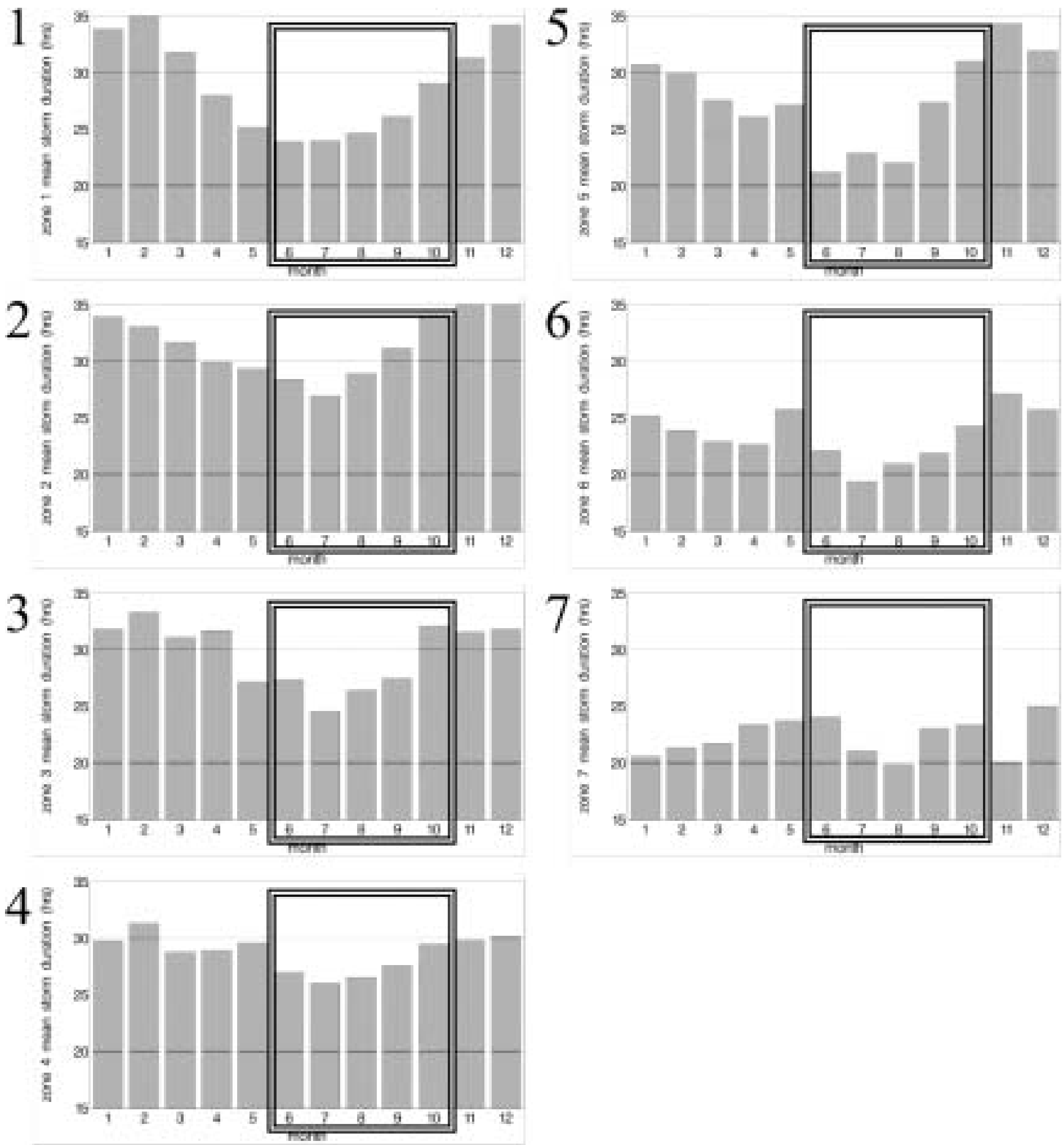

Figure 5: Mean duration of core winds (hours) by station by month, aggregated by sector. The box represents a rough open-water season.

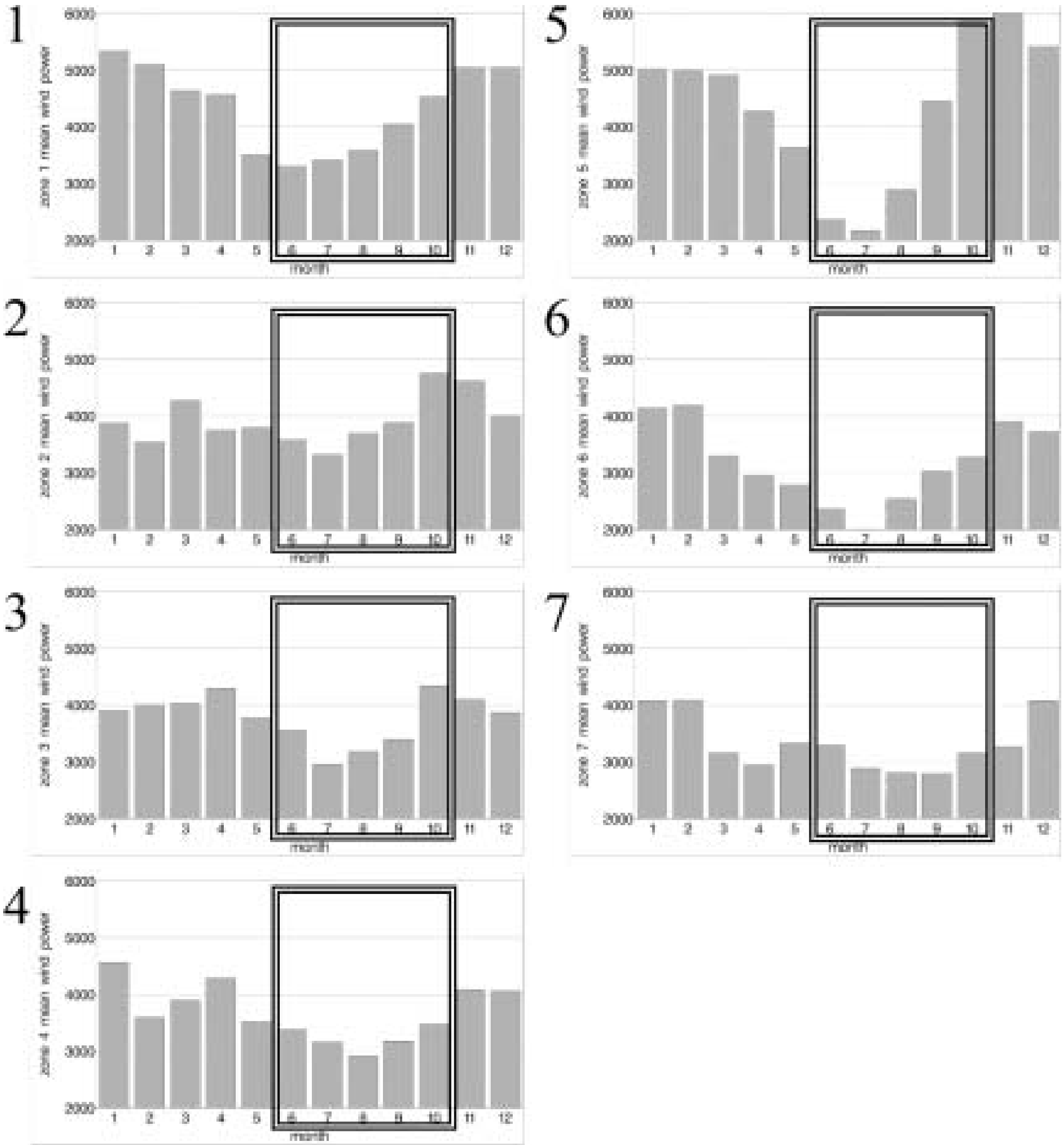

Figure 6: Mean storm power (speed^2 * duration) by station by month, aggregated by sector. The box represents a rough open-water season.

DEFINING LIMITS OF SUBMERGENCE AND POTENTIAL FOR RAPID COASTAL CHANGE IN THE CANADIAN ARCTIC

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Abstract

Strong gradients in postglacial isostatic adjustment across the Canadian Arctic Archipelago (CAA) and adjacent mainland coast produce widely varying rates of uplift and subsidence and associated variations in relative sea-level change (RSL). The transition between submergence in the east and west and emergence in the central region is poorly defined, as are present rates of vertical motion and sea-level change. A recently established network of colocated continuous GPS (CGPS) and tide-gauge stations and additional CGPS and epoch GPS sites will provide new opportunities to test and validate estimates of uplift or subsidence in existing and future geophysical models. Spaceborne, airborne, and ground-based imagery and surveys demonstrate clear evidence for submergence along the south, west, and north coasts of Banks Island and on western Victoria Island. Although erosion hazard may increase with RSL rise, among other factors, landward reworking of beach sediment under storm conditions is also observed within the zone of ongoing uplift. Sea ice limits wave action to varying extent throughout the region and landward motion of ice can cause significant reworking of the shore and backshore surface. There is a potential risk for rapid and substantial reworking of low-energy ice-bound shores when subjected to higher wave energy under conditions of reduced sea-ice cover, particularly if the coast is submergent. Accelerated global and regional sea-level rise under a future warmer climate may be sufficient to reverse the trend from emergence to submergence in some parts of the CAA. These scenarios point to the need for better knowledge of vertical motion, future sea-level trends, and the potential for changing sea-ice distribution and wave energy in the Canadian Arctic.

Introduction

This paper addresses critical boundary conditions and potential changes in forcing for coastal morphodynamics in the Canadian Arctic Archipelago and on adjacent mainland coasts. Among the key factors of concern for defining future stability of Arctic coasts under climate warming are the present and future rates of relative sea-level change (the sum of trends in regional sea level and vertical motion of the crust). Changes in coastal forcing, particularly related to changing sea-ice conditions, extent of open water, and storm wave energy, may be equally important for determining coastal change and the vulnerability of communities, coastal infrastructure, cultural resources, shore-zone habitat and other valued amenities of northern coasts.

Geological data on postglacial relative sea-level (RSL) change in the western Canadian Arctic (Andrews, 1989; Dyke and Peltier, 2000) demonstrate strong east-west gradients from ongoing emergence in the central Canadian Arctic Archipelago (CAA) to a band of submergence extending along the outer Arctic coast from the Beaufort Sea north to Prince Patrick Island or beyond (Fig. 1). This pattern is broadly consistent with the distribution of vertical isostatic adjustment in viscoelastic geophysical models (e.g. Peltier, 1994, 1996, 2003). A recently established network of GPS monitoring stations throughout the western Arctic and a newly re-established network of northern tide gauges together provide new opportunities to test model estimates of RSL trends. Of particular interest is the transition zone between present submergence and emergence, where accelerated regional sea-level rise may lead to eastward expansion of the band of submergence. Coasts in Lancaster Sound at the eastern end of the Northwest Passage are also submergent and rates of emergence through much of the passage are <4 mm/a, suggesting the possibility of a reversing trend through the middle of the CAA if rates of climate-induced regional sea-level rise approach or exceed that value in future. This issue, together with sea ice and wave hazards, requires better understanding to enable a proper assessment of coastal erosion potential in the Canadian Arctic.

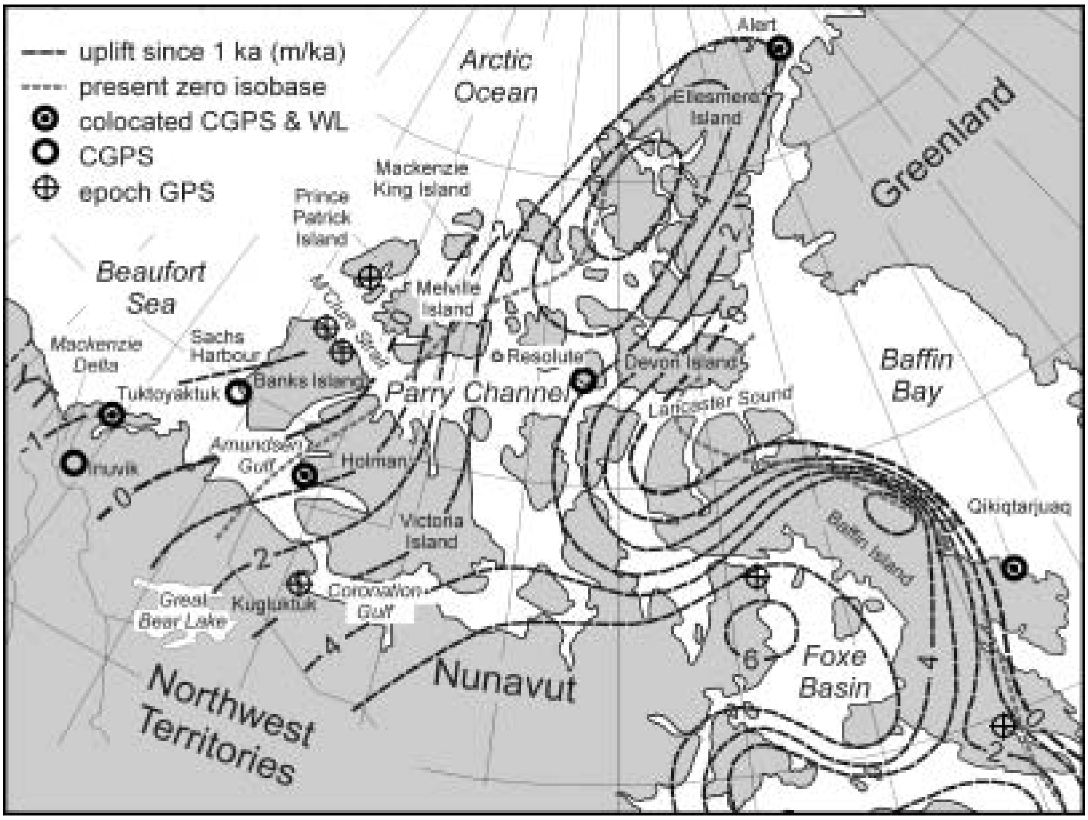

Figure 1. Estimates of relative sea-level change over the past 1000 years and locus of current zero isobase (Andrews, 1989). Point symbols indicate locations of epoch GPS stations, CGPS installations, and CGPS colocated with tide-gauges (all operational except Qikiqtarjuaq on Broughton Island, which will be installed in summer 2004).

Methods

Direct measurement of vertical crustal motion is underway at a number of sites throughout the region, following successful results from similar efforts elsewhere (e.g. Johansson et al., 2002; Milne et al., 2001; James and Ivins, 1998; James, 2000). Since the year 2000, epoch GPS observations (several days at a time) have been initiated on fixed monuments in bedrock at Mould Bay NWT (Prince Patrick Island), Cape M'Clure and Mercy Bay NWT (Banks Island) and Kugluktuk NU on the mainland coast of Coronation Gulf (Figs. 1 and 2a). Continuous GPS (CGPS) stations (Figs. 1 and 2b) colocated with tide gauges have been established at Alert NU (Ellesmere Island), Holman NWT (Victoria Island), and Tuktoyaktuk NWT (Beaufort Sea mainland coast). Other CGPS sites without tide gauges are operating at Resolute NU (Cornwallis Island), Sachs Harbour NWT (Banks Island), and Inuvik NWT (near the head of the Mackenzie Delta). Natural Resources Canada, with various partners, operates other CGPS stations in the eastern Arctic and southern Canada. The CGPS stations in this study operate at a 30 s sampling rate and data are downloaded daily to the Geodetic Survey Division in Ottawa, where they are reviewed for quality control, archived, and uploaded to the International GPS Service. At present, uncertainties (1□) range from ±3.2 to ±5.6 mm/a but estimates to better than ±1 mm/a are expected within about 6 years.

Figure 2. (a) Setting up RTK base station with ground-plane antenna on epoch GPS monument at Kugluktuk NU, August 2002. Insulated stainless steel pillar attached to gabbro outcrop near airport [GKM]. (b) CGPS installation with choke-ring antenna on concrete pillar based in limestone near airport at Inuvik NWT, July 2001 [DLF]. A hemispherical dome has since been added to minimize noise from variable snow load.

Archival aerial photography, airborne oblique video imaging, and new spaceborne remote sensing imagery are being used for reconnaissance and classification of shore-zone geomorphology, using the GSC Coastal Information System (Sherin et al., 2003). Ground validation surveys, involving shore-normal profile surveys and shoreline, barrier crest and/or cliff top plan surveys, have been undertaken at numerous sites including the mainland Beaufort Sea coast, the south, west, and north coasts of Banks Island, western Victoria Island

(Holman), Coronation Gulf (Kugluktuk), and Cornwallis Island (Resolute). Most have used real-time kinematic (RTK) dual-phase differential GPS techniques to provide survey precision to better than 5 cm horizontally and vertically. This combined approach provides information on coastal morphology and sediments, from which we can interpret geomorphic indicators of recent submergence and/or shoreline retreat.

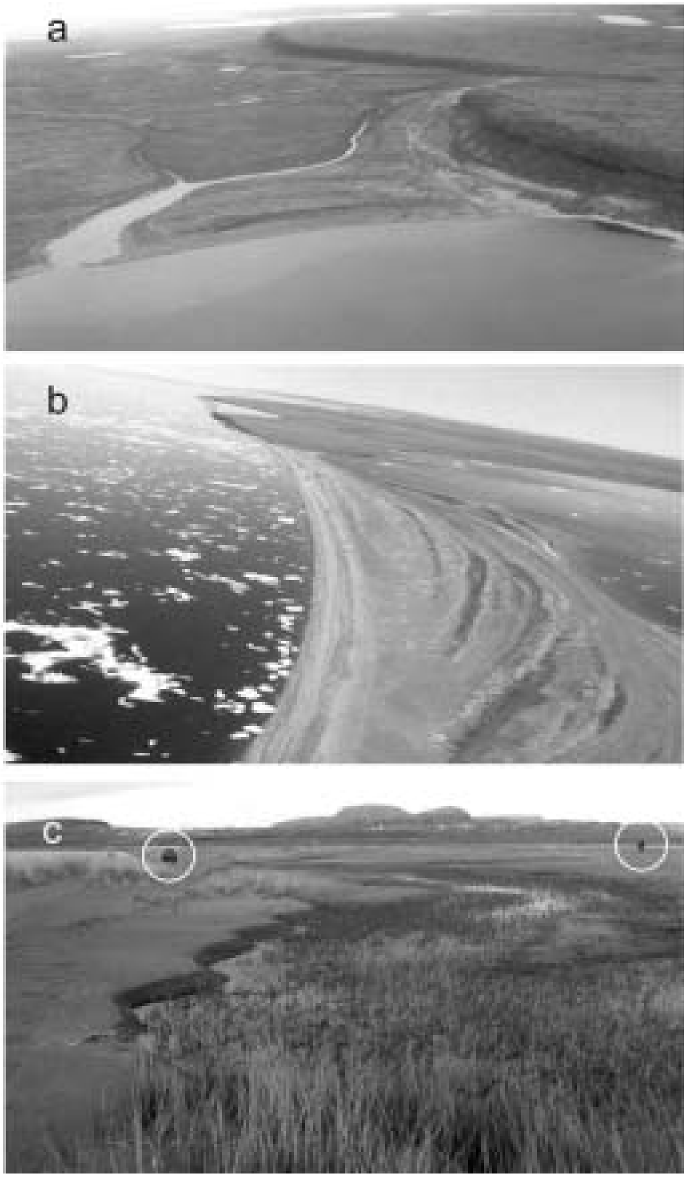

Figure 3. Coastal geomorphology providing evidence of recent submergence and storm-wave impacts in the western Arctic. (a) Flooded stream mouth near Holman, Victoria Island, NWT, August 2002 [DLF]. (b) Lennie Harbour barrier, southern west coast of Banks Island, NWT, July 2002 [DLF]. Multiple gravel storm ridges rising seaward reflect rising relative sea level as the barrier developed over several hundred years. (c) Storm washover deposits and backshore wetland at Kugluktuk NU, August 2002 [DLF]. For scale, circles show ATV and Gavin Manson running an RTK survey.

Results and Discussion

Evidence of recent submergence is seen in flooded river-mouth embayments from the Yukon coast and Tuktoyaktuk Peninsula (Forbes, 1980) east to Victoria Island (Fig. 3a) and north to Mackenzie King Island (Forbes et al., 1986). Recently acquired imagery from the west coast of Banks Island (Fig. 4) shows flooded ice-wedge polygon microtopography similar that seen in many places along the mainland coast of the Tuktoyaktuk Peninsula in the Beaufort Sea. This evidence of coastal plain tundra submergence, as well as the very extensive development of spits, attached barriers, and barrier islands backed by shallow lagoons, are clear geomorphic evidence of ongoing marine transgression and submergence on this coast. Other morphological indicators on Banks Island include seaward-rising crest elevations of multiple beach-ridge sets on barriers of the southern west coast (Fig. 3b), similar features surveyed in Mercy Bay on the north coast, and flooded-valley embayments on the north coast. Much of the Banks Island coast is marked by extensive and locally rapid erosion of unlithified deposits in coastal cliffs, again showing marked similarities in coastal geomorphology to features observed along the submergent mainland coast of the Beaufort Sea. Erosion processes include wave undercutting and sediment transport, combined with various thermokarst (thaw failure and volume loss) effects, which are sensitive to climate warming and contribute to coastal slope failure and overall erosion rates. Similar erosion features are seen both on the open-fetch west coast facing the Beaufort Sea and on the ice-choked north coast in M'Clure Strait, but the scale of beach and barrier development is much smaller in the latter area.

Moving eastward into the zone of previously reported emergence (Andrews, 1989), minor shore erosion has been documented in the community of Holman, where the shorefront street was undermined in a major storm in August 2000. This is consistent with other morphological evidence for recent submergence in that area (Fig. 3a). In southwestern Coronation Gulf, several lines of evidence have been interpreted to suggest that the coast near Kugluktuk (Coppermine) is still emerging (Andrews, 1989; Dredge, 2001). This would seem to be consistent with flights of raised beach ridges along the coast west of the Coppermine River delta and the community (Fig. 3 in Manson et al., 2003). On the other hand, our surveys show clear evidence of extensive washover sedimentation along the present shore (Fig. 3c), as well as exposure of back-barrier peat and marine clay in the shallow nearshore. Therefore, despite any ongoing crustal uplift (Fig. 1) and sediment input from the river at the west end of the bay, the shoreline is retreating in this area under the influence of slowly rising global sea level and storm-wave action during the limited open-water season. We observe similar evidence of wave overwash and backshore deposition in Parry Channel (Fig. 1) from southern Melville Island to Resolute and beyond, demonstrating that storm-wave activity in seasons with extensive open water can generate coastal landforms similar in small-scale topography to those seen on transgressive coasts. This is possible even where uplift is clearly ongoing, as at Resolute where the rate is estimated in the order of 2 to 3 mm/a.

The erosion hazard may increase with RSL rise, but it also depends on open-water fetch and wave energy, on coastal lithology and morphodynamics, and on the potential for and rates of thaw failure. The frequency and magnitude of storm-wave action diminishes with increasing duration and severity of sea-ice cover. On the other hand, direct ice action can cause significant reworking of the shore zone (e.g. Taylor, 1978; Forbes and Taylor, 1994). Along the west and north coasts of Banks Island, the relative importance of direct ice interaction in the shore zone increases toward the north and east, but the entire west coast shows wave-dominated morphology. From Prince Patrick Island north along the outer Arctic seaboard, persistent sea ice restricts wave development and the coast is marked by large and extensive ice-pushed shore ridges (Taylor and Hodgson, 1991; Hodgson et al., 1994).

There is a potential risk for rapid and substantial reworking of presently ice-bound shores when subjected to higher wave energy, particularly if accompanied by accelerated RSL rise or a reversal of trend to produce submergence. Northern coasts developed in non-resistant unlithified deposits of silt and sand may be particularly susceptible if more open water develops in response to climate warming. Rapidly developing northern coastal communities, shipping facilities, other coastal infrastructure, shore-crossing pipelines, cultural and archeological resources and critical ecological habitat in the coastal zone are all potentially at risk if exposed to flooding or erosion hazards. To minimize impacts, we urgently require improved prediction of future sea ice conditions, wave energy, and relative sea-level trends on Arctic coasts.

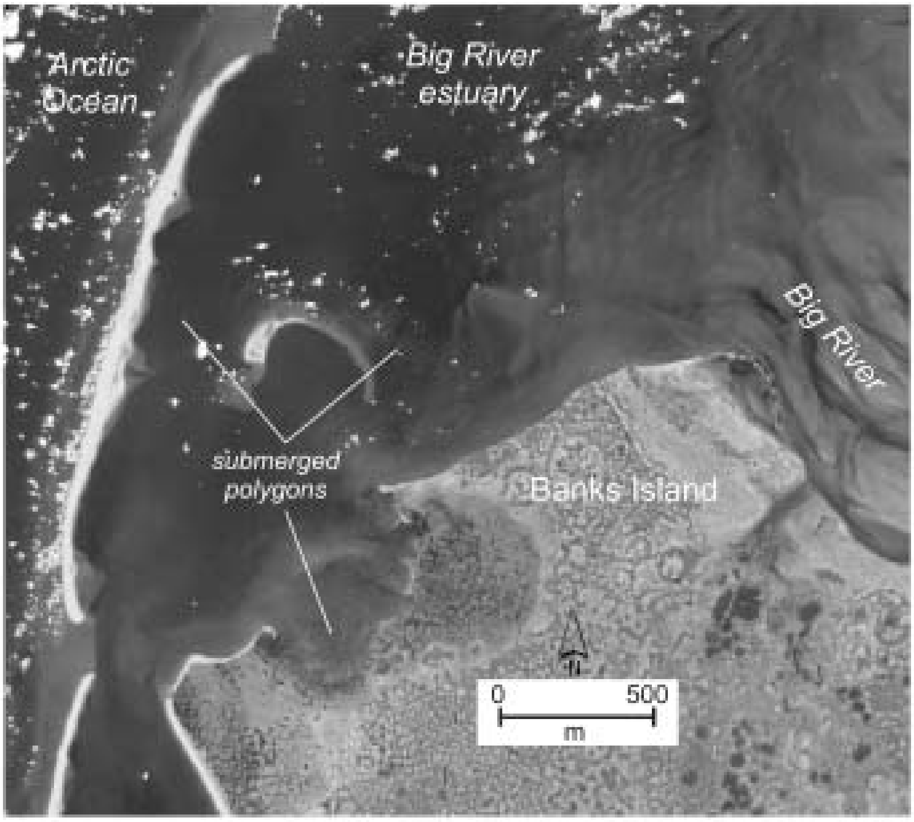

Figure 4. QuickBird pan-sharpened multispectral image south of Big River, southern west coast of Banks Island (July 2002). Note barrier island, nearshore bars, braided river outlet with complex prodelta bar system, breached lake basin, and submerged ice-wedge polygon tundra in the lagoon.

Acknowledgements

Field work for this study was supported by the Polar Continental Shelf Project and Aurora Research Institute. We also acknowledge assistance from the Canadian Hydrographic Service (DFO), the Nunavut Research Institute, and Parks Canada. JC Lavergne and Dave Frobel provided critical assistance both in and out of the field. Ron Solvason played a major role in undertaking the installation of new DFO tide gauges at Holman, Alert, and Tuktoyaktuk, and supporting the CGPS installations at those sites. We acknowledge funding from Natural Resources Canada (Earth Sciences Sector and Office of Energy Research and Development), Fisheries and Oceans Canada, and the Canadian Space Agency. Bob Taylor and David Atkinson provided expeditious and helpful reviews of an earlier draft, which helped to improve the paper.

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MODELING STUDY OF COASTAL EVOLUTION IN THE ARCTIC REGIONS

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Mathematical modeling is a useful tool to investigate the response of the coast to external forcings operating at different temporal scales. Recently a model was suggested which simulates coastal profile development over periods ranging from days to centuries (Leont'yev 2003a, 2003b). The essential short-term numerical component is a process-based model that simulates the short-term morphological changes induced by the "once-per-year" storm, which is assumed to determine the principal shoreface profile geometry. Into this are incorporated the long-term morphodynamic factors (global changes in sea level, wave activity, sediment supply).

When the longshore transport is uniform and sediment balance is mainly controlled by cross-shore transport, changes in depth (d) as a function of time (t) are determined by:

$$\frac{\partial d}{\partial t} = \frac{\partial q_x}{\partial x} + \frac{q_{aeol} - q_*}{l_*} + w \qquad (1)$$

where q_x is the sediment discharge due to short-term forcing (storm event), q_{aeol} and q_* are the long-term sediment fluxes across the upper and lower limits of coastal profile active zone (of length l_*), and w is the rate of change in relative sea level.

At the present time, processes of erosion and recession are dominant on most Russian Arctic coasts. This implies significant sediment flux q_* from the nearshore zone toward the sea (aeolian transport q_{aeol} is usually of secondary importance). An important mechanism responsible for this phenomenon is the high storm surges (more then 2 m) that can be generated in the shallow Arctic shelf. The associated water level gradients induce a seaward flow near the bottom, which balances the onshore mass flux created by wind shear stress at the free surface. Such a return current, or outflow, is found to exceed in magnitude the wave-induced onshore mass transport in the bottom boundary layer (Leont'yev, 2003a). The seaward sediment flux created by the outflow contributes to both the short- and long-term variables q_x and q_*, respectively.

Determination of q_x in the present model is based on the energetic sediment transport concept (Leont'yev, 2003a, 2003b). The value of q_* can only be estimated from the calibration procedure by setting the computed and observed rates of coastal recession equal to one another. Currently, the data required for this process are available for several regions of the Russian Arctic. These include profiles on abrasion coasts located in the northern part of the White Sea, at the Varandey site in the Barents Sea and on the Yamal coast in the Baydaratskaya Bay of the Kara Sea. Observational data from profiles on thermal-abrasion coasts along the Laptev, East Siberian, White, and Beaufort Seas were also used.

It was found that the long-term loss of sediments q_* (in $m^3m^{-1}year^{-1}$) for both types of coast could be determined from the same empirical relationship using the effective cliff height, h_{ce}, taking into account the subsidence of soil after ice thawing:

$$|q_*| = 11.2\sqrt{h_{ce}\overline{H}}\,\cos\Theta_W - 13.4\,, \qquad h_{ce} = (1-n)h_c \qquad (2)$$

where h_c is the actual cliff height, n is the percent volume of ice in cliff material, $\overline{H}$ is the mean deep-water wave height related to the once-per-year storm and the angle Θ_W characterizes the direction of dominant wind and waves relative to shore normal.

Based on results obtained one can conclude that, in spite of differences in transport and erosional mechanisms, there is little quantitative difference in the behavior of abrasion and thermal-abrasion Arctic coasts. Under the same storm impacts, the unfrozen escarpment loses almost the same amount of sediment and retreats at almost the same rate as the frozen cliff of corresponding effective height. In the course of the thermal-abrasion process, the coast is subjected to additional thermodynamic impact. However the results of various studies show that this effect itself does not contribute significantly to the volume of total sediment loss, but instead prepares the material for removal by hydrodynamic mechanisms (waves and currents). The latter can transport sediments only up to a certain limit. Hence whatever the potential of thermal abrasion determined by the thermal effect, the volume of lost material is controlled mostly by the potential of storm activity, as in the case of pure abrasion.

It is well known that the annual abrasion volume is controlled not only by the strength of storms, but also by the length of the ice-free season during which storms are able to impact the coastal regime (Razumov, 2000). Open-water season length exerts an implicit influence on the relationship specified by Eq. (2), by controlling its quantitative parameters. In other words, Eq. (2) implies a certain typical length of open-water season, when waves and currents can abrade the coast.

The model was employed to predict the recession of selected coasts in the western Russian Arctic over the next century. The rate of change was found to depend on the exposure of the coast relative to the direction of dominant winds. The open coast of Varandey is expected to retreat as much as 300-500 m over 100 years, while recession of the less exposed coasts of Baydaratskaya Bay would be by 2-3 times lower. If long-term sediment loss q_* is insignificant, the rate of erosion decreases with time, the morphodynamic system is adjusted to sea level rise, and the system ultimately tends to some quasi-equilibrium state. It was concluded that the expected sea level rise of up to 0.5 m by 2100 (Church et al., 2001) is not a crucial factor for the recession of coasts where erosion activity is already at high levels.

On the contrary, the modeling study of abrasion coasts in the polar region of the White Sea led to the conclusion that sea-level rise would result in some increase in the rate of cliff retreat by 2100. This difference is partly due to a more intensive dynamic regime as compared with that in the Varandey and Baydaratskaya Bay regions.

Coastal changes were also predicted for representative thermal-abrasion coast sites located in the central and eastern regions of the Russian Arctic, where sea-ice conditions at present are the most severe. It was assumed that global climate warming would lead to a reduction in sea ice cover and, as a consequence, a significant increase in heights of waves and surges. In response to these changes in environmental forcing, the recession of thermal-abrasion cliffs is expected to accelerate in the second half of the 21st century by 1.4 to1.5 times the currently observed rate.

The model was also applied to the barrier-lagoon type coasts of the Chukchi Sea. A prominent feature here is a coastal bar composed of pebble-sized material (in contrast to a bed covered by medium sand). A major result from the predicted evolution, assuming a rise in sea level and the attendant reduction in ice cover and increase in wave and surge magnitudes, shows the possible development of a berm protecting the coastal barrier from erosion. Alternative calculations for a medium sand-built barrier indicate its erosion under the same dynamical regime. Thus global climate warming presumably would not negatively influence coasts that possess a natural barrier composed of sufficiently coarse-grained material.

Acknowledgements

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SHORE DYNAMICS OF THE PJASINA DELTA AND BAY, THE KARA SEA

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The Pjasina river mouth area is situated in the northwest region of the Taymir Peninsula (fig.1). The length of the Pjasina river is 835 km and possesses an estimated mean annual runoff of 86 km^3/year (Atlas of the Arctic, 1985).

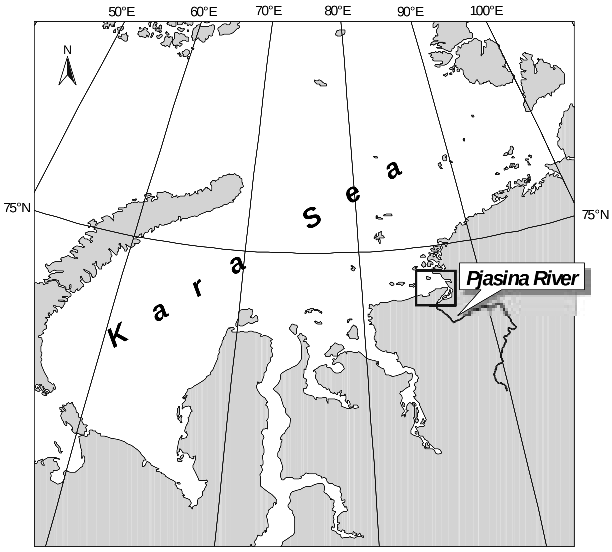

Fig.1. Location map

Delta

The delta is situated on an accumulative terraced plain, built by permafrost, and composed mainly of fine-grained deposits. There are some dolerite hills. The outer delta in the bay is protected from the open ocean by comparatively high (up to 160m) rocky islands (Pogrebitskii, 1970).

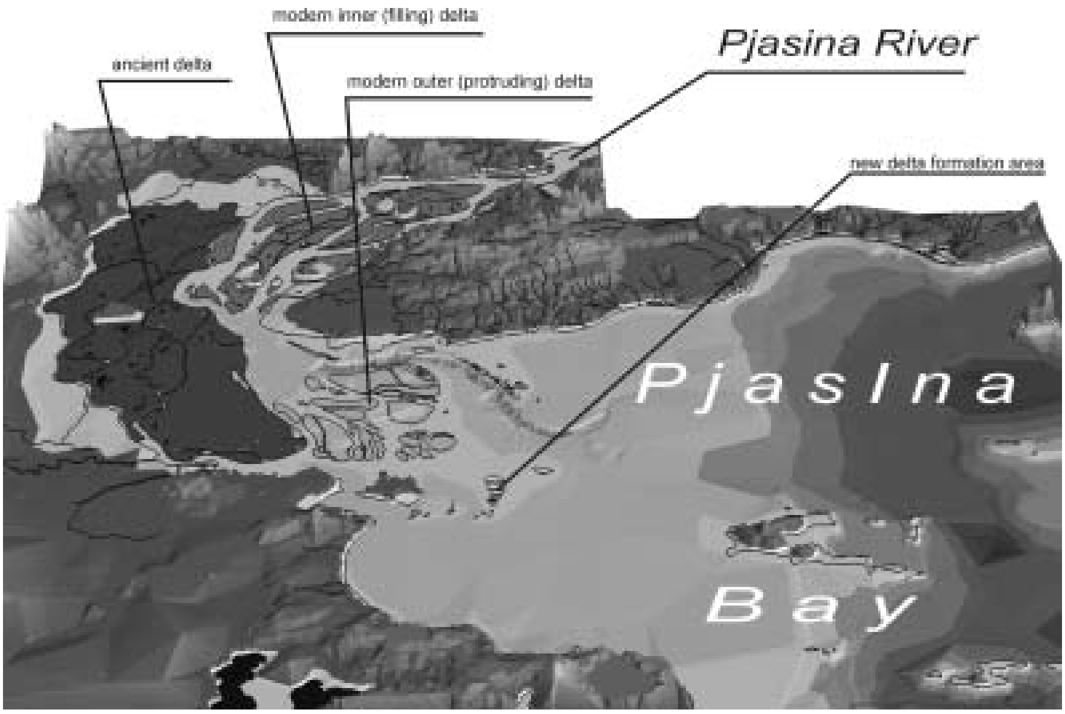

Fig.2. Delta formation stages

The delta can be subdivided into four parts according to stages in the deltaic evolution process (fig. 2). The most ancient region is situated in the east and is located between the Staritsa and Suhaya branches and Pjasina Bay. This delta is built by alluvium sediments of the River Pjasina as well as sediments of some small rivers. Narrow branches and stable banks are typical in the inner zone and active thermoerosional banks are found in the outer one. Annual coastal retreat is 1,5 – 2 m/year, with a maximum of 5,5 m/year (fig.3). A zone of land 72m in width which had separated the lake from the bay was eroded during a 13 year period (1954 – 1967).

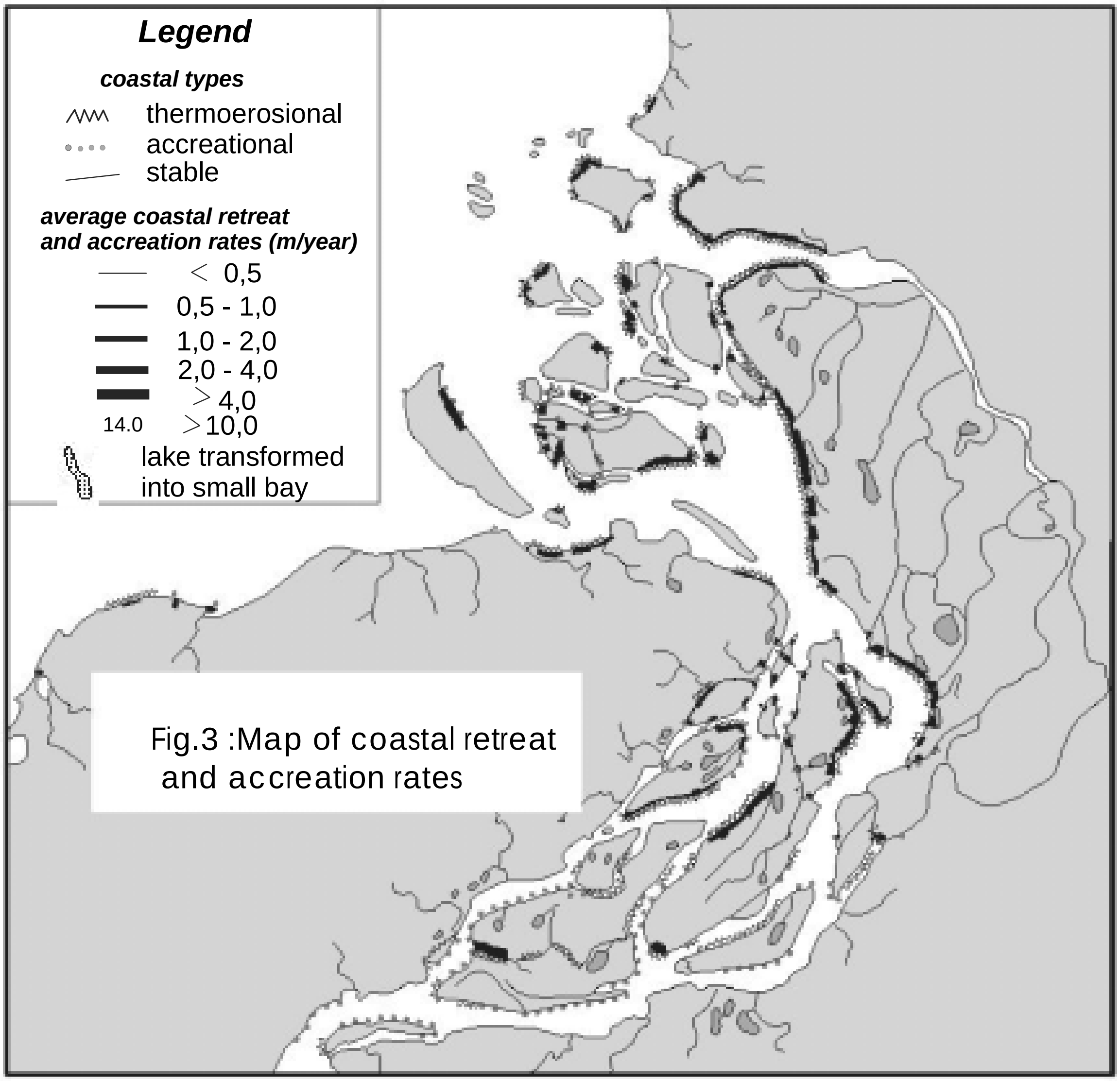

Fig.3 :Map of coastal retreat and accreation rates

The modern inner (filling) delta is located to the southwest (between Cape Sludskii and Cape Nachalnii). Its width reaches 35 km. Large changes in bank position (up to 10m per year) occur in the wide branches, which possess widths up to 4 km. This region is likely to be the transit zone for sediment.

The outer (protruding) delta is forming now in the Pjasina Bay shoal. The main islands are Labirintivie and Ragozinskogo. The tides and storm surges (up to 2,5 m) exert considerable influence on coastal erosion there. Reversal flows in the inner branches prevent active accumulation, but at the same time an average bank retreat of up to 3 m per year for a 13 year period was estimated from aerial photos in the 5 north oriented branches. The outer (marine) shores are eroded at almost all locations. The annual retreat rate is 1-2 m/year.

Currently, the most active sediment accumulation and new delta formation take place to the northwest of this area, in the Trio Islands.

Pjasina Bay coasts

Calculations of long-term average annual resultant wave energy direction and quantity, for longshore and on-shore components, were made for the Pjasina Bay coastal zone to estimate sediment transport rates and directions (fig.4).

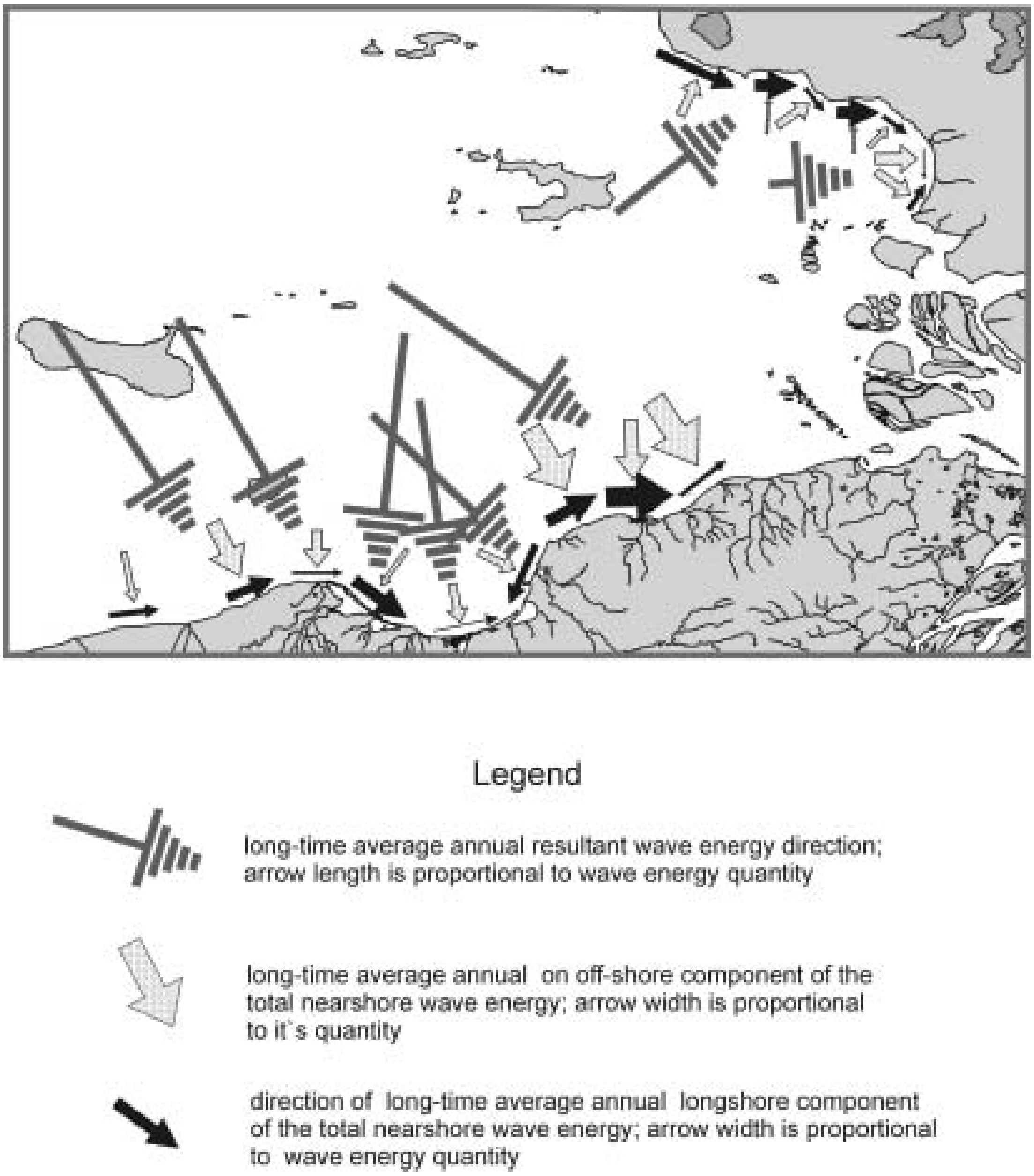

Fig.4. Wave energy characteristic in the Pjasina Bay coastal zone.

Data for this work included water depths, coastline morphometry, offshore limits of pack-ice, and wind speed and direction (measured at the Dikson meteorological station during open water season, 1936-77). The Popov – Sovershaev wind-energy method was employed (Popov, Sovershaev, 1982).

Cliffs of 10-20 m height in southern Pjasina Bay are composed mainly of limestone, sandstones and shales. Sandy beaches occur mainly near the mouths of the small rivers. Cliffs are generally stable; only 3 sections along a roughly 20 km length retreat with average rate of

1m/year. Longshore sediment transport is generally directed eastwards towards the river, as suggested by the direction of spit growth. The coastal section between Cape Zveroboy and Izba Domba are characterized by weak longshore sediment transport.

Morphometry of the coastline along the eastern bay is largely dependent on geological structure. The indented coasts, built by shales, are typical for northern coastal regions (e.g. Cape Ribnii – Cape Yugnii; Mutafi 1939). To the south (up to Cape Vostochnii), where the region is situated on a marine terrace, the shore is distinguished by low, wide beaches and large numbers of logs. There is a convergence of longshore sediment transport and accumulation. Loamy (with boulders) and muddy cliffs, which are situated to the south, are eroded everywhere. The average retreat rate is 1,5 m/year, with a maximum of 3m/year. The small island near Cape Ostrii Nos disappeared over the period 1954-72.

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COASTAL DYNAMICS IN THE KEY SITES OF THE WESTERN RUSSIAN ARCTIC SEAS UNDER CLIMATE CHANGE AND TECHNOGENIC IMPACT

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Technological and industrial development of the coastal zone in the western part of the Russian Arctic in the 21st century, which is inevitably accompanied by local technogenic impact, will be occurring under the broad milieu of global environmental change. Morpholithodynamic and cryogenic processes in the coastal zone that can be considered “normal” under unperturbed natural conditions can be transformed into unfavorable and even dangerous phenomena that can pose serious risks during the building and exploiting of industrial enterprises. The severity of natural conditions in the region of the Arctic seas gives rise to dangerous consequences which can include coastal erosion and thermo-abrasion of the shore and bottom, the action of sea-ice on the shore and bottom, and other destructive process including deflation, thermo-erosion, and thermo-denudation. Specific impacts associated with global warming, including increasing air temperature, rising sea level, and increasing severity of wind-wave activity, are of particular concern in the coastal environment. The issue of global warming and the fact that its manifestations are expected to appear first in the Arctic, coupled with the extent of the Russian Arctic coastal zone, means that the problem of understanding and forecasting of coastal dynamics is an extremely important issue, especially for Russia. Despite the great deal of interest over the last few decades, the problem still requires detailed investigation.

It should be stressed that the signature of natural-technogenic phenomena caused by disturbances associated with development can be observed within the signal of dangerous natural phenomena. The essential issue is that coastal systems have a low level of stability in the cryolitozone, which is evident in regions of active industrial development in the Russian Arctic. In particular, this applies to regions where technogenic impact has already led to the destruction of coastal regions. This can complicate development and incur additional cost to stabilize affected geosystems. Two main tasks may therefore be identified regarding arctic coastal dynamics: (1) to research coastal zone response to natural, long-term environmental changes (sea level increase, temperature rise, changes in the wind-wave and sea-ice regimes, and so on); (2) to understand how human activity can cause changes to the morpho-, cryo-, and litho-dynamic conditions. Once this work has been completed, it will be possible to forecast coastal process development in the western part of the Russian Arctic in response to changes in the natural and technogenic conditions over the course of the 21st century.

Through the use of correlation analysis between the results of observation of coastal dynamics and hydrometeorology data and the model of coastal development in the cryolitozone, it can be shown that there is no direct dependence between the temperature and level regime on the one hand and the rapidity of destruction of thermo-abrasion coasts on the other. Instead, the parameters of wind-wave and ice regime in combination with the temperature regime and precipitation amounts seems to be much more important.

The results of observations taken by the Laboratory for Geoecology of the North in the Geographical Faculty of Moscow State University, in collaboration with other organizations, clearly demonstrate that local technogenic impact is able to cause significant disturbances of the morpho-, cryo-, and litho-dynamic regimes. In particular, they can lead to an acceleration of coastal destruction and to other negative consequences. Their influence seems to be much stronger than that caused by global warming.

This work was supported by Russian Foundation for Basic Research grant no. 02-05-64935.

A FORECAST MAP OF ERODING COAST (KEY SITE CAPE MALII CHUKOCHII, EAST-SIBERIAN SEA COAST)

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The dynamic simulation a coastline is a difficult task due in part to the interplay of a wide array of complex natural and technogenic factors. The following factors are considered important for the destruction of marine shores in permafrost regions: composition, structure, density, ice content, and temperature of onshore and offshore permafrost; surface morphology on both onshore and offshore sediments; slope morphology; power of wave impacts; weather and climatic characteristics; and the mobility of deposited material on underwater slopes. Two types of models can be used to model coastal dynamics: 1) theoretical models of permafrost destruction and mass transfer, and 2) empirical models. Theoretical models are “first principles” approaches and are based on the mechanics of deformation, destruction, transfer and other elementary processes that are involved in the thermal destruction of coasts. They explicitly reflect separate components of the process complex that is responsible for coastal retreat. The development of an all-encompassing theoretical model faces a variety of difficulties, however. Thus, in practice, a more widespread approach for simulation of coastal dynamics in permafrost regions is based on the use of empirical models. While generalized models can be obtained within the framework of this approach, it must be noted that empirical models are usually effective only in a narrow range of conditions. They use a large number of parameters that can be determined only by lengthy monitoring. Given, however, that the modeling of coastline dynamics encounters difficulties associated with the description and understanding of factors related to permafrost destruction, the opportunity to use observational data is of particular interest for simulation of coastal dynamics in permafrost regions. The ACD monitoring program supports such data-gathering initiatives. The time series of coastal retreat rates are not sufficient to make a study of the factors involved with the destruction of permafrost coastal zones, however these time series reflect the character of coastal dynamics for conditions particular to each observing site.

The simplest use of observed time series of coastal retreat rates is the description of rate as a constant, average annual rate. In fact, however, the intensity of thermal abrasion changes over time in response to external factors, and there is no particular physical basis for selection of a given averaging period. Another approach is the use of observational data "as is" to represent the most widespread characteristics of coastal retreat dynamics. The direct use of time series, however, does not allow extrapolation of trends. A third approach is the use of trends or periodicity, which are observed in time series of retreat rates. This approach is also limited, however, because coastal degradational processes are not stationary in trend or periodicity. Another possible solution is the use of a probabilistic model based on Markov chains. This has several benefits: one, it allows use of the observational data "as is", and two, it enables generation of a probabilistic evaluation of future dynamics, one which reflects the observed changes in coast dynamics.

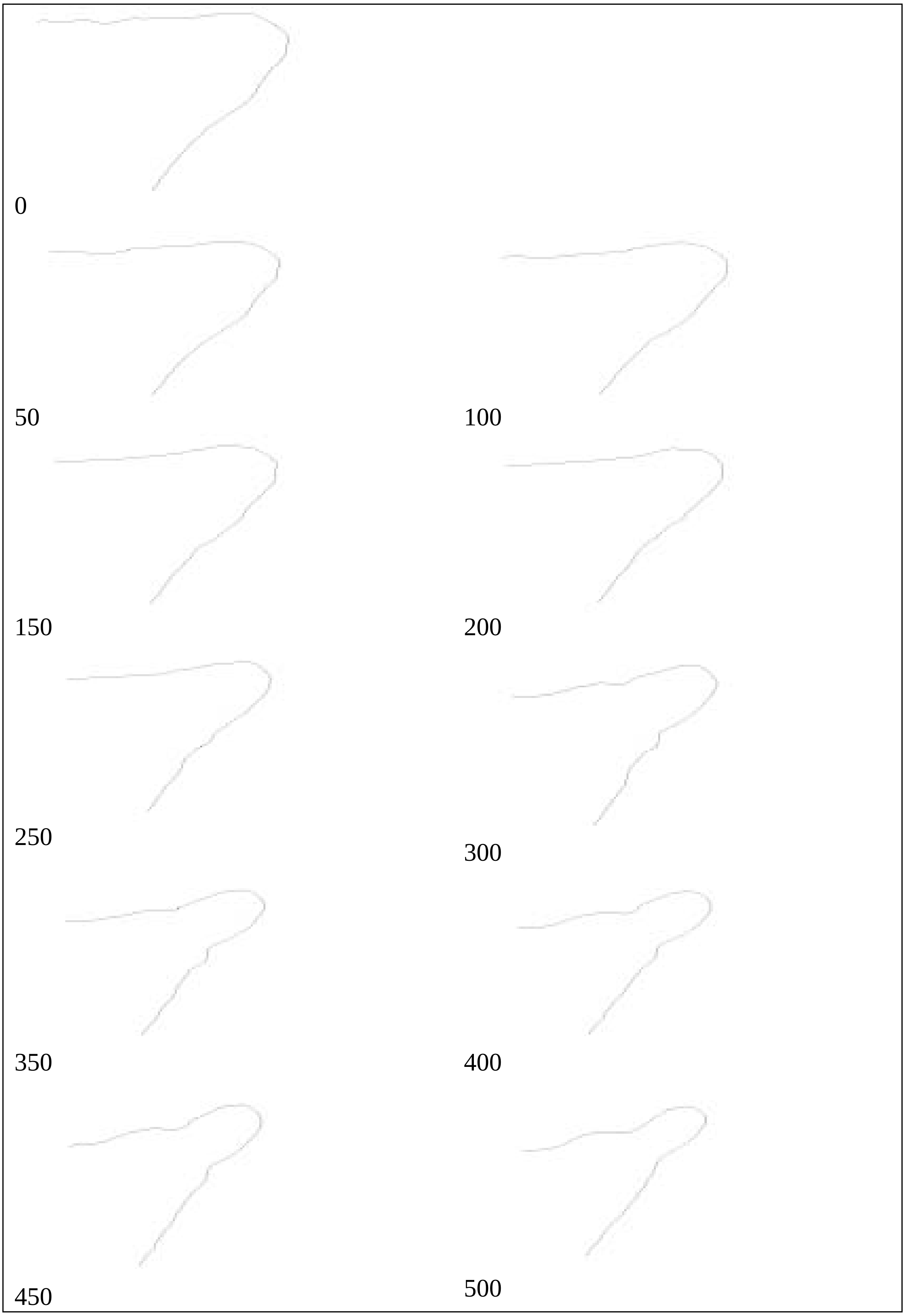

Figure 1. Simulated coastlines for a 500 year period with a 50-year step

The Markov model is based on the use of the properties of Markov chains. Markov chains are time sequences of a system "station", in which each current state (represented by a sequence of fixed length) determines not the consequent condition, but the probability of realizing a certain consequent condition. In case of coastal dynamics, a system state is defined as the retreat rate, expressed in discrete units. In the simplest case, the escape sequence has a single length for which the probability of a consequent event is determined only by the condition of the system in the present moment. The size of a matrix of transient probabilities is determined by a quantity of ranges, into which all ranges of observable speeds is broken. The common algorithm contains the following steps: transformation of the continuous time series of retreat rates; verification that the system possesses a Markov property; calculation of a matrix of transient probabilities; calculation of a simulated sequence on a matrix of transient probabilities; and finally transformation of the calculated discrete sequence into a continuous series of retreat rates. The appropriate model was tested on single profiles for homogeneous sites (using the case of a constant matrix of transient probabilities, when the entire profile may be considered to be governed by homogeneous conditions and the matrix of transient probabilities is not changed) and in conditions where the relative contribution of processes to the overall coastal dynamics situation does not remain constant along a coastline (piecewise constant matrixes of transient probabilities, when the profile intersects the boundaries between the sites with various matrixes of transient probabilities).

This work examines the approach based on the piecewise constant matrixes of transient probabilities to simulate the dynamics for an example of the extended coastline at the Cape Malii Chukochii key site (CMC). CMC is a unit of the ACD monitoring network. It is located on the western rim of the Kolyma Gulf (East-Siberian Sea). The cape is bounded by the Bolshaya Chukocii river estuary to the NNW. The introduction of sediment from stream run-off complicates the thermal abrasion dynamical situation here. East-facing shores on the CMC are open to the sea. The underwater slope has an extensive shallow band at this part of the shore. Coastal degradation due to thermal abrasion takes place here. Thermal erosion of the ice complex deposits (taberated permafrost) also takes place at CMC. Destruction of permafrost sediments is complicated by several factors, including variable levels of alas depressions (7 - 35 m depending on the depth of secondary frozen taliks and thaw settelment), activity associated with the linear depressions, thermal erosion of ravines, runoff of superpermafrost water, and other processes. Thus the dynamics of the coastline at this key site exhibits non-linearity, and under such inhomogeneous conditions, a description of coastal dynamics using the usual deterministic models is not satisfactory.

Time series of retreat rates form the input data for the Markov-chain model at CMC. They are the result of observations gathered from the four ACD monitoring profiles located at CMC. The data reflect the dynamics of retreat under typical marine conditions (which includes riverine acceleration of the submarine sediment run-off and the influence of an extensive shoal, which limits the effect of wave impact on both ice complexes and taberated deposits). To support the extrapolation work a digital schematic map was prepared which reflects the cryolithological conditions of the CMC (GeoGraph2 GIS format). 55 model profiles were selected from the schematic map for calculations. Each profile was classified into homogeneous sections pursuant to the landscape scheme. The matrix of transient probabilities is constant inside each section. The figure shows the dynamics of the coastline at the CMC key site calculated for a projected 500–year period.

The Markov-chain based model can be used in a complex with other models for prognosis of dynamics of sediment flux, and can be applied to estimate the input of organic carbon and other organic and inorganic components into the sea basin due to coastal erosion in permafrost areas.

THE PECULIARITY OF FAST ICE DYNAMICS IN THE WHITE SEA TIDAL-FLATS

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During expeditions conducted in January-February of 2000-2003 to the Kandalaksha' and Onega' Bays coasts of the White Sea, there were studied the structure and dynamics of fast ice and their influence on the coastline. The field work included the establishment of shore profiles, the drawing of an ice-cover map (using GPS), the completion of an ice structure atlas, the measurement of snow cover (Table 1), and the acquisition of ice and snow samples for physical and chemical analyses.

Table 1. The winter weather on the west shore of the White Sea. Weather conditions exhibited strong variability from year to year which resulted in differences in ice cover features.

Year	Mean air temperature during freezing (October-December), Gridino Station, ^{o}C	Snow cover height, sm. (January-February) by author's measurements
1999-2000	-1.7	60-80
2000-2001	0.3	30-50
2001-2002	-4.3	40-60
2002-2003	-5.8	60-80

On the southern coast of Kandalaksha Bay near the Biological Station operated by Moscow State University (MSU) (Rugosero Inlet) may be found remnants of marine terraces 6 m in height composed of rubble-sandy-clay sediments. These terraces descend in steps to the littoral zone, which ranges between 10-15 m and 1 km in width. Boulders and boulder ridges of 100-150 m in length are common in this zone. Rock scarps ranging up to 40m in height are also typical for this region. The width of the littoral zone near the foot of these scarps is not more than 4-6 m.

The coast near the settlement of Lyamtsa (at the mouth of the Purnema River) is composed mainly of sandy-mud sediments. Boulders are less common here, and boulder ridges are sporadic. Fragments of sandy marine terraces of 4-5 m height are also found here. The steps of an undulating surface of 35-45 m in height, composed of loam with boulder inclusions, runs the length of the shore.

On the shores of the tidal zone the fast ice, right from the time of its initial formation in the fall, shows constant movement up and down according to the movement of water during tides. This is the reason for its deformations, breaking, and formation of leads, ice ridges, and rubble fields throughout the freeze-up season. Tidal streams are responsible for the creation of stationary open leads above sea rapids (e.g., Velikaya Salma Straight, Chernaya Inlet) and intensive ice crushing. Wide embacle belts of 2 m in height with numerous open water zones (which do not freeze even during extreme cold) are specific to the eastern Solovetskaya Salma Straight between Gluboky Cape and Purluda Island, as well as in other regions.

"Ice tents" – conglomerations of large pieces of ice above and around big boulders - are dominant on the littoral zone of Kandalaksha Bay. They have salient cross profile and isometric form. These "ice tents" transform into ridges of 60-100 m in length and up to 3 m in height on the ice ridges and the outermost boulders, situated in the littoral zone.

Tides create excess water pressure under the fast ice. This is the reason for observed seawater expression through leads and attendant flooding of nearby ice lowerings, as well as water pumping into the cracks of “ice tents”. Seawater rises up along the cracks and freezes, promoting growth of “ice tents” up to 2.5-3 m in height (or to 4-6 m in height, according to unverified reports) and 6-7 m in diameter. The formation of ridges which combine the elements of an “ice tent” and ice push are common to the tidal flats near the settlement of Purnema on the Lyamtsa coast. Ice ridges of 200-300 m in length and up to 50-70 m in width consist of accumulations of small floes, fastened together with expressed water that has subsequently frozen in the gaps. The leads remain near their foots.

Sea-ice interferes with the natural wave grading of bottom and beach sediments, deforms the relief of the sea floor and tidal flats, creates pressure ridges, and transports sediments to other places. The Rugozero Inlet fast ice entrains quantities of bottom silts, boulders, scraps of algae, shells, and other material (on the order of 0.3-1 t/km). Sea ice in the eastern part of Onega Bay contains even more material of sandy-aleurity-pelitic size (on the order of 3 t/km), most of which is obtained from the sea floor. Removal of sediments from the shore due to aeolian transport is comparatively insignificant.

The weather conditions in a given year determine the nature and structure of the fast ice that forms. The number of ”ice tents” is relatively constant from year to year, however the width of fast ice and the distribution of various ice forms (e.g., fields of pancake ice, nilas, shuga, slush, ice cake, small floe and so on) varies significantly. Several periods of high wind surges and impressive hydrodynamic activity during January of 2001 caused repeated breaks of thin ice, which were hardly covered by snow. This led to the creation of numerous rubble fields on the shore and tidal flats, the mechanical breakdown of small floes, various forms of ice hummocking and the completion of the fast ice structure. During periods of thaw some insight into sea-ice destruction and drift to the boundaries of open water have been gained, and on the contrary, during the freezing periods, its creation and evolution.

Ice freezing in 2001-2002 was characterised by minimal ice movement and a low occurrence of ice crushing. During the cold winter of 2002-2003 fast ice was already built up as of late October and it thickness reached 0.7-0.9 m in early February. The usual variety of ice forms was not in evidence.

By this means the structure and dynamics of fast ice in the tidal flats is determined by the peculiarities of tidal waves, the irregularity of the coast, the relief of tide-flat zone, wind direction and speed, and air temperature. The presence of actively growing “ice tents” and numerous ice breaks is the main peculiarity of fast ice on the examined coasts of the White Sea.

This work was supported by Russian Foundation for Basic Research grant no. 02-05-64935.

HYDRODYNAMIC PARAMETERS OF THE KARA SEA AND THE RESPONSE OF COASTAL DYNAMICS TO CLIMATE CHANGES

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To assess the influence of natural factors on coastal erosion, one has to analyze data on the morphology and geological structure of the coastal zone, including data on the content and forms of ice in coastal sediments, as well as data on hydrodynamic parameters of the sea, including the duration of the ice-free season, as well as height, length, and period of sea waves and their predominant direction, and the pattern of wave refraction.

In this report, new data on the hydrodynamic parameters of the Kara Sea in the area of the Marre-Sale key site are analyzed. These data have been obtained by the authors in the course of fieldwork and from weather records at the Marre-Sale weather station.

The duration of the ice-free season in the Marre-Sale area varies from 31 to 125 days with a mean of 95 days. It displays a positive correlation with the mean summer air temperature for particular years. The correlation coefficient is 0.66 (Fig. 1)

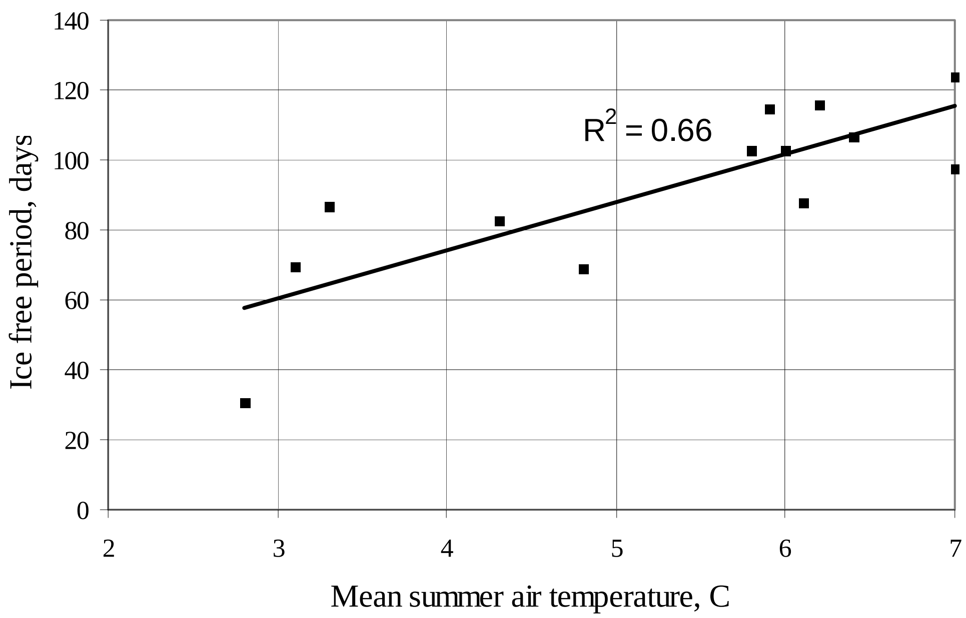

Fig. 1. Correlation between mean summer air temperature and ice free period.

Data on the temporal variability of the duration of the ice-free season for a period from 1989 to 2001 are presented in fig.2.

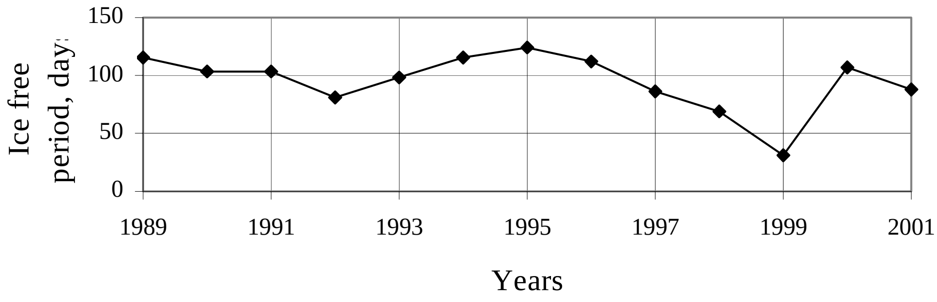

Fig. 2. Temporal changes of the ice free period.

A weak positive correlation also exists between the number of storm days and the coastal retreat rate; the correlation coefficient is only 0.35 (Fig. 3).

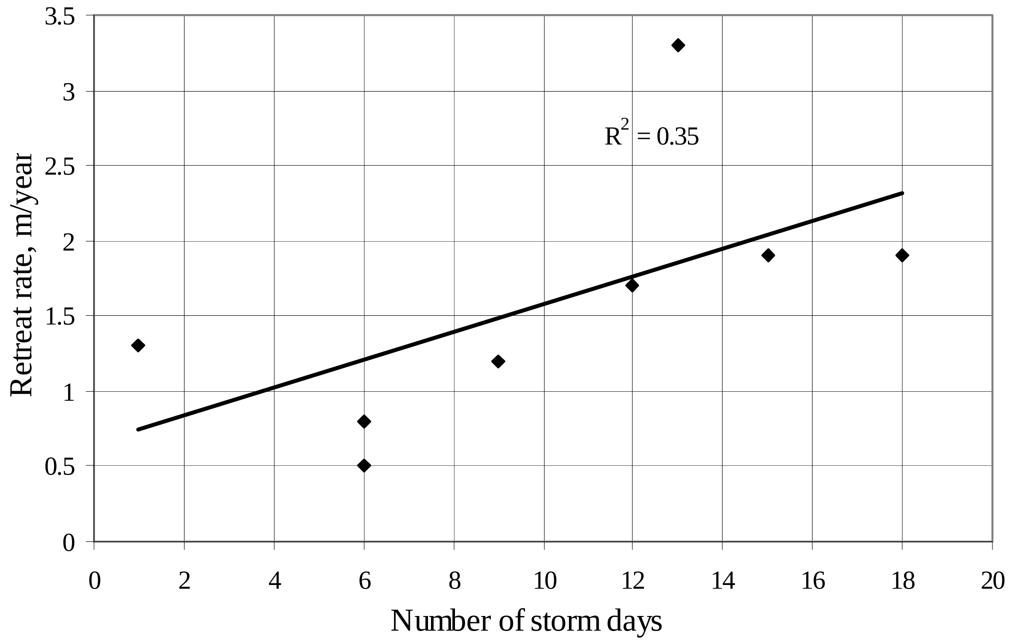

Fig. 3. Correlation between number of storm days and the coastal retreat rate.

The analysis of data on the height (H), length (L), and period (t) of sea waves in the Marre-Sale area shows that these parameters are reliably described by the following equations:

$t= 3.95\ H^{0.59}$; $L=19.1H-0.66$; $L=6.03\ e^{0.3t}$.

The corresponding correlation coefficients range from 0.9 to 0.99.

A comparison of daily wind velocity and wave height data during the ice-free season for 1998–2002 has shown that these values are also positively correlated with one another; however, the correlation coefficient is too low to establish a functional relationship between them. At the same time, the correlation coefficient increases if direction of sea waves with respect to the shore is considered. Thus the orientation of wind direction with respect to the coast should be taken into account when calculating wave heights and energy from wind data, otherwise calculation errors may exceed 100%.

As shown in previous works by Vasiliev et al. (2001) and Vasiliev (2003), a plot of temporal changes in the coastal retreat rates in the Marre-Sale area has a distinct peak at 1989–1990. Similar results were obtained along the Laptev Sea and East Siberian Sea coasts by S.

Razumov and M. Grigoriev (per. comm.). Atkinson and Solomon (2003) suggested that temporal dynamics in the coastal retreat rate should be compared with temporal changes in the Arctic Oscillation (AO) index (Atkinson and Solomon, 2003). The results of this comparison for the Marre-Sale area are displayed in the figure 4. As seen from this figure, temporal changes in the retreat rate correlate well with temporal changes in the annual sum of the AO index. A similar, though less distinct correlation is observed for Cape Krestovskiy in the East Siberian Sea. Lower values of correlation between the rate of coastal retreat and the AO index in the latter case can be explained by large periods between the measurements of the coastal retreat, which results in some leveling of the peaks. It is also possible that a lower correlation at Cape Krestovskiy is caused by the fact that the cliff at the key site faces northeast and east, which results in a lower response of coastal dynamics to the Arctic Oscillation.

The data obtained make it possible to relate the issue of coastal dynamics response in the Arctic to climate changes. It is evident that climate changes should affect hydrodynamic parameters of the atmosphere and the Arctic Ocean. In turn, this should cause changes in the rates of coastal erosion. Thus, it is necessary to compare climate change data with (a) data on changes in the particular hydrodynamic parameters of the atmosphere and sea and (b) data on the coastal retreat rate. The most feasible way of achieving this goal is to organize regular annual measurements of the coastal retreat rate at four or five sites along the Arctic coast combined with the monitoring of hydrodynamic parameters of the sea and weather records in adjacent areas.

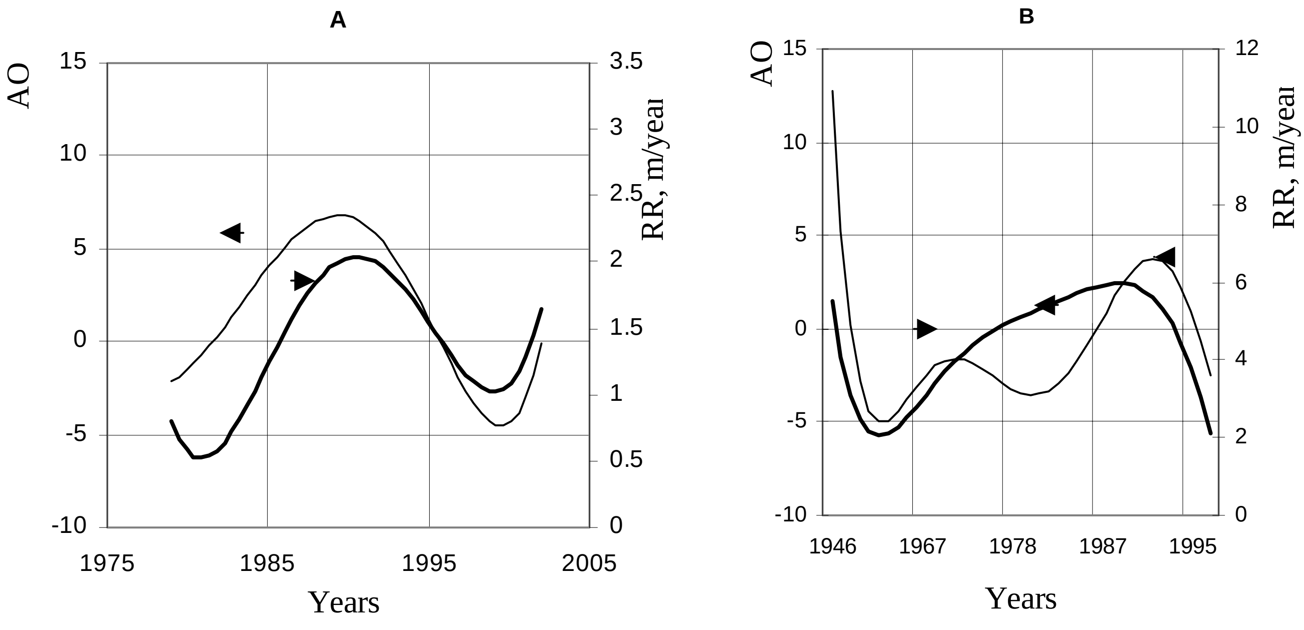

Fig. 4. Temporal changes in the AO Index and coastal retreat rate at (A) Marre- Sale, Kara Sea and (B) Cape Krestovskiy, East-Siberian Sea.

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GEOECOLOGICAL MONITORING OF THE COAST-SHELF ZONE IN THE PECHORA SEA

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[3] – M.V. Lomonosov Moscow State University, Russia

The AARI, VNIIOkeangeologiya, and MSU conducted multidisciplinary geoecological monitoring of the coastal-shelf zone of the Pechora Sea in the course of summer field research work undertaken over the years 1999-2003. This research work was carried out within the framework of the subprogram "Study of the nature of the World Ocean" of the following projects of the Federal Scientific Program "World Ocean":

- "Study of the variability of ice, hydrometeorological, lithodynamic, geocryological, and ecological conditions at different scales at selected key regions of the Arctic Seas and in local regions of resource exploitation underway on the shelf of the Barents and Kara Seas",
- "Study of the physical processes that determine the main features of the hydrological regime of the Russian Arctic seas",
- "Multidisciplinary study of hydrological-ecological state of river mouths of the Russian Arctic seas. Assessment of the impact of extreme ecological situations due to natural and anthropogenic causes on estuaries and coastal zones".

The principal monitoring observations in the Pechora Sea are conducted in regions of important oil and gas development projects. The most important monitoring region is located near Varandey Island. A submarine pipeline has been functioning here since 2000, and product shipment is carried out from a coastal tank park.

The geoecological monitoring of the coastal-shelf zone of the Pechora Sea included the following research work:

- investigation of the hydrological regime of the Pechora Sea during the summer period;
- study of sea floor microrelief to estimate the main parameters of ice gouges (depth, width, angle of gouge orientation and degree of their filling by sediments);
- study of the characteristics of modern sedimentation within the limits of local sedimentation basins;
- study of the specific features of solar radiation redistribution in the coastal waters of the Arctic seas;
- geomorphological study of the coastal region;
- monitoring of coastal dynamics and accompanying exogenous processes
- monitoring of accompanying meteorological conditions;
- assessment of background condition of terrestrial and marine complexes.

Data were obtained in the course of this 5-year cycle on environmental conditions. These data will allow us to identify quantitative links between components of the environmental complex in the region of the Varandey industrial region, to better assess the reaction of this complex to increasing anthropogenic impact and to elaborate further recommendations for optimization of environmental exploitation in this region.

4 Appendix

Appendix 1. Metadata of the existing ACD key sites.

DATE PREP.	COASTAL SECTION NAME	TYPE SITE	COUNTRY	REGION	LAT	LONG	CONTACT:
02 Nov 00	North Head	Key	Canada	Mackenzie Delta	69.72	-134.49	S.Solomon (solomon@nrcan.gc.ca)
14 Feb 01	Elson Lagoon, Barrow, Alaska	Key	United States	Alaska	70.32	-156.58	Jerry Brown (jerrybrown@igc.org)
25 Jan 01	Cape Krusenstern	Key	USA	NW Alaska	67.67	-163.35	J.W.Jordan (jwjordan@sover.net)
22 Jan 01	Marre-Sale	Key	Russia	West Siberia	69.70	66.50	Alexandr Vasiliev (emelnikov@mtu-net.ru)
25 Jan 01	Bolvansky cape	Key	Russia	European North	68.30	54.50	Alexandr Vasiliev (emelnikov@mtu-net.ru)
13 Mar 01	Muostakh Island, Buor-Khaya Bay	Key	Russia	Laptev Sea Coast	71.61	129.94	Mikhail N. Grigoriev (grigoriev@mpi.ysn.ru)
13 Mar 01	Bykovsky Peninsula	Key	Russia	Laptev Sea Coast	71.79	129.42	Mikhail N. Grigoriev (grigoriev@mpi.ysn.ru)
13 Mar 01	Bolshoy Lyakhovsky Island, Novosibirsky Archipelago	Key	Russia	Laptev Sea Coast, Dmitri Laptev Strait	73.33	141.35	Mikhail N. Grigoriev (grigoriev@mpi.ysn.ru)
13 Mar 01	Terpyai-Tumsa Cape	Key	Russia	Laptev Sea Coast, Olenek Bay	73.57	118.40	Mikhail N. Grigoriev (grigoriev@mpi.ysn.ru)
01 Sep 01	Pesyakov Island	Key	Russia	Pechora (Barents) Sea Coast	68.75	57.60	Stanislav Ogorodov (ogorodov@aha.ru)
01 Sep 01	Varandei Island - Peschanka River	Key	Russia	Pechora (Barents) Sea Coast	68.82	58.10	Stanislav Ogorodov (ogorodov@aha.ru)
01 Sep 01	Peschanka River - Cape Polyarnyi	Key	Russia	Pechora (Barents) Sea Coast	68.91	58.60	Stanislav Ogorodov (ogorodov@aha.ru)
01 Sep 01	Cape Konstantinovskii - Cape Gorelka	Key	Russia	Pechora Bay Coast of Pechora (Barents) Sea	68.56	55.50	Stanislav Ogorodov (ogorodov@aha.ru)
15 Sep 01	Kharasavei settlement area	Key	Russia	Kara Sea Coast, Yamal Peninsula	71.10	66.70	Stanislav Ogorodov (ogorodov@aha.ru)
15 Sepr 01	Cape Mutnyi - Ly-Yakha River	Key	Russia	Baidaratskaya Bay Coast of Kara Sea, Yamal Peninsula	69.30	68.10	Stanislav Ogorodov (ogorodov@aha.ru)
15 Sep 01	Yary village - Levdiev Island	Key	Russia	Baidaratskaya Bay Coast of Kara Sea, Ural region	68.80	66.90	Stanislav Ogorodov (ogorodov@aha.ru)
15 Sep 01	Yamburg Harbour area	Key	Russia	Ob' Bay Coast of Kara Sea	67.90	74.80	Stanislav Ogorodov (ogorodov@aha.ru)
10 Oct 01	Beaufort Lagoon, Arctic National Wildlife Refuge, Alaska	Key	United States	Alaska	69.88	-142.30	Janet Jorgenson (janet_jorgenson@fws.go) Torre Jorgenson (tjorgenson@abrinc.com)
22 Oct 01	Cape Maly Chukochiy	Key	Russia	East Siberia Sea, Kolyma Lowland Coast	70.08	159.92	Vladimir Ostroumov (Vostr@issp.serpukhov.su)
20 Nov 01	Onemen gulf	Key	Russia	Chukotka	64.81	176.92	A.N. Kotov (nauka@anadyr.ru)
11 Jan 02	Chukchi Sea, Barrow, Alaska	Key	United States	Alaska	71.30	-156.75	Bill Manley (William.Manley@ colorado.edu)
22 Jan 03	Kongsfjorden Area, Spitsbergen, Svalbard	Key	Norway	Barents Sea	78.93	11.83	Johan Ludvig Sollid (j.l.sollid@geografi.uio.no)
01 Feb 03	Nahodka Bay	Key	Russia	Kara Sea, Ob Estuary	67.23	72.21	Olga Medkova (Olga_Medkova@mail.ru)

Appendix 2. ACD Coastal Classification Template.

field	***entry options***
primary_contact_person	provide name and email
regional_sea_name	Chukchi Sea=CS, East Siberian Sea=ESS, Laptev Sea=LS, Kara Sea=KS, Barents Sea=BS, Greenland Sea/Canadian Archipelago=GSCA, Beaufort Sea=BS
regional_sea_code	code *(see GIS Working Group Report, chapter 3.1 this volume)*
segment	
segment_name	text field
segment_code	code*(see GIS Working Group Report, chapter 3.1 this volume)*
onshore (direction landward from the sea)	
onshore_form	delta=d, lowland(<10m)=l, upland(10-500m)=u, highland(>500m)=h, wetland=w
backshore (upper part of the active beach above the normal reach of the tides (high water), but affected by large waves occurring during a high water)	
backshore_form	cliff=c, slope=s, flat=f, ridged/terraced=r, anthropogenic=a, complicated=x
backshore_elevation	in meters
backshore_material_1	lithified=l, unlithified=u
backshore_material_2	mud-dominated=m, sand-dominated=s, gravel-dominated=g, diamict=d, organic=o, mixtures= e.g mg, sg
backshore_comment	text to be added if backshore_form=r or backshore_form=x
shore (strip of ground bordering the sea which is alternately exposed, or covered by tides and/or waves)	
shore_form	beach=b, shore terrace*=t, cliff=c, complicated=x
beach_form	fringing=f, barrier=b, spit=s (to be filled if shore_form=b)
shore_material_1	lithified=l, unlithified=u
shore_material_2	mud-dominated=m, sand-dominated=s, gravel-dominated=g, diamict=d, organic=o, mixtures= e.g mg, sg
shore_comment	text to be added if shore_form = x
offshore	
depth_closure**	in meters (if available)
distance_2m_isobath	in meters (if available)
distance_5m_isobath	in meters (if available)
distance_10m_isobath	in meters (if available)
distance_100m_isobath	in meters (if available)
offshore_material	mud-dominated=m, sand-dominated=s, gravel-dominated=g, diamict=d, organic=o, mixtures= e.g mg, sg
general	
ground_ice_1	low(2-20)=l, medium(20-50)=m, high(>50)=h
ground_ice_2	in % total volume of shoreline (best guess!)
ground_ice_comment	text to be added if ground ice template was filled out
change_rate	in meter/year (erosion=minus, accumulation=plus)
change_rate_interval	in years (years of observation, e.g. 1956-1999)
dynamic_process	erosive=e, stable=s, accumulative=a (interpretation, only to be filled out if change rate is not available)
dry_bulk_density	in t/m3 (if no data available use: clay=1.3, silt=1.5, sand=2, or mixtures, e.g. silty sand=1.8)
organic_C	in weight % (best guess!)
soil_organic_C	in kg/m2 (if available)
data_sources	text (provide the sources or references(citation) of used information, i.e. published, unpublished observations or reports)
comments	text (space for additional comments)
environmental data (not included here, will be available as separate GIS layers)	

*shore terrace = a terrace made along a coast by the action of waves and shore currents, it may become land by uplifting of shore or lowering of the water; **depth_closure = maximum storm wave base

Appendix 3. Agenda of the 4th ACD Workshop.

November 8/9

Arrival

November 10

09.00 – 09.30: Registration

09.30 – 09.45: Opening of the workshop (Georgy Cherkashov and Volker Rachold)

09.45 – 10.30: Plenary session with oral overview presentations (10 min. each)

- *Steven Solomon:* Activities in the Canadian Beaufort Sea
- *Jerry Brown:* Activities in the US Beaufort Sea
- *Georgy Cherkashov, Alexander Vasiliev:* Activities in the western Russian Arctic
- *Vladimir Ostroumov:* Activities in the East Siberian Sea

10.30 – 11.00: *Coffee*

11.00 – 13.00: Oral overview presentations continued (10 min. each)

- *Rune Odegard, Frits Steenhuisen, Christopher Cogan*: Segmentation and GIS development
- *David Atkinson:* Environmental forcing
- *Christopher Cogan:* Introduction to the biodiversity working group
- *Sergey Nikiforov, Yuriy Pavlidis:* Coastal activities of the Shirshov Institute (Moscow)
- *Feliks Are: Arctic shoreface profiles*
- *Michel Allard:* Canadian ArcticNet Program
- *Vladimir Romanovsky*: US Land-Shelf Initiative
- *Mikhail Grigoriev, Volker Rachold:* Coastal permafrost drilling in the Laptev Sea
- *Volker Rachold, Steve Solomon:* Report of the SEARCH (Study of Environmental Arctic Change) Open Science Meeting (Seattle, October 27-30)

13.00 – 14.15: L*unch*

14.15 – 15.15: Introduction to the poster session (1-2 minutes presentation per poster)

15.15 – 17.00: Poster session with coffee (posters will be up during the whole week)

19.00 – 21.00: *Ice breaker at Otto Schmidt Laboratory located in AARI*

November 11

09.00 – 09.30: Plenary meeting: identification of working groups:

- *GIS development*
- *Coastal Permafrost*
- *Biogeochemistry*
- *Arctic Coastal Biodiversity*
- *Environmental forcing*

09.30 – 10.30: Working group meetings

10.30 – 11.00: C*offee*

11.00 – 13.00: Working group meetings

13.00 – 14.15: L*unch*

14.15 – 15.30: Working group meetings

15.30 – 16.00: *Coffee*

16.00 – 17.30: Working group meetings

17.30 – 18.00: Plenary meeting (short reports of the working groups)

November 12

09.00 – 10.30: Working group meetings

10.30 – 11.00: *Coffee*

11.00 – 13.00: Working group meetings

13.00 – 14.00: L*unch*

14.00 – 15.15: Working group meetings

15.15 – 16.00: C*offee*

16.00 – 18.00: Working group meetings

November 13

09:00 – 13.00: Plenary session, reports of the working groups and general discussions

13.00 – 14.15: L*unch*

14.15 – 19.00: Cultural program, sightseeing, hermitage

20.00: *Conference diner/banquet aboard Icebreaker "Krassin"*

November 14/15

Departure

Appendix 4. Participants of the 4th ACD Workshop.

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* Steering Committee Member, ** Young Investigator, *** INTAS Team Leader

Appendix 5. Author index.