ACD

Arctic Coastal Dynamics

Science and Implementation Plan

Results of an International Workshop

Potsdam, Germany

October 18-20, 2000

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IASC

Alfred Wegener Institute
for Polar and Marine Research

Research Unit Potsdam
Telegrafenberg A43, 14473 Potsdam, Germany
contact: Volker Rachold (vrachold@awi-potsdam.de)
http://www.awi-potsdam.de/www-pot/geo/acd.html

Summary

An international workshop on Arctic Coastal Dynamics (ACD) sponsored by the International Arctic Science Committee (IASC) was held in Potsdam, Germany, on October 18-20, 2000. Participants from Canada (1), Germany (3), Norway (2), Russia (4), and the United States (1) attended. The group reviewed results of the November 1999 ACD workshop held in Woods Hole, USA (Brown and Solomon 2000), and developed a phased, five-year science and implementation plan. The overall objective is to improve our understanding of circum-Arctic Coastal Dynamics under the influence of environmental changes and geologic controls. The plan consists of two interrelated components: (1) a series of coordinated, synthesis activities, and (2) proposed focused research projects and long-term observations. The plan will be submitted to the IASC Council for review, approval and advice on future directions. An international steering committee will develop coordination with other related programs and encourage and seek funding to implement the proposed activities.

Workshop Participants and Members of the Steering Committee (*)

Felix Are*, St. Petersburg State University of Means and Communication
Ivar Berthling (young investigator), Oslo University
Jerry Brown*, International Permafrost Association, Woods Hole
George Cherkashov*, VNIIOkeangeologia, St. Petersburg
Dieter Fütterer, AWI, Bremerhaven
Mikhail Grigoriev*, Permafrost Institue, Yakutsk
Hans Hubberten*, AWI, Potsdam
Stanislav Ogorodov, (young investigator), Moscow State University
Volker Rachold*, AWI, Potsdam
Johan Ludvig Sollid*, Oslo University
Steven Solomon*, Geological Survey of Canada, Dartmouth

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1. Introduction

Arctic coastal dynamics refers to the process-response system, which operates on permafrost-affected coasts. The process-response system is defined as the product of the interaction between environmental variables (e.g. wind waves, water temperatures, sea ice, etc.), geology and morphology along those coasts. Investigations of the Arctic coast have a long history, dating back to the early European explorers of the 18th and 19th centuries, who were often accompanied by accomplished observers and naturalists. Observations recorded in journals from those expeditions form the foundations of modern Arctic coastal studies. Recent efforts to obtain similar observations based on traditional knowledge from indigenous groups are also helping to improve our understanding of conditions on a longer time scale. Studies of coastal dynamics have concentrated on the temperate regions like the eastern coast of the U.S. and tropical shore. In these areas, significant advances in the fields of coastal oceanography, morphodynamics and sediment transport have been made. However, Arctic coastal studies over the past two decades have identified many differences between the dynamics of permafrost-affected material and their temperate/tropical unfrozen counterparts. Of particular note are the influences of ice (ground-ice and sea ice).

Arctic Coastal Dynamics (ACD) is a multi-disciplinary, multi-national forum to exchange ideas and information. 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 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 (Annex 1). A consistent and generalized coastal classification scheme was established based on morphology and materials (Annex 2). Consensus was reached on direct and indirect methodologies for estimating ground-ice volumes and presentations of data on maps (Annex 3). Finally, a suite of standard tools and techniques for development of long-term coastal monitoring site was recommended (Annex 4). At the request of the IPA in April 2000 during the Arctic Summit Week the Council of the International Arctic Science Committee approved funding for a follow up workshop to develop a Science and Implementation plan for the ACD. The following report contains the results of a small workshop held at the AWI in Potsdam, October 18—20, 2000.

2. Objectives and Main Content

The overall objective of the ACD Science and Implementation Plan 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 (see Table 1 and Annex 5 for examples);
- 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.

3. Implementation

The program will be implemented in three phases (see Figure 1 showing a time line and milestones for each major component of the Plan). Throughout all three phases, the ACD web site will be updated and developed to facilitate communication and data exchange. An occasional electronic newsletter will present summary information to a wide audience.

3.1 Phase 1 (18 months)

The first phase is directed towards the assessment and synthesis of existing information on coastal properties and dynamics. The quality and availability of relevant information will be assessed using information developed from metadata forms, literature, and the classification of coasts and ground-ice (procedures developed during the Woods Hole Workshop, see Annexes 1, 2, and 3). Four Working Groups (WG) will be established to perform the tasks:

Literature WG: Regional representatives from the circum-Arctic countries will be responsible for conducting a review of relevant published papers, reports and coastal maps for their area. An annotated bibliography will be compiled and data on erosion rates, carbon content of soil and sediments of coastal sections and sediment input from erosion will be extracted for inclusion in the ACD database. The literature search will form the basis of a circum-Arctic coastal bibliography based on the format of the IPA/INTAS map and ground-ice bibliographies (see Streletskaya et al. 1998)

Metadata WG: Much of the information required for the development of a circum-Arctic coastal database resides in unpublished reports and personal databases of individual scientists. The metadata WG will be responsible for compiling an inventory of the following information from unpublished sources: erosion rates and magnitudes, ground-ice estimates, appropriate maps, charts, remote sensing data and air photos, existing key and observational sites, coastal sediment delivery and organic carbon content of coastal materials. This will be done using metadata forms, which will be distributed by the WG. Web-available maps of progress in metadatabase development will be vehicles for encouraging wide participation.

Environmental data WG: Environmental data refers to the meteorological and hydrodynamic variables, which affect the coast. This includes information on winds, waves, currents, water levels, water and air temperatures, sea ice, etc. (for details see Annex 6). Much of the data resides in existing national and international archives. Efforts are required to extract and format the relevant subsets of the data for inclusion in an Arctic coastal database. In addition, information which is specific to questions of coastal dynamics, such as the type, frequency and intensity of storms, is not necessarily available in an easily extractable form. Using this as an example, it may be necessary to devote some effort to querying historical databases (e.g. NCEP reanalysis) using criteria such as wind speed, direction and duration in order to extract data on storminess. Close coordination with international climate change projects will be necessary in order to avoid duplication of efforts.

Classification and mapping WG including ground-ice: This WG has the responsibility for the development of the database structure, compilation and maintenance of the classification databases (ground-ice and coastal properties) and development of the GIS-based map products (including CD-ROM, web-based and hardcopy). Initially, efforts will be focussed on refinement of the coastal and ground-ice classification schemes developed at the Woods Hole Workshop (included in Annex 3). This will be done by applying the schemes at 8-10 sites along the coasts of the Yamal Peninsula, Pechora Sea, Laptev Sea, Beaufort Sea, Svalbard, Kara Sea and the Canadian Arctic Archipelago. Mapping will be performed by regional experts as identified at Woods Hole. Coastal segments of approximately 50-100 km will be mapped on 1:500 000 map sheets and digitized into a GIS using a structure which will permit querying and display of individual map units both along-shore and across-shore. The

Working Group, assisted by the regional experts will evaluate the classification scheme and the database structure to ensure that it captures relevant information at an appropriate level of detail. Once consensus is achieved, the refined classification will be applied to the circum-Arctic coasts where sufficient data is available. Concurrent activities will include efforts to transfer information from existing digital and hard-copy classification schemes (e.g. the Geological Survey of Canada Coastal Information System and regional/national oil spill sensitivity maps) to the generalized/unified ACD system.

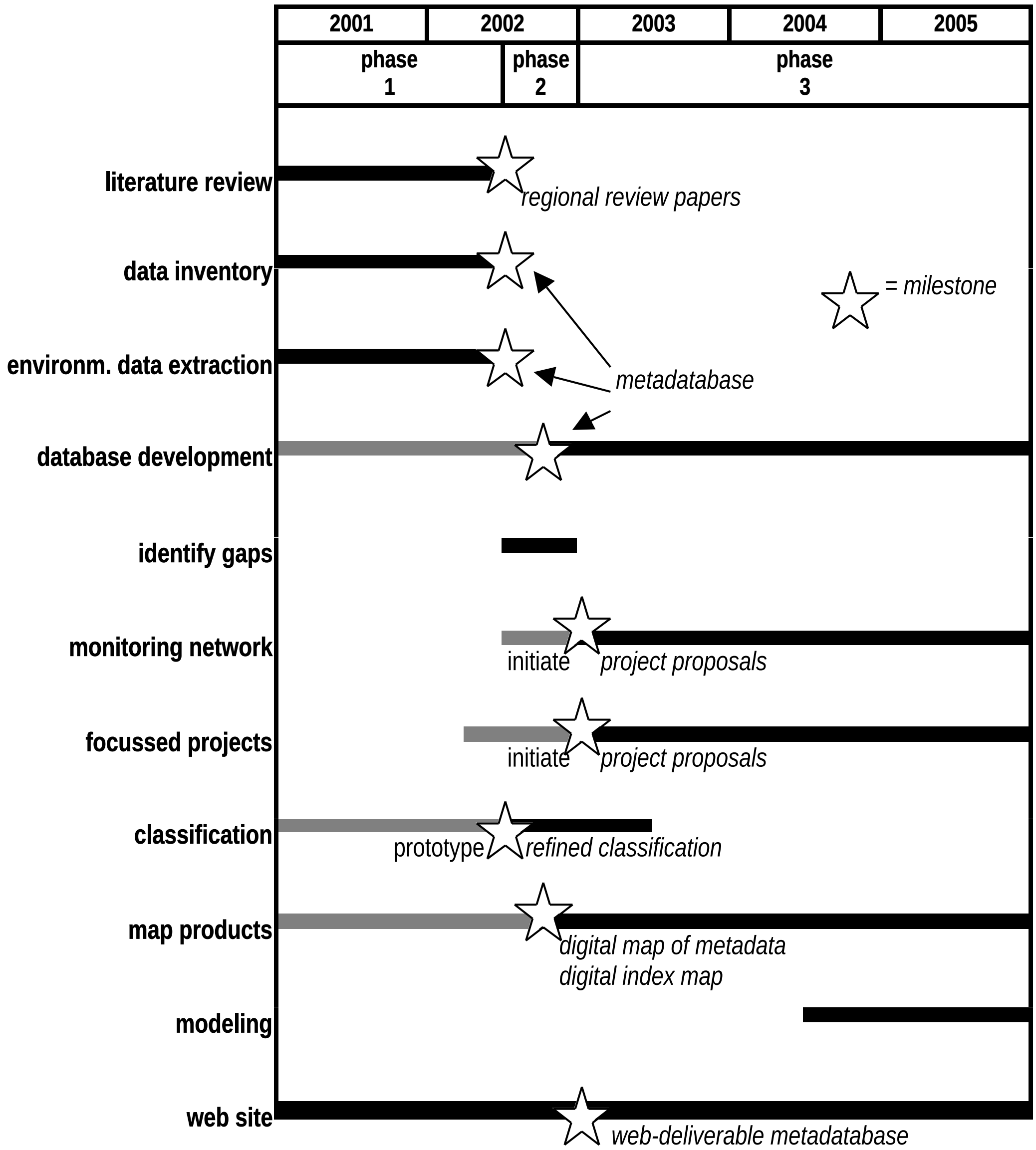

Figure 1: Main elements of the Science and Implementation Plan, schedule and milestones

3.2. Phase 2 (6 months)

During the second phase the databases developed in phase 1 will be analyzed. Based on these analyses the following steps will be undertaken to:

- identify gaps;
- establish a network of monitoring sites (considering identified gaps) using the protocols established at the Woods Hole Workshop (see Annex 4), this will be undertaken by regional groups (candidate key sites are shown in Figure 2);
- develop national and multi-national projects for focused research studies and to fill gaps (will be developed during annual workshops or based on national priorities);
- initiate coastal classification and mapping:
    - regional representatives will apply the coastal (see phase 1) and ground-ice (Annex 3) classifications by annotation of manuscript maps at the scales between of 1:200,000 and 1:1,000,000;
    - digitization of the information according to the database structure defined in phase 1.

3.3 Phase 3 (36 months)

During the third phase coastal monitoring will be performed and process-related research projects will be implemented. By the end of phase three, map production will be completed and models for prediction of coastal sensitivity will be developed. The tasks are to:

- maintain monitoring sites (see Annex 4);
- complete ground-ice and coastal mapping of Arctic coasts;
- using the GIS database produce circum-Arctic thematic and derived maps in CD-ROM, web-deliverable and hardcopy formats (e.g. coastal types, ground-ice, sensitivity, sediment and carbon input, coastal change)
- continue process-related field research, examples of potential projects are listed in Table 1 (implementations of individual aspects of some of the proposals are already underway as parts of national programs or academic research projects, ACD will endeavor to initiate collaborative projects and facilitate international cooperation for implementation of priority research);

Table 1: Examples of process or focused research related to ACD (for detailed description, see Annex 5)

Investigations of the thaw consolidation of subsea permafrost and its role on coastal erosion
Weathering and erosion of bedrock
Fate of eroded organic carbon and sediments
Natural hazards
Effects of human activities (e.g. coastal mining)
The role of sea ice processes
Influence of sea level on sediment dynamics

· adapt existing or develop new models to predict the sensitivity of Arctic coasts.

4. Products

Several continuing and final products are anticipated:

· Communications: The web site will be expanded for data access, delivery, and linkages. An occasional electronic newsletter will be used to present summary information to a wide audience.

· Map: A digital circum-Arctic index map at approximately 1:7,500,000 to display generalized information including coastal DEM, geologic material, ground-ice, erosion status, site locations, and selected representative coastal segments.

· Database: The digital coastal database with interactive map viewing capabilities will be a final product and available on the web and on a CD-ROM.

· Synthesis: A book or special issue of a polar journal will present final results of synthesis and focused research.

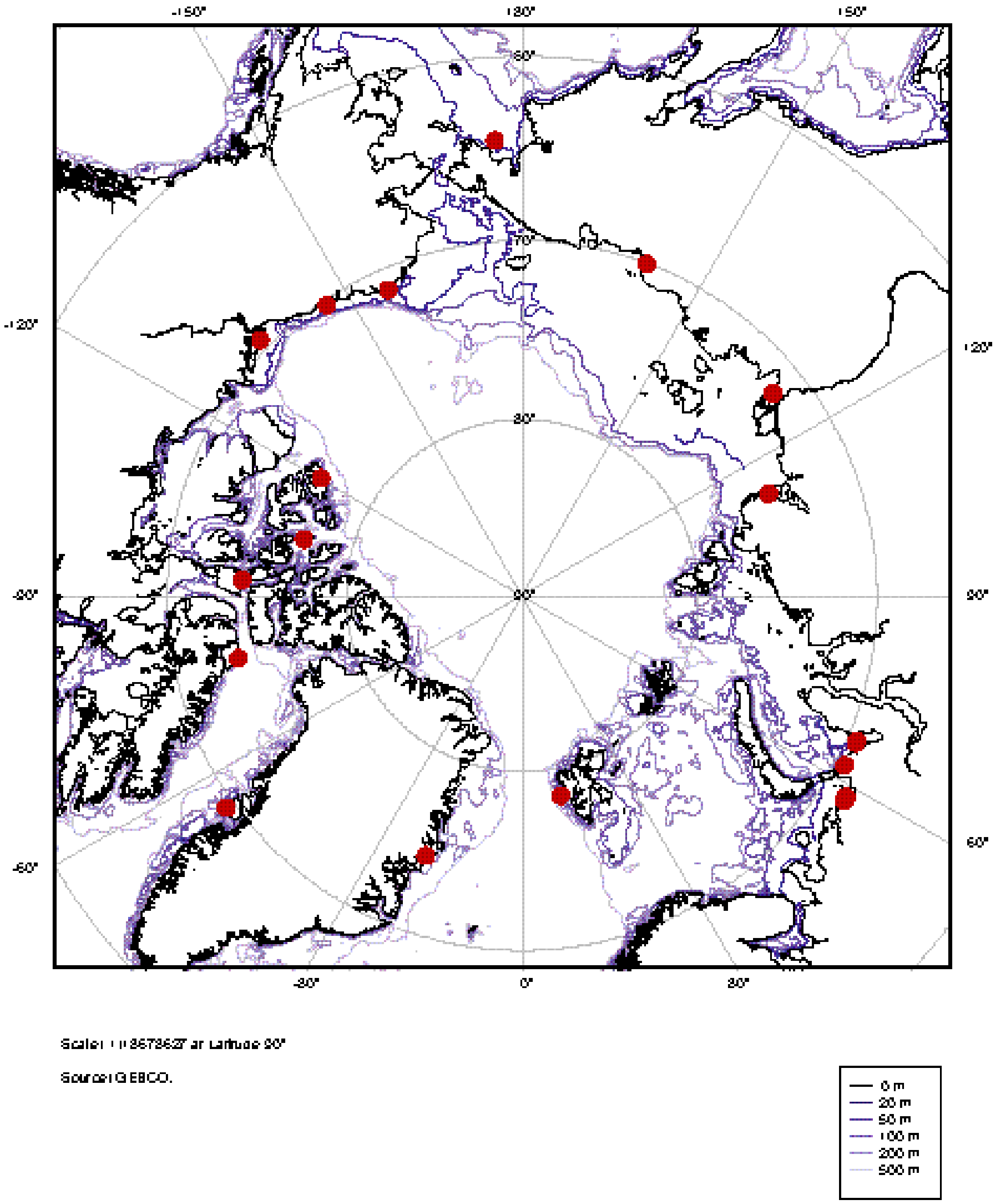

Figure 2: Candidate key sites

5. Project Management

During the Potsdam workshop, the participants selected Volker Rachold to be the official IASC Project Leader. Hans Hubberten, Director of the AWI Potsdam Department, agreed that a project office could be established at AWI-Potsdam with a secretariat to maintain international communications including the web site developed by Volker Rachold and an electronic newsletter. The secretariat will be assisted by the International Steering Committee (ISC) (see Potsdam Workshop participants for membership). The ISC responsibilities are to oversee development of ACD and the Working Groups activities, and actively participate in liaison and coordination with other international organizations and programs. The Working Groups will develop and conduct the tasks as outlined in the plan.

Annual meetings or workshops will be used to review progress and modify the plan as required. As a cost saving measure and outreach to other workers, we will use other permafrost meetings as the venue for the ACD 2-3 day annual meeting. The following is a tentative schedule.

- First European Permafrost Conference, Rome, April 2001.
- Eighth International Conference on Permafrost, Zürich, July 2003.
- Pushchino annual spring conferences 2001, 2002 and 2004.
- Final Conference with Special Conference Journal Issue, mid-late 2005.

6. International Coordination

Primary coordination will be with the parent IPA and IASC activities and projects. For IASC this includes LOIRA, ADD, IBCAO and the new basin sediment project. There are many bilateral and multinational programs and projects for which close coordination and joint activities will be pursued, particularly the IGBP LOICZ program. The Secretariat will keep other organizations informed of ACD status including the AOSB, APARD, and IGU commissions.

7. Potential Users and Funders

Users: A diverse group of users is anticipated including industry, local and regional governments, environmental organizations interested in habitat protection and utilization (CAFF, AMAP, WCMC), and policy organizations involved in assessments (IPCC, ACIA).

Funders: National research and mission funding agencies and regional and international organizations (ESF/EU, NATO, UNEP, UNESCO, INTAS), and industry (oil and gas, mining) are all potential sources of funding.

8. References

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Annex

Annex 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)

Annex 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 (50º) - C Slope (3-50º) - S Flat (<3º) - 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)

Annex 3: Ground-ice estimates and mapping

Annex 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

Annex 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

Annex 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

Annex 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

Annex 5: Examples of process or focused research related to ACD

Investigations of the thaw consolidation of subsea permafrost and its role on coastal erosion

There is considerable debate within the Arctic coastal community as to the relative roles of thaw subsidence, sea ice and hydrodynamic processes. Retreat of permafrost affected coasts results in the inundation of ice-bonded materials which often contain high concentrations of excess ice. The exposure of these materials to higher mean annual temperatures causes melting of interstitial and massive ice with consequent reductions in volume and subsidence of the sea floor (thaw consolidation). The rate and magnitude may vary substantially depending on ice content, water temperature and salinity, thermal and hydrodynamic properties of the sediments, initial water depth, etc. The rate of subsidence can easily exceed that of relative sea level rise. Local deepening of the sea adjacent to the shoreline causes an increase of wave energy and intensifies coastal erosion.

Weathering and erosion of bedrock

Arctic bedrock coasts may experience relatively rapid cliff retreat rates. This is mainly due to permafrost conditions, which cause a favorable environment for rock disintegration due to frost weathering. Frost weathering is caused by development of segregation ice as unfrozen water penetrates bedrock, and freezes. Temperature measurements from Arctic coastlines suggest that large temperature gradients may develop during spring thaw, so that water transport into the permafrost is facilitated through a period of time. Processes such as hydromechanical erosion and ice action effectively remove the weathered material and fresh bedrock is exposed. The rates of these processes, properties of the materials and contributions to the Arctic sediment budget are not well known.

Fate of eroded organic carbon and sediments

Organic carbon and sediments are supplied to the Arctic shelves and basins by rivers and rapid erosion of unlithified coastal materials. This information is important in order to understand the role of the Arctic in the global carbon budget; whether it is a source or a sink for carbon. An understanding of sediment input from modern coasts and rivers is critical to the interpretation of cores from Arctic shelves and basins and is therefore important for developing an understanding of the sedimentary history of the Arctic Ocean. Previous studies from the Laptev Sea and the Canadian sector of the Beaufort Sea including the Mackenzie Delta suggest pronounced regional differences and indicate that in some regions (e.g. the Laptev Sea) coastal sediment input can exceed riverine sediment supply (MacDonald et al. 1998, Rachold et al. 2000). Proposals to improve our understanding of sediment and carbon burial and transport will be encouraged.

Natural hazards

During the last decades the Arctic coastal zones have been a place of increasing human activity (especially since the beginning of the oil and gas production). Rapid development, combined with short periods of observation of natural phenomena creates a situation with considerable potential for natural disasters. A better understanding of coastal processes in high latitudes along with more information about reccurence of extreme events is critical for the safe development of the circum-Arctic coastlines. Ice hazards (ice push and ride up; open water extent), extreme waves and water levels, tsunamis, thermokarst and coastal retreat require further investigation.

Annex 5: Examples of process or focused research related to ACD (continuation)

Effects of human activities (e.g. coastal mining)

The coastal system in permafrost zones is very fragile and characterized by low levels of stability. Industrial development often initiates degradational morphodynamic processes. Projects which are designed to investigate the effects of human activities on Arctic coasts (e.g. coastal mining, construction, shore protection, etc) will be encouraged.

The role of sea ice processes in erosion and sediment transport

Sea ice plays a major role in controlling the dynamics of Arctic shores. During the winter the land-fast ice totally protects the coast from waves and bottom-fast ice transmits winter temperatures into the seabed causing aggradation of permafrost and frost heave. The timing of break-up and freeze-up relative to the storm season and the evolution and characteristics of the open water area are principal influences on coastal changes. Sea ice may also be and agents of sea floor erosion and sediment transport by the ice-keel scouring, ice ride-up and pile-up; sediment transport by anchor-ice, frazil-ice, and drift-ice etc. The relative role of sea in parts of the Arctic is reasonably well established. Work by Reimnitz and Barnes (1987) have shown the importance of sea ice processes along the Alaskan Beaufort Sea; Taylor et al. (1996) has identified a similar paramount role for sea ice in the Canadian Archipelago. In other areas (e.g. the Mackenzie River are), its role is less certain. Changing sea ice conditions under predicted warmer Arctic climate may have dramatic effects on coasts, which are habituated to a particular sea ice regime. Proposals to study the relative importance of sea ice in other Arctic locations would permit the development of analogues for predicting the effects of changing sea ice regimes.

Influence of sea level on sediment dynamics

Global sea level is predicted to rise 50 cm in the next century as a result of climate warming. Regional predictions for Arctic seas are few in number, but suggest that the rise may be significantly less in the north. However, even small accelerations in the rate of SLR in areas, which are currently stable or already subsiding may cause increases in coastal erosion and other transport processes. National tide gauges networks are being used to monitor Arctic sea level, however, long-term gauge sites are limited and those areas which are most susceptible to the rising sea level (unlithified coasts) are the ones which are most difficult to monitor. New satellite and GPS technologies may provide a partial answer to this problem. Research directed to monitoring Arctic sea levels and studying the effects of changes in the rate and direction of sea level change is required.

Annex 6: 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

<u>Permanent currents</u>: 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/).

<u>Wind-driven currents (surface):</u> 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).

<u>Tidal currents:</u> 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

<u>Sea level and storm surges</u>: 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).