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PREFACE

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Arctic Coastal Dynamics (ACD): an introduction

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Background and rationale

The coastal zone is the interface through which land-ocean exchanges in the Arctic are mediated and it is the site of most of the human activity that occurs at high latitudes. Arctic coastlines are highly variable and their dynamics are a function of environmental forcing (wind, waves, sea-level changes, sea-ice, etc.), geology, permafrost and its ground-ice content and coastline morphometry. Environmental forcing initiates coastal processes, such as the sediment transport by waves, currents and sea-ice and the degradation of coastal permafrost. The coastal response (erosion or accretion) results in land and habitat loss or gain and thus affects biological and human systems. Figure 1 schematically illustrates the major processes involved in Arctic coastal dynamics. Coastal processes in the Arctic are strongly controlled by Arctic-specific phenomena, i.e. the sea-ice cover and the existence of onshore and offshore permafrost. During the 7–9-month-long winter season, a thick and extensive sea-ice cover protects the coastline from hydrodynamic forcing. During the open water season, the sea-ice is an important transport agent for coastal sediments.

The Arctic coastal region is the transition zone between onshore and offshore permafrost. The degradation of permafrost, which can be connected with the release of permafrost-bonded greenhouse gases (GHG), is concentrated in the coastal zone. During the short ice-free period, the unlithified, ice-rich, permafrost-dominated coastlines are rapidly eroded (at rates of several meters per year) and it is assumed that the resulting coastal sediment, organic carbon, and nutrient fluxes play an important role in the material budget of the Arctic Ocean. Figure 2 shows as an example the rapidly eroding ice-rich permafrost coast of the Island Muostakh in the SE Laptev Sea (Siberian Arctic).

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

Development and implementation of a circum-Arctic coastal program

Arctic Coastal Dynamics (ACD) is a multi-disciplinary, multi-national program of the International Arctic

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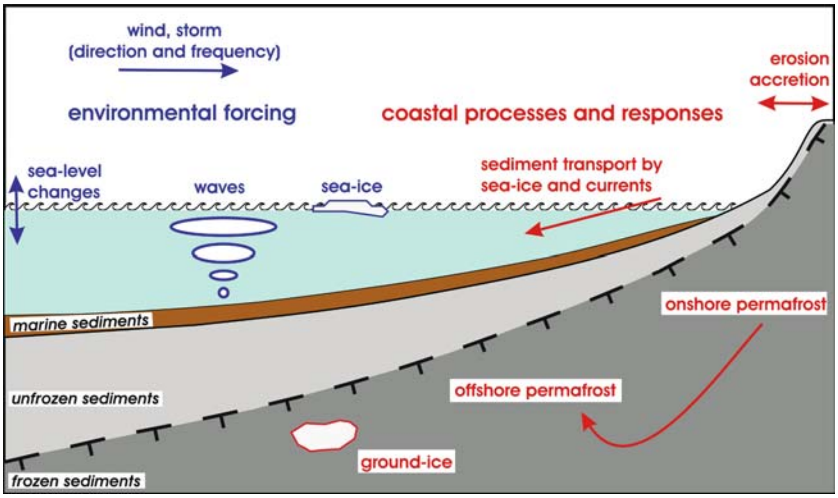

Fig. 1 Arctic coastal processes and responses to environmental forcing

Fig. 2 Coastal section of the island Muostakh in the SE Laptev Sea (Siberian Arctic). The coastal cliff, which is ca. 15 m high and composed of frozen, ice-rich deposits (so-called Ice Complex), is rapidly eroded. The coastal retreat rates are several meters per year and most probably the island will be completed destroyed within the next 50 years

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

- Establish the rates and magnitudes of erosion and accumulation of Arctic coasts and to estimate the amount of sediments and organic carbon derived from coastal erosion;
- Develop a network of long-term monitoring sites including local community-based observational sites;
- Refine and apply an Arctic coastal classification (includes ground-ice, permafrost, geology, etc.) in digital form (Geo Information System (GIS) format) and produce a series of thematic and derived maps (e.g. coastal classification, ground-ice, sensitivity, etc.);
- Compile, analyze and apply existing information on relevant environmental forcing parameters (e.g. wind

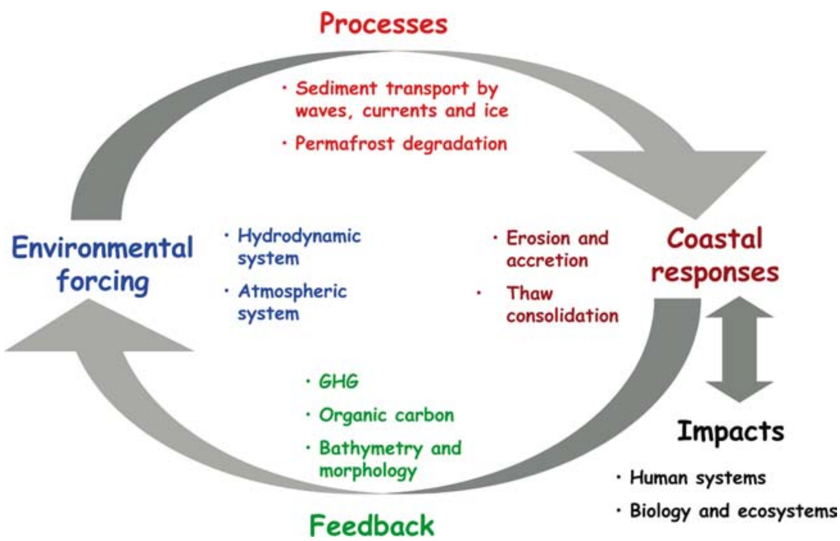

Fig. 3 Environmental forcing, coastal processes and responses, impacts and feedback

speed, sea-level, fetch, sea ice, etc.);
- Identify and undertake focused research on critical processes;
- Develop empirical models to assess the sensitivity of Arctic coasts to environmental variability and human impacts.

The project elements for ACD were formulated at a workshop in Woods Hole, Massachusetts, in November 1999 funded by the U.S. National Science Foundation (NSF) and organized under the auspices of the IPA, through its working group on Coastal and Offshore Permafrost and its Coastal Erosion subgroup. As a result of the workshop, a metadata form for the selection and establishment of key monitoring sites was developed. A consistent and generalized coastal classification scheme was established based on morphology and materials. A consensus was reached on direct and indirect methodologies for estimating ground-ice volumes and presentations of data on maps. Finally, a suite of standard tools and techniques for development of long-term coastal monitoring sites was recommended (Brown and Solomon 2000). During the Arctic Science Summit Week in April 2000 in Cambridge, UK, and at the request of the IPA, the Council of the IASC approved funding for a follow up workshop to develop a Science and Implementation Plan for ACD. The resulting international workshop, held in Potsdam (Germany) in October 2000, produced a phased, 5-year Science and Implementation Plan (2001–2005). The ACD project office was established at the Research Department Potsdam of the Alfred Wegener Institute with a secretariat to maintain international communications including the Web site and an electronic newsletter. The secretariat is assisted by the International Steering Committee (ISC) consisting of

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

The Science and Implementation Plan (IASC Arctic Coastal Dynamics 2001) was made available on the ACD Web page (http://www.awi-potsdam.de/acd) and submitted to the IASC Council for review, approval and advice on future directions. At the Council Meeting during the Arctic Science Summit Week in Iqaluit, Canada (April 2001), IASC officially accepted the ACD project.

In the following years, annual IASC-sponsored ACD workshops were held in Potsdam (Germany), 26–30 November 2001, Oslo (Norway), 2–5 December 2002 and in St. Petersburg (Russia), 10–14 November 2003. Workshop proceedings including extended abstract were published in the journal, Reports on Polar and Marine Research (Rachold et al. 2002, 2003a; Rachold and Cherkashov 2004). Currently, ca. 25 institutions from Austria, Canada, Germany, Norway, The Netherlands, Russia, Switzerland, UK and USA are contributing to the ACD project. A network of long-term monitoring sites has been established. Some of these sites have been studied for ca. 20 years and most of them are re-visited each year (see Fig. 4). The metadata information for these ca. 20 ACD key sites is available at the ACD Web site.

Results of the Arctic Coastal Dynamics project

The scientific results of the ACD project derived up to now are summarized in this special issue of GeoMarine Letters. The contributions are arranged thematically and cover both circum-Arctic, regional and local studies at ACD key sites.

Sediment and organic carbon flux from coastal erosion

Emphasis is currently on developing a circum-Arctic estimate of sediment and organic input from coastal erosion to the inner shelves. In the past, the contribution of coastal erosion to the material budget of the Arctic seas has been underestimated, but recent investigations have underlined its importance. Reimnitz et al. (1988) presented calculations for 344 km of Alaskan coast in the Colville River area and found that coastal erosion here supplied seven times more sediments to the Alaskan Beaufort Sea than rivers. Are (1999) suggested that the amount of sediment supplied to the Laptev Sea by rivers and shores is at least of the same order and that the coastal erosion input is probably even larger than the input of the rivers. This finding was supported by Rachold et al. (2000), who concluded that the sediment input to the Laptev Sea through coastal erosion is twice as large as the river input. In the Canadian Beaufort Sea on the other hand, the Mackenzie River input is the dominant source of sediments and coastal erosion is much less important (MacDonald et al. 1998). These pronounced regional differences in the riverine and coastal erosion sediment input have to be considered in any research related to the fluxes and budgets of the Arctic seas. Several papers on this topic have recently been published under the ACD framework (Brown et al. 2003; Grigoriev and Rachold 2003; Jorgenson et al. 2003; Rachold et al. 2003b). These studies indicate that coastal erosion forms a major source not only of the sediment input but also of the total organic carbon

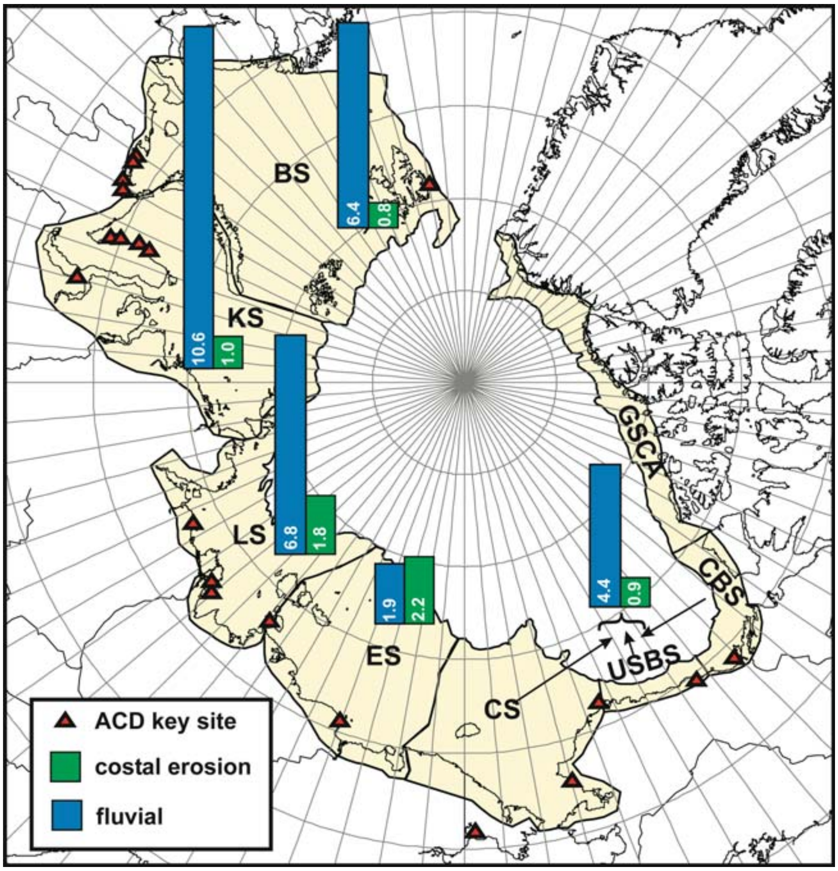

Fig. 4 Arctic Coastal Dynamics subdivision of the Arctic coastline by major seas (*BS* Barents Sea, *KS* Kara Sea, *LS* Laptev Sea, *ES* East Siberian Sea, *CS* Chukchi Sea, *USBS* US Beaufort Sea, *CBS* Canadian Beaufort Sea, *GSCA* Greenland Sea/Canadian Archipelago) and ACD key sites marked by *triangles*. *Bars* represent the riverine and coastal TOC input (10^6 t C year^{-1}) to the Arctic Ocean (data taken from Rachold et al. 2003c). *Blue bars* refer to river input and *green bars* to coastal input. Note that the sum is shown for Beaufort and Chukchi Sea and that Barents Sea input data include White Sea

(TOC) input to the Arctic seas. The comparison between riverine and coastal TOC input, based upon a combination of detailed field studies carried out in the Laptev and East Siberian Seas during the last several years (Grigoriev and Rachold 2003) and on a review of the existing literature, is shown in Fig. 4 (Rachold et al. 2003c). It has to be noted that the data given in the figure are the best currently available estimates, but may include errors ranging from ca. 30 % for the Laptev and East Siberian Sea (Grigoriev and Rachold 2003) to one order of magnitude for the other seas.

The development of a reliable assessment of the sediment and organic input through coastal erosion involves segmenting the entire circum-Arctic coastline into homogenous elements based primarily on morphology, composition and erosion rates. Each segment is to be classified according to a coastal classification template (ACD morphological classification, Rachold et al. 2003a). The paper of Jorgenson and Brown describes the methodology and results for the Alaskan Beaufort Sea. Other regional expert teams are currently applying the same methodology to the other sectors shown in Fig. 4.

GIS development and coastal classification

Geographical information of the segments and physical and geomorphologic attribute tables are stored and managed in GIS format for visualization and analyses. The first version of the circum-Arctic GIS product, available via the Internet and on CD-ROM, is anticipated by the end of 2004. The final data set (incl. Metadata) will be stored in the PANGAEA system (http://www.pangaea.de). A coastal GIS for the Russian Arctic is presented by Drozdov et al.

Based upon the general ACD classification, Nikiforov et al. present an extended so-called "morphogenetic" classification, which in addition to the morphological classification includes a general explanation for the evolution of a coastal segment.

Coastal processes in response to environmental forcing

Available data for various parameters, summarized under the term "environmental forcing", such as winds, waves, currents, sea-level, water and air temperatures, sea ice, etc., have been analyzed. The subsets relevant to the ACD project have been extracted from weather observatories and global reanalysis products and formatted for inclusion in the circum-Arctic GIS. Methodologies for correction of wind data from the reanalysis products and analyses of storms and storminess are by-products of this ACD effort and form an important contribution in their own right to the study of the Arctic coastal environment (Atkinson).

Spatial and temporal variations of coastal change

Four papers of this special issue deal with local and regional studies at ACD key sites and report on coastal dynamics as a function of environmental forcing, coastal geology and permafrost and morphodynamic behavior. Vasiliev et al. present a time series of coastal change measurements at a Kara Sea key site and Manson et al. and Solomon discuss spatial and temporal variations of coastal change in the Canadian Beaufort Sea.

Are et al. present a methodological approach, i.e. to quantify erosion rates based on thermoterrace dimensions, for an ACD key site in the Laptev Sea.

Sea-ice and glacier ice

Ice (sea-ice and glacier ice) plays an important morpho- and lithodynamic role in shaping the Arctic coasts. Ice coasts, i.e. coasts formed by glaciers extending into the sea, are relatively rare in the Eurasian Arctic (about 4% of the Eurasian coastline) but, nevertheless, have recently been receiving closer scientific attention since their dynamic environment and interesting natural scenery is proving highly sensitive to climatic change.

Two papers of this special issue concentrate on ice processes: Ogorodov et al. describes the role of sea-ice in coastal dynamics of the Pechora Sea and Sharov presents the use of space-borne image data to study changes of ice coasts in the European Arctic.

Offshore permafrost

The future degradation of the permafrost both on shore and on the Arctic shelf is of worldwide importance because GHG bound within and beneath the permafrost may be released. In this context the coastal areas are of specific interest because they are the site of the transition between onshore and offshore permafrost. Along the Arctic coastlines permafrost is exposed to the influence of relatively warm and saline sea-water, which potentially accelerates permafrost degradation. Changes occurring within the coastal zone control the characteristics of offshore permafrost and the associated geotechnical properties of the offshore materials.

Two papers of this special issue concentrate on offshore permafrost: Romanovsky et al. apply mathematical models to define the distribution of offshore permafrost and the gas hydrate stability zone in the Laptev Sea and Rekant et al. present seismic studies in the Kara Sea to detect submarine permafrost.

Impacts due to human activity

The coastal area is the site of most of the human activity that occurs at high latitudes. Geotechnical development in the coastal zone, such as offshore Arctic hydrocarbon resources, harbor and pipeline constructions etc., require profound understanding of the processes involved. Ogorodov presents an example from the West Siberian Pechora Sea, where human impact activates destructive coastal processes that considerably complicate industrial development of the coastal zone and increase expenditures for the elimination of negative environmental impacts and the regeneration of disturbed geosystems.

Coastal modeling

It is anticipated that during the second phase of the ACD project the circum-Arctic coastal GIS including information on coastal geology, morphology and dynamics, permafrost characteristics and subsets of relevant environmental parameters can be used as a base to assess the sensitivity of Arctic coasts to environmental variability on a circum-Arctic scale and to develop scenarios of future coastal changes. Based on long-term measurements of coastal retreat rates at ACD key sites, Ostroumov et al. describes coastline dynamics using a Markov-chain model. A model is discussed that combines Markov characteristic and information about the composition and structure of the permafrost sediments to simulate sediment flux dynamics.

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