Arctic Coastal Dynamics

Report of the 5th International Workshop

McGill University, Montreal (Canada), 13-16 October 2004

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Preface

Arctic Coastal Dynamics (ACD) is a joint project of the International Arctic Science Committee (IASC) and the International Permafrost Association (IPA) and it is a regional project of the International Geosphere-Biosphere Program Land-Ocean Interactions in the Coastal Zone (IGBP-LOICZ). 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 fifth IASC-sponsored ACD workshop was held in Montreal, Canada, on October 13-16, 2004. Participants from Canada (20), Germany (3), Malaysia (1), the Netherlands (1), Norway (1), Russia (14), and the United States (6) attended. The objective of the workshop was to review the status of ACD according to the Science and Implementation Plan, with the main focus on completing the circum-Arctic ACD segmentation and classification and initiating the development of web-deliverable GIS products.

During the first part of the workshop, progress reports of the working groups of the last workshop held in St. Petersburg (Russia) in November 2003 were presented, as were 44 scientific papers dealing with regional and/or circum-Arctic coastal dynamics. In addition to the established ACD working groups on (1) GIS Development, (2) Transition from Onshore to Offshore Permafrost and (3) Environmental Forcing, a new theme introduced at the Canadian workshop was (4) the Human Dimensions of Arctic Coastal Dynamics. Finally, the results of the workshop and the next steps to be taken 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. The Canadian Department of Foreign Affairs and International Trade (DFAIT) and the Canadian International Development Agency (CIDA) provided support for six Russian participants.

IASC

International Permafrost Association

Participants of the 5th International Workshop on Arctic Coastal Dynamics (ACD), Montreal, Canada, 13-16 October 2004.
(photo by Volker Rachold).

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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 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 1.1 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.

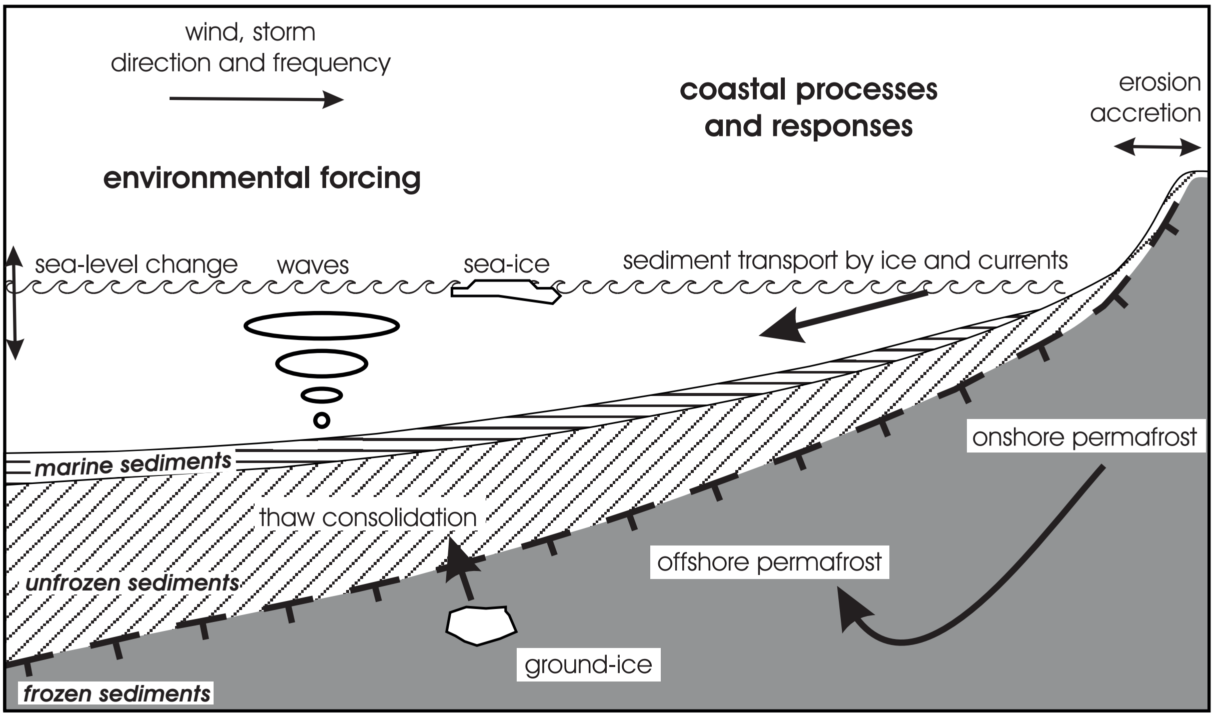

Figure 1.1. Arctic coastal processes and responses to environmental forcing.

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-bound 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 1.2). 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.

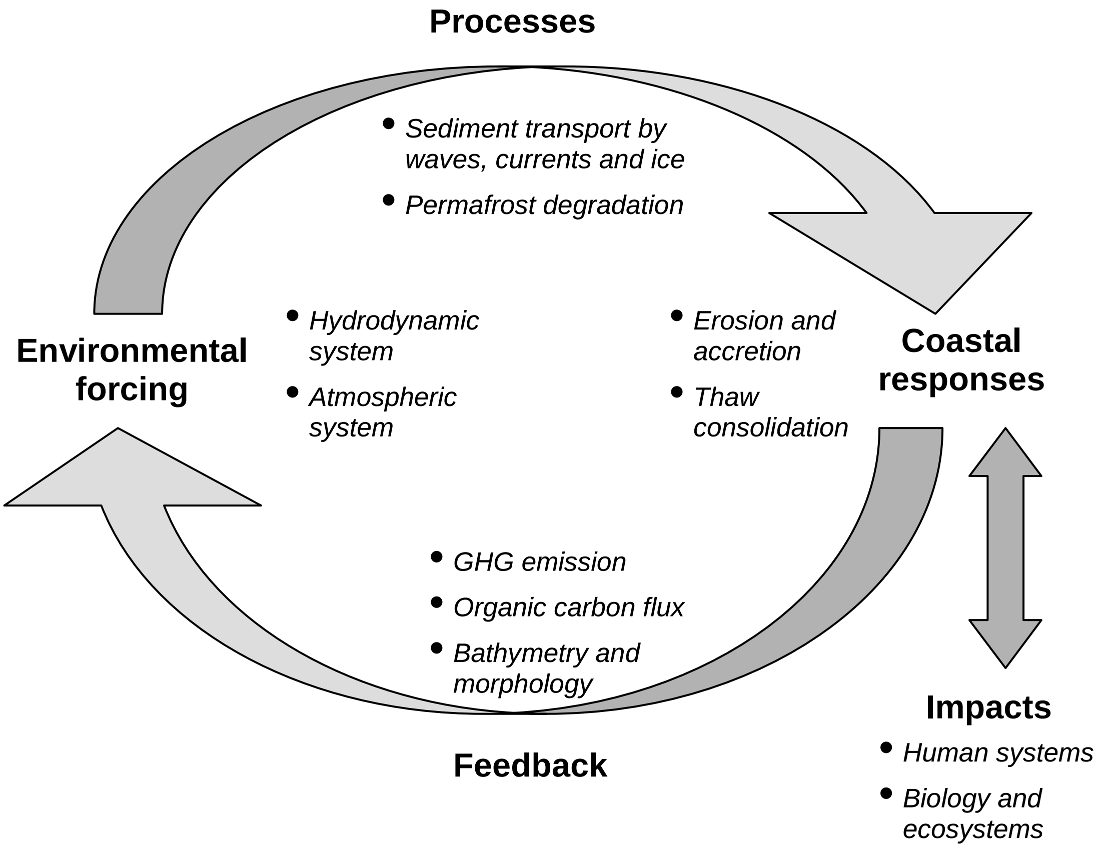

Figure 1.2. Environmental forcing, coastal processes and responses, impacts and feedback.

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/acd) 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)
- George Cherkashov, VNIIOkeangeologia, St. Petersburg (Russia)
- Mikhail Grigoriev, Permafrost Institute, Yakutsk (Russia)
- Hans Hubberten, AWI, Potsdam (Germany)
- Torre Jorgenson, ABR (Alaska Biological Research) Inc., Fairbanks (USA)
- 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, in Oslo (Norway), 2-5 December 2002, and in St. Petersburg (Russia), 10-13 November 2003. Workshop Proceedings including extended abstracts were published in the journal *Reports on Polar and Marine Research* (Rachold et al., 2002, 2003, Rachold and Cherkashov, 2004). Currently, ca. 25 institutions from Austria, Canada, Germany, Norway, The Netherlands, Russia, Switzerland, UK and USA are contributing to the ACD project.

1.3 Current Focus and Objectives of the 5th 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 years and most of them are re-visited each year. 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, a series of 15 papers on Arctic coastal processes and dynamics has been published in a special issue of the journal *Geo-Marine Letters* (Rachold et al., 2005). The online publication is available at http://www.springerlink.com/.

Emphasis is currently on developing a reliable circum-Arctic estimate of sediment and organic carbon input from coastal erosion to the inner shelves. This 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 (see Appendix 2). Geographical information about 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: WG 4 GIS Development).*

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. 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: WG 3 Environmental).*

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. 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: WG 1 Transition from Onshore to Offshore Permafrost).*

The coastal zone is the region of most high-latitude human activities. The coastal margin hosts a complex interaction of marine, terrestrial and atmospheric processes that are extremely vulnerable to predicted environmental changes and anthropogenic stressors. These coasts are typically permafrost-dominated and suffer from rapid erosion with serious implications for ecosystems and communities (Arctic Climate Impact Assessment (ACIA) – key finding #5). Therefore, it is both timely and appropriate to include the human dimension in the ACD program and a new theme being introduced at the Canadian meeting is the impact of coastal change on the inhabitants of the Arctic shore zones *(► 2. Program and Main Results of the Workshop: WG 2 Human Dimensions of Arctic Coastal Processes).*

2 Program and Main Results of the Workshop[1]

The fifth IASC-sponsored ACD workshop was held in Montreal, Canada, on October 13-16, 2004. Participants from Canada (20), Germany (3), Malaysia (1), the Netherlands (1), Norway (1), Russia (14), and the United States (6) attended. Of these, two were young scientists supported by IASC. The Canadian Department of Foreign Affairs and International Trade (DFAIT) and the Canadian International Development Agency (CIDA) provided support for six of the Russian participants. The Geography Department of McGill University, Montreal (Canada) organized the local logistics and hosted the workshop.

2.1 Program

During the first day of the workshop, progress reports of the working groups of the last workshop held in St. Petersburg (Russia) in November 2003 (Rachold and Cherkashov, 2004) were presented, as were 44 scientific papers dealing with regional and/or circum-Arctic coastal dynamics. Based on the results of the existing working groups and on the material presented in the plenary, four thematic working groups were defined. In addition to the established ACD working groups on (1) GIS development, (2) Transition from Onshore to Offshore Permafrost and (3) Environmental Forcing, a new theme being introduced at the Canadian workshop was (4) the Human Dimensions of Arctic Coastal Dynamics.

The second and third day of the workshop were mainly used for working group discussions. Parallel to the main working groups, smaller groups met to discuss future ACD related projects/proposals, such as the Canadian ArcticNet Program and potential future INTAS projects. Finally, the results of the workshop and the next steps to be taken were discussed in the ACD Steering Committee meeting.

Following the workshop, an excursion to Quebec City organized by Michel Allard (Laval University) was offered. The tour included a visit of the polar research vessel CCGS Amundsen and a walk through Old Quebec City.

2.2 Main Results of the Working Group Meetings

The working groups established during the last workshop in St. Petersburg (November 2003) continued their work according to the tasks defined earlier, i.e. the completion of the circum-Arctic ACD GIS. The newly formed working group on Human Dimensions discussed how human dimensions research might contribute to the other ACD themes.

General tasks for all working groups were to provide input to:

- an Arctic Coastal Dynamics Book to be published through McGill-Queen’s University Press,
- a planned journal paper in the American Geophysical Union publication EOS and
- an Expression of Interest (EoI) to be submitted for the International Polar Year (IPY 2007/2008).

At the end of the workshop the working group (WG) leaders reported on the progress of their groups.

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

WG 1: Transition from Onshore to Offshore Permafrost

Working Group Chairs: Hans-Wolfgang Hubberten and Michel Allard, Rapporteur: Pavel Rekant

Participants: Felix Are, Georgy Cherkashov, Georg Delisle, Don Forbes, Mikhail Grigoriev, Torre Jorgenson, Patrick Lajeunesse, Gregory De Pascale, Wayne Pollard, Volker Rachold, Felix Rivkin, Nella Shpolyanskaya, Steve Solomon, Irina Streletskaya, Dmitriy Streletskiy, Bob Taylor, Dustin Whalen.

(1) Introduction: problem statement

During the 4th ACD Workshop in St. Petersburg 2003, 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. These changes of state of the soils and of the sediments occur in different conditions that are defined by coastal dynamics. Some coasts are submitted to 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 submitted to a fall of relative sea level, in regions that are subjected to post-glacial isostatic uplift since the withdraw of the Pleistocene ice sheets. The outcome from the St. Petersburg ACD meeting was further developed in Montreal considering new ideas, facts and results obtained since that meeting.

The aim of the discussions at Montreal were:

- to identify the main scientific objectives related to Arctic Coastal Dynamic Research,
- to describe the methodology to answer these questions,
- to define the characteristics of Circum Arctic Coastal Observatories, and
- to relate these studies to other coastal aspects as biodiversity, human aspects and modeling.

(2) Scientific objectives

The main scientific 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 dynamic conditions around the Arctic will require a methodology and a set of techniques to acquire data and develop models. The working group therefore proposes the establishing of a circum Arctic net of coastal observatories with standardized observations and measurements.

(3) Specific tasks and general strategy

The working group identified different coastal processes and resulting scientific tasks for emerging coasts existing in areas covered by larger ice sheets during the last glacial as the eastern Canadian or western Eurasian coasts and retreating coasts in those areas not covered by ice in former ice ages as the Siberian or Alaskan coasts.

The eastern Canadian coasts are **emerging** with a rate of up to 1 cm/yr resulting in the freezing of the fine grained sediments in the tidal range. Open questions in these coasts are for example:

- what happens with the salt in the saline pore solutions during freezing?

- how do soil heaving processes work during freezing?
- the formation of gas bubbles in the newly formed ice
- the influence of groundwater on the thermal regime of permafrost
- to identify the complex processes of the formation of vegetation on the new and frozen land areas
- to understand the important role of the tidal zone in coastal dynamics

The processes described above are mainly important for the more lower latitude coasts in the transition of continuous to discontinuous permafrost. For the higher latitudes emerging coasts somewhat different processes are of relevance:

- polygonal structures formed in flood plains
- formerly emerging coasts which are now in subsidence and eroding
- the movement of salt and chemicals, and hydrodynamics in the freezing area of the bottom fast ice zone
- the interaction between permafrost and warm and saline waters
- complex sequences in emerging coasts of newly formed permafrost inter-layered with unfrozen saline sediments (technological problem for constructions)

Open questions for **submerging or stable** coasts are:

- the evolution of sub sea permafrost in delta areas
- the penetration of sea salts in fresh bottom sediments
- a need for more data on near bottom temperatures
- the existence or absence of permafrost on the deeper shelf
- the modeling of offshore permafrost development

General strategy

a) The process study on emerging coasts begins with the unfrozen sediments in the sea and follows the freezing process at the tidal zone to the newly formed land permafrost.

b) The process study on eroding coasts begins on land with the unchanged terrestrial permafrost sequences and follows the direct erosion at the coast to the interaction of subsea permafrost with sea water.

(4) Objects of investigation

Land based observations

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/accretional state of the shoreline and coastal type, and
- shallow submarine morpho-sedimentological conditions.

Comprehensive studies of the terrestrial frozen and unfrozen deposits should be made characterizing the composition of sediments and soils, the topography, hydrology and vegetation. Processes influencing landscape changes, like thermokarst, wind and water erosion, carbon turnover, etc should be studied. Geophysical sounding should reveal the transition from frozen to unfrozen sediments as well as changes in the sub ground composition. A full set of meteorological observations, including snow cover, snow drift etc. should be automatically monitored.

Observations on the transition zone

In the transition zone, the morphodynamics, i.e the surface changes have to be studied by characterizing the topography/morphology. Specific features as cryopegs, ground water and soil salinity have to be studied. Leaching of permafrost by sea water should be studied in short term (surges, tides) and long term scales. In boreholes of the transition zone, apart from long term monitoring of temperatures, parameters as conductivity (salinity), pore pressure, ground water flow, sound velocity, etc. should be measured. Important observations relate to sea ice composition and activity in the transition zone. Ice thickness, type of ice, sediment concentration in sea ice, and shore fast ice formation are some of these characteristics.

Offshore observations and monitoring

Bathymetrical surveys and geophysical soundings (seismo-acoustic, sound velocity, multi channel seismic) are essential for the understanding of the offshore situation. Sediment structures, permafrost boundaries, cryopegs and other features are revealed by these methods. Sediment properties (including gas content) and ice content should be studied on material obtained by coring. Borehole measurements (conductivity, heat flow, etc.) should be carried out. The boreholes are to be instrumented for long term monitoring. In addition, fluxes of methane or other gases should be recorded.

Oceanographic observations

Oceanographic parameters as wave action, nearshore and longshore circulation and water levels (tides) should be monitored. Important information will come from observation of sediment transport and suspended sediment using sediment traps and CTD, ACDP. Carbon turnover and methane content in bottom waters are additional important parameters.

(5) Methodology

A methodology for the detailed study of several transects shall be applied at a number of sites (see Table 2.1). The sites will be selected in a stepwise process (see Table 2.2) in order to represent the different coastal settings found around the Arctic Ocean based on the classification criteria of ACD.

Permafrost drilling and sampling

At least one core shall be drilled at each observatory in the permafrost in the terrestrial environment. A series of cores shall be drilled in the littoral zone and the shallow submarine zone along the transect. Exact location of cores shall be planned using geophysical and bathymetric surveys in order to reflect the different transient situations of the shoreline migration, i.e., under the shore fast 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 other geochemical parameters as well as gas contents.

Offshore geophysical survey

Sounding and side scan profiling are essential for the understanding of the subsea permafrost distribution. For this task both high frequency (2500-4000 Hz) and low frequency (200-500 Hz) seismic profiling shall be done. The combination of these methods will allow to define the topography of the permafrost table as well as the thickness of the frozen sediment sequence. The comprehensive examination of offshore drilling and seismic data will provide the basis for investigation of the permafrost table geometry and as result of this, the evolution of the subsea permafrost.

Observation and measurement of 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 monitored with proper equipment, for example tidal gauges or pressure gauge-equipped data loggers, or be sufficiently documented from nearby existing gauging facilities in ports or communities. Long term observations of the hydrodynamics should be carried out using ACDP instruments at least during the open water season.

Observation and measurement of 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 progrades seaward. Therefore, monitoring the ice regime along the coastlines is a necessary component of the methodology. Probably the safest way to obtain continuous observations on shore ice dynamics will be to integrate automatic cameras or videos in the instrumental setup with the automatic meteorological stations.

Monitoring of the 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. Permafrost temperatures need to be known both in the terrestrial component and the marine component of the transects as they are tributary 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. However, new technical designs will almost certainly be necessary in order to be able to protect thermistor cables, dataloggers and connections to shore stations for the shallow subsea permafrost. 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.

(6) Expected outcome of the project

The gathered data and observations along each transect at the coastal observatories will allow to explain how the differences in ice content, salinity, gas content, and cryostructure that are observed between terrestrial and offshore permafrost are generated during the transition from onshore to offshore. With proper geological and thermal data, with the support of the monitored visual data on processes and with contextual knowledge, a thorough understanding and knowledge of processes, rates and transformation of landscapes and permafrost along the arctic coastlines shall be obtained. It shall be possible to elaborate conceptual, graphic and numerical models. The putting together of the results from all the transects around the Arctic will provide the base 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. It will need an international effort requiring a large amount of funding to be conducted Circum Arctic. As this, it is a challenge for scientists, funding agencies and policy makers and should be one of the central topics of the International Polar Year (IPY).

Table 2.1. Potential sites for observatories.

Barrow (US Beaufort Sea)
Prudhoe Bay (US Beaufort Sea)
Mackenzie Delta (Canadian Beaufort Sea)
Tuktoyaktuk (Canadian Beaufort Sea)
Eureka or Expedition Fjord (Canada)
Resolute Bay (Canada)
Sachs Harbour (Canadian Archipelago)
Clyde River (Canadian Archipelago)
Qikigtarjiug (Canadian Archipelago)
Umijuaq and Salluit (Hudson Bay)
Zackenberg (Greenland)?
Svalbard
Kola Bay (Barents Sea)
Seven Islands Archipelago (Barents Sea)
Western Kandalaksha Bay (White Sea)
Dolgy Island (Pechora Sea
Varandey Peninsula (Pechora Sea)
Kharasavey (Kara Sea)
Baydaratskaya Bay (Kara Sea)
Sopkarga (Kara Sea)
Dickson (Kara Sea)
Marre Sale or Sphindler Cape (Kara Sea)
Mammontovy Klyk (Laptev Sea)
Bykovsky Peninsula (Laptev Sea)
Cape Mali Chukochi (East Siberian Sea)
Chauna Bay (East Siberian Sea)
Sireniki Polynya Area (Bering Strait, Chukotka)
Onemen Bay (Chukchi Sea)
Seward Peninsula (Bering Sea)

Table 2.2. Criteria for coastal observatories

Characterization and selection of a site

The sites should be selected based on studies of the terrestrial environment as well as the coastal and sub sea conditions including geophysical surveys. Depending on the local situation, two categories of sites should be established, key observatories and observational sites. Accessibility and infrastructure play an important role for this selection, if possible local communities should be actively involved in the program. For comprehensive data collection, the ACD observatories should be combined with CALM and GTN-P, and other sites as precipitation, isotope, or gas flux networks.

Coring transects and instrumentation

Coring transects from land (borehole down to below actual sea level) to deeper offshore should be done to detect and verify the upper (and lower) permafrost table. From each hole, cores should be taken to study the characteristics of frozen and unfrozen ground. Terrestrial and offshore boreholes should be instrumented with for long term automatic temperature monitoring. This is still a technical challenge for the offshore sites affected by bottom freezing or ice grounding.

Long term monitoring

Long term monitoring devices have to be installed at the key observatories including all meteorological parameters, ground temperatures etc., ocean parameters such as wave action, sea ice etc., as well as sediment transport, vegetation and landscape changes. Especially for remote sites, remote sensing techniques should be used as a major tool.

Interpretation

All data obtained should be evaluated from the ACD group and integrated in long term data series of a minimum of 5 to 10 years. The working group points out, that it is important to combine the observational data with related processes. Different methodologies have to be applied for the terrestrial, transition, offshore and marine zone.

WG 2: Human Dimension of Arctic Coastal Dynamics

Working Group Chairs: Claire Eamer and Shari Fox Gearheard, Rapporteur: Scott Heyes

Participants: Steve Baryluk, Don Forbes, John Keogak, Kathryn Parlee, Tristan Pearce.

For the first time since the establishment of the ACD, the human dimensions of arctic coastal dynamics were incorporated in the working group structure of the meeting. The Human Dimensions Working Group (HDWG) spent the two-day meeting brainstorming issues associated with the human dimension of the arctic coastal zone and considering how human dimensions research might contribute to the other ACD themes and WG projects, as reported at the workshop. The HDWG noted, in particular, that several ACD projects have not yet included the human dimension, nor have they had the opportunity to incorporate into their work the local and traditional knowledge held by northerners.

The HDWG identified key ACD activities, discussed or reported on at the workshop, that could benefit from this input:

- Site selection for a circumpolar coastal observation network;
- Observation procedures and indicators for the observation network;
- Development of GIS database of arctic coastal information.

In addition, the HDWG recognized that the past five years have seen significant developments in the study of the human dimensions of the arctic environment and in the participation of arctic peoples in the development of arctic knowledge, and that the ACD initiative to include the human dimension in its work is both timely and appropriate.

The HDWG agreed that a preliminary step to including the human dimension in the work of the ACD is an assessment of the current state of knowledge and activity related to the human dimension of arctic coasts, highlighting both areas of available information and significant information gaps. The assessment must include information associated with western science as well as information associated with traditional knowledge and local or regional land usage. The group agreed that an international literature search and series of workshops that bring together key knowledge-holders on arctic coasts would be appropriate for the assessment.

The HDWG is new to the ACD. However, if the HDWG continues along with the other ACD themes, human dimensions could contribute in a number of ways including:

- Data that can be used to incorporate the human dimension into the existing ACD GIS database of geophysical information.
- Recommendations of potential sites or site-selection criteria for the ACD observatory system, related to both the impacts of coastal dynamics on human societies and the impact of human activities on the coast.
- A catalogue of local and regional monitoring programs and data that can enrich and validate ACD models and projects.
- A research guide for coastal researchers, including contact information, licensing procedures, protocols and ethical guidelines, jurisdictional boundaries, etc.
- Filling in knowledge gaps and expanding scientific understanding of arctic coastal systems by incorporating the human dimension – both the impact of coasts and coastal

change on the human inhabitants of the region and the impact of human activity on the physical and biological components of the coastal system.

WG 3: Environmental Forcing

Working Group Chair: David E. Atkinson, Rapporteur: Olga Gruzdeva

Participants: Larisa Belova, Oceana Francis-Chythlook, Azharul Hoque, Stanislov Ogorodov, Alexander Vasiliev, Jennifer Turner.

The main objectives of the Environmental working group (EWG) at the ACD workshop were:

1. Establishment of wave energy calculation methodologies.
2. Begin transfer of data layers to GIS working group.
3. To consider EWG input to a possible article in the American Geophysical Union publication EOS.
4. To consider EWG input to a possible book on Arctic Coastal Dynamics.
5. Inclusion of other considerations as emerged during discussions.

Calculating wave energy

The issue of how to determine wave energy from wind was discussed at length by the members of the group. Specific points in this regard included:

- The spatial scales that should be considered,
- How the final output should be delivered, and
- How the calculation should be performed.

There was a fortuitous gathering of individuals with direct experience in these questions (Ogorodov, Francis-Chythlook, Hoque, and Turner) from a variety of perspectives. It was clear that the selection of an appropriate scale would dictate what calculation approaches could be considered, because a methodology that serves at one scale would not be suitable at other scales, and that results of interest to the ACD project included both the large and small scales. Use of two scales was thus suggested: a large scale, defined here to mean coastal regions at the circum-arctic scale as broken down by defined ACD zones, and the small scale, defined to mean situations local to individual key sites.

Various energy calculation approaches were forwarded for discussion, ranging from specified windspeed-wave energy relationships to densely gridded finite element modeling solutions. It was indicated that finite element solutions are not suitable at a hemispheric scale, and that a simpler approach should be used. Ogorodov, Francis-Chythlok, and Turner all had suggestions. Ogorodov’s method was derived from the Popov-Sovershaev method, and two other methods for application at the local scale had been derived in some form from the Coastal Engineering Manual, published by the US Army Corps of Engineers. Details of wave model operation were transferred and a conservative set of specifications was agreed upon for an initial arctic-wide energy calculation. It was also agreed that using several of the approaches discussed would be instructive for comparative purposes.

Immediately following the ACD workshop, work proceeded on a large-scale method that was derived from the Coastal Engineering Manual, the initial results of which were presented by Atkinson at the American Geophysical Union Conference in San Francisco in December 2004. Calculations at the local scale using finite element modeling as discussed at the ACD workshop are not being pursued in the short term but will be included as an objective in a proposal to the International Polar Year for a detailed monitoring network.

Data layer transfer to GIS WG

A set of melt season parameter grids were transferred to the GIS WG during the workshop, including:

- melt season start day – annual, 50-year mean, 50-year linear trend
- melt season end day – annual, 50-year mean, 50-year linear trend
- melt season length – annual, 50-year mean, 50-year linear trend
- melt degree day total – annual, 50-year mean, 50-year linear trend

Gridded layers concerning observed storm parameters will be transferred in the near future.

EOS article consideration

All WGs were asked to contribute a paragraph to a proposed article for the AGU publication EOS. Given this limited forum, representation of most environmental forcing agents is restricted to being mentioned only, with a sentence being devoted to specific topics, including melt season parameters, coastal storminess, and sea-ice conditions. Consideration of these topics in the article would include trends.

Coastal dynamics book consideration

All WGs were also asked to contribute an outline for a chapter/section for a possible book on coastal dynamics in the arctic. This was done in more detail than will be presented here, however the main environmental forcing agents that would be considered are as follows:

- melt parameters
  - melting degree days
  - open water season length
  - trend in temperature (length of trend period considered – recent more relevant)
- wind parameters, as they affect:
  - wave regime
  - sea ice
- meso-scale ocean circulation
- salinity
- water temperature
- sea ice
  - land fast ice formation/disappearance
  - summer/autumn fetch
  - loose ice floes being driven ashore

Other considerations

Discussions surrounding article and book inclusions prompted a broader consideration of all possible environmental forcing agents at work in the arctic coastal regime; these are listed above under the book consideration. Opportunities for integrative discussion were taken when the EWG merged with the Human Impacts WG for an afternoon. During that time it was clear that there exists significant potential and precedent for community based observation of environmental parameters that should be brought to bear whenever environmental monitoring efforts at arctic coastal zones are considered.

Finally, various potential projects that should be pursued at the IPY/INTAS/IASC level were considered. These include:

- Multi-level wave modeling (that is, small scale/large scale)
- shore-face integrative modeling (e.g., of a nature conducted by Vasiliev, Aré, or Gruzdeva)
- ocean currents in the arctic ocean and their effects on the coastal environment
- swell development as predicted ice retreat takes hold over the coming century
- remote sensing of circum-arctic (or key site) ice shove events
- wave monitoring

WG 4: GIS Development

Working Group Chairs: Frits Steenhuisen and Rune Odegard, Rapporteur: Hugues Lantuit

Participants: Jerry Brown, Nicole Couture, Dmitry Drozdov, Allison Graves Gaylord, Mikhail Grigoriev, Torre Jorgenson, Sergey Nikiforov, Volker Rachold, Feliks Rivkin, Steven Solomon.

The main objective of the GIS group during the 5th ACD WG meeting was to finish the segmentation and to add the databases to the geometric data.

The segmentation (geometry) is now completed for each sector. In several sectors, especially in the Barents Sea and Kara Sea some residual problems still need to be looked after. Most of these problem areas include islands or archipelago coasts which makes the definition of the segment polygon difficult. For a few segments this might need further discussion and maybe some additional polygons are needed. In some areas (i.e. US Beaufort and Chukchi Seas) barrier islands/lagoon areas have been given a separate segment polygon (Figure 2.1).

Areas that still need some attention are the Canadian Archipelago, Greenland and Spitsbergen. Most of the coastline in the areas is hard rock coast. ACD is focused on permafrost coasts and therefore the lack of data for these regions does not really influence the ACD results but it should be included in the final product.

For each sector the database with attribute information on all segments has been submitted by the regional experts. The database was delivered according to the ACD data template (see appendix 2). Due to the revised numbering system as agreed on during the 2003 St. Petersburg workshop some database tables had to be renumbered by the regional experts (Figure 2.2).

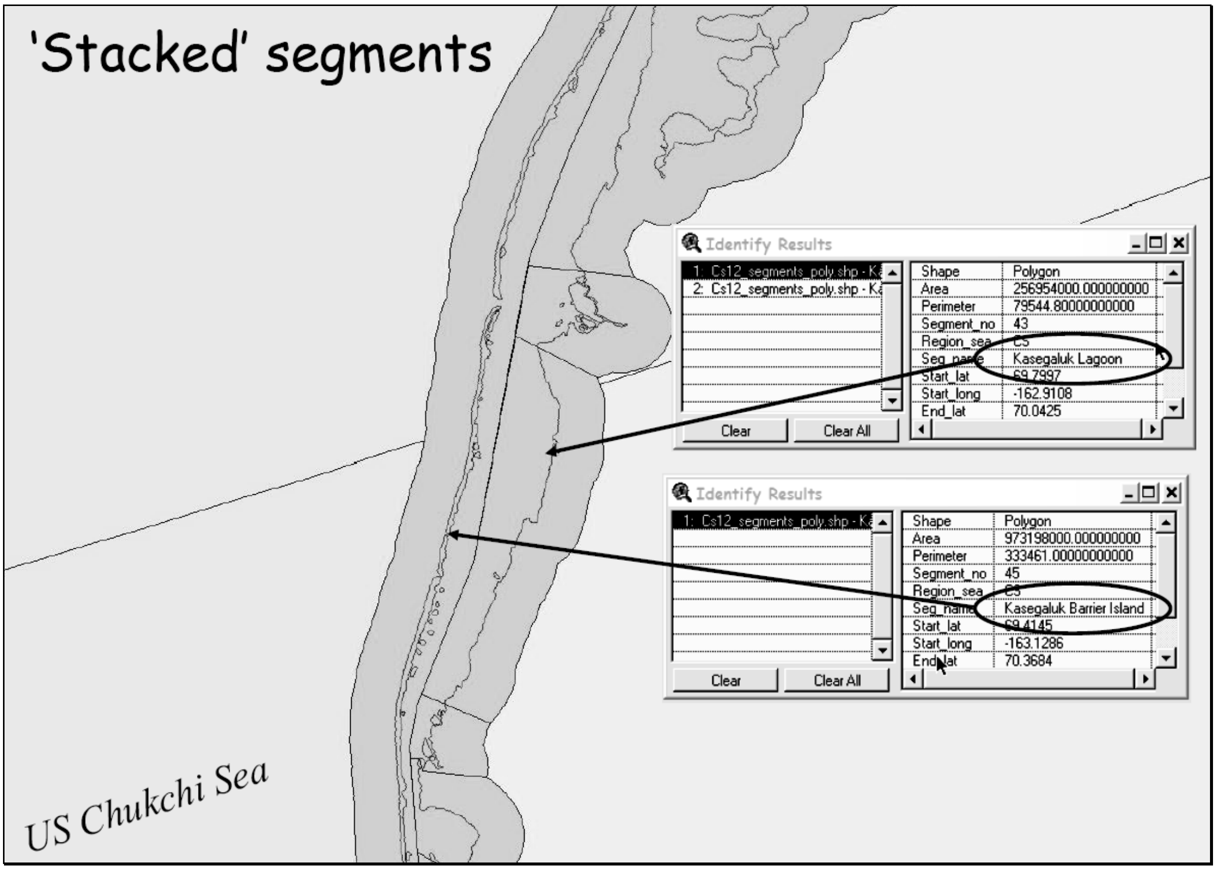

Figure 2.1. Segment polygons of barrier islands in the US Chukchi Sea.

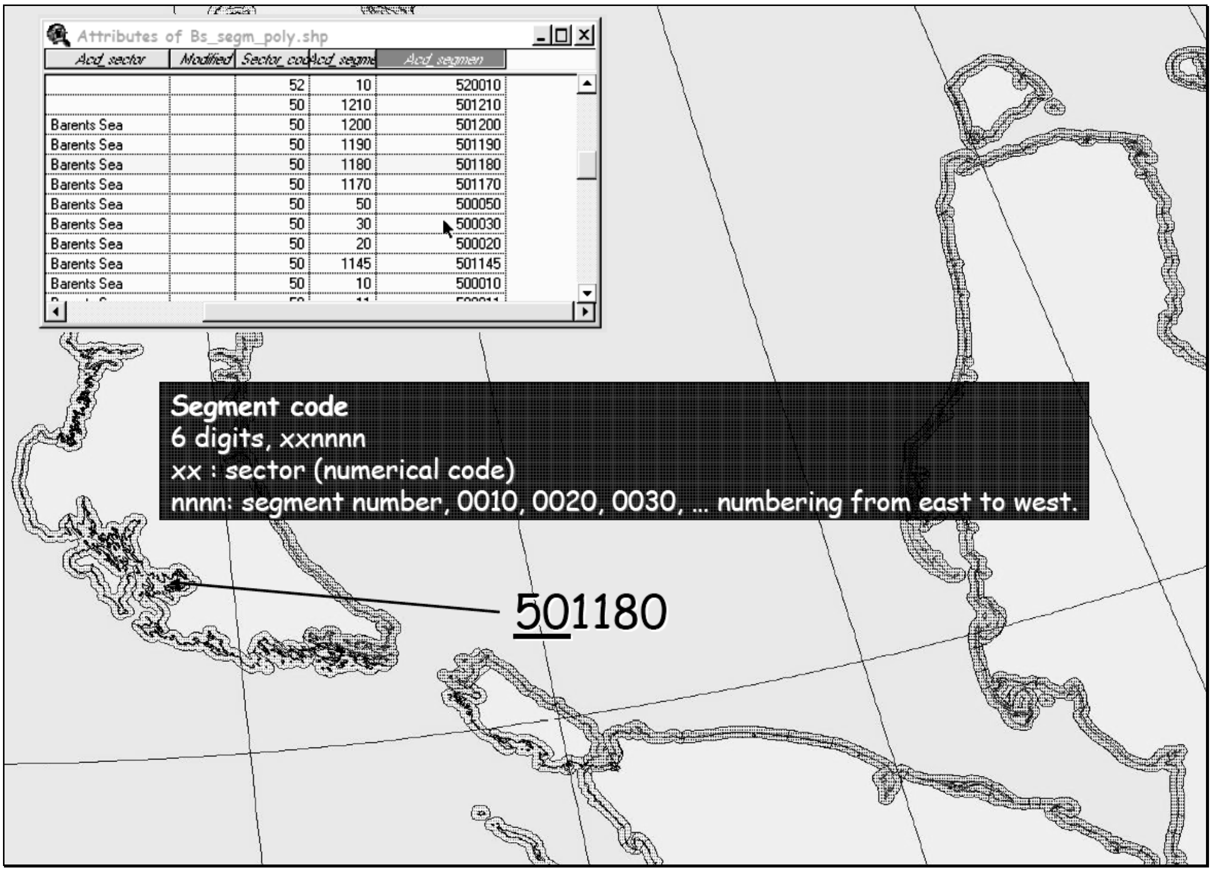

Figure 2.2. Revised numbering system.

In order to match all the regional datasets and to combine them into a circumpolar dataset, the structure of all the data tables must be the same. Also, the content of the tables must match the ACD data template. For the first version of the ACD circumpolar dataset a simplified database table is used. This still proved to have some pitfalls in it, and some problems with compiling the final dataset are expected. Most of these problems however are of a technical nature. These need to be solved during follow up meetings that will be held at either AWI (Potsdam) or at the Arctic Centre in Groningen.

Default projection

There are two perspectives from which to choose a default projection for ACD; storage and modeling. From the storage side, a simple geographic (lat/lon) projection would be preferable. This would be the most practical format to store data in PANGEA. Also this is the least platform/software dependent.

From the modeling perspective there are far more issues to consider, such as equal area or equal distance. Since all these considerations are affected by the scale on which the final model will run, it was decided to leave 'the working projection' to the modelers. All ACD data will be submitted and stored in lat/lon.

Products

The GIS datasets will be made available on CD-ROM and through an Arc-IMS web interface we are planning to establish on the AWI IMS-server in Bremerhaven. Some additional data which are needed for the ACD modeling will also be included on both the CD-ROM and the web interface.

In addition to the digital data product and the web interface (IMS) the WG decided to make a printed (or printable) map with the ACD results. This map will show a circumpolar overview of erosion of permafrost coast and its effect on ecosystems and its socio-economic impact. The map can either be printed or can be made available in PDF format.

2.3 Next Steps

Based on the presentations and on the results of the WG discussions, the following steps for future work were identified by the Steering Committee:

Field Work

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. An expedition is planned for spring 2005 whose target will be a coastal section in the western Laptev Sea. 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. A similar drilling program will be performed in the Beaufort Sea (Mackenzie Delta). Other Canadian activities will be carried out within the framework of the ArcticNet Network of Centers of Excellence.

Development of a Web-Deliverable Circum-Arctic Coastal GIS

The segmentation and classification of the circum-Arctic coastline was almost completed during the 5th ACD Workshop in Montreal (October 2004). This coastal GeoInformation-

System, which includes the coastal classification and the relevant environmental and climate forcing data, will be made available through an internet-map-server (ARC-IMS) and on CD-ROM. A first version will be presented during the 2nd European Permafrost Conference (EUCOP) in Potsdam (see below).

Scientific Planning

2nd International Conference on Arctic Research Planning (ICARP II)
The Arctic Coastal Processes Working Group (chaired by V. Rachold) will develop a detailed forward-looking Science Plan to be presented at the ICARP conference.

International Polar Year (IPY)
Based on the ACD project and the ICARP II Arctic Coastal Working Group, an expression of interest for an Arctic Circum-Polar Coastal Observatory Network (ACCO-Net) has been submitted for the International Polar Year (IPY).

Project Proposals

Two proposals for new INTAS projects focusing on (a) onshore/offshore permafrost dynamics and (b) forecast modeling of Arctic coastal change will be prepared.

ACD Publications

Workshop Report
All participants and those unable to attend were invited to submit extended abstracts for the present workshop report.

Arctic Coastal Dynamics Book
An Arctic Coastal Dynamics Book (edited by V. Rachold and W. Pollard) to be published by McGill-Queen's University Press (Montreal, Canada) is in preparation. The book will be comprised of 8 regional papers summarizing coastal processes for each Arctic Shelf Sea and 14 thematic papers on Arctic coastal processes.

Journal Paper to Announce the ACD GIS
A journal paper to be submitted to the American Geophysical Union publication EOS will be prepared to announce the publication of the circum-Arctic ACD GIS as soon as the map-server goes online.

ACD Relevant Meetings in 2005

- Shifting Lands, 2nd Workshop of the European Science Foundation (ESF) Network Sedimentary Source-to-Sink-Fluxes in Cold Environments (SEDIFLUX), Clermont-Ferrand (France), 20-22 January 2005: ACD presentation.
- EGU/AGU (European Geophysical Union / American Geophysical Union), Vienna (Austria), 24 - 29 April 2005: ACD poster.
- Annual geocryology conference, Pushchino (Russia), May 2005: several ACD presentations, ACD session.
- 2nd European Conference on Permafrost (EUCOP II), Potsdam (Germany), 12-16 June 2005: several ACD presentations, ACD session.

- LOICZ II Open Science Meeting, Egmond aan Zee (The Netherlands), 27-29 June 2005: ACD presentation.
- Canadian Coastal Conference, Halifax (Canada), 6-9 November 2005: several ACD presentations.
- 2nd International Conference on Arctic Planning (ICARP II), Copenhagen (Denmark), 10-13 November 2005: Working Group 3: Arctic Coastal Processes.

Next ACD Workshop

It was decided that the next workshop would be organized in Europe in late autumn 2005 and coordinated with the 2nd International Conference on Arctic Planning (ICARP II), which will take place in Copenhagen (Denmark), 10-13 November 2005.

Acknowledgements

The success of the workshop would not have been possible without the financial support of McGill University (Faculty of Science and Department of Geography) and the International Arctic Sciences Committee (IASC); in particular, we would like to express our appreciation to Odd Rogne of IASC. The Canadian Department of Foreign Affairs and International Trade (DFAIT) and the Canadian International Development Agency (CIDA) provided support for six Russian participants. Special thanks go to Michel Allard and his students for organizing the excursion to Quebec City.

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- McGill Centre for Climate and Global Change Research
- National Science Foundation: Study of the Northern Alaska Coastal System (SNACS)
- 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"
- German Ministry for Education and Research / Russian Ministry for Research and Technology: grant: "Permafrost Dynamics in the Laptev Sea"

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3 Extended Abstracts

(alphabetical by first author)

SNOW REGIME, COASTAL CLIMATE, AND PERMAFROST NEAR UMIUJAQ, NUNAVIK, CANADA

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A series of daily photographs at the joint BGR-Laval lithalsa study site illustrate the snow regime over discontinuous permafrost terrain from the first snowfall on 19 October until 17 April 2004. The site is located 20 km from the Hudson Bay shoreline. Snow regime on the ground is controlled by snowfall, melt periods and periods of wind erosion. The snow season can be divided into 4 periods: 1- From mid-October to the end of November, the snow cover kept thickening evenly over the mound and depression topography. 2- In December, a cold spell (-19 °C for 3 days between 3 and 6 December) was followed by a milder one with easterly winds until the 25th; snowfalls and wind erosion kept alternating. 3- A cold period from 30 December to 29 March, with a minimum of -44.5 °C on 14 January. The beginning of this cold period coincided with the freeze-up of the sea which turned the climate from an oceanic type to a continental one. The snow cover thickness remained unchanged, with deep snowpacks in depressions and continuing erosion by westerly winds on top of the lithalsa and other mounds. 4- From 29 March to the end of winter, new wet snowfalls alternated with melt periods leaving the general pattern unchanged. The distribution pattern of snow cover over the landscape from January to April corresponds closely with the ground temperature distribution observed in the permafrost.

THE SHAPE OF EROSIONAL ARCTIC SHOREFACE PROFILES

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The shape of 63 shoreface profiles along erosional Arctic coasts (Fig. 1) is investigated and compared with the shape of shoreface in temperate environments in order to identify differences caused by Arctic cryogenic processes. Two mathematical expressions were chosen for description of profiles:

(1) power function suggested by Bruun (1954)

$$h = - A \cdot x^{m},$$

where h is water depth, x is offshore distance from the shoreline, A is sediment scale parameter, and m is profile shape factor;

(2) exponential function suggested by Bodge (1992)

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

where B is an asymptotic depth at a great offshore distance, and k is decay constant.

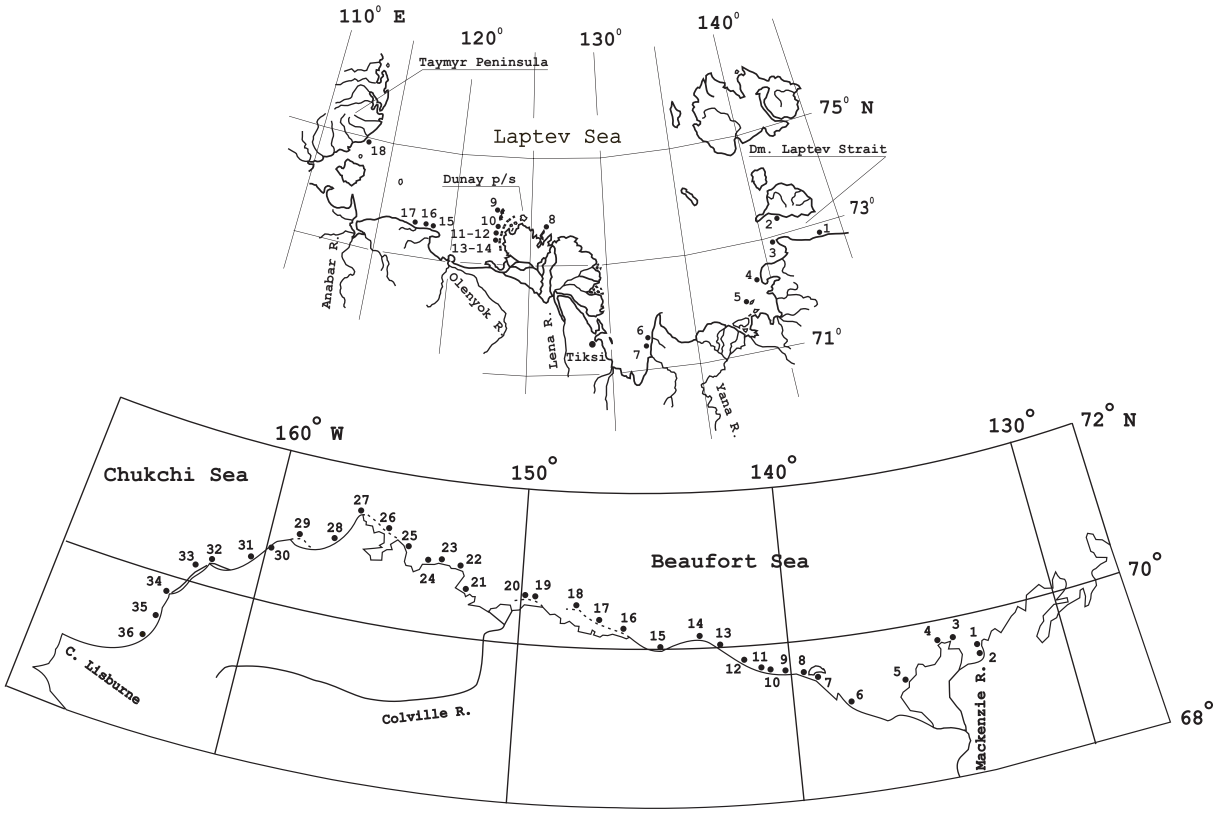

Figure 1. Location of the shoreface profiles investigated.

The shoreface outer boundary position was identified visually on profile diagrams by a change of sea floor slope. This change could be recognized with confidence on most profiles. Especially clear break of slope takes place in shallow seas like Laptev Sea or eastern part of Beaufort Sea. However, the change of slope is often not sharp enough to be generally agreed upon, leaving a questionable transition zone between shoreface and shelf. Therefore, having altogether 63 profiles, we made over 200 fits trying different parts of profiles.

The Grapher 3.0 software of Golden Software, Inc. was used to find the best fits for all profiles. Generalized results of the fitting are presented in Table 1.

The numbers in Table 1 show that

(1) All shape parameters ***m*** and ***A*** of Arctic profiles are in the range, obtained outside of the Arctic.

(2) The ranges of average ***m*** values for Arctic (0.42 - 0.68) and non- Arctic profiles (0.4 - 0.67) almost coincide.

It means that shoreface profiles in the Arctic and in the mid- and low latitudes have generally the same shape, despite the fact that cryogenic processes influence the Arctic shoreface morphology in several ways. Evidently the changes of the shoreface profile shape caused by cryogenic processes are short-lived because the storms restore the equilibrium profile.

Table 1

Coastal section	Number of profiles	**A**			***m***		
		Min.	Average	Max.	Min.	Average	Max.
Three Arctic Seas	63	0.007	0.36	2.43	0.24	0.52	1.00
Laptev Sea, all	18	0.008	0.32	1.38	0.27	0.58	0.81
Laptev Sea, ice complex coasts	9	0.008	0.12	0.81	0.34	0.68	0.81
Laptev Sea, sand coasts	7	0.054	0.37	0.77	0.30	0.51	0.76
Chukchi Sea	10	0.043	0.32	1.63	0.27	0.57	0.73
Beaufort Sea, Alaska	16	0.007	0.46	2.43	0.24	0.48	0.85
Beaufort Sea, Canada	19	0.017	0.46	0.88	0.25	0.42	1.00
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	
U.S. Pacific, San Diego region, after Inman et al. (1993)						0.4	
Caribbean beaches after Boon and Green (1988)						0.5	

All investigators of the shoreface profile shape aimed at obtaining average values of profile shape factor *m*. Dean, who had analysed 500 profiles along the U.S. Atlantic coast, found average *m* = 0.67 and adopted to use this value as a constant.

Histogram for all 63 Arctic profiles we have (Fig. 2), as well as some other histograms for particular seas and different coastal geology show that distribution of *m* values is rather far from normal Gaussian distribution. The predominance of average *m* is poorly expressed. Only about 8-10 % of profiles is characterised by average *m*. Actually prevail *m* values less than average value 0.52. On the whole our data lead to conclusion that the shape of Arctic shoreface profiles is highly variable and cannot be characterised by whatever average *m* even for geologically uniform erosion coasts.

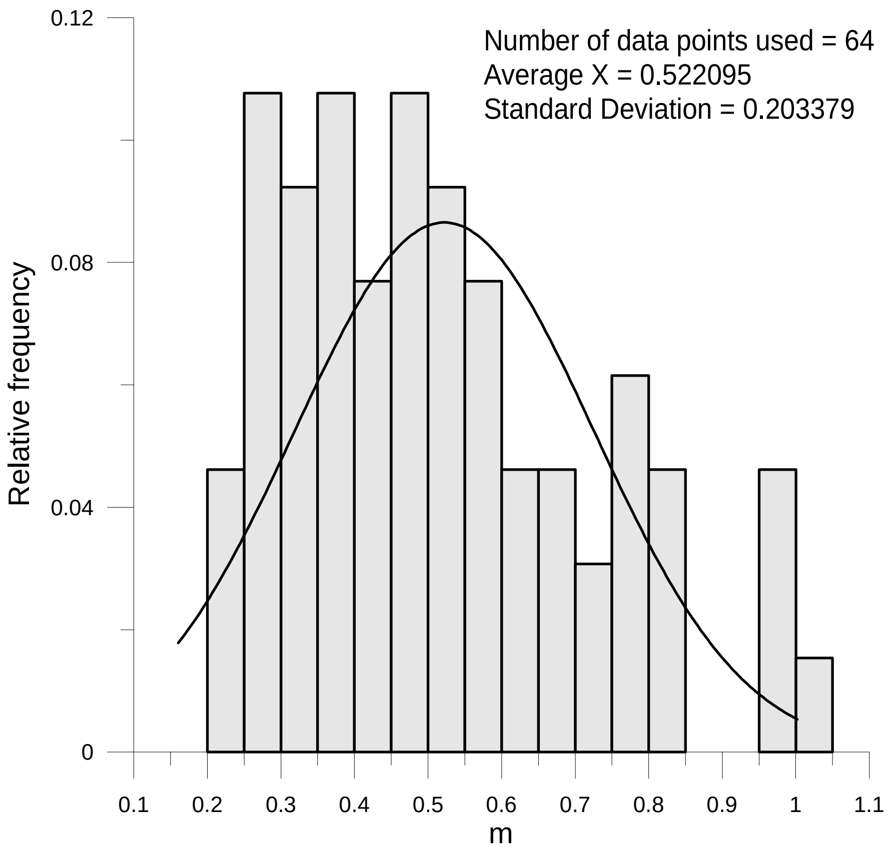

Figure 2. Histogram of the profile shape factor *m* values from 63 Arctic profile fits.

It is generally recognised, that shoreface shape reflects the interaction of environmental forcing and coastal material. The sediment scale parameter *A* in the Bruun power function is controlled by sediment grain size, and profile shape factor *m* reflects the wave energy dissipation on the shoreface. Therefore a functional dependence between these two parameters has to exist. Processing the data at our disposal showed that this is true indeed. The diagram in Fig. 3 clearly reveals an inverse reliance between ***m*** and ***A***. Existence of this reliance demonstrates that trying to find any average of ***m*** value, defining shoreface profile shape is senseless. All the more unacceptable is to use a constant ***m*** for general description of the shoreface profile shape. A constant ***m*** would mean constant ***A***. But according to Fig. 3, it is possible only for a particular combination of bed material and environmental forcing. Correspondingly the shoreface profile shape along any coastal section characterised by certain geological and hydrodynamical conditions may be described by a definite combination of ***m*** and ***A*** values.

Comparison of Bruun's power function and Bodge exponential function fits to Arctic shoreface profiles do not support advantage of exponential function revealed by Bodge (1992). In general power function fits Arctic profiles better. But the difference in fit quality is small. The general divergence of R^2 values for two functions equals 1.6 %. However, exponential function fits better the upper parts of profiles.

Bodge assumption about using parameter ***B*** from exponential function to define closure depth and thus to locate the shoreface outer boundary position did not find confirmation in this study.

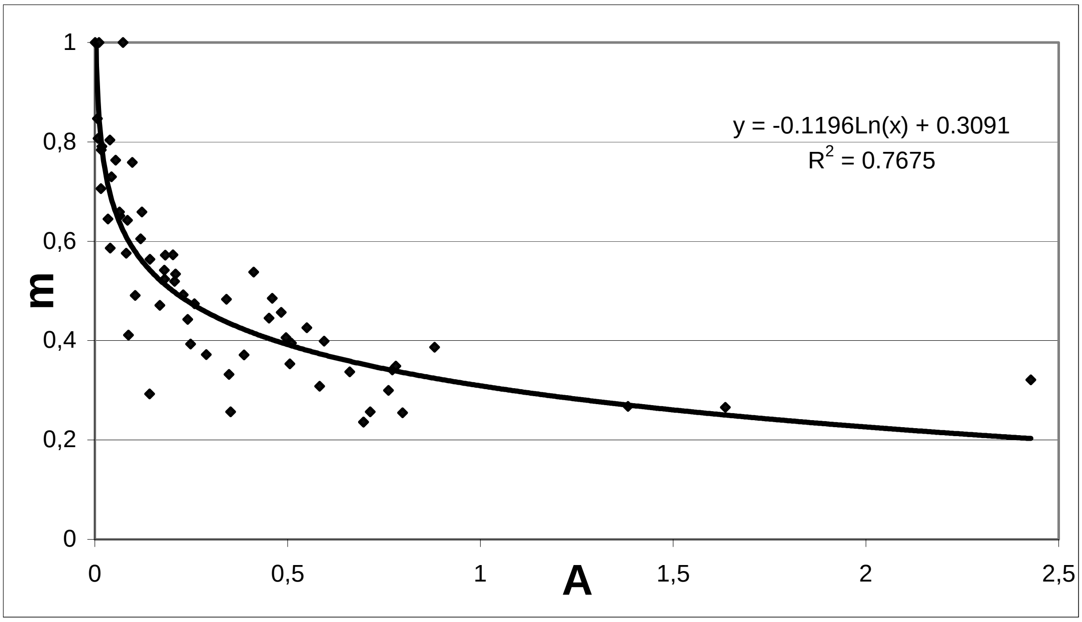

Figure 3. Relationship of sediment scale parameter *A* and profile shape factor *m*.

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CIRCUM-ARCTIC MELT SEASON TRENDS, 1950 – 2000

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An important component of environmental forcing in the cryosphere is the thermal element, especially the magnitude and duration of the melt season. From a coastal context, large seasonal melting degree-day (MDD) totals can result in enhanced erosion due to the combination of sediments weakened from ground ice melt and a long, ice-free season that prolongs wave-attack opportunities. Several melt-season parameters have been calculated, including: melt season start and end dates, melt season length, and annual MDD totals. Individual extreme years are contrasted and simple, long-term linear trends as well as spatial patterns in these parameters are calculated and presented.

Results indicated simple linear trends in MDD as great as +/- 20 days/year, however it is unlikely that such rates of change have been maintained over a 50-year period. This suggests greater temporal dynamics, similar to that exhibited by northern hemisphere temperature trends, such that trend periods should be further broken down and greater analysis performed. In terms of specific years, in certain regions of the Arctic the difference between two years can be very large, on the order of hundreds of MDD. This level of interannual variation can be of the same magnitude as MDD seasonal totals, and suggests large interannual cryospheric response to thermal forcing that should be taken into consideration when studying physical response of a cryospheric system. A better understanding of the thermal regime of a given melt-season can help place observed coastal dynamical response into context, e.g., response to a given storm regime.

ACD KEY SITES: THE BASIS FOR A COASTAL OBSERVATIONAL NETWORK

J. Brown

International Permafrost Association, Woods Hole, Massachusetts, USA

Beginning in the mid 1990s the International Permafrost Association stimulated a process of establishing long-term monitoring or observational sites and networks. It began with the Circumpolar Active Layer Monitoring (CALM) as an initial contribution to the International Tundra Experiment. CALM, currently comprises over 125 sites with 15 participating countries, is formally funded by the U.S. National Science Foundation through 2008, and has a number of international partners. In 1999 the World Meteorological Organization (WMO) and formally recognized the Global Terrestrial Network for Permafrost (GTN-P) as part of the Global Climate Observing System (GCOS). The GTN-P incorporates measurements of both active layer (CALM) and a network of existing boreholes employed for measuring the thermal state of permafrost (TSP). The TSP is being proposed as a basis for a project for the International Polar Year. Other IPA-related networks are in the process of development (carbon, periglacial, biodiversity, and ones in the Antarctic).

The Arctic Coastal Dynamics program has had a highly successful period of development, and it is timely to consider the ACD in light of other existing and future networks. The IPA established a Working Group on Coastal and Offshore Processes with a Subgroup on Coastal Erosion at the 1998 Yellowknife permafrost conference. As a first step in organizing a coastal program, an international workshop was held in November 1999 in Woods Hole sponsored by the US NSF. One recommendation of the workshop was the development of a series of key sites around the circumarctic coast at which periodic measurements including erosion rates are measured. Further planning for the ACD program and funding of subsequent workshops was approved by the International Arctic Science Committee in April 2000. The key sites were included in the ACD Science and Implementation Plan (SIP) that was developed during the Potsdam ACD workshop in 200l. In December 2003, the LOICZ newsletter formally presented ACD as the Arctic component of the IGBP-LOICZ program.

Presently there are a total of 23 key sites in Alaska, Canada, Greenland, Russia, and Svalbard. Metadata are reported on the ACD web. Photographs of the sites are in a photo library on the CAPS CR Rom and available on web sites. Observations at many of these key sites are reported in ACD workshop reports and open literature publications. Now that the ACD is entering a new phase, it is timely to re-assess the scope and role of the key sites in current and future programs. For instance both CALM and ACD share a number of common coastal areas (Arctic Alaska, Mackenzie, Ny Alesund, European Russia, West Siberia, Lena, Kolyma, Chukotka). A proposed soil carbon network would benefit from coordination with the key sites. Now that the first approximation of coastal transfers of sediment and carbon transfers are completed, we should ask questions related to how representative the existing key sites are and how to expand the number of sites into a formal reporting network such as is the case with CALM. Development and further implementation of such a network can be a topic for the McGill workshop and for discussion of the coastal theme during the International Conference on Arctic Planning (ICARP) in November 2005. The ACD key sites could become an integral part for the development of the Circumarctic Environmental Observatories Networks (CEON).

DETECTION AND MAPPING OF PERMAFROST DEGRADATION ON HERSCHEL ISLAND, YUKON, USING RADARSAT-1, SPOT AND IKONOS SATELLITE DATA

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The stability of many northern landscapes is derived from its frozen ground, thus climatic warming trends at high latitudes is one of the most important environmental issues facing polar regions today. Increases in mean annual ground surface temperatures can eventually cause a shift in the subsurface thermal regime, and lead to increased thawing and terrain instability. To map and monitor thaw-induced terrain changes over vast areas poses considerable challenges. To support these efforts, we investigated the information content available from satellite data.

At Herschel Island, Yukon Territory, we examined several sources of satellite data for providing information on landscape change. Orthorectified high-resolution images provided by panchromatic IKONOS data are at the appropriate scale to compare with older aerial photographs. Recent high-resolution data also complement information collected from detailed field studies where dm-scale GPS surveys were carried out. Cross-validation with ground data enables interpretations from other areas to be made with greater confidence.

With mm to cm scale sensitivity possible from radar, we considered radar coherence images from interferometric processing of RADARSAT-1 data for revealing terrain changes. Although coherence images do provide terrain-related information, the data are at times difficult to interpret. Understanding interferometric SAR information still requires further research in order to fully comprehend its potential information for our application in permafrost studies.

On decadal time scales, optical SPOT data (5-10 m resolution) from archives is capable of detecting retrogressive thaw slumps that have caused erosion or landscape changes with rates on the order of metres per year. An examination of these images revealed that permafrost degradation was not confined to the coastal areas, but has also occurred in land where no previous monitoring have taken place.

Earth observation data sets can be used as a cost-effective tool for providing monitoring information on the effects of climate change, particularly in remote arctic regions where routine access is not always possible.

GEOCHEMISTRY OF EXOGENIC PROCESSES OF THE RUSSIAN ARCTIC COAST

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Millions of square meters of land consisting of permafrost are lost every year as a result of global changes, in particular climatic changes in the coastal zone of the Arctic seas. These exogenic processes regulate the melting of ice in permafrost and influence sediment, organic carbon and nutrient balances in Arctic basins. A peculiarity of geochemical exogenic processes in the Arctic is that they are biogeochemical in nature to some extent. Oxygen as a product of the activity of plants has a substantial impact on exogenic processes. Despite the fact that oxygen usually is a hard oxidant, pure chemical oxidation processes have little effect at low temperatures. But these oxidation processes became substantial if affected by bacteria. Other gases formed under reduction processes during the destruction of organic matter are carbon dioxide, hydrogen sulfide, methane and hydrogen and they are no less significant then oxygen. These two geochemical redox processes governed by exogenic processes determine the environmental conditions during formation of autochtonous minerals in the coastal zone.

The oxidation of low valency transition elements (especially of ferrum) results in the absorption of atmospheric oxygen and this has great importance for exogenic processes because the auxiliary absorption of oxygen from the atmosphere during coastal erosion intensifies reducing processes.

Another problem related to the geochemistry of exogenic processes in Arctic coastal permafrost is the composition and volume of gas bubbles included in tabular ground ice. According to our data, the bubbles contain a small gaseous mixture of halogen-hydrocarbon compounds, e.g. natural freons which can destroy the ozone layer.

This study was supported by the INTAS (grant no. 2329)

ESTABLISHMENT OF STANDARDIZED STATIONS TO MONITOR THE RESPONSE OF PERMAFROST TO CLIMATE CHANGE

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The Université Laval (Quebec) and BGR monitor jointly the response of permafrost to climatic changes at one site near the village Umiujaq in Quebec, Canada. The site is located near the eastern shoreline of the Hudson Bay in discontinuous permafrost terrain (Fig.1a-b). The monitoring operation started in July 2000 by drilling eight holes through a circular palsa with a diameter of 50 m. The palsa features steep slopes, rising by 2.1 m to 3.4 m above the surrounding permafrost-free wetland. Six boreholes are instrumented since 2000 with temperature sensors to monitor temperature changes in the frozen core of the palsa. Two boreholes were used for a ground penetrating radar transillumination survey to determine the distribution of the frozen ice content within the palsa.

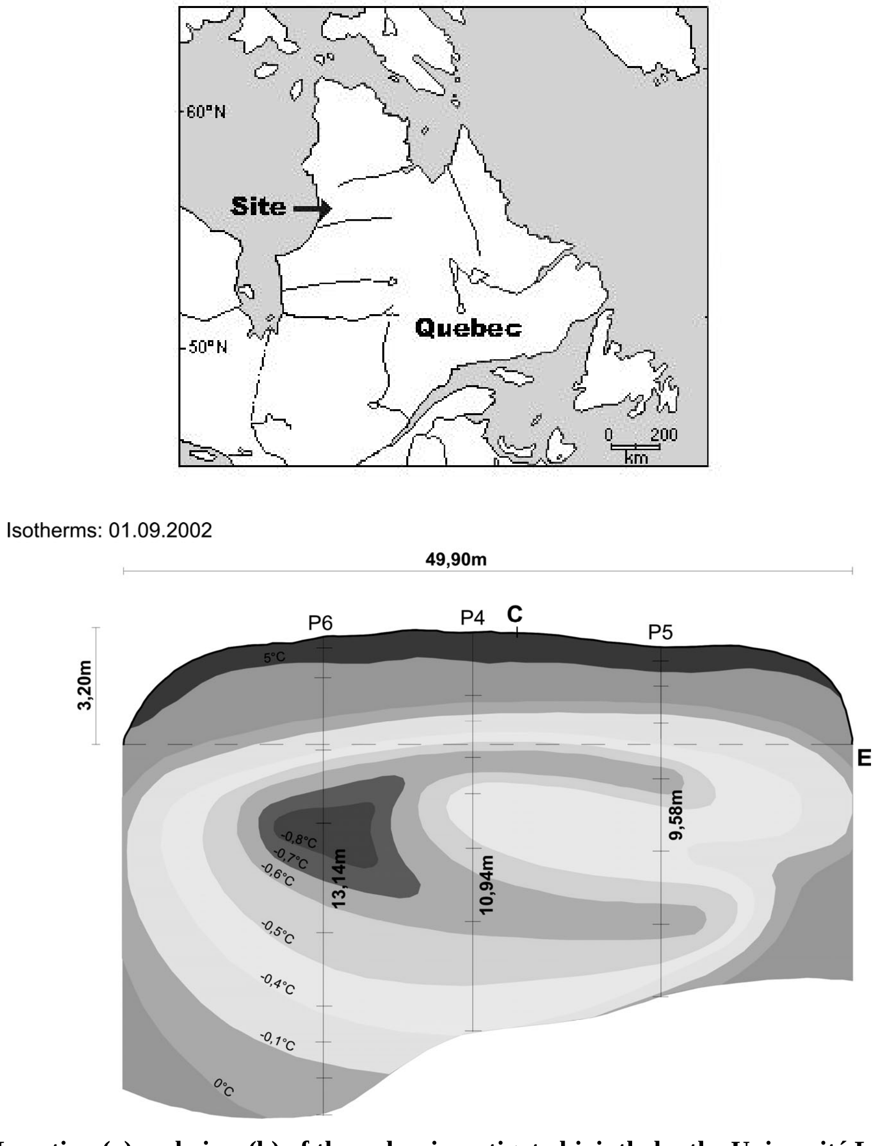

Figure 1a-b: Location (a) and view (b) of the palsa, investigated jointly by the Université Laval (Quebec) and BGR.

Now available is a four year record of the slowly advancing decay of the permafrost, being slowed down at this time by the effect of the harsh winter seasons of 2002/03 and 2003/04. First results were published in various papers (Delisle et al, 2003a, b, c).

Several significant observations were made as our monitoring program proceeded. Temperature recordings from the base of the permafrost (as well as the measurement of fluctuating pore pressure near the freezing front) suggest episodic cracking of the frozen basal soil, causing influx of groundwater into the permafrost body. Secondly, our temperature recordings demonstrate the strong thermal influence of slowly intruding fluids (Fig. 2).

Figure 2: Temperature field of the palsa as registered on 1. Sept. 2002. Note the strong positive geothermal anomaly caused by intruding groundwater from the right side.

Groundwater from the unfrozen surrounding terrain migrates laterally at various depth levels into the permafrost body, whose overall temperatures is now - as consequence of climate change - near the melting point. It appears that the thermal decay of permafrost in discontinuous permafrost terrain cannot be described as a stepwise downward enlargement of the active layer with each annual cycle in consequence of surface warming. Our observations suggest that permafrost near the melting point will decay along all boundaries: from above (surface warming due to climate change), the bottom (influence of terrestrial heat flow) and from the sides (intruding groundwater). This observation suggests that the rate of decay of permafrost might be significantly higher than predicted by numerical models, which consider conductive heat flow and uptake of latent heat alone.

We plan to expand in 2006 the cooperation between the Université Laval (Quebec) and BGR by the put in of standardized permafrost monitoring stations along a south–north trending profile extending from Umiujaq to Salluit. These stations will record standard parameters, (ground temperatures, pore water pressure in partially frozen permafrost and ground movement in active layer in response to the freezing/thawing cycle) in the interval from the surface to 20 m depth and, in addition, the annual buildup and decay of snow cover (considered is also an integrated technical approach to measure physical snow properties). In addition, already tested geophysical methods such as e.g. GPR transillumination surveys (Vertical ElectroMagnetic Profiling and ElectroMagnetic Tomography) between two boreholes will be applied.

These new stations will be located in progressively colder environments, where we can observe the reaction of permafrost to climate change under different climate conditions. Further aim of our work will be to improve our understanding of the properties of permafrost in a coastal environment including the shallow marine zone, where submarine permafrost is affected by the coastal wave regime, shore ice and the tidal regime.

We will introduce a newly developed instrument to drill about 20 m into permafrost at each new monitoring site. Standardized (and low cost) monitoring assemblages will be installed in the bore holes and activated for continuous recording. We hope to establish a recording system that will substantially contribute to a long-time “in depth” monitoring of the permafrost response to climatic changes expected for Northern Quebec.

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THE CANADIAN CLIMATE IMPACTS AND ADAPTATION RESEARCH NETWORK (C-CIARN): BUILDING LINKAGES IN A CHANGING WORLD

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The Canadian Climate Impacts and Adaptation Research Network (C-CIARN) consists of six regional offices, and seven sectoral offices. The Regions cover geographically significant issues, while the Sectors focus on areas of broad national interest such as fresh water, the coastal zone, fisheries, landscape hazards, and more. C-CIARN was created in 2001 to develop a network of researchers and stakeholders involved in climate change impacts and adaptation, facilitate research, and provide a voice and visibility to the climate change issue.

A priority and on-going task of C-CIARN is to identify climate change impacts and adaptation research needs and knowledge gaps through consultation with user groups and researchers. Since circumpolar regions are expected to experience the “first and worst” impacts of global warming, and are already seeing changes, many of the identified research needs and knowledge gaps pertain specifically to the North and its vast and sensitive coastal zone.

There is a clear need for those organizations and individuals involved in climate change issues to communicate across the boundaries of geography and discipline and to coordinate their efforts in order to assess what Canada needs to do, and know, to adapt to an ever-varying climate. Both researchers and the users of research are encouraged to join C-CIARN and use its resources to help focus their efforts as efficiently and effectively as possible.

DISTRIBUTION OF ICE-BONDED SEDIMENTS AND MASSIVE GROUND ICE ACROSS THE LAND-WATER INTERFACE IN A TRANSGRESSIVE BARRIER-LAGOON-DELTA SYSTEM, BEAUFORT SEA COAST OF YUKON TERRITORY, CANADA

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The lagoon estuary of Babbage River is predominantly less than 1.5 m deep and partially enclosed by a spit. There is a 2 km baymouth entrance opposite the delta front. Relative sea-level rise exceeds the rate of delta-plain sedimentation, resulting in slow inundation and landward migration of the delta front. Boreholes showed ice-bonded sediments beneath high ground, delta plain, tidal flats, and bottomfast ice in the lagoon. In 2 m water depth seaward of the spit, seabed sediments were unfrozen to a depth of 10 m and underlain by ice-bonded mud with ice lenses. In 8 m depth, sediments were unbonded to at least 22 m below seabed. Deposits beneath the spit were ice-bonded to 9 m at one site (11 m at another), below which was a 4 m thick talik of unfrozen silt. The unbonded layer at depth beneath the spit and thicker units of unbonded sediments beneath the lagoon suggest downward refreezing of shallow estuarine sediments as the spit migrates landward. The delta plain is a low-relief surface with shallow ponds and subtle levees. We hypothesize that anomalous higher surfaces of chaotic microtopography may be elevated in part by massive ice growth fed from taliks beneath adjacent deep channels in which high-salinity water remains throughout winter. These results confirm preservation in shallow coastal waters of massive ice and ice bonding developed below formerly subaerial surfaces which have subsequently been transgressed. Downward thaw of seabed sediments is initiated in the nearshore seaward of the spit as it migrates landward.

INUIT KNOWLEDGE OF ENVIRONMENTAL CHANGE DOCUMENTED AND COMMUNICATED THROUGH MULTIMEDIA TECHNOLOGY: AN INTERACTIVE POSTER

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This poster presents the multimedia, interactive CD-ROM, "When the Weather is Uggianaqtuq: Inuit Observations of Environmental Change." In this CD-ROM, Inuit from two communities in Nunavut (Baker Lake and Clyde River) share their observations and perspectives on recent climate and environmental changes. Topics include weather variability, sea ice, lake levels, snow, animals, glaciers, and icebergs, among others. The integration of interview video clips, maps drawn by Inuit, photos, music, and text, helps to illustrate Inuit observations of changes and the impacts on their livelihoods

"When the Weather is Uggianaqtuq" is a pilot project into using multimedia technology to improve research reporting to communities and designing more creative educational research products. The Inuit involved in this project have approved the CD-ROM as an educational tool for their own communities, as well as for students, researchers, decision-makers, and others in Nunavut and beyond who are interested in issues around Arctic environmental change.

ADDITIONAL EROSION OBSERVATIONS FOR THE ELSON LAGOON KEY SITE, BARROW, ALASKA

Oceana Francis-Chythlook[1] and Jerry Brown[2]

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New data has been added to the published rates of erosion for the Elson Lagoon key site (Brown et al. 2003). In the present study, additional time and spatial intervals were acquired for the 11-km long coastal section as shown in Table 1 (Figure 1). (Brown et al 2003; Francis-Chythlook 2004; Serbin et al 2004).

Table 1. Comparison of Erosion Rates for Elson Lagoon Key Site, Barrow, Alaska.

	Individual time intervals (meters/year)						Summary by major time intervals (meters/year)		
Segment	**49-62/64**	**62/64-79**	**1979-97**	**1997-7/00**	**7/00-8/00**	**2000-03**	**1948-79**	**1979-00**	**1948-00**
A									
Brown et al.	0.58	0.59	0.69	1.47	1.15	nd	0.56	0.86	0.68
Method 1	0.96	0.3	nd	nd	nd	nd	0.63	0.89	0.74
Method 2	0.78	0.32	nd	nd	nd	nd	0.55	0.79	0.66
Serbin et al.	nd	nd	nd	nd	nd	1.34	nd	0.69	nd
B									
Brown et al.	nd	nd	nd	nd	nd	nd	nd	0.65	nd
Method 1	1.54	0.43	nd	nd	nd	nd	0.91	0.69	0.82
Method 2	1.24	0.44	nd	nd	nd	nd	0.78	0.57	0.73
Serbin et al.	nd	nd	nd	nd	nd	1.04	nd	0.64	nd
C									
Brown et al.	nd	nd	nd	nd	nd	nd	nd	0.9	nd
Method 1	0.42	1.42	nd	nd	nd	nd	0.92	1.09	0.99
Method 2	0.53	1.51	nd	nd	nd	nd	1.02	1.13	1.08
Serbin et al.	nd	nd	nd	nd	nd	2.19	nd	0.86	nd
D									
Brown et al.	nd	nd	nd	nd	nd	nd	1.95	2.75	2.32
Method 1	2.42	1.54	nd	nd	nd	nd	1.99	1.92	1.96
Method 2	2.25	1.97	nd	nd	nd	nd	2.04	1.92	2.09
Serbin et al.	nd	nd	nd	nd	nd	0.48	nd	2.64	nd
A-D									
Brown et al.	nd	nd	nd	nd	nd	nd	nd	1.27	nd
Method 1	1.33	0.92	nd	nd	nd	nd	1.09	1.15	1.13
Method 2	1.2	1.06	nd	nd	nd	nd	1.09	1.10	1.14
Serbin et al.	nd	nd	nd	nd	nd	1.26	nd	1.27	nd

nd= not determined
Brown et al., 2003
Francis-Chythlook 2004, Methods 1 and 2
Serbin et al. 2004

Two methods were employed by the senior author to measure erosion. Method 1 involved using intervals of approximately 200 meters extending perpendicular from the length of the coastline for measuring the coastline erosion rate in meters (Figure 1). A grid was used to establish perpendicular lines for these intervals. Using these perpendicular lines, each coastline shapefile was measured across to the new coastline. Method 2 involved a similar method to that used by Brown et al. (2003). The average width of land lost per period was calculated as the area lost divided by the length of the coastline segment. The digitized coastlines were used to determine the area of land lost for each period by closing adjacent coastlines into polygon shapes (i.e. multi-sided closed shapes). The regression line between Methods 1 and 2 (Figure 2) shows a minimum deviation between these two methods used.

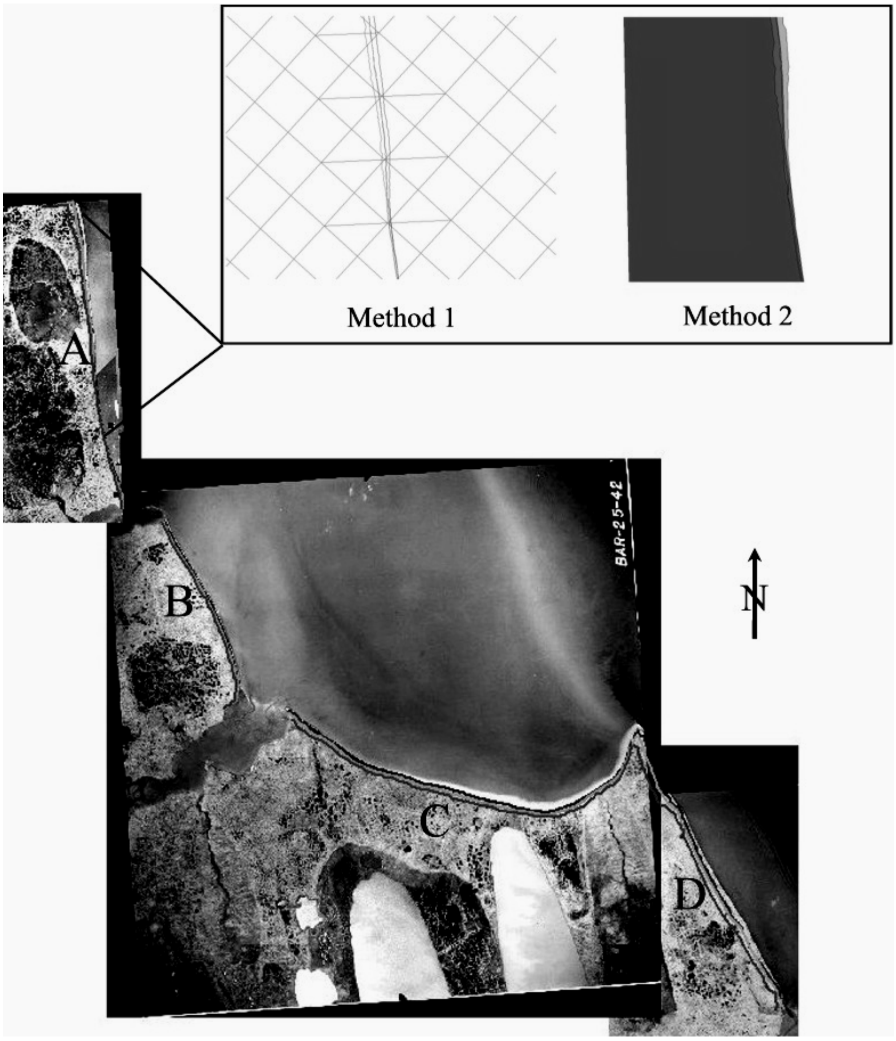

Figure 1. Comparison of 1962/64, 1979, and 2000 coastlines on a 1948 Elson Lagoon image and showing Methods 1 and 2, Francis-Chythlook 2004.

Methods 1 and 2 gave 1948/49-62/64 as yielding the highest erosion rate for Segments A, B, and D (Table 1). Methods 1 and 2 gave 1964-79 as having the highest erosion rate for Segment C. Method 2 also gave the highest erosion rate for the period 1979-2000 for Segment A. All segments combined gave the highest erosion rate for 1948/49-1962/64 for Methods 1 and 2.

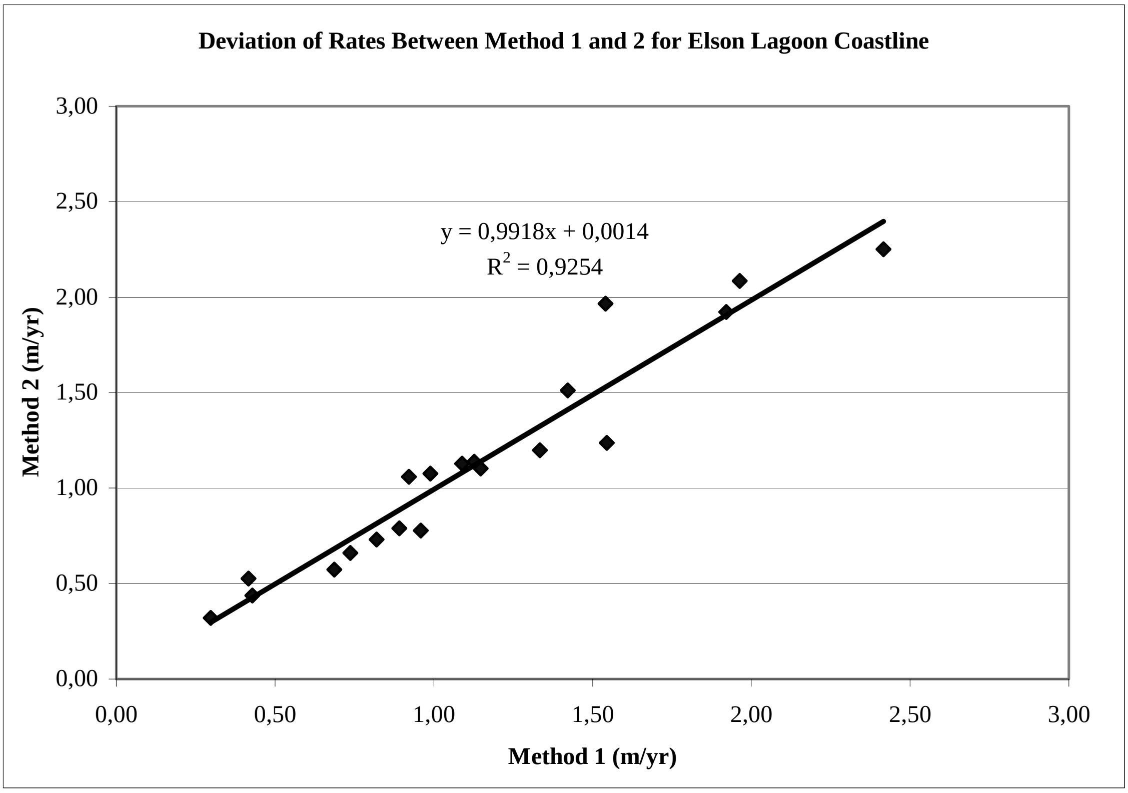

Figure 2. Deviation between Method 1 and 2 for measured erosion rates for Elson Lagoon coastline.

A comparison of mean width rate lost per period for Method 1 and Method 2 can be made with previous measurements from Brown et al. (2003) and Serbin et al. (2004) (Tables 1 and 2). Table 1 shows average errors (Δx/x) having high deviation from Brown et al. (2003) values for Segment A (1949-1979). Other lesser deviations include Segment C (1979-2000) and Segment D (1979-2000) when compared to Brown et al. (2003) values. All other values produced low average errors showing an acceptable match between the values.

Table 2. Comparison of four different methods for time interval 1979-2000, Elson Lagoon, Barrow, Alaska.

Segment	**Method 1** Mean Width Lost (m/yr)	**Method 2** Mean Width Lost (m/yr)	**Serbin et al** Mean Width Lost (m/yr)	**Brown et al** Mean Width Lost (m/yr)
A	0.89	0.79	0.69	0.86
B	0.69	0.57	0.64	0.65
C	1.09	1.13	0.86	0.9
D	1.92	1.92	2.64	2.75
A-D	1.15	1.10	1.21	1.29

Results of additional DGPS field studies for the summers 2000-2003 were reported by Serbin et al. (2004). In summer 2003 the entire coastline of Sections A-D was measured using DGPS and erosion rates were estimated for all four segments for the period 1979-2000 and 2000-2003 (Table 1 and 2).

A summary of erosion rates and storminess results is shown in Table 3. Category 2 storms have been summarized for the period of 2000-03 using Barrow CMDL hourly wind speed values (71°19.380'N, 156°36.540'W, 8-m elevation). As shown elsewhere in this volume (Francis-Chythlook) the period from the mid 1960s to the early 1980s had no occurrences of Category 2 storms (wind speeds ≥ 30 knots for at least six consecutive hours) (Hudak, 2001).

This lack of major storms corresponds to lower erosion rates in our periods of measurements (1964-1979).

Table 3. Summary of time-period based results for Elson Lagoon, Barrow, Alaska, 1948-2003.

Category	**1948/49-63/64**	**1963/64-78**	**1979-00**	**2000-03**
No. of Category 2 Storms	23	0	23	9
Aerial Profiles[1] (m/yr)	1.27	0.99	1.20	1.26

[1] All values are averages of Method 1 and Method 2 for Segments A-D except for 1979-00 which is average of Method 1 and 2 with Brown et al. value. 2000-03 value from Serbin et al. (2004).

Erosion rates generally increase in the southeasterly direction along Elson Lagoon during each of the three time periods during 1949-2000. Presumably, the submerged bar off Segments A, B, and C influence wave climate, particularly for easterly winds. Segment D has the highest erosion rate due to greater fetch and deeper water. During 2000-2003, Segment C is shown to have the highest erosion rate. The August-September 2002 storm observations in the southeasterly and southwesterly directions may be reflective of the shift in storm direction that produced a higher erosion rate for Segment C (Francis-Chythlook 2004), and lower rates at Segment D.

In a more regional study of Elson Lagoon and based on Orthorectified Radar Imagery (ORRI) acquired in August 2002, Manley (2004) reports erosion for the interval 1955 to 2002. That study yielded a mean erosion rate of 1.06 m/yr which included lower rates for the inner parts of many bays and inlets, and more exposed sections as far south as Admiralty Bay).

Acknowledgements: The authors thank the Barrow Arctic Science Consortium for logistical support. Support provided by an NSF Experimental Program to Stimulate Competitive Research (EPSCoR) fellowship at the University of Alaska Anchorage under the direction of Professor Orson Smith. Bill Lee (UAA) provided valuable GIS advice.

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FIELD OBSERVATIONS OF STORM-INDUCED WATER LEVELS FOR ELSON LAGOON, BARROW, ALASKA

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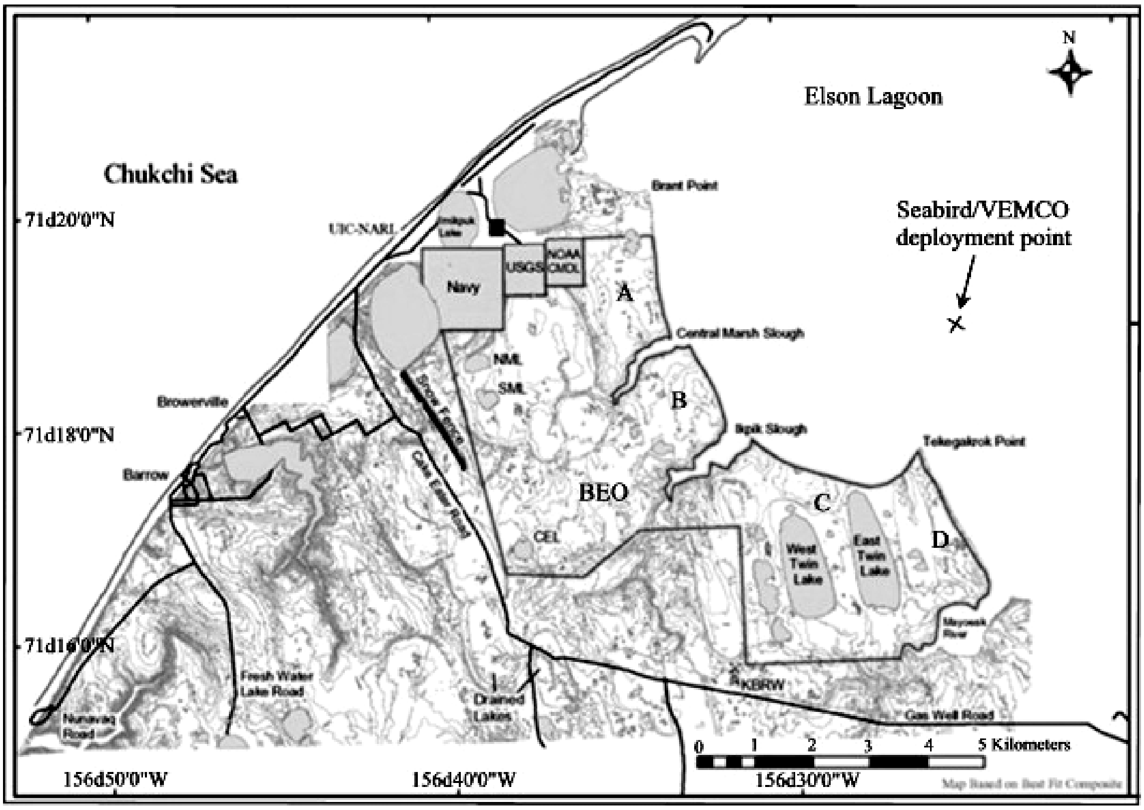
From August 17-September 29, 2002, a Seabird SBE 39 Temperature/Pressure Recorder gauge was deployed on the sea floor of Elson Lagoon (Figure 1, 71°18.942'N and 156°26.780'W). It recorded temperature and pressure in 30-minute intervals. For this experiment, the SBE 39 had initial accuracy of $\pm$0.002˚C for temperature, and $\pm$0.25 psia (or $\pm$0.17 decibars) for pressure. The approximate depth measured during deployment was 2.1 meters which accounts for tide level and wave height generated by the wind conditions at the time of deployment. A constant still water level (SWL) of d = 1.5 meters is assumed (USDOC et al., 1996).



Note: BEO map from BASC. Deployment point drawn in by O. Francis-Chythlook, 2004.

Figure 1. Approximate location of Seabird/VEMCO deployment point, August 2002.

The Barrow CMDL Hourly Wind Speed (Figure 1, 71°19.380'N, 156°36.540'W, 8-m elevation) and corresponding Water Surface Elevation, η for a sample period in 2002, are plotted in Figure 2. The water surface elevation shows a direct correlation to the wind speed. The outliers are a result of no data available during that time frame and should be ignored. Prevailing winds were westerly winds (46% from 180-360˚) and easterly winds (54% from 0-180˚). The vector wind directions are radially distributed and there is no prominent wind direction during August-September 2002.

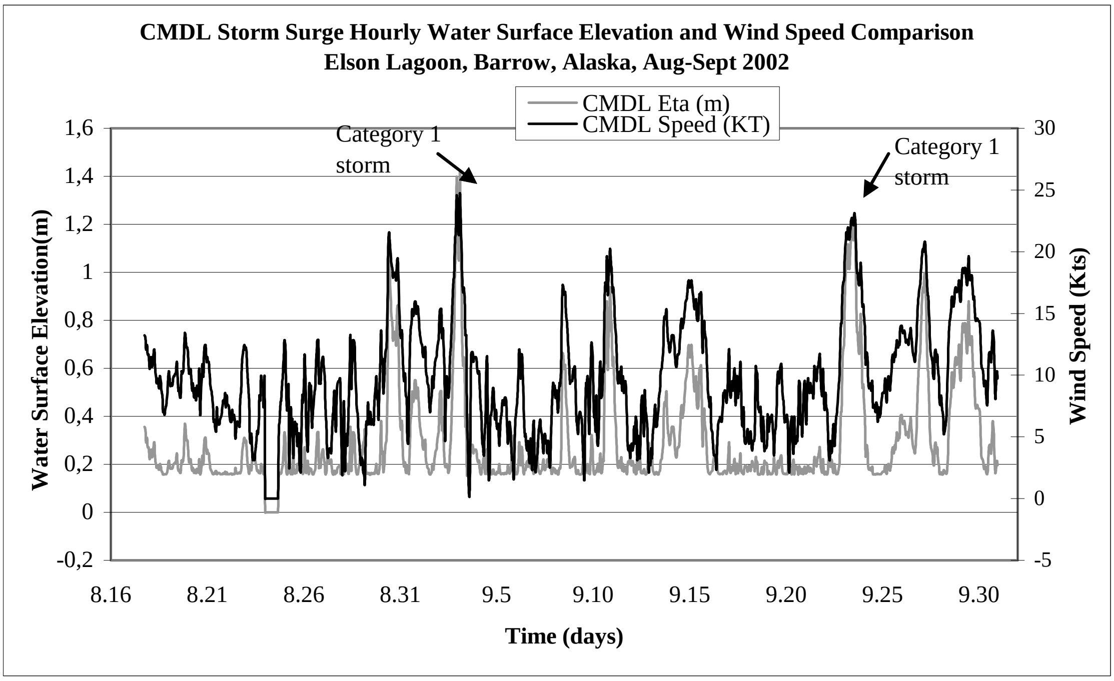


Figure 2. CMDL Storm Surge Hourly Water Surface Elevation and Wind Speed Comparison Elson Lagoon, Barrow, Alaska, August-September 2002.

Two Category 1 storms (wind speeds ≥ 20 knots for at least six consecutive hours) (Hudak, 2001) were recorded for the CMDL Barrow station (Figure 2). The storm occurring September 2-3, 8pm-4am, recorded southwesterly winds (i.e. 225-262˚). The storm occurring September 23, 2am-3pm, recorded southeasterly winds (i.e. 131-138˚). These storm surges had a maximum effect on the water surface elevations by raising their levels to sustained peak heights.

Due to the shallow water depth and high storm surge activity over the area, the water waves affecting the Elson Lagoon coastline are considered irregular shallow water waves. A simplified long wave equation in two-dimensional form describes the change in water level induced by wind blowing over Elson Lagoon. Wind is assumed to blow perpendicular to the Elson Lagoon shoreline for August-September 2002. This would produce a surface current toward land and a bottom current to travel seaward. Surface (wind) stress and bottom stress are assumed to cancel each other out. It assumes no water movement parallel to coast. The Coriolis force and moving pressure disturbance are not considered for short-term sea states. Combined bottom and surface wind stress are considered in which the following has been used to find the water surface profile. A constant depth is assumed.

Acknowledgements: The author thanks the Barrow Arctic Science Consortium for logistical support. Support provided by an NSF Experimental Program to Stimulate Competitive Research (EPSCoR) fellowship at the University of Alaska Anchorage under the direction of Professor Orson Smith. Additional guidance and support provided by Dr. Jerry Brown.

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USDOC, NOAA, NESDIS, NGDC, and MGG. 1996. NGDC NOS Hydrographic Database: Marine Trackline Geophysics, Hydrographic, and Aeromagnetic Survey Data. USDOC, NOAA, NESDIS, NGDC, MGG Vol I and II CD set. NGDC E/GC 325 Broadway, Boulder, Colorado USA 80305-3328.

RESULTS OF A WAVE CLIMATE STUDY FOR ELSON LAGOON, BARROW, ALASKA

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New results using wave climate applications have been employed to elaborate upon coastal erosion rates and processes for the 11 km long Elson Lagoon site. Wave climate study involving storm surge analysis and wave modeling is used to examine the relationship between storm surges and erosion rates.

Available wind data was used to generate wave heights and directions using CEDAS (Coastal Engineering Design and Analysis System software program). The results generate a shallow water wave growth model that depends on fetch length. Hourly wind speeds and directions for the Barrow station for 1948 to 1999 were obtained from the Alaska Sea Ice Atlas website (http://holmes-iv.engr.uaa.alaska.edu/default.htm). The majority of wind events with wind speeds between 10-39 knots occurring in the 67.5˚ (ENE) to 90˚ (E) direction (Figure 1). Other storm events (i.e. 40-59 knots) occurred from the 270˚ (W) direction. Elson Lagoon coastline (sections A-D), is affected primarily by positive storm surges. Easterly winds increase the height of sea level.

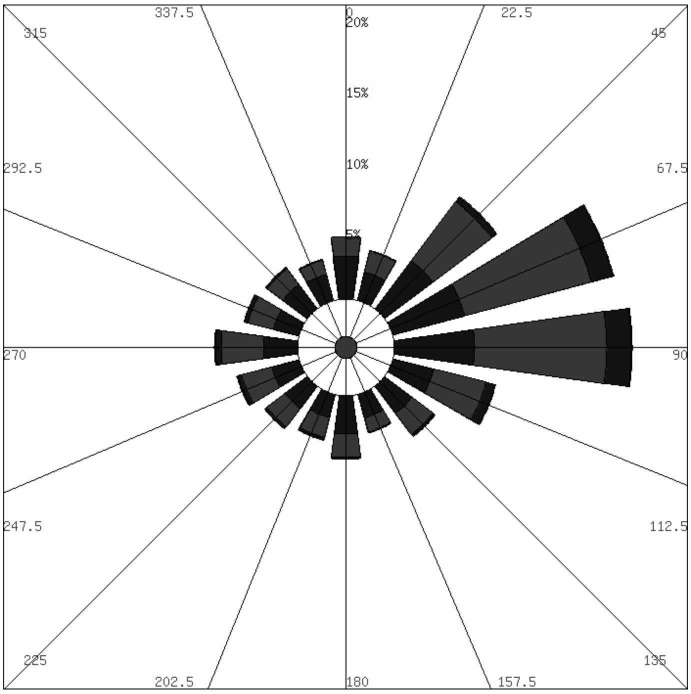

Figure 1. Annual wind rose from correlation of hourly wind speeds and directions from Barrow station 1948 to 1999.

During 1948-1999 there were a total of forty-six Category 2 storm events (wind speeds ≥ 30 knots for at least six consecutive hours) (Hudak, 2001). Figure 2 show half of these storm events (i.e. 23 events) in fall between 0 to 180 degrees (refer to Figure 1) which are considered positive storm surges created by easterly winds and increase the height of sea level. The other twenty-three events fall between 180 to 360 degrees, which are negative storm surges created by westerly winds and decrease the height of sea level. From this analysis, it shows that the type of storm surge is unaffected by extreme wind events but rather the number of occurrences of lesser wind speeds. From the linear regression, Figure 2 shows that the intensity of the extreme storm events is decreasing; however it is difficult to predict the storm event.

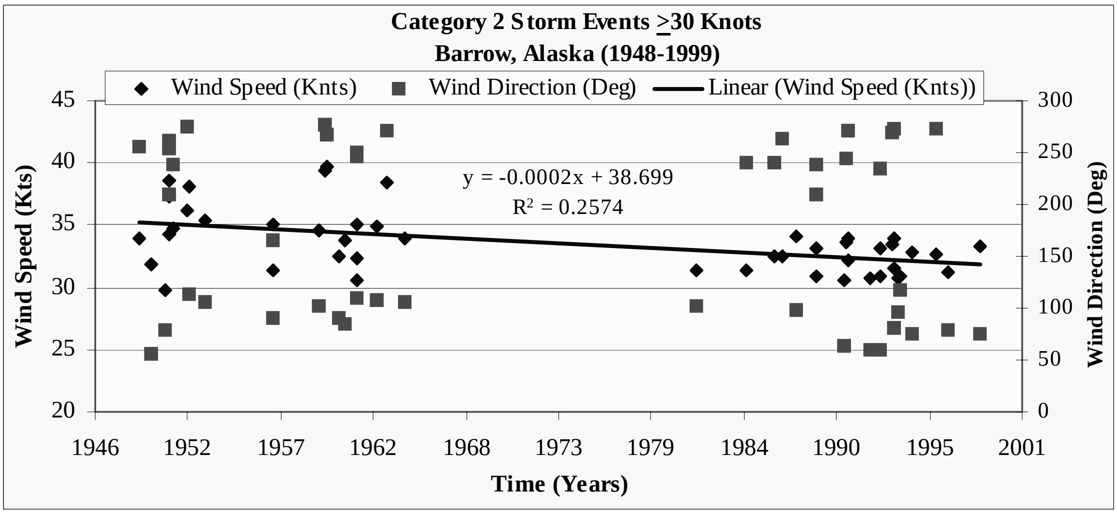

Figure 2. Category 2 Storm Events (≥ 30 Knots) for Barrow, Alaska from 1948-1999.

ACES was used to estimate wave growth over open water and restricted fetches in deep and shallow water. ACES is part of the CEDAS (Coastal Engineering Design and Analysis System) software program, Vicksburg, Mississippi, USA. A shallow restricted fetch condition was selected for ACES input. Fetch lengths were measured for locations across the water that would be affected by storm surge waves. One point was chosen per Segment with location approximately in the mid-coastline region of each Segment. Each point was measured from its Segment mid-point across Elson Lagoon to the nearest shoreline (Plover Islands) in increments of 5.625º. The wind fetch (measured) and the wind speed and direction from the Wind Rose (Figure 1) used for ACES input gave ACES output results of wind direction, mean wave direction, wave height, and wave period.

A bathymetry grid was created using ArcInfo and ArcView to create a grid in the X, Y, Z-coordinate system. The origin was identified in real-world coordinates of UTM Zone 4 WGS 84 and located perpendicular to the majority of the Elson Lagoon coastline. For the depth (Z-axis), NOAA Hydrographic survey for Elson Lagoon (USDOC et al, 1996) was used. A shapefile polygon was drawn for all adjacent land and the points with coverage in these parts were given an elevation of 3 meters to distinguish the land from the water.

A uniform grid was built in the Grid Generator in CEDAS converting the real world UTM X, Y-coordinates into an STWAVE Cartesian grid coordinate system (Figure 3). The grid has 3150 200-m^2 grid cells (63 in the longshore and 50 in the cross-shore direction). The coordinate system, vertical datum, and the units were specified when incorporating the data file. The area chosen for the grid used in STWAVE included the entire coastline of Elson Lagoon to halfway to the Plover Islands southeast of Point Barrow. This midway location in Elson Lagoon was chosen since fully formed wave data would be brought into STWAVE, and this point would best represent this type of wave data.

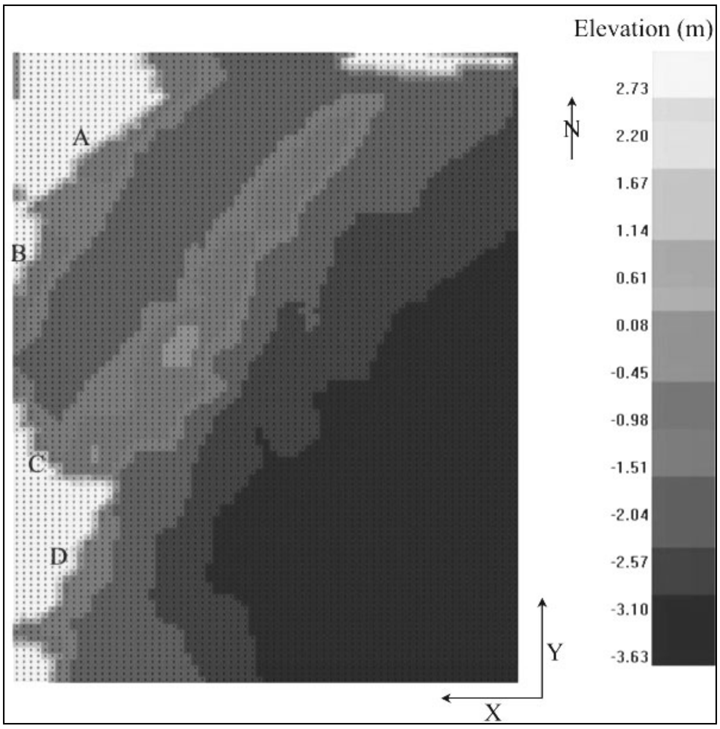

Figure 3. Bathymetric grid generated from CEDAS-NEMOS Grid Generator converted to Provincial Cartesian system, Elson Lagoon, Barrow, Alaska, 2004.

SPECGEN, part of CEDAS, was used to create spectrally derived wave parameters (i.e. significant wave height, wave period, wind-generated wave direction). SPECGEN creates or imports half-plane energy density directional spectra suitable for use in STWAVE. A water depth of 2.8 m (USDOC et al, 1996; Brown et al., 2002) and an x-azimuth of 217.66˚ from N were used for SPECGEN inputs for Stations A-D. JONSWAP spectrum of 3.3 was used. Sea wave conditions were entered for directional distribution of energy density.

During 1948 to 1999, ACES results revealed the highest level of storm surge activity for Segment A occurred at a 90° (E) wind direction and 94° (E) wave direction; Segment B occurred at a 90° (E) wind direction and 94° (E) wave direction; Segment C occurred at a 67.5° (ENE) wind direction and 67° wave direction (ENE); and Segment D occurred at a 90° (E) wind direction and 93° (E) wave direction.

The STWAVE input files generated from the Grid Generator and SPECGEN along with wind input parameters served to produce a bathymetric color contour maps showing wave height and wave direction (Figure 4). The wave direction for all four Segments is from the northeasterly direction. The wind-wave directions were chosen from averaged wave directions for significant wave heights. Wave heights are affected by the fetch. Shorter fetches from sheltered conditions due to the Plover Islands had shorter wave heights and periods than the fetches unrestricted from the open waters of the Beaufort Sea.

Acknowledgements: Support provided by an NSF Experimental Program to Stimulate Competitive Research (EPSCoR) fellowship at the University of Alaska Anchorage under the direction of Professor Orson Smith. Additional guidance provided by Dr. Jerry Brown.

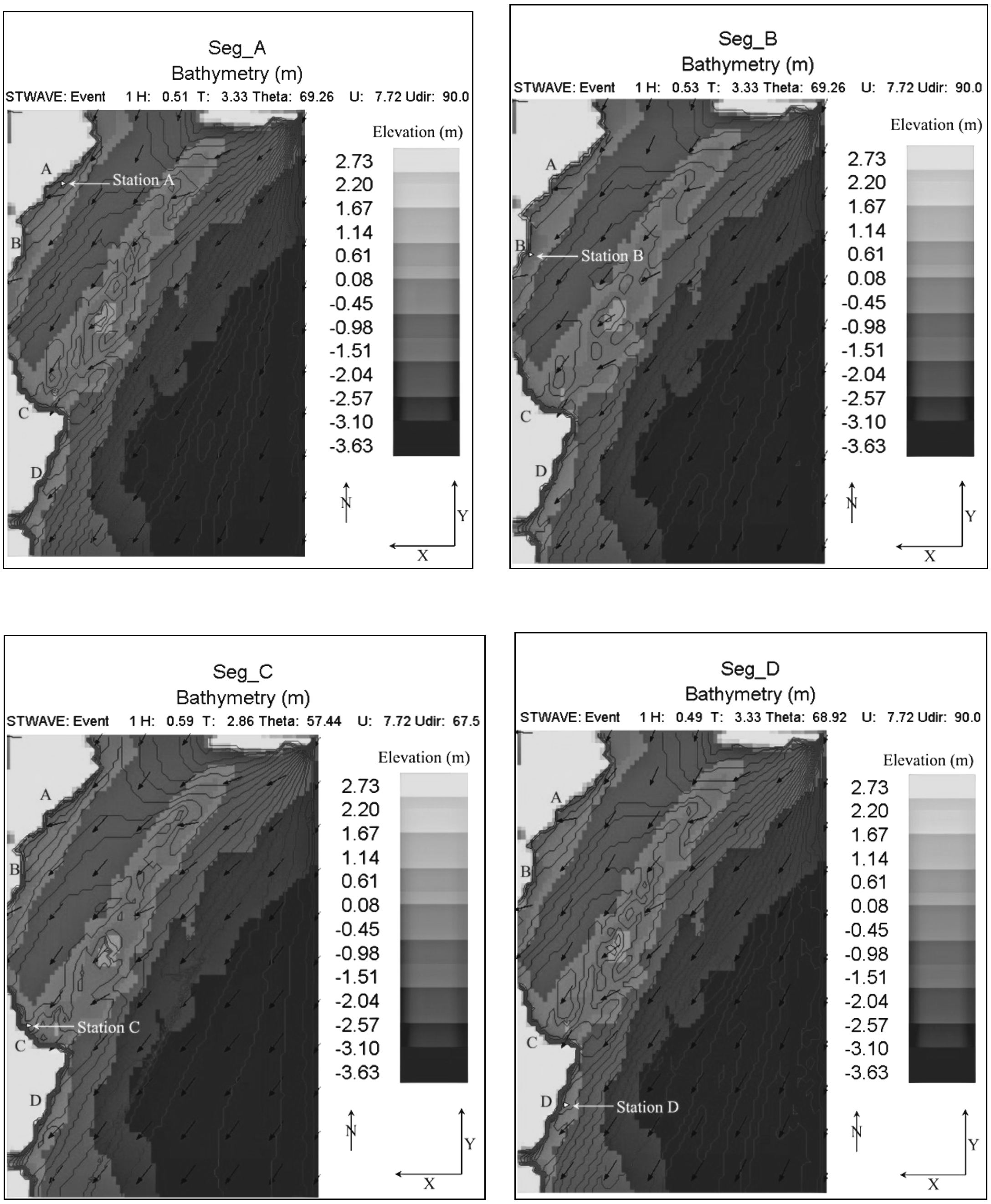

Figure 4. Wave height (red line) and wave direction (black arrow) shown for Segments A-D stations, Elson Lagoon, Barrow, Alaska, 1948-1999.

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THE IMPORTANCE OF METADATA FOR ARCHIVING AND PROMOTING SPATIAL DATA DISCOVERY

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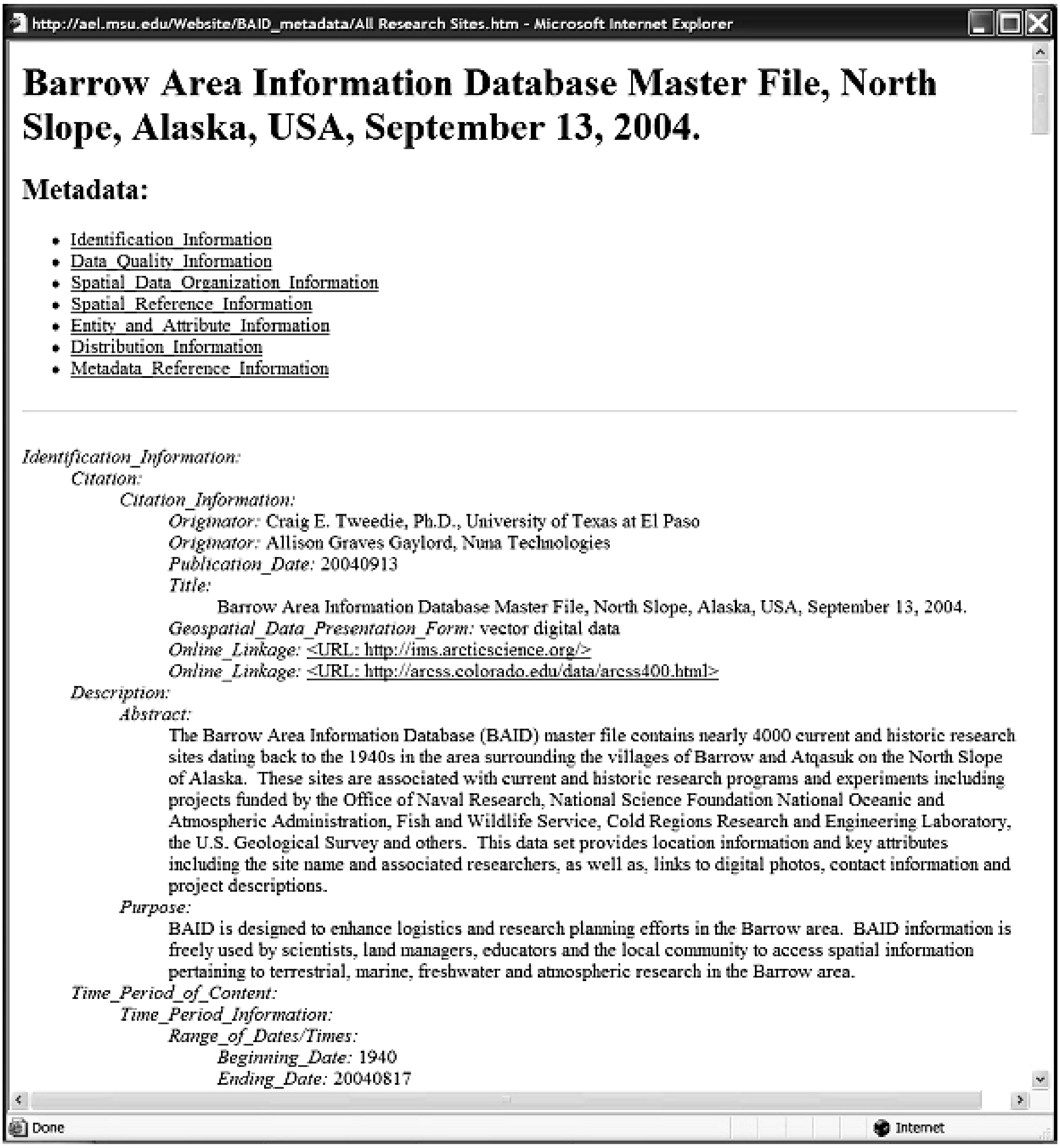
The coastal community of Barrow, Alaska, has fostered a long tradition of research dating back to the 1940s. Barrow is an Iňupiaq village located at the northernmost point of the United States where the Chukchi and Beaufort Seas converge. The geography of this location has been a determining factor for the settlement of the native population, the strategic location for military installations and Arctic research initiatives. The legacy of research activity in the region has resulted in amassing a tremendous wealth of data. Much of this data is not properly archived or documented. Increased interest in the impacts of climate change has made historical data sets more valuable. To date, over 4,000 terrestrial based research locations have been mapped in the Barrow region. These sites are associated with current and historic research programs and experiments including projects funded by the Office of Naval Research, National Science Foundation, National Oceanic and Atmospheric Administration, Fish and Wildlife Service, Cold Regions Research and Engineering Laboratory, the U.S. Geological Survey and others. Many of these efforts have a spatial component such as the location of bore holes, sensors, ground control points, vegetation plots, erosion control markers, aerial photography, satellite imagery, etc.

Metadata records address what type of information the data contain; why the data were collected; when, where, and how they were collected; and by whom. Documenting a data set is critical to preserving its usefulness over time and assessing data quality. Metadata protects a data investment, ensures preservation of institutional memory and provides liability protection (Nebert 2004). A metadata outreach effort has been initiated through a cooperative agreement between the Barrow Arctic Science Consortium (BASC) and the U.S. Geological Survey's Federal Geographic Data Committee (FGDC). The outreach is two fold. The first objective is to capture historic information through mapping and documentation. This data rescue typically involves interviews with long time Barrow area researchers and the compilation of associated references including grey literature that is not widely published such as dissertations, theses, government reports and old maps. The second objective is to promote the development of metadata for new research activities in the region. Publication, education and outreach activities help to facilitate stakeholder awareness as well as active information acquisition and documentation.


http://ael.msu.edu/Website/BAID_metadata/All Research Sites.htm - Microsoft Internet Explorer

Barrow Area Information Database Master File, North Slope, Alaska, USA, September 13, 2004.

Metadata:

- Identification_Information
- Data_Quality_Information
- Spatial_Data_Organization_Information
- Spatial_Reference_Information
- Entity_and_Attribute_Information
- Distribution_Information
- Metadata_Reference_Information

Identification_Information:
Citation:
Citation_Information:
Originator: Craig E. Tweedie, Ph.D., University of Texas at El Paso
Originator: Allison Graves Gaylord, Nuna Technologies
Publication_Date: 20040913
Title:
Barrow Area Information Database Master File, North Slope, Alaska, USA, September 13, 2004.
Geospatial_Data_Presentation_Form: vector digital data
Online_Linkage: <URL: http://ims.arcticscience.org/>
Online_Linkage: <URL: http://arcss.colorado.edu/data/arcss400.html>
Description:
Abstract:
The Barrow Area Information Database (BAID) master file contains nearly 4000 current and historic research sites dating back to the 1940s in the area surrounding the villages of Barrow and Atqasuk on the North Slope of Alaska. These sites are associated with current and historic research programs and experiments including projects funded by the Office of Naval Research, National Science Foundation National Oceanic and Atmospheric Administration, Fish and Wildlife Service, Cold Regions Research and Engineering Laboratory, the U.S. Geological Survey and others. This data set provides location information and key attributes including the site name and associated researchers, as well as, links to digital photos, contact information and project descriptions.
Purpose:
BAID is designed to enhance logistics and research planning efforts in the Barrow area. BAID information is freely used by scientists, land managers, educators and the local community to access spatial information pertaining to terrestrial, marine, freshwater and atmospheric research in the Barrow area.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 1940
Ending_Date: 20040817

Done Internet

Figure 1: An example of a classic FGDC metadata record in html format.

A synergistic activity related to this outreach is the capturing of grey literature associated with historical research in the Barrow area, which is being spearheaded by the advisory groups of the Barrow Arctic Science Consortium. Through this ongoing effort, metadata support has been provided by the Geophysical Institute Library at the University of Alaska Fairbanks where a collection of donated grey literature is being compiled from the personal archives of retired Barrow area researchers. The goal is to make these references available at the new library planned for the proposed Barrow Global Climate Research Facility (BGCRF). The close-knit community of current and retired researchers engaged in this activity provides a special opportunity to capture metadata associated with extant research locations.

Just as the World Wide Web is viewed as the information superhighway, metadata are increasingly becoming the vehicle for finding spatial data over the Internet. Scientific data are often published in the form of journal articles, but are not always archived in a format that makes it available for long-term use. Standardized metadata records preserve institutional knowledge and can extend the life of your data. Metadata records are required to submit data sets to a clearinghouse archive. The clearinghouse system is a distributed, but electronically connected network of over 240 international data archives. Each of these archives has adopted the Z39.50 protocol specified by the International Standards Organization (ISO), which is used in library sciences to support the search and retrieval of information. The adoption of a common metadata standard across Arctic data producers (such as the ISO/FGDC protocol which uses eXtensible Markup Language or XML) coupled with ongoing contributions to clearinghouse nodes would facilitate increased data access. The XML based metadata from all the archives is harvested over the Internet and can be queried by title, name, key word, place, etc. Figure 2 shows an example of how a clearinghouse gateway may be used to query various data archives for information. This information is often available for download via electronic File Transfer Protocol (FTP). Popular Internet search engines such as Google can also be used for locating metadata records. Many U.S. funding agencies now require the development of metadata as a step for properly archiving and publishing data.

While there are many data archives housing Arctic data, it is often a challenge to locate and obtain data. For this reason, the Barrow outreach effort strives to promote access to spatial data through increased data discovery via integration with the U.S. National Spatial Data Infrastructure (NSDI) clearinghouse system, and online data browsing through the Barrow Area Information Database – Internet Map Server (BAID-IMS) that can be accessed at http://www.baidims.org.

Much of the Barrow area data with FGDC compliant metadata are ingested into the NSDI clearinghouse system through a node at the Arctic System Science (ARCSS) Data Coordinate Center (ADCC) at the National Snow and Ice Data Center in Boulder, Colorado. Metadata tools provided by the Environmental Systems Research Institute (ESRI) ArcGIS ArcCatalog module have been adopted as the standard for the project. In addition, a series of XML based metadata templates have been developed to save time in entering redundant information that may be common to a group of data sets (such as contact information, key words, processing steps, etc.) Other helpful software tools include the U.S. National Park Service metadata tools extension for ArcGIS 8 and the U.S. Geological Survey Metadata Parser.

This metadata effort is a key part of the Barrow Area Spatial Data Infrastructure initiative. Spatial Data Infrastructure (SDI) provides the technology, policies and institutional arrangements that facilitate the availability of and access to spatial data. SDI provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia and by citizens in general. The development of an Arctic Spatial Data Infrastructure has been proposed for the International Polar Year and to the US National Science Foundation (*Collaborative Research: Developing and Implementing an Arctic Spatial Data Infrastructure to Support International Arctic Science.* Funding pending) which will link similar efforts across the region and thus further increase access to spatial data.

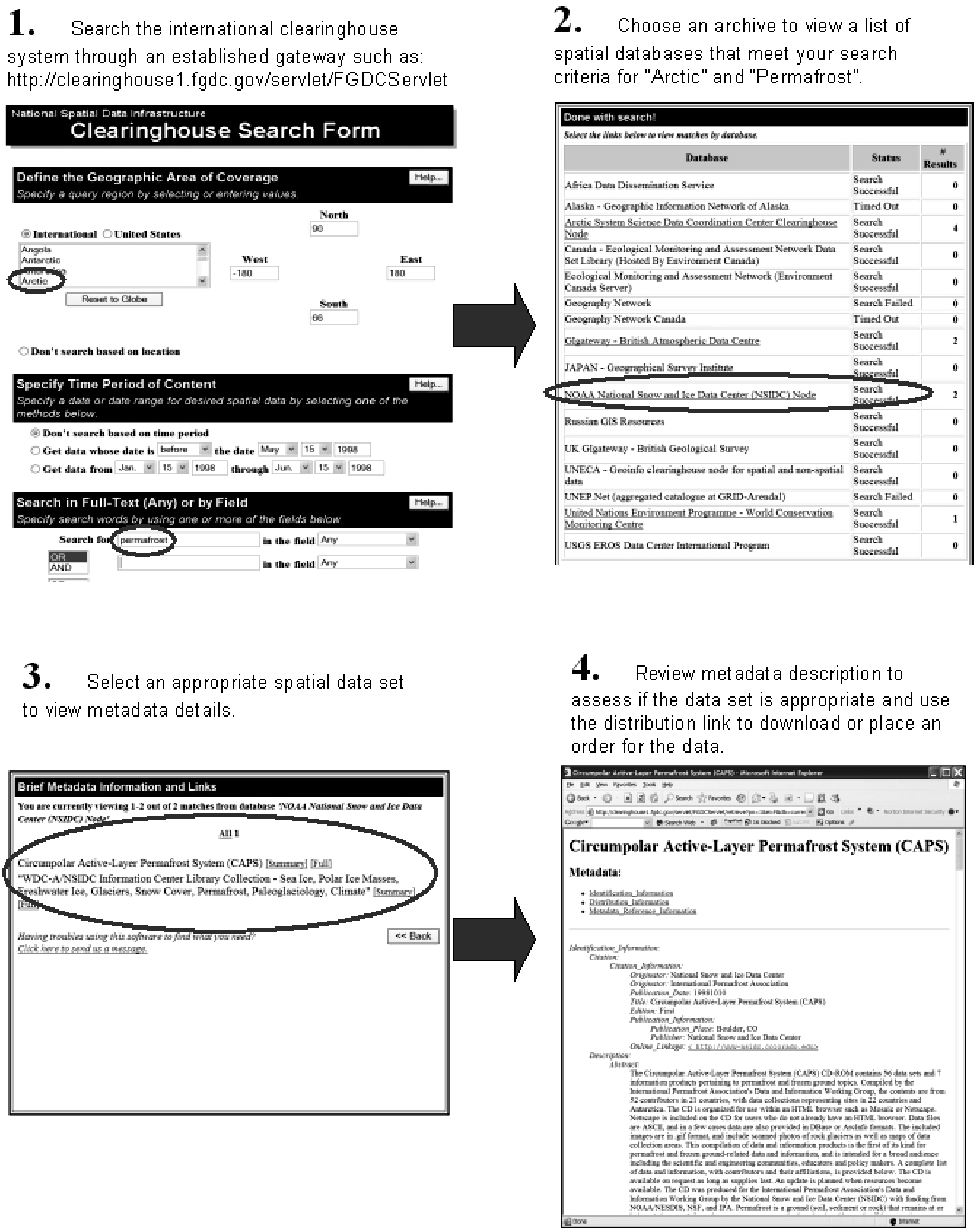


Figure 2. Example of a clearinghouse gateway.

Acknowledgements: The Barrow Area SDI effort is made possible through support from the National Science Foundation (NSF Award OPP-0004401) and the U.S. Geological Survey (USGS Award Number: 03HQAG0177) to the Barrow Arctic Science Consortium.

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THE DEGRADATION OF COASTAL PERMAFROST AND THE DEVELOPMENT OF SUB-SEA PERMAFROST IN THE NEAR-SHORE ZONE OF THE LAPTEV SEA

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The dynamics of onshore permafrost and the evolution of offshore permafrost in the near-shore zone are closely interrelated. However, only a few drilling transects within the shoreface of the Asian Arctic Seas have been studied. Under the shallow shelf of the Laptev Sea facing thermal abrasion coasts the sub-sea permafrost table is usually found at a depth of 5-60 metres. Sometimes new formations of sub-sea permafrost were observed on shallows within accumulative bottom deposits. Our previous studies of coastal permafrost degradation at Ice Complex coasts showed that the sub-sea permafrost table slowly submerges from the shoreline to greater water depth.

In the Laptev coastal zone sub-sea permafrost was found within many sites: Eastern Taimyr Peninsula, Khatanga Bay, Nordvik Cape, Kozhevnikov Bay, Mammoth Tusk Cape, around the Lena and Yana Deltas, Bykovsky Peninsula, Muostakh Island, Buor-Khaya Bay, Siellyakhsky Bay, Vankina Guba Bay, Svyatoy Nos Cape and around the Big and Small Lyakhovski Islands (Figure 1).

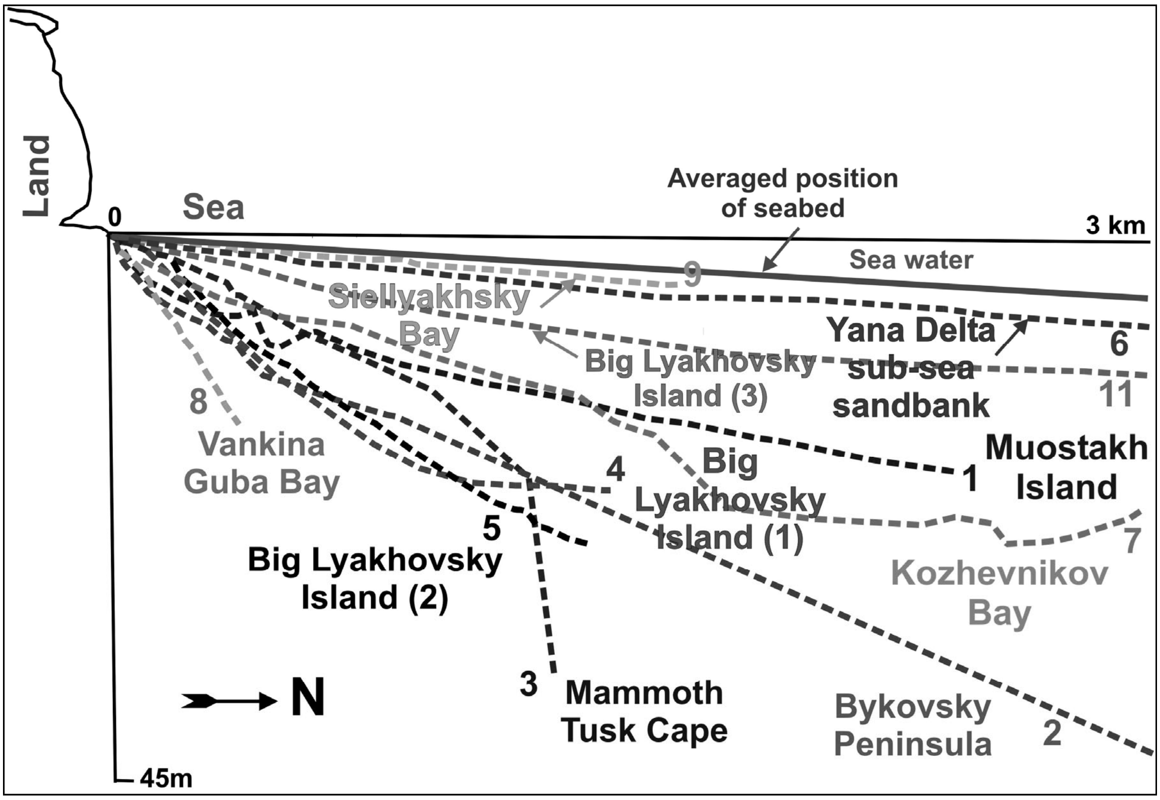

Figure 1. Sub-sea permafrost table position at key sites in the near-shore zone of the Laptev Sea.

During our studies the focus was on ice-rich sub-sea permafrost, which was investigated in detail, because more than 30% of the studied eroded coasts consist of the Ice Complex. According to published and our own data, the foot of the Ice Complex is very often lying below sea level (up to minus 10-20 m). When onshore ice-rich permafrost is transformed into the sub-sea state through coastal retreat its table changes very rapidly, at least initially. Based on coastal retreat rates, the time of submergence of a specific location can be dated back. If, for example, the depth of the permafrost table at a 2 km distance from the shoreline is determined at 15 m below sea level and the long-term coastal erosion rates are about 4 m/year, it is possible to conclude that 500 years ago this specific location was situated at the coast and that the mean trend of degradation of the sub-sea permafrost table is approximately 4 cm/year. However, it has to be noted that during the first stage of submergence the degradation of the permafrost table can be 10-times faster.

Preliminary studies show that depending on the average coastal retreat rate and other environmental conditions, including sediment features, water temperature and salinity regime etc., the dominant rates of degradation of the sub-sea permafrost table during the first stage of submergence vary from 1 to 10-15 cm/year, at a permafrost table inclination of 0.002-0.35 (from the shore to the sea). Preliminary analysis of the sub-sea permafrost table position at the key sites of the Laptev Sea near-shore zone allows us to reveal the regularities and peculiarities in permafrost evolution. The greatest inclination of the permafrost table (0.035) was found in the Vankina Guba Bay – profile 8. It is probably related to slow coastal erosion in this area and environmental specificity. Minimum permafrost table inclinations (0,002-0.003) were observed at the sites where accumulative sedimentation prevails (Yana Delta sub-sea sandbank – profile 6, Siellyakhsky Bay – profile 9). In this case new sub-sea permafrost formation is generated within the very shallow shoreface. Normally, the near-shore sites located at more or less open sea conditions are characterized by steep permafrost table inclination (north-west of Big Lykhovsky Island – profiles 5, 7; Mammoth Tusk Cape – profile 3; Bykovsky Peninsula – profile 2. Moderate permafrost table inclinations were found at Muostakh Island and Bykovsky Peninsula (Central Laptev Sea coast) - 0.007 and 0.013 respectively (average coastal erosion retreat rates are 13 and 3 m/year). In the Mammoth Tusk Cape area (Western Laptev Sea coast) the inclination of the permafrost table is very steep (0.015) within a distance of up to 1.3 km from the shore and extremely steep (more than 0.3) between the 1.3 and 1.4 km distance. This anomaly could be due to ancient thermokarst processes which occurred under subaerial conditions. An estimation shows that the average rate of permafrost table degradation at the studied transect is about 8 cm/year or slightly more.

SEDIMENT AND ORGANIC CARBON FLUXES IN CONNECTION WITH ERODING PERMAFROST COASTS OF THE SIBERIAN ARCTIC

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During the last decade detailed coastal studies along the Arctic Seas have been conducted within the frame of the Arctic Coastal Dynamics (ACD) Program. The results indicate that shore dynamics play an important role in the balance of sediment and organic carbon in the Arctic basin. Arctic coastal sediment flux exceeds river sediment discharge and other terrestrial sediment sources. Based on newly obtained data, this presentation evaluates average coastal erosion rates as well as sediment and organic fluxes within the Siberian Arctic coastal zone.

The Siberian Arctic sector includes four seas: the Kara, Laptev, East Siberian and Chukchi Seas. The total length of the Siberian Arctic coastline, including the islands, is about 29,500 km. Most parts of this coast are characterized by very active coastal erosion processes. A considerable proportion of the Siberian Arctic coasts (especially for the Laptev and East Siberian Seas) consists of ice-rich permafrost deposits, which are rapidly reworked by sea erosion. It has been found that the coastal sediment flux into the seas listed above plays a dominant role in their sediment budget. Based on the amount of coastal sediment released to the sea and the average organic carbon contents of the key types of coastal deposits, the total organic carbon (TOC) supplied to the Siberian Arctic Seas (SAS) has been estimated. The assessment of these lithologic-dynamic parameters is based on unified methods, which involve detailed coastal segmentation and GIS-analyses.

The calculated values of the sediment and TOC fluxes are considerably different from previously published data. Our results suggest that both coastal sediment flux (158 million tons per year) and coastal TOC flux (4.6 million tons per year) to the SAS significantly contribute to the Arctic Ocean sediment and carbon budget.

This study was supported by the INTAS (grant 01 - 2329).

BOTTOM SEDIMENTS ON EROSIONAL SHOREFACE OF THE LAPTEV SEA

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Rachold V, Alfred Wegener Institute, Research Unit Potsdam Germany

Bottom sediment sampling on the erosional shoreface of the Laptev Sea was carried out during 1999-2002 on 15 coastal key sections. Altogether 151 samples along 22 shoreface profiles off the coasts composed of ice complex (7), ice complex on the bedrock basis (5), sand (7), and bedrock (3) were taken at every meter of water depth and analyzed by laser-granulometry. Preliminary results of these analyses were presented at the 4th ACD workshop. After that, processing of the data was continued, and some new results were obtained. A part of them is published in "Reports on Polar and Marine Research", 482 (2004).

The distribution of the sediment grain-size across the shoreface was examined for all types of coasts using average and median grain diameters. A typical example is given in Fig. 1. The average and median are changing almost equally, decreasing regularly in offshore direction with water depth increase until the outer boundary of the shoreface (water depth about 8-9 m). However, this regularity gets broken outside of the shoreface.

All data at our disposal are plotted in Fig. 2. This diagram shows a very large spread of average diameter values. The relationship between sediment grain-size and water depth manifests itself very poorly if at all. It should be noted that the absolute majority of the average diameter values fall in the sand range (63-2000 µm), despite the fact that the sampling was carried out off the coasts composed of different sediments from silt to bedrock.

Fig. 3 show that the relationship between sediment grain-size and water depth manifests itself much better for geologically uniform coasts. Each point in the diagram of Fig. 3 represents a mean value of the median or average diameter for a given geological type of coast. In general, the linear dependence of the sediment grain-size on the water depth is fairly well seen from Fig. 3. This dependence is very weak off the coasts composed of ice complex and gets stronger in the sequence ice complex, sand, ice complex on bedrock, bedrock. The coefficient of determination R^2 increases in the same succession.

This study showed that sand prevails on the shoreface off all geological types of coast investigated. The sand content in bottom sediments is mostly in the range of 50-90% and exceeds 90% off the sandy coasts. The clay content nowhere exceeds 5-6%. The silt content does not exceed 10%, mostly 2-5%.

The average grain-size for sediments sampled off the coastal of a certain type has been calculated. The results show that all 4 median diameter averages fall into the range of fine and very fine sand (63-250 µm).

The prevalence of sand in the bottom sediments on the shoreface off the ice complex coasts is important for the general understanding of Arctic coastal dynamics. The mineral fraction of the ice complex is characterized by very high silt content (40-90% by volume), but on the shoreface the silt content is only 10-40%. This means that waves and currents remove almost all silt from the shoreface. Therefore the high silt content in perennially frozen unconsolidated sediments significantly favours coastal retreat in the Arctic.

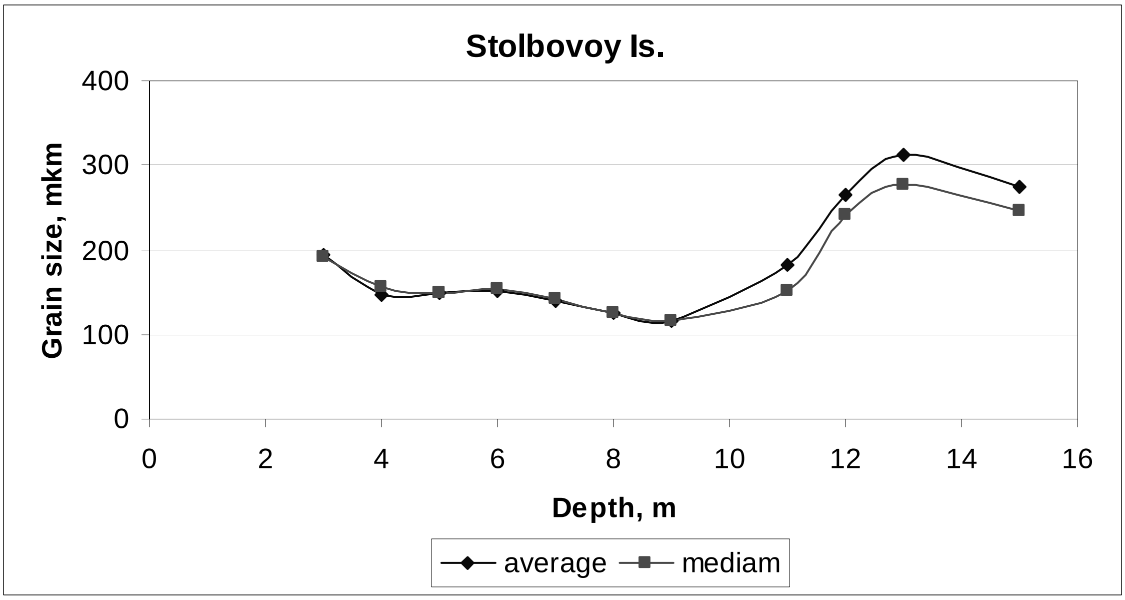

Figure 1. Distribution of the sediment grain-size across the shoreface.

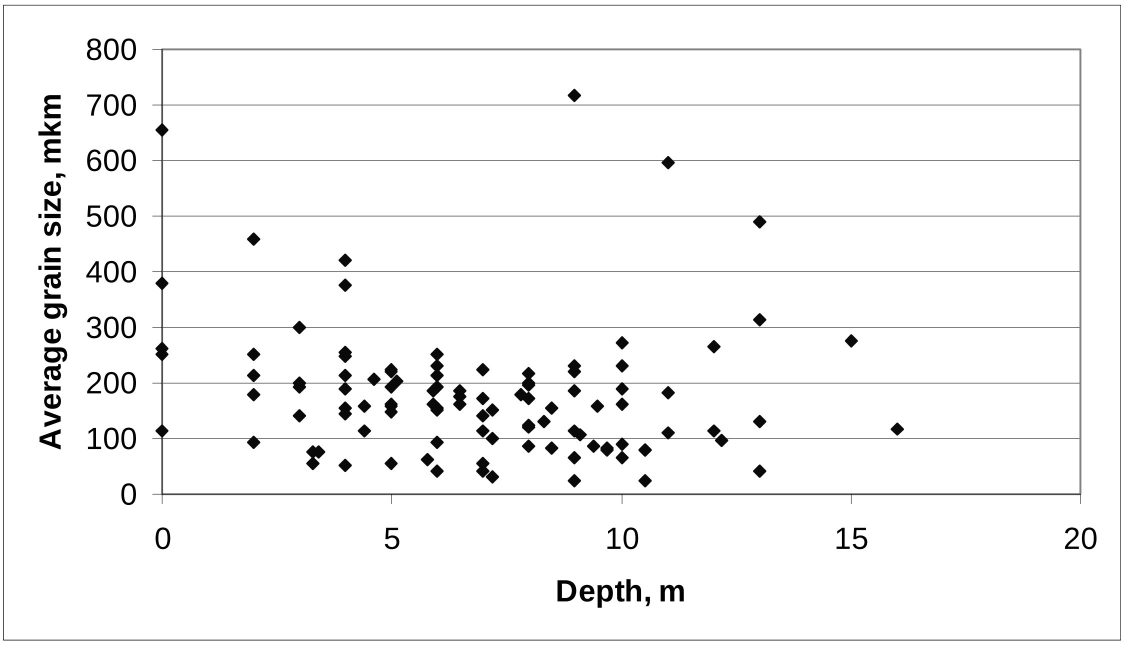

Figure 2. Relationship between average grain-size and water depth.

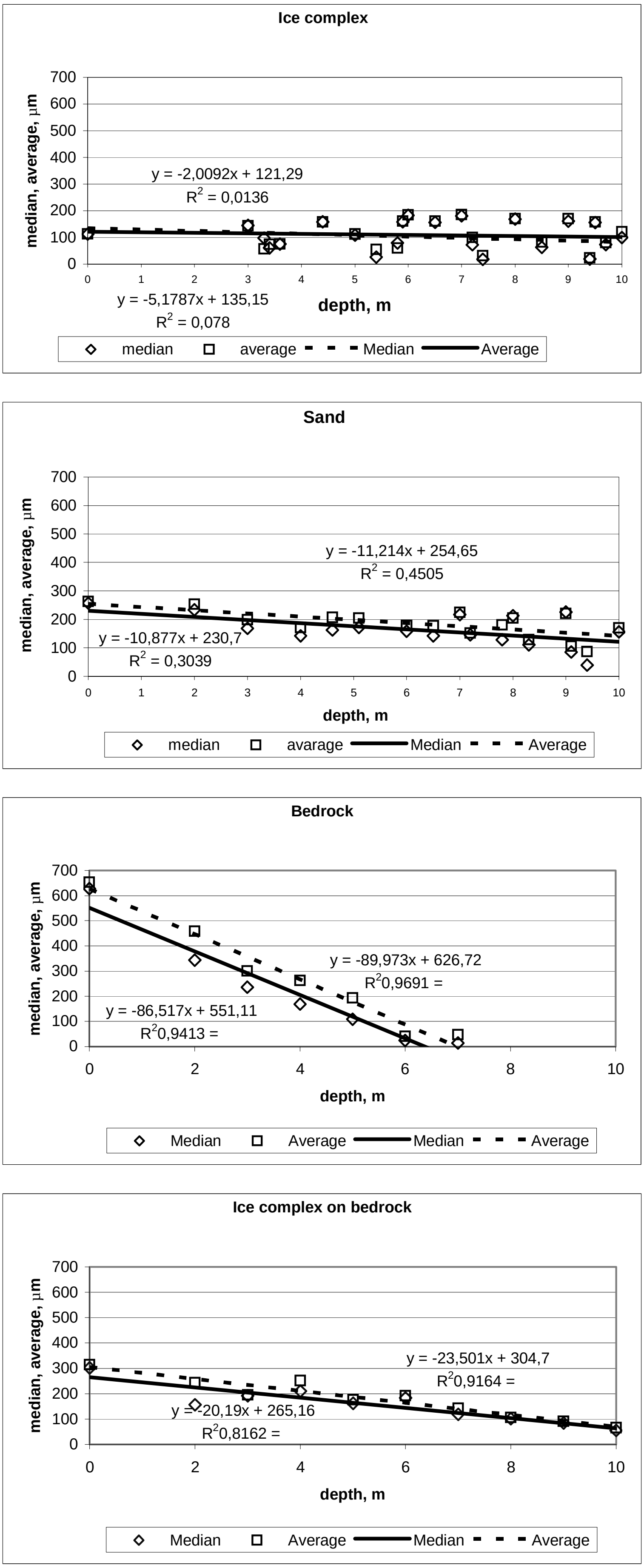

Figure 3. Relationship between median grain diameter and water depth.

INUIT KNOWLEDGE AND PERCEPTIONS OF THE LAND-WATER INTERFACE

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The geographical zone of the land-water interface flanking the Inuit village of Kangiqsualujjuaq, Nunavik, has been chosen as the setting to explore the dimensions of knowledge transmission and land/seascape perceptions among Inuit generations. Extreme tidal influences and seasonal variations combine to make Kangiqsualujjuaq a remarkable setting in which to measure and analyse the intergenerational transmission of Inuit knowledge and the processes by which knowledge is disseminated.

This research project involves the participation of six Inuit families that migrated to Kangiqsualujjuaq from various regions of Nunavik during the 1950s. A stratified sample of 12 Inuit Elders, 12 middle-aged hunters and 12 Inuit youth were interviewed on two separate occasions. A third fieldtrip to the community is planned for winter 2004-05 whereupon additional interviews with these participants and staff of the local school will be carried out.

By measuring the intergenerational transmission of knowledge the study will shed light on whether or not a loss of the traditional knowledge base is occurring. While knowledge transformations need not necessarily be considered a lost, the question arises as to whether the transformation of knowledge result in redundancy, and if so, whether the verbatim or partial duplication of knowledge in new formats carries with it the essential ingredients of the original knowledge base. Perhaps total knowledge remains embedded in a variety of forms, but is traditional knowledge in its original format being lost? And, does this transformation of knowledge matter? The study examines the ramifications of the use of navigational technologies such as GPS as a way of understanding the learning modes and patterns of knowledge acquisition among the Inuit.

MODELING BLOCK FAILURES IN VERTICAL CLIFFS OF ARTIC COASTS UNDERLAIN BY PERMAFROST

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Introduction

Artic coasts lie at the interface between terrestrial systems dominated by permafrost, and marine systems that are characterized by long periods of ice cover and short periods of open water when wave actions and storm activities are important. Permafrost sea ice and wind wave conditions are driven by regional and local climate forcing and interact in such a way that a change in one produces feedbacks affecting the other two. However under predicted climate changes scenarios of warming, increased storm activities and sea level rise will be profoundly affect all three leading to potentially devastating rates of coastal erosion and permafrost degradation. Permafrost coasts are subjected to complex erosional processes, however one of the most poorly understood but probably most important erosional processes is block failure. Thermo-abrasional falls or block collapses provides the most spectacular form of recession in permafrost area. The occurrence of horizontal thermo-erosional niches and ice wedges associated with permafrost are the two key reasons for block failure in the artic coast. The main purpose of the paper is to illustrate the different block failure mechanisms in the artic coast. The study provides computational models for block failure mechanisms and investigates the relative contribution of horizontal niche and ice wedge in block failure of permafrost cliffs fronted by a beach.

Model Formulation

Artic coastal retreat through block failure is initiated by the development of thermoerosional niches. Thermal energy of seawater is added to the normal erosive impact of waves and the erosion occurs due to the combined action of mechanical and thermal energy. Horizontal niche into a frozen cliff is formed during a storm if the base of the cliff is exposed to wave and current action (Solomon 1995). When such niches penetrate sufficiently deep, collapse of the cornice that overhangs the niche is likely.

Figure 1 shows a vertical cliff having an ice wedge and horizontal niche. The cliff is characterized by H_c: cliff height; x_n: horizontal depth of the niche; z_n: height of the niche at the cliff face; and x_w: distance of ice wedge from the cliff face. Due to the niche formation, the toe of the cliff has been shifted from its initial position *O'* to the new position *O*. Following Cullman's assumption for slope stability the potential failure plane is assumed to be inclined with an angle $\theta = (\alpha/2 + \phi/2)$, where, α is the slope angle and ϕ is the angle of internal friction of soil materials. In the areas where ice wedge are present, collapse usually occurs along the ice wedge (Walker, 1991). In presence of ice wedge and thermoerosional niche there are two possible modes of block failure: sliding and overturning.

Sliding failure occurs when a mass of frozen cliff soil block slides down along a relatively planner failure surface. The sliding mass is assumed to translate as a rigid body down the sliding surface. It does not undergo any rotation. When we apply a statically balance of forces, the factor of safety against sliding is then defined as the ratio of resisting force to driving forces. The driving force consists of the down slope components of the weight. Resisting forces are made up of shear strength of failure plane and the stabilization force exerted by weight component exerted perpendicular to the shear plane. If F_D is the driving force and F_R is the resisting force, then the factor of safety against overturning is expressed as: $FS_S = F_R/F_D$. On the other hand if overturning moment exceeds the resisting moment, the overturning failure will occur. An overturning moment due to the overhanging weight W_1 acts around the toe. There are also resisting moments due to weight component W_2 and the tensile strength (f_t) of the ice rich permafrost soil. If M_D is the driving moment and M_R is the resisting moment, then the factor of safety against overturning is expressed as: $FS_O = M_R/M_D$.

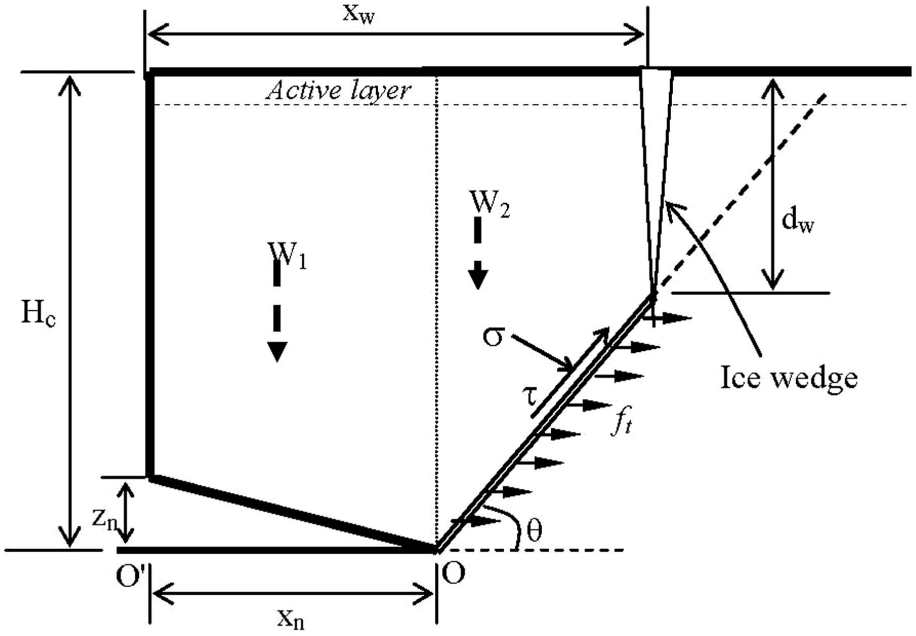

Figure 1: Vertical cliff with horizontal niche and ice wedge.

Results and Discussions

The depth of the horizontal niche extends until the shore cliffs collapse. Therefore for a particular coast the critical depth of the niche at which collapse occurs is of interest. Aré (1988) reported that the lithologic composition of sediment has little effects on the depth of the niche. To give a demonstrative overview of the generally complex processes of block collapse of frozen cliff, the failures mechanisms have been examined in a series of numerical computations for different cases of niche depth and ice wedge locations. Cliff height, horizontal niche depth and ice wedge dimensions used in model calculations have been considered within the allowable range as reported by existing studies (Happer, 1990; Harry, et al. 1985; Mackay, 1977; Mackay, 1992; Solomon, 1995) on artic coast. Calculated results show that for a given permafrost soil strength, the failure potential of smaller cliff heights is overturning whereas that of larger cliff heights is sliding. This is because of the reasons that at small height the sliding force exerted by the weight of the block is less than the total resisting force exerted by the cohesive strength of the cliff soil. But at certain critical depth of thermoerosional niche the block overturns while the overturning moment exceeds the resisting moment. On the other hand, at larger cliff heights the weight of the block exerts sliding force greater than the resisting force thus causing the shear failure of the block. Model calculations showed that the critical cliff height at which potential failure mode changes from overturning to sliding, H_{c0}, depends on cohesive strength (c) and angle of internal friction (ϕ) of cliff materials. For frictionless ($\phi = 0$) cohesive soil the critical cliff height H_{c0} can be determined from the relationships $\frac{\gamma H_{c0}}{c} \approx 1.5$ for the case without ice wedge and $\frac{\gamma H_{c0}}{c} \approx 1.0$ for the case in presence of ice wedge within the potential failure area. Vertical cliffs lower than H_{c0} are subjected to overturning and cliffs higher than H_{c0} are subjected to sliding. Critical cliff height, H_{c0}, increases with the increase in strength of the cliff materials.

The critical depth of horizontal niche depends on cliff height and permafrost soil properties. Figure 2 depicts the variations of x_{nc} with cliff heights for different cohesive strengths. It is found that the pattern of variation of the critical niche depth against cliff height is same for different cohesive strength. Niche depth increases with the cohesive strength of the cliff soil. For cliff heights less than H_{c0} (overturning potential), the critical depth of horizontal niche increases with cliff height provided the soil strength is same. On the other side for cliff heights greater than H_{c0} (sliding potential), the critical depth of horizontal niche decreases with cliff height. These findings are qualitatively in agreement with practical situation as in practice the overturning potential increases with the increase in horizontal niche depth.

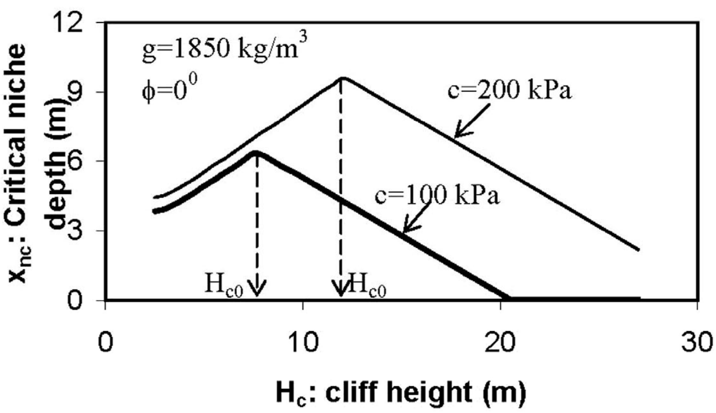

Figure 2: Variation of critical niche depth with cliff height and cohesive strength for block failure without the influence of ice wedge.

In cases of block failures due to the combined influence of horizontal niche and ice wedge, the critical depth of horizontal niche (x_{nc},) depends on soil strength parameters, cliff height (H_c) and the distance of ice wedge (x_w) from the face of the cliff. Model calculation shows that for given cliff height and the soil strength the dependency of x_{nc} on x_w is mostly linear as a result of which the ratio of x_{nc} to x_w can be considered as constant. For frictionless cliff soil the variations of non-dimensional parameter $\gamma H_c/c$ with x_{nc}/x_w for different cohesive strengths are shown in Fig. 3. It can be observed that smaller values x_{nc}/x_w (up to about 0.5) correspond to sliding whereas larger values correspond to overturning. So in sliding failure the depth of thermoerosional niche extends maximum up to $x_w/2$, whereas for the case of overturning failures the niche depth extends beyond $x_w/2$. It is also found that the smaller cohesive strengths (less than 100 kPa) corresponds to sliding failure and larger cohesive strengths correspond to overturning. It is because permafrost soil with high cohesive strength provide more shear resistance which can not be overcome by the developed shear force along the failure plane. In such case the overturning failure occurs while the thermo-erosional niche extends to the critical depth.

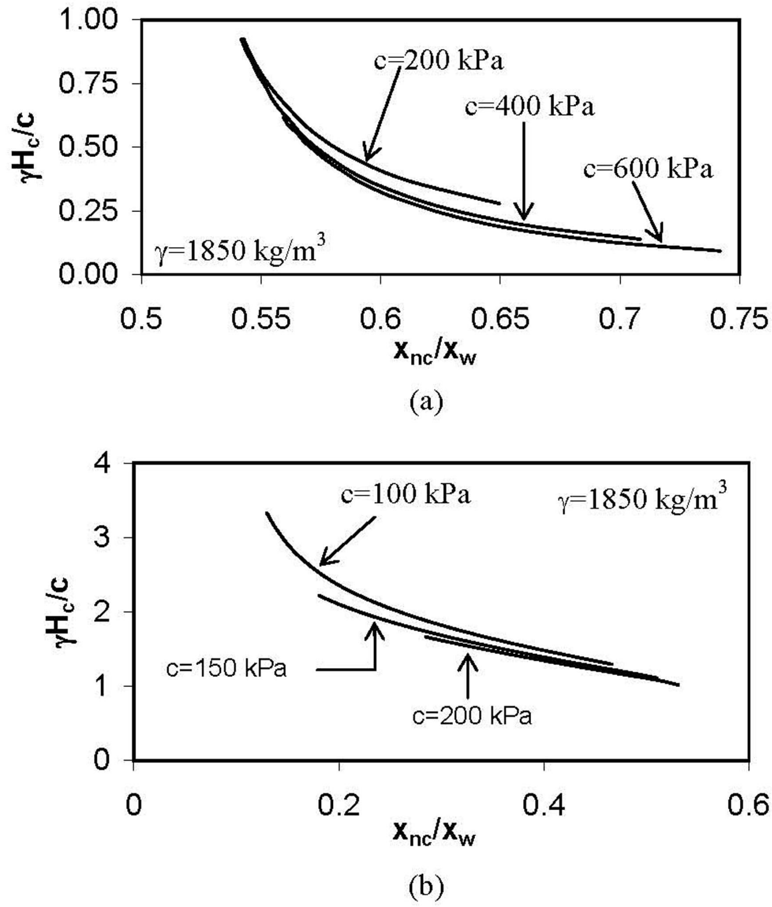

Figure 3: Variation of $\gamma H_c/c$ with x_{nc}/x_w and cohesive strength for potential block failure by (a) overturning and (b) sliding.

Concluding Remarks

Computational models for block failure of vertical cliffs of artic coasts have been developed. Model calculations have been expressed in simple expressions and graphical representations for predicting block failure of artic coastal cliffs. The cliff face is eroding due to thermal and weathering effects. The depth of thermoerosional niche also increases with time. As long as the information regarding the depth of horizontal niche, nearest ice wedge distance from the cliff face and soil properties can be provided then it is possible to predict block failure potentials and failure mechanisms of the cliffs. The strength of permafrost soil is dependent on temperature. The vulnerability of the cliffs at different temperature can also be predicted providing the expected soil strengths at different temperatures. Findings of this study can be used for modeling long-term coastal retreat in the Artic under predicted climate change scenarios.

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A MULTI-SCALE APPROACH TO ASSESSING THE FLUX AND TRANSFORMATION OF ORGANIC CARBON ACROSS THE ERODING COASTLINE OF NORTHERN ALASKA,

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Although first order estimates of the flux of organic carbon across the eroding coastline of northern Alaska have been developed (Jorgenson and Brown 2004), little is known about the transformation of terrestrial organic carbon (OC) as it crosses the land/ocean interface. Because the biogeochemical cycling of OC is controlled by the age, size and composition of the organic matter (Ping et al. 2001, Guo et al. 2003), it is critical to quantify the nature and magnitude of OC transformation in order to understand the carbon budgets of the Arctic Ocean (Figure 1). Also essential, is knowledge of how these factors relate to geomorphic environments and how they have been influenced by past soil development, and how permafrost development has affected soil properties (Shur and Jorgenson 1998). We hypothesize that the narrow, wave-washed foreshore zone is the most important coastal zone for the transformation of OC once it is released from storage through physical dispersion, leaching, and oxidation (Figure 1).

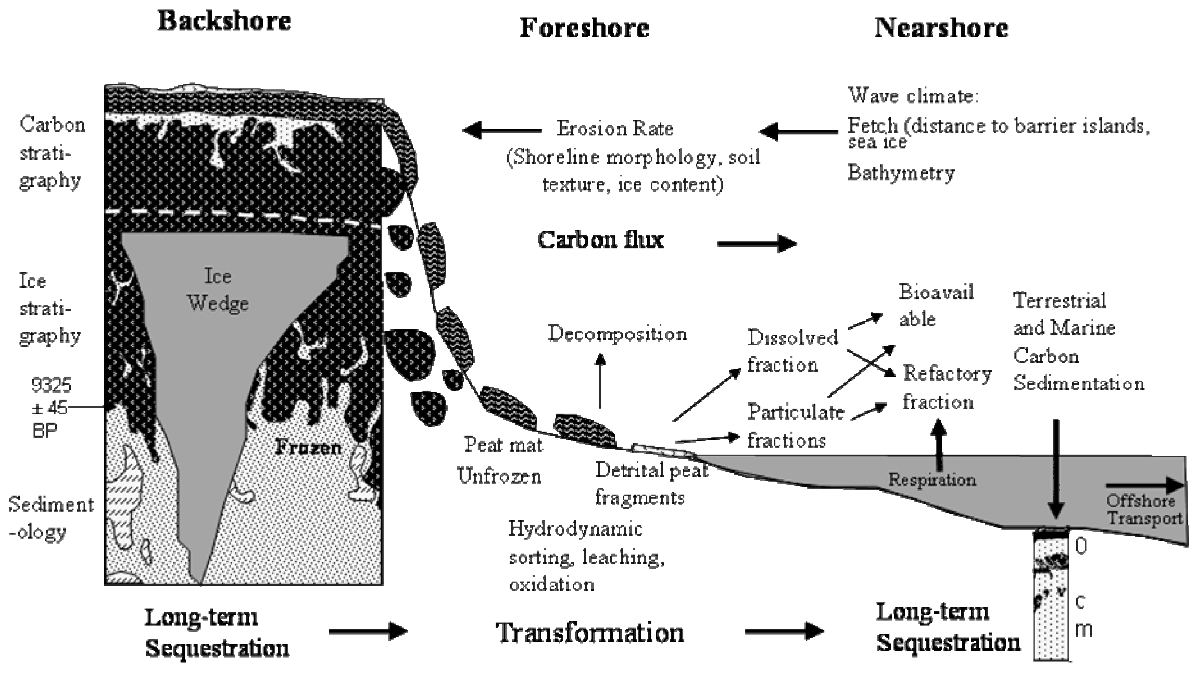

Figure 1. Schematic diagram illustrating the patterns and processes affecting the flux and transformation of soil organic carbon rapidly released from long-term sequestration in permafrost.

To investigate these issues, we are initiating a new research project funded by NSF that has eight components (Figure 2) designed to:

(1) characterize the nature (chemistry and age), abundance, and distribution of soil OC;

(2) characterize the nature, abundance, and distribution ground ice in relation to geomorphic environments;

(3) characterize erosion rates, age, and accumulation rates of varying geomorphic environments along the coast;

(4) determine the biogeochemical transformation and bioavailability of OC associated with various dissolved and particulate forms across the land/sea interface through laboratory experimentation and field study;

(5) estimate the total OC flux along the entire Beaufort Sea coast;

(6) integrate our results at the pan-arctic scale through international collaboration to better estimate total sediment and carbon fluxes into the Arctic Ocean;

(7) develop a shoreline sensitivity map based on a model of empirical erosion relationships.

(8) develop a village-based monitoring network to help in data collection and education of local residents.

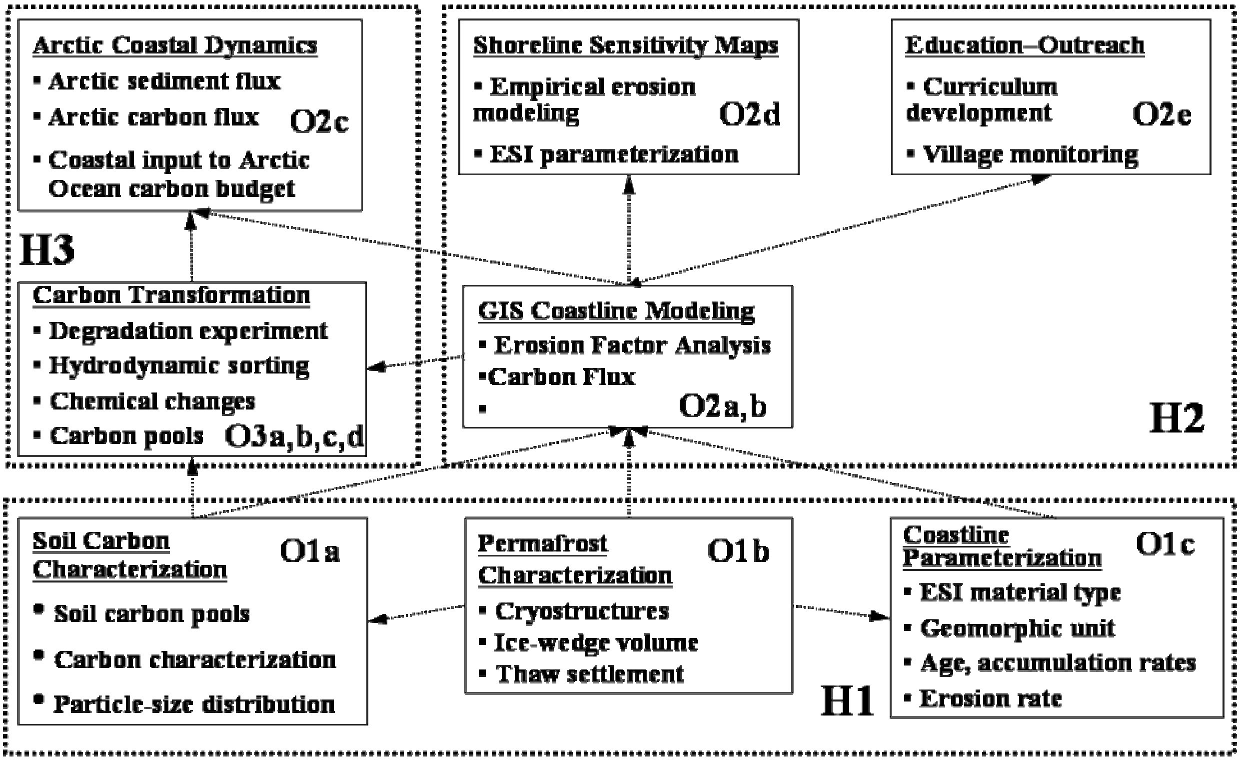

Figure 2. Framework for assessing carbon flux and fate associated with coastal erosion along the Beaufort Sea Coast.

The study is designed to assess the flux and transformation of terrestrial OC eroded across the northern Alaska coast at a range of scales from micro-scale laboratory experiments to circum-arctic analysis (Table 1). At the micro-scale, controlled laboratory experiments will be conducted to determine degradation rates and effects of leaching and hydrodynamic sorting of organic size fractions using soil samples collected from three coastal sites. At the site scale, field sampling will include both extensive sampling to evaluate the variability of OC flux across the entire region, and intensive sampling at six key sites for assessing OC transformation across the narrow, transient foreshore zone (Figure 3). Extensive sampling at 50 random points along the 2000 km Alaskan Beaufort coast will collect data on carbon density, dry density, ice contents, and erosion rates to be used to determine fluxes at each site. This will allow a precise estimate of the total OC flux along the coast with explicit confidence limits. Intensive sampling for carbon transformation and flux will be done at three primary key sites, Elson Lagoon (protected coastal type with very ice-rich silts), Nuiqsut (delta with accreting ice-poor silty/sand deposits), and Prudhoe Bay (protected coast with moderately ice-rich pebbly sand deposits with protective beaches), which are representative of major soil and coastal types. At each site samples will be taken from four zones: (1) backshore zone with carbon sequestered in permafrost, (2) foreshore zone with wave energy, (3) proximal nearshore zone at 10 m, and a (4) distal nearshore zone at 500 m. Three cores will be taken within each zone, and 5 samples will be taken from varying depths within each core. TOC and stable isotopes will be measured in all samples from all cores for evaluating changes in carbon pools. A subset of five samples from one core in each zone will be analyzed for organic chemistry and isotopic composition of size-fractionated samples. Results will be used to evaluate the proportions of marine and terrestrial OC relative to distance and time since erosion. The other three secondary key sites, located at Lonely, Barter Island, and Beaufort Lagoon will be included to broaden the sampling of coastal types. Monitoring at the Barrow, Nuiqsut, and Barter Island intensive sites will involve local students and residents, to facilitate education and communication of results to the communities vulnerable to coastal changes.

Table 1. Spatial and temporal scales of sampling and modeling efforts for assess the flux and transformation of organic matter.

Component	Length	Scale	Frequency	Measurements and Observations
3 Primary Key Sites	0.5 km transects	1:500	Annually	Topographic/bathymetric surveys, erosion rates, crest gauges for storm surge heights, time lapse photography, sediment sampling (only once) for carbon transformation and fate.
3 Secondary Sites			Years 2 and 3	Same as above without intensive carbon fate sampling.
Observational sites	50 Points	1:500	Once; Years 1 and 2	50 random points along entire 2000 km coast. Sample soil, permafrost, and coastal erosion modeling variables.
Landscape mapping	10 km segments	1:25,000	Three periods	Map coastal changes at all key sites using photos from 1949-55, 1979-82, and 2001-05. Determine erosion rates
Regional mapping	Entire 2000 km coastline	1,250,000	Once, Year 3	Classify and parameterize shoreline characteristics for sample stratification and modeling

At the landscape scale, coastal changes will be mapped at all key sites using aerial photography or satellite imagery from 1949-55, 1979-82, and 2001. At the regional scale, empirical models of erosion rates and carbon flux developed from the 50 sites, along with the coastal parameterization of the Environmental Sensitivity Index segments, will be used to model the spatial variability of carbon flux along the entire coast and to predict changes that would occur as fetch lengths increase from the predicted decrease of summer sea ice in the Arctic Ocean.

In summary, this project is designed to provide information critical to understanding the biogeochemical consequences of coastal changes in northern Alaska and can be used to estimate pan-arctic coastal OC and sediment inputs through international collaboration. Results can be used to increase our predictive capabilities in related models that address the carbon cycle and the arctic climate system. Of particular relevance will be the characterization of the bioavailability of long-sequestered OC across a range of soil environments, quantification of ground ice that is essential to assessing terrain stability in northern Alaska under a warming climate; and an improved understanding of the role of coastal erosion to the input of carbon and nutrients to the Arctic Ocean.

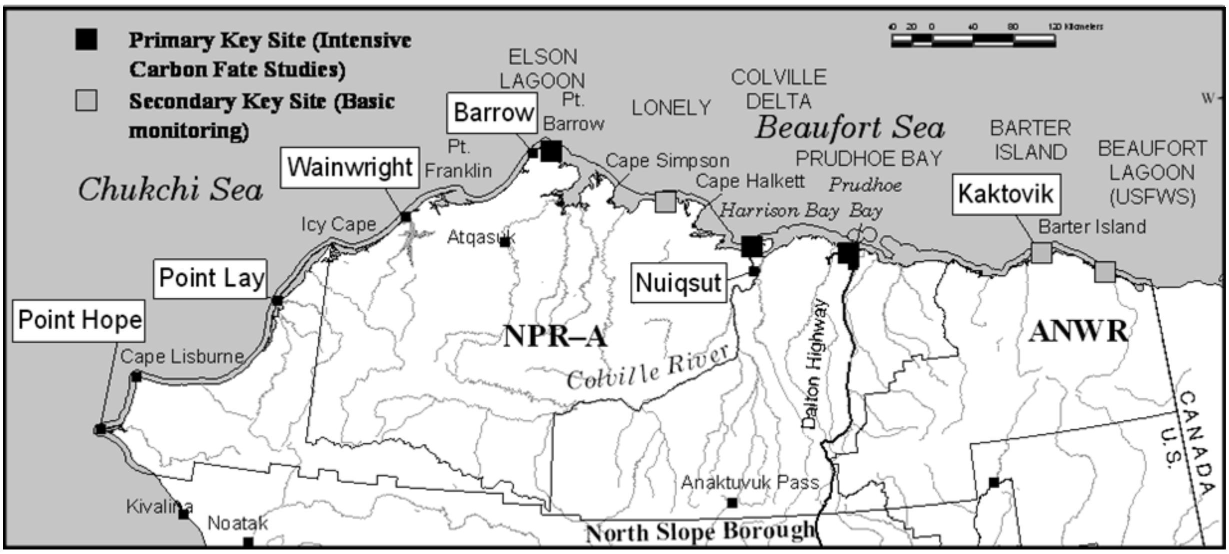

Figure 3. Location of primary and secondary monitoring sites.

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CRYOGENIC STRUCTURE AND ICE CONTENT OF COASTAL SEDIMENTS, WESTERN SIBERIA

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Ice content is one of the major factors affecting thermal erosion. Investigations of cryogenic structure and ice content of coastal sediments were carried out along the Kara Sea coast near Marre-Sale (Western Yamal) and in the southern part of the Enisey Gulf. In the study area perennially frozen Quaternary sediments composed of sands, sandy-loams, loams and clays have various origins – marine, littoral, alluvial, lacustrine, etc. The type of cryogenic structure depends mostly on the composition of the sediments and their cryogenic origin. Syngenetically frozen sandy-loams and loams are characterized by the prevalence of a microshlieren closely layered cryostructure; ataxitic and layered-reticulate cryostructures are also abundant. The main cryostructure in epigenetically frozen sands is massive, whereas in clays it is lens-layered and reticulate. The volumetric ice content of Quaternary sediments varies from 30% to 80%.

In coastal cliffs sections 20-30 m high in the Marre-Sale area, two main strata can be recognised. The upper stratum consists mostly of ice-rich syngenetically frozen sands, sandy-loams and loams with ice wedges. In some places the top part had thawed and then refrozen epigenetically; such sediments include ice-wedge casts. The lower stratum of folded marine and littoral deposits is formed by saline epigenetically frozen loams and clays with layers of sands and sandy-loams. As usual these sediments are ice-poor, but in several sections they include tabular ground ice. Along accumulative coasts, contemporary syngenetically frozen alluvial-marine sediments were studied. They are characterized by very high ice content (gravimetric moisture content reaches 150%) and include growing ice wedges.

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RECENT COASTAL DYNAMICS AND SEA LEVEL CHANGE ON MELVILLE ISLAND, WESTERN CANADIAN HIGH ARCTIC

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During the Last Glacial Maximum, Melville Island occupied the boundaries of the former Laurentide Ice Sheet to the south and the Innuitian Ice Sheet to the northeast. This glaciological setting generated complex glacio-iostatic adjustments of the earth's crust that are still active today. After more than 10 500 years of land emergence due to glacio-isostatic unloading, morphosedimentary evidence provided by field traverses and air-photo interpretation indicate that the coastline of the island is presently undergoing submergence. Recently activated coastal processes associated with submergence include beach retrogradation, drowning of coastal gullies and terrestrial vegetation, formation of lagoons, barrier reefs and islands as well as accelerated shoreline erosion. We estimate that regional submergence started on westernmost Prince Patrick Island sometime during the mid-Holocene and has progressed eastward, recently reaching eastern Melville Island. This study suggests that the current zero isobase, the threshold between submergence and emergence, is located farther east than previously reported. Submergence on Melville Island is attributed to peripheral crustal forebulge migration towards both the loading centres of the former NW Laurentide and Innuitian ice sheets. Although glacio-isostasy is considered to be the main mechanism acting on the current crustal re-equilibrium in the region, other factors such as subsidence of the Sverdrup Basin, neotectonism (manifested by recent earthquakes in the Byam Martin Channel Zone) and modern eustatic sea level rise may also be contributing to ongoing submergence. Recent climate warming may be playing a role in the intensification of shore-ice erosion, an increase in wave energy due to greater fetch during the summer, and the degradation of permafrost. These processes would have strong impacts on the fine-grained coastline of the northern sector of the island where modern submergence is apparent.

IDENTIFICATION OF STABILIZED AND REVEGETATED RETROGRESSIVE THAW SLUMPS FLOORS ON AN ICE-RICH ARCTIC COAST USING LANDSAT NEAR-INFRARED IMAGERY

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The potential of the near-infrared band of the Landsat-7 Earth observation Satellite to detect the change of vegetation between undisturbed land surface and stabilized slumpfloors was investigated on the south-west coast of Herschel Island, which is affected by strong retrogressive thaw slump activity. Using a false color composite image (Landsat-7 green, red and near-infrared bands) of the southwestern coastal zone of the island, we separated stabilized slumpfloors and non-disturbed land surfaces. We then led a statistical analysis of the spectral signatures of these two regions.

The delineation of the limit between stabilized slumpfloors and undisturbed surfaces on the color composite appeared to match adequately with the same limit drawn independently in a previous study from Ikonos panchromatic imagery.

Zones affected by stabilized slumpfloors exhibited larger radiometric values in the near-infrared band than those marked by undisturbed tundra surfaces. The occurrence of retrogressive thaw slump and the resulting disturbed ground, observed in the field to exhibit less hummocks and larger active layer depths is believed to be responsible for the observed difference.

These results acknowledge this method as a valuable tool for the remote detection of stabilized slumpfloors. Although preliminary, they demonstrate that stabilized slumpfloors undergo a perennial change of vegetation cover, even in some sections where no activity has been recorded since the last century.

SHORT-TERM EVOLUTION OF COASTAL POLYCYCLIC RETROGRESSIVE THAW SLUMPS ON HERSCHEL ISLAND, YUKON TERRITORY

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Study Area / Background

Herschel Island (Qikiqtaruk in Inuvialuktun) is located in the northern part of the Yukon Territory, Canada. The island is situated at 69°36'N and at 139°04'W and lies approximately 60 km east of the boundary between the Yukon Territory and Alaska and 3 km north of the continental coast. The island is located in the southern Beaufort Sea and is part of the Yukon Coastal Plain physiographic region (Rampton, 1982). Herschel Island covers an area of 108 square kilometres, is approximately 15 km by 8, and has a maximum elevation of 183 m asl. (De Krom, 1990).

Herschel Island is interpreted as an ice-push moraine formed during the late Pleistocene. It is located in the continuous permafrost zone. Ground ice underlies most of the island except recent coastal landforms such as sand spits and sandy-pebbly beaches, and constitutes up to 60-70% of the upper 10-12 m of permafrost (Pollard, 1990).

Massive ice is observed in coastal sections and retrogressive thaw slumps, on south, south-east and north-west facing shores. In some cases, retrogressive thaw slumps extend as much as 500 m inland and 1000 m laterally (Lantuit and Pollard, 2004). Retrogressive thaw slumps on Herschel Island are among the largest encountered in the Canadian Arctic. Slump dynamics and particularly headwall retreat rates have been documented in various locations in the Arctic at decadal (Burn and Lewkowicz, 1989; Lantuit and Pollard, 2004) or annual scales (De Krom, 1990). The only previous attempt to document annual headwall retreat rates on Herschel Island was de Krom’s study in 1990. In her study, de Krom used an engineer's level to survey the headwall position of two retrogressive thaw slumps on several occasions during 1987 and 1988. A total of 48 (24 for each slump) retreat stakes were also surveyed to facilitate measurements in 1989 and 1991. Since this dataset represents one of the few annual measurements available in the literature, it constitutes an ideal site for follow-up calculations of retreat rates.

Objectives

The objectives of this study were to (1) use a combination of Kinematic Differential Global Positioning System (KDGPS) surveys and satellite imagery to measure annual retrogressive thaw slumps retreat rates for the period 2000-2004 and (2) to compare it with earlier surveys by de Krom (1990) to achieve estimates of retreat since 1988.

Methods

Ten large retrogressive thaw slumps along the coast of Thetis Bay (Figure 1) were investigated during August 2004 and surveyed using KDGPS to map their locations as precisely as possible. Our surveys had an estimated precision of ± 2 cm. Measurements were collected every 20 meters along the headwall of each slump. Each measurement was assigned a direction corresponding to a line perpendicular to the headwall. We compiled annual headwall retreat rates for the period 2000-2004 using the survey data and two Ikonos high resolution panchromatic images from 2000 and 2001 which were orthorectified using a digital elevation model of the island (Lantuit and Pollard, 2005). The two Ikonos images were collected at the end of the thaw season (late August-early September) while the KDGPS points were collected at the beginning of August, which is roughly mid-way through the thaw season. As a result, the 2004 season was considered a "half-season" in the calculations.

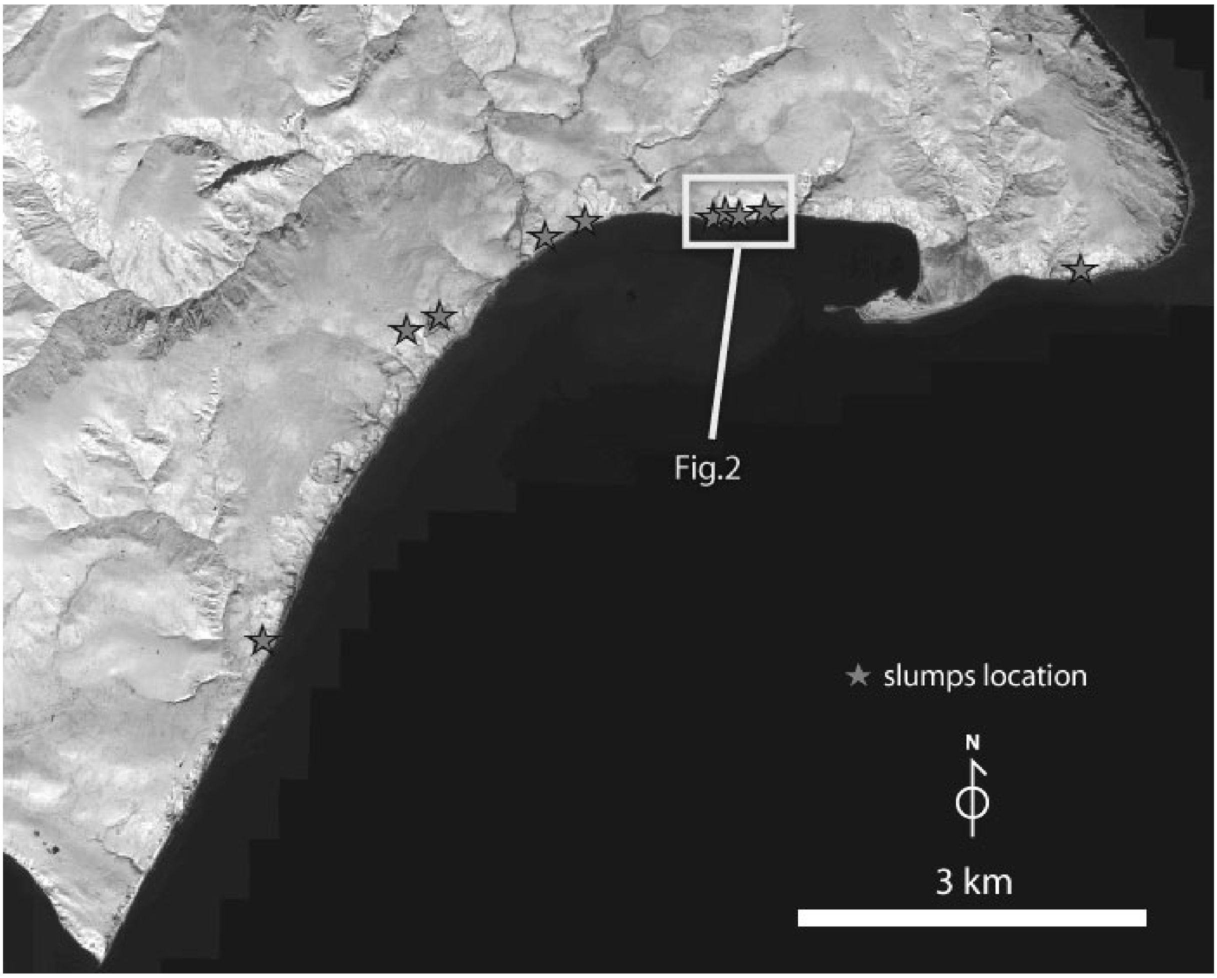

Figure 1. Location map.

Results

Average headwall retreat rates were 7.6 m/yr for the 2000-2001 interval and 9.6 m/yr for the 2001-2004 period. Headwall retreat rates ranged from 1.0 to 18.0 m/yr and showed strong variability from one year to the next. Figure 2 shows several of the retrogressive thaw slumps on the 2001 Ikonos image along with the survey points.

Simple retrogressive thaw slumps (i.e. one lobe) showed the least variability. Mean headwall retreat rates ranged between 3.0 and 18.0 m/yr. Simple retrogressive thaw slumps had little temporal variability as they showed an average rate of 10.7 m/yr for the 2000-2001 period and 11.1 m/yr for the 2001-2004 period. Variations for single point measurements on these slumps between the two periods did not exceed 40%.

Complex retrogressive thaw slumps (i.e. multi-lobes) such as the one shown on the right in Figure 2 had headwall retreat rates which ranged between 1.0 and 14.8 m/yr depending on the position along the headwall. Measurements made on the lateral headwalls exhibited the smaller retreat rates. The variability in retreat rates for these types of slumps was greater than for the simple type, ranging from 50 to 1000%, depending on the location of the measurement along the headwall. The greater variations generally corresponded to the coalescence of two simple retrogressive thaw slumps, resulting in the rapid degradation of the lateral headwalls between slumps (Figure 2).

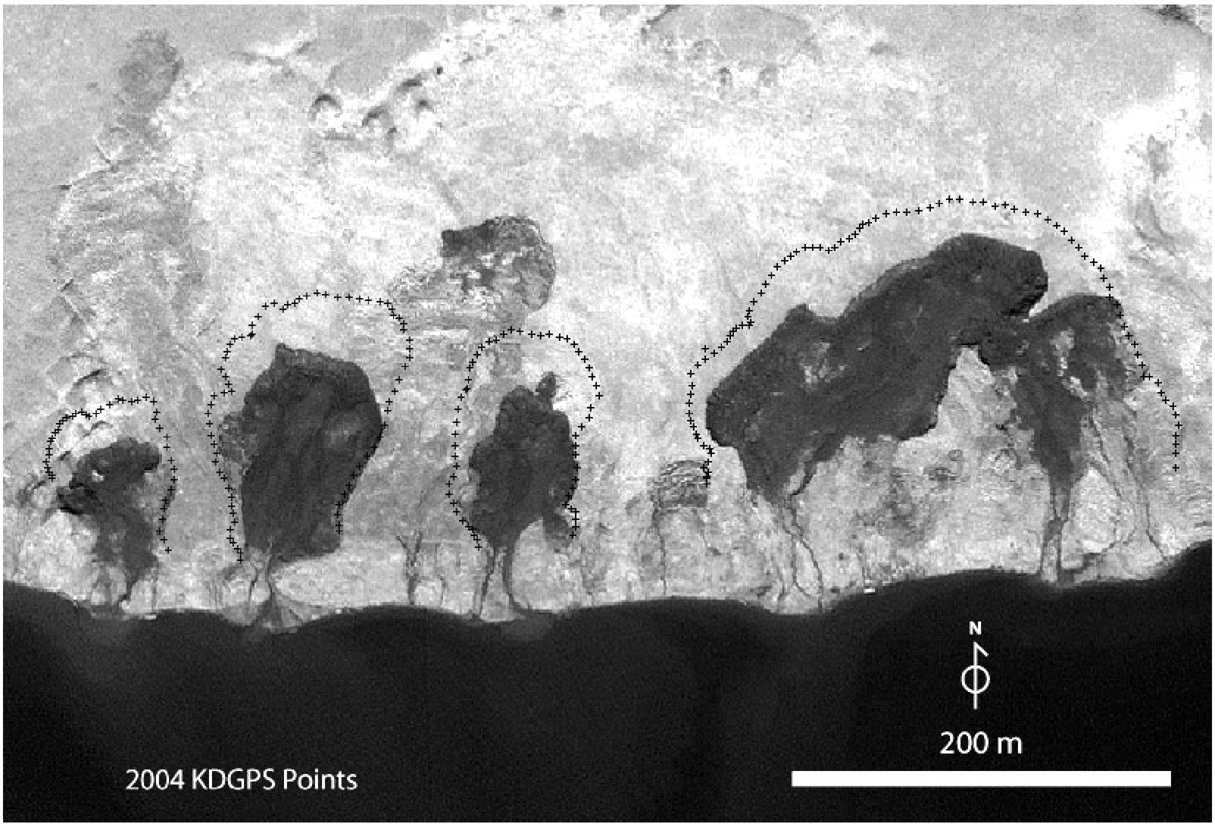

Figure 2: Investigated retrogressive thaw slumps. Survey points are overlaid on the 2001 Ikonos image

Conclusions and further research

The results show that there can be considerable variability in the intensity of headwall retreat of retrogressive thaw slumps depending on (1) the morphology of the slump and (2) the proximity of converging retrogressive thaw slumps. The influence of the orientation of slump headwalls was found to be minimal in the context of Herschel Island where mean headwall retreat rates for headwalls with southern exposures are similar to those with northern exposures. Our calculations are consistent with previous ones by de Krom (1990) who found a mean annual headwall retreat rate of 9.3 m/yr for the summer of 1988 in a slump located within our study area (but now stabilized). Measurements by de Krom (1990) over a six-week period for retrogressive thaw slumps on Herschel Island but outside our study area are also in the same range as our calculations.

Although tentative, our results suggest that mean annual headwall retreat rates have not increased noticeably since 1988. On the other hand, Lantuit and Pollard (2004) found that the number of retrogressive thaw slumps has largely increased on Herschel Island between 1970 and 2000, indicating that although the intensity of the slumping process may not necessarily increase, the frequency of it may.

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PECULIARITIES OF COASTAL EVOLUTION IN THE WESTERN AND EASTERN RUSSIAN ARCTIC

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Future changes in coastal dynamics both in the western and eastern parts of the Russian Arctic will be determined by global climate warming. Mean air temperature is expected to increase over the world by 1-2^{0}C after 100 years, however in the Arctic this increase could reach 4-8^{0}C. Positive temperature anomalies of up to 2^{0}C relatively to the period 1966-1995 are already registered at present time in high-latitude regions.

One of the serious consequences of changes in climate is the rise of the mean sea level. This leads to the shift of the wave erosion base to higher horizons and entails the general displacement of the shoreline toward the land.

Other important features of changes in coastal dynamics over the XXI century will be the decrease in the sea-ice cover and the increase in the duration of the ice-free season in the Arctic Seas. As a result the wind fetches and the depths to which the wind waves are developed will increase. This in turn stimulates the growth of both the dimensions of stormy waves and the total duration of wave impact on the coasts over the year.

Finally, global warming will trigger the intense thawing of permafrost, which consolidates the fine friable deposits forming the abrasion cliffs. Due to the increase in the activity of thermal abrasion and erosion the flux of solid material into the coastal zone will also noticeably increase.

Mathematical modeling of the evolution of Arctic coasts over the period of the nearest century (Leont'yev, 2003, 2004) shows that global changes can lead to distinct (sometimes opposite) consequences for the coasts situated in different Arctic regions. On the whole one can distinguish between the response of the morphodynamic systems located in the Western and Eastern parts of Russian Arctic.

Western region. The edge of the drifting ice in the Barents Sea is observed during the last decades at a relatively large distance from the continent in summer. It presumably does not form an obstacle in the way of generation of wind waves affecting the coasts. Hence, any visible increase in wave parameters is not expected here in the future. This means that the morphodynamic evolution can hardly change significantly in qualitative sense. In particular, if the abrasion cliff is high enough as compared with expected sea level rise (about 0.5 m to the end of century, Church et al., 2001), the principal features of the coastal profile geometry existing at present time will be kept.

Coastal recession in the Barents Sea can slightly accelerate mainly due to the growth of the total duration of storm events over the year and (to a smaller extent) the rise of sea level. Changes will be most pronounced on low coasts (where the washover during the storm may produce breaches of coastal barriers) and on coasts exposed to technological impact. In particular, in the Varandey site (Pechora Sea) the rate of coastal recession (2.5 m/year at present) is expected to exceed 3 m/year by the end of this century, what is partly due to aeolian deflation caused by numerous destructions of the vegetative cover.

The total annual flux of terrigenic material into the Barents Sea is estimated at present as 50 million tons, but according to Pavlidis et al. (2005) it can achieve 70-75 million tons at the end of XXI century (the main reason is the increasing thawing of glaciers covering the islands of Novaya Zemlya).

In the Kara Sea a warming-up of the water is expected due to the increasing inflow of Atlantic water masses into the Kara Basin. The point is that the strait between Novaya Zemlya and

Franz Josef Land will be free of ice during a longer period. At present this period is about 2.5-3 months, but at the end of the XXI century it can exceed 4 months. Warming of water will reinforce the thermal abrasion of coasts in western Yamal. Here the rate of recession is on average 1.5-2.0 m/year at present. However in the second half of the XXI century the frozen cliffs with an ice content of more than 30 % will retreat with rates of 3-4 m/year (Pavlidis et al., 2005).

At the same time the dynamics of sedimentary coasts in Baydaratskaya Bay will presumably not change significantly, and recession rates will remain at 0.5-1.5 m/year. This is due to the orientation of the coasts relative to the directions of dominant winds and storms. The coasts inside the bay are mainly influenced not by onshore but by oblique winds blowing along the NW-SE axis of the bay. Here losses of sediments due to offshore transport down the slope are not as large as, for instance, in Varandey (Leont'yev, 2003).

Eastern region. A remarkable feature of the Laptev and East Siberian Seas is the exceptional shallowness of the continental shelf. This condition is favorable for the development of storm surges, which quite often attain the height of 2 m. 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 a very important mechanism of seaward sediment transport contributing to coastal erosion.

Another principal feature of the coasts in the region of interest is the wide spread occurrence of thermal-abrasion cliffs composed of fine sediments with rather high ice-content. It might be expected that climate warming accompanied by thawing of ice could lead to very high rates of coastal recession. However, it should be taken into consideration that the thermal component of thermal abrasion only provides the material to be carried away by the 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 impact, the volume of lost material would be controlled mostly by the potential of storm activity, as in the case of pure abrasion.

At present time very severe ice conditions visibly restrict the wave activity in the Laptev and East Siberian Seas. During the summer season the width of the ice-free water band at the coasts does not exceed 70 km in average. At the end of the current century the wind fetch is assumed to increase up to 200 km. As estimations indicate, this would entail an increase in deep-water wave heights by 1.5-1.7 times (Leont'yev, 2004). However, waves approaching the coast decay over the shallow and gentle bed slope and become more uniform in height. Hence despite of appreciable growth of the open-sea storm parameters the wave heights closer to the shore would not change markedly. So the hydrodynamic component of thermal-abrasion would not be enhanced very remarkably.

These peculiarities determine a non-linear dependence between the thermal-abrasion potential and the actual coastal recession, which will increase more slowly. Nevertheless the modeling performed for series of typical coasts in the Laptev and East Siberian Seas shows that the recession rates may increase by 1.4-1.5 times at the end of the XXI century (Leont'yev, 2004). The models also leads to the conclusion that the rate of thermal abrasion is in inverse proportionality to the square root of the effective cliff height (which might be after thawing of ice).

According to Pavlidis et al. (2005) the total sediment flux into the Laptev Sea due to thermal abrasion can be estimated as 18 million tons per year at the end of the century. Presumably, a sediment mass of the same order of magnitude will be delivered into the East Siberian Sea.

At cape Billings and in eastern regions located in the Chukchi Sea lagoon-type coasts are widespread. A common feature of those lagoon systems is a coastal bar separating the lagoon from the sea which is composed of coarse sand, gravel or pebble. At present time ice conditions limit the wave impact on the coast considerably. The continental shelf at these coasts is not as shallow as in the eastern regions considered earlier, and so a future widening of the ice-free water area would lead to a noticeable increase in wave heights both in the open sea and in near-shore zone.

The model shows, that the coastal evolution in this case would be accompanied by a significant reshaping of the coastal profile. This process would lead to the development of berm, which could form a natural structure protecting the coast from further erosion (Leont'yev, 2004). A similar behavior has been observed in certain circumstances as a result of sea-level rise (Cowell et al., 1995, Forbes et al., 1995). In the present case, however the sea-level changes are of secondary importance and the appearance of berm is mainly due to the increase in storm parameters.

Thus it may be concluded that changes in the coastal evolution caused by global environmental changes can be expected to be more various and dramatic in the Eastern Arctic. Coastal dynamics in the Western Arctic will show a more conservative behavior in the future.

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ERODIBILITY AND SEDIMENT STRENGTH IN KUGMALLIT BAY, SOUTHERN BEAUFORT SEA

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In shallow water areas of the Beaufort Sea (<10m) wave oscillations combine with strong coastal currents during storms to cause high bottom shear stress and high rates of resuspension. This storm resuspension is thought to be a major, if not the most important, mode of sediment transport during the openwater season. This paper gives preliminary results of investigations aimed at determining bed strength in Kugmallit Bay. Sediment strength has been measured along a nearshore to offshore transect in Kugmallit Bay by two different methods. The first method uses an insitu underwater annular flume which gives details of the response of the bed to increasing shear velocity, and provides the critical threshold for erosion. The second method uses a laboratory shear vane to give strengths at frequent vertical intervals down pushcores. The measured erosion parameters are compared to available wind and wave data, alongside in situ measurements of suspended concentration. The results of the shearvane analyses show overall decreasing strength from the mouth of the East Channel to more seaward stations. At all stations there is a weak layer between the surface and deeper sediment, rather than a more typical direct relationship between depth and strength. This provides evidence of the deposition of graded silt and sand beds as previously described in the literature, and/or may delineate a mobile upper surface sediment from a more stable lower sediment. Sediment property tests are currently being undertaken to help explain the variation in erodibility and bed strength. These data will help investigators to determine the conditions required for resuspension to occur, and will provide important inputs to models of sediment, carbon and contaminant transport.

GEOMORPHOLOGICAL SEABED MAPPING BASED ON GIS-TECHNOLOGY

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The Arctic coastal evolution is the result of both exogenic and endogenic processes. In the Arctic region this evolution differs from that in other areas of the world's oceans as a result of interactions between modern wave and ice factors, and the influences of glaciations and large-scale sea level changes in the past. Natural relief-forming processes are important links in the system of "land-ocean interactions" and must be taken into consideration in research of any scale. Among exogenic and endogenic processes it is possible to identify active processes, directly participating in the formation of coastal relief, and passive processes, which predetermine the display of active ones and direct the course for their development. The approach of the present paper is to simultaneously consider all natural factors that took part in relief formation and its evolution. Using GIS technology we suggest to create four layers: bathymetry; structural basement; paleorelief and relief caused by the action of modern processes. As a result of their overlapping a geomorphologic map will be received. In a GIS system various forms of display can be used. For example, the structural basis could be shown in color, the relic forms could be indicated by various lines and the modern relief could be displayed by shading. Using this and other combinations, it becomes possible to create other maps and schemes in GIS format. The poster will include a geomorphologic map of the Pechora Sea in GIS format as an example.

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BATHYMETRIC SEABED MAPPING BASED ON GIS-TECHNOLOGY

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Morphology appears to be one of the most significant relief characteristics, but it is controlled by a set of interactive processes acting over long periods. Initial structures form the basement surface that has been reworked, or is now being reworked, by a complex of environmental processes. Relief morphology does not appear steady and changes with time. Analogous changes took place in the past, occur in the present and will continue in the future. We have developed our understanding that the origin of relief is the main factor that created the existing coastal morphology. Our approach, in which a multitude of interacting factors are simultaneously analyzed and determined, could be called "morphogenetic". Bathymetric seabed mapping is the main component of the developed morphogenetic approach and forms the base of geomorphologic mapping as well.

Today bathymetric digital mapping is developed rather intensively, however, mechanical interpolation of depths is still used during processing, available geophysical, geological, morphological and other data are not involved and complex analyses are not carried out either. Electronic maps usually have a base scale of 1:1 000 000, which does not reflect the complete variety of the seabed relief. At the same time, the definition of relief origin already at a preliminary stage of processing has a basic value. Our technique of bathymetric mapping includes (1) joint analysis of structural and exogenic peculiarities aimed at the determination of relief origin (2) manual map processing on the base scale of 1:200 000 (3) digital transference. In this poster bathymetric maps of the Pechora Sea, the Laptev Sea (eastern sector) and the offshore bathymetry of Yamal Peninsular will be presented.

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THE ROLE OF WAVE ENERGY IN THE DYNAMICS OF ARCTIC COASTS FORMED BY DEPOSITS WITH LOW ICE CONTENT

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It is a widely held opinion that sea coasts consisting of frozen deposits develop by thermoerosion (thermoabrasion). However, observations of coastal dynamics in the different regions of the Russian Arctic show that this is not always so. Coastal bluffs consisting of frozen deposits with low ice content are not subject to thaw slumping, permafrost creep, gully thermoerosion and thermokarst. The dynamics of such coasts are largely characterized by features that are typical for coasts of unfrozen deposits.

A significant percentage of coasts in the Russian Arctic are made up of deposits with low ice content, particularly along the Barents (Pechora) sea. These consist primarily of large accumulative coastal landforms generated during the Holocene, such as barriers and spits (Ogorodov et al, 2003). Large Holocene accumulative forms occupy a third of the mainland coastline along the Pechora Sea. These forms consist mainly of sands and are characterized by specific transverse profiles. The maximum elevation of barriers and some spits can be as high as 10-15 m due to dune superstructures. The low ice content of the sand deposits is favorable for the development of active aeolian processes. The well-drained dune belts of these Holocene accumulative forms composed of sand beds with low ice content are very convenient locations for settlements, oil terminals and storehouses. They are more stable from an engineering-geological point of view than the surrounding swampy tundra lowland. Thus, coastal dynamics research is of a heightened interest.

The high slope of the seaward side of the dune belts (foredunes) are favorable for the formation of shores with transverse erosional profiles. At present, some of these coasts have erosional bluffs, while others represent typical full-profile beaches. Coastal thermoerosion is insignificant for the evolution of both types of coasts. The periodicity of extreme storm surges and the total wave energy in the coastal zone during the active dynamic period are the main factors which determine the dynamics of the low ice content coasts. Based on the theory of Actualism, we can assume that in case of climate warming, the dynamics of coasts with low ice content deposits will be similar to what we currently see in warmer years or decades. Thus, to forecast the dynamics of similar coasts under conditions of climate change it is only necessary to predict changes in the regional wind-wave regime. Coastal retreat values obtained by direct stationary observations during a period with certain wind-wave parameters can be used as a baseline.

To substantiate this supposition, we performed correlation analyses of stationary coastal dynamics and hydrometeorological observations. Varandei Island (Barents Sea) made up of sandy deposits with low ice content was chosen as a key site. The Laboratory of Geoecology of the North (MSU) has carried out observations on coastal dynamics here for the last 20 years. Hydrometeorological parameters are calculated from the data provided by Varandei HMS founded in 1940. The wave energy volume at the external border of the coastal zone is calculated using data on wind direction and speed for each year between 1981 and 2002.

To determine coastal wave energy characteristics we used the method for calculating wave energy fluxes based on wind data that has been worked out in the Laboratory of Geoecology of the North (Popov, Sovershaev, 1979, 1981, 1982; Ogorodov, 2002). The method is based on the theory of wave processes and takes into account established correlations between wind speed and parameters of wind-induced waves (Rukovodstvo…, 1969).

For deep-water conditions, when the sea floor does not influence wave formation, the wave energy flux per second (for 1 m of wave front) at the outer coastal zone boundary is calculated by an equation similar to the one used in Longinov's method (1966):

$E_{0dw} = 3\times10^{-6} V_{10}^{3} x$, (1)

where V_{10} is the real wind speed measured by anemometer at a height of 10 m above sea level, *m/s*; *x* is the real or maximum distance of wave travel, *km*; the coefficient 3×10^{-6} corresponds to the value of ρ / g (ρ is density, g/m^3; *g* is acceleration due to gravity, *m/s²*), i.e. $\frac{t/m^3}{m/s^2}$, thus, E_{0dw} is expressed as $\frac{tm}{ms}$, or *t/s* as is the convention in coastal dynamics.

The same equation for the shallow sea zone appears in the following form:

$E_{0sw} = 2\times10^{-6} \left(\frac{gH}{V_{10}^{2}} \right)^{1,4} V_{10}^{5}$, (2)

where E_{0sw} has the same units as in equation (1). Equation (2) is valid in cases where two conditions are fulfilled. For shallow sea basins, i.e. for most of the arctic seas, wave energy is determined according to a kinematic index of shallowness $\frac{gH}{V_{10}^{2}}$ based on water depth, *H*, along the wind direction and wind speed, V_{10}. At $\frac{gH}{V_{10}^{2}} \leq 3$ water depth hampers the formation of wind-induced waves. The second condition is determined by the following: a wave starts to interact with the sea floor when it becomes high enough after covering a certain ideal distance way without touching the sea floor, i.e. when it has developed in a deep-sea basin where the equation (1) is valid. Hence, at the boundary between the deep-sea and shallow zones, both equations should be valid. From this it follows that the correlation between the minimum distance of wave travel at which the interaction between waves and sea floor starts and the water depth at the distance of wave racing travel is:

$\frac{x_{\min}}{H} \geq 6{,}5 \left(\frac{gH}{V_{10}^{2}} \right)^{0,4}$, (3)

where $x_{\min}$ is expressed in kilometers, and *H* is in meters.

At $\frac{gH}{V_{10}^{2}} = 3$ equation (3) becomes $\frac{g x_{\min}}{V_{10}^{2}} \geq 30$, (4)

From (4) we can get the value of the maximum distance of wave travel for deep-sea conditions equal to the value obtained by other means (Titov, 1969):

$x_{\lim} = 3 V_{10}^{2}$. (5)

This value could be neglected if other factors limiting the distance of wave travel are absent.

In order to convert from the energy flux per second to the total energy of waves from a certain direction, values of E_0 (calculated for all gradations of wind speed from each direction) are multiplied by the overall duration of winds of each gradation per month, or per ice-free period of the month expressed in seconds. The resulting values are then summarized for each rhumb.

The rhumb fluxes of wave energy – E_r represent the total energy of all gradations of waves within a certain rhumb during the dynamic period (July to October).

These calculations yielded a total value of the wave energy flux E_{fr} for the most wave-intensive rhumbs for the dynamic period. We also calculated the sum of the wave energy flux $E_{fr10(NW,N)}$ generated by north-west and north (rhumb sector) winds with a speed of 10 m per second or more. These winds form high storm surges, which is a primary cause of coastal erosion. We then conducted a correlation analysis between wave energy flux and temperature characteristics, and coastline retreat near the settlement of Varandei.

The results obtained permit us to conclude that:

1. Wave activity during the dynamic period oscillates in the Varandei area. From 1981 to 2002, the wave energy flux from the most wave-intensive rhumbs was variable. During some periods (1984-1986, 1998-2002) wave activity was reduced, while in other years (1982-1983, 1989, 1991) it increased slightly.
2. From 50 to 85 percent of the total wave energy flux is generated by north-west and north winds with a speed of 10 m per second or more. At the same time, these winds have a periodicity of only 5-15 percent. Wave development in the north-west and west rhumb sectors is at an acute angle to the coastline. It is the reason for high storm surges. In addition, high values of wave energy are determined by maximum values of wave acceleration and current depths. Wave development in the west and north-east rhumb sectors, on the contrary, is limited by shallows and natural barriers like islands.
3. For coasts made up of deposits with low ice content (Varandei area), there is a clear dependence between the wave energy at the external border of the coastal zone and the coastal retreat rate. The correlation index (R) is a very high – from 0.82 to 0.83. The coastal erosion rate observed in the Varandei area between 1981 and 2002 ranges from 0.2 to 5.5 metres per year; while the total value of wave energy flux varies from 330000 to 2750000 standard units.
4. No relationship could be determined between average temperatures during the dynamic period and wave activity. The average temperature of the dynamic period varies between +2ºC and +8ºC.
5. For coasts made up of deposits with low ice content (Varandei area) no reliable correlation could be determined between the coastal erosion rate and the average temperature of the dynamic period.
6. Under climate change, coastal dynamics for deposits with low ice content will be determined more by wind energy than by temperature regime.

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FEATURES OF STATISTICAL DISTRIBUTION OF ORGANIC CARBON IN CONTINENTAL PERMAFROST OF ARCTIC SHORES (EAST SIBERIAN SEA)

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To calculate the flux of organic carbon (OC) into the Arctic Ocean from coastal thermal erosion, the OC content of the eroding permafrost deposit has to be evaluated. Depending on the facies of the deposits, the OC concentrations in syncryogenic continental permafrost sediments vary between zero and tens %.

We have considered OC data of permafrost deposits of both ice complex and alas complex of the ACD key site Malii Chukochii Cape, East Siberian Sea (276 measurements totally). These sediments are typical for thermal-erosive shores of the East Siberian Sea. The statistical tests showed that the distribution of the OC contents has a binomial character. The form of the histogram with two maxima confirms the binomial character of the statistical distribution. The first maximum is situated at a mean concentration of 0.85 % of OC and corresponds to "mineral layers" of the continental sediments. These layers do not have morphological indictors of subaerial soil formation such as specific soil structures, horizons and profiles. The second maximum (4.05 %) is observed for lenses of peaty horizons of buried soils inside the permafrost massif. The peaty horizons of the buried soils account for about 9 % of the permafrost massif of the alas complex deposit, which is compacted and does not contain thick ice wedges.

The binomial statistical distribution of the OC concentrations confirms, that the permafrost deposit can be described as a product of both sedimentation and soil formation under cold climatic conditions (cryopedolite). An updated technique for the determination of the contents of OC in eroding permafrost deposits is suggested. It is based on the binomial non-uniformity of the statistical distribution of the OC concentrations in permafrost deposits.

COASTAL OFFSHORE OF NOVAYA ZEMLYA ISL, RELIEF AND SEDIMENTS

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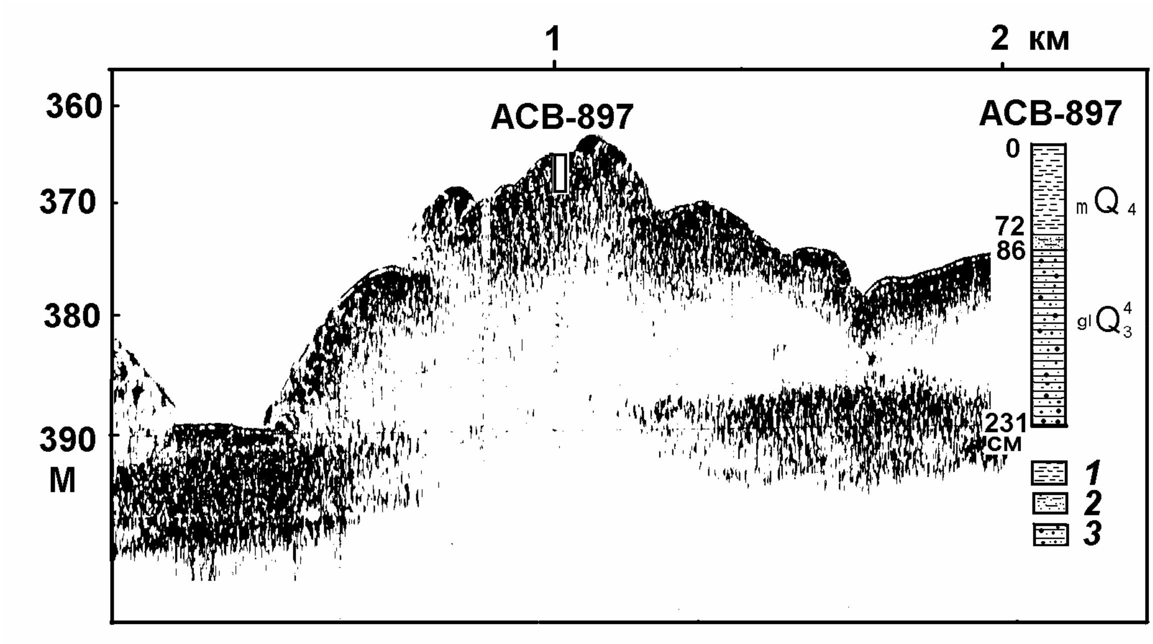
Novaya Zemlya is one of the centers of past and modern glacial covers in the Arctic region. Several marine cruises were carried out in that area with the Russian research vessels "Professor Shtokman" and "Sergey Vavilov". Seismic profiling with a Parasound system has been carried out.

The data confirm that during the Late Wurm an ice "bridge" that formed some seabed moraines existed between Novaya Zemlya and Franz Josef Land for a long time (Sedov Trench in Fig. 1A and offshore coastal zone near Borzov and Nordenshelda Bays in Fig. 1B). The height above the modern seabed surface reached 25 meters and more. North of Novaya Zemlya "red moraines" composed of clays and detrital sediments have been observed. During the Late Wurm only the northern island of Novaya Zemlya has been covered by glaciers. The data suggest that in the southern offshore regions (beginning from Mashigina Bay to the south) the ice cover degraded.

Today the total area of onshore glacial coverage is about 22 500 km^2. Ice tongues form a long ice shoreline relief and supply a large volume of suspended material. Our measurements show that the concentration of suspended material in the thawing ice varies from 0.71 to 4.29 g/l with an average value of about 2.5 g/l. In total, onshore glaciers supply around 10 million tons of suspended material per year to the offshore zone of the northern island of Novaya Zemlya. The highest concentrations of suspended material in marine waters have been observed during autumn: Nordenshelda Bay (304.2 mg/liter), Russkaya Gavan Bay (67.6), Bunge Bay (23.4) and Inostranseva Bay (12.3). The suspended material supply causes the formation of light-colored surface sediments which are also found in the shallow coastal zone.

A



B

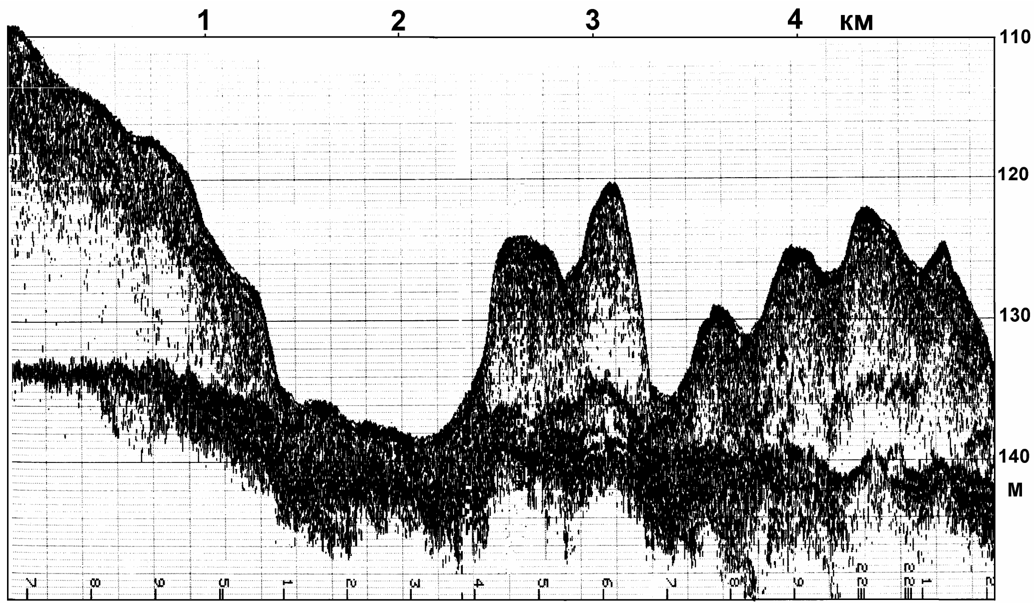


Figure 1. Moraines within Sedov trench (A) and offshore coastal zone near Borzov and Nordenshelda Bays (B). "Parasound" seismoprofiling (7-th cruise of "Sergey Vavilov").

CARBONATE SYSTEM DYNAMICS IN THE EAST-SIBERIAN REGION: COASTAL ZONE

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The Arctic Ocean's role in determining regional CO_2 balance has been largely ignored, though understanding CO_2 exchange between atmosphere, ocean and land is important, because marine and terrestrial environments are currently absorbing about half of the CO_2 emitted by fossil-fuel combustion (IPCC, 2001). Where and how land and ocean vary in their uptake of CO_2 from year to year has been the subject of much scientific research and debates.

The East Siberian Region (ESR, defined as the East-Siberian Sea and adjacent parts of the Laptev Sea and the Chukchi Sea: from the Lena Delta to the Bering Strait) has the widest and shallowest continental shelf of the World Oceans, yet it is the least explored. ESR is probably the region of the Arctic most damaged by Global Change, because the highest rates of coastal (and maybe bottom) erosion (Fig. 1) and river water discharge were found over the ESR shelf (Savelieva et al., 2000; Semiletov et al., 2000; Stein and Macdonald, 2003).

The coastal zone in this area plays a significant role in the regional budget of carbon through redistribution of terrestrial carbon in the land-shelf system, including sediment accumulation, offshore transport, and CO_2 exchange. The offshore transport of the eroded carbon (both fluvial and coastal) and its degradation have an influence on the carbonate system and the air-sea water and air-sea ice-water CO_2 exchanges, especially in the near-shore zone of the Laptev and East-Siberian seas (Semiletov, 1999ab; Pipko and Semiletov, 2001). The transport of eroded particulate carbon (PC) plays a major role in the biogeochemistry of the ESR because its mass transport is particularly important (Stein and Macdonald, 2003; Dudarev et al., 2001) and because eroded carbon is biodegradable (Semiletov, 1999a; Guo et al., 2004), while major portion of fluvial PC is refractory (Dittmar and Kattner, 2003) and settles in the low streams/delta areas, even during flooding time.

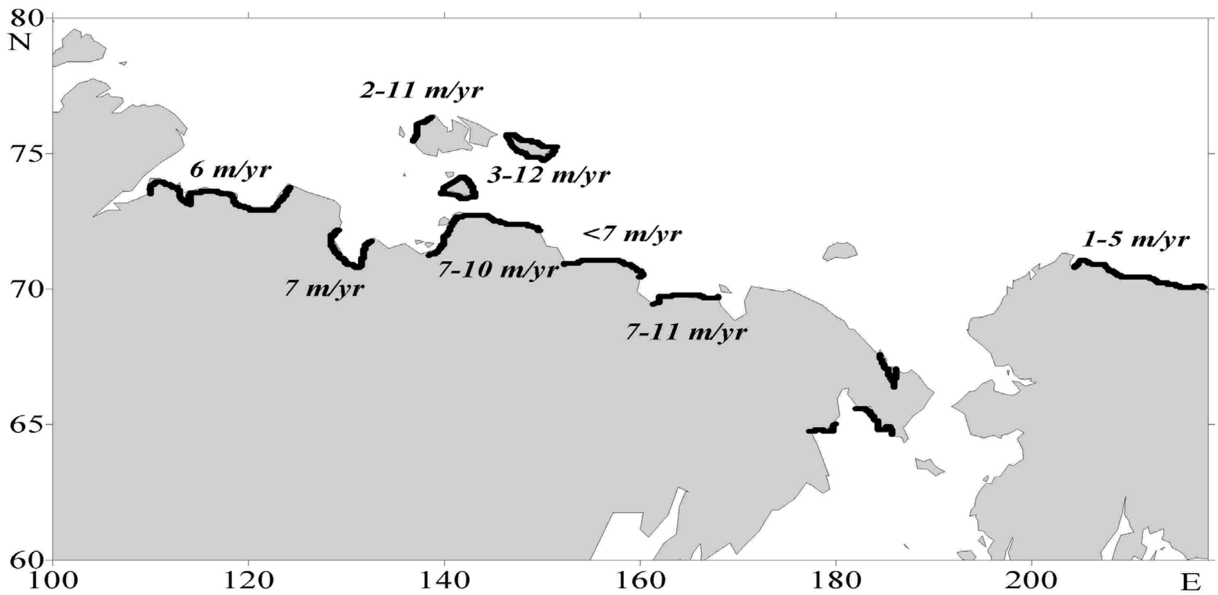

Figure 1. Coastal erosion in the study area in the Amerasian Arctic

The coastal zone of the Laptev Sea is strongly affected by river discharge and coastal erosion. The Lena discharge is about three-times larger than the combined discharges of the Kolyma and Indigirka rivers and its "thermal effect" is high enough to increase the effect of coastal thermoerosion east of the Lena mouth where its plume is directed (Semiletov et al., submitted to GRL). Data obtained during five marine and four riverine (along the Lena river) expeditions demonstrated that during summer-autumn season (late August –September) the coastal waters of the south-eastern part of Laptev Sea and Lena River waters were supersaturated by CO_2 (as compared to atmospheric CO_2). Accumulation of ground and surface water enriched by CO_2 contributed to the CO_2 super saturation of the Lena River waters. During the summer season, the Lena River pCO_2 values normally ranged between 400 mkatm and 1000 mkatm, with oxidation of the eroded carbon forming anomalies through the water column with values up to pCO_2 2,000 mkatm and more (Semiletov 1999a). In winter destruction of the organic carbon increased pCO_2 values up to 5,000 mkatm (Semiletov et al., 2004). Therefore the coastal zone of the Laptev Sea can be considered as a source of atmospheric CO_2 throughout the year.

The Chukchi Sea waters, on the contrary, are a sink for atmospheric CO_2 during the summer-fall season. Three field investigations were led in the Chukchi Sea in September 1996 (“Alpha Helix”), September 2000 (“Nikolay Kolomietsev”) and late August 2002 (“Professor Khromov”). Surface waters were observed to be consistently undersaturated relative to the atmosphere during all expeditions. Nevertheless the mean gradients of pCO_2 between air and water ($DpCO_2 = pCO_2^{sw} - pCO_2^{air}$) compiled during each of these expeditions differed from year to year (Fig. 2). Our studies thus demonstrated that the Chukchi Sea acts consistently as a sink for atmospheric CO_2 during the summer season, but that different factors explain the surface pCO_2 distribution during the early or late summer. In the fall time (end of September), a major sink of the atmospheric CO_2 was governed by cooling effect, whereas photosynthesis in the sea water dominated in summer (Pipko et al., 2002).

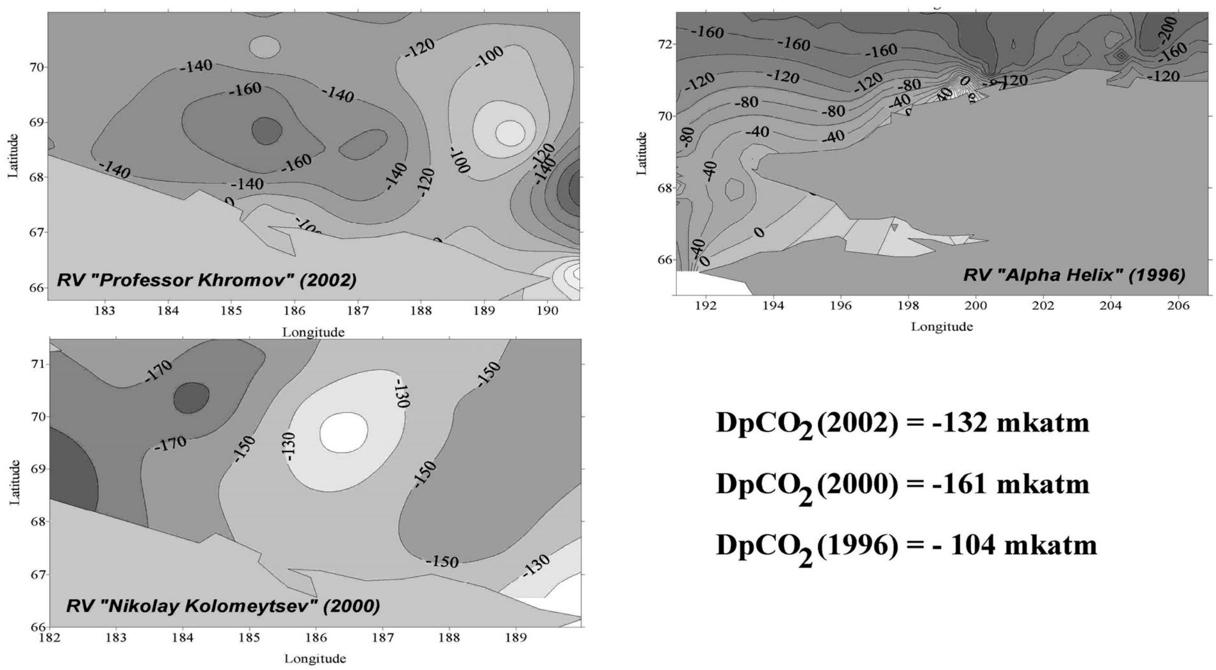

Figure 2. Distribution of $DpCO_2$ values in the Chukchi Sea surface waters (late August-September).

Mean CO_2 flux values (F_{CO2}) obtained during the 1996 and 2002 cruises differed significantly. The flux compiled for late August 2002 was 60% higher than the one of September 1996 (-16.2 mmol m^{-2} day^{-1} and -10.2 mmol m^{-2} day^{-1}, respectively). Wind speed was only slightly higher during late August 2002 than in early September 1996: 7.55 m s^{-1} and 7.05 m s^{-1}, respectively. Thus, this difference in F_{CO2} values was attributed yearly $DpCO_2$ variability.

The East Siberian Sea (ESS) is a transitional zone characterized by water exchange between the eastern Laptev Sea (shelf water diluted by river input) and the Chukchi Sea (modified Pacific Ocean water). The western ESS as well as the Eastern Laptev Sea nearshore zone are strongly affected by eroded carbon transport induced by coastal (and also bottom) erosion (Fig.1). We investigated the dynamics of the CO_2 system in the ESS waters during expeditions onboard HV "Nikolay Kolomietsev" (September 2000) and HV "Ivan Kireev" (September 2003, 2004). Results showed that during summer/fall season the ESS as a whole acted as a sink (F_{CO2}= - 2.52 mmol m^{-2} day^{-1}, September 2000) or a source (1.099 mmol m^{-2} day^{-1} and 10.071 mmol m^{-2} day^{-1} during September 2003-2004, respectively) of atmospheric CO_2 depending on hydrometeorological and biogeochemical processes taking place in the coastal zone.

Water in the eastern part of the East-Siberian Sea was characterized by high concentrations of total inorganic carbon (TCO_2) and high pH values. On the contrary, freshened waters of the ESS western part, additionally diluted by Kolyma and Indigirka inflow, had low TCO_2 and pH values. The pCO_2 values in the surface layer were observed to decrease along a West (Dm. Laptev-Sannikov Straits, 400-500 mkatm) -East (Long Strait, 250-300 mkatm) gradient. The western nearshore zone was thus considered as a source of atmospheric pCO_2 and the eastern nearshore zone as a pCO_2 sink. Figure 3 shows that the most high surface pCO_2 values are associated with the Kolyma input and coastal erosion.

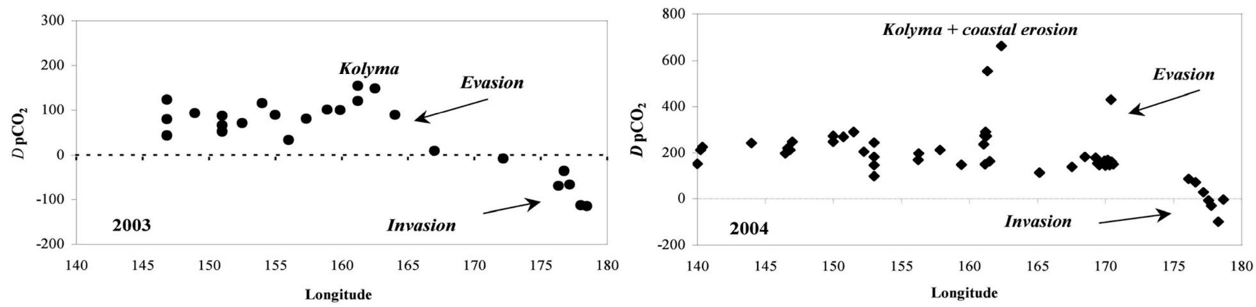

Figure 3. Distributing of pCO_2 gradients between sea and atmosphere ($DpCO_2$) in September 2003 and 2004, East-Siberian Sea.

The CO_2 flux between the atmosphere and the ocean is determined by $DpCO_2$ and by the rate of gas exchange (k), that is, a function mainly of wind speed (Wanninkhof and McGillis, 1999). Because of relatively low wind speeds during much of the 2003 expedition (mean value ~4 m s^{-1}), a low positive average flux of 1.099 mmol CO_2 m^{-2} day^{-1} with a maximum value of 4.219 mmol $d^{-1}m^{-2}$ (evasion) and a minimum value of -1.924 mmol m^{-2} day^{-1} (invasion) were recorded. Changes in the CO_2 flux direction were observed at the hydrological frontal zone (FZ) near 170°E (Fig. 3). The hydrological FZ position met the position of sediment geochemical FZ between the "local shelf waters" and the transformed Pacific waters which was identified using distributions of stable C, N isotopes in the surface sediment organic matter (Semiletov et al., submitted to GRL). During the 2004 expedition, we obtained similar distributions of $DpCO_2$ values – the western part of the ESS being a source of CO_2 and eastern part a sink (Fig. 3) – though the area of F_{CO2} direction change was shifted to the east (roughly near 178°E) together with the hydrological FZ. This shift was due to significant eastward movements in the coastal FW transport induced by changing atmospheric forcing and increase of river discharge. The mean value of F_{CO2} in ESS increased in September 2004 and reached 10.071 mmol CO_2 $m^{-2}day^{-1}$. This peak was attributed to an increasing pCO_2 gradient in the sea-atmosphere system (Fig. 3) and higher wind speeds (mean value 6 m s^{-1}).

Conclusions

The freshened waters of the southeastern part of the Laptev Sea and the western part of the East-Siberian Sea, which are strongly influenced by river discharge and coastal erosion, act as a source of atmospheric CO_2, whereas the Pacific-derived waters of the Chukchi Sea and eastern part of the ESS are a CO_2 sink. The interaction between the Pacific-derived waters and the diluted shelf waters is driven by the atmospheric circulation and river discharges. Our measurements demonstrate that the coastal zone of the Arctic marginal Seas plays a significant role in the regional carbon budget. Emission of atmospheric CO_2 from the coastal zone may increase if global warming induces enhanced permafrost degradation. As a result, the “climate warming - permafrost degradation - carbon dioxide release” feedback may be strengthened.

Acknowledgements

This study was supported by the Headquarters of the Far Eastern Branch of Russian Academy of Sciences, RAS (through the RAS Program 13, Direction 7: “Environmental Changes in the East-Siberian region under climate effects and catastrophic processes”), Russian Foundation for Basic Research (02-05-65258, 04-05-64818), Russian Federal Programs “World Ocean” and “Integration”(P0017), USA National Science Foundation (OPP-0230455, OPP-0342837) and grants of the International Arctic Research Center (small East-Siberian Sea’s projects)/University of Alaska Fairbanks.

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ARCTIC COASTAL DYNAMICS OF EURASIA – RESULTS OF TWO ACD-RELATED INTAS PROJECTS

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Under the framework of the Arctic Coastal Dynamics (ACD) program two projects of the International Association for the Promotion of Co-operation with Scientists from the New Independent States of the Former Soviet Union (INTAS) focused on ACD related topics.

The objectives of the first project **“Arctic coastal dynamics of Eurasia: classification, modern state and prediction of its development based on GIS technology”** (2002-2004) had been to develop a coastal classification and to generate GIS based map products for the coastal zone of the Eurasian Arctic. The Russian part of the circum-Arctic ACD classification and segmentation has been completed within this project.

The overall objective of the second project **“Arctic coasts of Eurasia: dynamics, sediment budget and carbon flux in connection with permafrost degradation”** (2002-2005) is to quantify the material flux through coastal erosion in order to improve our understanding of the Arctic sediment and organic carbon budget.

This presentation summarizes the main results of the two projects and provides an overview of more specific results which are shown in a series of posters.

PERMAFROST DISTRIBUTION OFFSHORE OF WEST YAMAL

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The results of seismic studies in the near-shore, shallow waters of the south-western Kara Sea – at the Shpindler, Kharsavey and Mare-Sale sites - showed the presence of a seismic interface which can be interpreted as a submarine permafrost table. The proposed permafrost exhibits a continuous distribution and a strongly dissected top surface overlain by unfrozen sediments. The permafrost table is located at a depth of 4-6 m and 5-10 m below the sea floor at the Shpindler and Mare-Sale sites, respectively. Three dimensional modeling of the permafrost table suggests the presence of relict buried thermodenudational depressions (up to 2 km across) at a minimum sea depth of 40-45 m at the Shpindler and Mare-Sale sites. The depressions may be considered as paragenetic to thermocirques found in cliffs at the Shpindler site. At the Kharasavey site, the permafrost table has an elongated depression parallel to the modern shoreline. The maximum depression depth is 20 m below the seafloor. At present, the relict thermocirques (Shpindler and Mare-Sale) and the elongated depression (Kharasavey) are completely filled in with sediment and are not evident in modern bottom topography.

THE MAIN RESULTS OF AN ASSESSMENT OF HUMAN IMPACT ON ARCTIC THERMAL-ABRASION COASTS IN THE PROCESS OF INDUSTRIAL EXPANSION

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Within the frame of the INTAS project "Arctic coastal dynamics of Eurasia: classification, modern state and prediction of its development based on GIS technology" an industrial impact assessment of Arctic coasts was carried out. The main tasks of this project involved developing a classification of coastal types and preparing a series of different scale maps of engineering geocryological zones. The scales of the engineering geocryological zone maps varied from 1:8000000 to 1:200000.

The engineering geocryological zoning was carried out in matrix form. This allowed different coast types to be connected to the main types of materials (rocks and sediments) found along the coast. Based on this methodological approach, 26 engineering-geological areas of the Arctic coasts of Russian Eurasia were parcelled and a map of engineering geocryological zones (1:8000000) was compiled.

The next step of the investigation was the engineering geocryological zoning and mapping of the European portion of the Russian Arctic coast (Barents Sea coast) (1:1000000) and an engineering geocryological zoning and mapping of the Varandey Peninsula key site (1:200 000).

Based on the series of maps of the engineering geocryological zones, additional maps illustrating the intensity of destructive coastal processes and maps presenting an assessment of industrial impact on Arctic coasts were compiled. These maps were prepared for each level of engineering geocryological zoning.

First level maps (1:8000000 scale):

- Engineering geocryological zoning of the Arctic coast of Russia
- Estimation of the intensity of natural exogenous processes on the Arctic coast
- Industrial impact assessment of the Arctic coast.

Second level map (1:1000000 scale):

- Engineering geocryological zoning of the Arctic coast of the European North of Russia (Barents Sea coast). The zoning of the coast was correlated with the segmentation of the Barents Sea coast and with the ACD data base.
- Estimation of industrial impact on the activation of natural exogenous processes along the Barents Sea coast.

Third level maps (1:200000 scale):

- Engineering geocryological zoning of the Varandey Peninsula key site (Barents Sea coast).
- Zoning of geocryological process activity (frost heaving) at the Varandey Peninsula key site (Barents Sea coast).
- Zoning of potential hazards associated with geocryological processes as a consequence of industrial impacts.

BIOGEOCHEMICAL STUDIES (2000-2003) IN THE EAST-SIBERIAN SEA: THE COASTAL ZONE

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The continental shelf of the East Siberian Sea (ESS) is the widest and shallowest of the World Oceans, yet the least explored. The shelf acts as an important region for production and processing of organic matter before the material is transported into the Arctic Ocean. It is heavily influenced by the extent of ice coverage in the ESS and will therefore likely be impacted by global climate change and warming in the Arctic.

The Arctic Ocean receives about 10% of the global river discharge and 25 Tg of terrigenous dissolved organic carbon (DOC) every year (Carmack, 2000; Stein and Macdonald, 2003). The shallow shelf of the ESS is an important region for processing this carbon, and exhibits the largest gradients in freshwater and nutrients observed for the entire Arctic Ocean. The ESS is influenced by water exchange with the eastern Laptev Sea (where local shelf waters are diluted mostly by Lena River outputs) and by inflow of Pacific waters from the Chukchi Sea. Pacific water inflow occurs through the Bering Strait, crossing the Chukchi shelf and entering the Arctic Basin through the Barrow and Herald Canyons (Weingartner et al., 1999).

The coastal zone in this area plays a significant role in the freshwater budget; processes involved include carbon transport, accumulation, and transformation, and seaward export of particulate and dissolved materials to offshore shelf/slope regions. Warming causes thawing of the permafrost which underlies a substantial fraction of the Arctic. This process could accelerate river discharge and carbon losses from soils (Savelieva et al., 2000; Freeman et al., 2001). Siberian freshwater discharge is expected to increase with increasing temperatures (Semiletov et al., 2000; Peterson et al., 2002), potentially resulting in greater riverine export of old terrigenous organic carbon to the Arctic Ocean. In this context, the role of the ESS coastal zone in transport and fate of freshwater and terrestrial organic carbon has not been discussed sufficiently, mostly because reliable oceanographic data are lacking. The only available source of data in the ESS was collected using Nansen bottles. In addition, several intensive multi-agency Soviet oceanographic ESS studies were cancelled in the 1980s. At the time of the Soviet studies, temperature was measured using reversed thermometers mounted on Nansen bottles, and conductivity-temperature-depth (CTD) profilers were not used to obtain data. Measurements of hydrochemical variables, especially of nutrients, were therefore of low quality and made using a variety of different techniques, impossible to replicate now.

The switch of atmospheric circulation regimes (from Az- to Zn-mode) causes a significant inter-annual shift in position of the Trans-Arctic Current, and its correlation (0.78) with hydrological conditions (anomalies of the temperature [T] and salinity [S]) in the ESS is quite high (Shpaikher and Yankina, 1969). Due to intensification of the Icelandic Low (Zn-mode of circulation) and eastward winds, the direction of freshwater transport is shifted to the east and the sea level in the western parts of the Kara and Laptev Seas has lowered, while in the East-Siberian and Chukchi Seas the surface layer is freshened and sea level has risen. This phenomenon induces a decrease in the pressure gradient between the Chukchi and East-Siberian seas, which subsequently causes a decrease of Pacific water inflow through the Long Strait and an eastward shift of the FZ.

The opposite case, which refers to the intensification of the Az-regime of circulation moves the FZ westward because of increased inflow of Pacific water (Nikiforov and Shpaikher, 1980). We can thus consider the variability in position of the FZ between the “Pacific waters” and “local shelf waters” as an indicator of regional climate change as reflected in alternations of the Zn and Az circulation regimes.

These results are among the first reliable hydrological and geochemical data reported for the ESS from the Dmitry Laptev Strait to the Long Strait, and they reveal new insights into the interaction between Pacific and local shelf waters. In the present study we report hydrological (T and S) and hydrochemical data obtained during a Russian Trans-Arctic cruise in 2000 onboard the Hydrographic Vessel (HV) Nikolay Kolomeytsev, and describe the top sediment layer (a typical sample was taken from the upper 0-5 cm layer of bottom sediment) and the distribution of the organic carbon ($\delta^{13}C_{org}$) and nitrogen ($\delta^{15}N_{org}$) isotope ratios in the bottom floor. Using both historical water data and data from the expdition, we divided the ESS into two specific areas: the Western area, influenced strongly by Lena River input, and the Eastern area, under direct influence of Pacific-derived water (Table 1). We also used the stable $\delta^{13}C_{org}$ and $\delta^{15}N_{org}$ isotopes to detect the sediment geochemical boundary (or “geochemical FZ”) between Pacific “marine-derived sediments” and “terrestrial derived sediments” which can be considered to reflect the long-term (on a scale of 10^2 years) position of the most westward extension of Pacific water.

For the present study, nutrients, dissolved oxygen, total inorganic carbon (TIC), pH, and particulate material (PM) were measured in water samples taken from Niskin bottles. Total nitrogen (TN), organic carbon (OC), C/N molar ratio and stable isotopic composition data were obtained from surface sediments sampled by Van-Veen grab. The same sediment measurements were conducted in the ESS (44 oceanographic stations) during the First Russia-US Cruise in 2003 onboard the Ivan Kireev (http://www.iarc.uaf.edu/cruises/east_siberian_cruise2.php). Thus far, 79 surface sediment samples from the ESS have been analyzed for ^{13}C and ^{15}N isotope ratios.

The Quartz/Feldspar (Q/FS) ratios in the Western and Eastern areas are the same (Q/FS=0.26), while the Q/FS ratios typical for the Lena solid discharge are 10 times higher; Q/FS ratios range between 2 and 2.3 (Serova and Gorbunova, 1997). This suggests a hitherto neglected direct influence of Lena transport of PM into the ESS. Our direct observations (late August – early September of 1997 and 1999, and July-August of 2003) of PM fluxes detected along the Lena river from mid-stream (Yakutsk) down to the Laptev Sea demonstrate that almost all riverine PM settles in the delta, even during flooding time (Semiletov and Dudarev, unpublished data). In summer-fall the solid discharge of the major ESS rivers, Indigirka and Kolyma, is also limited by the near-mouth areas (V. Ivanov, personal communication). Thus we can argue that transport of the eroded material plays a major role in accumulation of carbon in this part of the Arctic Ocean. The eroded carbon is biodegradable (Semiletov, 1999a; Guo et al., 2004), whereas riverine OM is refractory (existing mostly in the form of dissolved organic carbon) and is mainly composed of soil-derived humic substances (Dittmar and Kattner, 2003). The PM data obtained in the Dmitry Laptev Strait where the river PM signal is negligible (Semiletov, Dudarev, McRoy, September 1999, unpublished) show that “new production” is formed from the old terrigenous carbon with a typical terrestrial signal of $\delta^{13}C_{ter} < -26.5$. Thus the river OM discharge has probably no direct influence on marine productivity, while coastal erosion and consequent degradation of “fresh” old terrestrial organics (Semiletov, 1999a,b; Dudarev et al., 2001; Guo et al., 2004) plays a significant role in biogeochemical processes especially in the Western area of the East-Siberian Sea where coastal retreat is the highest.

We draw two major conclusions from the results of this study.

1. Based on distribution of the hydrological and hydrochemical data, two areas were identified in the shallow ESS: a western area that is influenced strongly by the fresh water flux and PM transport of the coastal eroded material (the solid Lena discharge signal is

negligible), and an eastern area that is under the influence of Pacific derived waters. From year to year, the longitude shift of the FZ between western and eastern areas may reach 10 degrees or more.

2. Eroded terrestrial carbon plays a major role in sedimentation and biogeochemical processes in the shallow ESS.

Table 1. Water and sediment characteristics of the Western and Eastern areas of the East-Siberian Sea

Parameters	Western area			Eastern area		
	min	max	$\bar{x}$	min	max	$\bar{x}$
Depth, m	7	20	13	7	41	25
Surface water						
Temperature, °C	1.41	4.70	2.62	-0.88	2.11	0.58
Salinity, %o	10.5	29.7	22.3	27.5	31.7	29.7
Particulate matter, mg/l	4.7	79.7	24.2	1.2	7.3	3.3
pH	7.9	8.1	7.9	7.9	8.4	8.2
Dissolved oxygen, %	96.6	106.2	98.4	90.9	105	100.2
Nitrite, µM	0.03	0.16	0.08	0	0.04	0.02
Nitrate, µM	0.11	5.54	1.69	0.05	3.52	0.51
Silicate, µM	8.2	73.9	31.5	0.5	9.1	2.4
Phosphate, µM	0.53	1.5	1.05	0.33	1.66	0.77
TIC, mM	0.86	1.25	1.1	1.47	2.06	1.78
Near bottom water						
Temperature, °C	0.22	3.61	2.23	-1.76	0.76	-0.17
Salinity, %o	17.1	31.0	24.5	31.2	33.4	32.2
Particulate matter, mg/l	5.2	106.4	25.3	2.4	7.9	5.3
pH	7.7	8.1	7.9	7.8	8.2	7.9
Dissolved oxygen, %	76.1	98.4	95.1	69.5	106.8	85.8
Nitrite, µM	0.04	0.16	0.09	0.02	0.21	0.05
Nitrate, µM	0.12	5.56	1.94	0.21	15.61	4.34
Silicate, µM	7.9	48.6	28.6	0.5	43.5	12.8
Phosphate, µM	0.1	1.92	1.21	1.02	2.41	1.68
TIC, mM	0.85	1.73	1.26	1.75	2.26	1.97
Bottom sediment						
Psammite fraction, %	0	45	15	0	95	38
Aleurite fraction, %	13	75	50	3	47	29
Pelite fraction, %	6	63	35	2	66	33
Organic carbon, %	0.33	1.88	1.04	0.1	1.28	0.85
Molar ratio C/N	7.3	12.5	10.2	5.5	10.0	7.6
$\delta^{13}C$ (%o)	-27.8	-25.2	-26.7	-25.1	-22.7	-24.0
$\delta^{15}N$ (%o)	3.25	6.23	4.69	6.09	9.02	7.40
Contribution of terrestrial organic carbon, CTOM (%)	70	100	86	28	70	52

DISSOLVED METHANE IN THE EAST-SIBERIAN AND LAPTEV SEAS: THE COASTAL ZONE

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At present, the maximum concentration of atmospheric CH_4 occurs over the Arctic and subarctic; the values of CH_4 concentrations over Greenland exceeds those over Antarctica by 8-10% (Rassmussen and Khalil, 1984; Steel et al., 1987). Recent evidence that atmospheric CH_4 is increasing globally has made it an urgent necessity to understand the natural processes, both physical and biological, which control methane concentrations (Rassmussen and Khalil, 1984; Steele et al., 1987; Blake and Rowland, 1988; Cicerone and Oremland, 1988). In our study we are looking for connections among warming, permafrost state, northern lake evolution, gas hydrates, and CH_4 release into the atmosphere. In general, we consider how onshore and offshore permafrost can react to global change and contribute to the climate system energy balance through CH_4 release. We believe that this feedback should become an integral part of all global climate models.

The distribution of CH_4 in the subsea-ice layer in the coastal zone of the Laptev Sea is presented in Fig. 1. Because the source of CH_4 is located at the bottom, it is evident that the transfer of CH_4 towards the surface is determined mainly by ebullition. The same vertical distribution, including a maximum concentration just beneath the ice, was observed in the thaw lakes of the Kolyma Lowland during or after cyclonic weather systems crossed the study area, initiating drastically enhanced CH_4 ebullition (Semiletov et al., 1996a). We did not find, however, dissolved CH_4 in such high concentration in summertime at the same location.

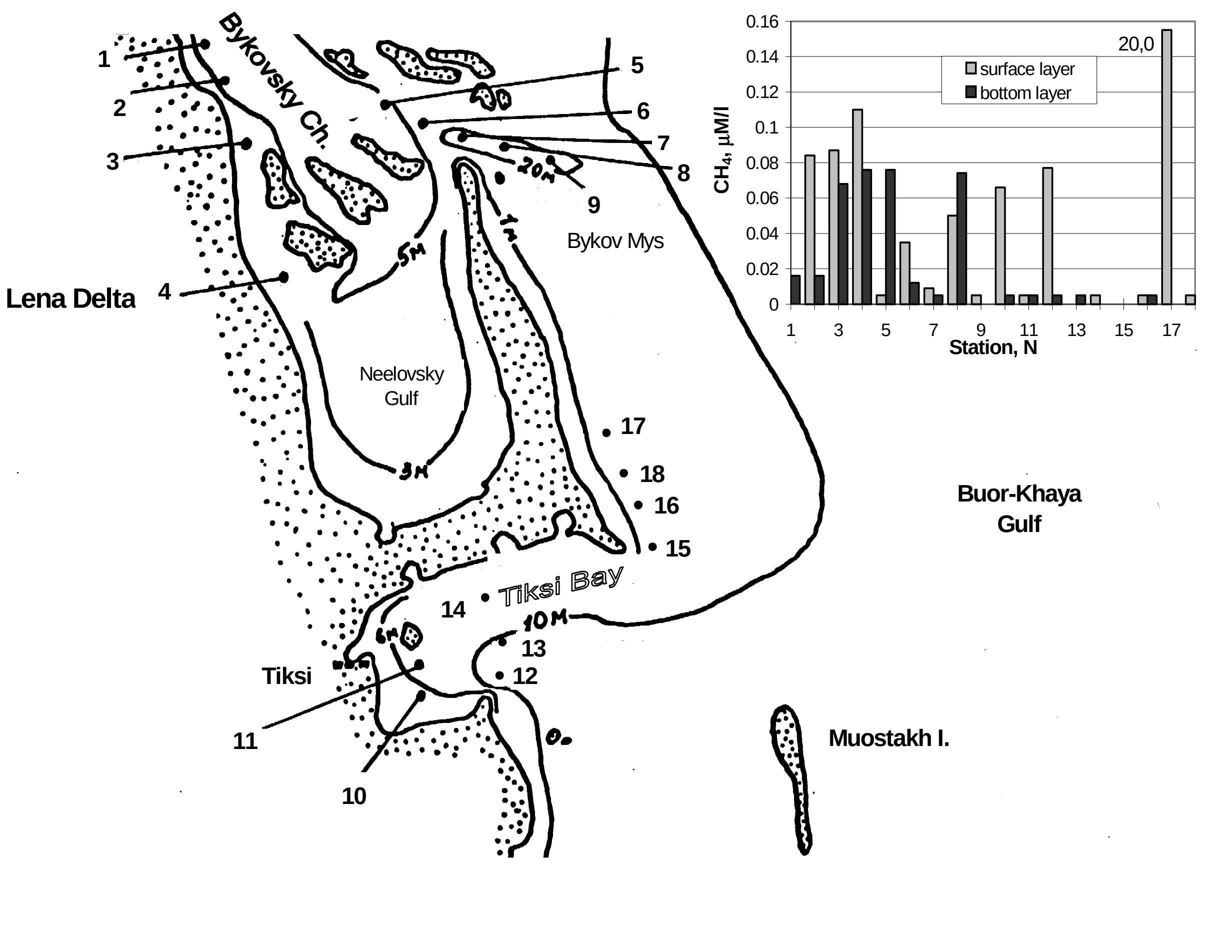

Figure 1. Distribution of dissolved CH_4 in the surface and bottom layers of the Laptev Sea in November 1996.

The range of variability of CH_4 concentrations in the thermokarst lakes of the Bykovskiy Peninsula (on-shore permafrost) during wintertime 1994-95 (Semiletov et al., 1996a,b) is similar to the range of CH_4 variability obtained over shallow off-shore permafrost (Fig.1) which has the same origin as on-shore Pleistocene ice complexes. An anomalously high value of sub-ice CH_4 is observed at point 17 (Fig.1), where maximum of CH_4 concentration was observed just beneath the ice, 20 µM. We explain the episodic increase in CH_4 ebullition from this site by a preceding drop in the atmospheric pressure, which might induce CH_4 ebullition (Semiletov et al., 1996a). A similar episode was observed previously at temperate latitudes at Mirror Lake, New Hampshire (Matson and Likens, 1990).

Recent data obtained by the first (2003) Russia-US Expedition in the East-Siberian Sea (Semiletov et al., 2004) using a high-precision GC (BTU series, made in the USA) shows that the surface waters are supersaturated by about 3-6 times compared to the atmosphere, but the bottom waters are supersaturated up to 10-15 times (Fig.2 a,b).

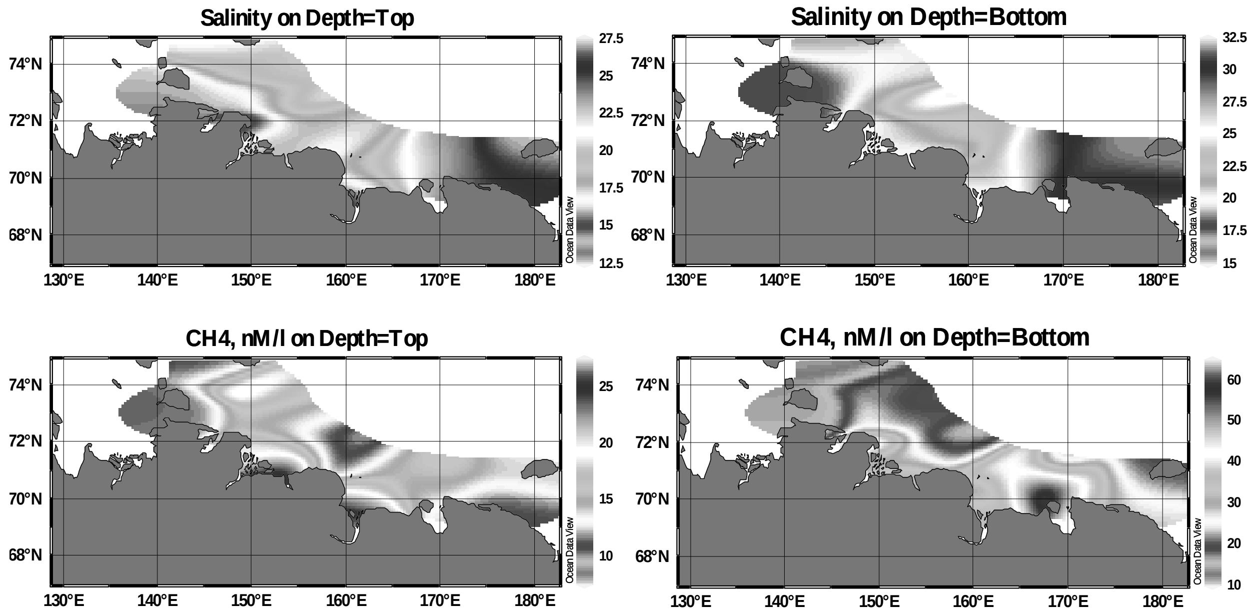

Figure 2. Distribution of salinity and dissolved CH_4 in September 2003 in the surface (left) and bottom (right) waters of the East-Siberian Sea.

The source of high dissolved CH_4 in surface waters is the Kolyma and Indigirka rivers (Fig.2a). High CH_4 concentrations were also measured near the right bank of the Kolyma river, where many alluvial lakes, enriched in CH_4, are connected with the river through small channels (called “viska” in the native language). Another spot of high CH_4 concentration (Fig.2b) was found in the bottom layer adjacent to the Chaunskaya Bay (between 165°E and 175°E).. We suggest that this plume may be caused by CH_4 emission from sub-sea gas hydrates which are located in this area (www.usgs.com). There is not much data to support the statement that hydrate instability is increasing at present, but it is clear that hydrates definitely will become unstable if warming continues.

Up-to-date experimental studies of offshore permafrost distribution are very limited, especially in the northeastern Siberian region; instead, a modelling approach is usually applied (Romanovskii et al., 2000). The results of sub sea permafrost degradation modelling demonstrate the possibility of a significant feedback between climate change and a change in the thermal state of permafrost. Sea level changes and history of climatic variations during the Late Pleistocene through Holocene determine the subsea permafrost existence and dynamics (Fig.3).

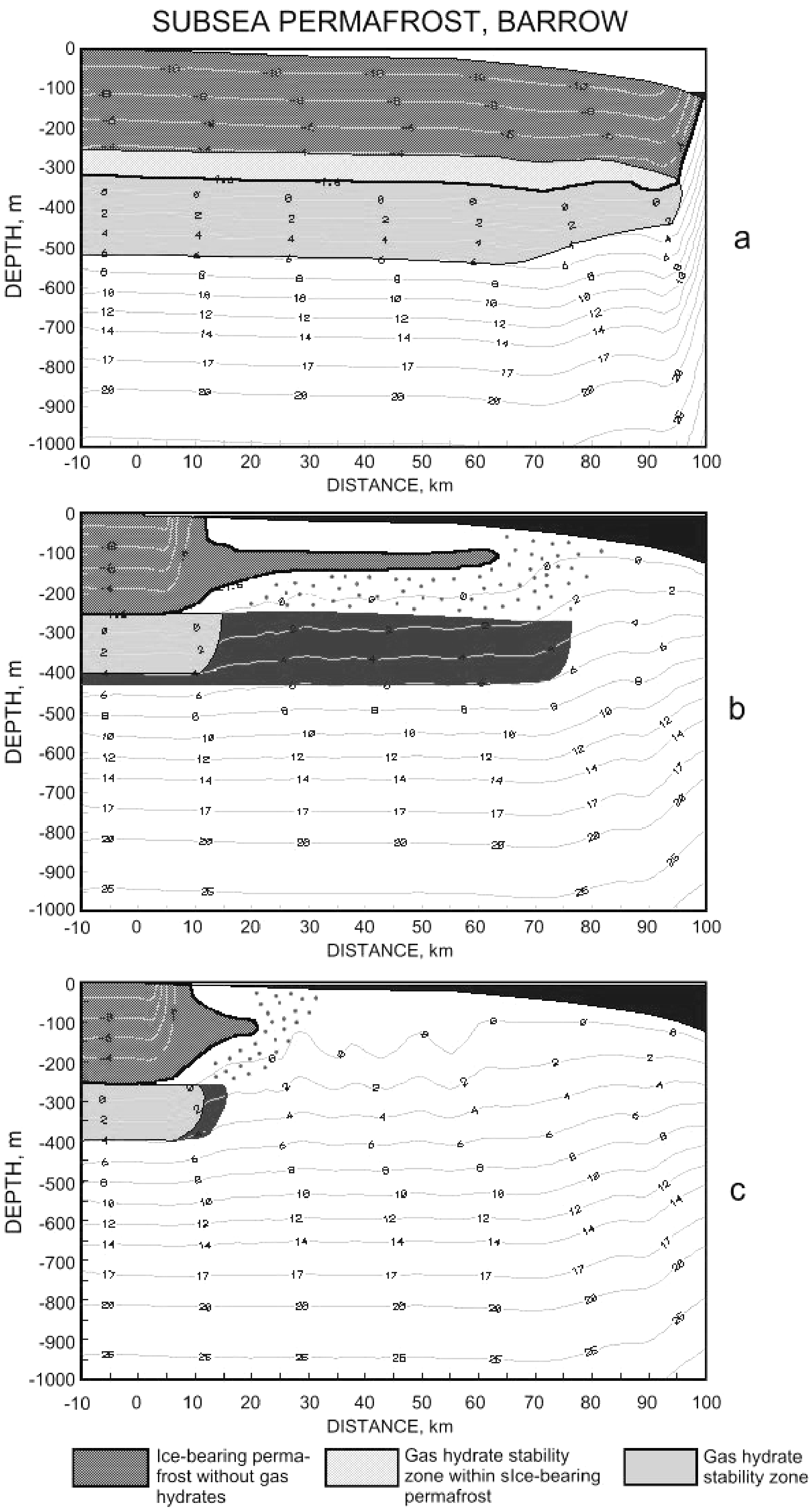

Figure 3: a) 15,000 years ago. The shelf at Barrow was exposed and frozen. The hydrate stability zone was at its largest; b) 4,000 years ago. Subsea permafrost and hydrate stability zone continued to degrade. The free gas at 65-80 km offshore could have been released to the atmosphere; c) Present time. Subsea permafrost at Barrow exists 8-10 km offshore. The contribution of greenhouse gases to the atmosphere from hydrate destabilization during the last 3,000 years was much less than 3,000-4,000 years ago, assuming rapid transport of the gases to the seabed.

Due to contacts with relatively warm shelf water above, the submarine permafrost receives heat energy from the seawater, while its bottom position and its dynamics are driven by the geothermal flux (which is higher in tectonically active areas). The present warming and higher river runoff could induce additional heat influx from the top. This energy flux leads to a warming of the submarine permafrost, nearly to the thaw temperature. The geological model (Fig.3) predicts a mean annual temperature of the sea floor equal to the near bottom seawater temperature, which varies usually within limits of –0.5 to –1.8°C, although in some coastal areas the temperature of near bottom seawater and surface sediment has already become positive. Our first in situ measurements of bottom sediment demonstrated positive temperatures (up to 3°C in the top 1 m sediment layer in the Dmitry Laptev Strait), and across the East Siberian shelf the temperature of marine sediments ranged from negative values (down to –1°C) to positive values (up to 2-3°C). We associate the formation of such warm local conditions with the presence of the heating plume of the Lena River (Semiletov et al., 2005), which is one of the largest Arctic rivers. During the last three decades the Lena runoff has increased significantly (Savelieva et al., 2000), perhaps because of warming and consequent thawing of discontinuous permafrost in the watershed. Using original and historical measurement of seawater temperature in all seasons (about 2-3°C in summer and near –1°C in winter) we calculated the present mean annual sea floor temperature in the Dmitry Laptev Strait area to be 1°C. Thus relict offshore permafrost in this area thaws not only from below under the impact of geothermal heat flow as stated in the existing geological model (Romanovskii and Hubberten, 2001), but also from above due to energy input from the sea floor surface. The sea floor temperature may continue to increase if the heating effect of increasing warm river discharge continues.

During the second Russia-US expedition (2004) a spot of high CH_4 concentration was detected in the Dmitry Laptev Strait (which geographically separates the Laptev Sea from the East-Siberian Sea). At this location, CH_4 concentrations as high as 150 nM from the bottom to the top of the water column were found. The excess CH_4 in the surface waters allowed us to approximate the net flux of CH_4 from the sea surface into the atmosphere Estimated CH_4 fluxes from this area are on the order of 1.0-1.5 g CH_4 $m^{-2}y^{-1}$ which we believe is similar to the rate of CH_4 release from the sea bottom in this area, judging from the homogenous CH_4 distribution in the water column. This flux is of the same order of magnitude as mean CH_4 flux from the seafloor of shallow hydrocarbon-rich areas (Hovland et al., 1993).This location is thereafter associated with the location of a geological fault zone called the “Bel’kovsko-Svyatonosskiy Rift”(Imaev et al., 2000), where the geothermal heat flux may be roughly equal to 100 mW/m^2. The magnitude of the geothermal heat flux is a crucial component of the Laptev Sea geological model (Romanovskii and Hubberten, 2001), which predicts the existence of open taliks under faults and in fault zones with high geothermal heat flux values (100 mW/m^2 and more). This plume can also be associated with a possible deposit of gas hydrates. We can thus suggest that the submarine permafrost under the fault might have decayed, in part or completely, allowing the release of CH_4 from the gas hydrates. A positive mean annual sea floor temperature may be an additional indirect piece of evidence suggesting the existence of an open talik under the spot where high values of dissolved CH_4 were observed.

Acknowledgements: This work was supported by the Far-Eastern Branch of the Russian Academy of Sciences, RAS (through the RAS Program #13, Direction #7: “Environmental changes in the East-Siberian region under climate effects and catastrophic processes”), the International Arctic Research Center of the University Alaska Fairbanks, and the Russian Foundation for Basic Research.

SUSPENDED PARTICULATE MATTER DYNAMICS IN THE NORTHERN DVINA DELTA, THE WHITE SEA, DURING THE FLOOD

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Introduction

Study of biogeochemical processes in estuaries and deltas is of particular significance in understanding their role in global cycles of carbon and many other chemical elements. Most of the suspended matter is trapped in the estuaries where freshwater and salt water are mixed (salinity of about 2–15 psu), and rapid accumulation (precipitation) of fine-grained suspension occurs due to coagulation processes. According to A.P. Lisitsyn (1995), more than 90% of the suspended matter (including particulate organic carbon) and about 30% of the dissolved matter probably accumulate within this so-called “marginal filter”.

The Northern Dvina river is the main source of riverine suspended matter supply of the White Sea (Gordeev et al., 1996). The most part of this suspended particulate matter (SPM) is delivered to the White Sea during the floods, but the particulate matter dynamics in estuaries and deltas of rivers, flowing into the White Sea, practically is not studied (Lisitzin et al., 2003). The aim of the expedition to the Northern Dvina delta in May 2004 was to study SPM during the floods.

Materials and methods

The distribution of SPM and hydrological characteristics of Northern Dvina river and its tributaries and branches (Fig.1) were studied during the flood period from 13 till 30 May, 2004. The studies were carried out onboard the RV “Iceberg-2”. 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 through pre-weighted Nuclepore filters 47 mm in diameter (pore size 0.45 µm). After filtration filters were washed with distilled water and dried at 50–55°C, packed in plastic Petry dishes and then sealed in plastic envelopes for later analyses in the land laboratory. In more detail working procedures are described elsewhere (Lisitzin et al., 2003). 141 samples of SPM have been collected. At each station temperature, salinity and turbidity were measured by CTD90 and 3”Micro CTD probes.

Results and discussion

Continuous measurements of water level and discharge at the Ust’-Pinega cross-section (position of section is shown at Fig. 1) by specialists of gauging station of SEVHYDROMET show that in March and the first week of April both water level and discharge were very low (about 210 cm above the sea level and 880 m^3/s, correspondingly). They sharply increase in the period from April 20 to May 19 (up to 750 cm and 16400 m^3/s, correspondingly). Our field studies were carried out during the peak of flood. Both water level and discharge sharply decreased from June 2 to June 17.

Concentration of SPM at the Ust’-Pinega cross-section varied from 4 to 14.7 mg/l (8.9 mg/l on average, n = 16 samples). Near the same values were registered upstream this cross-section in the Pinega River (6.7–11.3 mg/l) and in Northern Dvina 10–50 km upstream the Ust’Pinega (7.3 mg/l). In the Maimaksa Branch from the Solombala Island to Lapominka concentration of SPM in the surface layer varied from 5.8 to 13.9 mg/l (10.2 mg/l on average, n = 11). It is at the same level as it was previously reported (Shevchenko et al., 2004) for this branch for the end of flood at 11.06.2003 (13.2 mg/l); at middle of April 2003 it was 2.48 mg/l and 20.08.2003 – 6.14 mg/l (Fig. 2). All these values were much lower than concentrations in marginal filters of the large Siberian rivers (Gordeev et al., 1996; Lisitzin et al., 2003).

In the mixing zone the concentrations of SPM sharply decrease with the increase of salinity. Near the Mud'yug Island they were 1.9 mg/l. In the marginal filter of N. Dvina the same as in Siberia (Lisitzin et al., 2003), the following processes sequentially change each other at the way from the river to the sea: gravitational sedimentation, physico-chemical processes in colloid system (coagulation and flocculation, formation of sorbents), and, finally, biological processes (growth of phytoplankton with conversion of dissolved elements to biogenic suspended matter and the process of biofiltration).

Even in the outer part of the delta riverine water dominated. The distribution of temperature, salinity and turbidity (SPM) were influenced by tidal movements. In the mouth of Murmansky Branch near Kumbysh Island the concentrations of SPM at the Station 36 were 3.4–4.6 mg/l during the tide and 13–14 mg/l during the ebb (Fig. 3). During the maximal tide the depth increased to 11 m and termo- and haloclynes were pronounced. Turbidity decreased under the picnoclyne. During the ebb all water column (water depth was 10 m) was gomogeneously mixed, values of temperature, salinity and turbidity were constant with the increasing the depth.

Near the southern part of the Mud'ug Island at the Station 89 during the maximal tide the saline wedge was registered in 3-m layer over the bottom. Turbidity in this layer decreased. During the ebb at this station salinity was constant and very low (0.05 psu), temperature slowly decreased with the increase of depth, turbidity and SPM concentration increased in this direction.

Conclusions

During the flood period the concentration of SPM in the lower stream and delta of the Northern Dvina were comparatively low.

Near the mouths of Northern Dvina the distribution of SPM concentrations, temperature and salinity are influenced by tides.

At the outer part of the delta the SPM concentration is decreased with increasing of salinity.

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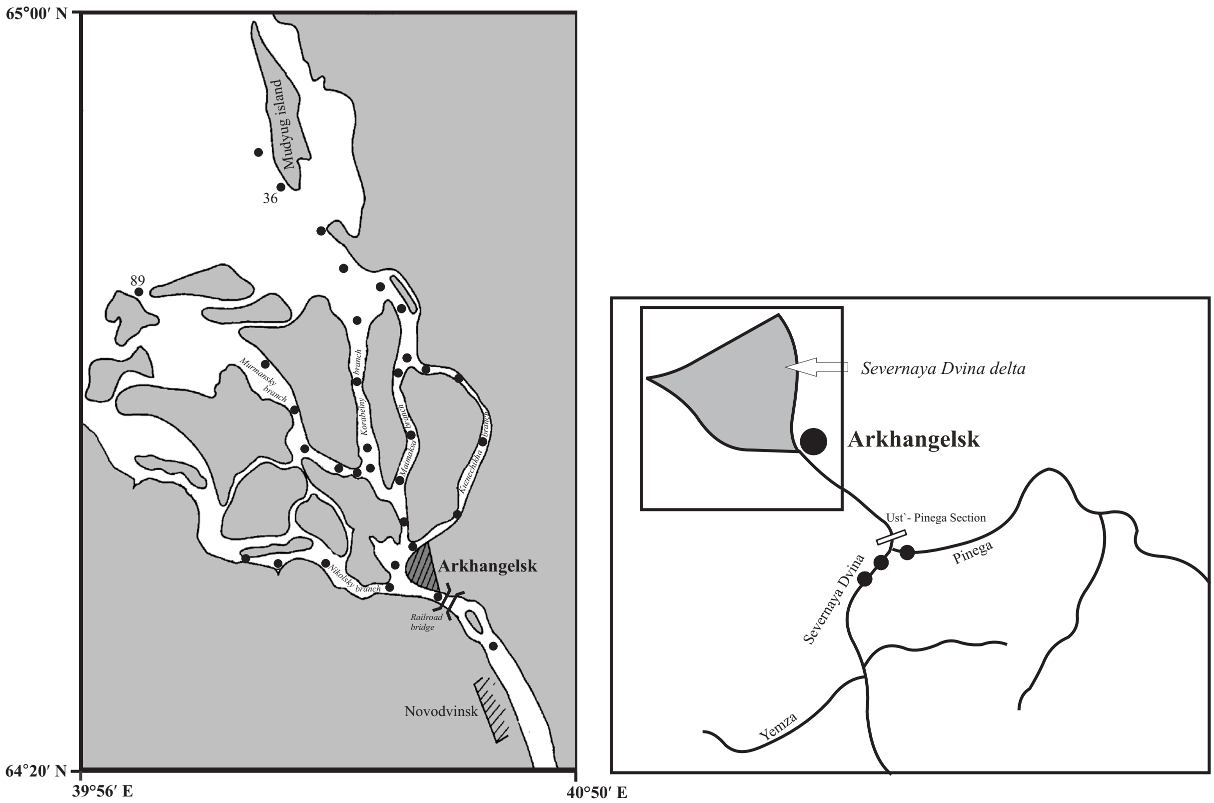

Figure 1. SPM sampling sites in the Severnaya Dvina river and its tributaries and branches, May 2004.

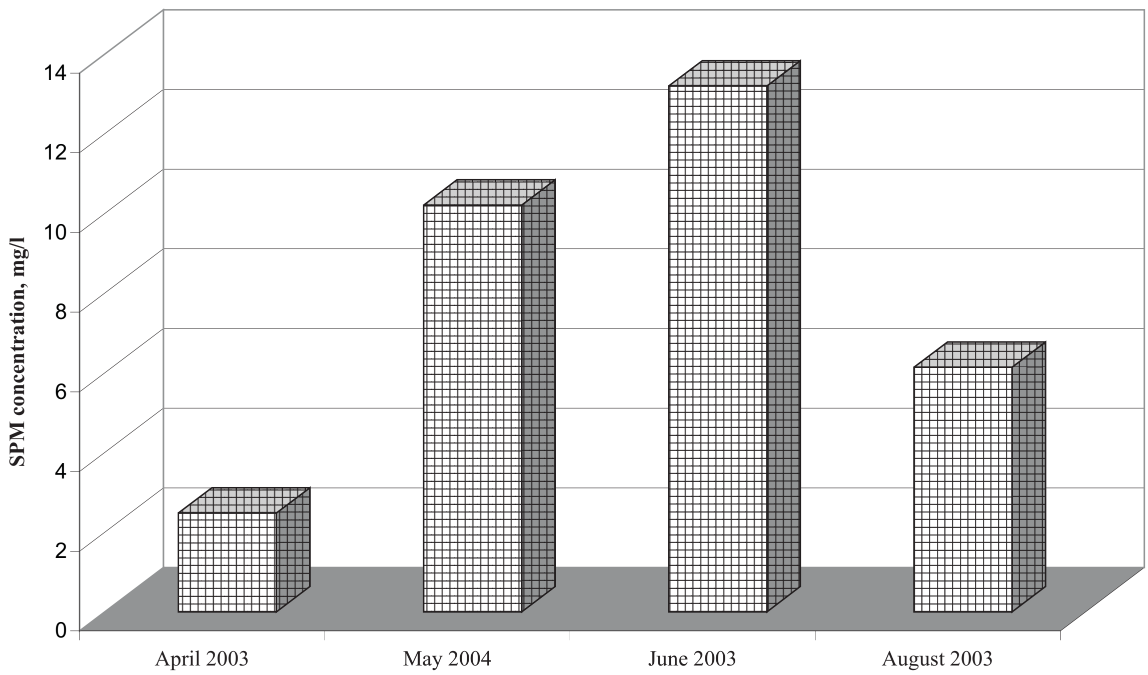

Figure 2. Seasonality of SPM concentration in the Maimaksa Branch.

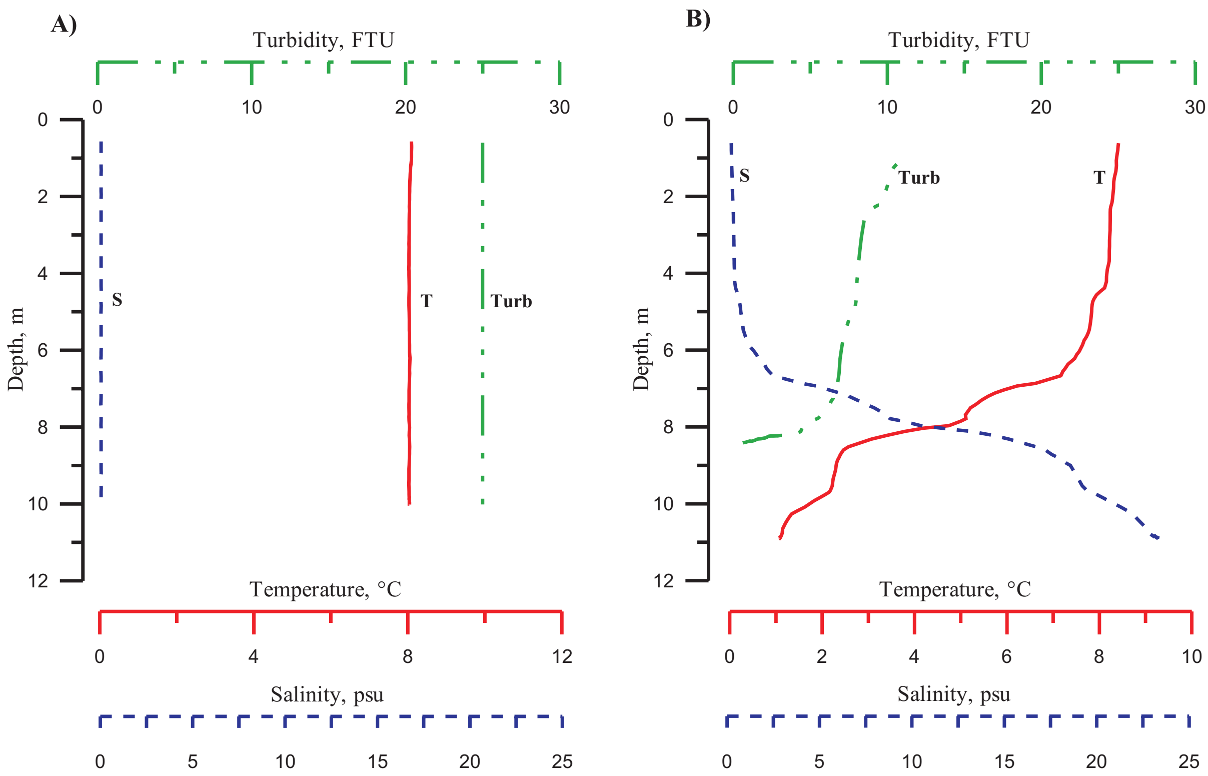

Figure 3. Distribution of salinity, temperature and turbidity at station 36 on May 21, 2004 a) during the ebb; 14:00 (GMT+3:00) b) during the tide; 21:00 (GMT+3:00).

EFFECT OF MASSIVE GROUND ICE ON THE DYNAMICS OF THE RUSSIAN ARCTIC COASTS

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The current Russian Arctic shelf and coastline were formed since the Late Cenozoic (250 kyr BP) under the action of two types of natural processes: (1) the astronomic cycles that caused considerable changes in sea levels and (2) the permanent local exogenous processes modified by the presence of permafrost. Massive ground ice (i.e. ground ice characterized by gravimetric moisture content > 250%) played and continues to play a crucial role in the coast formation. It is however unevenly distributed along the Russian arctic coasts.

Eurasian massive ground ice shall be divided into four main genetic types: (a) *syngenetic submarine ice* is formed under deep sea conditions (40-200 m) in regions of ancient transgressions; (b) *syngenetic offshore-marine ice* is confined to the marginal parts of ancient sea basins and formed under periodically flooded offshore areas and on laidas; (c) *injective ice* – which formed epigenetically in subaerial regions under favorable hydrogeological conditions for replenishment; (d) *buried ground ice* – which is most often observed as large buried remains of glaciers in mountainous regions.

Most submarine and offshore-marine ices occur in the coastal zone within Pleistocene sea plains (Fig.1). We can therefore confidently state that, during the Pleistocene, the formation and the modification of the shoreline and the coastal was related to the presence of a frozen sea floor on the shelf and of massive ground ice of these types.

At **the end of the Pliocene - beginning of the Pleistocene,** deterioration of climatic conditions and intensification of tectonic movements caused sea transgression and creation of ice caps and permafrost everywhere on Arctic coasts. In **the Mid Pleistocene (II_{2-4}),** the coasts of the western part of Russian northern regions, Urals, Taimyr, and the mountainous regions of Eastern Siberia and Chukot Peninsula were covered with glaciers slipping into the sea, which were subjected to glacial processes, and were not affected by waves. The northeastern part of the East European Plain and the northern part of Western Siberia, the deltas of large Yakut rivers, and the Chukot lowlands were occupied by a cold-water basin.

The low-temperature thick cryolithozone conditions necessary to the growth of an offshore-marine ice type were then met in the shallow offshore parts of the shelf. The submarine cryolithozone (Shpolyanskaya, 1996) represented by marine, ice-marine, and glacial-marine dense silty-clayey sediments with low ice content and without massive ground ice was present in deep sea sectors (Shpolyanskaya and Streletskaya, 2003).

Coastal processes were inactive. A short ice-free period and low temperature of frozen ground composing the coasts hindered thermal abrasion and erosion of coasts and river banks and simultaneously limited the release of sediment material. Accumulative coasts were formed only in deltas and inner parts of bays.

The Late Pleistocene Mikulino (Kazantsev) Interglacial (III_1) is a warm epoch. The position of the Arctic coastline reflected the complex processes that occurred at that time. On one hand, major tectonic movements were occurring (e.g. pronounced upward movements of the shelf and coast in the western sector; downward movements of the shelf, neutralized by accumulation of fine-grained alluvial and lacustrine-alluvial continental sediments in the central and eastern sectors (Danilov, 1974); and upheaval of the eastern margin of the Chukot Peninsula). On the other hand, major eustatic movements due to the disappearance of the ice caps induced a rise of the sea level. The transgression observed in the western sector and the Chukot Peninsula was however less pronounced. As a result, the bottom of the sea floor froze and thick massive ground ice of a submarine type was formed on the shelf of Western Siberia and Chukot Peninsula (Shpolyanskaya, 1991). The coasts of mountainous regions that became free of ice were dissected in fiord-type shorelines. The coastal plains located in a subaerial context during this period were composed of very dense perennially frozen silty clay with low ice content. A longer ice-free period and a wider area free of pack-ice, caused greater fetches, and favored enhanced thermal abrasion. Thermoabrasion flattened coasts with high cliffs and predominantly generated deep offshore. Thermoabrasive-accumulative and accumulative coasts were formed in shallow straits. The submarine cryolithozone hindered accumulation of released material due to the transformation of seafloor sediments.

The Late Pleistocene Valdai (Zyriansk-Sartan) epoch (III_{2-4}) is a prolonged cold stage. The Arctic transgression continued and reached the current 110-140 m isobath at about 18-20 kyr ago (Pavlidis et al., 1998). The air temperature at the latitude of the present-day coastline was -15 - -17 ^{0}C (Rozenbaum and Shpolyanskaya, 2000). Coastal processes could not be active. The only area where the stability of the coasts was decreased was the area of the Kazantsev plains where the ground was characterized by high ice contents and large amount of massive ground ice. According to Vasiliev (2001), the action of less than 1 m high waves is an important contributor to the destruction of coasts. The slow action of these waves in ice-free periods results in erosion of the cliff bottom, destabilization of the cliff, and recession of the coast. During this period, coasts were mainly thermoabrasive-accumulative with indistinct features.

Holocene (IV) is a ongoing warm interglacial period which started 10.5 kyr ago. The post-glacial (Flanders) transgression took place in the Holocene. As a result of this transgression, sea level reached its present-day position 6 kyr ago and only insignificantly fluctuated afterwards (Kaplin et al., 2001). In the Holocene, coastal processes were intense and diverse. They were most intense in regions of maximum occurrence of underground ice, particularly where submarine and offshore-marine massive ground ice were present in coastal zones. Many coastal areas including such types of ice eroded at average rates of 1 – 2 m/yr (for the Yamal, Gydan, Yugor and Taz peninsulas) and 2-5 m/yr (for the coasts of the Chukchi and East Siberian seas with polygonal-wedge ice). Injective and buried ground ice was usually encountered far from the coastal zones and, therefore, almost did not affect coastal processes.

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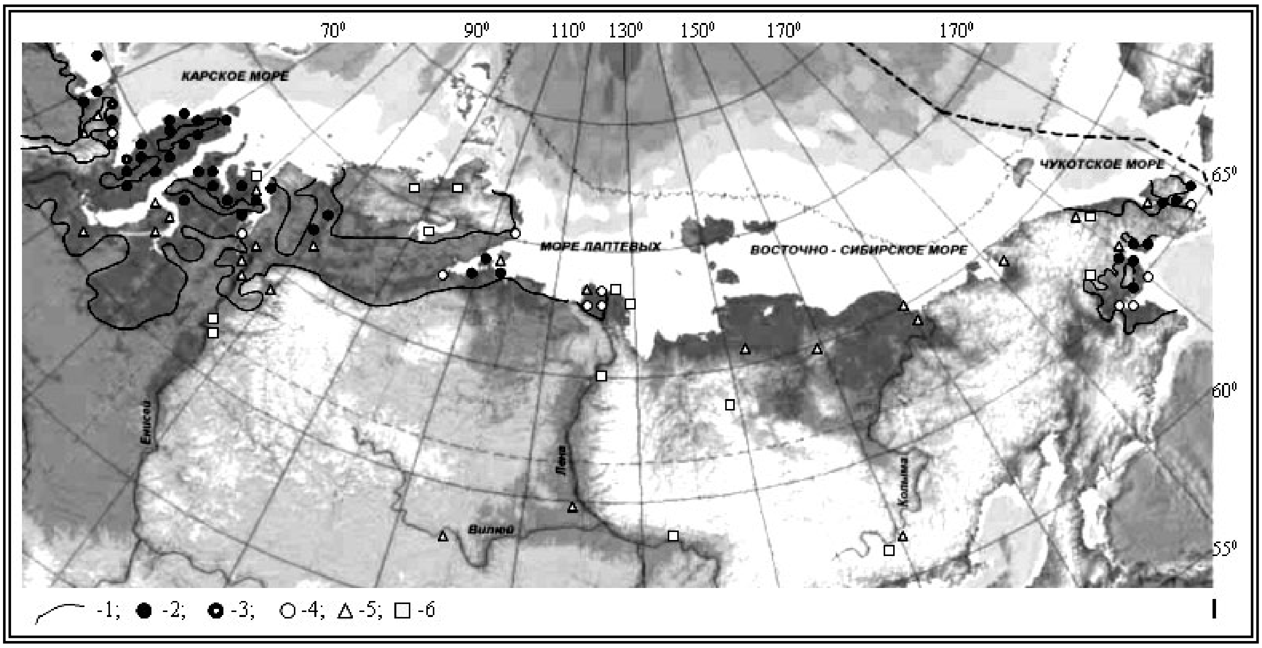

Figure 1. Massive ground ice occurrence in the Russian Subarctic region. Key: 1, the boundary of Late Pleistocene marine plains; 2, syngenetic submarine massive ground ice; 3-6, Massive ground ice of different genesis: 3, syngenetic submarine and syngenetic offshore ice; 4, syngenetic offshore ice; 5, injected ice; 6, buried glacier ice.

REMOTE SENSING OF BOTTOM-FAST ICE IN THE MACKENZIE DELTA REGION, NORTHWEST TERRITORIES, CANADA

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Bottom-fast ice (BFI) refers to sea- or lake-ice that freezes to the bed during the course of the winter season. The timing and distribution of BFI controls the mean annual temperature at the lake(sea) bed and therefore the potential for development and maintenance of permafrost and the thickness of the subaqueous active layer. The areal extent of BFI has been mapped using ground-penetrating radar (GPR) from the ice surface and satellite synthetic aperture radar (SAR). Regions of low radar backscatter are associated with charted shallow water in lakes and the Beaufort Sea region of the outer Mackenzie Delta. Relatively higher backscatter is found in the deeper parts of the lakes and of the nearshore region. The maximum extent of low radar backscatter occurs in April and is associated with regions of the sea and lake bed that are generally less than 1.5 m water depth. Interpretations of the radar imagery become problematic in May and June because of the presence of a wet snowpack and flood or meltwater on the surfaces of the ice. A time series of Radarsat scansar images is used to monitor the growth of these low backscatter zones beginning with inception around subaerial shoals in November and culminating in extensive regions by April. Differences between interpretations of BFI extent based on Radarsat and GPR suggests that the former may be more sensitive to areas that are either marginally bottom-fast or potentially subject to tidal influences (i.e. periodic lift-off from the seabed). Additional validation of the technique in the shallow coastal estuarine environment is presently underway.

ORGANIC CARBON IN THE COASTAL QUATERNARY SEDIMENTS OF THE BARENTS AND KARA SEAS

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The organic carbon content of coastal sediments of the Barents and Kara Seas is still under investigation (Bady, Khar'yuzov, 1987; Natural conditions…,1997; Romankevich, Vetrov, 2001; Grigoriev, Rachold, 2003). During fieldwork, samples of Quaternary sediments from different sections were taken in the regions of Shpindler, Marre-Sale, Maresalskie Koshki, Bovanenkovo Gas Field and others (Fig. 1).

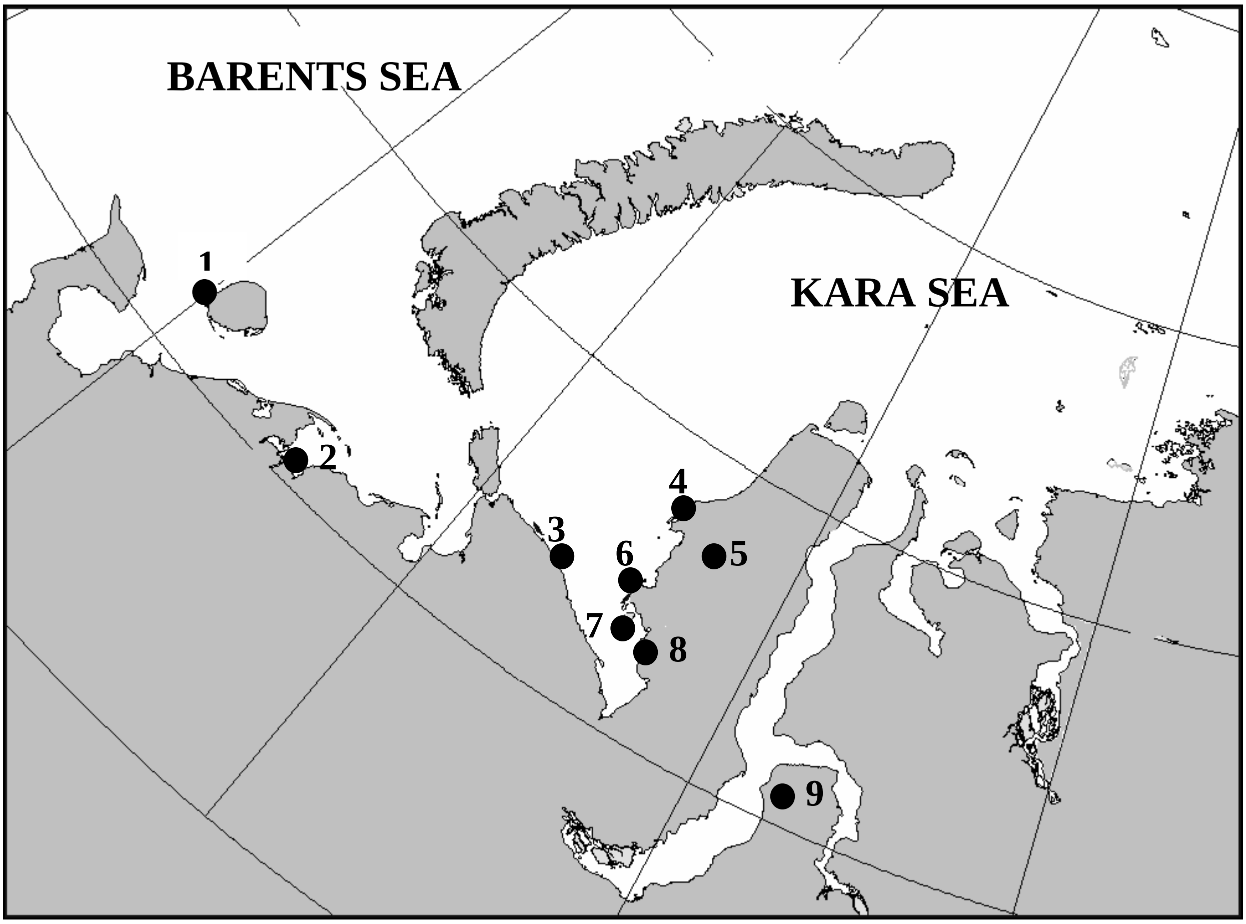

Figure 1. Location of the studied sites. The numbers of the organic carbon sampling sites in Quaternary coastal sediments correspond with those in Table 1.

In general, 2 – 3 samples were taken from each lithological layer in the geological sections studied and were analyzed for organic carbon content. The results for the coastal sediments of the studied region are shown in Table 1. Data in this table is grouped by sediment type and depth.

Our results and previously published data allow us to make first approximations of the organic carbon content in coastal sediments of the Barents and Kara Seas. Analysis shows that existing data is still not enough for representative conclusions about the distribution of the organic carbon content. For thermoerosional coasts, organic carbon content was 0.1 – 0.6% in sands and 0.8 – 1.2% in clays, and was found to be independent of geological characteristics (genesis, age and others). In regions with accumulative forms such as places where low sandy islands form, the organic carbon content is fairly low and is usually only 0.1%. In the laidas, especially in rivers estuaries, the organic carbon content in sands increases to usual levels of 0.1 - 0.7% in sand and up to 1.2% in clay sediments. Another source of organic carbon in the Arctic basin could be the coastal erosion of soil and peat, but these sources were not found to be significant. Our investigations of the organic carbon distribution in coastal Quaternary sediments in the Mare-Sale region show that organic carbon content does not depend on the history of ground freezing. Under repeated thawing and freezing the organic carbon content does not change.

Table 1. Organic carbon-content (%) in the coastal sediments of Barents and Kara Sea.

Number of studied region from Figure 1.	Site	Geological index	Lithology	Depth of sampling, m	C_{org}, %
1	Kolguev Island (West Coast)	mII^{4}	Loam with boulders	0-17	1.2
		amII^{3}	Sand	17-23	0.8
		m, gm II^{1}	Clay	23-30	0.8
2	Bolvanskii Cape	l IV	Peat	0-5	82
		?	Sand	0-25	0.3
		?	Loam	0-25	0.8
3	Shpindler Cape	fg,aIII$^{2-4}$	Sand	2-30	0.08-0.3 0.15
		mIII^{1}	Clay	5-35	0.86-2.3 1.5
4	Kharasavei Cape	mIII$^{3-4}$	Sand	> 10	0.1-0.8 0.4
		mIII$^{2-4}$	Loam, clay	5-10	0.1-0.8 0.4
		mIII^{1}	Loam, clay	> 10	0.6-0.9 0.85
		mIII^{1}	Loam, clay	5-10	0.6-0.9 0.85
		mII$^{2-4}$	Loam , clay	1-5	1-1.2 1.1

This work was supported by INTAS (grant 01 - 2329), a Science Schools grant – 2067.2003.5 and by the Russian Foundation for Basic Research (project no. 02-05-64263) and a "Russian Universities 2004" grant.

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COASTAL EROSION ALONG THE CHUKCHI COAST DUE TO AN EXTREME STORM EVENT AT BARROW, ALASKA

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University of Colorado – CIRES, UCB 216, Boulder CO 80309-0216

Background

Along the north slope of Alaska, shorefast ice protects the coast up to 9 months of the year and negligible tides and waves minimally disturb the shore during the remaining summer months. Most of the coastline change, then, is thought to occur during summer and autumn storm conditions, where heightened sea levels and increased wave action accelerate movement of coastal materials. Changes in storm climate due to climate change may mean that short-term extreme events such as the intense storm experienced by Barrow, AK (established as a key site with the Arctic Coastal Dynamics program) on 3 October 1963 may become more frequent (Easterling). The October 1963 storm was the worst storm ever recorded by the U.S. Weather Bureau at Barrow. Winds reached 25 m/s, the storm surge reached 3.6 m, and wave heights reached 3 m. Homes, buildings, airplanes, and fuel were lost, mostly within reach of waves or located on eroded bluffs (Hume). Studies indicate that the longshore transport from the Barrow area between 1962 and 1964 was 153,000 cubic meters, 20 years of normal transport (Hume).

The coast to the southwest of Barrow consists of a narrow beach separating 10m-high bluffs from the Chukchi Sea. These bluffs are comprised of poorly consolidated sand and clay, with frequent drainage outlets cutting through to the beach below. Several prehistoric sites and ancestral homes are located along the edge of these bluffs and are in constant danger of damage and loss due to the significant erosion occurring along this section of coast. From the town of Barrow extending northeast to the base of the sand spit (leading to Point Barrow), the shore consists of a low elevation sand and gravel beach backed by grassy tundra, with numerous lakes just landward of the Chukchi Sea shore. Buildings, houses, and infrastructure in the Barrow area are in close proximity to the shore, susceptible to beach erosion. (MacCarthy)

Purpose

Our research examines the coastline change on the Chukchi Sea shore experienced during the intense storm at Barrow on 3 October 1963. We compare this to the normal transport of coastal materials and examine the processes at work to assess the vulnerability of the Barrow community to erosion from increased storm activity due to climate change.

Methods

Two sets of aerial photographs (from August 1962 and July 1964) were scanned and georectified to a 2002 Quickbird satellite image (.7 m resolution) using an image-to-image second-order polynomial transformation in the ArcGIS software package; the root mean square (RMS) alignment error was 1.05 meters, with a maximum error of 1.8 meters. The resulting aerial photograph resolution was better than 0.5 meters. The coastlines of 1962 and 1964 were then digitized and compared to obtain the coastline change over the two-year period covering the October 1963 storm. Along 2 km of the bluffs to the southwest of Barrow, changes in the location of the top edge were measured, as well as changes in the water line for about 10 km from the town of Barrow northeast to the base of the sand spit. Sample spacing of the digitized waterline and bluff top was 10 meters.

Bluff Results

Figure 1 shows the shoreline change over the entire analyzed area for the period covering the October 1963 storm. Only erosion was found to occur along the bluffs. The average bluff change was -3.75 meters (erosion), with a maximum of –11.57 meters and a standard deviation of 2.3 meters. This section is characterized by low-level erosion (<4 meters) with greatly increased erosion (>8 meters) concentrated in a few areas. These areas are located around drainage outlets and the Old Barrow Townsite, an ancient Inupiat village marked by sod houses built into the permafrost. Several of these sod houses have been exposed over the years on the eroding bluff face. Because of the large amount of ground ice here, melting of this ice by exposure to air and sea water greatly reduces the structural integrity of the bluffs and lubricates any unstable material at the bluff edge, accelerating movement of bluff materials onto the beach. Undercutting of the bluffs by waves during storm conditions causes further instability, and the bluff face slumps onto the beach. The well-developed soil polygons here also have a tendency to break along the ice wedges that border them, causing whole sections of bluff to slide to the beach when the ice wedge begins to melt. These migrated bluff materials break up and wash away with the next storm. (MacCarthy)

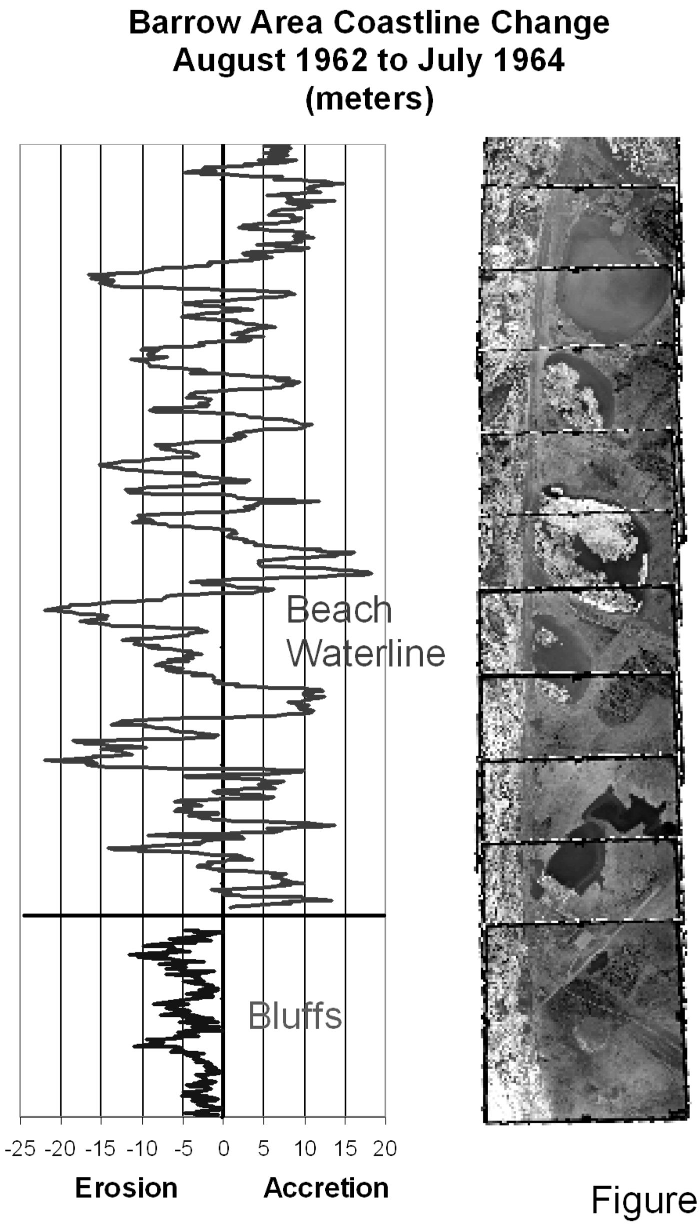

Figure 1

Over the 49-year period between 1948 and 1997, Lestak et. al. report an average -17.6 m bluff-bottom retreat near Barrow, corresponding to -0.36 ± 0.04 m/yr, and a maximum -34 m retreat at the Old Barrow Townsite (-0.69 m/yr). Doubling the figures reported by Lestak to evaluate the bluff change over the 2-year period between 1962 and 1964, we would expect an average retreat of –0.72 m and a maximum retreat of -1.38 m over the 1963 storm, assuming that the bluff bottom retreats at the same rate as the bluff top. The erosion seen along the bluffs in this area far exceeds the expected average and maximum values (including uncertainty), with the average of -3.75 m and the maximum of -11.57 m erosion. Figure 2 shows a 1964 aerial photograph of the bluffs near the Old Barrow Townsite, just to the south of Barrow village, where the location of the bluff edges in this study and the study performed by Lestak are easily compared. Although the aerial photographs used in Lestak's study are not coregistered with those in this study and the bluff bottom is used instead of the bluff top, the bluff edge locations are visually comparable to illustrate the proportion of bluff change due to the 1963 storm. At places along the Old Barrow Townsite, the erosion occurring over the 1963 storm contributed to over 1/3 of the total erosion occurring over the 49-year period. These results show that the intense storm of 1963 significantly affected the long-term bluff erosion experienced near Barrow.

Comparison of Bluff Edge Locations
1948, 1962,1964,1997

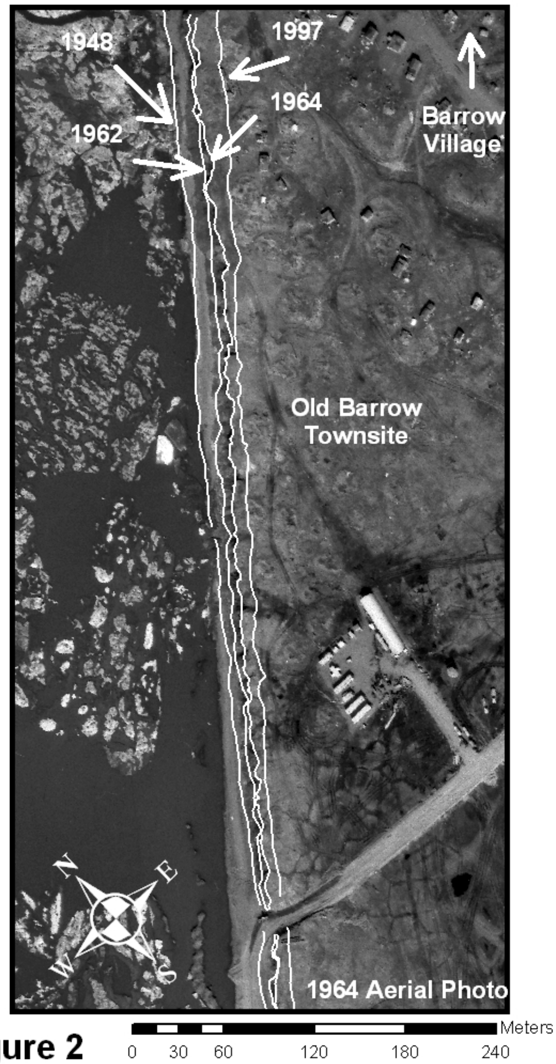

Figure 2

Beach Results

A mixture of erosion and accretion over the two-year period was found to have occurred along the beach segment of Figure 1. The measured beach shoreline change over the 1963 storm was highly spatially variable, with a range of -22.0 m erosion to 18.2 m accretion, with a standard deviation of 8.0 meters. The net beach change over the study region, however, was only 0.11 meters accretion. Different processes govern the movement of beach materials near Barrow as opposed to the bluff erosional processes described earlier. Many factors affect how much beach material is moved and where it is deposited, including wave energy and angle with respect to the shore, setting up onshore and along shore currents. Sediment size and density are also among the factors affecting the movement of beach materials. The fall storm season provides a dominant current to the northeast, producing the net longshore transport of materials in this direction due to the protection of beach materials by ice during the remainder of the year (Hume). In a study evaluating the period between 1955 and 2002, Manley found erosion rates immediately adjacent to Barrow to be averaged in the range –0.2 to –0.8 m/yr with an uncertainty of 0.07 m/yr and high local variability. This high local variability is also seen in the beach change over the 1963 storm, however with inconsistent patterns compared with the Manley 1955-2002 and the Lestak 1948-1997 study. This could indicate that intense storms affect the beach coastline differently than the processes producing the patterns seen in long-term change. Considering that the net change measured over the 1963 storm for the area of study was only 0.11 meters of accretion and that the local variability seen is not consistent with long-term trends, there seems to have been minimal contribution from the 1963 storm to long-term beach coastline change in the Barrow area.

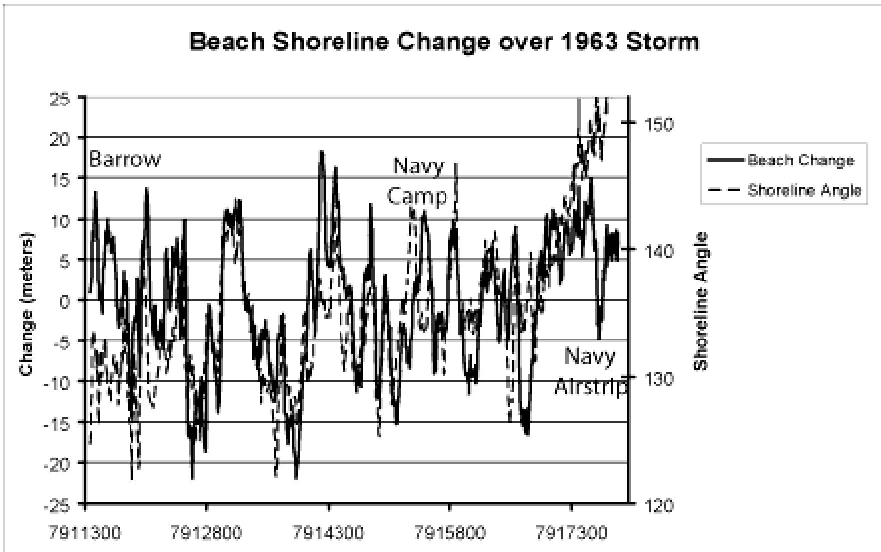

Figure 3

Addressing the spatial variability seen in the beach change over the 1963 storm, the 100-m moving average smoothed shoreline angle was compared with the shoreline change results to evaluate one main factor in beach erosion processes. Figure 3 shows this comparison for the evaluated beach waterline. This comparison is not provided for the bluff change results due to the brevity of this report and no significant correlation. Two different scales represent the angle of the shore and the measured shoreline change. A correlation is directly noticeable when the scales are adjusted for comparison. There are two distinct regions of disparity between the shoreline angle and the shoreline change, located directly in front of Barrow and at the end of the study region near an airstrip used by the Navy (currently NARL/UIC) during this time. Among the remaining factors affecting the transport of materials along the beach, these main deviations could be attributed to the human interaction with the beach in front of Barrow and at the airstrip. During this time as well as presently, beach materials were routinely moved during storms in an effort to protect valuables. Beach borrowing was also a common practice to provide gravel for construction projects by both the Navy and the town of Barrow. How much these practices affected the movement of beach materials during the 1963 storm is unknown. The correlation seen between the beach results and the shoreline angle provides a starting point for further analysis into the beach shoreline change patterns emerging from intense storm activity and is not meant to be presented as sole explanation of the results seen here.

Conclusions

As the climate continues to change, the 1963 storm represents an event that the Barrow community could see increase in frequency and intensity. From the results presented here, intense storms are the major contributors to the erosion occurring at the bluffs to the southwest of Barrow. An increase in frequency and intensity of autumn storms could substantially accelerate the erosion of these physically and culturally sensitive bluffs. The beach shoreline change experienced from the 1963 storm was highly spatially variable and quite substantial in places along the length of study. The net change, however, was minimal and the patterns seen in the shoreline change were not consistent with long-term results, suggesting different processes at work than those contributing to significant long-term change. The angle of the shoreline shows correlation with the beach change measured from the 1963 storm, guiding the direction of future work to understand the influence of intense storms on the beaches near Barrow.

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THE SEDIMENT AND ORGANIC CARBON INPUT TO THE KARA SEA FROM COASTAL EROSION

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An estimate of the sediment and organic carbon input to the Kara Sea due to coastal erosion was made based on coastal mapping and a study of the composition and the ice and organic carbon contents of coastal sediments. A total length of 15000 km of the Kara Sea coast was evaluated using GIS (Drozdov and Korostelev, 2003) and includes thermally eroded (2600 km), accumulative (6200 km), stable (5900 km), and glacierized coasts (about 300 km).

For each homogeneous segment the following values were determined: length, elevation, retreat rate, ice content, organic carbon content of sediments, organic carbon content of soils, and salinity. The main problem difficulty was to evaluate the content of organic carbon in the coastal sediments. Based on previously published data and the results of our own field work, it was established that the average organic carbon content was 0.8-1.2% in clays and 0.1-0.6% in sands. The total input of sediment, organic carbon and soluble salts was calculated as the sum of values determined for each homogeneous segment. The results of calculations are shown in Figure 1.

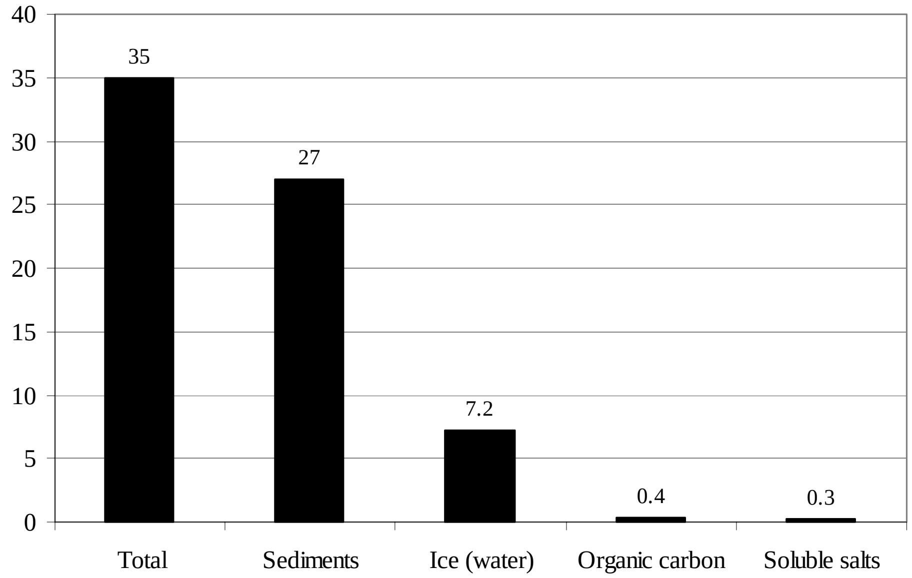

Figure 1. Coastally eroded sediment input to the Kara Sea (mil. ton/year).

A comparison of these results with the published data (Romankevich and Vetrov, 2001; Mikhailov, 1997) shows that the organic carbon input from coasts subject to thermal erosion determined by our calculations is approximately 2-3 times less than had been evaluated previously.

This work was supported by INTAS grant no. 01-2329.

MEASURING COASTAL CLIFF EROSION BY MEANS OF TERRESTRIAL PHOTOGRAMMETRY IN THE KONGSFJORDEN AREA, SVALBARD

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[2] Gjøvik University College, Gjøvik, Norway

Four sites for measuring coastal cliff erosion in the Kongsfjorden area on Svalbard (79˚ N, 12˚ E) were established in the period August 2nd to 8th 2002. The sites were measured again in August 2nd to 9th 2004. Comparison and calculation of changes in surface morphology are done. The sites were chosen to compromise different kinds of material and exposure. Both cliffs consisting of rock and deposits were chosen. The changes are generally small in this two year period. More details will be given in the presentation at the workshop.

At each of the sites fixed points were established and surveyed with GPS and traditional surveying equipment in 2002. Photos were taken at distances ranging from 7 to 15 meters from the cliff walls with a Hasselblad camera. The camera positions were also measured by surveying from the fixed points. At each site photographs were taken from 2-3 different camera positions to get 3-D coverage of the cliffs. The same procedure of surveying and photographing was repeated in 2004.

The photos are scanned and digital terrestrial photogrammetry is applied to construct digital terrain models of the cliffs. The erosion rate is simply the difference between these two sets of terrain models. Due to the short distance between camera and cliff, the accuracy is in the millimetre to centimetre range and small enough to enable measurement of the low erosion rates.

ROCK-LOADED ICEBERGS IN THE NARES STRAIT A THREAT TO NAVIGATION: TRACKING THEIR SOURCE AND POSSIBLE LINKS WITH ARCTIC WARMING

M. Zentilli, J. Crealock

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During the foggy night of August 17th, 2001, the Canadian-German Nares Strait Geo-cruise 2001 expedition on board the icebreaker CCGS Louis S. St-Laurent encountered a large tabular iceberg weighed down with dark rocks and thus barely visible to radar. The locality (80o 07.705’ N; 069o 53.908’ W) is near Cape Hayes, northeast Ellesmere Island. The iceberg had an area of ca. 6300 m2 and an average elevation of ca. 5 m. The loose rock cover formed an irregular layer between 0.01 and 1 m in thickness. The (angular) rock fragments ranged in size from 4 m blocks to fine sand and brown silt, all lying on the surface of, rather than embedded in the ice. Samples collected consist of sedimentary rocks, some fossiliferous, and a few petroliferous. Petrography, fossil identification, and limited organic maturation analyses allow matching the geology and petroleum maturation levels of the debris to strata in southern Hall Land and Washington Land. The most likely source of the rafted debris is in the 500m high steep slopes flanking the Petermann Glacier of NW Greenland. It is speculated that warm summer temperatures and a record breaking precipitation in July 2001 may have triggered mass wasting and possibly glacial surging which resulted in the calving of the encountered debris-loaded iceberg. A tanker-iceberg collision reported from near Valdez, Alaska, and recent sightings of rock-loaded icebergs as far south as the offshore petroleum producing areas of Atlantic Canada indicate that these barely buoyant icebergs may pose a significant threat to navigation.

4 Appendices

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 5th ACD Workshop.

Tuesday, October 12, 2004

19:00 – 21:00	**Ice-breaker and registration** (***Billiard Room of McGill Faculty Club, 3500 McTavish Street)***

Wednesday, October 13, 2004 ***(Thomson House, 3650 McTavish Street)***

9:00 – 9:30	**Registration**
9:30 – 10:30	**Official Welcome**, *Alan Shaver, Dean, Faculty of Science*
	Introductory Remarks, *Wayne Pollard and Volker Rachold*
10:30 – 11:00	**Coffee break**
11:00 – 12:30	**General outline of workshop program**, *Volker Rachold*
	Reports from 2003 ACD working groups (10 minutes each)
	- Coastal and Offshore Permafrost, *Hans Hubberten and Michel Allard*
	- GIS , *Frits Steenhuisen and Rune Odegard*
	- Environmental Forcing, *David Atkinson*
	- Biogeochemistry and Biodiversity, *Volker Rachold*
12:30 – 13:30	**Lunch**
13:30 – 15:00	**Plenary presentations** (10 minutes each)
	- The Shape of Erosional Arctic Shoreface Profiles, *Feliks Are*
	- ACD Key Sites: The Basis for a Coastal Observational Network, *Jerry Brown*
	- Establishment of Standardized Stations to Monitor the Response of Permafrost to Climate Change, *Georg Delisle*
	- Modeling Block Failure in Vertical Cliffs of Arctic Coasts Underlain by Permafrost, *Azharul Hoque*
	- Initiation of a Study on the Flux Transformation of Organic Carbon Across the Eroding Coastline of Northern Alaska, *Torre Jorgenson*
	- The Human Dimension of Arctic Coastal Change, *Kathryn Parlee*
15:00 – 15:30	**Coffee break**
15:30 – 17:00	**Plenary presentations** (cont'd):
	- Arctic Coastal Dynamics of Eurasia – Results of Two ACD-Related INTAS Projects, *Volker Rachold*
	- Overview of posters (1 minute each)
18:00 – 20:00	**Reception** (***Dept. of Geography, Burnside Hall, 5th floor)***

Thursday, October 14, 2004 ***(Thomson House, 3650 McTavish Street)***

9:00 –10:30	**Plenary session: Establishment of working groups and discussion of taskings,** *Volker Rachold*
	- WG1: Definition and understanding of the processes involved in the transition from onshore to offshore permafrost, *Co-chairs: Hans Hubberten and Michel Allard, Rapporteur: Pavel Rekant*
	- WG2: Impact of coastal dynamics on human populations in the Arctic, *Co-chairs: Shari Fox Gearhead, Kathryn Parlee. Don Forbes, Rapporteur: Scott Heyes*
	- WG3: Analysis of environmental forcing variables, *Co-chairs: David Atkinson and Sasha Vasiliev, Rapporteur: Olga Gruzdeva*
	- WG4: Compilation of the circum-Arctic coastal GeoInformationSystem, *Co-chairs: Frits Steenhuisen and Rune Odegard, Rapporteur: Hugues Lantuit*
10:30 – 11:00	**Coffee break**
11:00 – 13:00	**Working group meetings**
13:00 – 14:00	**Lunch**

14:00 – 15:30	**Working group meetings** (cont'd)
15:30 – 16:00	**Coffee break**
16:00 – 17:30	**Working group meetings** (cont'd)
17:30 – 18:00	**Recap of working group progress**

Friday, October 15, 2004 *(Thomson House, 3650 McTavish Street)*

9:00 – 9:30	**Plenary session. Taskings for the day**, *Volker Rachold* **Presentation**: - Recent Coastal Dynamics and Sea Level Change on Melville Island, Western Canadian High Arctic, *Patrick Lajeunesse*
9:30 – 11:00	**Working group meetings** **ArcticNet meeting,** *Co-chairs: Don Forbes, Wayne Pollard and Michel Allard*
11:00 – 11:30	**Coffee break**
11:30 – 13:00	**Working group meetings** **ArcticNet meeting** (cont'd)
13:00 – 14:00	**Lunch**
14:00 – 15:30	**Working group meetings** (cont'd)
15:30 – 16:00	**Coffee break**
16:00 – 17:00	**Working group meetings** (cont'd)
17:30 – 18:00	**Recap of working group progress**
19:00 – 22:30	**Banquet** (***Main Dining Room, McGill Faculty Club, 3500 McTavish Street)***

Saturday, October 16, 2004 *(Peel and De Maisonneuve Rooms, Marriott Residence Inn)*

8:30 – 10:00	**Discussion about ACD book and recap of workshop**, *Volker Rachold* **Free afternoon / ACD Steering Committee Meeting**
10:00 – 12:00	**Final plenary session**

Sunday, October 17, 2004

9:00	**Departure from Montreal**
12:00	**Arrival in Quebec City**
12:00 – 12:30	**Lunch**
12:30 – 14:30	**Tour of the polar research vessel CCGS Amundsen**
14:30 – 17:00	**Free time to visit Old Quebec City or tour of Laval University's Centre d'études nordiques with M. Allard**
17:00 – 19:00	**Dinner at Cochon Dingue restaurant**
20:00	**Depart Quebec City**
23:00	**Arrival in Montreal**

Appendix 4. Participants of the 5th ACD Workshop.

1. **Michel Allard** (Michel.Allard@cen.ulaval.ca), Université Laval, Sainte-Foy, Quebec, Canada
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Appendix 5. Author index.