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Environmental change and impacts in the Kangerlussuaq area, west Greenland

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Background

During the past four decades there has been a growing interest in research on climate-induced environmental change and impacts in the Arctic. This is a response to acknowledging that a disproportional increase in surface air temperature is expected in the Arctic throughout the twenty-first century, owing to climatic feedbacks related to changes in sea ice and snow cover referred to as Arctic amplification (e.g., Serreze and Francis 2006). Not only will this Arctic amplification contribute to enhanced global sea-level rise because of accelerated melting and calving from glaciers (Church et al. 2013), rapid climate changes will also affect Arctic terrestrial and marine ecosystems and the linkage between these ecosystems and ecosystems located further south (Hawkings et al. 2015). Entire Arctic landscapes may change as glaciers recede, flood events become more frequent, the active layer deepens, and the duration of the growing season increases.

In the Arctic, ecological, geomorphic and climatic changes are closely linked and occur across a range of spatiotemporal scales (Anderson et al. 2017). Current research efforts focus on documenting the contemporary state of individual parts of the Arctic system and the rates of ongoing changes, and on providing new knowledge on responses and feedbacks of the underlying dynamic processes and biotic community structures in Arctic environments. These findings are used to refine models of future changes and to quantify available resource pools (water, nutrients, carbon) and their transport across glacial landscapes. In order to achieve a cross-system understanding of how climate-driven changes and impacts affect the linkages between ecosystem and geomorphological processes, it is of utmost importance to have study sites in the Arctic with a long history of multidisciplinary research and monitoring.

Although the geographical range of research locations is spreading across the Arctic, logistic constraints mean that long-term research has been limited to relatively few sites. This has enhanced our appreciation that one explanation (e.g., warming) for recent environmental change at high latitudes does not fit all areas. The most notable of these are the Toolik Lake long-term ecological research (LTER) site (O'Brien 1992), which is located north of the Brooks Range, northern Alaska; the Abisko Research station, which straddles the ecotone boundary between birch forest and subarctic tundra in Swedish Lapland (Jonasson et al. 2012); and the Zackenberg facility located in the high Arctic landscape of northeast Greenland (Meltofte et al. 2008). Research at these sites is diverse (e.g., meteorology, aquatic and terrestrial ecology, soils and geomorphology) but it is, perhaps, not as broad as that undertaken around Kangerlussuaq, as highlighted in this special section, in part because of the diverse ecological and physical systems located in a small spatial area.

The Kangerlussuaq area

One of the most studied areas in the Arctic is the Kangerlussuaq area in southern west Greenland (Figure 1). This landscape extends from the Greenland Ice Sheet (GrIS) in the east to the inner part of the 190-km long fjord Kangerlussuaq in the west. The area between the GrIS and the fjord consists of floodplains with dunes, braided and meandering river systems, raised marine terraces, moraine ridges,

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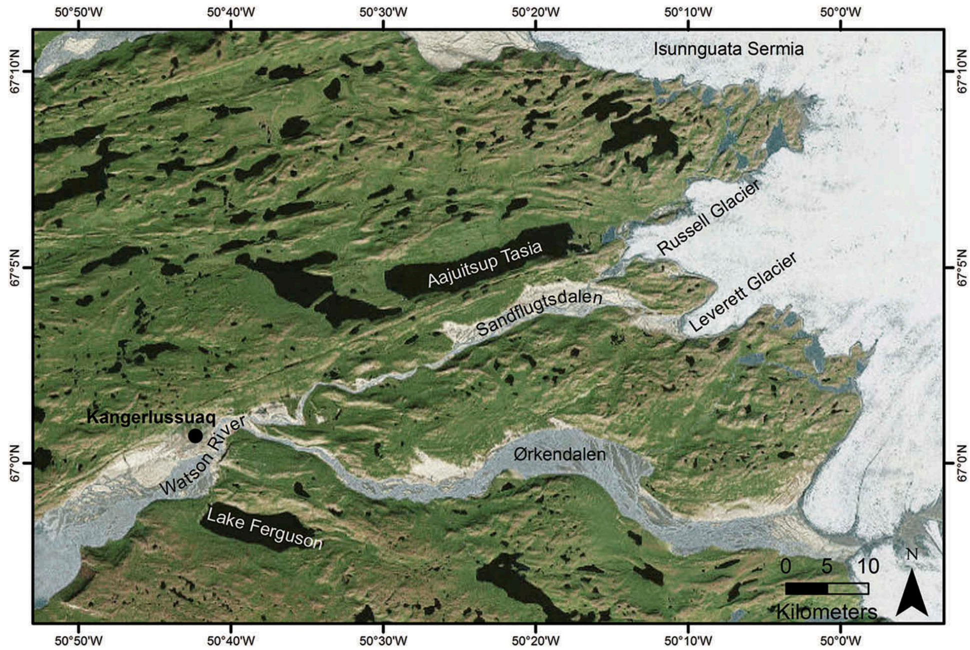

Figure 1. Map of the Kangerlussuaq area (based on ESRI world imagery).

numerous lakes with various morphologies and geochemical composition (e.g., ice-dammed, fluvial, and endorheic lakes), low mountains and an extensive marine delta where the main river, Watson River, enters the fjord. The climate is dry polar, and the permafrost is continuous. Deciduous shrubs, forbs, and graminoid species characterize the tundra vegetation. The geology comprises granitic and gneissic rocks with basic intrusions (Escher and Watt 1976). In many ways, the Kangerlussuaq area is a representative site for studying a continental Arctic landscape under transition.

The research history in the Kangerlussuaq area began with the University of Michigan Greenland expeditions of 1926–1933 (Hobbs 1926, 1927a, 1927b, 1941; Fergusson 1931). The primary purpose of the expeditions was to study anticyclones based on meteorological observations on the GrIS and near the head of the fjord, but members of the expedition were also dedicated to botanical, zoological, and glaciological studies. Many of the local place names derive from this expedition, such as the two outlet glaciers: Russell Glacier and Leverett Glacier (named after the University of Michigan geology professors Israel Cook Russell [1852–1906] and Frank Leverett [1859–1943]) and Lake Ferguson (named after U.S. Weather Bureau meteorologist Sterling Price Fergusson [1868–1959], who participated on the expedition). With the establishment in 1941 of the air base Bluie West Eight (BW-8) at the head of the fjord by the U.S. Army Air Force, this part of Greenland became more accessible for pioneering researchers such as Tyge Böcher (1949) and Anker Weidick (1968). The Kangerlussuaq area was a good choice for an airfield in Greenland because of its dry and stable weather conditions. After World War II, a civilian community developed adjacent to the air base and the airport became the main international entry point to Greenland from the 1960s to the present. The military air base was closed in 1992 and the facilities were transferred to the Danish and Greenlandic authorities. One of the former barracks now serves as a logistic support center for international researchers.

Scope and content

The scope of this special section, *Environmental Change and Impacts in the Kangerlussuaq Area, West Greenland*, is to compile and present process studies and cross-system analyses within a broad range of bio- and geoscience disciplines. Together, these articles contribute to a better understanding of how processes and linkages within an Arctic landscape are connected.

Knowledge of past, present, and future climate change is fundamental for understanding the climatic impacts on ecosystems, nutrient transport, and landscape development. In this context, Utrecht University has done commendable work in maintaining weather stations along a transect on the Kangerlussuaq sector of the GrIS for more than two decades since 1993. This transect is known as the K-transect, and data from these stations have been vital for modeling of GrIS surface mass balance changes. Here, Smeets et al. (2018) present a summary and trend analysis of twenty-three years of K-transect weather data, while Kuipers Munneke et al. (2018) examined variability and trends in the surface energy balance along the K-transect. With respect to past climate change, the deglaciation history in west Greenland during the early Holocene is well known, but it is very patchy during the mid- and late Holocene; especially after the Holocene Thermal Maximum (9000–5000 years BP) when the ice-sheet margin receded further inland than the present ice-sheet margin. Two articles by Levy et al. (2018) and Carrivick et al. (2018) now provide new insights into the dynamics of the ice-sheet margin during the Holocene based on ^{10}Be dating of boulders and bedrock and ^{14}C dating of roots and leaves in sediment profiles from drained ice-marginal lakes. Future climate change simulations are presented by Boberg et al. (2018), who used the climate scenarios to suggest that by the end of the twenty-first century the mean annual air temperature in the Kangerlussuaq area will be similar to the temperature in south Greenland today, and that the huge, local ice caps south of the fjord will almost disappear entirely by the end of the twenty-first century.

The best visual evidence of regional climate warming is the peripheral thinning of the GrIS. Ross et al. (2018) measured the ice thickness at Leverett Glacier to determine the present situation and obtain knowledge on the subglacial drainage pattern at the margin of the GrIS. Mernild et al. (2018) simulated surface mass balance and runoff from the Kangerlussuaq sector of the GrIS during a thirty-five-year period from 1979–1980 to 2013–2014. The nearby presence of the GrIS has a dominant influence as a source for sediment and nutrients to foreland and fjord systems, and both field observations and modeling of the GrIS are important to elucidate the magnitude and change of these fluxes. Based on runoff monitoring and sample collection at the outlet of Watson River, Hasholt et al. (2018) quantified the export of sediment and solutes into the fjord. Van As et al. (2018) used air temperature data from Kangerlussuaq and runoff data from lake Tasersiaq, located south of the Kangerlussuaq area, to extrapolate the Watson River runoff time series back to 1949. The runoff record shows that the recent extreme runoff years in 2010, 2012, and 2016 had longer and more intense melt seasons.

Wind acts as a key distributor of glacier-derived sediment and nutrients in dry polar regions. Bullard and Mockford (2018) analyzed the seventy-year record of dust observations from the Kangerlussuaq area and find that the magnitude of dust events has increased over the years. Aeolian processes are also an important geomorphic agent. Heindel et al. (2018) used Structure-from-Motion photogrammetry to estimate erosion rates of deflation patches formed by strong katabatic winds from the GrIS. Dust events, dunes, and aeolian erosion are topics that must receive more attention in our effort to improve our understanding of fluxes within glacial landscapes.

Arctic ecosystems are very diverse. One of the ecosystems that has received increasing focus in recent years is the supraglacial ecosystem on the GrIS because of the impact of pigmented microorganisms on surface darkening, which enhances ice melting (Stibal et al. 2017). The ice-sheet margin in the Kangerlussuaq area is likely the most investigated glacial ecosystem worldwide. The most active microbial habitat on glacier surfaces is within cryoconite holes, and this special section presents two novel studies on cryoconite holes. Cook et al. (2018) show that ice-surface topography has implications for the morphology of cryoconite holes and carbon exchange, while Poniecka et al. (2018) explore microscale anaerobic environments in cryoconite holes.

Climatic changes affect both the physical and ecological characteristics of the many lakes in the Kangerlussuaq area (Saros et al. 2016; Osburn et al. 2017; Whiteford et al. 2016). In this special section, several studies analyzed the environmental change and impacts on Arctic lakes. Mariash et al. (2018) show that benthic and pelagic primary production decrease as the dissolved organic carbon (DOC) content increases in lakes, while Fowler, Saros, and Osburn (2018) conducted experiments to evaluate potential mechanisms, such as dust addition, bacterial activity, and photodegradation, responsible for changing DOC concentrations and quality in lakes. These findings can be applied to predict how changing DOC concentrations can affect the aquatic food web. Thompson, White, and Pratt (2018) investigated spatial variations in the stable isotope composition of macrophyte species and littoral and profundal sediments and found that the organic matter in an endorheic lake primarily derive from primary production of macrophytes within the lake. Henkemans et al. (2018) combined geochemical analyses and a range of environmental isotopes to examine the geochemical processes along a transect of lakes. They found that evaporation is the dominant control on lake chemistry, while groundwater interaction has little impact. Burpee et al. (2018) compared the ecological, chemical, and physical characteristics of glacier-fed lakes with the characteristics of nonglacial lakes. Their study shows how glacial meltwater from the GrIS impacts the ecology of Arctic lakes.

Climate-induced changes are also evident in terrestrial ecosystems (Post and Pedersen 2008). For example, previous monitoring of plant phenology and herbivore production in the Kangerlussuaq area show that the growing season has advanced by approximately twenty days, while the timing of caribou calving has not (Kerby and Post 2013; Post and Forchhammer 2008). Radville, Post, and Eissenstat (2018) examined recent plant phenological responses to climate warming, and they find that the growing season is no longer advancing. Urbanowicz, Virginia, and Irwin (2018) analyzed pollination and plant reproduction across an air-temperature transect. Their results demonstrate that interactions between pollinators and plants may mediate the consequences of climate warming on plant reproduction. Another topic that has received much research interest in recent years is the carbon cycle in Arctic tundra soils. Bradley-Cook and Virginia (2018) quantified the spatial variation in soil carbon stocks in the Kangerlussuaq area and estimated carbon fluxes in different vegetation types. They expect a possible trend toward decreasing soil carbon storage and increasing carbon dioxide emissions.

The fjord system in the Kangerlussuaq area is characterized by a turbid meltwater plume during the summer (Lund-Hansen et al. 2010; McGrath et al. 2010) and sea ice and snow cover during the winter and spring. Lund-Hansen et al. (2018) determined a series of ecological, chemical, and physical parameters in the water column during two cruises in late summer and early spring. Their results show that turbid glacial meltwater is the primary control on primary production during the summer. The authors conclude that increasing future meltwater runoff from the GrIS will lead to reduced primary production due to increased turbidity and reduced light transmittance.

Synthesis

As well as rapid warming, the Arctic is subject to a range of stressors, ranging from long-range atmospheric pollutants, including reactive nitrogen (e.g., Zou et al. 2017), metals such as mercury and lead (e.g., Bindler et al. 2001a), and changing hydrology (e.g., Ahlstrøm et al. 2017). How these factors will influence the different components of the wider Arctic system will undoubtedly be complex and vary at a range of spatial and temporal scales: compare, for example, the contrasting response of weathering rates in recently deglaciated landscapes with the stratification of regimes in adjacent lakes. The range of ecological and physical processes covered in this special section illustrates the diverse nature of environmental change in the Arctic and the importance of a holistic overview. With this special section, we hope that we can stimulate Arctic researchers to include a broader landscape-scale approach in their research as well as combine and exchange ideas with researchers working on adjacent environments within the same study area and elsewhere in the Arctic.

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