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Present-day geomorphological activity in the Arctic

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Introduction

The landscape uniqueness of the Arctic polar zone manifests itself in morphological traces of older glaciations and marine transgressions, areas of present-day glaciations, multi-year permafrost, multi-year snow covers, deglaciation processes variable in time and space and resulting in an expansion of ice-free areas, multi-directional geosuccession, and finally in the various responses of the Arctic peoples to landscape changes and the growing human impact. The present study rests on the following assumptions:

- the state of geoecosystems in the Arctic polar zone is the product of their former and current development varying over space and time;
- the operation of present-day geoecosystems is affected by climatic variability and a growing human impact;
- the seasonal rhythm of polar geoecosystems is disturbed by processes of above-average and extreme nature which bring about changes in their internal structure or lead to the disappearance of the existing geoecosystems and the emergence of new ones; and
- a research on the present-day polar geoecosystems of the Arctic should be organised, integrated, and based on comprehensive projects, both national and international, involving the participation of the Northern peoples.

The abrupt landscape changes taking place over a period shorter than the life span of a single generation have currently become readily visible in the Arctic region. They can be due to a wide variety of natural causes, whether endogenous or exogenous, or to the increasing, multi-directed human activity. At present, however, their principal cause is believed to be climate change at a variety of spatial scales. The paper presents examples of contemporary changes of morphologic surfaces from all the territory of the Arctic, with special attention paid to Spitsbergen.

Spatial extent of the environmental changes in the Arctic

Irrespective of the adopted criterion of delimiting the boundary of the Arctic (Fig. 1, Kostrzewski et al. 2006), one can note ever greater changes in its southern course after the Little Ice Age has ended (Halsey et al. 1995; Laberge, Payette 1995; Osterkamp, Romanovsky 1999). They are first of all regional in nature (Burgess et al. 2001; Osterkamp, Romanovsky 1999; Romanovsky 2006). Thus, a distinct shrinkage in the area of permafrost can be observed in Alaska, the valley and delta of the Mackenzie, Spitsbergen, and the Dvina and Pechora Plains; the decay rate is somewhat slower in the Canadian High Arctic, northern Norway, the Kola Peninsula, and the northern regions of West Siberia, while the extent of permafrost stays the same or tends to grow slightly in the middle reaches of the Yukon, the eastern Canadian Arctic (in the late 1980s and early '90s), and the eastern margins of East Siberia[1]. The cause of those changes is the northward succession of boreal forests pushing far-

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1 Detailed data are supplied by the international research programmes, Circumpolar Active Layer Monitoring – CALM, and the Global Terrestrial Network for Permafrost – GTN-P.

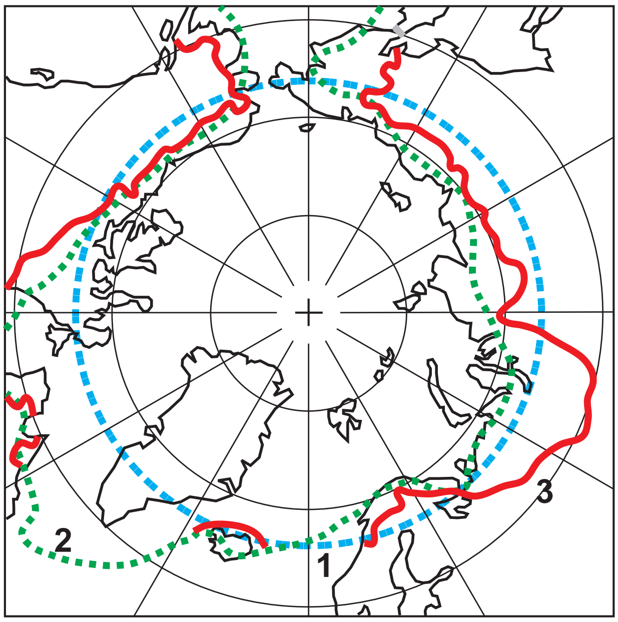

Fig. 1. Different boundaries of the Arctic
1 – northern polar circle, 2 – course of July isotherm equal to 10°C, 3 – northern limit of boreal forest

Fig. 2. Comparison of Hans Glacier' front extent in the 50-years interval
A – year 1957 (Archive of the Institute of Geophisics), B – year 2007 (photo A. Nawrot)

ther north their usual limits in many places. This development has been brought about by several types of feedback, e.g. warming, an increase in the thickness of the active layer, increased evaporation, a decline in the area of wetlands, etc. Irrespective of the current trends in the shifting of the Arctic limits, one should note that the prepared scenarios anticipate their northward shift by hundreds of kilometres, and this means changes in the functioning of terrestrial geoecosystems that will embrace an area of thousands of square kilometres.

Environmental changes in the Arctic

The changes observed in the polar environment, especially in the Arctic terrestrial geoecosystems, are connected with the many signals of global and regional changes that conform to the global change pattern. The latter has been particularly discernible over the last half-century (Fig. 2), which has also been characterised by an ever-intensifying human impact (IPCC 2002, Macdonald et al. 2003). It is assumed (ACIA 2004) that in the Arctic the mean annual temperature grew in the second half of the 20th century by 2-3°C in Alaska and Siberia, while it dropped by about 1°C in the southern regions of Greenland. The extent of floating ice has shrunk by 8% over the last three decades, but the changes are most conspicuous during summer when the marine ice area dwindles by 15–20%. Among the most significant environmental changes noted in the polar regions, Zwoliński (2007) lists the following:

- air temperatures frequently exceeding the hitherto absolute maxima,
- an increase in annual precipitation totals, first of all in the form of rain, also during the cold period,
- cold periods becoming milder and shorter,
- transitional periods becoming longer: spring coming earlier and autumn ending later,
- a decrease in the thickness, persistence and area of the sea-ice cover,
- an increase in the number of icebergs from intensively calving glaciers,
- an increase in the temperature and a decrease in the salinity and density of ocean waters; changes in the thermohaline circulation,
- an increase in the level of the world ocean,
- intense ablation and rapid recession of the majority of polar glaciers,
- a decrease in the area of nival covers,
- intensive thawing of multi-year permafrost, mainly in continental parts,
- changes in the water cycle manifested by an increase in the surface runoff in streams and a shortening of the period of freezing of streams and lakes,
- an increase in the area of some wetlands and a decrease in others,

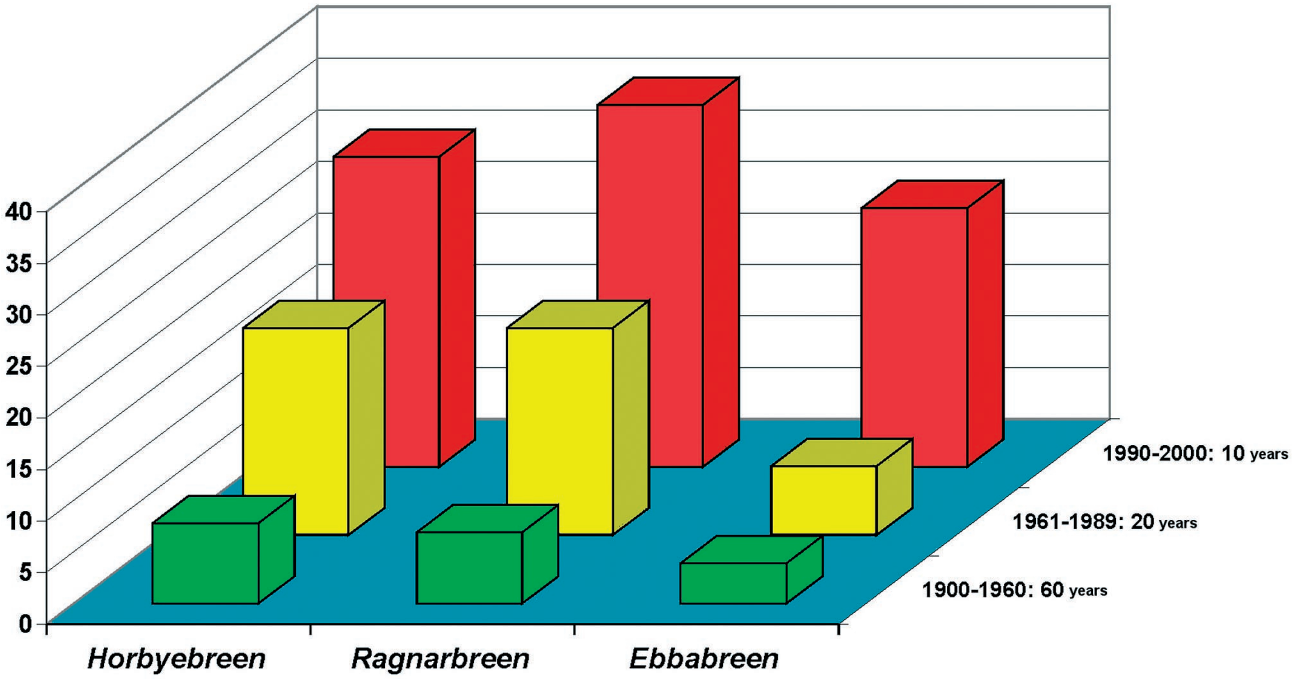

Fig. 3. Rates of glacier front recession for glaciers in the vicinity of Petuniabukta, Central Spitsbergen (acc. Rachlewicz, Szczuciński (2002), changed)

- a northward shift of geoecological, including vegetation, zones,
- changes in the carbon cycle in the geoecosystems manifesting themselves in an increase in biogenic carbon dioxide and methane, and
- an increase in the frequency and magnitude of forest fires.

All those symptoms of climate change affect the terrestrial geoecosystems of the Arctic to a greater or lesser degree. The ever-growing role of rock geoecosystems, crucially dependent on glacier and nival geoecosystems, results from intensive glacier recession (Fig. 3) and the melting of permafrost and snow covers. It has been estimated (ACIA 2004; Haeberli et al. 1989) that losses in the cumulative volume of glaciers in the other half of the 20th century amounted to nearly 500 km^3 in the North American Arctic and more than 100 km^3 in the Russian Arctic, and it was only Eurasia, mostly Scandinavia, which recorded an increase of some 200 km^3.

Geomorphological changes in the Arctic terrestrial geoecosystems

The observed geosuccession phenomena are especially conspicuous in paraglacial areas. Throughout the Arctic, on each of the continents one can find numerous examples of geosuccession changes. One of the most striking is the foreland of the Breidamerkur ice-cap (Iceland), whose margin has retreated several kilometres over the last 30 years leaving behind a diversified morphological surface with a variety of morphogenetic and sedimentary environments (Fig. 4). The stabilisation of such areas is a rather slow process and each year one can note

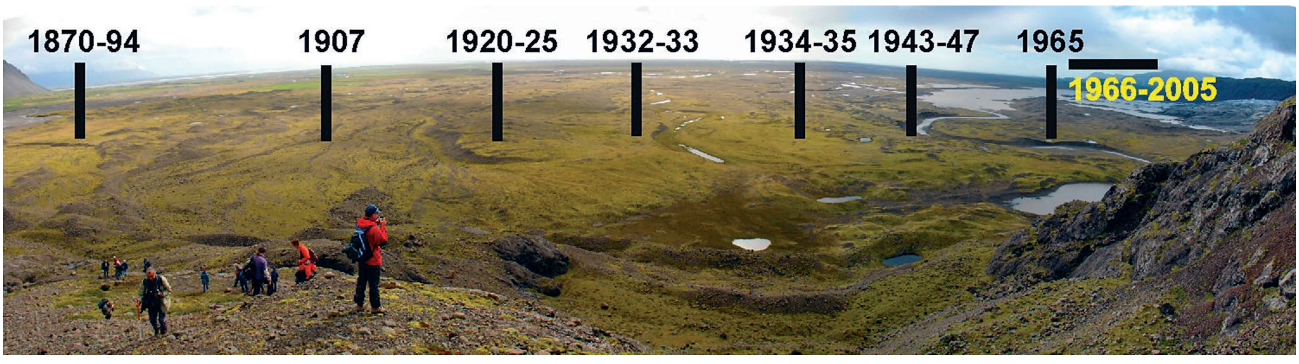

Fig. 4. Geosuccession traces of fast recession of the Fláa Glacier (Iceland); black labels depict moraine-recessional stages (acc. Dąbski 2002) during last 130 years (photo Zb. Zwoliński)

Fig. 5. Surface of alluvial fan modified by "desertification" processes, southern side of the Ebba Valley, Central Spitsbergen (photo Zb. Zwoliński)

morphological changes in the freshly forming topographic surface.

The intensive glacier retreat, downwasting of nival covers, thawing of permafrost and an increase in precipitation over land areas have altered the water cycle: the amount of water in streams, rivers and surface bodies has grown. The six principal Eurasian rivers: the Dvina, Pechora, Ob, Yenisey, Lena and Kolyma, discharge a total of 2,000 km^3 of fresh water (ACIA 2004) to the Arctic Sea, up 7% from the late 1930s (Peterson et al. 2002). In the 21st century, in winter European rivers carry some 100 km^3 of water more than they did in the mid-20th century (ACIA 2004). The increase in the discharge of water by Arctic rivers accelerates thermal erosion of their bank scarps with their underground glaciation (Siberia) and reduces the salinity of sea waters in the Arctic Ocean, especially in the coastal zone (Arctic Change 2006).

The rising level of the world ocean makes abrasion processes more intensive in the Arctic coastal zones. It is especially readily visible on high coasts, cliffs built of loose rocks of glacial origin, where frequent landslides occur. Abrasion is intensive e.g. in the coastal morainic zones of Spitsbergen or along the distributaries of the Mackenzie delta. Abrasion processes on the Arctic coasts and increased discharges of the pan-Arctic rivers enrich the coastal sea waters with sediment, but such developments as the building up of spits or beaches are rare and occur at a more significant rate only locally.

One can also observe an increase in the proportion of high winds, which reinforce abrasion processes through an increase in waving which affects the far-from-stable, fresh shores in the immediate neighbourhood of polar oases, as well as deflation and accumulation processes of eolian and niveo-eolian deposits. The deposits come from supraglacial moraines and marginal zones, but also from areas drying as a result of permafrost melt-out. An unfavourable development is the blowing out of fine-grained sediment covers in tundra-supporting areas, especially in the case of pioneer tundra moving onto land newly available for colonisation. Sometimes this process can even resemble desertification as an effect of the morphogenetic sequence of the thawing of the active layer, permafrost melt-out, drainage of meltwater, and the drying of land through evaporation and deflation, i.e. a typical example of a geosuccession (Fig. 5).

A result of the increase in precipitation in the Arctic regions has been a higher frequency of ephemeral snow covers during summer. They do not last long and usually form in the highest parts of elevated areas, but even so they do affect the summer water cycle. Such occurrences have been observed in Spitsbergen, among other places. In 2002 the melting of snow and ice covers in Greenland was recorded up to an altitude of 2,000 m a.s.l. Also the earlier coming of spring and the later ending of autumn changes the duration, extent and thickness of nival covers, both on glaciers and their surrounding areas.

The Spitsbergen area (77–80°N), because of its location within a very dynamic maritime influences, is especially susceptible to processes of intensified activity of energy circulation and matter transfer. It is favoured by general tendency of climate warming, with the elongation of the period of morphogenetic processes activity, as well as the rise of frequency of above-average phenomena. A number of signs of environmental changes on areas of Polish research activity on Spitsbergen were denoted in extensive monographs edited by Kostrzewski, Pulina, Zwoliński (2004) and Kostrzewski, Zwoliński (2003).

Contemporary changes of Arctic climate are influencing a number of geomorphologic processes leading to essential structural and external aspects transformations of the landscape. These changes are visible in the functioning of contemporary terrestrial geoecosystems of Spitsbergen, among which one can rank (e.g. taking into account Ebba Valley, the area of investigations of Poznań University – fig. 6):

Fig. 6. Spatial pattern of selected morphogenetic domains in the Ebba Valley, Central Spitsbergen (photo Zb. Zwoliński)
Morphogenetic domains: 1 – glacial, 2 – marginal, 3 – braided proglacial, 4 – meandering fluvial without vegetation cover, 5 – meandering fluvial with vegetation cover, 6 – littoral of raised marine terraces, 7 – estuarial, 8 – littoral of bay/fjord, 9 – fluvial of alluvial fans, 10 – slope with talus cones, 11 – rock weathering, 12 – weathering within waste cover, 13 – permafrost (periglacial), 14 – eolian.

A – in morphogenetic (hierarchical) depiction:
- weathering sub-system,
- nival sub-system,
- glacial sub-system,
- glacifluvial, glacilimnic, glacimarine sub-systems,
- fluvial sub-system of proglacial rivers: braided and meandering,
- denudational-fluvial sub-system,
- limnic sub-system,
- eolian sub-system,
- litoral sub-system,
- permafrost related sub-system,

B – in spatial (cascade) depiction
- field sub-system,
- slope sub-system,
- valley sub-system,
- piedmont sub-system,
- coastal sub-system.

Presented sub-systems are not depleting the full inventory of morphogenetic and sedimentary environments of polar areas but are realizing about two facts: a large diversification of quality of factors and morphogenetic processes in an apparently monotonous polar environment and a very fast spatial migration of these sub-systems observed over past 25 years, referring to changes of their extents – some of them growing and some shrinking.

Geomorphological trends within the Arctic terrestrial geoecosystems

The polar research to date and scenarios of development of the Arctic polar regions indicate that the Arctic landscapes have been undergoing rapid changes recently. Their pace and intensity over the last 100 years have varied owing to climate change connected with the ever-growing human impact. The Arctic is an especially interesting area whose transformation brings about global changes in the surface of the Earth.

According to the models and scenarios of ACIA (2004), for the Arctic regions the increase in air temperature should be 5°C (scenario B2) or 7°C (scenario A2) as compared with the 1981–2000 figures. It should be the steepest in Siberia and the eastern Canadian Arctic. Precipitation in the form of rain should grow by some 20%, mainly in summer. The anticipated areas of increased rainfall are the North American Arctic and northern Russia, while northern Scandinavia is expected to receive lower rainfall. Sea ice may be expected to dwindle by as much as 50%. According to some models, in the summer of 2100 there may be no ice cover whatsoever on the Arctic Ocean. The rise in the level of the world ocean is expected to range from 10 cm to 70 cm in both scenarios, A2 and B2. The extent of the terrestrial ice cover should shrink by about 20%, mainly in spring, causing an earlier start of flow of the pan-Arctic rivers, whose discharges may grow by 10–25% in winter and spring to decline in summer owing to increased evaporation. It should be emphasised that all the analysed scenarios anticipate roughly the same increase or drop in the parameters in question over the 21st century. However, observation to date has shown that their pattern may be different.

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