Arctic Coastal Dynamics

Report of an International Workshop

Potsdam (Germany) 26-30 November 2001

Edited by Volker Rachold, Jerry Brown and Steve Solomon

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Preface

Arctic Coastal Dynamics (ACD) is a joint project of the International Arctic Sciences Committee (IASC) and the International Permafrost Association. 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 second IASC-sponsored international workshop was held in Potsdam, Germany, on November 26-30, 2001. Participants from Canada (2), Germany (8), Norway (3), Russia (6), Austria (2) and the United States (5) attended. The main objective of the workshop was to review the status of ACD according to phase 1 of the Science and Implementation Plan. During the first part of the workshop status reports of the ACD working groups and several papers dealing with different aspects of circum-arctic coastal dynamics were presented. During the second part the progress and the next steps of the ACD working groups were discussed and, based on these discussions, the next steps were identified in the Steering Committee Meeting. The present report summarizes the program and the results of the workshop.

Financial support from the International Arctic Sciences Committee (IASC) is highly appreciated and was essential for conducting the workshop. Additional support was provided by the International Permafrost Association (IPA).

Table of Contents

Preface

1 **History and Development of ACD** 1

2 **Program of the Workshop** 5

3 **Extended Abstracts** 11

Establishment of the Elson Lagoon ACD Key Site, Barrow, Alaska *(J. Brown, T. Jorgenson, O. Smith and W. Lee)* 13

PANGAEA – an information system for environmental sciences *(M. Diepenbroek, H. Grobe, M. Reinke, U. Schindler, R. Schlitzer, R. Sieger and G. Wefer)* 16

Shore dynamics on the northwest coast of the Lena Delta, Laptev Sea, Siberia *(M. N. Grigoriev, F. E. Are, H.–W. Hubberten, S. O. Razumov and V. Rachold)* 17

Numerical modeling of shelf and estuary hydrodynamics in the Kara Sea *(I. H. Harms, J. O. Backhaus and U. Hübner)* 18

Sediment flux in arctic rivers *(R. M. Holmes, J. W. McClelland, B. J. Peterson, A. I. Shiklomanov, I. A. Shiklomanov, A. V. Zhulidov and V. V. Gordeev)* 20

Monitoring of coastal dynamics at Beaufort Lagoon in the Arctic National Wildlife Refuge, Northeast Alaska *(M. T. Jorgenson, J. C. Jorgenson, M. Macander, D. Payer and A. E. Morkill)* 22

A circum-arctic coastal geo information system (GIS) *(M. Lack, V. Rachold and H. Asche)* 29

Integrated assessment of the impacts of climate variability on the Alaska North Slope coastal region *(A. Lynch, R. Brunner, J. Curry, A. Jensen, J. Maslanik, L. Mearns, G. Sheehan and J. Syvitski)* 30

Describing Beaufort Sea coastal climate variability *(G. Manson, S. Solomon and A. MacDonald)* 31

Evolution of the coastal lake-lagoon-barrier island system of North Arctic Alaska – a synthesis *(A. S. Naidu and J. J. Kelly)* 35

Application of the wind-energetic method of Popov-Sovershaev for investigation of coastal dynamics in the Arctic *(S. A. Ogorodov)* 37

Organic carbon in permafrost sediments under thermal abrasion: load into marine basin and oxidation in aeration zone *(V. Ostroumov, D. Fyedorov - Davydov and V. Sorokovikov)* 43

Modeling coastal erosion near Barrow, Alaska *(S. D. Peckham, W. Manley, M. Dyurgerov and J. P. M. Syvitski)* 46

Ice content and sensitivity analysis based on landscape interpretation for several sites along the Beaufort Sea coast *(W. Pollard, C. Omelon, N. Couture, S. Solomon and P. Budkewitsch)* 48

Investigation of sea level change in the Arctic Ocean *(A. Proshutinsky)* 52

Terrestrial material fluxes in the North-Asian Arctic Seas: coastal erosion vs riverine transport *(I. P. Semiletov)*....54

Amethyst project overview *(A. I. Sharov)*....55

Coastal erosion in Alaska *(O. P. Smith)*....65

Beaufort Sea coastal mapping and the development of an erosion hazard index *(S. Solomon and P. Gareau)*....69

Arctic Paleo-River Discharge (APARD) - report on 2000 activities *(R. Stein)*....71

Siberian river run-off in the Kara Sea: characterization, quantification, and variability through late Quaternary times *(R. Stein and the SIRRO Scientific Party)*....72

Sediment inclusions in Alaskan coastal sea ice: spatial distribution, interannual variability and entrainment requirements *(A. P. Stierle and H. Eicken)*....74

Carbon content in coastal ecosystems of Russian Arctic *(V. Stolbovoi)*....75

Some problems of coastal mapping in the Russian Arctic *(A. A. Vasiliev)*....77

Coastal dynamics in Marre-Sale, Kara Sea: a new observation program *(A. A. Vasiliev, G. A. Cherkashev, B. G. Vanshtein, Y. G. Firsov and M. V. Ivanov)*....78

New approaches for the metadata development *(E. Vyazilov, N. Mikhailov, V. Ibragimova and N. Puzova)*....80

Measurements of coastal change in the Russian Arctic and at Svalbard by means multi-temporal aerial photographs and digital photogrammetry *(B. Wangensteen, R. Ødegård, T. Eiken and J. L. Sollid)*....85

4 Appendices 91

Appendix 1: Information to be included in a metadata form for arctic coastal key section....93

Appendix 2: Proposed coastal classification....94

Appendix 3: Ground-ice estimates and mapping....95

Appendix 4: Recommendation for coastal change monitoring sites....96

Appendix 5: Environmental data requirements....97

Appendix 6: Guidelines for Arctic Coastal Dynamics mapping and data template....99

Appendix 7: Program of the 2nd ACD Workshop....101

Appendix 8: List of participants of the 2nd ACD Workshop....103

1 History and Development of ACD

Shore dynamics directly reflecting the complicated land-ocean interactions play an important role in the balance of sediments, organic carbon and nutrients in the Arctic Basin. Nevertheless, the contribution of coastal erosion to the material budget of the Arctic Seas has often been underestimated. In recent years, however, several studies underlined the importance of coastal erosion for the sediment budget of the Arctic Seas. Reimnitz et al. (1988) made calculations for 344 km of Alaskan coast in the Colville River area and found that coastal erosion here supplied 7 times more sediments to the Alaskan Beaufort Sea than rivers. Are (1999) suggested that the amount of sediment supplied to the Laptev Sea by rivers and shores is at least of the same order but that the coastal erosion input is probably much larger than the input of the rivers. This finding was supported by Rachold et al. (2000), who concluded that the sediment flux to the Laptev Sea through coastal erosion is twice larger than the river input. In the Canadian Beaufort Sea on the other hand, the Mackenzie River input is the dominant source of sediments and coastal erosion is much less important (MacDonald et al. 1998), which indicates that pronounced regional differences in the ratio between riverine and coastal erosion sediment input have to be considered. Figure 1 shows satellite images of the East Siberian and the Beaufort Sea, which clearly show the major sources of sediment. The strong river plume of the Mackenzie River is visible in the Beaufort Sea, whereas in the East Siberian Sea high turbidities, which are related to coastal sediment input, are observed along the coastline.

The Arctic Coastal Dynamics (ACD) program is a multi-disciplinary, multi-national forum to exchange ideas and information. The overall objective of ACD is to improve our understanding of circum-arctic Coastal Dynamics as a function of environmental forcing, coastal geology and cryology and morphodynamic behavior. In particular, we propose to:

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

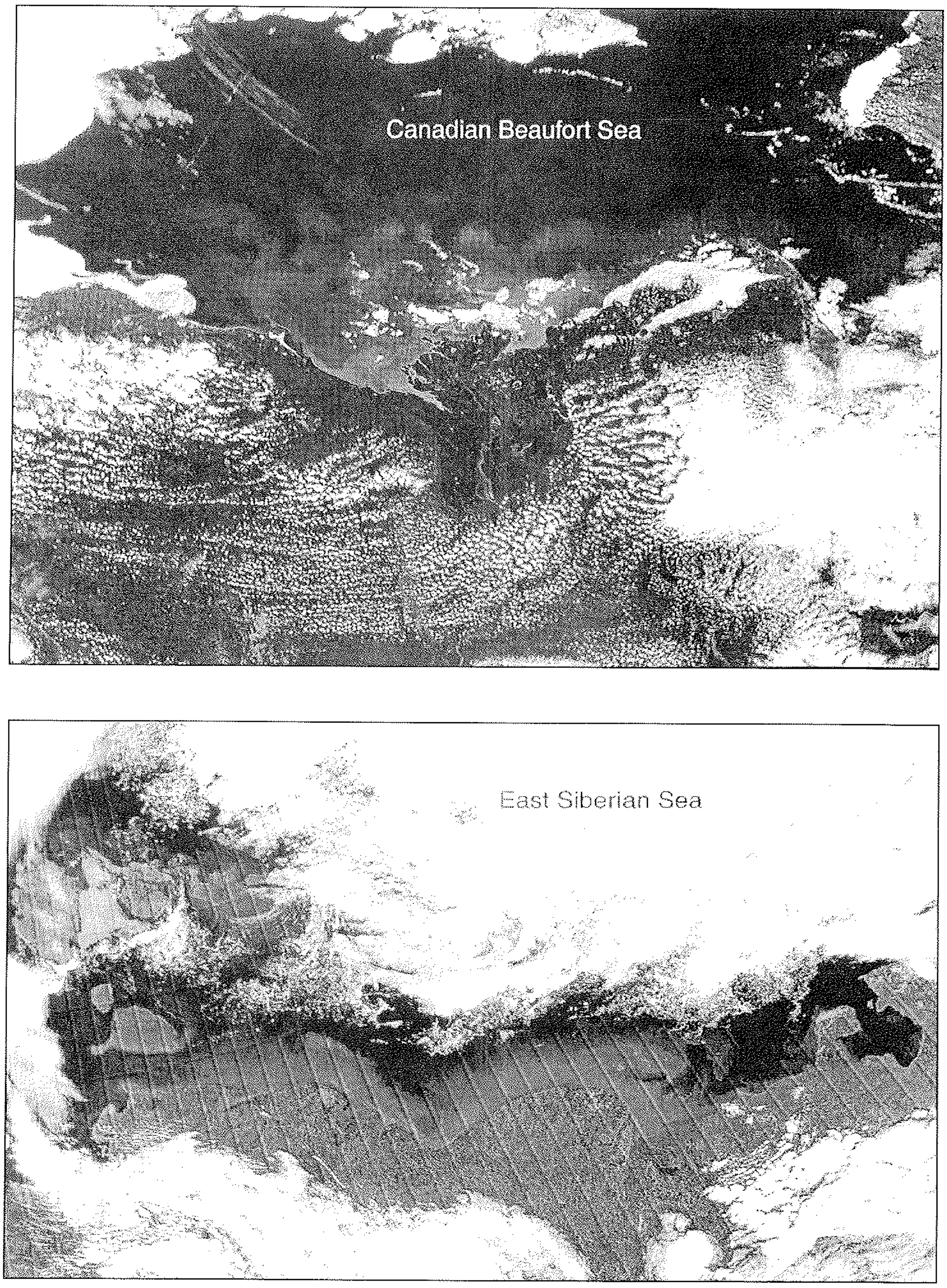

Figure 1. Satellite images of the East Siberian (bottom) and Beaufort Sea (top) showing the distribution of suspended sediments. The strong river plume of the Mackenzie River is clearly seen in the Beaufort Sea, whereas in the East Siberian Sea very high turbidities are observed along the coastline. Images are taken from http://www.visibleearth.nasa.gov.

The project elements were formulated at a workshop in Woods Hole in November 1999 carried out under the auspices of the International Permafrost Association (IPA), its working group on Coastal and Offshore Permafrost and its Coastal Erosion subgroup (Brown and Solomon 2000). As a result of the workshop a metadata form for the selection and establishment of key monitoring sites was developed (Appendix 1). A consistent and generalized coastal classification scheme was established based on morphology and materials (Appendix 2). Consensus was reached on direct and indirect methodologies for estimating ground-ice volumes and presentations of data on maps (Appendix 3). Finally, a suite of standard tools and techniques for development of long-term coastal monitoring sites was recommended (Appendix 4).

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) on 18-20 October 2000, produced a phased, five-year Science and Implementation Plan (Figure 2).

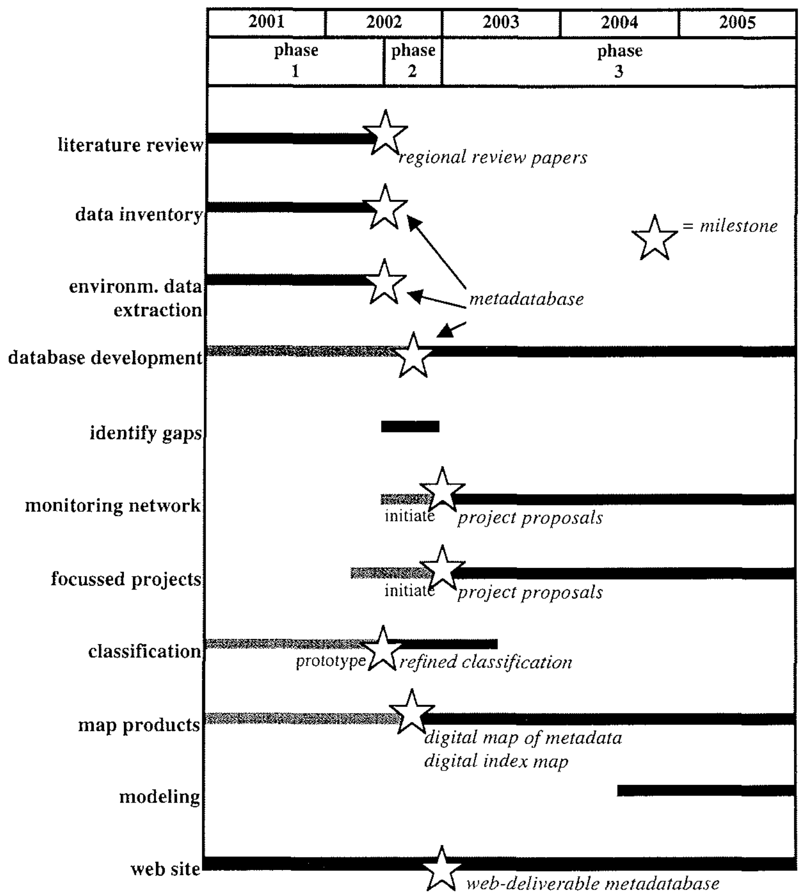

Figure 2. Main elements of the ACD Science and Implementation Plan, schedule and milestones.

The participants selected Volker Rachold to be the official IASC Project Leader. Hans Hubberten, Head of the AWI Potsdam Department, agreed to establish an ACD project office at AWI-Potsdam with a secretariat headed by Volker Rachold to maintain international communications including the web site (http://www.awi-potsdam.de/www-pot/geo/acd.html) and an electronic newsletter. The secretariat is assisted by the International Steering Committee (ISC) consisting of

- Felix Are, St. Petersburg State University of Means and Communication
- Jerry Brown, International Permafrost Association, Woods Hole
- George Cherkashov, VNIIOkeangeologia, St. Petersburg
- Mikhail Grigóriev, Permafrost Institute, Yakutsk
- Hans Hubberten, AWI, Potsdam
- Volker Rachold, AWI, Potsdam
- Johan Ludvig Sollid, Oslo University
- Steven Solomon, Geological Survey of Canada, Dartmouth

The Science and Implementation Plan (IASC Arctic Coastal Dynamics, 2001) was made available at 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 22-28, 2001), IASC officially accepted the ACD project and approved funding for the 2nd ACD workshop in Potsdam, November 26-30, 2001.

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Reimnitz E, Graves S.M., Barnes P.W. (1988) Beaufort Sea coastal erosion, sediment flux, shoreline evolution and the erosional shelf profile. U.S. Geological Survey. Map 1-1182-G, and text, 22 pp.

2 Program of the Workshop[1]

The main objective of the workshop was to review the status of ACD according to phase 1 of the Science and Implementation Plan. During the first part (Tuesday November 27 and morning of Wednesday November 28) several papers dealing with the following topics were presented. The extended abstracts are presented below.

(A) Status reports of the ACD working groups of phase 1 of the Science and Implementation Plan

- Literature review
- Metadata
- Environmental data
- Mapping and classification

(B) Scientific reports on different topics

- Reports on recent field studies and mapping (9 papers)
- Reports on remote sensing and modeling (8 papers)
- Reports on data management (3 papers)
- Reports on the sediment and organic carbon flux (7 papers)

During the second part (afternoon of Wednesday 28 to evening of Thursday 29) the progress and the next steps of the four working groups (WG) listed above were discussed:

Literature WG: Regional review articles summarizing the published information about coastal geomorphology, sediment and organic carbon yield are anticipated. At the first stage three papers dealing with the Laptev Sea (M. Grigoriev, F. Are and V. Rachold), the Beaufort Sea (S. Solomon and J. Brown) and Spitsbergen (J.L. Sollid, R. Ødegård and B. Wangensteen) will be prepared. Based on a bibliography of Russian literature related to ACD, which was presented during the workshop, review papers of the Russian coasts will follow (for names of responsible persons see Mapping and Classification WG).

Environmental data WG: Appendix 5 shows a list of environmental data, which will be considered. The Canadian Geological Survey (S. Solomon) is recruiting a post doctoral researcher who will be responsible for the extraction of ACD relevant environmental data.

Metadata WG: A circum-arctic coastal geographical information system (GIS) to display the metadata information was presented during the workshop (see Lack et al. abstract, p. 29). The existing ACD key sites are listed in Table 1 and indicated in Figure 3, which shows the Digital Elevation Model of the circum-arctic coastal GIS. During the following discussion on metadata it was decided to include the Metadata WG in the Mapping and Classification WG and to add a section on data management.

[1] The complete program and the list of participants are given in Appendices 7 and 8.

Table 1. List and locations of 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)

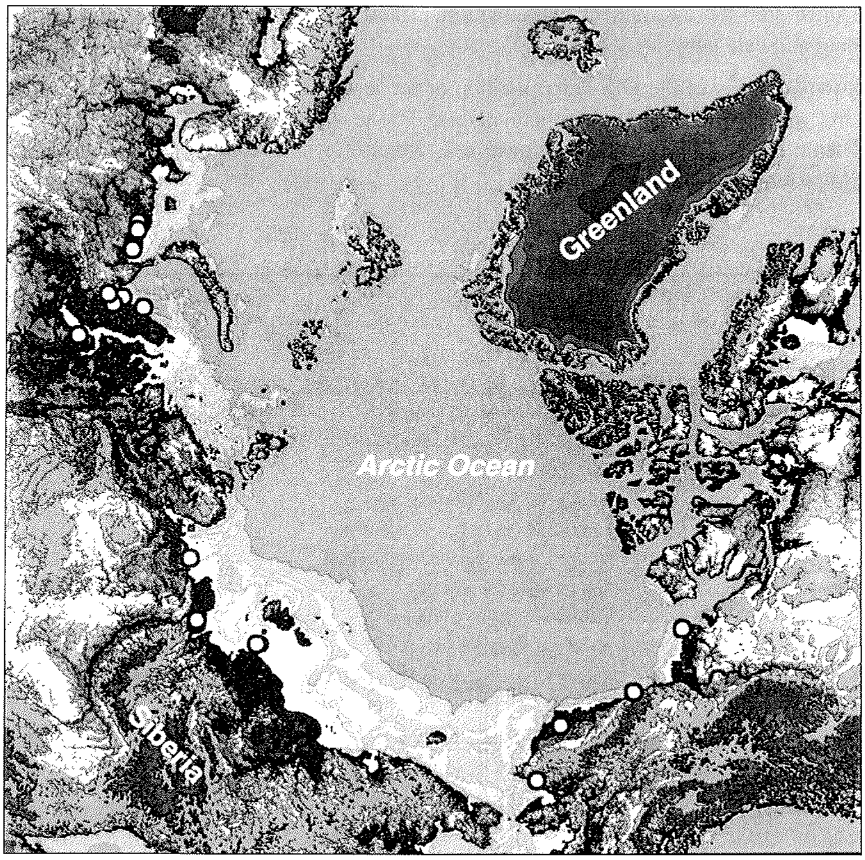

Figure 3. Circum-arctic coastal geographical information system (GIS) showing the digital elevation model and the ACD key sites.

Classification and Mapping WG: The participants agreed that at this stage of the project the highest priority is given to the assessment of sediment and organic carbon fluxes to the Arctic Ocean through coastal erosion. Accordingly, a coastal mapping template (Table 2), which allows coastal scientists to record information about arctic coasts, was developed. It will be used for a circum-arctic database of coastal retreat and sediment and organic carbon input. Regional experts will be responsible to define homogeneous coastal segments and apply the coastal mapping template following the instructions presented in the guidelines for the ACD mapping and data template (Appendix 6). The completed templates are to be submitted to vrachold@awi-bremerhaven.de and, after quality-check, will be imported into PANGAEA (www.pangaea.de). PANGAEA is the AWI web-deliverable data system for environmental and geological sciences (see Diepenbroek et al. abstract, p. 16). For further GIS based analyses the coastal data can be exported from the PANGAEA system. These analyses will include:

- the determination of the length of the coastline for the individual coastal segments based on the GEBCO coastline;
- the quantification of volume of eroded material based on morphology; and

- as a third step the assessment of the sediment and organic carbon flux based on the mapping and data template.

To check the accuracy of the GIS determination of the length of the coastline (fractal error), GIS-experts will compare the values obtained on the basis of the GEBCO coastline with that obtained from high-resolution digital coastlines, which are available for test areas (Lena Delta and Spitsbergen).

Table 2. ACD mapping template.

Coordinates of Segments	Latitude Start Longitude Start Latitude End Longitude End
Information Used to Define Segments	Surficial Geological Unit Source of Surficial Geological Unit (Reference) Soil Unit Source Soil Unit (Reference) Landscape Unit Source Landscape Unit (Reference)
Organic Carbon	Soil Organic Carbon (%) Sediment Organic Carbon (%) Average Organic Carbon (%) Source Organic Carbon Data (Reference)
Material	Material Source Material (Reference)
Ground Ice	Upper Ground Ice Content (%) Thickness of Upper Ground Ice Unit (m) Lower Ground Ice Content (%) Average Ground Ice Content (%) Source Ground Ice Content (Reference)
Change Rate	Change Rate (m) Change Rate Interval (years) Source Change Rate (Reference)
	Backshore Elevation (m) Source Backshore Elevation (Reference) Vertical Datum Reference Distance to 10 m Isobath (m) Source Distance to 10 m Isobath (Reference) Depth of Closure (m) Source Depth of Closure (Reference)
Remarks	Problems, Comments, Additional Information
Classification According to ACD Science and Implementation Plan	ACD Onshore Classification ACD Backshore Classification ACD Frontshore Classification ACD Nearshore Classification

Regional experts:

- Spitsbergen, Northern Norway, Greenland: Sollid, Ødegård, Wangensteen, Møller
- Barents and Kara Sea: Vassiliev, Ogorodov (supported by Nikolaev for Barents Sea and Bolshiyanov for western Taymyr Peninsula)
- Laptev Sea: Grigoriev, Are, Rachold
- East Siberian Sea: Ostroumov, Rasumov
- Chukchi Sea: Pavlidis
- Alaskan Beaufort Sea: Brown, Jorgensen, Naidu et al.
- Canadian Beaufort Sea: Solomon, Taylor, Pollard, Omelon, Forbes

Based on the WG discussions, the following next steps were identified in the Steering Committee meeting (Friday 30 November):

1. Classification and Mapping: The regional expert submit the completed EXCEL table with the coastal data following the guidelines for the ACD mapping and data template to vrachold@awi-bremerhaven.de. The data will be imported to the PANGAEA system. Since this topic has the highest priority, we agreed to start with the ACD key sites.

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

3. Literature review: The bibliography of the Russian coastal literature will be revised and completed. The regional experts identified in the Mapping and Classification WG are responsible for writing the literature review articles. We did not announce a deadline, but expect the articles to be ready for submission by mid- 2002.

4. ACD relevant meetings

- Arctic Workshop (Boulder, 14-16 March 2002): ACD presentation by S. Solomon
- Arctic Science Summit Week (Groningen, 21-27 April 2002): ACD presentation at the Arctic Ocean Science Board by V. Rachold
- Annual Meeting of the Russian Permafrost Community (Pushchino, 12-15 May 2002): special ACD session to be organized (chairpersons: Are and Rachold)
- International Permafrost Conference (Zurich, 21-25 July 2003): special session on coastal permafrost
- Arctic Margins Meeting (Halifax, 29 September – 3 October 2003): special session on arctic coasts

5. Next ACD workshop

- To be organized in Oslo, November 2002

3 Extended Abstracts

ESTABLISHMENT OF THE ELSON LAGOON ACD KEY SITE, BARROW, ALASKA

Jerry Brown[1], Torre Jorgenson[2], Orson Smith[3] and William Lee[3]

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[2]*ABR, Inc, P.O. Box 80410, Fairbanks, AK, 99708; email: tjorgenson@abrinc.com*

[3]*School of Engineering, University of Alaska Anchorage, 3211 Providence Dr., Anchorage, AK 99508-8054; email: afops@uaa.alaska.edu*

During summer 2001 a key site was established at Barrow, Alaska, as part of the Arctic Coastal Dynamics program (Brown and Solomon 2000). The site is located along Elson Lagoon, extending approximately 11 km and composed of four distinct segments (see Figure 1 and Table 1). This lagoon coastline forms the eastern boundary of the Barrow Environmental Observatory (BEO); a protected research area of 3021 hectares.

Observations of erosion rates along this section of the Beaufort Sea coast date back to the late 1940s by MacCarthy, and later by Lewellen in the 1960s. Bluff elevations in the study area average 2.5 m and are dominated by polygonal ground consisting of ice-rich, fine-grained sediments, reworked peats, and ice wedges.

During the past year, three activities were accomplished: (1) establishment of historical rates of erosion based on a time series of aerial and satellite images between 1949 and 2000; (2) establishment of permanent transects and bench marks; and (3) bathymetric surveys offshore from selected benchmarks.

Table 1. Metadata parameters for Elson Lagoon key site, Barrow, Alaska.

Segment	Length (km)	Ave. loss (m/yr) [ha] 1979-2000	No. bench marks	Length of offshore profile (km) [max. water depth (m)]
A	2.9	0.74 [4.4]	4	8.8 [6.0]
B	2.0	0.65 [2.8]	1	10.7 [3.7]
C	3.4	0.90 [6.4]	2	7.9 [3.2]
D	2.5	2.75 [14.6]	3	10.1 [3.8]

(1) Erosion rates: A time series of coastline changes using sequential aerial and satellite imagery from 1949, 1962-64, 1979, 1997, 2000 was established and reported as a poster at the Spring meeting of the American Geophysical Union. Aerial photographs were rectified to a high-resolution (1 m) IKONOS summer 2000 satellite image base map. Rectification accuracy (relative to the 2000 image) ranged from 0.69 to 2.56 m RMS among periods. Photogrammetric analysis reveals high spatial variation in rates of coastal erosion. In a macroscale comparison of the 4 segments, erosion rates ranged from 0.7 m/yr to 3.0 m/yr for the period 1979 to 2000, with an overall erosion rate of 1.3 m/yr. For Segment A, mean

annual erosion rates were remarkably similar among the earlier three periods for 1949–1964 (0.6 m/yr), 1964–1979 (0.6 m/yr), and 1979–1997 (0.7 m/yr), but were much higher for 1997–2000 (1.5 m/yr). The more recent period of 1979–2000 (0.9 m/yr) is 47% higher than the period of 1949–1979 (0.6 m/yr), and 23% higher than the 51 year average (0.7 m/yr). Over the last 50 years, Section A of Elson Lagoon lost 8.6 ha of coast. Total lost for all sites between 1979 and 2000 was 28.2 ha. Field observations this past summer along Segment D revealed that this segment is composed of extensive areas of large exposed ice wedges and blocks of calving peaty tundra. This explains the greater rates of erosion as compared to Segments A, B, and C.

(2) Additional benchmarks (BM) were established at U.S. Geological Survey survey locations (MacCarthy 1953) and several additional sites. Rebars with BEO numbered survey caps were installed at 50 m and 20 m intervals from the USGS BM and perpendicular to the coast. GPS positions were recorded and measured distance from the top of the coastal bluff to the 20-m rebar were recorded.

(3) Seven offshore bottom profiles were measured on 9 and 10 August 2001. Four profile lines to 10.7 km length extended across Elson Lagoon to the shores of the enclosing the barrier islands. Three shorter lines of approximately 2 km length were measured at 500 m intervals parallel to the longer line off the most rapidly eroding Sector D. The hydrographic survey used a single-beam acoustic fathometer system with a 200 kHz narrow-beam transducer. GPS positions of soundings were logged with a horizontal accuracy of 5 to 10 meters. No broadcast of differential (DGPS) corrections was available in the area at the time of the survey.

(4) Lines off Sectors A and B reveal a submerged shoal about 1 m deep along its crest parallel to the coast, approximately 2 km offshore. The trough between the shoal crest and the mainland shore was approximately 2.5 m deep. The shoal corresponds to bathymetric trends that appear on the 1950's era topographic map, outwardly unchanged. Lines approaching Sector D are steeper nearshore than lines at corresponding offsets from adjacent Sectors A, B, and C, which is an indication of active submarine erosion. Deeper water nearshore furthermore allows more wave energy to reach further inshore. Fetches from north to northeast are longer than for Sectors A, B, and C in that directional sector.

Establishment of the Elson Lagoon site was supported by the Barrow Arctic Science Consortium (BASC) through a Cooperative Agreement with the Office of Polar Program, U.S. National Science Foundation. During summer 2001 Eric Hammerbacher and Craig Tweedie (Michigan State University) and David Ramey (BASC) assisted in site establishment and bathymetric survey, respectively. Matt Macander, ABR, assisted with the photogrammetric analyses.

In addition to this Elson Lagoon site, observations of erosion and related DEM surveys were obtained along the Chukchi Sea coastline between the town of Barrow and Point Barrow by a group headed by William Manley, INSTAAR, University of Colorado, Boulder, Colorado. Ideally this stretch of Chukchi Sea coastline will be incorporated into the Barrow ACD Key Site. This area will be the subject modeling of coastal erosion by the INSTAAR group (see Manley et al. abstract).

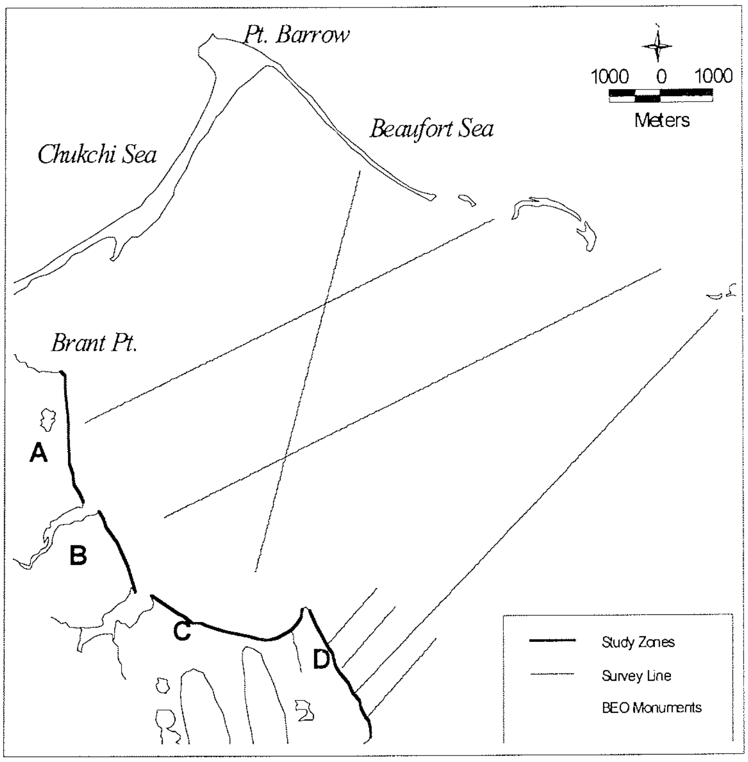

Figure 1. Location of Elson Lagoon Erosion Segments and Hydrographic Survey, Summer 2001, Barrow, Alaska.

PANGAEA – AN INFORMATION SYSTEM FOR ENVIRONMENTAL SCIENCES

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PANGAEA is an information system for processing, longterm storage, and publication of georeferenced data related to earth science fields. Essential services supplied by PANGAEA are project data management and the distribution of visualization and analysis software. Organization of data management includes quality control and publication of data and the dissemination of metadata according to international standards. Data managers are responsible for acquisition and maintenance of data. The data model used reflects the information processing steps in the earth science fields and can handle any related analytical data. The basic technical structure corresponds to a three tiered client/server architecture with a number of comprehensive clients and middleware components controlling the information flow and quality. On the server side a relational database management system (RDBMS) is used for information storage. The web-based clients include a simple search engine (PangaVista) and a data mining tool (ART). The client used for maintenance of information contents is optimized for data management purposes. Analysis and visualization of metainformation and analytical data is supported by a number of software tools, which can either be used as 'plug-ins' of the PANGAEA clients or as standalone applications, distributed as freeware from the PANGAEA website. Established and well documented software tools are the mini-GIS PanMap, the plotting tool PanPlot, and Ocean Data View (ODV) for the exploration of oceanographic data. PANGAEA is operating on a longterm basis. The available resources are sufficient not only for the acquisition of new data and the maintenance of the system but also for further technical and organizational developments.

SHORE DYNAMICS ON THE NORTHWEST COAST OF THE LENA DELTA, LAPTEV SEA, SIBERIA

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During the last decade the dynamics of the Laptev Sea coastline have been investigated in detail at a number of sites, mainly along ice-rich coasts. Nevertheless, there are some gaps in respect of the evolution of accumulative coastal forms and retreating sandy cliffs in the Lena Delta. Previous studies of erosive sandy coasts in the north of the delta (1999) have shown that the retreat rate of such shores is very high - up to several meters per year. However, there is no reliable information about shoreline dynamics in the area where accumulative and erosive processes proceed jointly. Such section, about 100 km long, characterized by active sedimentation in the near-shore zone was selected on the West Coast of the Lena Delta.

In July-August 2001 field studies of the chosen section have been conducted by the coastal team of the Russian-German expedition "LENA 2001". Seven key sites, including retreating erosive sandy shores with low ice content and accumulative longshore sandbars (barrier islands), were investigated in order to define the long-term (about 30 years) rates of shoreline changes. Geodetic measurements have been carried out at the key sites, using a laser theodolite, to obtain the modern position of the shores and their altitude. Theodolite profiles and bench marks recorded in the field were identified and compared with aerial photographs and maps.

The preliminary analysis of our field data shows that the rates of shore accretion and retreat are moderate in this area. The average retreat rate of the cliffs is 0.6 m • year^{-1} (0.2-1.5 m • year^{-1}). The lowest retreat rates were observed at cliffs blocked by vast shallows and the highest rates at sites adjacent to a relatively deep shoreface. A displacements of the crest of the long and narrow barrier islands in both offshore and onshore directions as large as 2.5 m/year during 32 years were measured in several sections. But on the whole these islands remain stable. Only marginal parts of barrier islands show a distinct movement towards the land. New field data allow us to evaluate more precisely the Laptev Sea coastal dynamics and sediment balance, and promote better understanding of the evolution of arctic coasts.

NUMERICAL MODELING OF SHELF AND ESTUARY HYDRODYNAMICS IN THE KARA SEA

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Climate relevant processes such as ice formation and river runoff but also environmental issues caused increasing research activities in Arctic shelf regions during the last years. Compared to other Arctic Shelf Seas, the Kara Sea receives the largest amount of freshwater and offers a rather complex topography ranging from very shallow estuaries down to 400 m deep troughs.

In the frame of the bilateral German/Russian project SIRRO and the EU project ESTABLISH, a high resolution baroclinic 3-d circulation and sea ice model is applied to the Kara Sea. The model is forced with realistic atmospheric winds, heat fluxes, river runoff and tides.

Previous model simulations revealed a strong seasonal variability in circulation and hydrography. Whereas in winter, the water column is vertically mixed by strong thermohaline convection due to cooling and ice formation, the spring and summer situation is characterized by pronounced vertical stratification due to freshwater runoff, atmospheric warming and ice melting. A frequently observed phenomena in summer is the intrusion of cold and saline bottom water into the estuaries of Ob and Yenisei which leads to a sharp vertical boundary layer between two essentially different water bodies, even in these very shallow coastal zones.

Strong river runoff in spring but also high wind speeds during winter produce temporarily high current speeds in the estuaries and along the Taymyr coast. Simulated tidal currents are strongest in the Baydaratskaya Bay and near the Ob estuary. In a small strait between Yamal and Belyy Island, tidal currents may exceed 50 cm/s due to considerable horizontal gradients in tidal elevation. Tracer simulations show that these areas are significantly influenced by tidal mixing.

In order to reproduce complex estuary and shelf processes more realistically, a newly developed Vector Ocean Model (VOM) is applied to the existing Kara Sea shelf topography. One main advantage of VOM is the vertical adaptive gridding technique which provides high resolution in critical areas such as shallow estuaries, slopes and topographic obstacles. The surface and bottom following boundary layers are resolved uniformly in 4 m intervals. This allows for a better reproduction of stratified flows (current shear), coastal currents and slope currents.

Our recent model investigations concentrate on coastal processes in the Ob and Yenisei mouth. A main focus is the shape and extent of the river plume which is of vital importance for the freshwater export to the Arctic Ocean but also for transport of river effluents and the position of the fast ice edge in winter.

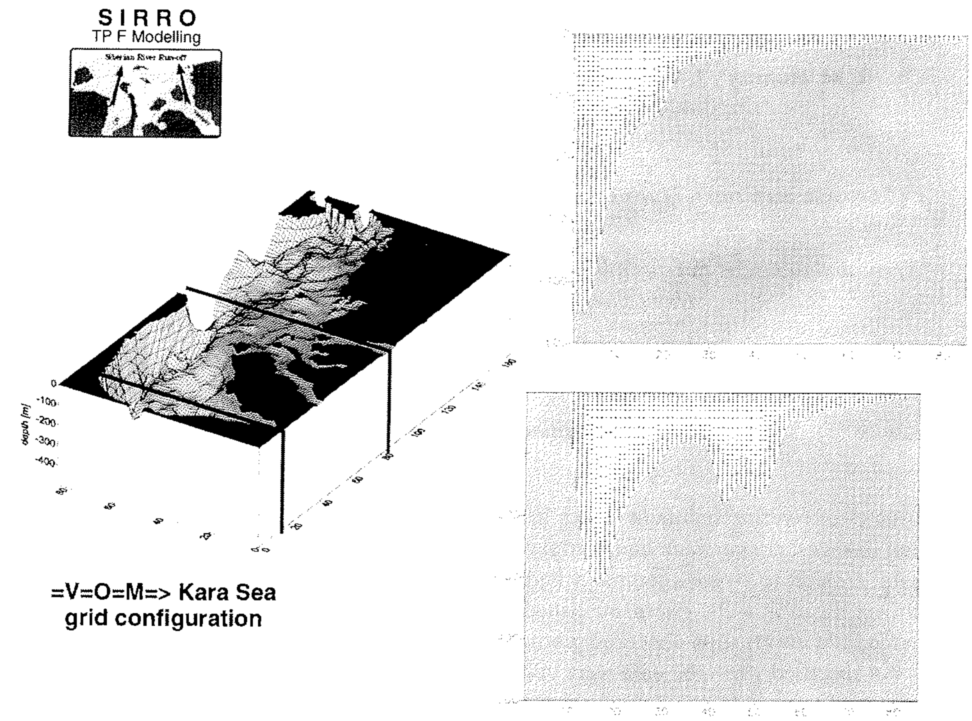

Figure 1. Vector Ocean Model (VOM) of the Kara Sea.

SEDIMENT FLUX IN ARCTIC RIVERS

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Estimates of riverine sediment fluxes in the Arctic are fundamental to understanding land-ocean linkages, contaminant and nutrient transport, coastal processes, and the significance of coastal erosion to overall sediment budgets. Although numerous estimates now exist for sediment fluxes in arctic rivers, published values for a given river often vary substantially yet provide little information concerning how the estimates were actually derived. In some cases it is not specified when the data were collected, even though substantial changes in sediment fluxes might result from dam construction, deforestation, agricultural activities, dredging, and/or climate change. Propagation of old estimates into the recent literature does not take these changes into account. Moreover, several different methods are used for determining sediment concentrations and calculating sediment fluxes. These methods often yield different results, further confounding comparisons of various estimates. Direct measurements and sediment rating curves can both yield good estimates of sediment loads, but reliability of estimates made with either approach only can be determined when details of sampling, calculations, and correction factors are reported. Given the likelihood of significant temporal changes due to recent anthropogenic influences and the potential for differences in estimates depending on methodological approaches, interpretation of sediment flux estimates in the absence of detailed accessory information is tenuous.

Our overall objective is to provide a pan-Arctic synthesis addressing sediment flux from large rivers to the Arctic Ocean and coastal seas. We focus on 9 of these rivers, namely the Yenisey, Lena, Ob', Mackenzie, Yukon, Kolyma, Pechora, Severnaya Dvina, and Colville rivers. Ideally, for each river we would be able to answer 1) How much sediment is transported annually? 2) How much sediment is retained in deltas or estuaries compared to being transported all the way to the coastal ocean? 3) How does sediment flux vary over the course of the year? 4) How has sediment flux changed over the past several decades? and 5) How might sediment flux change in the future?

Using existing data, some published but some not (we also rely on newly compiled Russian data), we answer these questions as fully as possible. In some cases the answers are relatively complete, whereas in other cases a great deal of uncertainty is apparent. For example, a recent publication thoroughly documented contemporary sediment flux to the Mackenzie River delta, including a detailed description of methods and estimates of uncertainty, whereas in some other cases essentially no accessory information is available. This summary serves to clarify issues requiring further investigation and helps to focus future efforts in these areas.

MONITORING OF COASTAL DYNAMICS AT BEAUFORT LAGOON IN THE ARCTIC NATIONAL WILDLIFE REFUGE, NORTHEAST ALASKA

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ABSTRACT

A key site for monitoring coastal dynamics was established along the Beaufort Lagoon in the Arctic National Wildlife Refuge, northeastern Alaska, in 2001 to contribute to the international network of monitoring sites coordinated by the Arctic Coastal Dynamics working group. At the key site, three monitoring transects 400–2350 m long were permanently established for periodic measurements of water levels, current velocities, surface elevations, thaw depths, and electrical conductivity. Offshore, maximum water depths were 3.3 to 3.6 m on the three transects and current velocities in the lagoon ranged from 0.01 to 0.08 m/s. Eroding bluffs were 1.7–3.4 m high and had a thin (10–11 cm) fibrous peat accumulations at the surface underlain by a thin (17–23 cm) eolian silt deposit. Below these surface layers were thick accumulations of disrupted, amorphous peat clumps extending as deep as 1.5 m. Ice contents were higher in the sand-sheet deposit with intermixed organic masses (72–79% vol.) at Transect 2, than in the two abandoned floodplain deposits (45–79%). Photogrammetric analysis of aerial photography from 1948 and 1978, and IKONOS imagery from 2001, revealed a mean erosion rate of 0.5 m/yr (SD ±0.3, n=61) for the 1948–1978 period and 0.5 m/yr (SD ±0.4) for the 1978–2001 period along a 10 km stretch of coastline. Erosion, however, varied from 0 to 1.5 m/yr along the coast over the 53-yr period, indicating that permafrost characteristics have a large affect on erosion rates.

INTRODUCTION

Erosion rates of coastlines dominated by ice-rich permafrost are among the highest on Earth. Although erosion is limited to 3-4 months of ice-free water, rates may exceed 10 m/yr (Lewellen 1970). While numerous studies in the 1970's and 1980's provided a wealth of data on the spatial distribution of erosion along the Beaufort Sea coast (Lewellen 1970, Hopkins and Hartz , Naidu et al. 1984, Reimnitz et al. 1988), little work has been done to document recent erosion or the temporal changes in erosion rates. Accordingly, erosion and accretion of northern coasts are the focus of a new international project on Arctic Coastal Dynamics (ACD) designed to assess the contribution of coastal erosion to the sediment and carbon budget of the inner continental shelf (Brown and Solomon 2001).

The Beaufort Lagoon site in northeastern Alaska was selected as a monitoring site for this international effort because the site already is a long-term terrestrial ecological monitoring site for the U.S. Fish and Wildlife Service, it is representative of a broad length of coastline with a barrier island and lagoon system, and it is accessible by plane. In addition, data collection at the site supports the Arctic Refuge's Ecological Monitoring Plan by augmenting the existing ecological monitoring at the site, and by providing information relevant to management of the refuge's ambulatory Beaufort Sea coast boundary, which is defined by the dynamic barrier islands (Morkill and Vandergraft). Specific objectives of this monitoring were to: (1) establish three baseline transects for future erosion assessment, (2) to assess oceanographic, topographic, and pedologic conditions at the sites, and (3) document past erosion rates by developing a time series of georectified aerial photography from 1949 and 1980 and IKONOS imagery from 2001.

METHODS

Establishment of a key site at Beaufort Lagoon followed the protocols of the ACD program. Three transects for monitoring onshore/offshore profiles were set up perpendicular to the coast within a 10-km shore segment (Figure 1). Each transect started from 100 m onshore. Transect 1 (N69.88424°, W142.3350°; NAD83) was 400 m long, Transect 2 (N69.8848°, W142.3009°) was 2350 m long, Transect 3 (N69.87194°, W142.2854°) was 420 m long. Ground surface elevations along the terrestrial portions of the transects were measured with an autolevel and measuring tape. A permanent benchmark was established at the beginning of each transect and reference stakes were driven into the ground every 25 m. The elevations of the benchmarks were approximated by measuring water levels periodically during the field visit. Offshore bathymetry was measured using a portable depth sounder for water depth, and distance along the transect was determined with a military GPS (accuracy 1-5 m). The transect course was maintained by backsighting on the row of reference stakes.

Environmental data collected at each transect included measurements of bluff stratigraphy, estimates of ground ice volume based on soil observations or thaw pond depths, thaw depths, driftline locations, vegetation composition, and electrical conductivity of surface/soil water. On the tundra portion of each transect, data were collected on ground surface elevations (every 1 m), water surface elevations (where present), thaw depths (every 2 m), and electrical conductivity of surface water (every 25 m). For each bank exposures, descriptions were made of soil texture and ice morphology, and samples were collected for ice content, particle size, organic carbon, and radiocarbon dating. Ground and oblique aerial photographs were obtained for each transect for a visual record. Water levels in the lagoon during ice-free periods in 2000 (15 July – 17 August) and 2001 (1 August – 27 September) were obtained with a VEMCO Minilog TDR submersible temperature and depth sensor with a 0.1 m depth resolution. Water levels were recorded every 15 minutes.

To assess rates of past coastal erosion, a time series of coastline changes was developed using sequential aerial photographs (1948–1950, 1979) and IKONOS satellite imagery (2001). Using ERDAS Imagine software, aerial photographs were rectified to the high-resolution (1 m) IKONOS satellite image based on prominent features, such as the intersection of ice-wedge polygons. Rectification accuracy (relative to the 2001 image) was 1–3 m. After rectification, coastlines for each year were digitized on screen following the edge of the vegetated surface (usually top of bank). Changes in coastline were measured at 61 points along the coastline by measuring perpendicular distances between lines. Mean changes in distance were calculated for the two periods 1948-1979 and 1979 and 2001.

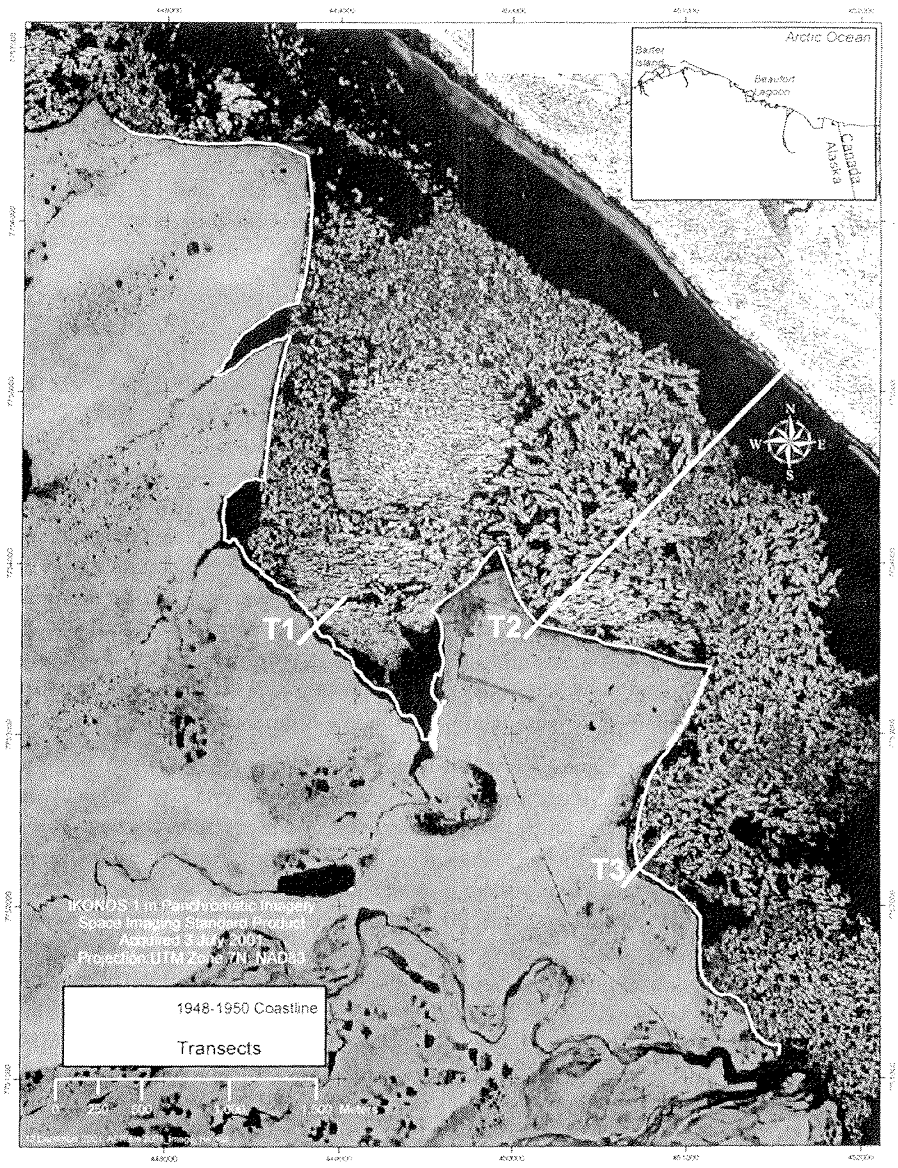

Figure 1. Location of coastal monitoring transects at Beaufort Lagoon, Arctic National Wildlife Refuge, northeastern Alaska. The coastline derived from 1948-1950 photography (white line) is overlaid on an IKONOS image acquired in 2001.

RESULTS AND DISCUSSION

OCEANOGRAPHY

Water-level monitoring for 65 days in 2000 and 58 days in 2001 revealed peak water surface elevations of 1.0 m and 0.5 m above mean sea level, respectively (Figure 2). Mean daily tidal variations were 0.31 m in 2000 and 0.29 m in 2001. Seasonally, high tides varied by 0.3 to 0.5 m on a weekly basis depending on atmospheric conditions.

The unusually high water levels on 11 and 12 August 2000 were the result of a severe storm that originated over northern Siberia, tracked east over the Chukchi Sea, and then moved to the northeast into the Beaufort Sea. The National Weather Service reported a sustained wind at 54 mph and a peak wind at 64 mph between 3 and 5 PM at Barrow, and 38-mph sustained winds, with gusts to 54 mph at 7 AM on August 11th, at Barter Island. At Barter Island, the storm caused damage to homes and flooding of the airport runway. A recent driftline at Transect 1 had a maximum elevation of 1.1 m and presumably resulted from the 2000 storm.

The coastal bluffs are protected by a long barrier island system extending from the mouth of the Kongakut River to Camden Bay. Fetch distances for wave development from northeast winds for Transects 1–3 are 2750 m,1980 m, and 2600 m respectively. Spit development evident on the aerial photography is to the northwest, indicating dominant northwest flow of water. Two measurements of currents in the middle of the lagoon indicated very low current velocities (0.1–0.8 m/s).

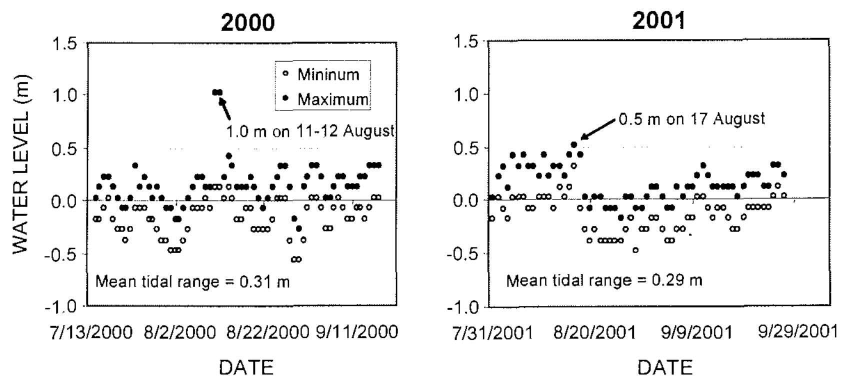

Figure 2. Mean daily maximum and minimum water levels during the ice-free periods in 2000 and 2001 at Beaufort Lagoon, Arctic National Wildlife Refuge, northeastern Alaska.

TOPOGRAPHY AND BATHYMETRY

Bank heights for Transects 1–3 were 1.7 m, 3.4 m, and 2.1 m respectively. The foreshore slopes were narrow, ranging from 4 to 8 m wide (Figure 3). Maximum water depths in the lagoon ranged from 3.3 to 3.6 m. At Transect 2, which extended all the way across the lagoon, the barrier island had steep landward and seaward profiles and rose only 0.5 m above water level.

PERMAFROST CHARACTERISTICS

Soil stratigraphy obtained from bank exposures at the three transects revealed a range of soil characteristics. Transects 1 and 3 were situated on abandoned floodplain deposits and Transect 2 was situated on a sand sheet possibly of glacial origin. All exposures had a thin (10–11 cm) fibrous peat accumulation at the surface underlain by a thin (17–23 cm) eolian silt deposit. Below these surface layers were thick accumulations of disrupted, amorphous peat clumps extending as deep as 1.5 m. Ice contents were higher in the sand sheet deposit with intermixed organic masses (72–79% vol.), than in the two abandoned floodplain deposits (45–79%). Ice wedges were wider (4 m across at the surface) and more dense in the older sand sheet deposit that in the abandoned floodplain (2 m).

Despite having the highest contents of both segregated and wedge ice, Transect 2 had the lowest erosion rate (see below). We attribute this lower erosion rate to the height of the bank and coarser soil materials. Because the bank at Transect 2 was about twice a high as the other transects, the volume of material that must be removed by erosion is nearly double. The coarser soil reduces erosion by providing small amounts of gravel that accumulates on the beach surface and reduces movement of fine-grained material.

COASTAL EROSION RATES

Photogrammetric analysis of aerial photography from 1948–1950 and 1978, and IKONOS imagery from 2001, revealed a mean erosion rate of 0.5 m/yr (SD ±0.3, n=61) for the 1948–1978 period and 0.5 m/yr (SD ±0.4) for the 1978–2001 period along a 10 km stretch of coastline (Figure 1). The comparison of erosion rates between periods indicates there has been no change in long-term erosion rates. Erosion, however, varied from 0 to 1.5 m/yr over the entire coastline. Specific erosion rates for Transect 1–3 were 0.7, 0.5, and 1.0 m/yr, respectively.

Erosion rates observed at Beaufort Lagoon are less than those observed along other stretches of the Beaufort Sea coast. At Elson Lagoon near Barrow, erosion rates over a 21-year period from 1979 to 2000 were 0.9, 0.7, 0.9, and 2.8 m/yr for 4 short (2.0–3.4 km) coastal segments (Brown et al. 2001). Over a broader area near Elson Lagoon, Lewellen (1970) measured mean erosion rates of 2.8 m/yr (SD ±2.5, n=13) with a maximum of 10.0 m/yr. Mean rates of coastal bluff retreat at Simpson Lagoon over a 25-year period (1955–1980) were 1.1 m/yr (SD ±1.0, n=33) with a maximum of 5.4 m/yr (Naidu et al. 1984). For the coast between the MacKenzie Delta and Demarcation Bay, Mackay (1963) determined a mean retreat rate of 2.5 m/yr. For a 344 km stretch of coast extending from Drew Point to Prudhoe Bay, the mean rate of coastal retreat was 2.5 m/yr (excluding accretionary shoreline along Colville Delta) over a thirty year period with a maximum of 18 m/yr (Reimnitz et al. 1988). We attribute the lower rates at Beaufort Lagoon to: (1) shallow water in the lagoon which reduces wave height, (2) close proximity of barrier islands to the coastal bluffs which reduces fetch, and (3) to the prevalence of pack ice outside of the lagoon system (northeast corner of Figure 1) which dampens wave energy during storm surges.

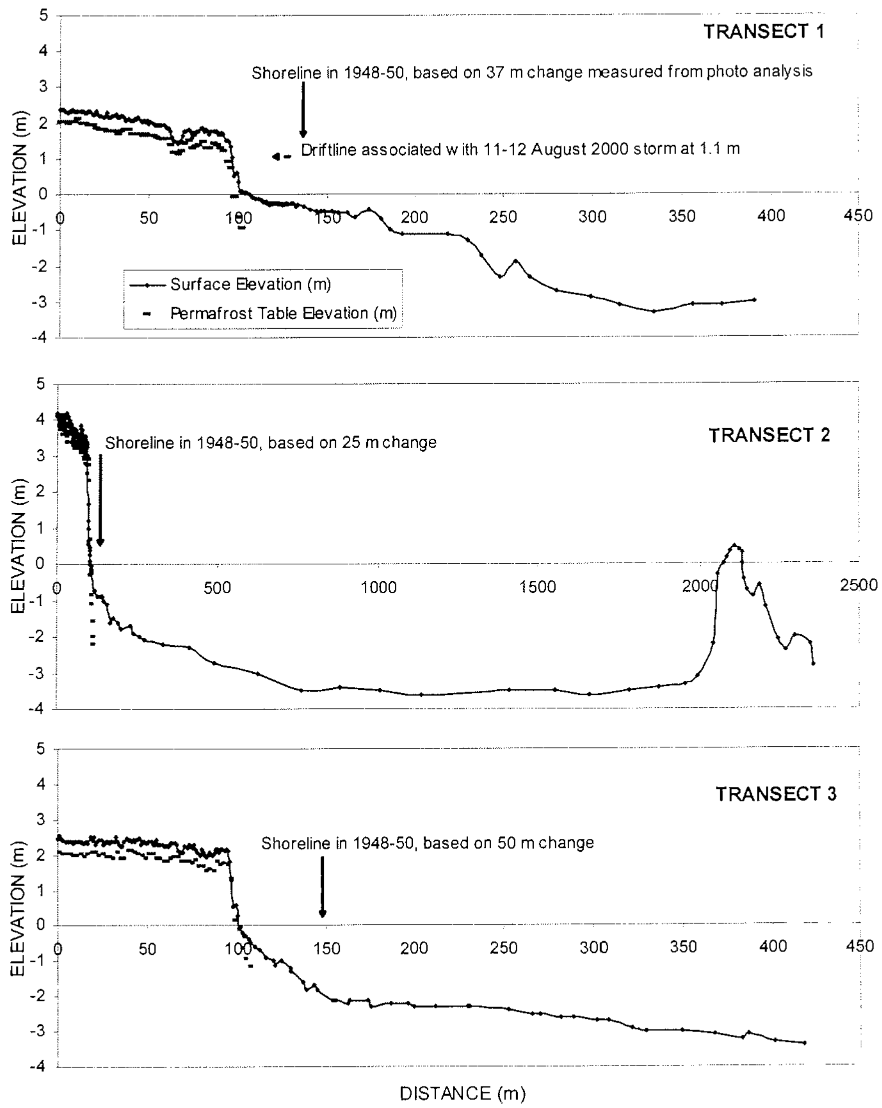

Figure 3. Topographic profiles for permanent monitoring Transects 1–3 at Beaufort Lagoon, Arctic National Wildlife Refuge, northeastern Alaska.

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A CIRCUM-ARCTIC COASTAL GEO INFORMATION SYSTEM (GIS)

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In this talk a circum-arctic Geo Information System (GIS) to display generalized information on coastal characteristics, which is currently being developed according to the ACD (Arctic Coastal Dynamics) Science and Implementation Plan, is presented.

To establish a Digital Elevation Model (DEM) data of the «International Bathymetric Chart of the Arctic Ocean (IBCAO)», which are available in ASCII format (x,y,z) on the Internet (www.ngdc.noaa/mgg/bathymetry/ artic/arctic.html), were used. The data were imported into ArcView / ArcInfo and transferred to a GRID with a spatial resolution of 2.5 x 2.5 km. The Lambert Azimuth Equal Area Projection with the North Pole in the center (0,0) has been selected. The Metadata information of the ACD key sites has been added. Permafrost parameters adopted from the Circumpolar Active-Layer Permafrost System CD-ROM were incorporated and are available in a separate layer.

This Arctic coastal GIS will serve as a basis for the visualization of coastal characteristics and for further GIS-based analyses.

INTEGRATED ASSESSMENT OF THE IMPACTS OF CLIMATE VARIABILITY ON THE ALASKA NORTH SLOPE COASTAL REGION

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The focus of this project is to understand, support and enhance the local decision-making process on the North Slope of Alaska in the face of climate variability on seasonal to decadal timescales, both natural and anthropogenically induced. The primary goal is to help stakeholders clarify and secure their common interest by exchanging information and knowledge concerning climate and environmental variability. Climate variability includes slow change such as variations in average temperatures, the extent of sea ice, and the level of the permafrost over years and decades. It also includes extreme events such as storm surges, flooding events and high wind events - when they happen, how often they happen, and how severe they are.

We are now collecting what is already known by residents and scientists about (1) climate changes, including extreme events, in the region, (2) their impacts on people, animals, and plants, and (3) responses by individuals, groups, and communities.

Using this data, which includes traditional knowledge, and a range of models from local erosion models and mesoscale atmospheric models to GCMs and statistical models, we will generate a range of scenarios for changing sea ice variability, extreme weather events, storm surges, flooding and coastal erosion, and other environmental factors. These scenarios can be used to predict the probability of states that affect coastal communities, surveys and management of marine mammals, transportation and offshore resource development.

DESCRIBING BEAUFORT SEA COASTAL CLIMATE VARIABILITY

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Understanding coastal stability requires a means of describing past and future climatic forcing in such a way that it captures those variables of direct relevance to coastal processes. For the Beaufort Sea, coastal stability is largely dependent upon wind induced storm surges and associated waves. The surge height and wave intensity may in turn be functions of sea ice distribution and wind direction. Meteorological records for the Tuktoyaktuk and Pelly Island stations (1958 to 2000) were acquired from the Meteorological Service of Canada, available tide gauge data for Tuktoyaktuk (1961 to 1997) were obtained from Fisheries and Oceans Canada and the weekly Beaufort sea ice charts (1968 to 1998) were acquired from the Canada Ice Service in order to investigate the historical variability of coastal environmental forcing in the Beaufort Sea during the June to November open water season..

Using a semi-automated procedure in a GIS, areas of open water and sea ice were calculated from weekly sea ice charts for a region of interest extending from Barrow, Alaska east to Banks Island and from the Beaufort coast north to about 72°N (Fig. 1). For our purposes, open water extent was defined as the percentage of a region that was occupied by 5/10 ice or less, a cut off chosen based on literature which suggests that the development of waves is suppressed where ice cover is greater than 5/10. Our analyses show the extent and distribution of sea ice is variable over weekly to interannual and decadal time scales which is superimposed on a trend towards increasing open water in the 1990s (Fig. 2). Breakup generally occurs in June and freeze-up in October; the maximum extent of open water (reached usually in September) in any given year is related to the prevailing winds during the open water season, as wells as to the timing of breakup and freeze-up.

Investigations of the ice, wind and tidal records at Tuktoyaktuk indicated that the largest open water season surges are associated with strong winds from the NW quadrant. We examined several different cut-offs for wind speed and found that storms with wind speeds greater than 50 km/h produced many of the surges at Tuktoyaktuk. A list of 105 open water season wind events from all directions with winds speeds greater than 50 km/h for at least 6 hours was compiled. For the 58 of these with concurrent water level and ice data, peak water levels and open water extent during the event were calculated. Correlation analysis revealed statically significant positive correlation ($\alpha = 0.05$) of peak water level with mean wind speed, mean wind direction and open water extent. Stepwise multiple regression revealed that wind speed and direction contributed significantly to peak water level (together explaining 66% of the variability in water levels reached during wind storms) but that the presence of more open water did not significantly increase peak storm surge amplitude. This may indicate that, as long as open water extent is over some undetermined threshold value, there is no limiting effect of sea ice on surge amplitude. The same may be true for wave development but wave data for validation in the Beaufort Sea are unavailable.

The frequencies of occurrence of northwesterly open water season storms show a pronounced interannual and decadal variability with no apparent trend (Fig. 3). Extreme events (wind speeds over 70 km/h) are not necessarily associated with higher frequency storm periods and can occur during seasons with few other storms. To account for the coastal impacts of both individual storm events and prolonged periods of increased storm frequencies, we have investigated the development of an erosion forcing index. Daily mean squared northwest directionally weighted wind speeds were combined with interpolated daily mean percentages of open water to identify periods of both high northwesterly winds and extensive open water. The results show that climatic forcing of coastal change is highly variable from year to year with an increasing trend since 1968 (Fig. 4) which is statistically significant in the three year running mean ($\alpha = 0.05$).

The analyses for the Beaufort Sea summarized here suggest that increasing coastal instability should be anticipated during the 1990s as a result of more extensive open water coupled with more or less average storm frequency. Work is underway to examine changing erosion rates at selected locations to compare with variations in environmental forcing.

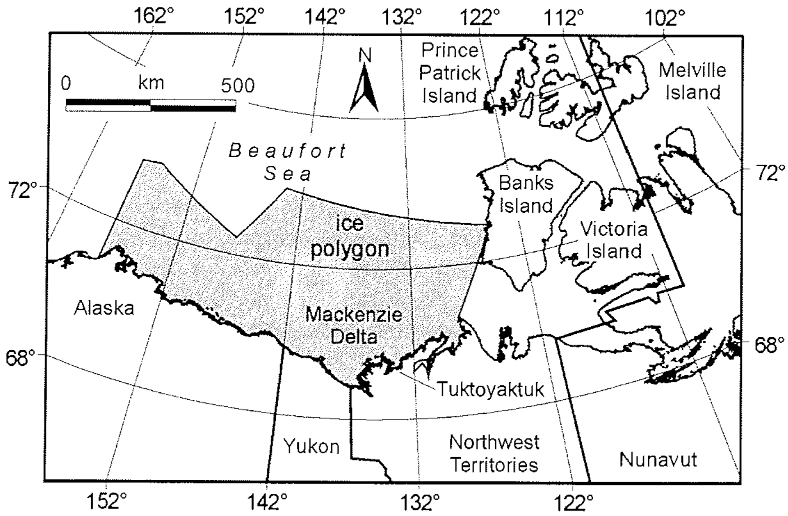

Figure 1. Polygon considered in ice analyses.

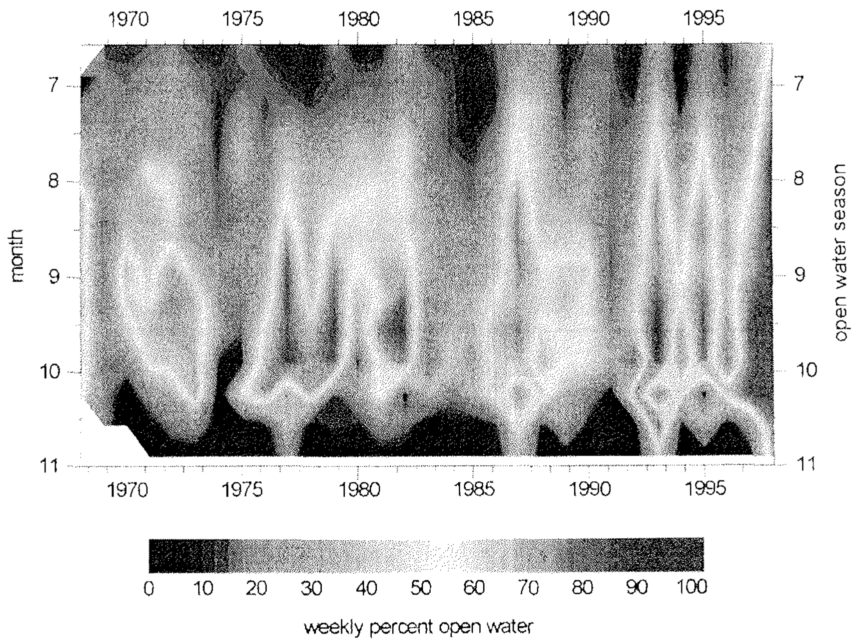

Figure 2. A time-time plot of weekly percent of open water during the open water season showing differences in timing of freeze-up and breakup since 1968. Large amounts of open water occurred in the late 1970s to early 1980s, 1987 and also since the mid 1990s.

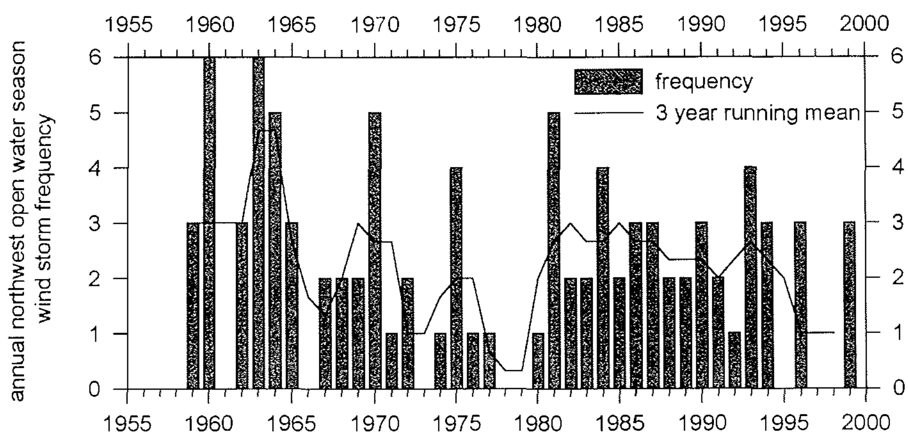

Figure 3. Annual frequencies of occurrence of northwesterly open water season wind storms greater than 50 km/h for at least 6 hours.

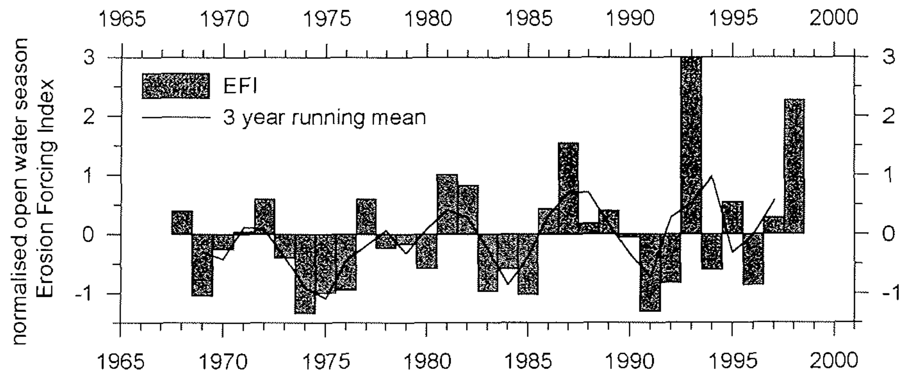

Figure 4. Normalized open water season Erosion Forcing Index (EFI) constructed from daily mean squared northwest directionally weighted wind speeds and interpolated % open water.

EVOLUTION OF THE COASTAL LAKE-LAGOON-BARRIER ISLAND SYSTEM OF NORTH ARCTIC ALASKA – A SYNTHESIS

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The Pleistocene geological processes and the presence currently of prolonged ice have led to unique geomorphic features within the coastal and near shore region of the Alaskan North Arctic. For example, from ice-wedge polygons of the Arctic Coastal Plain are evolved numerous thaw ponds and shallow (< 2 m) oriented lakes which eventually coalesce laterally to form lagoons. The processes leading to the orientation of the lakes are debatable. Generally the long axes of the lakes are oriented NNW-SSE (N. 9o W to N. 21o W.), and is popularly believed to be a consequence of the differential erosion at the axes' ends by wave-induced currents generated from prevailing NE wind. The lake's depth is restricted to <2m by the thaw bulb.

The progressive evolution of the shallow (<3 m depth) lagoons from coastal lakes is demonstrated by the gradual litho- and biostratigraphic variations showing terrestrial to marine facies changes exhibited in vibrocore samples from the Simpson Lagoon. The basal section (140-150 cm from core top) of the cores is mostly peat admixed with fine sand, silt and fossil remains of freshwater gastropod Valvata, and the pelecypod Psidium. Overlying this section is a 65-cm sequence of cross-bedded medium sand intercalated with intact (unfragmented) shells of pelecypods Cyrtodaria kurriana and Serripes groenlandicus, and several estuarine/marine species of foraminifera and ostracods. The top 75-cm of the cores is constituted of sandy silt which is mottle structure in the basal sequence and laminated at the top. A 14C date of 4500 y. B.P of the basal peat suggests that the Simpson Lagoon and, by implication other North Slope lagoons, have evolved since the post-glacial stability in the sea-level. As suggested by 210^{Pb}-based sediment accumulation rate measurements, the lagoons are a net sink for sediments derived from fluvial outflow, coastal erosion and littoral drift.

There are two types of islands off the North Slope coast. One is a disjointed remnant of the coastal plain. This island type has well-established tundra on the surface and a stratigraphy matching that of the adjacent plain and including the Pleistocene Gubik Formation. The second island type is, by definition, a barrier island as it is a recent depositional feature by littoral currents, evolving generally from progradation subaerially from bars. Some also represent breached barrier spits extending from the downcurrent end of the first type of islands. A notable feature is the presence of barrier island chains extending westward from the mouths of the major rivers of the North Slope, suggesting that the rivers are the primary sources of the gravelly-sand entrained on the island and that the sands are deposited by the westward littoral drift. Long-term monitoring of the barriers' stability indicates that many of the islands are migrating west- and landward at a rate of 6-11 m/y. At this rate the island would normally be expected to overlap the shoreline in a relatively short time. However, some distance between the islands and the shoreline is maintained presumably because of the compensating affect resulting from rapid retreat of the coast. This retreat is consequent to the loss of shoreline from high thermo-erosion (1-10 m/y) of the permafrost-dominated coast and due to the generation of lagoons from lake coalescence. Barrier islands with relatively low migration rates have well established tundra on their surface. Episodic storms (up to 100 knot wind velocity and common washovers)) accompanied by occasional intense ice-push (ivu) have devastating affect on the barrier stability and structures emplaced on them.

APPLICATION OF THE WIND-ENERGETIC METHOD OF POPOV-SOVERSHAEV FOR INVESTIGATION OF COASTAL DYNAMICS IN THE ARCTIC

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Introduction

Engineering and constructing of ports, hydrotechnical facilities and coastal terminals in the arctic coastal zone demands investigations of both coastal profile dynamics and alongshore drift characteristics over considerable distances. Interference into natural environment might disturb its equilibrium and cause negative changes in coastal zone regime and exploitation of hydrotechnical facilities.

The wave energy flow is the main driving force for both normal and alongshore drift. Wind, as an energy-carrier, determines the flux of wave energy by initiating waves and currents in the sea. It is also responsible for non-periodic sea-level changes and, as a result, re-distribution of bottom deposits. It is wind that generates waves and determines the intensity of coastal abrasion, direction and amount of sediment flux. Sediment discharge indices are usually proportional to the wave energy flux values. Thus, remote determination of the lithodynamic conditions in the coastal zone of a certain region demands calculation of the wave energy characteristics.

The main advantage of this method is the fact that it is cheaper than field observations. Another advantage is the possibility to determine parameters of sediment fluxes and evolution of the coastal zone for several years, that is usually impossible to do during one field season. An essential fault of the method is approximate and sometimes questionable results because of insufficiently developed theory of lithodynamic processes. Lithodynamic systems are a multi-factor phenomenon, and introduction of any new parameter into a model increases the extent of deviation of the result from the natural characteristics. Hence, it is expedient to justify the results of modeling by field observations.

Several hydrometeorological methods to calculate wave energetic characteristics exist now. Besides this, numerous empirical formulae could be also used but with certain caution because most of them have been obtained in course of local observations and could be hardly applied for general situations. Most of the above mentioned methods are usually based on semi-empirical correlations. Fluxes of wave energy are expressed in arbitrary units. The methods find limited use because they do not take into account the effect of swell and, sometimes, the influence of water basin depth. It is appropriate to use these methods for unraveling the general tendency of coastal evolution. The latter is important for forecasting future development of coastal processes especially in case of finding ways for coastal protection. They also play an essential role in reconstructing the history of coastal evolution.

To solve more specific engineering tasks, for instance, silting up of ports or channels, it could be sometimes more useful to apply wave-energetic methods instead of calculating wave energy on the basis of average multi-annual wind regime. These methods take into account the influence of swell and, also, the degree of deformation and refraction of waves in the coastal zone.

Application of the wave-energetic methods in the arctic seas is limited by the absence of reliable instrumental data on wave regime. Besides this, most stations of wave monitoring are usually located in the areas protected from the waves and do not reflect the wave regime of the open sea. In the shallow seas the boundary of the coastal zone is often located far offshore being invisible for an observer. Under such conditions the elements of waves could be hardly reliably determined.

Calculation of the wave energetic characteristics

To determine coastal wave energetic characteristics of the arctic coastal zone, the special method for calculating the wave energy fluxes based on wind data has been worked out in the Laboratory of Geoecology of the North, Moscow State University (Popov, Sovershaev, 1979, 1981, 1982).

The method is based on the theory of wave processes and takes into account the established correlations between wind speed and parameters of wind-induced waves (Rukovodstvo, 1969).

Calculation of the wave energetic characteristics for the outer coastal zone boundary

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

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

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

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

$$E_{0sw} = 2\times10^{-6}\left(\frac{gH}{V_{10}^2}\right)^{1.4} V_{10}^5 , \quad (2)$$

where E_{0sw} has the same dimension as in the equation (1). Equation (2) is valid in case two conditions are fulfilled. For shallow sea basins, i.e. for most of the arctic seas, wave energy is determined in accordance with kinematic index of shallowness $\frac{gH}{V_{10}^2}$ between water depth H along the wind direction and wind speed V_{10}. At $\frac{gH}{V_{10}^2} \leq 3$ water depth hampers formation of wind-induced waves.

Another condition is determined by the following reasons: a wave starts to interact with the sea floor when it becomes high enough after it has covered a certain ideal way without touching the sea floor, i.e. when it has developed in the deep-sea basin where the equation (1) is valid. Hence, at the boundary between deep-sea and shallow zones both equations should be valid. From this it follows that that the correlation between the minimum distance of wave racing at which the interaction between waves and sea floor starts and the water depth at the distance of wave racing is:

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

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

At $\frac{gH}{V_{10}^2} = 3$ equation (3) becomes

$$\frac{gx_{\min}}{V_{10}^2} \geq 30, \quad (4)$$

that is in good correlation with the shallow water conditions described by other equations (Bychkov, Strekalov, 1971). From (4) we can get the value of extreme distance of wave racing for deep-sea conditions equal to the value obtained by other means (Titov, 1969):

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

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

In order to turn from the energy flux per second to the average multi-annual monthly sum of energy of waves of a certain direction, values E_0 (calculated for all gradations of wind speed of each direction) should be multiplied by the average multi-annual overall duration of winds of a certain gradation for a month or ice-free period of a month expressed in seconds:

$$t = 8{,}64\times10^2\, pn, \quad (6)$$

where p – frequency of the winds of certain gradation in %, n – average number of dynamically active days during a month. Then the obtained values are summarized for each rhumb.

The average multi-annual rhumb fluxes of wave energy – E_r are represented by a sum of energy of waves of all gradations within a certain rhumb during dynamically active period.

Energy resultant of waves at the outer (marine) boundary of the coastal zone could be calculated by geometrical summation of rhumb components by constructing energetic polygons (Munkh-Peterson, 1933).

Calculation of wave energetic characteristics in the nearshore zone

Calculations by the Popov-Sovershaev's method are aimed at estimation of the wave energetic characteristics in the most dynamically active nearshore zone where waves interact with the shore.

Calculations are performed for certain coastal patches where the shore-segment could be considered linear. This allows considering the effect of wave refraction (Popov, 1965). Wave energetic characteristics for nearshore zone are calculated with the use of average multi-annual rhumb fluxes of wave energy per year (E_r) and the angle at which waves reach the outer coastal zone boundary (α_0) expressed by the angle between bisectrixes of rhumb sectors and coastline. In case rhumb sector is partly overlapped by the coastline, necessary corrections are introduced into the angle values.

To calculate the average multi-annual values of the normal (E_n) and alongshore (E_l) components of the total wave energy flux of a certain rhumb and taking into account the refraction effect, the following equations were obtained:

$$E_n = E_r \sin\alpha_0 \sqrt{1 - 0{,}32\cos^2\alpha_0}\ , \qquad (8)$$

$$E_l = \frac{0{,}16 E_r \sin\alpha_0 \cos^2\alpha_0}{\sqrt{1 - 0{,}32\cos^2\alpha_0}}\ . \qquad (9)$$

Equation (8) gives the value of the total normal wave energy flux at the outer coastal zone boundary against 1 m of the coastline. Equation (9) gives the approximate estimation of the alongshore wave energy flux per about 1 m of the nearshore zone width. In these equations, numerical factors reflect the joint influence (within the rhumb sector 45°) of corresponding angular functions and averaged function of the wave steepness, thus giving evidence for the refraction effect. In reality, they have maximum ± 5% error and could be applied for both deep-sea and shallow water conditions.

Algebraic sum of rhumb values (E_n) and (E_l) for all rhumbs gives overall average multi-annual normal and alongshore fluxes of coastal energy at the given coastline section.

The method was practically tested by comparison of the calculations with the results of the wave-energetic method, and also by compiling schemes of coastal dynamics of the arctic, Caspian and Baltic seas. In most cases the calculation data are in good accordance with morphological characteristics of the coasts.

Coastal fluxes of wave energy and their role in coastal dynamics

Intensity of coastal abrasion, direction and discharge of sediment drift flows and sedimentation rates are determined by direct influence of waves and wave-induced alongshore and other currents that consume most part of wave energy. Thus, calculation of wave energy fluxes including their normal and alongshore components is the initial stage in the analysis of coastal zone evolution and engineering investigations in the coastal zone.

In particular, correlation between the normal and alongshore components gives evidence for the tendency of the coast evolution, i.e. predominance of either abrasion or accumulation (Popov, 1972), and also about lithodynamics of submarine coastal slope. In the latter case alongshore energy fluxes are of special importance since they produce alongshore drift of sediments playing essential role in coastal dynamics.

The character of alongshore drift is closely related to composition of sediments. Gravel and pebbles move at relatively strong waves. They are usually dragged over the sea floor. Maximum discharge occurs in the zone of beach sands. At such waves up to 60% of sands are transported in the form of suspension. At weak and moderate waves most sand particles are also dragged over the sea floor. As a whole, under similar conditions sands are by an order of magnitude more mobile than pebbles.

Alongshore drift could be rather long near straightened coasts (Zenkovich, 1962). Such drift is able to pass several zones with different hydrometeorological and morphological conditions.

At certain parts of the coasts alongshore fluxes of wave energy may either strengthen or weaken. Correspondingly, this results in either enhanced coastal abrasion or intensive sedimentation in the coastal zone and formation of coastal accumulative forms.

Short drifts of different direction appear along embayed coasts. They usually end in the innermost points of bays or at the protruding shore cusps like accumulative capes (Zenkovich, 1962). In this case zones of divergence of sediment drifts intercalate with the zones of convergence. These zones play an important role in the process of size and density distribution of transported sediments.

Wave energetic characteristics do not allow to quantitatively estimate the drift capacity and its variations. They rather give evidence for relative intensity of sediment transportation at different parts of the coast. Calculated alongshore wave energy fluxes reflect peculiarities of the evolution of coasts over considerable distances because they allow determining dynamic characteristics of this evolution (zones of divergence and convergence, zones of enhancing and weakening energy fluxes).

Accumulation of poorly size-sorted sediments should take place in the zones of convergence of alongshore wave energy fluxes. Well-sorted sediments are accumulated in the regions where these fluxes sharply weaken. Such zones are of little use for construction of ports and seaway channels. However, if sufficient amounts of sediments are accumulated on the submarine slope it could be used as submarine quarries of building materials.

In the zones of divergence, i.e. enhancement of alongshore wave energy fluxes, coastal and bottom erosion takes place. These areas are well suited for construction of ports and seaway channels, but could be hardly used as quarries. Under favorable metallogenic conditions zones of divergence of weak fluxes are promising for enrichment in mineral component.

Thus, information about the structure of alongshore wave energy fluxes allows estimating the regime of sediment drift along considerable parts of the shore and its small patches. As mentioned above, this is important for analysis of coastal dynamics for the purpose of industrial development of coasts.

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ORGANIC CARBON IN PERMAFROST SEDIMENTS SUBJECTED TO THERMAL ABRASION: INPUT TO THE MARINE ENVIRONMENT AND OXIDATION IN THE ZONE OF AERATION

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INTRODUCTION

The Kolyma lowland is the object of long-term research of the Pushchino Cryosol Laboratory. The following processes are studied within the framework of Arctic Coastal Dynamics program: coastline retreat, superpermafrost water drainage, runoff of organic matter, carbon dioxide emission, and oxidization processes in the aeration zone of sediment. This work estimates the flow of organic carbon into marine environment under the influence of thermal abrasion of permafrost sediments. The oxidation of organic carbon is studied to determine its losses and for indication of thermal abrasion intensity on the base of the degree of oxidization transformation in the zone of aeration.

The Kolyma lowland represents a typical example of coastal lowlands of northeast Eurasia. The steady lowering of the surface has taken place during the upper Pleistocene and Holocene. During these periods, the continental syngenetic permafrost sediments were formed. The upper part of permafrost sediments is combined mainly by water continental aleurite. Less often a thin layer of eolian sand is present. The syngenetic ice-rich sediments of Edoma formation (ice complex) is widespread in the zone of potential thermal abrasion. The Taberite silts occur in the secondary frozen closed lake taliks. Complexes of slope sediments are present in the thermal abrasion cliffs. Areas of both thin eolian sands (Khalarcha formation) and the ice-free ancient Taberited silt (Olor formation) are absent in the modern zone of thermal abrasion.

METHODS

The following simple equation describes the intensity of organic carbon flow into marine environment under the thermal abrasion:

$$I = C*V - L,$$

where I is the flow of organic carbon from unit of vertical section of abrading cliff (kg/m^2 year); C is the content of organic carbon in the eroding section (kg/m^3); V is the rate of thermal abrasion (m/year); and L is flow of organic carbon into the atmosphere (emission of the carbon dioxide formed at the expense of oxidation in a zone of an aeration, kg/m^2 year).

The method of wet combustion was used for determination of organic carbon. The observations for the coastline retreat were carried out at fixed key sites. Losses of organic carbon (l) were calculated as the difference between the bulk emission of carbon dioxide and the emission connected with the total CO_2 content in permafrost sediment. The bulk emission was determined by chamber technique. The CO_2 content was determined by gas analysis of thawed sediments.

RESULTS AND DISCUSSION

Organic carbon contents

The Edoma icy complex consists of ice-rich, bog-lake (marsh) sediments. Aleurite material contains 0.5 - 4 % of organic carbon in the form of a scattered detritus. The buried peat lenses contain up to 15-20 % organic carbon. The greatest content of organic carbon (more than 30 %) are associated with woody deposits.

The Olor formation was formed as a marsh deposits, however it has experienced thawing under reducing conditions (closed lake taliks?). Similar to the Edoma silt, they are combined mainly by aleurites and contain buried lenses of peat. In contrast to the Edoma deposits, the Olor sediments are compacted, have low ice content, and are rich in casts of ground-ice wedges. The Olor aleurite contains 0.5 - 3.5% of organic carbon. The buried peat lenses have up to 10-15% of organic carbon.

The young permafrost Taberites are dated from the bottoms of the thermokarst depressions. Their secondary freezing occurred under opened system conditions with formation of segregation of ice and ice wedges. The content of organic carbon is 2-6 % in allevrite material of this Taberites. As a rule, it is covered by modern peat with the organic carbon contents of 20-30 %.

The slope deposits are extremely inhomogeneous in a structure. They have a lower ice content compared to the Edoma sediment and are usually more compacted. The contents of organic carbon varies between zero (pure silt) and 30-35 % (peat facies).

Rate of thermal abrasion

The important factors influencing the thermal abrasion rate are: composition and structure of sediment, ice content, slope morphology, intensity of wave dynamics, and temperature of frozen ground and marine water. The direction of flow of the superpermafrost water plays an important role for the intensity of thermal abrasion.

If the superpermafrost flow is directed to the thermal abrasion slope, the intensity of thermal abrasion is at a maximal. For Edoma deposits these maximum values reach 4-7 m/yr. For compacted Taberites, the maximal intensity of thermal abrasion is equal 0.5 - 2.7 m/yr. If superpermafrost water flow drains away from the cliff (usually to a lake depression), the thermal abrasion has minimal intensity (tens of centimeters per year for Edoma and close to zero for compacted deposits).

The geochemical data show that specific profiles form on steady slopes. These profiles are differ based on massive cryogenic structure (orientation of the segregated ice inclusions), contents and distribution soluble salts, metallic species, magnetic susceptibility, and other parameters. Oxidizing processes takes place in the zone of aeration of thawing deposits on slopes. The degree of the transformation of material in the aeration zone can be used for determination of the surface age and of the intensity of thermal abrasion. The parameters of organic carbon can by use as indicators of transformation, including those of iron and sulfide systems.

Losses of the organic carbon during the oxidation

The losses of organic carbon at the expense of CO_2 emission do not exceed the percent of total organic carbon content. At the same time, the available data show that the oxidizing transformation of organic carbon takes place in the zone of aeration on the slopes under low intensities of thermal abrasion.

TASKS FOR FUTURE STUDIES

1) Statistical determination of organic carbon contents in sediments in different permafrost deposits of the arctic lowlands;

2) Determination of thermal abrasion intensity employing direct observation of the coastline retreat;

3) Evaluation of quantity of quantity of coastal sediments as a function of thermal abrasion rates; and

4) Development of the new techniques of organic matter transformations to estimate the age of surfaces and thermal abrasion intensity.

MODELING COASTAL EROSION NEAR BARROW, ALASKA

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Coastal erosion in the vicinity of Barrow, Alaska, and elsewhere along the North Slope coastal region appears to be accelerating, and there is mounting concern for city structures and utilities. This increase in coastal erosion and flooding in the Arctic, as well as changes in the extent and thickness of sea ice, seems to be due to changes in climate and climate variability. In an effort to ascertain the current rate of coastal erosion and to understand the linkages to climate variability, our group has recently started to study this problem.

As a first step, we used differential GPS technology during the summer of 2001 to make high-accuracy measurements of the current coastline near Barrow, as well as the edge and bottom of near-shore bluffs. Differential GPS was also used to measure 63 Ground Control Points (GCP's) near Barrow. The GCP's were measured on the corners of buildings, ends of snowfences, base of telephone poles, and other features visible on small- to large-scale imagery. They are concentrated generally within 2 kilometers of the Chukchi coast (coinciding with extent of the year 2000 air photos). The GCP's will help researchers and other scientists working in the area to establish precise geographic or UTM coordinates for field sites, and to assist with georectification of aerial photography and satellite imagery. Other datasets and imagery being developed are: a high-precision DEM of the Barrow triangle (based on the 1964 CRREL 1:5000 topographic maps); nearshore and shelf bathymetry (based on a local navigational chart); and time-series orthorectified aerial photography for years 1948, 1964, 1979, 1984, and 1997. We plan to use the time series of orthophoto images to empirically document erosion rates for the last half century. All of our data products are being made publicly available on the web (www.colorado.edu/Research/HARC), and in publications as part of our objectives for data sharing and outreach to both the scientific community and the public at large.

The next phase in our project is to use a sophisticated commercial software package called Delft3D (with the Delft-Chess modules, (www.wldelft.nl/soft/d3d)) to model coastal erosion in the region in response to different climate forcing scenarios and proposed mitigation efforts such as beach nourishment. This module-based package incorporates the effects of wind, waves, tides, currents, sediment transport, and other nearshore processes. The time scale for our erosion model will be monthly to decadal, and our spatial scale will be 5 to 20 kilometers, with a grid spacing on the order of 5 meters or less. We expect, however, that we will need to develop specialized subroutines to model Arctic erosional processes that involve fast ice. A new mesoscale climate model for the region will be used to generate required wind/wave data for the hydrodynamic portion of the Delft3D model.

At this early stage in our five-year project, we are very interested in learning about similar efforts elsewhere and in getting feedback on our proposed methods. We have already begun to incorporate feedback from the Barrow and North Slope communities -- as well as from collaborative research programs in the area -- to fine-tune our research objectives and results. We recently added the Chukchi Sea, Barrow, Alaska site to the list of key sites of the Arctic

Coastal Dynamics (ACD) initiative. Our project is part of a larger, multi-investigator award from the Human Dimensions of Arctic System (HARC) program to examine the human dimensions of arctic climate variability.

ICE CONTENT AND SENSITIVITY ANALYSIS BASED ON LANDSCAPE INTERPRETATION FOR SEVERAL SITES ALONG THE BEAUFORT SEA COAST

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Climate change is one of the most important environmental issues facing the North today and its consequences will affect all northern ecosystems and human activities. Not only will the effects of climate change be observed sooner in the Arctic than in temperate regions, but also the magnitude of this change will be greater. Furthermore, nowhere else are landscapes, ecosystems and human activities more vulnerable to its effects, especially in coastal areas underlain by ground ice.

The Mackenzie Delta – Yukon Coastal Plain region of the western Canadian Arctic (Figure 1) is potentially one of the most sensitive permafrost areas in Canada. The combination of widespread ground ice, relatively moderate climate and the predicted magnitude of warming suggest that this area will change dramatically in the next 100 years. The iterative effect of climate change will involve warming permafrost, increased active layer depth, increased thermokarst, thinning sea ice, longer open water, increased storm activity, rising sea levels and accelerated coastal erosion. The synergy of these changes will produce an outcome that far exceeds impacts expected for other Arctic regions.

The research presented here aims to assess and map the sensitivity of Arctic coastal environments. Focusing on the Beaufort Sea coast, we employ (1) morphological methods to estimate ground ice content, and (2) remote sensing technologies to observe surficial changes in coastline conditions reflecting permafrost degradation. More specifically, refinements have been made to the morphological method for assessing ground ice content and a larger, additional region of coastline has been evaluated. Secondly, we have begun exploring various remote sensing and GPS tools as a means of monitoring retrogressive thaw slump erosion in this region.

PART I

The sensitivity of the Beaufort Sea coast to erosion depends on a number of factors. In order to understand the impact of storms and the effects of changing climate on coastal cliffs and shorelines, it is essential to have some estimate of their ice content. Ground ice investigations have been conducted at several locations across the Arctic yielding valuable information on the relationships between different forms of ground ice, the enclosing sediments, and the geomorphology of the terrain units in which the ice is formed. Sample data on ground ice along the Beaufort Sea coast is available for a limited number of sites, including Komakuk Beach, King Point and Kugmallit Bay; nevertheless, ice content in other areas can be estimated by extrapolation of this data as well as the combined evaluation of surface morphology and sediment texture.

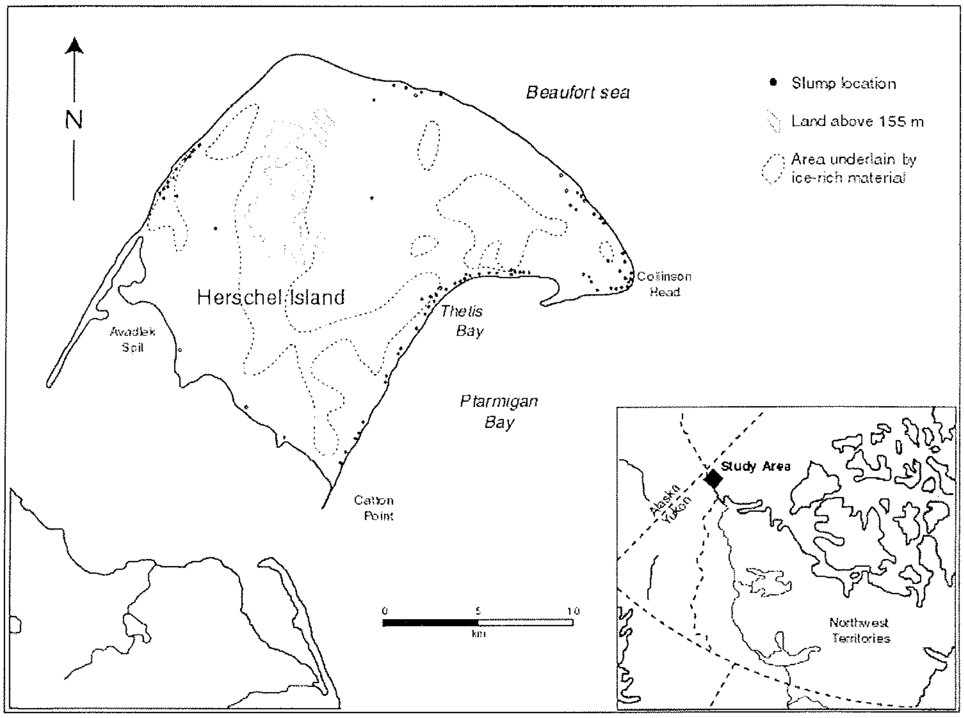

Figure 1. Herschel Island study area, Yukon coast, Canada.

In 1999 the development of a morphological method for assessing ground ice content was devised and applied to several sites along the Beaufort Sea coast (Figure 2). Based on the surface geology, layers in each terrain unit are assigned a percentage ice volume due to pore ice and thin segregated ice lenses. Pingo ice, beds of massive ice, and ice wedges are considered to

be pure ice, with a percentage volume of 100%. Massive ice is considered to underlie a terrain unit only if it or retrogressive thaw slumps have been positively identified in a coastal unit, either by observation or from air photo evidence. The volume of ice wedge ice is calculated using mean widths and depths for the ice wedges, assuming a triangular geometry and percent coverage based on the mean spacing measured from air photos.

In 2000 we refined this method by incorporating cliff heights and determining excess ice for each geologic terrain unit at Komakuk beach, King Point, and Kugmallit Bay. Ground ice contents were determined along greater sections of coastline. This additional criteria has resulted in more accurate prediction of ground ice and excess ice, especially wedge ice volume and coastlines with cliff topographies. This information is now presented visually using GIS software.

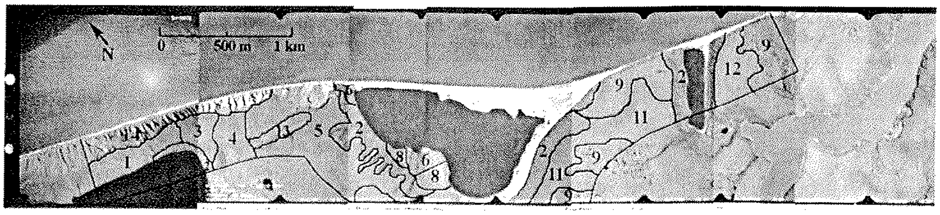

Figure 2. Terrain units at King Point site in a 500 m-wide strip of coastline. The length of coastline considered was dependent on what was visible on available air photographs.

PART II

More recently, the use of satellite imagery in combination with GPS surveying, air photos, and archived data have been employed to map coastal permafrost sensitivity. High-resolution GPS survey data combined with a variety of satellite images and airphotos allow for accurate correlation of images, which can then be compared to previous and future images to determine degrees and rates of change of thermokarst associated with ground ice degradation and associated environmental influences.

For this study, two types of remotely sensed data are used: airphotos and satellite images. Although airphotos offer the best resolution of any image available commercially (<1m), the temporal "one-time" coverage typically limits their use for monitoring needs, particularly in remote regions. The use of such images to establish a reference baseline for surveying is hampered by the fact that much of the active areas are substantially different today than they were almost 30 years ago. In contrast, whereas satellite data is normally viewed at lower resolution, the importance of repeat temporal cover over years and decades makes this data and its archive a valuable data source for monitoring and detecting change. Figure 3 provides an example of both information types.

Combining these images with high-resolution GPS surveys establishes an accurate baseline reference system for monitoring change, as shown in a headwall trace of thermokarst erosional scars overlain on an IKONOS image (Figure 4). To minimize possible temporal changes, an image was ordered for the study on September 18, 2000, corresponding to the period when ground surveying of the thermokarst features was being carried out on Herschel Island (September 20, 2000). GPS survey points of the headwall limit from active thermokarst features selected in this study are shown as * symbols. The accuracy of this preliminary work underscores the importance and requirement for precise field-based ground GPS surveys for establishing a baseline reference system in change monitoring work.

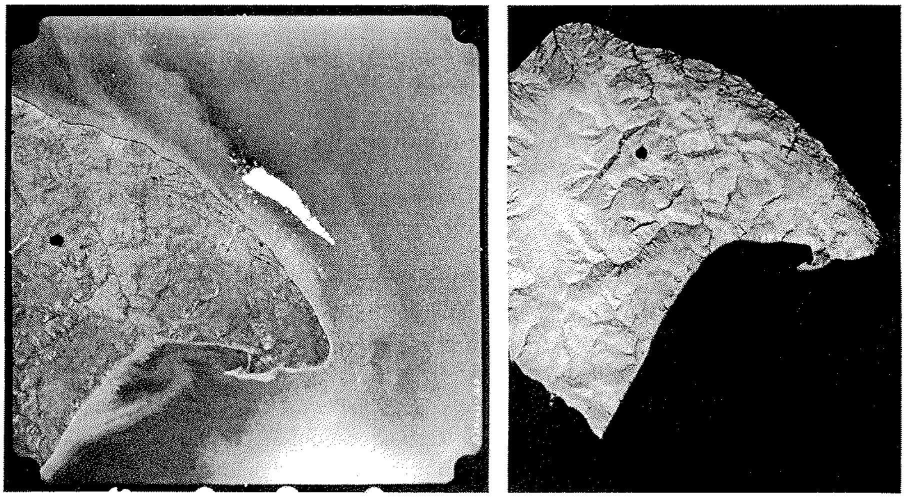

Figure 3. Eastern part of Herschel Island. Left image – airphoto taken in 1972; right image – ICONOS satellite image acquired 2001.

Figure 4. GPS survey points of the headwall limit from active thermokarst features; the match of GPS survey points shown here is in very good agreement with the position of the headwall scar in the image.

INVESTIGATION OF SEA LEVEL CHANGE IN THE ARCTIC OCEAN

Andrey Proshutinsky

Woods Hole Oceanographic Institution

The significance of global warming and the anticipated sea level rise in the Arctic has been the subject of several meetings and workshops whose participants repeatedly remarked about the influence that sea level changes will exert on shoreline erosion, sediment transport, navigation conditions, and oil and gas operations. But what is the current rate of sea level rise in the Arctic Ocean? There is no robust answer to this question. Sea level is a natural integral indicator of climate change. It reflects changes in practically all dynamic and thermodynamic terrestrial, oceanic, atmospheric, and cryospheric processes, but using estimates of eustatic sea level rise as an indicator of climate change incurs the difficulty that sea level change is the net result of many individual effects mentioned above. Some of these effects can offset others, so that the exact response of the Arctic Ocean sea level to climate change remains somewhat uncertain. This conflict leads to another question: What is the role of each of the various factors individually in the Arctic Ocean sea level change?

According to the International Panel on Climate Change prediction, the global sea level will rise 0.49 m by 2100. What is the expected rate of sea level change in the Arctic in the 21st century?

These and other fundamental problems related to sea level change in the Arctic Ocean are under investigation in our project . Based on analysis of existing but previously not available time series of sea level heights from Russian archives, atmospheric, cryospheric, terrestrial, and oceanic data sets and results of numerical modeling and data reconstruction, we propose to further our understanding of the Arctic climate system (1) by identifying links among sea level variability and atmospheric, hydrologic, cryospheric and oceanic processes, (2) by quantifying the regional and temporal variability of relevant processes in terms of sea level response, and (3) by determining the relative importance of each factor influencing sea level change under global warming conditions.

The observed sea level variability, which acts to integrate the complex contributions of these factors, will serve as the primary indicator of the ocean's response to climate change. Based on this analysis, the impact of linkages between hydrography, atmospheric circulation, hydrologic conditions, and the sea ice regime over the Arctic Ocean will be assessed in a conceptual model of sea level change.

This project is an international effort and a research team of scientists from the US (A. Proshutinsky, Woods Hole Oceanographic Institution; Z. Kowalik, University of Alaska Fairbanks; B. Douglas, Florida International University), Russia (E. Dvorkin et al., Arctic and Antarctic Research Institute), Canada (W. R. Peltier, University of Toronto), United Kingdom (S. Laxon, University College London), and Norway (V. Pavlov, Norsk Polar Research Institute) will collaborate in order to answer the major scientific questions formulated above.

Problem formulation and some preliminary results were published by Proshutinsky et al. (2001).

References

Proshutinsky, A., V. Pavlov, R. Bourke, Sea level rise in the Arctic Ocean, Geophys. Res. Letters, 28(11), 2237-2240, 2001.

TERRESTRIAL MATERIAL FLUXES IN THE NORTH-ASIAN ARCTIC SEAS: COASTAL EROSION VS RIVERINE TRANSPORT

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Global effects on the Arctic (including the Bering sea) are reflected in regional climate changes and their impacts and consequences. Global climate models have long projected that greenhouse-induced changes in climate would be first felt in the polar regions, especially in the Arctic, with subsequent global feedbacks (Walsh, 1995; Kattsov et al., 2000; Morrison et al., 2000). Under the greenhouse scenario underlined by "polar amplified" warming essentially all cryospheric features of the Arctic will be affected, and there will be increased wind and precipitation (Serreze et al., 2001), larger freshwater input into the margins from the rivers (Shiklomanov et al., 2000; Semiletov et al., 2000), reduced sea ice extent and thickness (Rothrock, 2000; Wadhams, 2001). Energy and water fluxes clearly shape the regional temperature regime, which is a primary factor in determining the surface state (frozen vs. thawed), trace gas fluxes, rates of productivity, and the link to regional climate (Sarmiento and Toggweiler, 1984; Broecker and Peng, 1989; Weller *et al.,* 1995; Everett *et al.,* 1998; Forman et al., 2000; Serreze et al., 2000).

Any attempt to understand the effect of the Arctic Ocean on global change or the effects of global change on the Arctic Ocean requires thorough knowledge of the coastal processes as a linkage between land and ocean processes in the Arctic and SubArctic. The coastal zone plays an important role in the Arctic/SubArctic land-shelf-basin system (Codispoti et al., 1990; Grebmeir and Whitledge, 1996), because the major transport of fresh water and solid material (including ancient organics) into the Arctic Ocean is determined by 1) the riverine discharges from Eurasia and North America and 2) coastal erosion. The permafrost-derived material is dispersed and settled in the coastal zone. The terrestrial flux of organic carbon is considered as a significant source of shelf productivity limiting nutrients (Semiletov, 1999, 2001).

In this report I examine transport and fate of terrestrial organic material entering the shallow shelves of all North Asian Marginal Seas using data obtained on the field research of 1994-2000. Positive feedback loop between increased atmospheric emission of carbon dioxide and methane from the Northern ecosystems, greenhouse warming and amplification of atmospheric circulation could be important in present, past, and future.

AMETHYST PROJECT OVERVIEW

Aleksey I. Sharov

Institute of Digital Image Processing, Joanneum Research, Wastiangasse 6, A-8010 Graz, Austria. E-mail: aleksey.sharov@joanneum.at)

Preface

Three months ago, Dr. V.Rachold from the Alfred Wegener Institute in Bremerhaven, co-ordinator of the Arctic Coastal Dynamics Project (ACD), invited me to participate in the Second ACD workshop in Potsdam, Germany. I was very glad to learn more about the ACD project and agreed to attend this meeting and to give an overview of our current research activities in the area of arctic coastal hydrography and polar remote sensing. The present paper provides a concise summary of our AMETHYST research project and concludes with some ideas on possible interactions among both projects.

Frameworks

The AMETHYST [1] project is a non-commercial international research activity (RTD) co-funded by the INCO European Commission, the 5th Framework Program. The framework of the AMETHYST project is defined as follows.

Research program: Confirming the International Role of Community Research (INCO COPERNICUS 2)

Research area: Environment and industry: problems of selected regions and sectors

Thematic priority: Sustainable management of natural resources in the coastal areas of the Arctic with special emphasis on land-ocean interaction (a.i)

Project title: Satellite Hydrographic Monitoring and Assessment of Environmental Trends Along the Russian Arctic Coast

Key words: Russian Arctic, coastal hydrography, ice shore, satellite monitoring, change detection, radar interferometry (INSAR)

Set up

Short history: The project proposal No. ICA2-1999--10079 was submitted on 15.09.1999, positively evaluated on 17.11.1999 and passed the negotiation phase on 01.08.2000. The project contract No. ICA2-CT-2000--10028 was signed on 18.09.2000. The 1st of October, 2000 is considered to be the project commencement date. The kick-off meeting took place on

[1] The acronym AMETHYST stands for Assessment and Monitoring of Environmental Trends regarding Hydrographic Situation along the Russian Arctic Coast.

October 30-31, 2000 in Graz, Austria. Progress meetings were held in Moscow, Russia (March 2001) and in Bergen, Norway (October 2001). The first progress report was delivered to the INCO Commission in May 2001. In November 2001, the first annual scientific report was provided to the INCO Commission.

Project consortium includes 6 organizations from 4 different European countries.

Coordinator: Institute of Digital Image Processing, Remote Sensing Group, Joanneum Research, Graz, Austria. Dr. Mathias Schardt, Dr. Aleksey I. Sharov

Principal contractors:

Nansen International Environmental and Remote Sensing Center, Bergen, Norway. Mr. Stein Sandven;

Technical University of Munich, Chair for Photogrammetry and Remote Sensing, Germany. Dr. Olaf Hellwich, Mr. Franz Meyer;

Institute of Geography, Russian Academy of Sciences, Moscow, Russia. Dr. Andrey F. Glazovskiy;

Nansen International Environmental and Remote Sensing Center, St.Petersburg, Russia. Dr. Leonid P. Bobylev;

NPO Mashinostroeniya, Scientific and Engineering Center ALMAZ, Moscow Region, Russia. Dr. Igor V.Elizavetin.

Project duration: 24 months *INCO funding:* 497880 Euro

Project homepage: http://dib.joanneum.at/amethyst

Objectives

The present project is focused on arguing and conducting coastal hydrographic monitoring in the WeRA on an economical basis by resurvey from automatic polar-orbiting satellites carrying high-resolution instruments, both optical and radar. The *general objective* of the AMETHYST project is to evaluate and utilize the full potential of satellite remote sensing for the coastal hydrographic monitoring in the Western Russian Arctic (WeRA) aimed at the support of natural exploration, maritime operations and environmental protection with reliable up-to-date hydrographic information in the form of regional coastal reference database (RECORD). Main emphasis has been put on regional and local studies of hydrographic regime, spatial changes of coastlines and related environmental trends in the Barents and Kara seas, and major attention is paid to the following *specific objectives*:

1. Argumentation of the concept of satellite hydrographic monitoring along Russian Arctic coasts.
2. Development of an efficient methodology and program tools for the reliable delineation of coastlines, coastal change detection and precise spatial modeling of glacier surface, bedrock topography, glacier ice thickness and ice motion at insular ice caps by means of stereophotogrammetric and interferometric processing of multisensor and multitemporal satellite imagery, both optical and radar, being supported with ancillary non-image data from spaceborne radar altimeter and airborne radio-echo sounder.

3. Detection, measurement, classification, interpretation, forecast and documentary representation of typical, significant and steady hydrographic changes at regional and local level including

- changes of ice shores in the Barents and Kara seas due to glacial flow, marine abrasion and calving,
- spatial evolution of coastlines due to the eustatic rise of the sea level and current tectonic movements,
- annual variations in superficial velocities of glacier ice motion,
- variations in coastal currents and long-term changes in the sea ice extent and distribution of icebergs,
- changes in coastal hydrographic networks, coastal changes in ports and port facilities etc.

4. Conclusion on the kinds and origin of detected hydrographic changes, assessment of main tendencies in evolution of glaciated, cliffy, and sandy coastlines, and expertise on perspectives and risks of maritime operations in the WeRA considering climatic trends, ecological aspects and economic effects.
5. Integration, demonstration and implementation of results for use as source material in the compilation and revision of nautical charts and sailing directions as well as for planning harbor improvements, conducting long-term economic projects and environmental protection in the Russian Arctic.

Main *social objective* of the AMETHYST project is to attract general public attention to economic, environmental and demographic problems in the extreme North of Russia and to promote the efficient solution to those problems on the basis of regular and safe merchant shipping along the Northern Sea Route towards the reactivation of trade in the region and the improvement of living conditions of the local human population.

Curriculum of monitoring

Coastal hydrographic monitoring is defined here as a repeated (systematic) hydrographic survey of a concrete coastline, its portion or separate coastal features aimed at the detection, measurement, analysis, forecast and documentation of historical, actual and potential coastal changes. All basic ideas of coastal hydrographic monitoring can be get from its curriculum (See next table and further explanations in text).

CV

TITLE:	COASTAL HYDROGRAPHIC MONITORING
FUNCTIONAL TYPE:	REGULATORY
COMPLEXITY:	COMPLEX
TECHNOLOGICAL SCHEME:	PROSPECTIVE
METHODOLOGY, BASIC:	SATELLITE RADAR INTERFEROMETRY (INSAR)
RESERVE:	SATELLITE PHOTOGRAMMETRY, DATA FUSION
TERRESTRIAL SCALE:	REGIONAL & LOCAL
TIME SCALE:	PAST 50 YEARS
WORKING SCALE, BASIC:	1:100 000
RESERVE:	1:200 000, 1:500 000, 1:1000 000, 1:2 500 000
BEGIN:	OCTOBER 1, 2000
FREQUENCY:	5 – 7 YEARS
STUDY REGION:	WERA
SIZE:	2 000 000 KM_
TEST AREAS:	FJL, SZ, NZ, BB, V
SIZE:	7 000 – 23 000 KM_
KEY SITES:	TO BE DEFINED
OBJECT:	ARCOS
SUBJECT:	RECORDING COASTLINE CHANGES
MAIN TASK:	UNSUPERVISED CHANGE DETECTION AND ANALYSIS
KINDS OF CHANGES:	TYPICAL, STEADY, SIGNIFICANT
OUTPUT PRODUCTS, GENERAL:	RECORD
SPECIFIC:	ARCHIVE, ARTIST, AMETIST, ARCTUR
TOOLS:	ARCTUR, RSG
USERS:	TBD
END:	?

Study region and test sites

The study region WeRA comprises the whole Kara Sea and a large part of Barents Sea belonging to the Russian Arctic Sector. Several representative test sites of smaller size situated at insular and continental coasts are selected for detailed investigation. These are

- the Franz Josef Land archipelago (FJL) with key sites in Wilzeck Land, Prince George Land, Hall Island and La Ronciere Island;
- the Severnaya Zemlya (SZ) archipelago with key sites at Komsomolets and October Revolution islands
- the northern part of Northern Island in the Novaya Zemlya archipelago (NZ) with observational sites at both, western and eastern coast;
- the Baydaratskaya Bay (BB) test site comprising the western and eastern coast of 'Baydaratskaya Guba' between settlements Amderma and Morrasale;
- the Varandey (V) test site representing a significant portion of the continental coast and islands between Pechora Mouth, Khaipudyrskaya Mouth and Yugorskiy Sound.

The FJL, SZ and NZ test sites exemplify insular coastlines, mostly ice shores, which demonstrate the highest rate of coastal changes. Two other test sites (BB and V) represent ice-free coasts with various modes of hydrographic changes. The location of all test sites (and the AMETHYST logo) is shown in Fig. 1

Methodology

In the AMETHYST project, practical image processing is based on methods of satellite radar interferometry (INSAR) and stereophotogrammetric modeling. The shoreline even of small islands and its changes are well detectable in interferometric products (Figure 2). Glacier fronts and streams, inland borders of outlet glaciers, ice shores and areas of fast ice can be reliably delineated. The exact measurement and representation of glacier motion is also possible. An original gradient approach (GINSAR) is applied to the interferometric modeling of coastal slopes. New promising opportunities for the unsupervised change detection in coastal areas in the WeRA are provided by using differential interferometry (DINSAR) and appropriate selection of tide-coordinated radar image pairs.

However, there is still some doubt as to the accuracy of spatial interferometric modeling, both vertical and horizontal. This is largely due to the limited ground resolution of SAR imagery, the lack of reliable ground control, topographic/decorrelation effects and uncertainties in imaging geometry. Therefore, additional optical images and methods of stereophotogrammetric processing are needed in order to provide additional control, to complete obscured areas, to cover gaps in temporal and terrestrial (at the local scale) coverage and to classify hydrographic details. Field observations and ground-control surveys in several key-sites are planned as well. The first field campaign in the northern part of Northern Island, NZ took place in September – October 2001 and provided comprehensive ground-truth data and additional ground control for further studies. Methods of numerical modeling and regression analysis will be applied to the assessment of environmental trends and hydrographic change forecast in the WeRA.

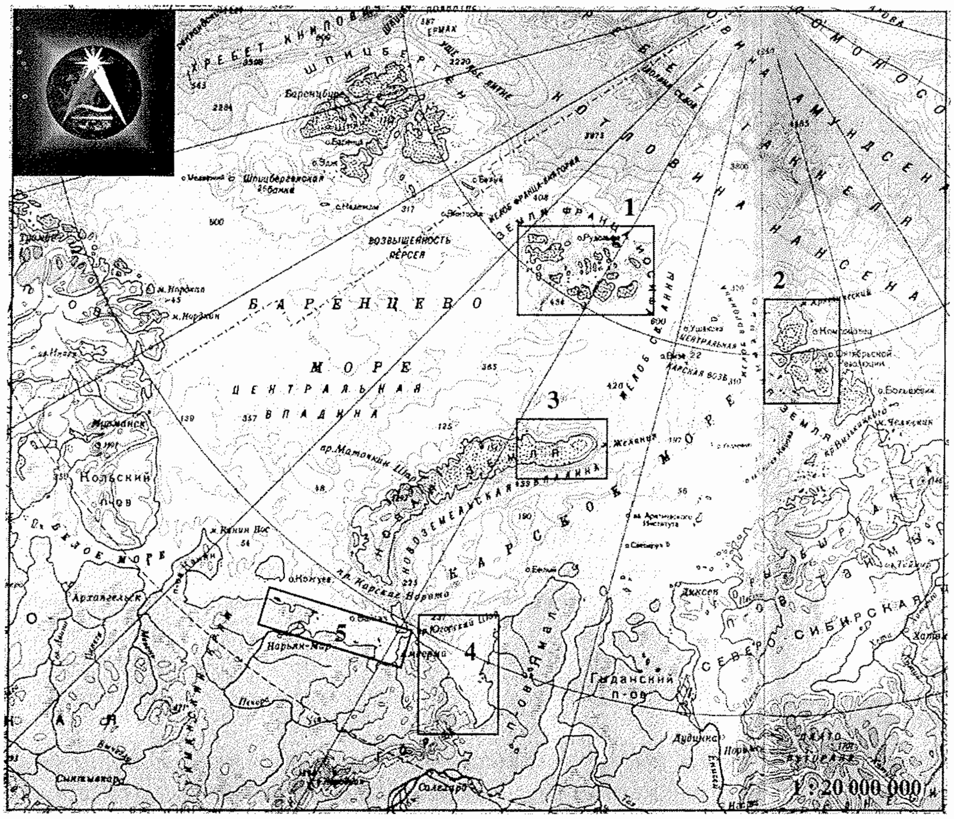

Figure 1. Location of test sites in the WeRA (1 – FJL, 2 – SZ, 3 – NZ, 4 – BB, 5 – V).

Basic data set

In our project, image scenes recorded over the WeRA by synthetic aperture radar (SAR) on board the European remote sensing satellites ERS-1/2 are considered to be basic remote sensing data of the highest priority. The SAR active instrument can image through cloud cover independently of natural illumination, i.e. operates also during the polar night. The repetition interval is as short as 35 or 3 days and even 1 day for ERS-1/2 tandem mission. The ERS-1/2-SAR system in normal operation provides strips of imagery 100 km in width to one side of the satellite with a nominal resolution of about 30 m. The use of ScanSAR images from Canadian RADARSAT having larger terrestrial coverage ensures the full coverage of test sites with homogeneous image data, convenient geocoding, hydrographic change detection and mapping over vast areas.

The experimental multitemporal image data set including 83 SAR and ScanSAR image scenes, 70 spaceborne optical scenes of high (AFA-TE100, CORONA KH-4A, ASTER) and medium (LANDSAT and KATE-200) ground resolution, and more than 300 airborne photographs covers the whole land area in the study region, at least three times, and provides the sevenfold coverage of the key sites. We are especially proud with the historical images obtained during the first aerial survey in the WeRA from the airship "Earl Zeppelin" in July

1931, i.e. 70 years ago, which have been found out and acquired after the long quest initiated by the author and performed by Mr. F.Meyer. Not long ago (1978) I.D.Papanin wrote that *"the scientific community still wonders where those photos might be."*

Available Russian topographic maps of coastlands at 1:200 000 scale will be applied to the coastline change detection & measurement, and hydrographic charts shall be used as a source of additional semantic information. The full list of available remote sensing data, cartographic materials and ancillary data as well as the specification of RS methods to be used is given in the next table.

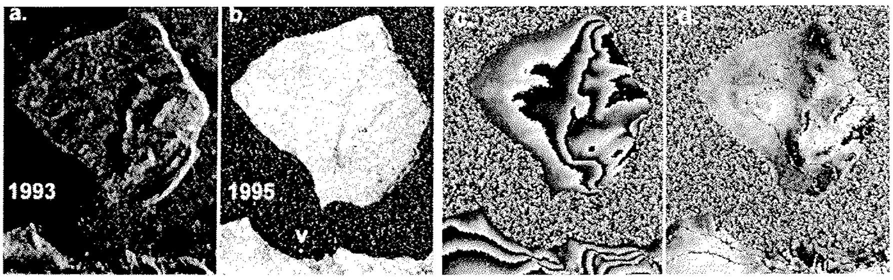

Figure 2. Precision SAR image (a), map of coherence (b), fringe image (c) and topogram (d) showing Kane Island and new Renta Island (marked with **v**), Franz Josef Land, WeRA.

BASIC DATA SET AND MAIN TECHNIQUES TO BE USED

Remote sensing data	Cartographic and hydrographic / geodetic data
SAR scenes	Cartographic materials
▪ ERS-1/2-SAR (PRI (s), SLC)	▪ World Atlas of Ice Resources, 1999
▪ RADARSAT ScanSAR (wide B)	▪ Atlas of the Arctic, 1985
▪ ALMAZ-1-SAR	▪ Atlas of the Arctic Ocean, 1980
▪ ENVISAT-ASAR*	▪ Russian topographic maps at 1:200000 and 1:500000 scale
	▪ Russian hydrographic charts at 1:100000 - 1:500000 scale
Optical images	▪ Catalogue of glaciers (volume 3, parts for FJL, SZ, NZ)
▪ ZEPPELIN-RMK aerial (s), PAN, HH	▪ Hydrometeorlogical maps for the INSAR instants
▪ AFA-TE100, aerial (s)*	▪ Thematic maps (geology, geomorphology, sea ice etc.)
▪ CORONA-KH-4A (s)*	▪ Historical and unpublished maps
▪ RESOURCE-F1, KATE-200 (s)*	
▪ ASTER	Hydrographic / geodetic data
▪ LANDSAT	• Tide-gauge data for the WeRA (1970 – 2000, 14 stations)
▪ NOAA-AVHRR	• Spirit leveling data from the field campaign 2001
	• Relative heights of 37 geodetic spots in test areas
Non-image data	• Physical-geographical descriptions of test sites
• ERS-1/2 radar altimeter data	• Factual data on the glacier thickness and velocities
• RES data, aerial & terrestrial	• Other relevant published data
• LDI-3 laser distometer, terrestrial	
(s) – stereo, PRI – precision, SLC–single-look, complex, HH – hand held, RES – radio-echo sounding *) – not yet operational	

Main techniques / products to be used			Area of application
Mosaicking	-	CORONA mosaic	Basic image layer representing the former state of coastlines
	-	ScanSAR mosaic	Basic image layer showing the present state of coastlines
INSAR	▪	Amplitude image	Interpretation of shorelines, glacier zones, sea ice
	▪	Map of coherence	Delineation of shorelines, inland borders of tidewater glaciers
	▪	Fringe image	Transferential measurement of frontal glacier velocities, tides
	▪	INSAR-DEM	Determination of absolute elevations, highest positions
GINSAR	▪	Topogram	Motion velocity gradients, strain rate, ice-divides, cracks
	▪	Slope map (SM)	Slope values, character of the glacier flow and sun radiation
DINSAR	-	3 or 4 SLCIs	Discrimination between glacier topography and motion
	-	Combinatorial	Glacier motion estimation, unsupervised change detection
	-	SM differencing	Basic metalayer representing coastal changes
OPTICAL STEREO	▪	Optical DEM	Stereoplotting in glaciated and ice-free coastal areas
	▪	Optical SM	Mapping of steep, cliffy coastlines. Accuracy control
DATA FUSION	-	OPT+SAR	Coastline classification, sea ice, icebergs, currents, polynyas
	-	DINSAR+OPT (s)	Enhanced modeling of the coastline, glacier surface
	-	INSAR+OPT+RES	Bedrock topography, glacier thickness, coastal bathymetry
	-	NOAA, NIR + ThIR	Nephanalysis for the appropriate data selection

Output products and services

The main output service of the AMETHYST project is related with designing, testing, demonstrating and implementing the regional coastal reference database RECORD. The RECORD database includes following basic sub-systems (Fig. 3), which (all together or separately) will be our main output products:

- Coastal hydrographic inventory ARCHIVE (or simply ARCHI) showing the present state of ice shores in the WeRA;
- Arctic regional topographic information system ARTIST, which represents coastlines as they are given in available and already obsolete topographic maps;
- AMETIST metainformation system representing real and potential changes of the coastline in the WeRA;
- ARCTUR administration software and databank with interactive viewing / processing / analyzing functionalities.

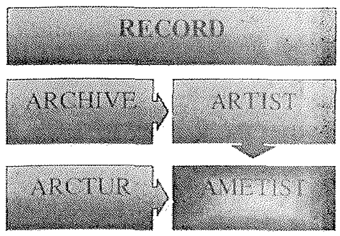

Figure 3. Basic output products.

Collaboration with related projects

The AMETHYST project is directed in such a way to support the European Union's environmental policy and assist in solving the objectives of the European Network for Research Into Global Change (ENRICH). In addition, account is taken of the scientific requirements expressed in the Arctic Monitoring and Assessment Program (AMAP) and in other scientific environmental programs by the International Arctic Science Committee (IASC) regarding mass-balance of arctic glaciers and links with sea-level change. The project scope has been coordinated with the European Space Agency (ESA) Polar Ice Sheets Program, which focuses on satellite remote sensing and monitoring of polar ice sheet variability. The co-operation with ESA and CSA is based on the incorporating satellite SAR data from both operational (ERS, RADARSAT) and upcoming (ENVISAT, RADARSAT-2) satellites as well as techniques and subsidiary program tools for interferometric image processing into the project work (with kind permission by the ESA).

From the very beginning, measures were foreseen in our working plan to establish actual collaboration with the IASC ACD project focused on improving the understanding of circum-Arctic coastal dynamics. Several particular ACD objectives aimed at establishing the rates and magnitudes of erosion and deposition at Arctic coasts, developing a network of long-term monitoring sites, producing series of thematic map, and developing empirical models to assess the sensitivity of Arctic coasts to environmental variability and human impacts show some thematic overlaps with the AMETHYST specific tasks and indicate promising opportunities for the ideas / data / information exchange and integration, and the implementation of products. Our project could provide some valuable inputs for the ACD project in terms of transferring new technologies for coastal remote sensing, designing efficient algorithms for the reliable spatial modeling of ice coats and coastal change detection in the High Arctic, ground-truth data provision and quality control. I believe that adding one or two of our test sites in the High Eurasian Arctic to the ACD list of key sites might serve a good base for clustering our research activities with the ACD project and for planning and executing joint field campaigns (if any) in the test areas of mutual interest.

Acknowledgements

The given opportunity of meeting and communicating with interesting people at the 2-d ACD Workshop in Potsdam is greatly acknowledged.

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COASTAL EROSION IN ALASKA

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Abstract: Alaska is bounded by over 50,000 km of extraordinarily diverse Arctic and sub-Arctic coastline, most of which is uninhabited (Figure 1). Over 90% of its population lives within 20 km of the coast, however, so coastal development is critical to the economy and social well being of nearly all Alaskans. Fisheries and oil and gas developments are concentrated along the coast. Markets for minerals and other resources from the hinterland require affordable export through widely scattered seaports. Tourism, especially aboard cruise ships, is growing rapidly.

Alaska's coastal zone includes a broad range of temperate, sub-Artic, and Arctic characteristics. Coastal dynamics of the northern half of the State are affected directly or indirectly by the presence of permafrost (Figure 2). The southern half of the State has coastal characteristics complicated by erodable glacial deposits and high tides. Cook Inlet, in southcentral Alaska, has a 10-m tidal range at its northern extreme and a rapidly eroding bluff shoreline (Figure 3, Smith et al 2001). Freezing of brackish water at the northern end and ice deposition of broad tidal flats creates huge blocks of "beach ice" that carry coarse sediments for long distances over 100 km (Figure 4, Smith 1999).

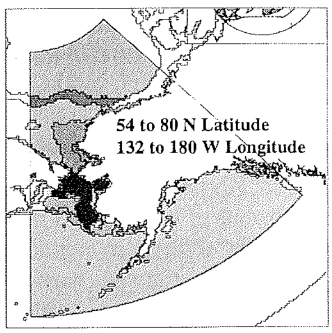

Figure 1. Coastline of Alaska, as portrayed in the "Alaska Sea Ice Altas" (Smith and Lee 2001).

The incentives to address comprehensive long-term coastal erosion trends in Alaska are mainly academic, to date. The history of coastal erosion studies is one of isolated site-specific efforts aimed at design of erosion control works. Erosion control measures in place are generally small expedient works that run the gamut of low-cost alternatives. Exceptions to this rule occur at Dutch Harbor in the Aleutian archipelago and Sitka in southeastern Alaska where protection of critical regional airports justifies large investments of both State and Federal funds in erosion control. Another significant erosion control project has taken place at Homer Spit (Figure 5), on southern Cook Inlet, where the road traversing the 6-km Homer Spit has been threatened by erosion (Smith et al 1985 and Chu et al 1987). These transportation-related erosion control efforts are offset by large-scale regional benefits by preventing loss of air and road access to

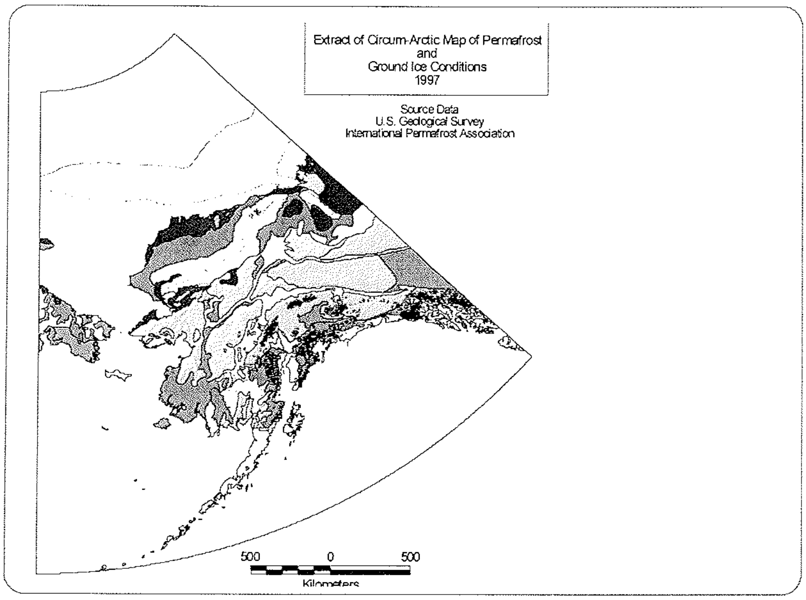

Figure 2. Permafrost conditions across Alaska (USGS 1997).

valuable commercial operations and facilities. Problems of erosion at rural locations, such as Kivalina and Shishmaref, on the Chukchi Sea coast of northwest Alaska (Figure 5), are not associated with the same scale of tangible economic losses; therefore only small-scale low-cost control measures are typically attempted.

The State of Alaska is subject to federal coastal erosion policies that evolved with attention to the coastal zone of the lower 48 states. Federal attention to coastal erosion is generally limited to public lands of direct economic importance to the national economy. Federal programs for keeping up Alaska nautical charts and topographic maps are severely under-funded. The State government does not have a consistent policy in this regard and rather responds to coastal erosion concerns through political processes. Through the Department of Transportation and Public Facilities, the State government relies a great deal on technical resources of the federal government, primarily the US Army Corps of Engineers, to investigate coastal erosion concerns and to design erosion control measures. Other State agencies, such as the Department of Natural Resources and Division of Governmental Coordination, generally only involve themselves in erosion control problems from a regulatory versus a problem-solving perspective. The net effect is that the severe constraints on federal appropriations for coastal erosion matters also apply to the State government and large-scale trends of coastal change in Alaska are largely unknown.

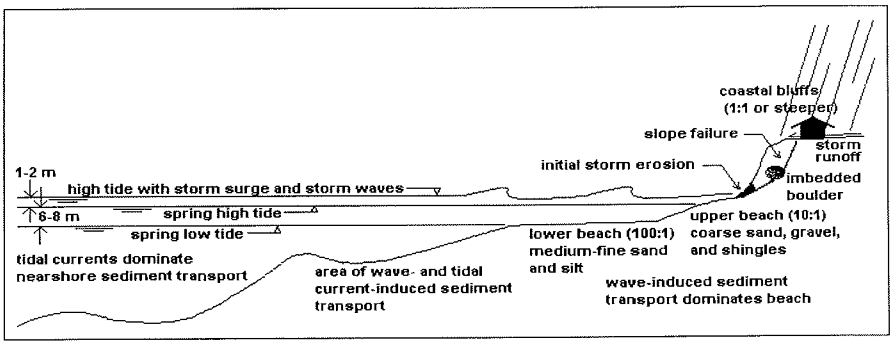

Figure 3. Bluff erosion of glacial deposits in macro-tidal Cook Inlet in southcentral Alaska.

Only recently has interest in global warming effects and international initiatives, such as the Arctic Coastal Dynamics program, catalyzed attention in Alaska to comprehensive analyses of long-term shoreline trends (*e.g.*, Smith 2001). A number of proposals are now being discussed to establish a practical baseline for and monitoring of coastal change. The guidance of the Arctic Coastal Dynamics program could play an important role in setting standards for implementation of these proposals.

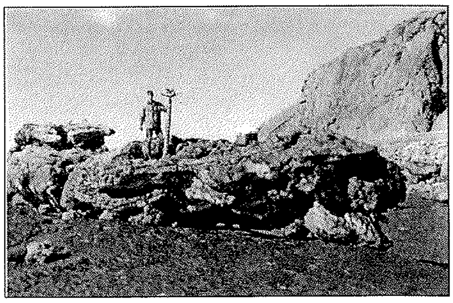

Figure 4. Beach ice in macro-tidal zones of Alaska, such as upper Cook Inlet (shown), is a significant agent of sediment transport.

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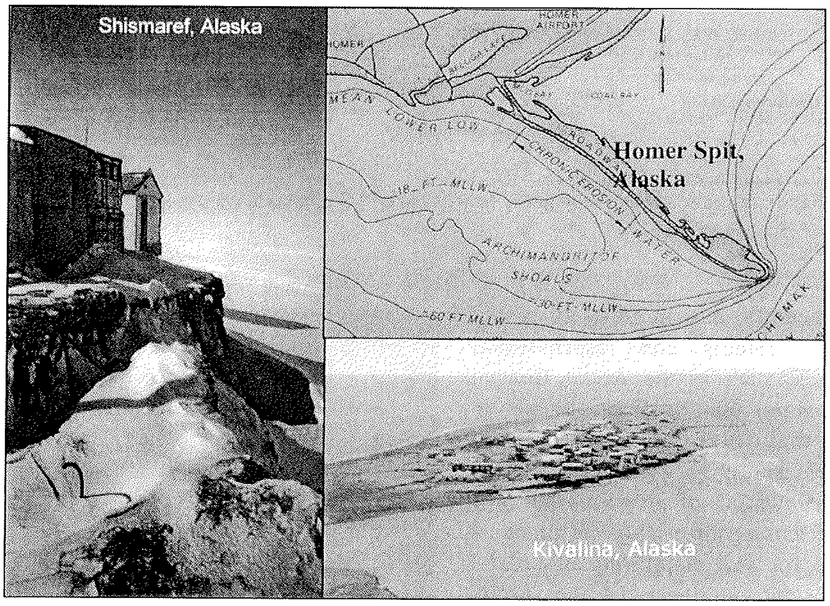

Figure 5. While the Homer Spit road gives access to valuable commercial enterprise, the rural communities of Shishmaref and Kivalina lack this economic incentive for erosion control measures.

BEAUFORT SEA COASTAL MAPPING AND THE DEVELOPMENT OF AN EROSION HAZARD INDEX

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Erosion in any environment is a function of coastal geology, morphology and oceanographic forcing. The geological attributes of the coast control the strength (or resistance) of coastal materials and the availability of sediments for transport. Oceanographic forcing includes the wave, current, and water level regimes which supply the energy for abrading, entraining and transporting sedimentary materials. Coastal morphology (or form) controls the transformation of energy at the interface between the water, seabed and subaerial coast. In high latitudes, ice plays a role in both protecting the coast during the portion of the year when the sea is ice covered and in entraining and transporting materials by frazil ice development and ice scour. In addition, water temperature influences the rate of ice-bonded permafrost thawing in the nearshore and coastal environments which in turn controls the rate of sediment release during. Air temperature may also be an important influence on the rate of thermokarst development.

As a first step towards a comprehensive treatment of the influences of climate change on coastal erosion along the Beaufort Sea, we have mapped important attributes of the coastal geology of the Beaufort coast and developed an index which describes the relative erosion hazard. By concentrating on the geological and morphological attributes, we can separate the potential erosion hazard which is more or less constant through time from that aspect which is likely to change as a result of climate change (e.g. oceanographic and meteorological forcing). The Beaufort Sea Erosion Hazard Index (BEHI) is based on coastal geological attributes compiled in the CIS database. The index is calculated by summation of all of the scores for each segment of coast with a unique set of form and material attributes. Additional morphological attributes were added to the score to account for differences in exposure to erosion-inducing NW storms, variations in the potential storm surge elevations due to morphological factors and nearshore slope (which controls maximum storm wave height).

Raw erosion hazard scores range from 1 to 24 with a mean of 11.7 and a median of 11. These scores represent a total of 1637 km of coastline. The median score of 11 represents 193 km of the coastline. The raw scores were aggregated to reduce the number of scores to five by using an algorithm which minimizes the differences between the in-class values of the average for each range. Table 1 shows the breakdown of classes and the amounts of coastline (in km) represented by each class. The classes were assigned relative qualitative erosion hazard rankings from ranging from very low to very high.

Table 1. Erosion hazard classes and the amounts of coastline (in km).

Score	Rank	Length of coast
1 to <9	very low	161
9 to <11	low	270
11 to <13	moderate	344
13 to <16	high	393
16 to 24	very high	470

In general the rankings agree with our perception of the relative stability of the coastal regions. An analysis of the BEHI versus the retreat rate (RR) show that the BEHI accounts for approximately 25% of the variance associated with the RR. In general, high BEHI scores were strongly associated with high RR, but as the BEHI decreases the relation between noisier. The fact that the BEHI accounts for only a portion of the variance in RR reflects the fact that the RR is sensitive to factors other than geology and morphology. It is therefore important to recognize that the BEHI is not a proxy for erosion rate measurements, but can serve as a guide to those locations which exhibit geological conditions which make them susceptible (to varying degrees) to coastal erosion. Incorporation of wave and current energy and more extensive coastal change measurements may improve the correlation between EHI and RR. However, the complexity of the Beaufort Sea coast and coastal processes in this region indicate that the index will never be a substitute for site specific engineering design studies. The BEHI can provide a means for identifying coastal reaches with the most potential for high erosion rates.

ARCTIC PALEO-RIVER DISCHARGE (APARD) - REPORT ON 2000 ACTIVITIES

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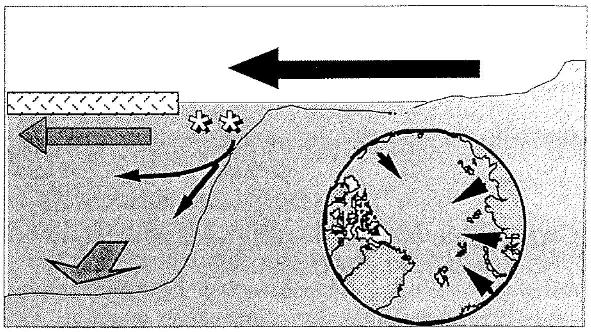

In 1996, the "Arctic Ocean Sciences Board" initiated a new multidisciplinary and international research program on river discharge and its change through time ("Arctic Paleo-River Discharge, APARD"). The APARD Science Plan was published in 1998 (Stein 1998). During the following years, a large number of APARD-related research activities were performed in the western as well as eastern Arctic continental margin and a huge amount of new data on circum Arctic river discharge were obtained (see APARD Newsletters 1 to 4; http://www.awi-bremerhaven.de/GEO/Arctic/APARD.html). In the last issue of the *International Journal of Earth Sciences (Vol. 89/3)* new data and an overview of the present knowledge of research on circum Arctic river discharge and its change through geological times has been published in December 2000 (Stein, R. (Ed.), 2000).

In 2000, new international projects and programs in which the Arctic river discharge is a major component, have been developed, and APARD-related expedition were carried out:

* Siberian River Run-off (SIRRO): The Nature of Continental Run-Off from the Siberian Rivers and its Behavior in the Kara Sea Area
* Western Arctic Shelf Basin Interactions (SBI)
* Expedition LENA 2000 (Studies of modern processes and environmental history of the Lena Delta)
* Kara Sea Expedition 2000 (Studies of biological, geochemical and geological processes relevant for the understanding of the freshwater and sediment input by the Siberian rivers Ob and Yenisei and the impact on the environments of the inner Kara Sea)

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SIBERIAN RIVER RUN-OFF IN THE KARA SEA: CHARACTERIZATION, QUANTIFICATION, AND VARIABILITY THROUGH LATE QUATERNARY TIMES

Ruediger Stein and the SIRRO Scientific Party

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Overall goal of our present research related to Arctic shelf-basin interactions is the understanding of biological, geochemical and geological processes in relationship to the freshwater and sediment input by the major Siberian rivers and its impact on the present and past environments of the Eurasian continental margin. Of particular importance are the Kara and Laptev seas receiving almost 2,000 km^3/yr of river discharge , which constitutes more than 50% of the total Arctic continental run-off. The major part of this volume is provided by the Siberian rivers Ob, Yenisei, and Lena.

Within the Russian-German multidisciplinary research project on "Siberian River Run-off (SIRRO)" our studies concentrate on surface sediments and sediment cores from the Kara Sea, obtained "Akademik Boris Petrov" expeditions in 1999, 2000, and 2001 (Fig. 1). Sediment cores display changes in lithologies which are probably related to changes in river discharge and climate. First AMS ^{14}C datings allow the development of a stratigraphic framework which will be the basis for future detailed studies of paleoenvironmental change.

Core BP99-04 (Yenisei Estuary) representing the last about 10000 calender years BP as based on numerous AMS^{14}C datings, indicates distinct changes in magnetic susceptibility, grain size, total organic carbon, assemblages of palynomorphs and diatoms, and accumulation rates. These changes are dominantly related to the post glacial sea-level rise and short-term variability in freshwater discharge.

Station Map of BP-2001

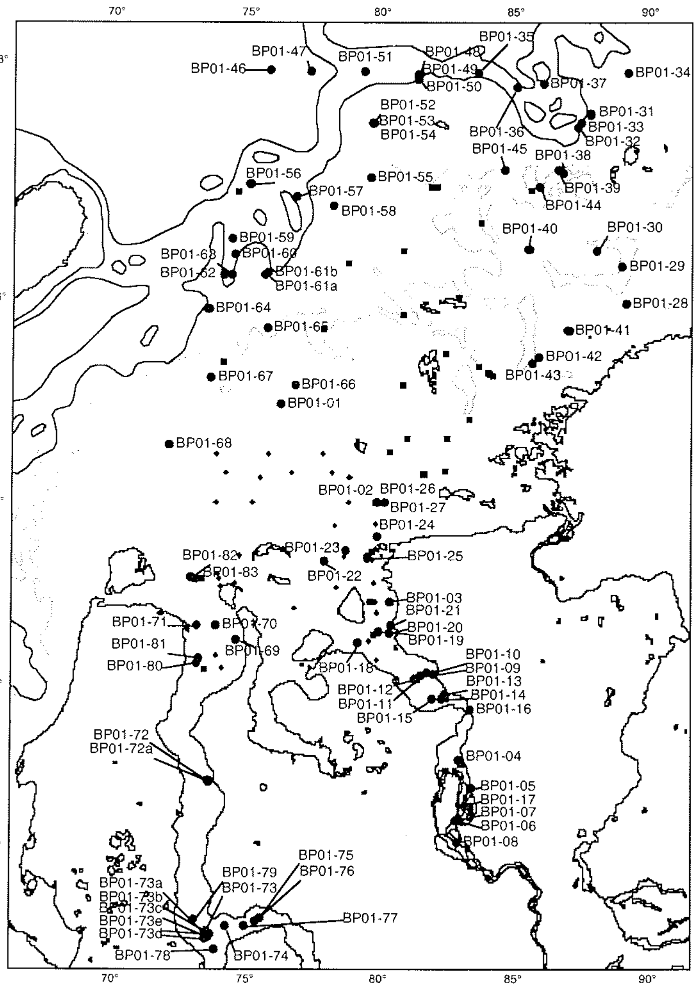

Fig. 1:
Station map of Boris Petrov Expeditions 1999, 2000, and 2001

■ BP00
◆ BP99

SEDIMENT INCLUSIONS IN ALASKAN COASTAL SEA ICE: SPATIAL DISTRIBUTION, INTERANNUAL VARIABILITY AND ENTRAINMENT REQUIREMENTS

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We investigated the spatial characteristics of sedimentary inclusions and elucidated processes controlling their spatial and temporal variability in the fast ice cover of the shallow-marine environment of Elson Lagoon near Barrow, AK. This was accomplished by examining the frazil ice layer of sea ice cores representing the 1998, 1999 and 2000 fall freeze-up periods and comparing the results with a sediment resuspension model. Sediments occur exclusively as aggregates of clay to fine-silt sized particles that were confined to brine inclusions in the frazil ice. The average cross-sectional area of these aggregates is positively correlated with sediment concentration of the frazil ice (R^2 =0.82, P<0.01). The minimum distance between neighboring aggregates (nearest-neighbor distance) is negatively correlated with sediment concentration (R^2 =0.78, P<0.01). However, little correlation exists between the number of aggregates and sediment concentration. Sediment concentrations ranged from 24 mg/l to 1470 mg/l and sediment loads ranged from 2 g/m^2 to 384 g/m^2, with 1998 and 2000 sediment loads being one to two orders of magnitude smaller than 1999 sediment loads. Similarly, the potential for bottom-sediment resuspension was greater in 1999 than in 1998 and 2000 by more than a factor of two. Resuspension potential is controlled spatially by the local bathymetry and interannually by wind velocity and fetch. At sub-meter scales, increases in bottom sediment resuspension result in greater sea ice sediment concentrations, larger aggregates and smaller nearest-neighbor distances.

CARBON CONTENT IN COASTAL ECOSYSTEMS OF RUSSIAN ARCTIC

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The international conference on "Dynamics and Challenges of Cryosols" (Copenhagen, 20-24 August, 2001) stated an urgency to incorporate coastal ecosystem research into the circumpolar framework. The implementation aspects have been focused on a working group initiated by Bjarne Jakobsen (Denmark, the conference organizer), Walter Oechel, Jerry Brown (both USA) and Vladimir Stolbovoi (Austria/Russia). Current paper originates from the discussion mentioned.

The length of Russia's segment of the Arctic coastal line is defined as approximately 39 940 km (Kalinina *et al.*, 1992). Various subzones of tundra dominate along this line, e.g. polar (13%), arctic (24%), northern (14%), southern (16%). Bogs (6%), northern taiga (5%), halophytic meadows (3%) are insignificant. Carbon (C) density in phytomass of the coastal ecosystems varies from 0.65 kg m^{-2} (average for tundra) to 1.87 kg m^{-2} (average for forest tundra and northern taiga). The most widespread soils (30%) are Histosols (international FAO-WRB nomenclature) with shallow peat (about 0.3-0.5 m). Histosols with deep peat (more than 0.5 m) occupy about 6% of the coastal zone. Histic Gleysols represent about 30% of the zone. Coarse textured Podzols (15%), Histic Fluvisols (10%) play minor role. The share of Calcaric soil units is considerably less than 1%. Effective soil depth is about 0.5 m and limited by shallow ground water, hard rock and permafrost. Average organic C density for topsoil (0.3 m) of the tundra biome is about 12 kg m^{-2}, forest-tundra and northern taiga comprise about 13 kg m^{-2}. The concentration of organic C in topsoil of the coastal zone is much higher due to dominance of Histosols (21 kg m^{-2}) and Gleysols (18 kg m^{-2}). Organic content in topsoil of excessively drained Podzols is 6.7 kg m^{-2}. The warming effect of the sea might cause prevalence of Histic horizons in soil of the coastal zone. Total ecosystem C content (soils depth 0.5 m) in the coastal zone is approximately 10-12 kg m^{-2} for well-drained and 35-40 kg m^{-2} for poorly drained sites. Segments along the coastal line have very different soil-vegetation associations depending on height above sea level, texture and mineralogy of parent materials, depth to ground water, permafrost, etc.

The annual sediment delivery in the Arctic coastal zone of Russia is about 338 million tones (Romankevitch and Vetrov, 2001). The lithoral deposits suggest containing some 3.8 million tones (about 1%) of organic and 4-5 million tones (about 1.5%) of inorganic C. This C concentration does not meet previously mentioned organic C pools of the coastal ecosystems that are subjected to the erosion. Clearly, coastal sea erosion is different from terrain erosion due to excessive amount of water. This causes separation of C substances on heavy and light weighted fractions. The heavy weighted fraction tends to deposit in the lithoral zone. It comprises mainly minerals, including carbonates relatively accumulated in the sediments and organo-mineral compounds. The latter are not common for permafrost-affected soils with limited humufication rate that explains the low concentration of organic C in the sediments.

The light weighted fraction contains vegetation fresh tissues, raw underdecomposed residues, peat, etc. and floats in the surface of the sea. This fraction comprises up to 99% of C pool of the coastal ecosystems and transported out of the coastal zone.

Conclusions: 1) a considerable amount of ecosystem phytomass and soil organic matter delivered by coastal erosion does not deposit in the lithoral zone. This C flux is ignored in the land-ocean interaction and does not account in the C cycle at present; 2) organic C flux derived from destruction of the coastal ecosystems is easy to account from land. There is an urgency to incorporate coastal ecosystem research into the ACD framework and introduce relevant data in the Arctic metadata form.

SOME PROBLEMS OF COASTAL MAPPING IN THE RUSSIAN ARCTIC

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Coastal mapping in the Arctic is of great importance since accurate maps provide information on the interaction of land and ocean. They can be used to evaluate the flux of material in the coastal zone, including carbon. The main contents of maps are a description of zones of onshore, offshore and active interactions. For onshore mapping the most important components are morphology, dominant landscapes, and composition of sediments (rocks), and permafrost, and for offshore are the bottom surface morphology and composition of bottom sediments.

A coastal classification was proposed and approved at the International ACD Workshop in Woods Hole in November 1999. For approbation of the classification and coastal mapping methodologies an attempt was undertaken to prepare a coastal map of West Yamal at the scale 1:1,000,000. However, a problem immediately appeared as to what exact objects must be represented on the map.

One possible approach was to present coded parameters of the coastline classification on the map. However, there were problems of distinguishing parameters. The classification did not maintain the principle of highlighting different coastal areas and independent of the coastal mapping scale. Under this approach it is not possible to reflect on the map the particularities of geological structure and permafrost which play an important role in the dynamics and mechanism of arctic coastline destruction.

The best approach is to represent the main elements of the natural-territorial complexes on the map. Each complex is characterized the original geographical and geological symbols or codes: morphology, vegetation, complex of ground, composition of soils (rocks), cryogenic structure, ice-content, ground temperature, and others. Classifying the natural-territorial complexes for the whole arctic coastline of Russia can be developed. The hierarchy is well known for different scales of mapping.

Under such an approach the natural-territorial complexes and their parameters appear on the map. The width of mapping band for continental part of the shore consists of not less then two sizes of natural-territorial complexes. On the basis of the main ACD classification for each natural-territorial complex the certain parameters are drawn: onshore, backshore, frontshore, and offshore in the prescribed manner. In the same way the data on elevations, retreat rate and literature references are presented

This approach was implemented in the coast mapping program for Western Yamal and can be recommended for circum-Arctic coastline mapping Presently there are a digital topographical and landscape maps of Russia Arctic at the scale 1:2,500,000, which can be recommended as the basis for the circum- Arctic coastal mapping.

COASTAL DYNAMICS IN MARRE-SALE , KARA SEA: A NEW OBSERVATION PROGRAM

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Coastal dynamic observations in the Kara Sea (Marre-Sale site) have been started in 1978. They included studies of the coastal geology, permafrost features, geomorphology and landscapes, onshore and offshore cryogenic processes and retreat rate observations. Observations were carried out annually at a thermally eroded coastal site about 4.5 km long. More than 60 section lines were arranged perpendicular to the coastline. These observations have been used to compile a database on retreat rate over 22 years and to obtain data on geology and geocryology of the coast, ice content and permafrost thermal regime.

It has been found that retreat rate varies cyclically in time. Periods of relatively low retreat rates give way to those of high rates. The entire cycle lasts about 20 years. The ice content impact on the retreat of the coasts has been revealed. Close correlation has been established between energy of sea waves and coast retreat rate. A new approach to the forecast of the coast retreat caused by climate changes has been elaborated. In context of the ACD Science and Implementation Plan, it has been decided to develop a new extended observation program on coastal dynamics in Marre-Sale. The basic idea of this new program involves observations to be conducted not only at the thermally eroded but also at accumulative sites of the coast. This enables to understand and assess the balance and matter flows in the offshore zone and estimate the dynamics of the accumulative coasts in the future. This program includes some data obtained using advanced GIS technologies in addition to previous results. In 2001 the following studies were carried out in the framework of this new comprehensive program:

1. The coastal monitoring site has been considerably expanded in order to cover both thermally eroded and accumulative types of the coast.
2. Reconnaissance of the existing geodetic control points has been conducted within the site area to define their exact coordinates in the WGS-84 system. This operation is necessary to calculate corrections which provide the use of topographic maps and navigation charts as well as old aero images compiled in the national coordinate system. The new benchmark was established to provide reference for both shoreline and offshore survey and remote-sensing analyses.
3. A detailed and precise survey with electronic total station has been conducted at the thermally eroded site of the coast about 100 m wide and more than 4.5 km long. Special attention has been paid to the detailed survey of the cliff edge and structural topographic lines.
4. A detailed survey of the seabed topography between the water line (MSL) and 10 m contour was conducted using portable NAVSTAR differential equipment and a digital echo sounder with the appropriate hydrographic software. The nearshore seabed survey was carried out from small boat (Zodiac). The offshore section of the coastal monitoring

site is about 3 km^2 (twenty offshore profiles located perpendicular to the shore with 50 m spacing).

5. The exact position of the present coastline (MSL line, flood limit line, cliff base line, location of the cliff edge) has been defined along vast sections of both retreating and accumulating sites using high-precision portable GeoExplorer 3 equipment and Pathfinder Office software.

An original method of joint use of DTM-350 electronic total station, DGPS (GeoExplorer 3) hardware and software operating with the database on sea level tidal variations has been elaborated to survey the dynamically active coast. All information is presented in a digital form enabling to produce a terrain model for the subsurface and surface parts of the coastal monitoring site for further analyses and GIS storage. The 3-D accuracy of the cliff edge line (4.5 km) is in order of 0.1-0.3 m. The positioning accuracy of the present shoreline related to the mean sea level (MSL) is in order of 2-3 m.

It would be reasonable to include the tide gauge measurements as a part of the standard procedures during subsequent investigations to establish long-term monitoring site. Regular level observations are necessary to obtain reliable data on the height of modern MSL with respect to the Russian national sea level - Baltic Elevation System (BES).

By this means during summer season of the 2001 we have prepared the monitoring site to study the active dynamic coastal zone near the Marre-Sale Polar Station.

NEW APPROACHES FOR THE METADATA DEVELOPMENT

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During the last decades there have been created thousands of original, converted and modeled global, regional and local data sets. In Russia alone information on more than 35,000 expeditions have been collected. Hundreds of software programs were developed on the basis of which there are thousands of calculated characteristics. There is a necessity to archive and document the information according to conditions of the natural environment. This requires the knowledge of the observed network characteristics; observed platforms, parameters, methods and format; and under a variety of registration methods (books, magazines, paper graphs, electronic formats - magnetic, optical, other).

In all this information flow it is necessary to very quickly search the information. Unfortunately, the information available in books, paper catalogues, lists, information received from technical carriers, does not help. First, the information changes very quickly; data sets are added, are corrected and are recalculated. Secondly, the volume of such information are very large. Thirdly, the referral information is a basis for transition to a paperless processing technology of environmental data. The attributes of required metadata sometimes are not present in the initial data sets. Thus for a successful search of the high-quality data it is necessary to have various types of metadata (information on data sets, formats of their exchange, software's of their processing, organization's data processing and storage, and others).

The role of metadata has increased considerably. For example, under the characteristics of coastal station (the date of opening of station and kinds of observations carried out) may contain a sample of temporary data on the appropriate parameters. When the search of data is carried out by the users working on one subject, the address of organization suffices as to where the data are located.. More complex situations is for persons working in different subject domains. More complete information is necessary such as details not only about data sets, but also about how data were collected data, within the framework of what projects were they are created, and programs were used for data processing.

A characteristic feature of metadata is the lack of updating. It is important to maintain changes in each parameter over time, the structure of attributes, for example, date of development and creation of the data, beginning of their application etc. Specifications are necessary for creation of the metadata in various sorts of the engineering projects. The process of creating metadata includes the following operations: choice of the characteristics, development of database structure, formalization of the documents, and entering of data on the technical carrier.

The metadata develops at the moment of observation, and are later generalized, and supplemented by new attributes. Metadata describe properties of the data determining their structure, allowable meanings and ways of their representation, interrelation with other data, accommodation and other characteristics of the data, which help to interpret and to use them correctly. Metadata are information on the existence of data, and referral at data processing. For example the metadata for the Arctic Coastal Dynamic (ACD) project is given on Figure 1. Sources of metadata are presented in [1-7], and the systems of metadata in [8-20].

Date prepared	13 March 2001
Coastal section name	Muostakh Island, Buor-Khaya Bay
Type site	Key
Country	Russia
Region	Laptev Sea Coast
Latitude	71.61392
Longitude	129.94387
Section length	2
Observation period	1960-2000
Observation frequency	1960, 1962, 1982-85, 1994-95, 1997-2000
Onshore methods	GPS, theodolite survey, tape-line measurements of coastal relief elements a
Offshore methods	Measurements of shoreface profile through sea ice, core drilling, geophysic.
Remote sensing	Aerial photographs (1951, 1:30 000 scale), photos (1982-2000) , video (19 shoreline and cliff top edges on oldest aerial photographs with theirs up-to-
Cliff height	20 m
Cliff angle	40-90
Local relief	Erosive cliff, sea wave niches (5-8 m), residual hillocks (4-8 m)
Offshore slope	0.0001-0.0005
Geology	Silty sand - sandy silt with peat layers. Predominantly Late Pleistocene dep
Geocryology	So-called Ice Complex, ice wedges and segregation ice, ice content 0.4-0.8 - -12 C

Figure 1. An example of metadata for the ACD project.

Sources of metadata

The different types of metadata objects are the following:

- Sources of data - observing networks, platforms (RVs, coastal stations, satellites, planes, buys), observing projects (programs), marine organizations, equipment's, cruises descriptions;
- Information resources - data sets descriptions, spatial information, bibliographic, social - economic databases, methodical, legislative documents, Web resources;
- Information for data management and processing - formats, codifies, software - processing, models, experts, methods of observations, data coverage, parameters dictionary;
- Information on production - on-line, real time data, prognoses, climatic data on Web and media.

The metadata are at all technological stages of data processing:

- Observation - information on networks and methods of observations, methods of definition of polluting parameters, information on measuring equipment,

- Acquisition - information on RVs, coastal stations, companions, planes, purchases;
- Data processing - information on technologies of data processing, formats of transfer data, descriptions of transmitted data sets, standards of transfer of the data and metadata on Web;
- Data storage - description of data sets, information on organizations - suppliers, owners, users, formats, observer's projects, cruises RV, observations coverage, dictionary of parameters, codifies, technologies, methods of the control of the data;
- Interagency and international exchange - information on technologies and data formats, description of data sets, observer's projects;
- Applied processing - information on data processing methods, control and analysis, software's, calculation algorithms, data coverage;
- Modeling - information on models, methods, formats of a modeled data;
- Distribution data - information on productions (analyses, bulletins, yearbooks, directories, forecasts), software, Web resources).

The metadata reflect data at the international level (global metadata on sites of World Data Centers, National Oceanographic Data Centers, users - wide, software - Web browser); national - (metadata on sites of Ministries, users - government and national organizations, software - Web browser); corporate - (metadata on sites of organizations, users - database managers, software - relational Data Base Management System); local -(special metadata on sites of firms, users - decision makers, software, for example, informers - very small data sets for state weather on this Web site).

The characteristics of information resources are the results of metadata bases processing. The aggregated characteristics may be a number of data sets for organizations, regions; number of RVs cruises obtained in 1990 - 2000 from various countries, organizations; number of cruises RVs obtained in 1990-2000 for kinds of observation; number of stations for squares, periods, parameters, etc.

The characteristics of data flows in a system of data processing depend on the sources of the information (RVs, coastal stations, buys etc.), volumes of received information from the source (day, month); number of stations, cruises for region; volume of output information for day, week, decade, month, year.

An example of the realization for different metadata objects

The first attempt to realize a system with full sets of metadata was made by the Russian National Oceanographic Date Center. The CD-ROM "The directory Information resources of Russia" was created. The directory was prepared with the purpose of representing information resources on a marine environment. The directory is intended for searching of metadata about data sets, formats, organizations, cruise description, platforms and others. The size of directory is more than 30,000 documents. It uses html, XML and Word files. Metadata had been presented on Web site for Russian Federal Program "World Ocean" (http://www.oceaninfo.ru). Metadata are being used for the monitoring, management and development of Russian information resources in the fields of marine environment. The directory structure is presented in the Table 1.

Table 1. The directory structure "Information Resources of Russia"

Type object	Metadata object	Amount
Sources of information	Observant networks and equipment	10
	Expeditions, projects and programs	70
	Marine organizations	60
	Experts	110
	The information on RVs	850
	The information on coastal stations by the seas of Russia	750
	Satellites	25
	Information about equipment	150
	Information on marine maps	150
Information resources	The descriptions of data sets and databases with connection of the information about formats, maps of coverage data, bibliography	250
	Information on foreign data sets	250
	The information on databases on CD-ROM	24
	Information on cruises description	32500
	The legal information	150
	The methodical documentation with electronic copy	500
	Socially - economic information for marine objects	1000
	Information about Web sites	2000
	Catalogue of bibliographic sources	190
Facilities of data management and processing	Codifies, used in various departments	150
	Formats of the acquisition, storage and exchange	15
	Software's of the acquisition and applied data processing	11
Information production	On-line initial, climatic, forecastle data	50

Conclusion

For ocean and coastal data searches the development of metadata bases for many objects are required; to use the metadata language XML; to combine the metadata objects on base of the languages XML, XLinks, Xpointer; and to use metadata for integration environmental data and the information production.

These new approaches for the metadata development (creating different metadata bases, integrating objects of metadata, using dynamic presentation of metadata, connecting metadata bases in DMS and Web technologies, computing of aggregating characteristics of information resources) may be used for the ACD project. For best results in the search of metadata for the ACD project the following is required:

- to collect and include the data sets description in EDMED system [12];
- to send to ICES the ROSCOP forms for cruise descriptions [11];
- to send the information on experts in IOC, GLODIR [17], (for AMAP projects[16]).

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11. ICES, ROSCOP - Information on cruises (http://www.ices.dk/ocean).

12. BODC, EDMED- The common information on data sets http://www.sea-search.net)

13. IASC, ADD- Information on organizations for Arctic (http://www.grida.no/prog/polar/add)

14. AODC, Blue Pages- Information on data sets (http://www.aodc.gov.au/Inventory/index.html).

15. NOAA, EOSDIS - Information on data sets (http://redhook.gsfc.nasa.gov/~imswww/pub/imswelcome/plain.html),

16. Norway, AMAP - Information on projects for Arctic (http://pusnes.grida.no/amap/amappd/index.asp)

17. IOC, GLODIR - Information on experts (http://iode.org).

18. BODC, GLOSS - Information on sea level observations for coastal stations (http://www.bodc.ac.uk/services/glosshb/glosshb.html).

19. RU, ESIMO - Information on data sets, cruises, experts, platforms, etc. (http://www.oceaninfo.ru)

20. GERMANY, PANGAEA - Information on data sets, projects, institutes, publishes, software, data (http://www.pangaea.de).

MEASUREMENTS OF COASTAL CHANGE IN THE RUSSIAN ARCTIC AND AT SVALBARD BY MEANS MULTI-TEMPORAL AERIAL PHOTOGRAPHS AND DIGITAL PHOTOGRAMMETRY

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Introduction

The purpose of the work presented here was to examine the possibilities of using digital photogrammetry for quantifying earth surface changes at two selected localities, at the Brøggerhalvøya peninsula, Svalbard (79° N, 12° E) and at Bykhovsky peninsula, Laptev Sea (72° N, 129 ° E). Two sets of aerial photographs from 1951 and 1982 were used at Bykhovsky peninsula in the Laptev Sea and two sets from 1971 and 1995 were used at Brøgger Peninsula at Svalbard. The general idea is to automatically generate a digital elevation model (DEM) for each locality and year, and then calculate the volume change by subtracting the two DEMs from the same locality. Z/I Imaging is the name of the digital photogrammetric workstation that is used and Match-T (Krzystek 1991) is the algorithm used for the automatic DEM generation. The ESRI software Arc Info is used in the analysis of the DEM.

The study areas

The Bykhovsky peninsula is situated near the Lena delta in the Laptev Sea and has continuous permafrost. The peninsula mainly consists of ice complex deposits of silt and sand. The volumetric ice content of the ice complex deposits is often greater than 50%. Drilling on the Bykhovsky peninsula has revealed that the ice complex foot is found at 8-10 meters below sea level and the surface of the deposits reaching 40 meters above sea level (Rachold & Grigoriev 2000). This area is selected as one of the ACD key sites. The area also consists of several thermokarst lakes (see figure 1).

The Brøggerhalvøya peninsula (see figure 2) is situated at the western coast of Spitsbergen, the largest island of the Svalbard archipelago. Brøggerhalvøya peninsula also has continuous permafrost. The shores of the peninsula are made up of a mixture of rocky shores, low cliffs in unconsolidated material, low and high cliffs in bedrock and glacier fronts terminating in the sea. The selected study area consists of low cliffs in bedrock with sandy and stony beaches in front (Ødegård et al. 1987). The geology of the peninsula is a fold and overthrust complex of Tertiary age (Challinor 1967). The locality is close to the research settlement in Ny-Ålesund. There has also been some research activities here, concerning coastal processes like cryogenic weathering of cliffs (Ødegård & Sollid 1993). Brøggerhalvøya peninsula is also selected as one of the ACD key sites.

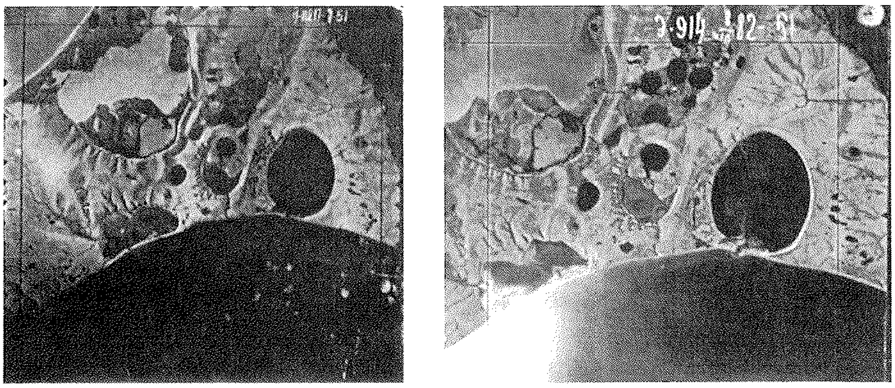

Figure 1. Air photos of Bykhovsky Peninsula from the years 1951 (left) and 1982 (right).

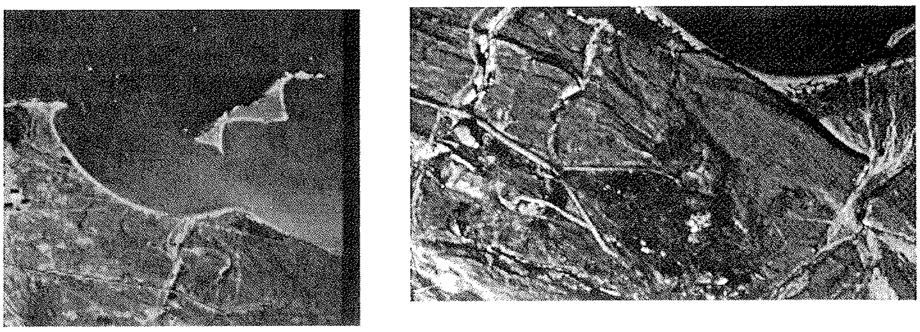

Figure 2. Air photos from Brøgger Peninsula from the years 1971 (left) and 1995 (right).

Techniques and precision

To use digital photogrammetry one needs a stereo pair of scanned photos. The scanner must operate at a resolution below 20 micrometers. One also needs a powerful PC with some especially developed software and visualization tools, such as a polarization screen and glasses. Z/I Imaging is the name of the digital photogrammetric workstation used in this project. The Match-T algorithm (Krzystek 1991) uses a correlation algorithm to detect the same points in the two photos in a stereo model and then measure the elevation. This makes it possible to automatically generate high precision digital elevation models (DEMs). The accuracy of the elevation measurements are about 0.10-0.20‰ of the flying height. Hence about 30 cm given a flying altitude of 2300 meters, which equals an air photo scale of 1:15.000. The spatial resolution in the xy-plane can then be less than a meter for the DEM with a xy-accuracy of 20-30 cm. For terrestrial photos, which is planned to be utilized later in the Norwegian part of the ACD project, the resolution is far better. Having air photos and hence DEMs from different points of time makes it possible to calculate volume changes in the earth surface. It is also possible to create elevation profiles and orthophotos from the DEM that can be used to measure coastal retreat.

Results

The generation of the DEM for the Bykhovsky peninsula failed. A stereo model was created but the Match-T algorithm did not manage to create a DEM. This may be to a rather crude interior orientation of the photos due to missing camera information or maybe because of coarse scanning resolution of the 1:50.000 scale air photos. The absolute precision of the control points used is also fairly bad due to the 1:100.000 scale map that was uses to collect them. This does not affect the matching and the DEM generation since the same points are identified in different photos in the same model. Though it would have introduced a problem when comparing two DEMs.

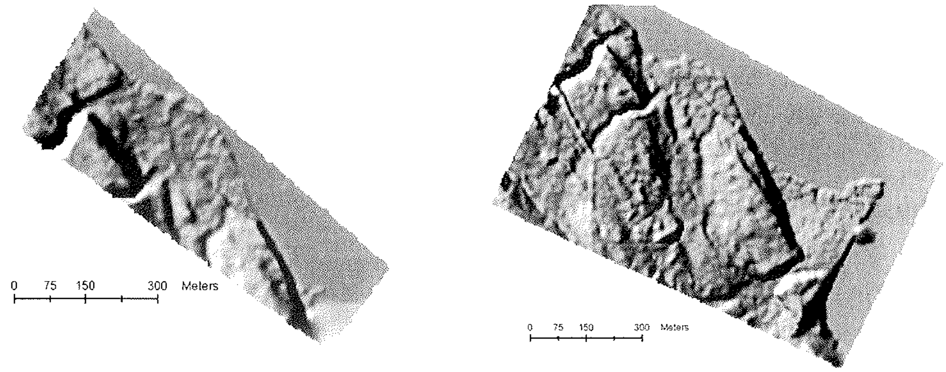

Figure 3. A hillshade representation of the DEM generated form the 1971 (left) 1995 (right) air photos.

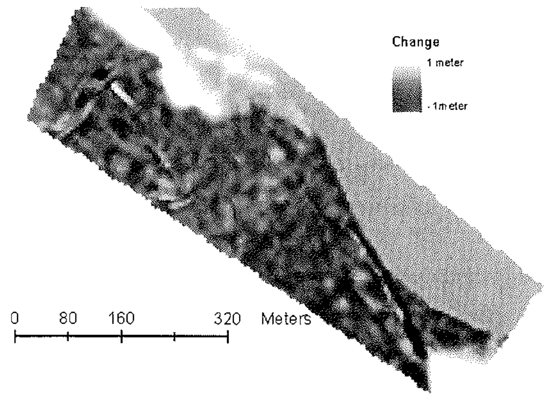

Figure 4. The difference between the two DEMs (1971-DEM minus 1995-DEM).

For the air photos from Brøgger peninsula, all the necessary information was available and a DEM for both 1971 and 1995 was generated. The scale of both these air photos is 1:15.000. Hillshade representations of the DEMs are given in figure 3. The result of the subtraction of the two DEM is given in figure 4. Both the two DEMs and the grid showing their difference, have a grid size of five meters.

In figure 4 it seems like the greatest changes have taken place in the areas of the greatest slope (dark areas in figure 3 and 4), around a small canyon in the upper left corner and near the cliff in the lower right corner of the image. These are the areas were one would expect the greatest change. But it is also the areas were a small error in the geo referencing of the two DEMs would cause most harm. So it is difficult to say how large the error in the change measurements in these areas is. Reducing the cell size from 5 to 1 meters in the generation of the DEM would probably give some valuable information on this. It also seems to have been some accumulation on the beach in the upper part of the image (bright area). This is feasible due to the mouth of the creek, but can also be caused by differences in the tide at the two points of time when the air photos were taken. The bright area in the lower part of the image is caused by an error. This area is on the outside of one of the photos from 1995, and Match-T has probably created an artefact here due to a registration mark on the border of this photo.

Conclusion

Using the technique of digital photogrammetry seems promising for detecting changes in the coastal zone. But the scale of the images used has to be chosen based on the magnitude of the erosion rates that is expected for the area. In areas that suffer great changes, like in ice rich deposits as those on Bykhovsky peninsula, it would probably by sufficient with aerial photos in the scale of 1:15:000 to 1:50.000. But for localities with bedrock and lower erosion rates one should probably use terrestrial photogrammetry with photos of a much larger scale and precision. The error of the elevation measurement versus the expected erosion rate therefore has to be taken in consideration before using this tool in volume change detection of coastal land surfaces. Hence we plan to user terrestrial photos to measure the erosion and retreat rates on Svalbard in the ACD project.

Finally I want to thank Mikhail Grigoriev and Volker Rachold who kindly made the air photos from Bykhovsky peninsula available to me.

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4 Appendix

Appendix 1. Information to be included in a metadata form for arctic coastal key section.

COASTAL KEY SECTION NAME

COUNTRY AND REGION

LATITUDE AND LONGITUDE (degrees, minutes, seconds if available)

SECTION LENGTH (km)

OBSERVATIONAL PERIOD (years of observation, frequency of observation, etc.)

METHODS AND TYPES OF MEASUREMENTS

Onshore methods (GPS, theodolite, etc.)

Offshore methods (bathymetry, shallow seismic, etc.)

Remote sensing (aerial photographs, video, etc.)

SECTION MORPHOLOGY

Onshore (cliff height (m), cliff angle, local relief (m), etc.)

Offshore (shoreface profile, etc.)

GEOLOGY AND GEOCRYOLOGY (types of sediments [onshore and offshore], ice content and type, etc.)

DOMINANT SITE VEGETATION

METEOROLOGICAL CONDITIONS (air temperature, snow cover, wind speed and direction, frequency of storms, etc.; indicate frequency of observations)

OCEANOGRAPHIC CONDITIONS (sea level, tides, wave height, sea water temperature, currents, etc.; indicate frequency of observations)

ACCESSIBILITY OF COASTAL SECTION
Mode of transportation (helicopter, road, offroad vehicle, river, etc.)

NAME AND LOCATION OF CLOSEST CLIMATE STATION (latitude, longitude, and distance from section, km; provide both meterolociacal and oceanographic data separately as available)

RESPONSIBLE INDIVIDUAL(S) AND ORGANIZATION FOR DATA COLLECTION (complete mailing address, email and fax addresses)

RELEVANT PUBLICATIONS (complete citation, use additional space)

SKETCH, PHOTO, VIDEO OF KEY SECTION (as available)

OTHER COMMENTS: (use additional space)

Appendix 2. Proposed coastal classification.

Onshore	**Backshore**	**Frontshore**	**Offshore**
(Zone which immediately landward of the backshore zone to 1 km from extreme high water)	(from the high water large tide line land-ward to the local cliff tops or the landward extent of marine processes)	(from the high water large tide line to the outer boundary of the surf zone	(seaward of surface)
FORM - code Delta - D Lowland (<10m) - L Upland (10-500m) - U Highland (>500m) - H	FORM - code Cliff (50) - C Slope (3-50) - S Flat (<3) - F Ridged (terraced) -R Ridge and basin - RB Anthropogenic -A	FORM - code Cliff (50°) - C Slope (3-50°) - S Flat (<3°) - F Ridged (terraced) -R Ridge and basin - RB Anthropogenic -A	FORM - code Steep -S Gentle - G (based on 2/10 m isobaths capture shape)
RELIEF (distance to) 10 m contour (###) 100 m contour (###) 500 m contour (###) Lakes (presence/ absence/thaw)	Shorezone complexity ###		RELIEF (distance to) 2 m isobath (###) 10 m isobath (###) 20 m isobath (###) 100 m isobath (###)

MATERIAL for four cross-shore zones are classified as follows:

Unlithified - code	**Lithified** -code	**Ice** - code
mud-dominated - m sand-dominated - s gravel-dominated - g diamict - d organic - o Mixtures- e.g. ms,sg Ground-ice: wedges and massive	sedimentary igneous/metamorphic poorly lithified	floating - f grounded - gr **Man-made structures**

Table notes: Mapping methodology: use coding convention of onshore_Form/ /backshore_Fm/frontshore_form/offshore_Formm
Onshore_material/backshore_material/frontshore_material/offshore_material
Relief distance may be undefined if there is no elevation contour found which is orthogonal to the coast (e.g. island or peninsula)

Appendix 3. Ground-ice estimates and mapping.

Appendix 3.1. Methods for estimating ground-ice volume

Direct measurements			**Indirect measurements**	
Label	Type	Confidence level	Label	Type
A	Large natural exposures	5	a	Graphic (video, still, historical of natural exposures) Photogrammetric
B	Boreholes/cores (single, multiple, using geophysics)	3-4	b	Geophysics (seismic, GPR, EM, electrical resistivity, gravity)
C	Shotholes	2-3	c	Terrain analysis (thermokarst features,ice wedge polygons, frost heave, slopes processes)
D	Limited Exposures	1-2	d	Satellite remote sensing

Appendix 3.2. Visible/non-visible ice classification.

VISIBLE ICE				**NON-VISIBLE**	
Depth	**Low 0-20%**	**Medium 20-50%**	**High 50+**	**Bedrock**	**Dry**
Upper	UL	UM	UH	Ubr	UD
Lower	LL	LM	LH	LBr	LD

Appendix 3.3. Example of database template.

Layers	Lithology	Method of Estimate	Confidence	Visible ice volume, %	Total	Ice bodies (Massive ice)
0-5 m	Sand	1	High	5+1	6	Ice wedges
5-15 m	Silt	1	High	10	10	No
15-20 m	Clay	3B	High	20+60	80	Tabular ice

Appendix 4. Recommendation for coastal change monitoring sites.

Key sites will be identified throughout the circum-arctic for implementing a long-term monitoring program. A key site is defined as a site representative of a significant percentage of the coastline in the study region. Observational sites are areas where any information on coastal change is available to complement the key sites. Local researchers could nominate their study sites for key sites, if the minimum criteria are met. The following criteria and steps would be employed for site selection and study:

Assess the availability of the above-mentioned data: Ideally, sites for which baseline survey data and/or ancillary data are already available would be eligible for selection as a key site.

Study area size: The minimum length of the shoreline to be studied at each key site is 300 m (length could be longer, depending on the type of coast to accommodate local variances). Within the 300 m, a minimum of three offshore/onshore profiles will be established perpendicular to the shore (see methods above).

Data standards: In order to eliminate differences among regional and national use of datums, all investigators should refer to the national sea level for conducting shoreline profiles. The WGS 84 map projection should also be used for the circum-arctic coastal monitoring program. General information required for each site include: date of survey; time and time zone; investigator(s); methods used; profile survey line orientation; status of ground control points; and ancillary data (e.g., photos, active layer measurements, core sampling, etc.).

Establish and document ground control points: It is critical to establish ground control points at stable features that are not expected to change through time. These ground points will provide a benchmark for all shoreline survey field work and remote-sensing analyses at the key site, and they must be easily located on the ground as well as from the air. Full documentation of the ground point location and description (e.g., GPS location, photograph, recognizable site features) is essential for relocating by different investigators over time.

Mappable parameters: To supplement the coastal classification and mapping effort, key site investigators should record the following qualitative categories for rate of change: rapid retreating, moderate retreating, slow retreating, stable, accumulating. Both key and observational sites should have detailed information stored in a database management system that can be keyed to map presentation

Appendix 5. Environmental Data Requirements.

1 Atmospheric conditions

Standard wind parameters: frequency distribution of wind speed and direction (wind rose) as well as frequency distribution for strong winds (>10 m s^{-1}) based on synoptic weather station data (6-hour to daily intervals). Data sources: weather stations reporting to World Meteorological Organization (WMO, available through U.S. National Climatic Data Center (NCDC), reanalysis data fields from the U.S. National Center for Environmental Prediction (NCEP) or the European Center for Medium-Range Weather Forecasts (ECMWF).

Positive/negative degree days: compute the sum of daily ground-level air temperatures for summer period (temperatures >0 °C) and for winter (temperatures <0 °C). Data from either synoptic weather stations or medium-range forecast reanalysis data (same sources as for wind parameters).

Standard storm parameters:

Number of cyclones per year (or season) based on sea level-pressure data obtained from (re)analysis data (data source: NCEP, storm-track atlas from Institute on Climate and Planets at NASA Goddard Institute for Space Science; see Serreze, 1995).

Fetch: total length of open water between coast and ice edge or other landmass along principal wind direction; compute fetch distribution for open-water season based on wind-rose data (see above) and maximum distance to ice edge data (see below).

Precipitation: total snowfall and total liquid precipitation; data based on atmospheric circulation model results or snow accumulation databases (e.g., Russian snow accumulation data base available through U.S. National Snow and Ice Data Center (NSIDC)).

Spacing of data points along coast: Data point spacing should be based on resolution of the respective data sets (50 km for standard sea-ice concentration maps, 50 to 100 km for GCM grid cells determining reanalysis data).

2 Oceanographic conditions

2.1 Current regime: Summary currents in Arctic Seas are composed of permanent, wind-induced, and tidal currents

Permanent currents: seasonal variability of the surface and bottom currents (monthly mean) direction and speed. Space resolution is 50 km. Sources: RSMOT [1993], Atlas Arktiki [1985], Atlas Okeanov [1980], Proshutinsky et al. [1995], and International Northern Sea Route Project (see http://www.ims.uaf.edu:8000/insrop-2/).

Wind-driven currents (surface): frequency distribution of current speed and direction (current rose). Maximum currents and their statistics including probability of occurrence of maximum speed. Probability of occurrence of direction of maximum currents. Some information is available from Proshutinsky et al. [1995] (see http://www.ims.uaf.edu:8000/insrop-2/). Wind-driven circulation models can be used to simulate wind-driven currents (including intermediate water and bottom layers) based on wind statistics (Proshutinsky, 1986, 1993, 1995).

Tidal currents: maximum tidal currents, ellipses of tidal currents, residual tidal currents. Major sources: Kowalik and Proshutinsky [1993, 1995], gridded data with a space resolution of 14 km for 8 tidal waves is presented at: http://www.ims.uaf.edu:8000/tide.html (see instructions how to access tidal data base).

2.2 Storm surge parameters and wave regime

Sea level and storm surges: Probability of occurrence (monthly) of sea level heights greater than 50 cm, 100 cm, 150 cm etc. with a space resolution of 50 km. Statistics of duration of storm surges. Statistics of combination of storm surges with drifting ice. Sources of information: Proshutinsky, 1993, 1995, http://www.ims.uaf.edu:8000/insrop-2/. Storm surge statistics can be simulated using storm surge models of the Arctic Seas and 6 hour atmospheric pressure fields described above.

Wave regime and ice concentrations: These parameters include probability of occurrence of waves heights and wave direction. Special attention should be paid to the statistics of combination of high wind wave and heavy ice with concentration of 30-50% (ice storm conditions). Sources of information: RSMOT [1993], Atlas Arktiki [1985], Atlas Okeanov [1980], Proshutinsky et al. [1995], and International Northern Sea Route Project (see http://www.ims.uaf.edu:8000/insrop-2/).

2.3. Water temperature and salinity.

Seasonal variability of water temperature and salinity with a space resolution of 50 km. Sources of information: Atlas Arktiki (1985), Atlas Okeanov (1980), Proshutinsky et al. (1995), and International Northern Sea Route Project (see http://www.ims.uaf.edu:8000/insrop-2/), EWG (1997,1998), Morley, R. and M. Steele, (1999; The

Polar Science Center Hydrographic Climatology (PHC), a global physical oceanographic atlas at : http://psc.apl.washington.edu/Climatology.html).

3 Hydrologic conditions

Fluvial water input: seasonal means of water discharge at river mouth. Data obtained from Global Runoff Data Center (GRDC) in Koblenz, or Pan-Arctic Hydrologic Database (University of New Hampshire (Charles Vorosmarty) and Cort Wilmont, University of Delaware; see also Gordeev et al., 1996).

Fluvial sediment input: annual mean supplied at river mouth. Data to be obtained through National Hydrological Data Centers or possibly from runoff/discharge models (Gordeev et al., 1996).

Break-up date: date of initial river-ice break-up during spring flooding. Data to be obtained through National Hydrological Data Centers (for Lena and other rivers draining into Laptev Sea, see Bareiss et al., 1999).

4 Sea-ice conditions

Freeze-up dates: determine start of freeze-up based on identification of local minimum in ice extent record prior to autumn decrease in open water. Iice extent data based on passive-microwave satellite data (available through NSIDC, or ice-chart databases (digitized Russian ice charts, available through NSIDC, or digitized ice charts from the U.S. National Ice Center (NIC).

Break-up dates: determine start of break-up based on time series of ice-concentration data (same as that listed above for freeze-up dates).

Width of bottom-fast ice zone: distance between shore and bottom-fast ice edge in mid-winter; due to lack of direct measurements parameterization based on distance between shore and 2-m isobath.

Distance to (1) ice edge (in summer) and (2) polynya (in winter):

(1) Distance between shore and ice edge (as defined by 15% ice concentration contour) during summer minimum ice extent (or alternatively for fixed date, e.g., September 1). Ice edges derived from passive-microwave satellite data or digitized Russian or NIC ice charts.

(2) Distance between shore and margin of polynya (if present, based on nearest locations) in mid-winter. Polynya data from digitized ice charts, possibly derivation from passive microwave data or AVHRR (Pathfinder) data.

Ice-storm probability: number of occurrences of ice storms (motion of brash ice and floe fragments in wave field onto beach during storm) per year or season. Data derived from model output (cf. database compiled by Andrey Proshutinsky).

Appendix 6. Guidelines for Arctic Coastal Dynamics mapping and data template.

The coastal mapping template is an excel spreadsheet which allows coastal scientists to record information about arctic coasts to be used for a circum-arctic database of coastal retreat and sediment and organic carbon input.

Step 1: Division of the coast (segmentation)

Divide the coast into homogeneous regions. It is important to remember that the primary objective of this mapping project is to estimate sediment and carbon flux to the Arctic Seas. Therefore, the basis for dividing the coast will depend largely on where there are substantial changes in sediment texture, ice content, or organic carbon content. Because there is no consistent circum-arctic coastal map, there are no firm criteria for how to perform this division of the coast. We suggest that each participant uses a combination of his/her expert opinions and the existing information such as coastal and surficial geology maps, landscape or terrain units and geocryology maps. Given the scale of this undertaking, we suggest that you subdivide the coast into units, which are greater than 1 km in length. In general, we expect that most coastal segments will be greater than 10 km and perhaps larger than 100 km in length. To assess consistency and quality of the information you provide to this project, it is essential that you provide an explanation of the basis on which the classification was performed. Columns are provided so that additional information about surficial geology or other classifications can be included. If existing published maps are used in the classification, they should be clearly and completely referenced. The explanation should not take more than 1 page of text. For most participants, we expect that subdivision and mapping will be performed using paper maps. At the end of step one, your maps should be annotated with marks indicating the beginning and end of each segment. We will need the coordinates of the start and end points of the segment. Ideally, these coordinates will be referenced to the GEBCO International bathymetric chart of the world high-resolution shoreline. This shoreline will be made available via the web or on CD to all participants along with a simple display software which can be used to identify the coordinates of any point on the shoreline. It will be necessary to identify the points from paper maps on the GEBCO map and then to extract the necessary coordinates. If it is not possible to do this, simply report the coordinates from your paper map using decimal degrees (with negative longitude of coordinates which are west of the Greenwich meridian). Islands which are homogeneous should have the same start and end coordinates. For coasts with many small islands, we ask you to generalize in order to fulfill our primary objectives of the project (sediment and carbon input from coastal erosion).

Step 2: Coastal parameters

For each homogeneous segment of the coast we need to have information about the sediment grain size, ice content and organic carbon. The backshore zone is the most important for the purposes of sediment and carbon input. Therefore, the coastal attributes of interest refer to the backshore zone (i.e., the region from high tide line to the top of the local cliffs, slopes or the landward extent of marine processes). The specific attributes of the coastal segments have to be calculated and annotated on the hard copy map and entered into the spreadsheet template. This is an oversimplification of the coastal processes and we recognize that some coastal segments will be problematic. For example, lagoon-barrier island and "lace" coasts may have erosional backshore areas, but the sediment and carbon are trapped in lagoons, rather than transported to the sea. For these coasts we still ask that you report the backshore information, but provide a comment in the comment/problem field about the specifics of that segment of the coast and that the sediments might be temporarily trapped.

Material type

Material type refers to the backshore sediments. These should be reported in the terms of the backshore material classes as identified in the Woods Hole workshop. Average material type is sufficient. Please provide information about the publication or report of the material description (e.g. existing surficial geology map, etc).

Backshore material description

Unlithified coasts
- Mud-dominated
- Sand-dominated
- Gravel-dominated
- Diamict
- Organic

Lithified coasts
- Sedimentary
- Igneous
- Metamorphic

Ice coasts

- Floating
- Grounded

Ground ice

Use the technique described in the Wood Hole workshop report. This method involves the division of the backshore into layers with the calculation of a single total excess ice estimate to be reported as volume percent.

Organic carbon

The workshop participants indicated that natural ecosystems and land-use play an important role in the coastal dynamic. The appearance of vegetation and initial stages of pedomorphism at the advanced and stable coast lead to progressive carbon sequestration. Plant rooting systems together with humus adhesion of mineral particles prevent the shore surface from exogenous destructive processes and wind erosion supporting stabilization processes. Retreated coasts destroy coastal ecosystems and result in organic oxidation and CO2 release into the atmosphere. A considerable amount of organic matter is translocated to the sea and influences vulnerable aquatic ecosystems. The knowledge of the processes mentioned above is very limited and episodic. The magnitude and particular effect on the Arctic Ocean is unknown. The tremendous extent of the coastal land-ocean interaction zone presumes the paramount significance of these processes for Arctic, land and the atmospheric carbon balances. In this respect the focus of the ACD is a detailed investigation of the specific carbon cycle at the coastal zone in order to understand in depth major processes and mechanisms driving organic metabolisms in this unique environment. This knowledge should be incorporated into the context of the functioning of the Arctic and contribute to the fundamental understanding of the global carbon turnover.

Organic carbon reporting will be based on soil carbon and sediment carbon measurements if they are available. Soil units and soil map references should be provided if available. Soil carbon should be reported as a weight percent with any information about soil thickness. Sediment carbon should be provided as weight percent as well and the methodology used should be reported along with an appropriate citation. If no carbon information is available, and you are able to estimate, please do so and identify the result as an estimate.

Backshore elevation

The elevation of the backshore zone is required so that we can calculate the volume of material being eroded per meter of shoreline. The average elevation of the coastal segment should be reported along with the source of the elevation data (e.g. 1:250000 topographic map, GTOPO30 database, etc.) and the vertical datum (ukazat nulevoy uroven moray, uroven moray ot kotorogo otschityvalis glubiny, pokazynnyye na karte) for reference (e.g. chart datum, mean sea level).

Change rate

The coastal change rate will usually refer to a shoreline retreat rate using the convention that erosion is negative and accretion is positive. An average of the coastal segment should be reported, but you are welcome to provide additional information about the range as well. An appropriate citation to reports, data or methods (field measurements, remote sensing etc.) should be provided in the source field and it is also essential to provide information on the time interval used for the estimate.

Depth of closure

In order to estimate the contribution of submarine erosion to the material flux, it is necessary to incorporate a simple geometric calculation based on the depth of closure. The depth of closure refers to the concept that there is a particular point along the cross-shore profile at which cross-shore sediment transport due to coastal processes becomes nil. This is often defined by the maximum storm wave-base. However, this information may not be available, or the concept may be considered inappropriate. If you are able to provide the depth of closure, please provide that in meters and include information about the basis on which the calculation was made.

Distance to 10 m isobath

The distance to the 10 m isobath is required to calculate the slope of the nearshore zone and the volume of material from submarine erosion. The best estimate of the average distance to the 10 m isobath based on your hydrographic maps, so that should be the primary source. Please include the map citation and the scale of the map in the spreadsheet.

Appendix 7. Agenda of the 2nd ACD Workshop.

Monday, November 26

Arrival

18.00: Ice-breaker

Tuesday, November 27

09.00 - 09.15 Welcome and opening of the workshop – V. Rachold

09.15 - 10.30: Reports of the working groups according to the ACD Science and Implementation Plan

Literature WG – G. Cherkashov and F.E. Are

Metadata WG – A circum-arctic coastal Geo Information System (GIS) - M. Lack, V. Rachold and H. Asche

Environmental data WG – Describing Beaufort Sea coastal climate variability - G. Manson, S. Solomon, A. MacDonald

Classification and Mapping WG - Beaufort Sea coastal mapping and the development of an erosion hazard index – S. Solomon

10.30 - 11.00: Coffee break

11.00 - 12.30: Reports: field work I

Establishment of the Elson Lagoon ACD key site, Barrow, Alaska - J. Brown, T. Jorgenson, O. Smith and W. Lee

Shore dynamics on northwest coast of the Lena Delta, the Laptev Sea, Siberia - M.N. Grigoriev, F.E. Are, H.–W. Hubberten, S.O. Razumov and V. Rachold

Evolution of the coastal lake-lagoon-barrier island system of north Arctic Alaska – a synthesis - A.S. Naidu and J.J. Kelley

Coastal erosion in Alaska- O.P. Smith

12.30 - 14.00: Lunch break

14.00 - 14.45: Reports: data management

PANGAEA – an information system for environmental sciences - M. Diepenbroek, H. Grobe, M. Reinke, U. Schindler, R. Schlitzer, R. Sieger and G. Wefer

14.45 - 15.45: Reports: modeling and remote sensing

Numerical modeling of shelf and estuary hydrodynamics in the Kara Sea - I.H. Harms, J.O. Backhaus and U. Hübner

Satellite hydrographic monitoring and assessment of environmental trends along the Russian Arctic Coast (AMETHYST Project) - A.I. Sharov

Modeling coastal erosion near Barrow, Alaska - S.D. Peckham, W. Manley, M. Dyurgerov and J.P.M. Syvitski

Measurements of coastal retreat in the Russian Arctic and at Svalbard by means multi-temporal aerial photographs and digital photogrammetry - B. Wangensteen, R. Ødegård, B. Etzelmüller and J.L. Sollid

15.45 - 16.15: Coffee break

16.15 - 17.45: Reports: sediment and organic carbon input

Siberian river run-off in the Kara Sea: characterization, quantification, and variability through late Quaternary times / Arctic Paleo-River Discharge (APARD) - report on 2000 activities - R. Stein

Sediment flux in arctic rivers - R.M. Holmes, J.W. McClelland, B.J. Peterson, A.I. Shiklomanov, I.A. Shiklomanov, A.V. Zhulidov and V.V. Gordeev

Organic carbon in permafrost sediments under thermal abrasion: load into marine basin and oxidation in aeration zone - V. Ostroumov, D. Fyedorov – Davydov and V. Sorokovikov

Carbon content in coastal ecosystems of Russian Arctic - V. Stolbovoi

17.45- 18.15: Reports: poster presentation

Coastal monitoring along Beaufort Lagoon in the Arctic National Wildlife Refuge, Northeast Alaska - T. Jorgenson, M. Macander and J. Jorgenson (Poster presented by J. Brown)

Integrated assessment of the impacts of climate variability on the Alaska north slope coastal region - A. Lynch, R. Brunner, J. Curry, A. Jensen, J. Maslanik, L. Mearns, G. Sheehan and J. Syvitski (poster presented by S.D. Peckham)

Terrestrial material fluxes in the North-Asian Arctic Seas: coastal erosion vs. riverine transport - I.P.Semiletov (Poster presented by J. Brown)

18.15 - 18.45: General discussion

Wednesday, November 28

09.00 - 10.00: Reports: field work II

Dynamics of coasts and shelf of the Arctic Seas - S.A. Ogorodov

New research program for coastal dynamics investigations of Marre-Sale site on western Yamal Shore (Kara Sea) - A.A Vasiliev, G.A. Cherkashov, B.G. Vanshtein, Y.G. Firsov and M.V. Ivanov

Ice content and sensitivity analysis based on landscape interpretation for several sites along the Beaufort Sea coast - W. Pollard, C. Omelon, N. Couture, S. Solomon and P. Budkewitsch

10.00 - 10.40: Reports: mapping, classification and metadata

The new approaches for the metadata development - E. Vyazilov, N. Mickhailov, V. Ibragimova and N. Puzova

Some problems of coastal mapping in the Russian Arctic - A.A. Vasiliev

10.40 - 11.15: Coffee break

11.15 - 12.30: Identification of working groups, definition of objectives for working groups

12.30 - 14.00: Lunch break

14.00 - 16.00: Working group meetings

16.00 - 16-30: Coffee break

16.30 - 18.00: Working group meetings

Thursday, November 29

09.00 - 10.30: Working group reports and general discussion

10.30 - 11.00: Coffee break

11.00 - 13.00: Working group meetings

13.00 - 14.00: Lunch break

14.00 - 16.00: Working group meetings

16.00 - 16.30: Coffee break

16.30 - 18.00: Working group reports and general discussion

Friday, November 30

09.00 - 11.00: Russian teams to organize synthesis / Steering Committee meeting

11.00 - 11.30: Coffee break

11.30 - 13.00: Russian teams to continue to organize synthesis / Steering Committee meeting

13.00 - 14.00: Lunch break

14.00 - 15.00: Synthesis reports

15.00 - 15.30: Coffee break

15.30 - 17.00: Final discussion and next steps

Appendix 8. Participants of the 2nd ACD Workshop.

1. Feliks Are*, St. Petersburg University, Russia (email: but@peterlink.ru)
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25. Evgeny Viazilov, Russian Research Institute of Hydrometeorological Information - World Data Center), Obninsk, Russia (email: vjaz@meteo.ru)
26. Bjørn Wangensteen**, Oslo University, Norway (email: bjorn.wangensteen@geografi.uio.no)

* Steering Committee Member, ** Young Investigator

Folgende Hefte der Reihe „Berichte zur Polarforschung" sind bisher erschienen:

- * **Sonderheft Nr. 1/1981** – „Die Antarktis und ihr Lebensraum" Eine Einführung für Besucher – Herausgegeben im Auftrag von SCAR
- * **Heft Nr. 1/1982** – „Die Filchner-Schelfeis-Expedition 1980/81" zusammengestellt von Heinz Kohnen
- * **Heft Nr. 2/1982** – „Deutsche Antarktis-Expedition 1980/81 mit FS „Meteor" First International BIOMASS Experiment (FIBEX) – Liste der Zooplankton- und Mikronektonnetzfänge zusammengestellt von Norbert Klages
- * **Heft Nr. 3/1982** – „Digitale und analoge Krill-Echolot-Rohdatenerfassung an Bord des Forschungsschiffes ‚Meteor'" (im Rahmen von FIBEX 1980/81, Fahrtabschnitt ANT III), von Bodo Morgenstern
- **Heft Nr. 4/1982** – „Filchner-Schelfeis-Expedition 1980/81" Liste der Planktonfänge und Lichtstärkemessungen zusammengestellt von Gerd Hubold und H. Eberhard Drescher
- * **Heft Nr. 5/1982** – "Joint Biological Expedition on RRS 'John Biscoe', February 1982" by G. Hempel and R. B. Heywood
- * **Heft Nr. 6/1982** – „Antarktis-Expedition 1981/82 (Unternehmen ‚Eiswarte')" zusammengestellt von Gode Gravenhorst
- **Heft Nr. 7/1982** – „Marin-Biologisches Begleitprogramm zur Standorterkundung 1979/80 mit MS ‚Polarsirkel' (Pre-Site Survey)" – Stationslisten der Mikronekton- und Zooplanktonfänge sowie der Bodenfischerei zusammengestellt von R. Schneppenheim
- **Heft Nr. 8/1983** – "The Post-Fibex Data Interpretation Workshop" by D. L. Cram and J.-C. Freytag with the collaboration of J. W. Schmidt, M. Mall, R. Kresse, T. Schwinghammer
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- **Heft Nr. 10/1983** – „Fluor im antarktischen Ökosystem" – DFG-Symposium November 1982 zusammengestellt von Dieter Adelung
- **Heft Nr. 11/1983** – "Joint Biological Expedition on RRS 'John Biscoe', February 1982 (II)" Data of micronecton and zooplankton hauls, by Uwe Piatkowski
- **Heft Nr. 12/1983** – „Das biologische Programm der ANTARKTIS-I-Expedition 1983 mit FS ‚Polarstern'" Stationslisten der Plankton-, Benthos- und Grundschleppnetzfänge und Liste der Probennahme an Robben und Vögeln, von H. E. Drescher, G. Hubold, U. Piatkowski, J. Plötz und J. Voß
- * **Heft Nr. 13/1983** – „Die Antarktis-Expedition von MS ‚Polarbjörn' 1982/83" (Sommerkampagne zur Atka-Bucht und zu den Kraul-Bergen), zusammengestellt von Heinz Kohnen
- * **Sonderheft Nr. 2/1983** – „Die erste Antarktis-Expedition von FS ‚Polarstern' (Kapstadt, 20. Januar 1983 – Rio de Janeiro, 25. März 1983)", Bericht des Fahrtleiters Prof. Dr. Gotthilf Hempel
- **Sonderheft Nr. 3/1983** – „Sicherheit und Überleben bei Polarexpeditionen" zusammengestellt von Heinz Kohnen
- * **Heft Nr. 14/1983** – „Die erste Antarktis-Expedition (ANTARKTIS I) von FS ‚Polarstern' 1982/83" herausgegeben von Gotthilf Hempel
- **Sonderheft Nr. 4/1983** – "On the Biology of Krill *Euphausia superba*" – Proceedings of the Seminar and Report of the Krill Ecology Group, Bremerhaven 12. - 16. May 1983, edited by S. B. Schnack
- **Heft Nr. 15/1983** – "German Antarctic Expedition 1980/81 with FRV 'Walther Herwig' and RV 'Meteor'" – First International BIOMASS Experiment (FIBEX) – Data of micronekton and zooplankton hauls by Uwe Piatkowski and Norbert Klages
- **Sonderheft Nr. 5/1984** – "The observatories of the Georg von Neumayer Station", by Ernst Augstein
- **Heft Nr. 16/1984** – "FIBEX cruise zooplankton data" by U. Piatkowski, I. Hempel and S. Rakusa-Suszczewski
- * **Heft Nr. 17/1984** – Fahrtbericht (cruise report) der ‚Polarstern'-Reise ARKTIS I, 1983" von E. Augstein, G. Hempel und J. Thiede
- **Heft Nr. 18/1984** – „Die Expedition ANTARKTIS II mit FS ‚Polarstern' 1983/84", Bericht von den Fahrtabschnitten 1, 2 und 3, herausgegeben von D. Fütterer
- **Heft Nr. 19/1984** – „Die Expedition ANTARKTIS II mit FS ‚Polarstern' 1983/84", Bericht vom Fahrtabschnitt 4, Punta Arenas-Kapstadt (Ant-II/4), herausgegeben von H. Kohnen
- **Heft Nr. 20/1984** – „Die Expedition ARKTIS II des FS ‚Polarstern' 1984, mit Beiträgen des FS ‚Valdivia' und des Forschungsflugzeuges ‚Falcon 20' zum Marginal Ice Zone Experiment 1984 (MIZEX)" von E. Augstein, G. Hempel, J. Schwarz, J. Thiede und W. Weigel
- **Heft Nr. 21/1985** – "Euphausiid larvae in plankton from the vicinity of the Antarctic Penisula, February 1982" by Sigrid Marschall and Elke Mizdalski
- **Heft Nr. 22/1985** – "Maps of the geographical distribution of macrozooplankton in the Atlantic sector of the Southern Ocean" by Uwe Piatkowski
- **Heft Nr. 23/1985** – „Untersuchungen zur Funktionsmorphologie und Nahrungsaufnahme der Larven des Antarktischen Krills *Euphausia superba* Dana" von Hans-Peter Marschall

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* **Heft Nr. 25/1985** – „Die Expedition ANTARKTIS III mit FS ‚Polarstern' 1984/1985" herausgegeben von Gotthilf Hempel.
* **Heft Nr. 26/1985** – "The Southern Ocean"; A survey of oceanographic and marine meteorological research work by Hellmer et al.
* **Heft Nr. 27/1986** – „Spätpleistozäne Sedimentationsprozesse am antarktischen Kontinentalhang vor Kapp Norvegia, östliche Weddell-See" von Hannes Grobe

Heft Nr. 28/1986 – „Die Expedition ARKTIS III mit ‚Polarstern' 1985 mit Beiträgen der Fahrtteilnehmer, herausgegeben von Rainer Gersonde

* **Heft Nr. 29/1986** – „5 Jahre Schwerpunktprogramm ‚Antarktisforschung' der Deutschen Forschungsgemeinschaft." Rückblick und Ausblick. Zusammengestellt von Gotthilf Hempel, Sprecher des Schwerpunktprogramms

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