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Rapid Assessment of Circum-Arctic Ecosystem Resilience (RACER)

THE NORTH WATER POLYNYA

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The ice edge near Qaanaaq, Greenland. May 2014. Photo: Mette Frost/WWF-DK

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RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE

WWF'S RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE (RACER) presents a new tool for identifying and mapping places of conservation importance throughout the Arctic.

Recognizing that conservation efforts targeting the vulnerability of Arctic habitats and species are not keeping pace with accelerating climate change, RACER instead locates sources of ecological strength. RACER finds places that generate what scientists call ecosystem resilience to fortify the wider ecological regions in which these places are found. RACER then looks ahead to whether these wellsprings of resilience will persist in a climate-altered future.

The RACER method has two parts. The first part maps the current location of land or sea features (such as mountains, wetlands, polynyas, river deltas, etc.) that are home to exceptional growth of vegetation and animals (productivity) and varieties of living things and habitats (diversity). These key features are especially productive and diverse because the characteristics that make them up (e.g., the terrain of mountains or the outflow at river mouths) act as drivers of ecological vitality. The exceptional vitality of these key features – in the places where they are currently found – is what makes them local sources of resilience for the ecosystems and ecosystem services of their wider regions (Spalding et al 2007). The second part of RACER tests whether these key features will continue to provide region-wide resilience despite predicted climate-related changes to temperature, rain, snowfall, sea ice, and other environmental factors important to living systems. Changes to these climate variables affect the drivers of ecological vitality (which depend on these variables) at key features. RACER uses forecast changes to these climate variables to predict the future vitality of key features and the likely persistence of ecosystem resilience for Arctic ecoregions through the remainder of this century.

RACER's new method focuses conservation and management attention on the importance of minimizing environmental disturbance to places that are – and will be for the remainder of this century – sources of ecosystem resilience in the Arctic. In particular, RACER's ecosystem-based approach equips resource managers and conservationists with new targets for their efforts – managing not just our impact on species and habitats but on the combinations of geographical, climatic, and ecological characteristics that drive ecosystem functioning in the far north. Identifying the sources of resilience for region-wide Arctic ecosystems and protecting them for the future may be the best hope for the survival of the Arctic's unique identity; its habitats, plants, animals and the ecological services that northern people and cultures depend upon.

Source: Christie, P. and Sommerkorn, M. 2012. RACER: Rapid Assessment of Circum-Arctic Ecosystem Resilience, 2nd ed. Ottawa, Canada: WWF Global Arctic Program. 72 pp.

PREFACE

Seasonal and perennial sea ice constitutes an important habitat for the marine ecosystems of Greenland as well as throughout the Arctic marine ecoregions (Wilkenson et al. 2009). Polynyas and leads are areas of open water surrounded by sea ice that are highly productive and sustain a diverse and abundant array of marine Arctic and migratory species. These remote and icy refuges may thereby sustain species throughout the marine food web, from the tiniest copepod that grazes on the mass of algae on the ice edge, to the elusive ivory gulls that may be seen feasting on the abundant fish stocks that thrive in these ice-encircled open water areas. The migratory patterns of narwhals and bowhead whales are shaped by the melting and freezing of the ice, and seasonal movements to a series of predictable open water areas of high productivity as the northern polynyas, sustain these long lived species and the trophic food chain upon which they subsist (Meltofte 2013).

This report focuses on the most biologically productive open water area between Canada and Greenland, in northern Baffin Bay; the North Water Polynya (NOW). It is the world's largest Arctic polynya at about 80,000 square kilometers. Named the 'North Water' by 19th century whalers who relied on it for spring passage, the polynya is kept open by wind, tides and an ice bridge on its northern edge. Although thin ice forms in some areas, the North Water Polynya occurs seasonally at the same time and place each year (Smith and Barber 2007)

Culturally, the lives of the Inuit's in Greenland and Canada have been shaped by the extreme conditions these populations have existed under, their dependency on natures resources in the form of fish, birds, and land- and marine mammals. The Inuit communities of Avanersuaq (Northwest Greenland) and Pond Inlet, Nanisivik, and Grise Fjord in Canada have historically relied on the abundance of marine life in and around the North Water for their food, clothing, shelter, and essential cultural and economic well-being (Nuttall 2005).

Today, the Arctic regions are facing new challenges as changes in climate and resource utilization opens up these pristine areas for development and new industrial activities, e.g. oil, gas, and mineral-exploration and exploitation. These changes in climate and development activities threaten crucial habitat for many endemic and migratory arctic species, and the subsistence communities in these areas (Nuttall 2005). The North Water Polynya represents a region within the two northern Arctic marine ecoregions, North Greenland (1) and Baffin Bay (2) that is exceptionally productive and diverse, and has shown resilience to changes in climate (Rosentrater and Ogden 2004). Newer studies though show evidence of changes in productivity in the area related to the less frequent formation of the ice bridge that constitutes the northern border of the North Water (Dumont et. al. 2009) (Karnovsky et. al. 2007) (Egede 2014). We therefore hope this report will bring focus to this highly important area, and that the documentation presented in this report will be used towards reaching constructive conservation efforts that may uphold these areas characteristics, and the lifeline it provides the abundant range of species that utilize the area.

ABSTRACT

WWF'S RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE (RACER) presents a new tool for identifying and mapping places of conservation importance throughout the Arctic. We used adapted RACER methodology to evaluate the North Water Polynya (NOW), an area of especially high primary productivity and a key area for an abundant and diverse array of species in terms of its level of resilience towards changes in climate both now and in the future.

The North Water Polynya in Baffin Bay is situated in the northern Arctic marine ecoregions M26 and M42. The polynya itself is a huge stretch of open water surrounded by ice situated in the waters between Canada and Greenland. This key wintering area attracts marine mammals such as polar bears and narwhals and numerous seabirds. The mixing of water currents originating from the Atlantic and Pacific causes the upwelling of nutrients to the surface. This triggers plankton blooms, which in turn boost the rest of the food web. Furthermore, the formation of an ice bridge in Kane Basin contributes to the high productivity by blocking the otherwise constant flow of sea ice from the Arctic Ocean.

Subsistence hunting and fishing occur in the main inhabited areas of Avanersuaq (Northwest Greenland) and Pond Inlet, Nanisivik, and Grise Fjord in Canada. The rich biological habitat of the North Water has sustained indigenous inhabitants as well as earlier settlements that followed the earliest immigration of human populations from North America to Greenland beginning as early as 2,500 B.C.

Over the past two decades, the polynya occurrence and timing has changed significantly, affecting the timing, the localization and the intensity of the spring bloom. This may in turn affect species that utilize the open water area seasonally for feeding or breeding. On an overall scale, we assessed the persistence of key features' future above-average productivity/diversity through the predicted main changes to GCM climate variables to be medium.

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RESUMÉ

WWF'S RAPID ASSESSMENT OF CIRCUM-ARCTIC ECOSYSTEM RESILIENCE (RACER) præsenterer et nyt værktøj til at identificere og kortlægge vigtige naturområder i Arktis. Vi har brugt en tilpasset RACER-metode til at vurdere Pikialasorsuaq/Nordvandets modstandsdygtighed mod klimaforandringer i dag og i fremtiden. Nordvandet er et område med særlig høj primærproduktion og et område, der er hjemsted for mange forskellige dyr.

Nordvandet ligger i Baffin Bugten i de nordlige, arktiske marine økoregioner M26 og M42. Åbentvandsområdet er et stort område omgivet af is i farvandet mellem Canada og Grønland. Det er et nøgleområde for overvintrende dyrearter som isbjørn, narhval og flere havfugle. Blandingen af havstrømme fra Atlanterhavet og Stillehavet betyder, at næringsstoffer føres mod havoverfladen. Det fører til opblomstringen af plankton, der virker som motor for resten af fødekæden. Derudover betyder dannelsen af en isbro i Kane Bassin, at niveauet af produktivitet holdes højt, idet isbroen blokerer for en konstant strøm af havis fra Det Arktiske Ocean.

Jagt og fiskeri finder sted ud for Nordgrønlands kyster og ud for Pond Inlet, Nanisivik og Grise Fjord i Nunavut, Canada. Det rige dyreliv i Nordvandet har understøttet lokalbefolkningen her siden de tidligste indvandringer fra Nordamerika til Grønland år 2500 f.Kr.

I løbet af de sidste to årtier har Nordvandets udbredelse og timing ændret sig betragteligt, hvilket igen har ændret timingen og intensiteten af forårets opblomstring af plankton. Dette vil muligvis også påvirke de dyrearter, der bruger åbentvandsområdet til at finde føde og formere sig. På overordnet niveau vurderer vi, at områdets modstandsdygtighed mod klimaforandringer er medium.

A MARINE STUDY: THE NORTH WATER POLYNYA

THE NORTH WATER POLYNYA (NOW) is the world's largest polynya (area of year-round open water surrounded by sea ice) at 80,000 square kilometers that lies between Greenland and Canada in northern Baffin Bay. The polynya provides refuge for a wide variety of Arctic species and present day Inuit communities in Northwest Greenland and Canada rely on the polynya's concentration of marine mammals to sustain their traditional way of life.

Inuit narwhal hunter throwing his harpoon, Qaanaaq, Greenland. Foto © Staffan Widstrand / WWF

The North Water Polynya is located within two ecoregions, the North Greenland ecoregion (M42) and the Baffin Bay – Canadian Shelf ecoregion (M26) (Fig. 1 and 2 and Ap1).

The North Water Polynya extends between (~76°N to 79°N and 70°W to 80°W) , but its expanse is dependent on season (Dunbar 1969). The mixing of different water masses originating from the Atlantic and Pacific oceans along with sea ice conditions renders the North Water Polynya the most productive area in the Arctic. The peak extension (85000 km^2 in 2000) of the sea ice is normally registered in March where it expands down the Greenland coast and southward and westward towards Ellesmere, Devon, and Baffin Island. The boundaries separating it from the rest of Baffin Bay melts in April and May until open water conditions prevail in June-July. There is a considerable annual variation in the extent of the sea ice coverage in all months (Barber D.G and Masson, R.A 2007). The process is reversed in autumn when the Baffin Bay fills with ice for the winter, except for the North Water which remains relatively ice-free. The northern boundary of the North Water is a well-defined structural ice bridge which forms during winter and prevents southward flow of ice through Smith Sound. As ice continues to form throughout the winter, it drifts southward under the influence of both strong northerly winds from Smith Sound and southward currents (Smith and Barber 2007)(Dumont and Gratton 2009).

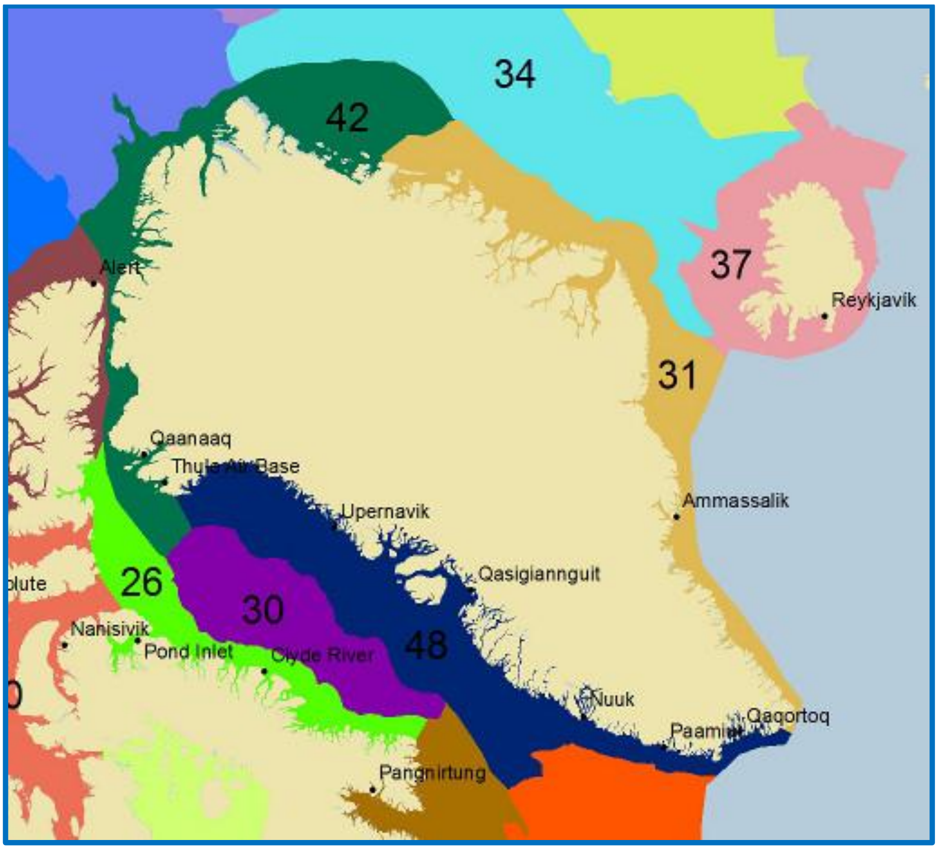


Figure 1 Marine Arctic ecoregions. The dark green and the light green area are the marine ecoregions M42 (North Greenland) and M26 (Baffin Bay – Canadian Shelf) where the North Water Polynya are situated (see also fig. 2). Source: WWF, adapted from Spalding et al. 2007.

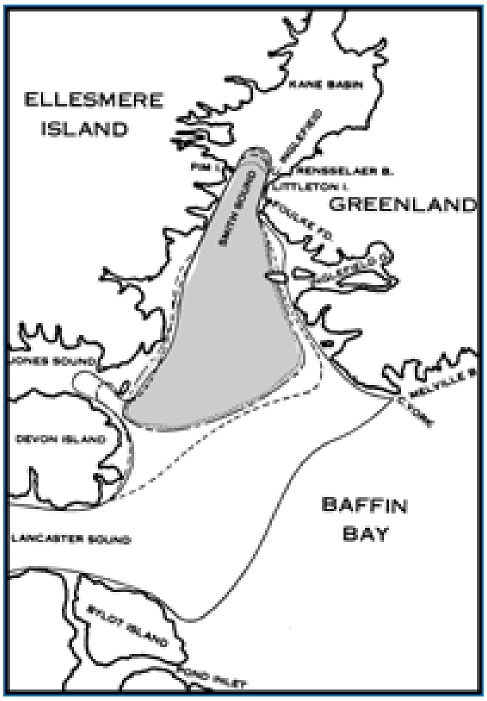


Figure 2 Map of location of the North Water Polynya.

The Greenlandic name for the North Water Polynya is “Pikialasorsuaq”, which means “The great upwelling” (Lyberth et. al. 2013) (Egede 2014). This is due to the production and southward transportation of sea ice that brings water and nutrients from the deeper layers to the surface that helps create a highly productive food web sustaining a large number of marine mammals and sea birds (Stirling 1980) (Dunbar 1981) (Heide-Jørgensen 2012).

The North Greenland ecoregion (M42) and Baffin Bay-Canadian shelf ecoregion (M26) are characterized by low biodiversity compared to non-Arctic regions but with often numerous and dense animal populations. The most significant ecological event is the spring bloom of planktonic algae (phytoplankton) – the primary producers in the food web (Boertmann et. al. 2009). These are grazed upon by zooplankton, including the copepods *Oithona similis*, *Oncaea borealis*, *Metridia longa*, *Microcalanus pygmaeus*, *Calanus glacialis*, *Pseudocalanus* sp., and *Calanus hyperboreus* [1]. Especially the two Arctic species *Calanus hyperboreus* and *Calanus glacialis* (Appendix 2) are one of the key species groups in the marine ecosystem (Merkel et. al. 2012) and adapted to the cold waters of the Arctic regions, containing large amounts of fat which are important for the species higher in the food web (Grenvald et. al. 2012).

In the benthos, the bottom dwelling community consists of clams, scallops sponges, sea worms, anemones crabs and sea stars (Wilkenson et. al. 2009) (Hargrave et. al. 2002). The rich spring summer zooplankton population in the North Water Polynya consumes much of the primary production before

[1] http://www.arcodiv.org/Minigrants2/Fortier.html

it reaches the benthos, therefore the benthos of the North Water does not display enhanced rates of carbon processing compared to other Arctic sediments, including other polynyas (Grant et. al. 2001). The high levels of primary production therefore, are mainly due to the protracted production season of the North Water enabling a longer period over which the benthos can receive and mineralize organic carbon (Lewis 1996). Northern shrimp (*Pandalus borealis*) are found in the pelagic zone (Hammeken and Kingsley 2010).

During the brief Arctic summer, many species of migrating birds make use of the open water areas that appear in the ecoregion, to feed, stage and molt during their migratory stop-overs. This includes common eider (*Somateria mollissima*), thick-billed murre (*Uria lomvia*), little auk (*Alle alle*), black-legged kittiwake (*Rissa tridactyla*), ivory gull (*Pagophila eburnean*), Arctic skua (*Stercorarius parasiticus*), Arctic tern (*Sterna paradisaea*), alcids (family *Alcidae*), and northern fulmars (*Fulmarus glacialis*) (Wilkenson 2009). Almost all the marine birds leave the area for the winter to return in April and May. Thick-billed murre, common eider, black-legged kittiwake and ivory gull are all red-listed in Greenland due to declining, or in case of the common eider previously declining, populations. Other red-listed bird species which occur in the marine part of the assessment area include Sabines gull (*Xema sabini*), Arctic tern, and Atlantic puffin (*Fratercula arctica*) (Boertmann 2008). The North Water Polynya region also supports the largest single-species aggregation of marine birds anywhere on earth, namely the vast colony of little auks at Crimson Cliffs near Qaanaaq (Meltofte et al 2013).
In winter, the unfrozen North Water Polynya serves as a refuge for marine mammals. As the pack ice breaks up, ice edges become vital areas for mammals and seabirds. The open water areas are habitat for bearded seals (*Erignathus barbatus*), harp seals (*Pagophilus groenlandicus),* ringed seal (*Phoca hispida*), and hooded seals (*Crystophora cristata*). Polar bears (*Ursus maritimus*) are found throughout the ecoregion (Wilkenson 2009). Walrus (*Odobenus rosmarus*) reside mainly over shallower waters in the ecoregion (Heide-Jørgensen). Fish diversity is low, with Arctic cod (*Boreogadus saida*) being the dominant species (Wilkenson et al 2009). Along with Greenland cod (*Gadus ogac*), and Arctic char (*Salvelinus alpinus*), large schools of Arctic cod support the populations of seals, narwhal (*Monodon monoceros*) and beluga whale (*Delphinapterus leucas*) in the area (Boertmann and Mosbech 2011). The bottom dwelling Greenland halibut (*Reinhardtius hippoglossoides*) also occur in these northern regions, its distribution reaching up to Smith Sound and is the major food source for narwhals (Christensen et. al. 2012).

The physical characteristics of the ecoregions are depicted by bathymetry, water column structure, main currents, physical processes, and wind and weather patterns. The bottom topography underlying the North Water Polynya is complex, ranging from a shallow sill of 160-200m at the southern end of Kennedy Channel, and a 250m shoal at the Smith Sound entrance to Kane Bassin to the central lying channel of 700 meters depth. The average depths range from 400-500m (Bâcle 2000). The eastern side of the North Water also overlies several seamounts and plateau of about 200 m in depth. Further south, the North Water opens into Baffin Bay, where average depths of 500 m gradually descend to a 2.400 m basin in the central western portion of the bay. A 600 m sill across Davis Strait separates the deep waters of Baffin Bay from the Labrador Sea (Fig.5) (Dunbar 1969) (Stirling 1980). The water masses in the North Water Polynya undergo relatively deep mixing and strong convection along the

Canadian side due to the combination of southerly currents and strong northerly winds. On the eastern side of the polynya air temperatures are several degrees higher than on the Canadian side due to heat input from the atmosphere (Barber et. al. 2001). This leads to delayed freeze up and thinner ice cover in winter, and earlier break up in spring. The West Greenland current brings warm water close to the sea surface contributing to the persistence of the polynya (Bäcle et. al. 2002) (Steffen 1985). The polynya reaches maximum size during July, when the ice formation that separates the polynya from Baffin Bay melts off (Dunbar 1969).

Box 1.

The functionality of polynyas

A polynya is an ice-free site in an otherwise ice-covered area. Polynyas occur throughout the Arctic as flaw leads that form along the edge of fast ice areas. These may be recurrent or stable. Polynyas vary in size and shape and may be caused by wind, tidal fluctuations, currents, upwellings, or a combination of these factors. Within the polynyas, the presence of thin ice along with open water means that a large winter heat exchange can occur between ocean and the atmosphere. Furthermore, when polynyas are at the freezing point, it may serve as a source of ice and produces a salt flux to the underlying ocean.

Polynyas are distinguished by being sites of either enhanced or early season productivity sites, thereby deeming them as important biological hotspots (Meltofte et. al. 2013). The larger recurrent polynyas provide ideal conditions for ice associated seals and whales as well as a diverse array of overwintering birds, especially common eiders (*Somateria mollisima*), king eiders (*Somateria spectabilis*), and long tailed ducks (*Clangula hyemalis*) (Christensen et. al. 2012).

In areas where strong tidal currents occur, polynyas may remain open throughout winter providing refuges for species when shore leads close during winter. Such areas serve to concentrate species that may serve as potential prey to ice based predators, i.e. polar bears (*Ursus maritimus*), and arctic foxes (*Vulpes lagopus*). The overwintering of ice associated whales within impermanent polynyas, as well as in mobile pack ice, occasionally cause entrapments involving hundreds of thousands of whales (termed *sassat* in inuit), which Inuit hunters as well as marine predators may gain advantage of. In polar regions nutrients are a limiting factor of productivity, however, it is thought that due to the high abundance of marine mammals at polynyas, nutrient recycling occurs through their faeces (Roman and McCarthy, 2010) (Heide-Jørgensen et al. 2013), this may significantly enhance the productivity of the area.

Archaeologists hypothesize that Inuit settlements in northern regions have been dependent on polynyas to support life throughout the cold winter months, a theory supported by archaeological sites throughout the Arctic, where specialization in marine mammal hunting is found near recurring polynyas. Today the Inuit of the Arctic still rely on polynyas to hunt and trap animals throughout the winter months (Mallory et. al.2007). Polynyas, with their multiple functionality across trophic levels and their role as critical components of polar systems, may be primary targets of climate change impacts (Smith and Barber 2007).

Human presence is sparse in this northern ecoregion, the main inhabited areas are Avanersuaq (Northwest Greenland), Pond Inlet, Nanisivik, and Grise Fjord in Canada (Wilkenson 2009) where subsistence hunting and fishing occur. The rich biological habitat of the North Water has sustained these indigenous inhabitants as well as earlier settlements since the earliest immigration of human populations from North America to Greenland beginning from 2500 B.C. (Heide-Jørgensen 2013).

Figure 3. Working at the ice edge. Photo: ©H.Saxgren.

Tour operators are present in the area, cruise ships operate in the waters in summer, and oil and gas exploration is also found as well as scientific expeditions. The permanent ice though, poses extensive challenges to attempted petroleum exploration and drilling. As with its neighboring ecoregions, this relatively isolated northern system is also affected by substances such as polychlorinated biphenyl (PCB), dichlorodiphenyltrichloroethane (DDT) and mercury (Hg) from urban and industrial areas and human activities far to the south. Concentrations of persistent organic pollutants (POP) have been found to be magnified up through the trophic levels in the Arctic marine food web in the North Water for example, are a known contaminant in the breast milk of Inuit women (Miller 2000). Although the direct effect of climate change on the atmospheric transport and fate of POP´s and Hg to the Arctic is predicted to be moderate under present studied climate scenarios, the changes in climate may affect the substantial verified effects of the changes that occur in the volume of emissions (Hansen et. al. 2014).

Historically commercial overharvesting of mammals and birds has endangered wildlife populations, most notably the bowhead whale (*Balaena mysticetus*) (Wiken et al. 1996), hunted to near-extinction in the 19th and early 20th centuries by the European whalers. While their numbers have rebounded in western waters, and are rising again in other areas of the ecoregion and along the West Greenland shelf, the eastern stock is still severely depleted and the species is considered endangered (Heide-Jørgensen 2013) (Karnovsky et.al. 2009). Furthermore climate change has been altering the ecology of the region (Stirling 1981) and is expected to cause major impacts in the future.

The new and large-scale industries and accelerating climate-related impacts on the environment as well as on human societies add urgency to the need for a strategic and forward-looking approach to resource development and fish and wild life management. This RACER assessment provides conservation targets to encourage resilience in the North Greenland and Baffin Bay ecoregions and to help this unique and ecologically important Arctic area respond and adapt to rapid change.

KEY FEATURES IMPORTANT FOR RESILIENCE

This rapid assessment of ecosystem resilience involves analysis of satellite remote sensing data (Tremblay et. al. 2011, Appendix 3), and relevant scientific literature and reports. The North Water Polynya was identified as one key feature within the marine ecoregions M42 (North Greenland) and M26 (Baffin Bay-Canadian Shelf), and as a significant designated area with current and future conservation value.

The North Water Polynya key feature described in this report were identified by evidence suggesting exceptional productivity (Fig. 4, Appendix 4) and diversity during specific times of the year when plankton is most abundant and wildlife and Inuit hunters and fishermen tend to congregate in these areas. This ecological vitality is used to infer the importance of these features as sources of ecological resilience for the wider ecoregions that encompass the North Water Polynya. The map of the main areas in this key feature (Fig. 6) is intended to inform discussions about the best management approaches to safeguard the exceptional productivity and/or diversity of the North Water Polynya (and the drivers responsible for them) to better fortify the resilience inherent in the larger ecosystem.

The second part of RACER evaluates the likelihood that key features will continue to contribute to region-wide resilience when 21st century climate change affects the drivers at work in these ecologically vital places. The main drivers behind the exceptional productivity and/or diversity of the ecoregion's key features are described in Table 1. Drivers susceptible to the impacts of climate change, such as sea surface temperature, sea ice, and salinity (Hansen, 2012) figure prominently in the ecological performance of key features. But climate-impervious drivers, such as seabed terrain responsible for nutrient-rich upwelling, are also important. These drivers will provide an important focus for future conservation efforts.

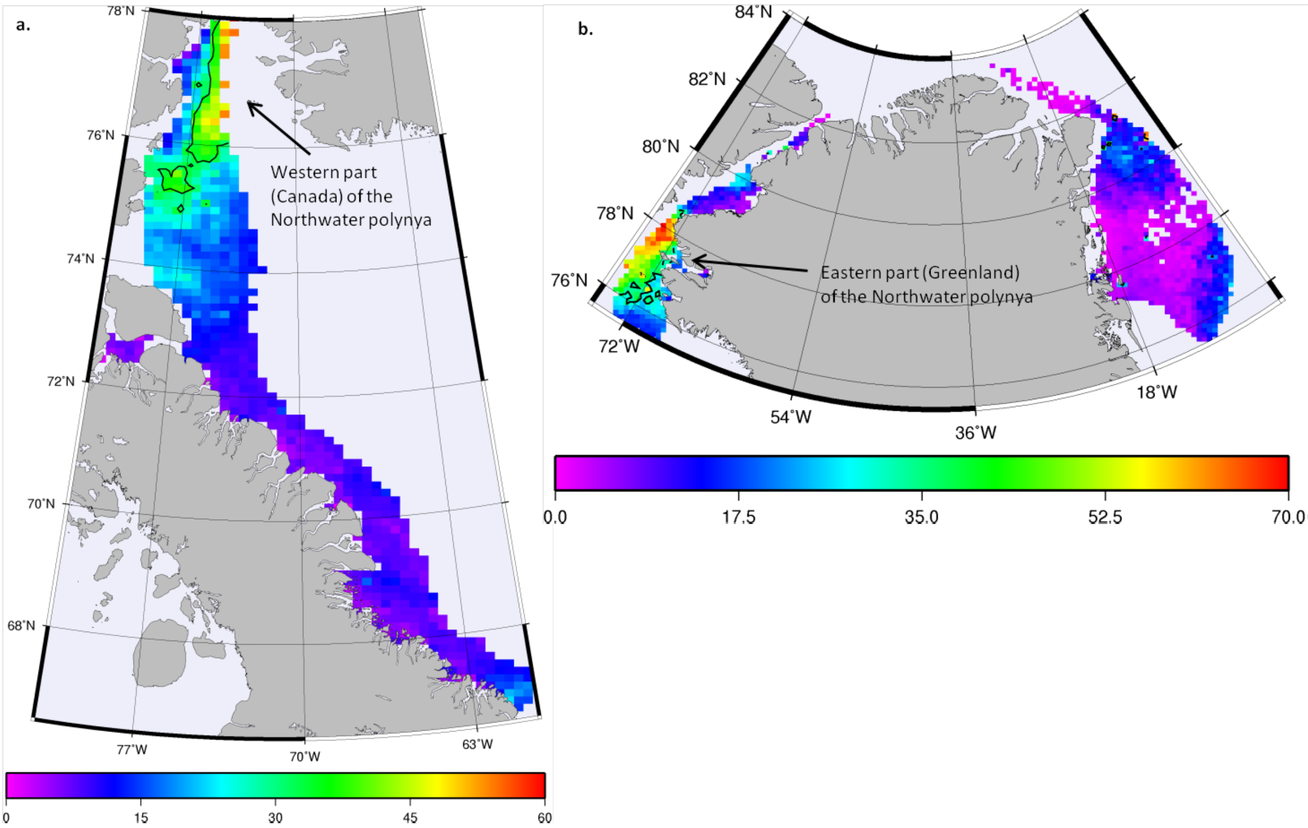


Figure 4 A, B. Primary production rates (g C m^{-2} y^{-1}) of the Baffin Bay – Canadian Shelf (a) and North Greenland ecoregions (b). Contour lines indicate the 10% most productive pixels based on the 90th percentile analysis (ACTUS inc. & WWF, 2011: Rapid assessment of the marine primary productivity trends in the Arctic Ocean and its surrounding seas). Based on data collected over a thirteen-year period from 1998-2011.

GLOBAL CLIMATE MODELLING

RACER uses forecasts from current General Circulation Models (GCMs) to predict climate-related changes to ecologically significant variables within ecoregions for the remainder of this century. GCMs are a broad group of internationally developed computerized models designed and tested to forecast likely effects of global climate change on rain, snow, temperature, ice, and many other variables for different greenhouse gas emission scenarios into the future. GCMs form the basis of the predictions and warnings by the Intergovernmental Panel on Climate Change (IPCC 2007).

Although the unique relationship between the ocean, land, and atmosphere in the Arctic often complicates these forecasts (e.g., through unexpected lag periods or difficult-to-anticipate climate feedbacks), the prediction accuracy of several GCMs has been proven in the region. RACER relies on data from four of these models that have shown the best agreement between climate projections and reality in the Arctic (Appendix 5). Similarly, RACER uses GCM results for a realistic greenhouse gas emission scenario that reflects a "business as usual" outlook. The so-called A2 scenario offers results for all four selected GCMs (Fig. 5A). The scenario matches current observations closely and projects a degree of warming for the year 2100 in line with predictions resulting from current global commitments to the reduction of greenhouse gas emissions.

Twenty variables were selected from the GCM data for the RACER analysis. Variable values relevant to the ecoregions were then calculated from nearby GCM values using a weighted average from the GCM data grid to accommodate the irregular shape of the region (Fig. 5B). The details of this method are described in Huard 2010.

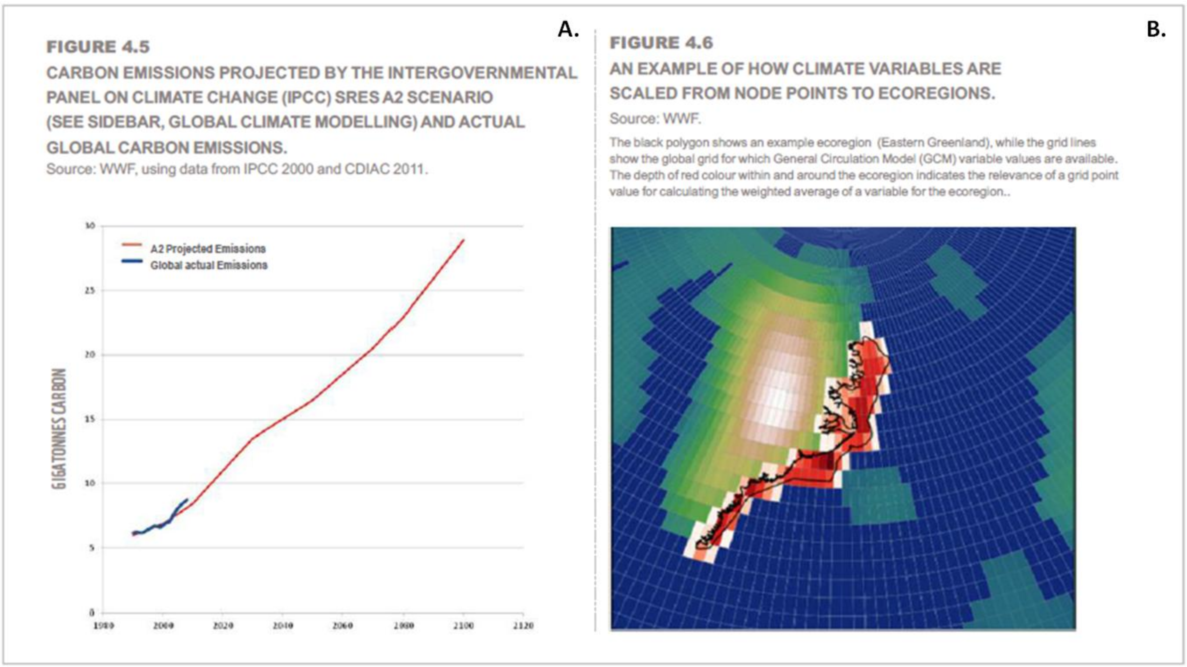


Figure 5 A, B *Carbon emissions projected by IPCC SRES A2 scenario and actual global carbon emissions (4A). Example of how climate variables are scaled from node points to ecoregions (4B).*

ECOREGION CHARACTERISTICS

The North Water Polynya lies in the region enveloped by the two ecoregions M42 (North Greenland) and M26 (Baffin Bay–Canadian Shelf) extending roughly from the middle of Ellesmere Island, along the eastern edge of Baffin Island, and onto the coast of Labrador and northern Newfoundland (Wilkenson 2009) (Fig. 1 and 2). One of the central areas in the joined ecoregion area is the North Water Polynya. On the North/South trajectory a transition zone is formed between the cold northern waters and the more temperate southern waters, and the ecoregion is in fact subarctic in nature in some parts as a result of the influx of warmer waters from the West Greenland Current. The Labrador Current—the main current in the region — flows south to meet the Gulf Stream in the more southern Canadian Atlantic.

The region is characterized by seasonal ice that begins to form off the coasts of Ellesmere and Baffin Islands as well as Labrador in November or December; by February or March, it usually reaches the northeast coast of Newfoundland, accompanied by thousands of icebergs. Fjords, cliffs, and rocky areas characterize much of the immense coastline contained in this region. Its continental shelf extends 50–150 km from shore, at a depth of 200–300 m.

On the Eastern side, the region extends across the Nares Strait to the Lincoln Sea and down into the Greenland Sea where it encompasses the North East Water Polynya (NEW) in an area of otherwise constant ice cover. Bathymetry of the North Greenland ecoregion ranges from 200 m in near coastal areas on the eastern coast of Greenland, to 1,000 meters depth in outer pelagic ranges of the ecoregion, and in Baffin Bay (Fig. 6). Overall, sea ice is common throughout much of the region, depending on the season and latitude. Within the ecoregion, the polynyas are special key features characterized by a high productivity due to the early spring bloom of phytoplankton (ACTUS inc. & WWF, 2011) and are thus important breathing and feeding areas for marine mammals and sea birds during winter and spring (Boertmann et al 2001)(Heide-Jørgensen 2013).

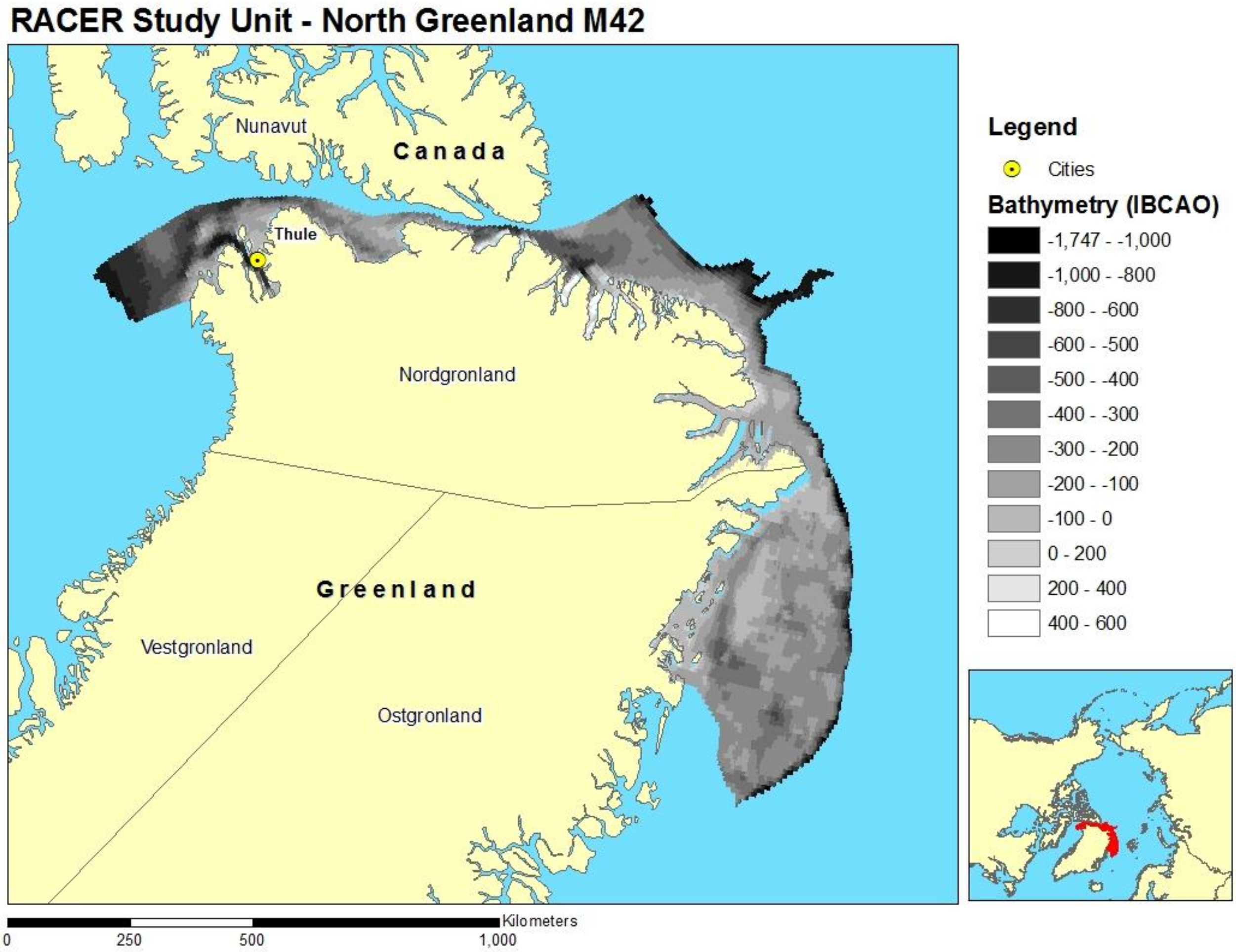


Figure 6. *Bathymetry of the North Greenland (M42) ecoregion.*

Biological Setting

Three sources contribute to the total primary production in the area; phytoplankton, ice algae embedded in fast or drift ice, and benthic algae. The relative importance of the three sources is likely to vary geographically with depth and extent of ice cover. The strength of the benthic-pelagic coupling (the total amount of produced organic carbon that is recycled through the microbial loop) is difficult to determine on an overall scale, due to the variation in primary production being considerable within the region. In the North Water Polynya, which is one of the most biologically productive marine areas in the region as well as overall in the Arctic, productivity is in the highest range of the scale (50-70 g C m^{-2} y^{-1}) (Fig. 3) while it in other areas of regional high productivity scales at between 20-30 g C m^{-2} y^{-1}. Low productive areas range between 0-17.5 g C m^{-2} y^{-1}.

The region also encompasses the North East Water Polynya, which is slightly less productive than the North Water Polynya, due to shorter periods of open water and the main mechanism behind the polynyas existence being current contra upwelling. Still, primary production onsets earlier at the ice edge than in the surrounding areas, and leads to heightened productivity that sustains a rich diversity of species.

The Northern Arctic marine ecoregions M26 and M42 are collectively home to a great number of marine mammals, fish and birds. Humpback whale (*Megaptera novaeangliae*), sei whale (*Balaenoptera borealis*), fin whale (*Balaenoptera physalus*), bowhead whale (*Balaena mysticetus*), and blue whale (*Balaenoptera musculus*), as well as beluga whale (*Delphinapterus leucas*) and minke whale (*Balaenoptera acutorostrata*) subsist within this combined region, along with four seal species; harp and hooded seals that breed and migrate along the coastal areas while ringed seals and their main predator, the polar bear, roam throughout the region. Bearded and harp seals are found along the east coast of Ellesmere Island, where open waters promise easy breathing during the brief Arctic summer, dozens of species of migrating birds make use of the unpredictable sections of open water that appear in the ecoregion. As the pack ice breaks up, ice edges become vital areas for mammals and seabirds. The Atlantic walrus (*Odobenus rosmarus*) winters in Northwest Greenland, where it occurs along banks and in the North Water Polynya.

RACER EXPERT WORKSHOP/CONSULTATION 2014

The RACER marine workshop was held at WWF Verdensnaturfonden's office in Copenhagen, Denmark, 8th of January 2014. The workshop assessed the overall RACER method and persistence of key feature's future above-average productivity/diversity.

This final report is a product of work produced entirely by WWF Verdensnaturfonden.

Participants/experts:

- Anders Mosbech, senior scientist, Department of Bioscience, Arctic Environment, Aarhus University.
- Christine Cuyler, scientist, Department of Birds and Mammals, Greenland Institute of Natural Resources.
- Flemming Merkel, senior researcher, Department of Bioscience, Arctic Environment, Aarhus University.
- Tom Christensen, advisor, Department of Bioscience - Arctic Ecosystem Ecology, Aarhus University.
- Elmer Topp-Jørgensen, Department of Bioscience - Arctic Ecosystem Ecology, Aarhus University.

Comments and conclusions of workshop:

- RACER focuses on primary productivity and the services that an ecosystem can provide for animals and humans but are not drawing specific attention to threatened endemic species. Using the RACER method ecosystem services will therefore be protected but not implicitly protects those species unique to the Arctic regions and that are vital important species both culturally and economically to the people living here.
- The RACER method works within a context of identifying and designating areas of high netto primary productivity/biological production today and in the future and these areas are important to take into account in regional nature management, but the method is not suitable to ensure the protection of the High Arctic species that are most threatened by climate change.
- Experts pointed out that even though it is assessed that a specific key feature's above-average productivity and diversity will remain high in the future it is not necessarily the same productivity and diversity consisting of the same species/same food chain structure that characterize that key feature today.
- Experts took reservations to the General Circulation models (GCM's) used in the RACER method. The resolution in the models is too low to make precise predictions and assessments of ecosystem resilience and the assessments given in this report are therefore only estimations. There is a need for regional climate models, with sufficient resolution for the ecoregions.

- Remote sensing of productivity does not measure under ice productivity. This impedes challenges when using this essential factor to identify key features at high latitudes. Therefore only open water productivity is accurately measured. Sea ice cover of high percentages can have very high productivity as there will be lots of sunlight penetration to create productivity between ice floes and under the sea ice.
- Experts distinguished between productivity and biodiversity why the column in Table 1 regarding assessed persistence of key feature's future above-average productivity/diversity is separated into two assessments (productivity and diversity) instead of one assessing these together as shown in the RACER handbook (page 51).
- It gives strength to the RACER method that it designates areas also identified by other methods to be of high ecologically importance.
- All experts agreed that resilience is an important concept and that this is a useful approach, even if challenging to apply.
- The biodiversity of the North Water Polynya has been intensely studied in the International North Water Polynya study (NOW) (Fortier et al. 2001). However, more recent data are lacking, and data for certain fauna and flora groups like benthos or macro algae are still missing which makes a full picture of the biodiversity in this ecoregion currently unattainable.
- A report containing a summary of the overall biodiversity found in Greenland is expected to be published from the Danish Centre for Environment and Energy (DCE) in the near future.. This report will give an important overview of the species found within the key features described in this document.

THE NORTHWATER POLYNYA AS A KEY FEATURE

Polynyas are local hotspots for biological production and biodiversity (Dunbar and Dunbar 1972) (Stirling and Cleator 1981). Reduced ice coverage provides conditions for an enhanced primary production, which in turn supports large populations of arctic birds and maintains marine mammals such as walruses, narwhals, and belugas, for instance, have been known to adapt their winter strategies to polynya regularity, using them as dependable feeding grounds. At the on-set of spring, reduced ice coverage also allows earlier penetration of light into the ocean surface layer.
This makes polynyas the focal points for early, large production of planktonic herbivores responsible for transferring solar energy from planktonic microalgae to the rest of the Arctic food chain.

The North Water Polynya (NOW) (Fig.7) lies in the entrance to Smith Sound/ Nares strait. It has been categorized as the most productive area in the Arctic (Deming et al. 2002). The North Water Polynya is characterized by upwelling and currents/ wind conductivity as physical drivers that uphold the open water zone and instigate the high primary productivity. The natural resources and ecosystem services related to the presence of the polynya created the basis for the historical migration of Inuit, from Canada to Greenland, and therefore also represent cultural values (Christensen 2012).

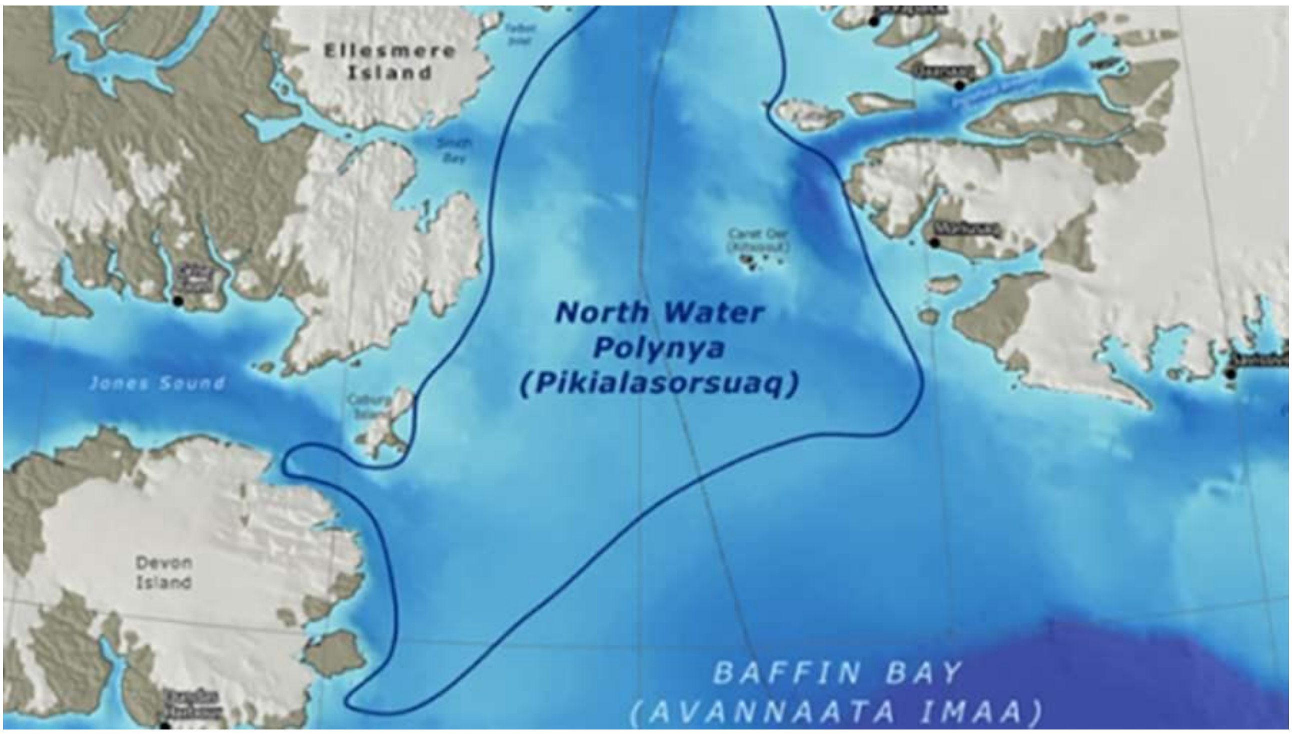


Figure 7. Key feature 1, the North Water Polynya, is by the dark blue line in the enlargement. Source: http://www.pewtrusts.org/en/research-and-analysis/fact-sheets/0001/01/01/north-water-polynya

The North Water is a crossroad in the Arctic, owing much of its complexity to the interaction of dissimilar waters over a highly varying bathymetry (Bâcle 2000). Both Arctic water coming through Smith and Jones Sounds, as well as Atlantic Water coming with the West Greenland Current are much less saline which is due to its pacific origin. Once under the polynya, the horizontal distribution of both Arctic and Atlantic Water is highly influenced by bottom topography, particularly the 500 m isobath defining Smith Sound Canyon and its entrance into Baffin Bay Basin (Bäcle 2000).

In the North Water Polynya, the planktonic bloom starts extremely early, already in April which is similar to the timing in temperate oceans. This is believed to be due to stratification (shallow mixing) in the eastern part of the polynya (Tremblay et al. 2006). The prolonged phytoplankton bloom measured in years with a high occurrence of storms is likely caused by storm-driven admixture of nutrients (primarily nitrate) from deeper waters (Lovejoy et al. 2002) (Tremblay et al. 2002) (Tremblay et al. 2006) and it is possible that the bloom would be more short-lived in years with fewer storms during spring and summer (Barber et. al 2001), which would lead to a lower subsurface chlorophyll maximum. Studies in the North Water Polynya (Fortier et.al. 2001) of the microbial food web have shown the interactions to be complex and its internal and external pathways change with seasonal development (Berreville et. al. 2008). In this regard the North Water differs from the North East Water Polynya in the Greenland Sea (NEW) where the interactions are less complex. This is probably caused by differences in their longevity, i.e. the longer-lived North Water Polynya having more time to develop complex trophic interactions (Arrigo 2007).

The ecological significance of the high level of primary productivity is expressed in the high species diversity and abundance found in the area. While some of these species presence is seasonal, others depend on the abundant resources all year round. For the marine mammals, the North Water is critical habitat for beluga whales: an estimated population of about 14,000 animals migrates from Lancaster Sound in Canada to the North Waters and adjacent waters; a large proportion of these whales primarily overwinter in the western parts of the polynya. The bowhead whale uses the southern parts of the North Water in summer and an unknown number of the whales overwinter in the polynya (Boertmann and Mosbech 2011) (Marz 2010). In the northern parts of the North Water the Kane Basin subpopulation of polar bears number a few hundred individuals. These bears are connected to the larger subpopulations found in Baffin Bay and Lancaster Sound. The polar bears prey amongst other species on the ringed seals, found abundantly in the North Water which is an important wintering ground for younger ringed seals, found mainly in the thinner ice in the eastern part of the polynya (Born 2008) (Dowsley 2005). The availability of prey for the polar bear population though, is also influenced by the changing climate, and this may in turn affect the amount of persistent organic pollutants that are transferred through the food chain to the polar bears at the top trophic level (Fisk et al 2013) risking effects on reproduction and lifespan.

A summer population of approximately 1,500 walruses lives in the North Water Polynya. They overwinter mainly in the eastern parts of the polynya while the western part off Ellesmere Island is the primary summer ground. Narwhals from the Baffin Bay population occur in the North Water Polynya especially during summer, utilizing the northernmost parts of the North Water and Inglefield Bredning as important summer grounds (Boertmann and Mosbech. 2011) (Harwood, 2001).

The North Water Polynya is an equally important habitat for bird species, and more than 80 % of the world population of little auks is dependent on the North Water between May and September, where approximately 30 million pairs breed exclusively along the Greenland side of the polynya (Marz 2010) (Meltofte 2013) (Karnovsky 2008). The endangered ivory gull uses the North Water during the summer months and breed at the nearby Ellesmere Island (Spencer 2014). Furthermore eiders, black-legged Kittiwake, little tern, thick-billed murre, and puffin are all species on Greenland's Red List that are found or breed in the North Water Polynya. For the thick-billed murre, the population in the region accounts for more than half of the total breeding population in all of Greenland (Gaston 2002) (Marz 2010) (Meltofte 2013) (Stirling I 1981).

Resilience

The combined effects of the main drivers, the bathymetry, the upwelling patterns, and main currents as well as the surrounding sea ice cover and the presence of the ice bridge creates this key feature that supports not only high primary productivity but constitutes essential feeding grounds for populations of Arctic birds and marine mammals, while maintaining a low level of human induced disturbance/degradation (Lyberth 2013).

The high biological productivity is highly dependent on the formation of an ice bridge in Kane Basin (Fig. 8). The ice bridge is a major determinant for the opening of the polynya, as the ice bridge and the predominant northerly wind are preventing ice floes from moving south into the North Water Polynya, leaving it open for light to reach the water and fuel the primary production. When the ice bridge is absent the productivity is much lower. The physical coupling of the polynya to the ice bridge prevents a northern recession of the polynya, but may lead to a decrease in its size and duration, and simultaneously an increased sea ice concentration in the area. This due to more sea ice being advected through Nares Strait from the Lincoln Sea. This result suggests, rather counter-intuitively, that the North Water may respond to a warmer climate by showing an increase in sea-ice concentration and reduction in the amount of time the polynya is distinguishable from a marginal ice zone in this region (Barber et al. 2010) (Ingram et. al. 2012). Over the past two decades, the polynya occurrence and timing has changed significantly, affecting the timing, the localization and the intensity of the spring bloom. This may in turn affect species that utilize the open water area seasonally for feeding or breeding. This isn't just a question of the amount of open water available, or the resulting total primary production within the polynya—it's more a question of timing, i.e. the dates and lengths of time that sea ice recedes, reforms, and recedes again (Fig. 9). When the timeline of seasonal climatic events change unevenly across the Northern Hemisphere this might severely affect the phenology of migrating animals, and especially long-distance migrating birds relying on local climatic cues to regulate the timing of migration (Clausen and Clausen 2013). For Arctic breeding species in particular, following highly profitable food is important, so that they can replenish resources along the way and arrive in optimal body condition to start breeding early (Kölzsch et al 2014).

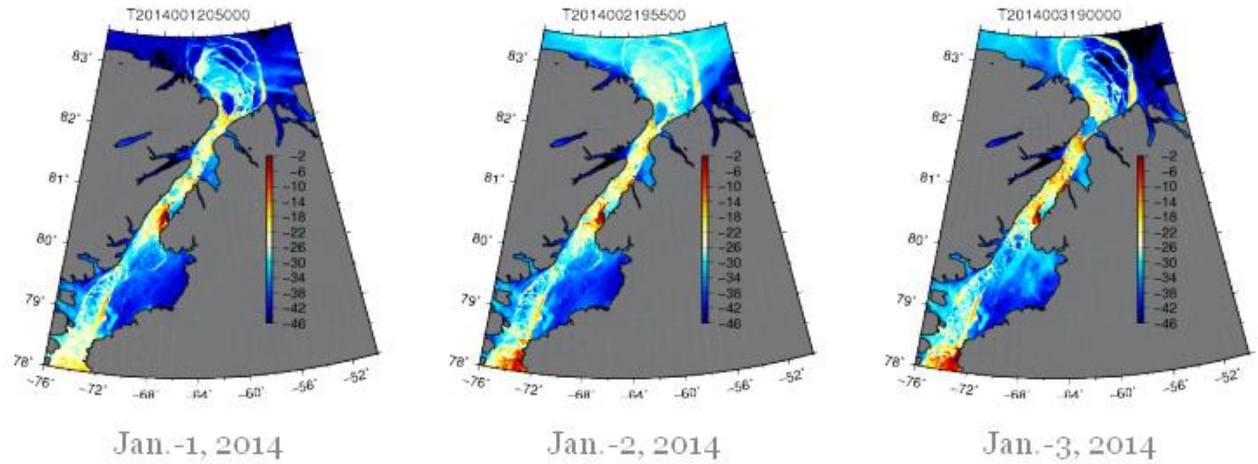


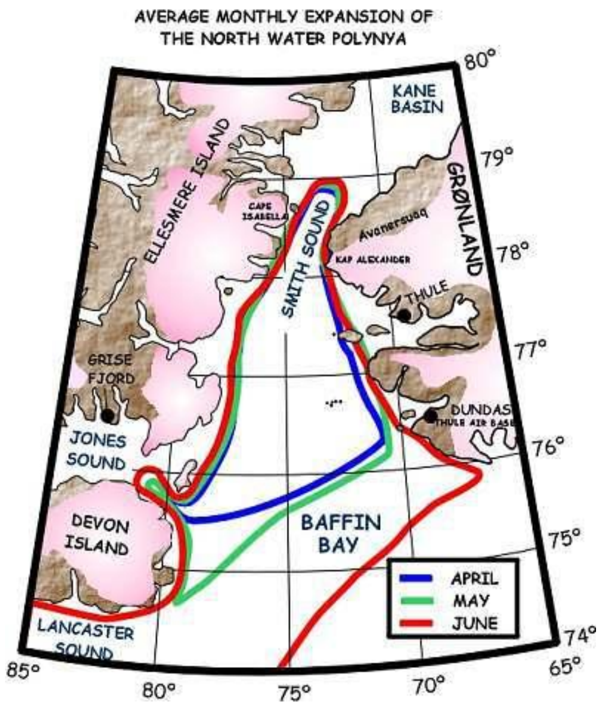
Figure 8. Ice bridges forming in Nares Strait (January 1st, 2nd and 3rd, 2014) from MODIS thermal imagery. The ice bridges that span from Greenland to Canada, stops the ice motion while the waters under the ice are moving. Source http://neven1.typepad.com/blog/2014/01/2014-nares-strait-ice-bridges.html

Arctic polynyas, like the North Water Polynya, are already dramatically influenced by the overall increase in surface temperature, and the replacement of multi-year ice with first year ice. These changes may in the future lead to the release of feed-back mechanisms, where with longer ice-free seasons, the overall evaporation would be expected to be greater, and therefore more precipitation and cloud concentration can be expected. Reduced ice concentration will also decrease the local albedo, allowing for larger heat absorption by the ocean surface layer, and conjunctively leading to a later ice formation in the following season. While less sea ice increases the amount of irradiation that penetrates the ocean, the potential increase in production is offset by increased stratification and reduced surface nutrient flux, which overall will result in a total decrease in summer primary production (Smith and Barber 2007).

Despite their obvious biological importance, most polynya areas are threatened by extensive disturbance and possible pollution as a result of proposed offshore petrochemical exploration and year-round shipping activities (Stjernholm 2011). Licenses have been issued for hydrocarbon exploration in the vicinity of the North Water Polynya, including five license blocks in the Melville Bay region. In a warming climate, this threat and the potential detrimental effects will only increase. However, we cannot evaluate what the effects of such disturbances might be, or what the net change for many of the above depicted polynya associated biological processes will be, because as yet insufficient research is conducted to enable a quantitative understanding of the critical ecological processes and balances that may be unique to the North Water Polynya, and its surrounding ecoregions (Marsden et. al. 2004).

On an overall scale, we assessed the persistence of key feature's future above-average productivity/diversity through the predicted main changes to GCM climate variables to be medium.

International agreements exist between Greenland and Canada on the conservation of shared marine areas (Agreement for cooperation relating to the marine environment, 1984) as well as agreements on management of shared populations of marine mammals, and implementing further collaborative legal protective measures for this unique area is strongly advised.



Figuer 9. Map of North Water Polynya, showing the average monthly expansion. The main settlements within the area, and the several glaciers that characterize this area of conservation importance (Glaciers marked in pink). Source: http://icecubicle.net/2009/08/03/phenom-polynyas/

Table 1. The likely persistence of key features in the face of climate change.

The likelihood that key features will continue to confer resilience to the ecoregion in the future is scored as high (H), medium (M), or low (L) based on projected changes to main climate variables using GCMs and their effect on geophysical drivers.

Key feature	**Main driver**	**Current biological productivity & habitat heterogeneity**	**Main changes to GCM climate variables**¶	**Assessed persistence of key feature's future above-average productivity/diversity* (High, Medium, Low)**
1. The North water Polynya (NOW)	Seabed terrain Sea and tidal currents Seasonal ice cover Persisting ice bridge Salinity Nutrients Sea surface temperature Glaciers (melt off)	High productivity; high marine species diversity; Up-welling driven by currents and glaciers ; sea ice driven spring bloom	Sea Surface Temp (SST) Surrounding Sea Ice (SIC) and seasonal ice cover (Particularly the ice bridge) Salinity Nutrients	M** / M

¶Climate variables: Sea Surface Temperature (SST); Salinity; Sea-Ice Thickness, Sea-Ice Concentration (SIC); Precipitation (P); Surface Air Temperature (SAT). Persistence index: H – High; M – Medium; L – Low. Relevant, though not main, climate variables are shown in italics.

* Diversity of species may change from the current composition consisting of both High Arctic, Arctic, and temperate species to a composition mainly consisting of more temperate species as climate change progresses for the remainder of this century. High Arctic and Arctic species will potentially migrate further north as temperate species move into the Arctic regions from more southerly latitudes. The assessments of diversity presented in this table is therefore not an assessing of whether Arctic biodiversity as we know it today will remain at the designated key features but an assessment of whether ‘any’ biodiversity will remain high, medium or low.

**Uncertainty regarding the assessment of productivity at changed sea ice regimes caused by climatic changes.

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APPENDICES

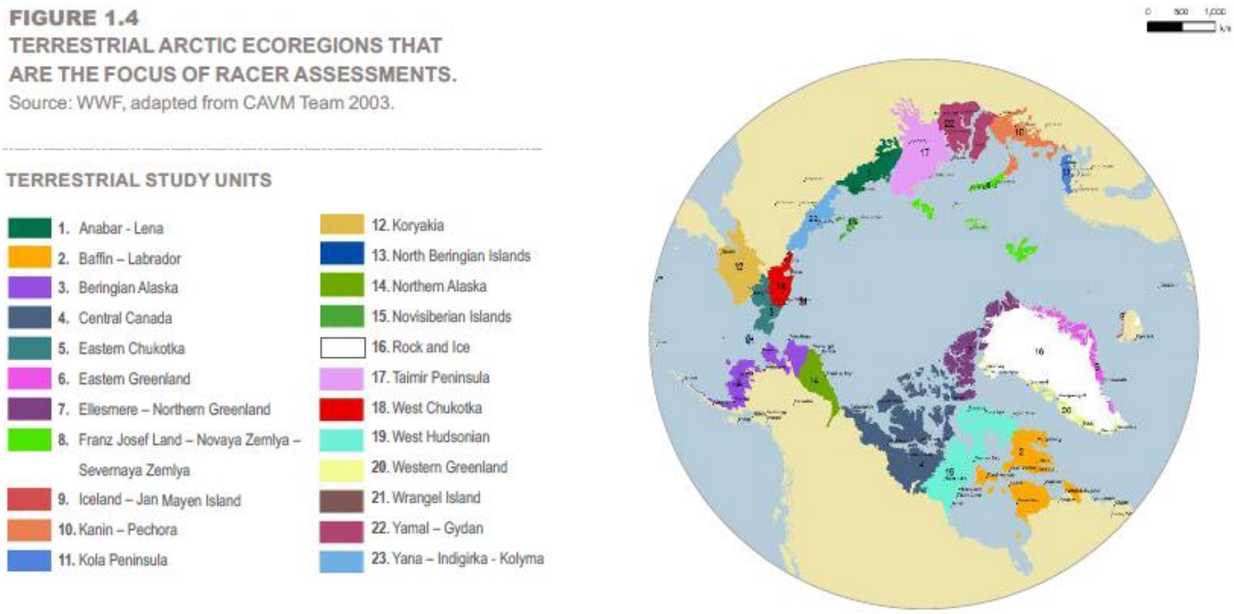
Appendix 1

ECOREGIONS

The Arctic is home to 50 representative ecoregions that reflect the wide range of unique ecosystems and varieties of life found throughout the far north. These regions are distinguished and located on a map using two broad bio-geographic ecological classification methods: the Circumpolar Arctic Vegetation Map (CAVM team 2003; Walker et al. 2005) for regions on land and, at sea, the Marine Ecoregions of the World project (Spalding et al. 2007) (Fig. Ap1).

CAVM classifies the variation in plant species groups and communities found in clearly recognizable regions across the Arctic. Although many plants occur throughout the circumpolar north, variation in other species groups reflects the Arctic's diverse glacial histories, topography, and other factors that may have isolated plant populations and contributed to regional differences. Importantly, the CAVM classes also fall into categorical distinctions according to regional differences in the soil type, soil moisture, and temperature.

At sea, ecoregions are classified based on distinctions described by the recent Marine Ecoregions of the World (MEOW) project. The team of international researchers involved in MEOW used recognizable species groups of both plants and animals to make regional distinctions. Marine ecoregions are defined as "areas of relatively homogeneous species composition that clearly differ in this regard from adjacent systems." These identifiable species groupings are likely the consequence of characteristics in the seascape that encourage biological isolation and difference, such as seafloor mountains and canyons, temperature, ice, currents, upwelling, or coastal complexity (Spalding et al. 2007).



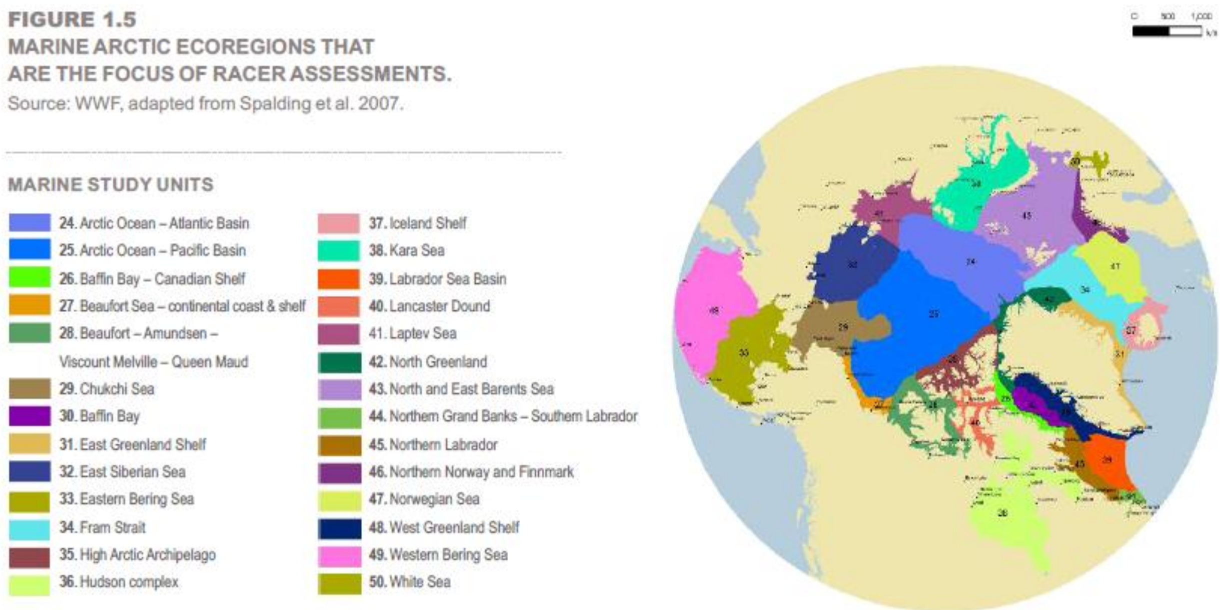


Fig. Ap1. Terrestrial and marine ecoregions that are the focus of RACER assessments. Source: the RACER Handbook, pp. 18-19.

Appendix 2

BIODIVERSITY

Primary production
Three sources contribute to total primary production in Arctic regions: phytoplankton, ice algae embedded in fast or drift ice, and benthic algae. The relative importance of the three sources is likely to vary geographically with depth and extent of ice cover. Phytoplankton is contributing the most to total primary production, however the contribution from ice algae are locally important (Boertmann and Mosbech 2011).

The spring bloom in Greenland has its onset in the open water area in southern Greenland before it moves northwards. North of the open water area the primary production starts under the ice but the actual spring bloom depends upon the retraction of the sea ice. The species composition of the phytoplankton changes throughout the season. At the onset of the spring bloom it is dominated by the diatoms *Nitzschia*, *Thalassiosira*, *Navicula*, *Fragilaria* and *Coscinodiscus* whereas minor species such as *Phaeocystis*, *Chaethoserus, Ceratium* and the dino- and nanoflagellate will take over after the spring bloom (Jensen 2003).

Zooplankton
The zooplankton are the secondary producers, they feed on the primary producers and are themselves food for higher organism in the pelagic ecosystem. Zooplankton includes one-and multicellular organisms that can be grouped into heterotrophic micro- and macro organisms. The heterotrophic microorganisms consists e.g. of bacteria and protozoas, whereas the macroorganisms consists of e.g. crustaceans and jellyfish. The copepods are the most dominant zooplankton and make up the majority of the zooplankton biomass. They graze on the phytoplankton and are of great importance for the carbon cycling. The genus *Calanus* are the largest group consisting of >80 % of the copepods. It is thus one of the most important animal groups in the Arctic regions and is a key group in the food chain (Jensen 2003). Calanus are an important food item for fish larvae, benthic animals, marine birds and marine mammals (Boertmann and Mosbech 2011, Merkel et al. 2012). The two Arctic species *Calanus hyperboreus* and *Calanus glacialis* are adapted to the cold waters of the Arctic regions while a third species, er *Calanus finmarchicus*, is a north-Atlantic species adapted to warmer temperatures. The two former species contain large amounts of fat which are important for the species higher in the food web feeding on Calanus (Grenvald et al. 2012).

Benthos
The benthic invertebrates can be divided into three groups: the infauna that is buried in the sea floor e.g. worms and clams, epifauna that lives on the sea floor e.g. anemones, barnacles and northern shrimp, and interstitial fauna that live in the sand e.g. kinorhyncha and loricifera (Jensen 2003). Information about benthos diversity and distribution in Greenland are sparse. Studies suggest that the ecoregions have a highly heterogeneous substrate and that the associated benthic community is dense and diverse compared to other Arctic areas. In the benthos of the North Water Polynya, the bottom

dwelling community consists mainly of clams, scallops sponges, sea worms, anemones crabs, and sea stars (Wilkenson et. al. 2009) (Hargrave et. al. 2002). It has been estimated that 90% of the 5000 invertebrate species present in the Arctic live on the sea floor and an estimated 25% of all the species present in Greenland (including terrestrial flora and fauna) are marine benthos (Boertmann and Mosbech 2011). Furthermore, the benthic habitats in Greenland are considered to play a key role in the marine food web since they provide an important food source for fish, seabirds and marine mammals. Benthos in the Arctic generally has long life spans compared to similar species at more southern latitudes. Changes in these communities happen very slowly and as recovery is prolonged, they are exceptionally vulnerable if disturbed (Boertmann & Mosbech 2011). The most important areas in relation to marine benthos is expected to be in shallow waters as well as in areas seldom affected by sea ice and thus with a high annual production of phytoplankton, as in the North Water Polynya (Merkel et al. 2012).

Benthic diversity often decline significantly along a shelf-slope-basin gradient. In addition to depth, other factors such as sediment heterogeneity, disturbance, food availability, geographical setting, sea-ice cover, particle load from land and hydrographical regimes also influence benthic diversity and species composition (Boertmann and Mosbech 2011).

Benthic macrophytes

In general, there is a lack of data on macro algal biomass, production, species specific coverage and associated fauna for the ecoregions encompassing the North Water Polynya.

A relatively dense flora can be found until 20-30 metres depth, but macro algae may occur as deep as 50 metres (Merkel et al. 2012). The marine macro algae are found along shorelines with hard and stable substratum, such as stones, boulders and rocky coast. The most important environmental conditions for the macro algal flora are the low temperatures, strong seasonal changing light regime and ice cover throughout a large part of the year. The littoral- and sublittoral canopy of macro algae is important for higher trophic levels of the food web by providing substrate for sessile animals, shelter from predation, protection against wave action, currents and desiccation or directly as a food source. Climate change will probably affect the macro algal vegetation by especially longer season with open water, and thereby a longer season for growth. This coupled with oceanic warming therefore may change many species distribution towards north. On the other hand, melting of glaciers leads to increased runoff of freshwater with suspended material, which results in lowered salinity and increasing water turbidity, and which again may have a negative impact on the local macro algae vegetation (Boertmann and Mosbech 2011).

Fish

Fish diversity is low, with Arctic cod being the dominant species (Wilkenson et al 2009). Along with Greenland cod (*Gadus ogac*), and Arctic char (*Salvelinus alpinus*), large schools of Arctic cod support the populations of seals, narwhal (*Monodon monoceros*) and beluga whale (*Delphinapterus leucas*) in the area. (Boertmann and Mosbech 2011) The bottom dwelling Greenland halibut (*Reinhardtius hippoglossoides*) also occur in these northern regions, its distribution reaching up to Smith sound and is the major food source for narwhals (Christensen et. al. 2012)

The Atlantic cod is rare in the northern Greenland region and rated vulnerable on the IUCN red list which is primarily ascribed an extensive fishery. With a warming climate the species is projected a northward expansion. The Greenland halibut is a slow growing deep-water flatfish present along the entire coast of the West Greenland Shelf ecoregion, but it is also found in the North Water Polynya. Highest abundances are found at Fyllas Bank, Store Hellefiske Bank and the Disko Bay area. The Greenland halibut spawns in the southern Davis Strait area, and the eggs are carried with the currents northwards where they settle as larvae. The lifecycle of the Greenland halibut is poorly known. Juveniles mainly feed on crustaceans and smaller benthic invertebrates, whereas adults prey on a variety of fish species in the pelagic layers. Inshore and offshore fisheries of Greenland halibut is of key importance for the Greenlandic community, both as a source of food and as a commercially exported product (Boertmann and Mosbech 2011, Merkel et al. 2012).

Marine mammals

The North Water and the surrounding polynyas are one of the richest areas of marine mammals in the world, this due to the high primary production and Arctic Cod, which constitutes the main part of many arctic marine mammals diet, are abundant. The North Water Polynya hosts most of the global Narwhal (*Monodon monoceros*) population in the summer, and one third of North Americas Beluga (*Delphinapterus leucas*) population all year round and the Eastern population of the endangered Bowhead whale (*Balaena mysticetus*) during the summer. The Ringed Seal (*Pusa hispida*), Bearded seal (*Erignathus barbatus*), Harp seals (*Pagophilus groenlandicus*), and the Walrus can be found concentrated in this major polynya during all seasons. These pinniped species are closely associated with the ice, using it for feeding, breeding and as a resting platform. Walrus are benthic feeders and forage mainly on mussels on the shallow water banks near the coast. Due to the high density of Ringed seals (*Pusa hispida*) which occur all year round, a large proportion of the Canadian polar bears (*Ursus maritimus*) are concentrated in this region as well as Arctic foxes (*Vulpes lagopus*), both of which rely on this polynya for prey throughout the year. Polar bears found in the ecoregion mainly belong to the Baffin Bay sub-population and spend their summer on Baffin Island east of the West Greenland Shelf. Some bears stay throughout the summer in the fast ice in the Melville Bay area. The ringed seal is the primary food item for polar bears.

Several species of whales visit the North Water Polynya including both baleen and toothed whales (Table Ap2). Three whales remains in the Arctic areas throughout the year. These are the bowhead whale, the narwhal and the beluga whale. Other species of whales visit the area to feed in the open water areas.

Many of these marine mammal species are hunted by man and are considered an important cultural and economic resource[2][3].

Seabirds

The North Water Polynya sustains tens of millions of birds that come to nest in and near the Polynya area. This includes 30,000 pairs of black legged kittiwakes (*Rissa tridactyla*) northern fulmars (*Fulmarus glacialis*) and over 350,000 pairs of thick-billed murres (*Uria lomvia*). Furthermore, thousands of pairs of black guillemots (*Cepphus grylle*), Arctic terns (*Sterna paradisaea*) and 700-800 ivory gulls (*Pagophila eburnea*) also inhabit the area, as well as large colonies of greater snow geese (*Chen caerulescens*). The Eider duck (*Somateria mollissima*) is a constant resident of the Arctic.

The North Water Polynya hosts the largest single species colony on the planet due to the abundance ($>100\times10^6$) of little auks (*Alle alle)* which arrive between May and July as the availability of their copepod prey, *Calanus* species, increase.[4]

Baleen whales	**English name**	**Latin name**
	Bowhead whale	*Balaena mysticetus*
	Fin whale	*Balaenoptera physalus*
	Minke Whale	*Balaenoptera acutorostrata*
	Humpback whale	*Megaptera novaeangliae*
	Sei Whale	*Balaenoptera borealis*
	Blue whale	*Balaenoptera musculus*
Toothed whales	Narwhal	*Monodon monoceros*
	Beluga whale	*Delphinapterus leucas*
	Harbour porpoises	*Phocoena phocoena*
	Killer whale	*Orcinus orca*
	Sperm whale	*Physeter macrocephalus*
	Long finned pilot whale	*Globicephala melas*
	White-beaked dolphin	*Lagenorhynchus albirostris*
	Northern bottlenose whale	*Hyperoodon ampullatus*

Table Ap2. Baleen and toothed whales found in Greenlandic waters. The Bowhead whale, narwhal and beluga whale are endemic to the Arctic regions.

[2] http://extrememarine.org.uk/osue0d/arctic-north-water-polynya/
[3] http://awsassets.wwfdk.panda.org/downloads/final_racer_report_western_greenlandcmm_1.pdf
[4] http://oceanlink.island.net/ONews/ONews7/polynya.html

Appendix 3

REMOTE SENSING OF PRIMARY PRODUCTIVITY

Abstract

A 13-years time series of SeaWiFS imagery was employed to estimate the primary productivity (PP) rates taking place in the Arctic Ocean and its surrounding seas. The objective is to identify regions of biological interest and to assess how they are responding to the recent climate changes. A semi-analytic PP model ingesting satellite observations of cloud cover, sea ice concentration (SIC) and ocean inherent optical properties as determined ocean color (OC) measurements were employed to assess PP in both phytoplankton-dominated and colored dissolved organic matter (CDOM)-dominated waters.

A preliminary validation suggested that the model produced PP rates within the range observed in situ over the arctic interior shelves, but may be underestimating PP in other regions. Unlike the previous satellite-based PP estimates, our model shows realistic estimates over the continental shelves supporting the necessity of using semi-analytical approaches to estimate both chlorophyll-a (CHL) concentration and diffuse attenuation coefficient to minimize the CDOM contamination. Hot-spots of high productivity, identified at the ecoregional scale, were found in areas influenced by large arctic rivers, in the marginal ice zone, at shelf breaks or in straits. A statistically significant trend in the temporal variation of PP was found at the pan-arctic scale (5.05 Tg C y-1). To explain the sources of this variation, the PP model was run several times with different input parameters set as constant. It was found that the main parameter that controlled the temporal trend reported above was the changes in OC (2.88 Tg C y-1). The second most important parameter (1.1 Tg C y-1) was SIC which incorporates light availability for photosynthesis through measurements of the shrinking of the sea ice cover. The ecoregional trends analysis indicates that both type of changes (OC versus SIC) operate in different proportions among regions. In general, increasing light availability explained most of the increase in PP over the arctic interior shelves, while changes in biomass are responsible for the increase in PP in permanently open waters. Although positive trends were observed in most ecoregions, significant negative trends were also observed in regions that are normally recognized for their great biological importance. This is the case with the North Water Polynya in the Canadian Arctic where the decrease in PP reaches as much as 5.6 gC m-2 y-1, corresponding to a >100% relative decrease in PP over 13 years. These results suggest that major environmental changes, yet not well understood, can locally have negative impacts on the marine ecosystem productivity. Finally, a more detailed analysis at ecoregional scale was exemplified at two ecoregions: the Beaufort Sea - continental coast and shelf and the Laptev sea.

Abstract from: Rapid assessment of the marine primary productivity trends in the Arctic Ocean and its surrounding seas. ACTUS inc. and WWF 2011. Link to full report: http://awsassets.panda.org/downloads/rapid_assessment_of_the_marine_primary_productivity_trends_in_the_arctic_ocean_and_its_s.pdf

Appendix 4

PRIMARY PRODUCTION AT NORTH GREENLAND AND BAFFIN BAY – CANADIAN SHELF ECOREGIONS

Fig. Ap4. Primary production (PP) at the North Greenland (Figs. Ap4a-b) and Baffin Bay – Canadian Shelf (Figs. Ap4c-d) ecoregions. Source: 'Rapid assessment of the marine primary productivity trends in the Arctic Ocean and its surrounding seas'. ACTUS inc. and WWF, 2011.

North Greenland

Area study unit (1000 square km): 346.1
Area image within study unit (1000 square km): 222.6
Percentage covered: 64.3%
Mean Yearly Primary Production (gC/m^2/Year): 13.31
90th percentile of Primary Production (gC/m^2/Year): 31.86
Total Yearly Primary Production (TgC/Year): 2.96
Total Yearly Primary Production of 90th percentile (TgC/Year): 1.09
Part of total Primary Production by 90th percentile: 36.9%

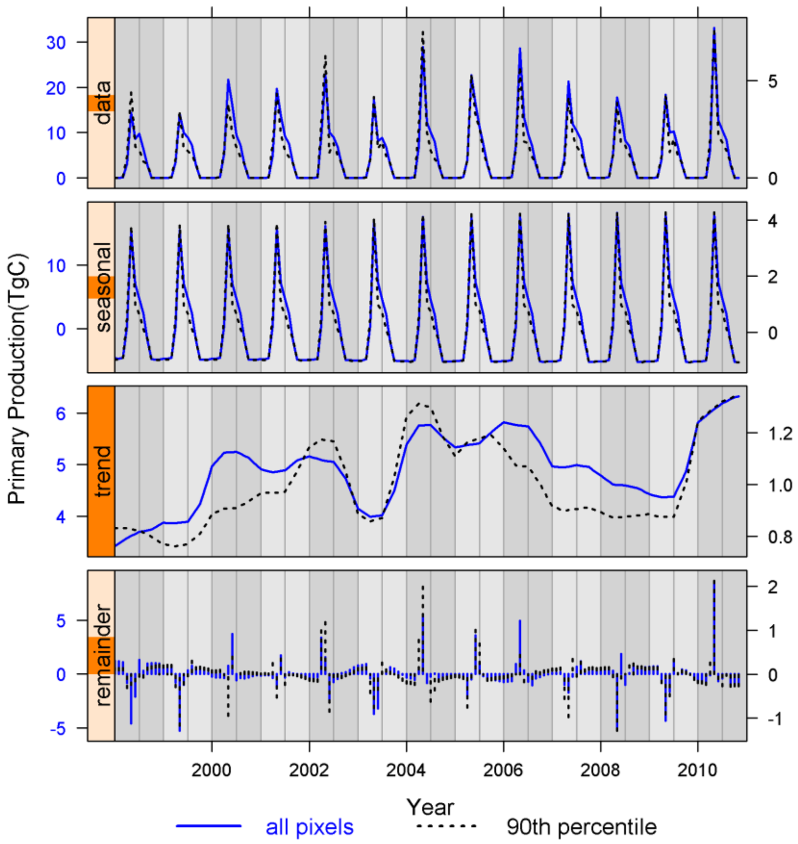


Fig. Ap 4a. Monthly decomposed total PP time series of the North Greenland ecoregion for all pixels (blue) and the 10% most productive pixels (black).

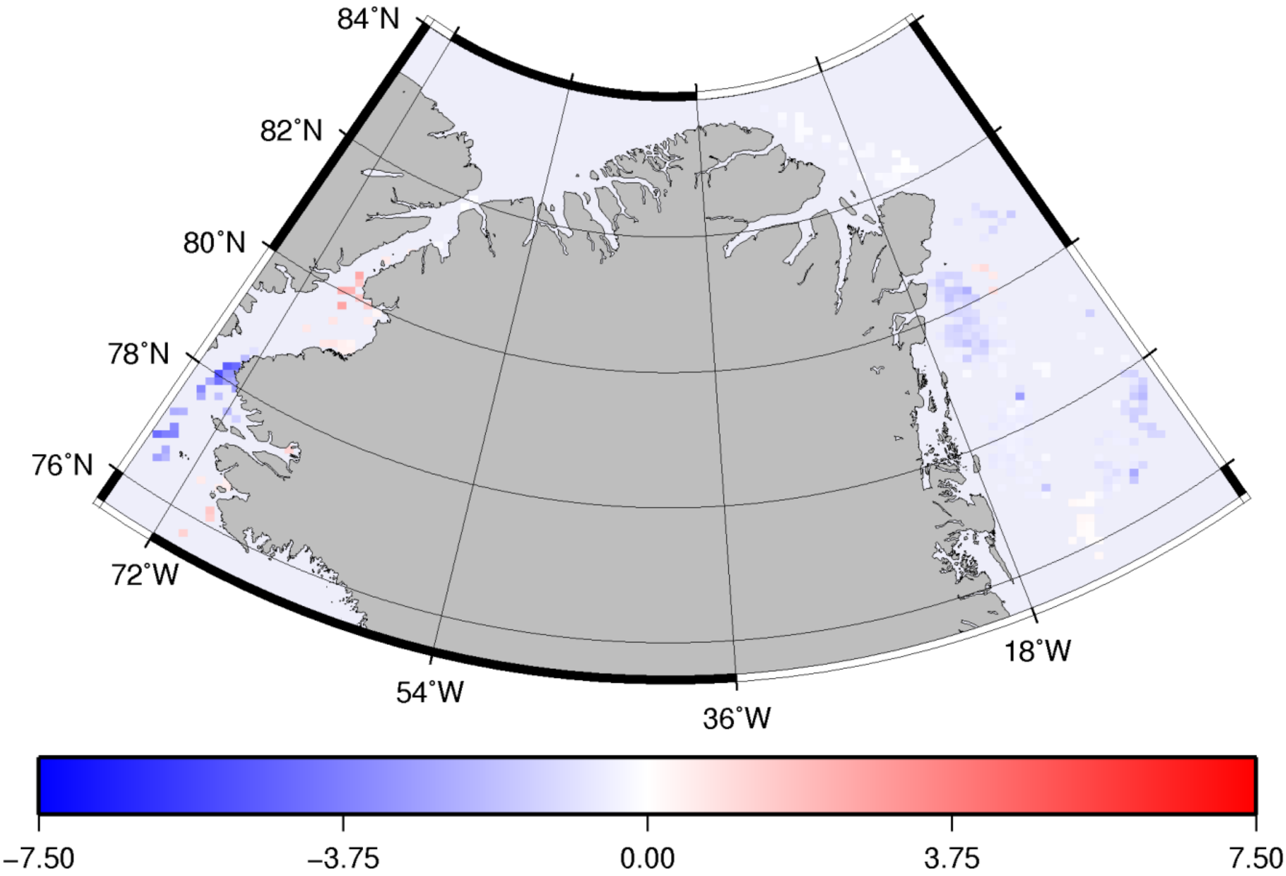


Fig. Ap 4b. Primary Production trends of the North Greenland ecoregion computed using TSA (The trend estimator). Only pixels with significant trend (90% confidence level) are plotted.

Baffin Bay - Canadian Shelf

Area study unit (1000 square km): 181.2
Area image within study unit (1000 square km): 150.2
Percentage covered: 82.9%
Mean Yearly Primary Production (gC/m^2/Year): 16.91
90th percentile of Primary Production (gC/m^2/Year): 33.52
Total Yearly Primary Production (TgC/Year): 2.54
Total Yearly Primary Production of 90th percentile (TgC/Year): 0.64
Part of total Primary Production by 90th percentile: 25.3%

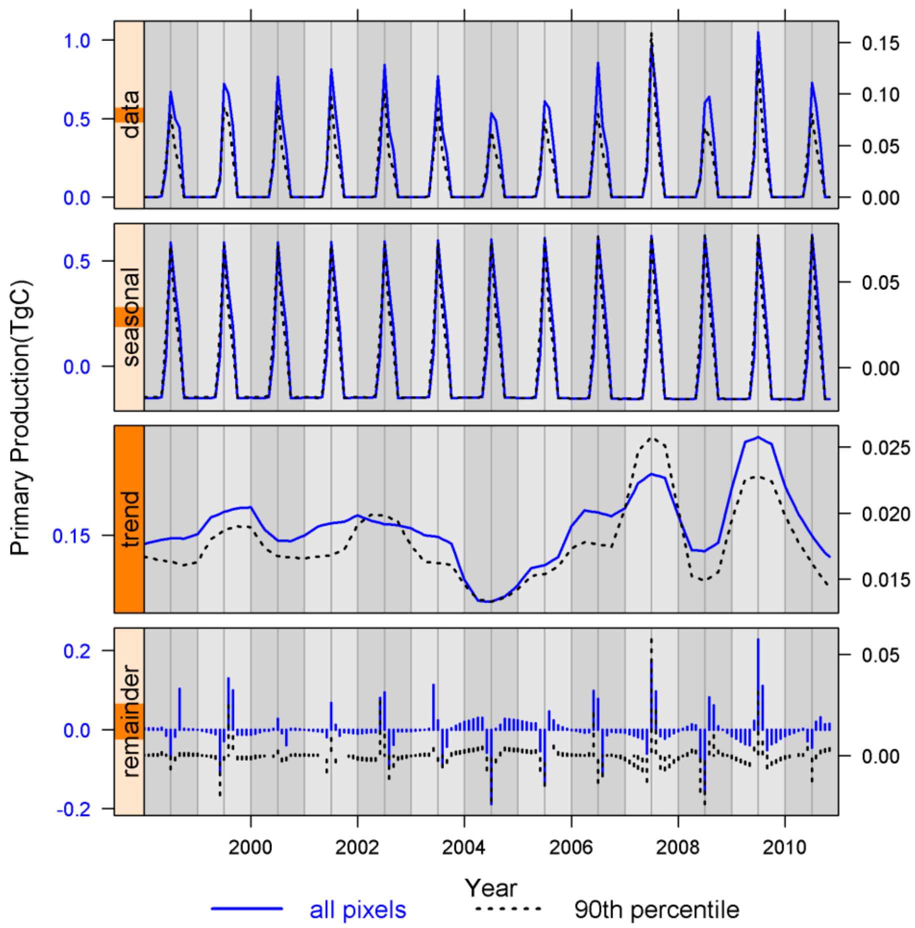


Fig. Ap 4c. Monthly decomposed total PP time series of the Baffin Bay – Canadian Shelf ecoregion for all pixels (blue) and the 10% most productive pixels (black).

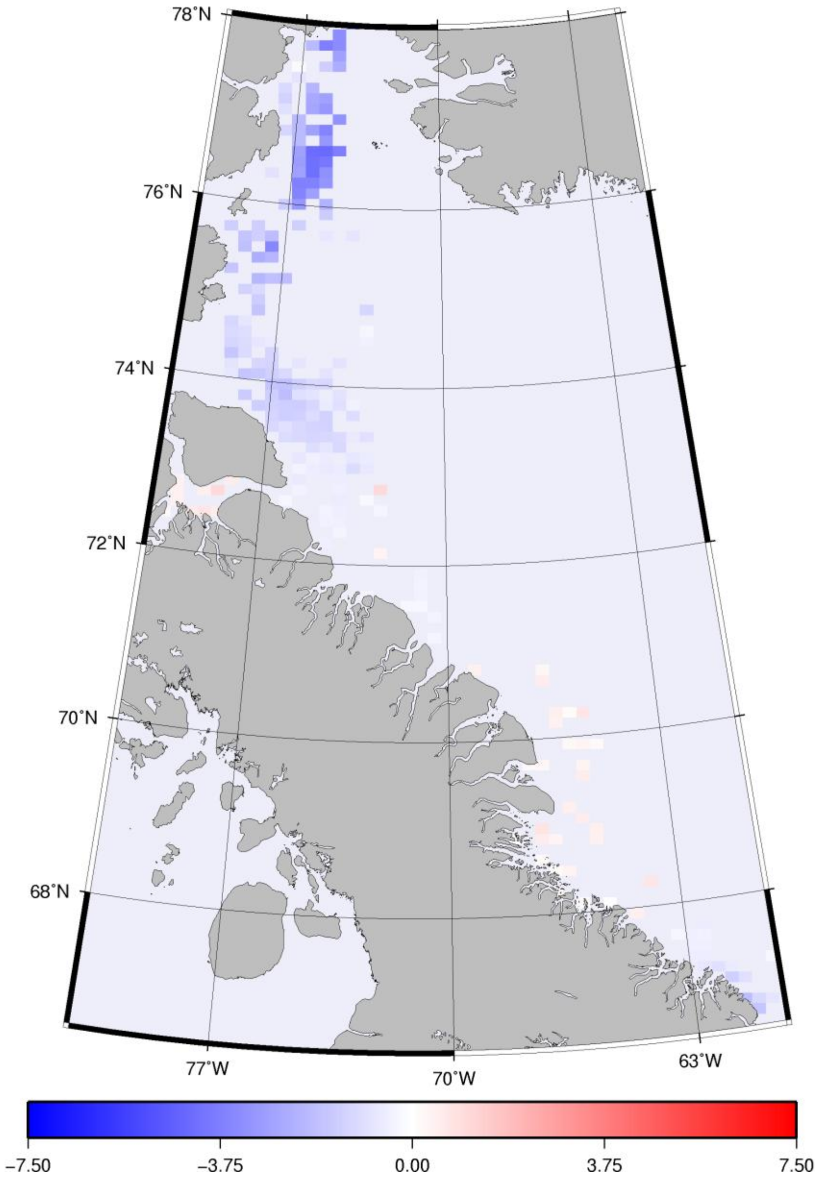
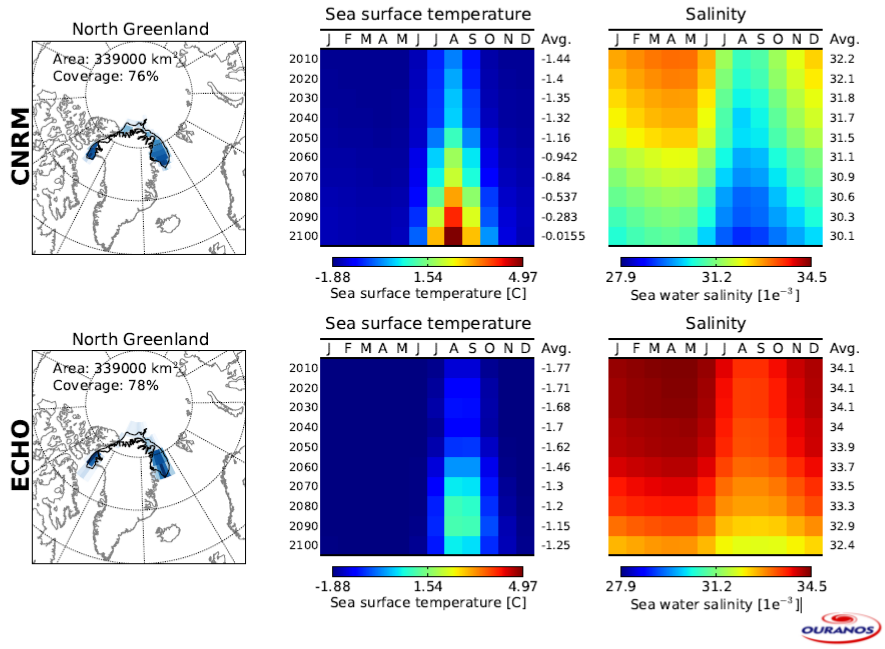


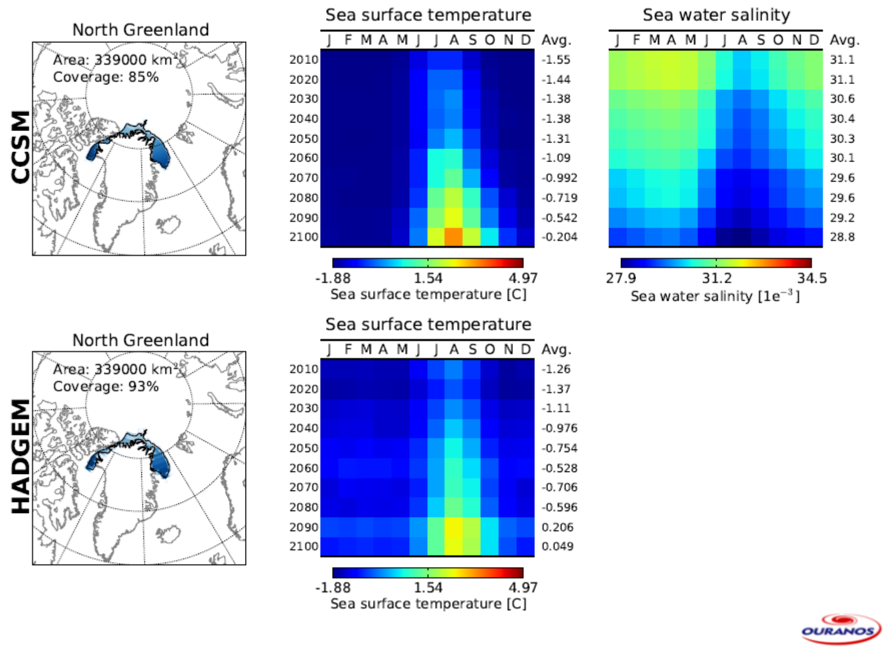
Fig. Ap 4d. Primary Production trends of the Baffin Bay – Canadian Shelf ecoregion computed using TSA (The trend estimator). Only pixels with significant trend (90% confidence level) are plotted.

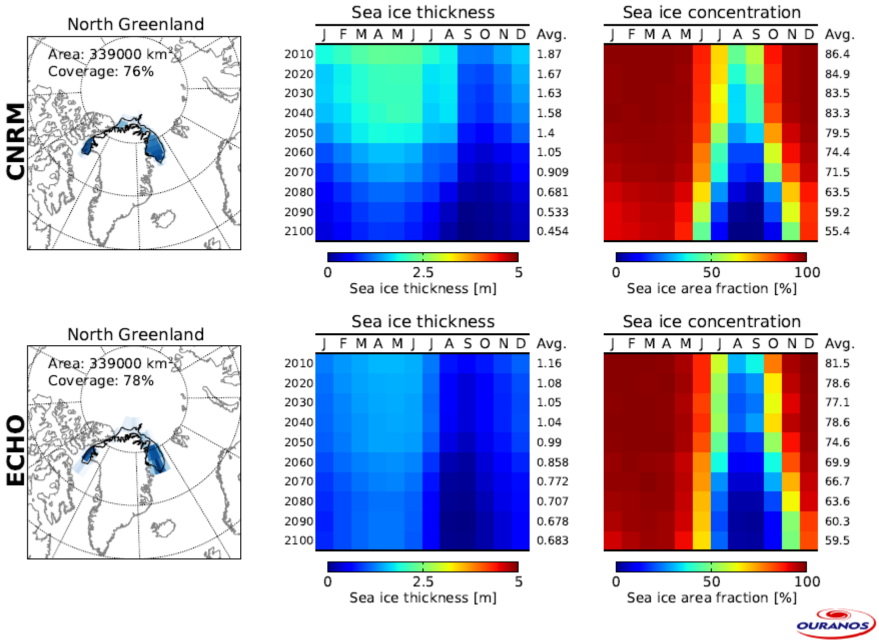
Appendix 5

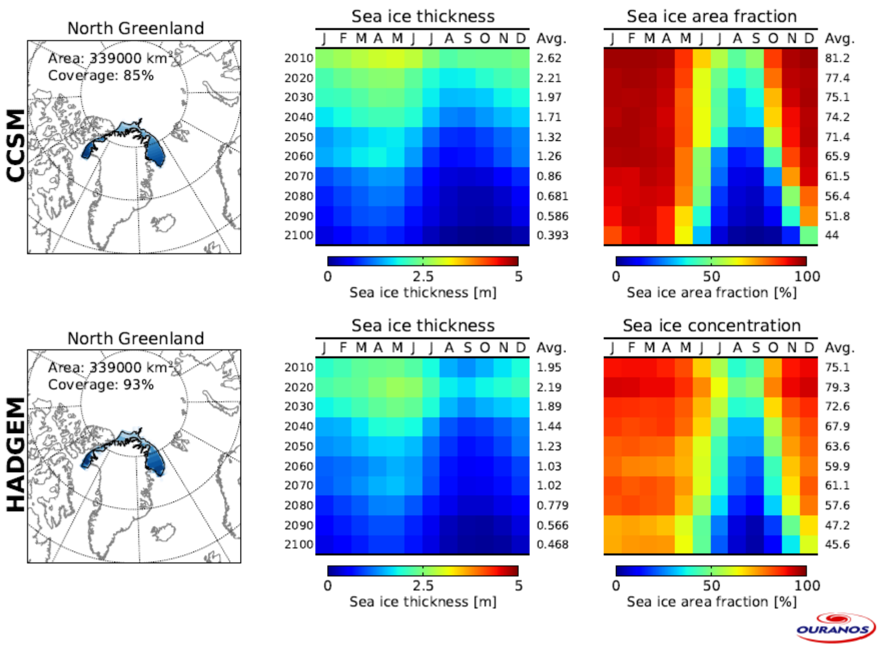
GENERAL CIRCULATION MODELS (GCM'S) FOR NORTH GREENLAND AND BAFFIN BAY – CANADIAN SHELF ECOREGIONS

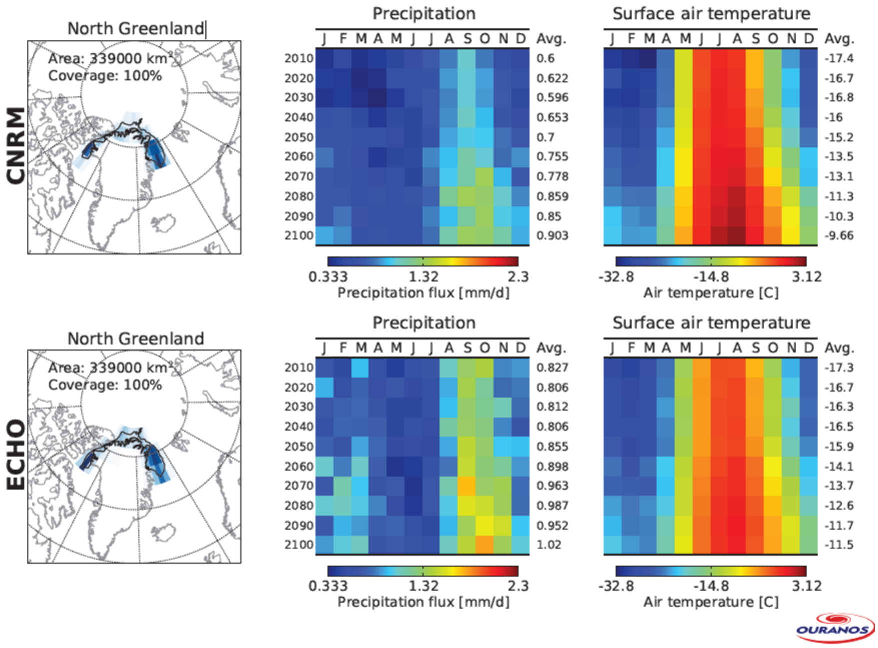
Projections for sea surface temperature, salinity, sea ice thickness, sea ice concentration, precipitation and air temperature based on General Circulation models (GCM's) for North Greenland and Baffin Bay – Canadian Shelf ecoregions through to the 21st century.

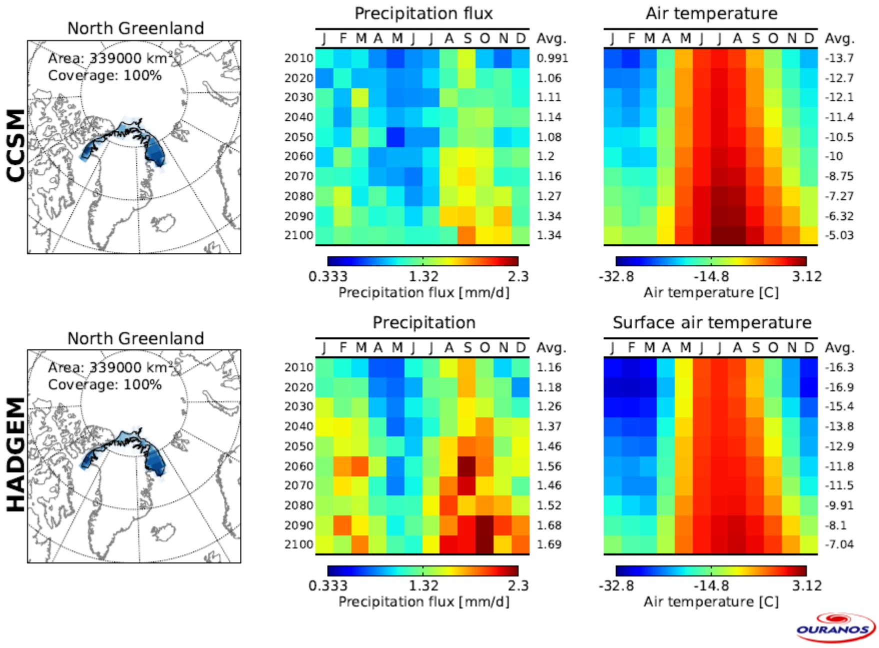




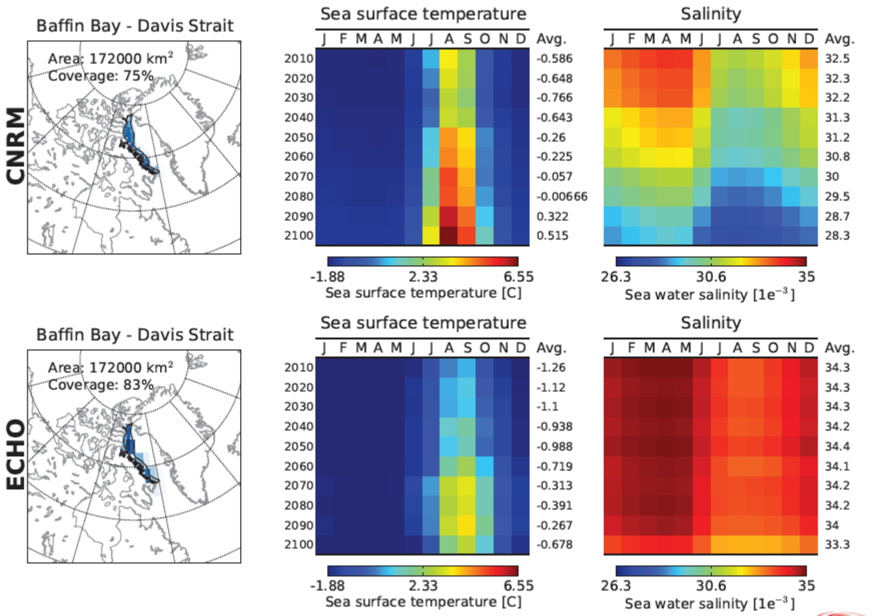

CNRM
North Greenland
Area: 339000 km²
Coverage: 76%
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
1.87 1.67 1.63 1.58 1.4 1.05 0.909 0.681 0.533 0.454
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
J F M A M J J A S O N D Avg.
86.4 84.9 83.5 83.3 79.5 74.4 71.5 63.5 59.2 55.4
0 50 100
Sea ice area fraction [%]
ECHO
North Greenland
Area: 339000 km²
Coverage: 78%
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
1.16 1.08 1.05 1.04 0.99 0.858 0.772 0.707 0.678 0.683
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
J F M A M J J A S O N D Avg.
81.5 78.6 77.1 78.6 74.6 69.9 66.7 63.6 60.3 59.5
0 50 100
Sea ice area fraction [%]
OURANOS

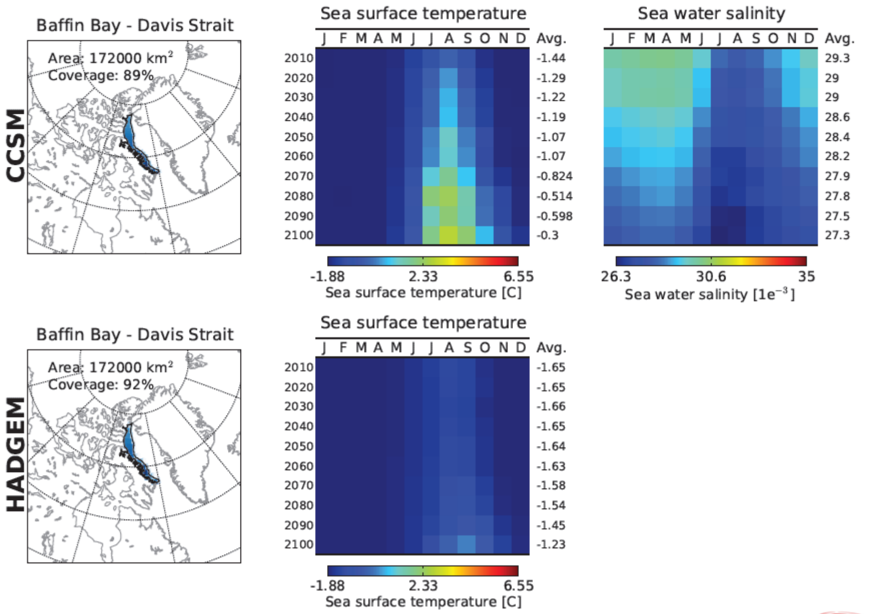

CCSM
North Greenland
Area: 339000 km²
Coverage: 85%
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
2.62 2.21 1.97 1.71 1.32 1.26 0.86 0.681 0.586 0.393
0 2.5 5
Sea ice thickness [m]
Sea ice area fraction
J F M A M J J A S O N D Avg.
81.2 77.4 75.1 74.2 71.4 65.9 61.5 56.4 51.8 44
0 50 100
Sea ice area fraction [%]
HADGEM
North Greenland
Area: 339000 km²
Coverage: 93%
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
1.95 2.19 1.89 1.44 1.23 1.03 1.02 0.779 0.566 0.468
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
J F M A M J J A S O N D Avg.
75.1 79.3 72.6 67.9 63.6 59.9 61.1 57.6 47.2 45.6
0 50 100
Sea ice area fraction [%]
OURANOS

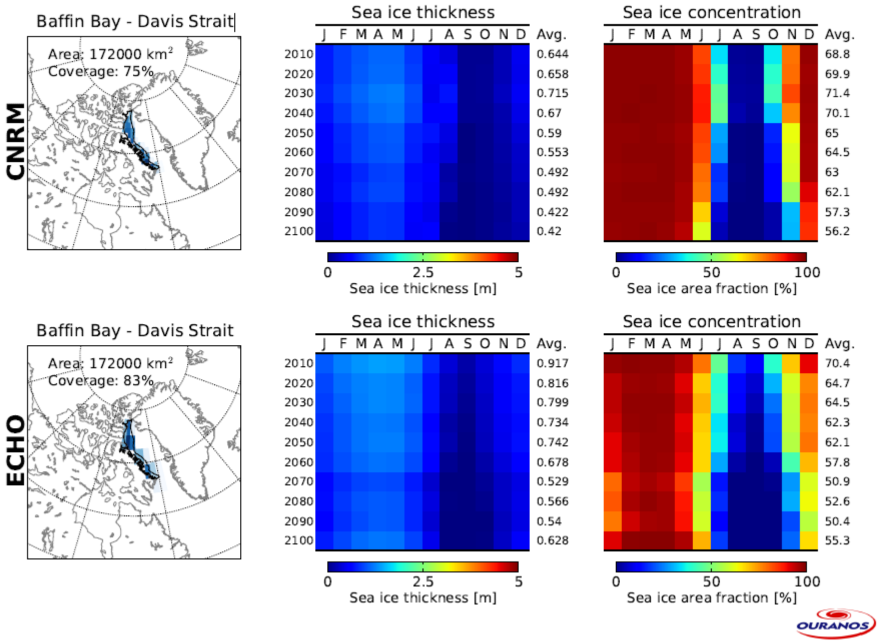


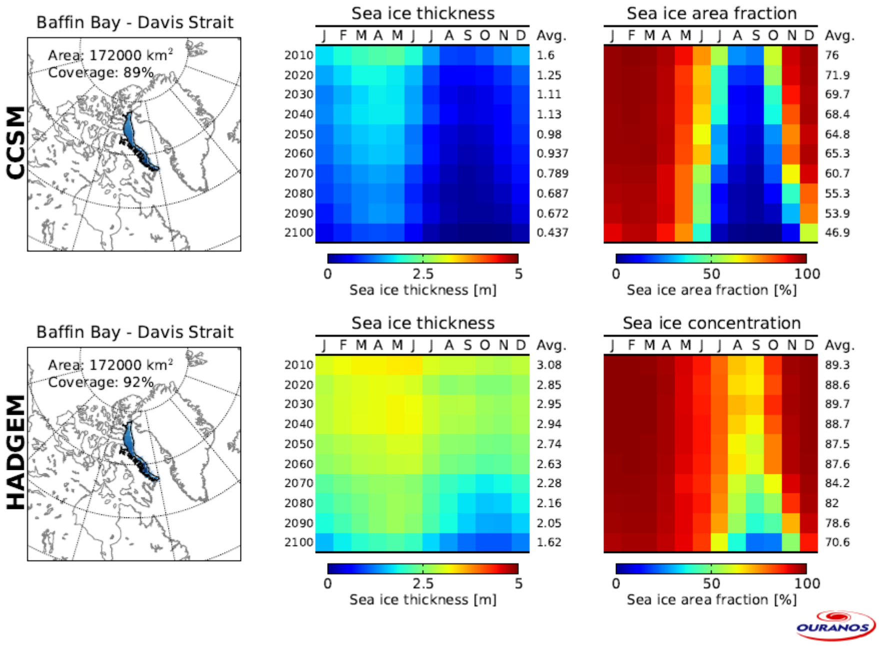


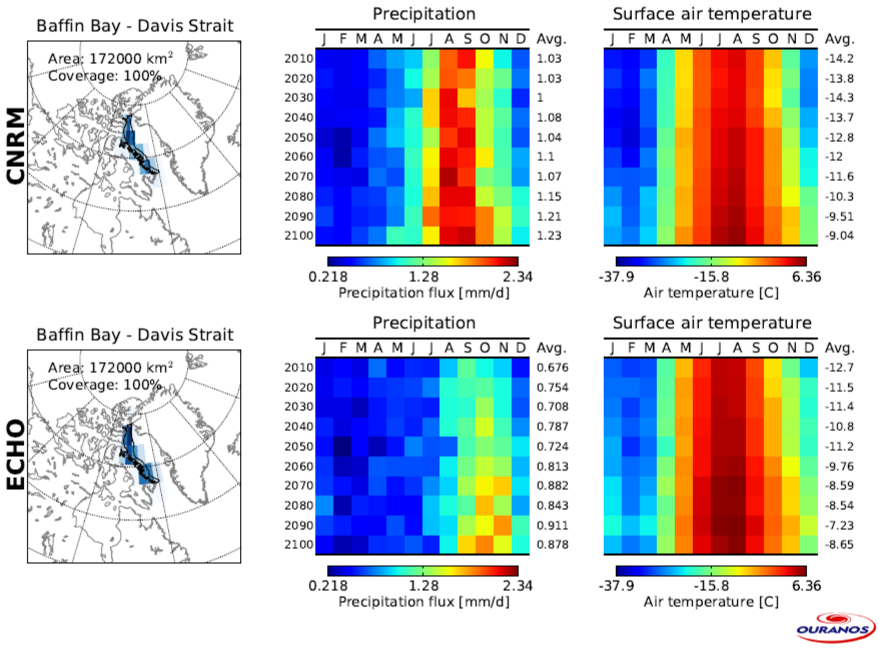
Trend: Sea surface temperature – Increasing; Salinity – Decreasing; Sea ice thickness – decreasing; Sea ice concentration – Decreasing; Precipitation – Increasing; Surface air temperature – Increasing.

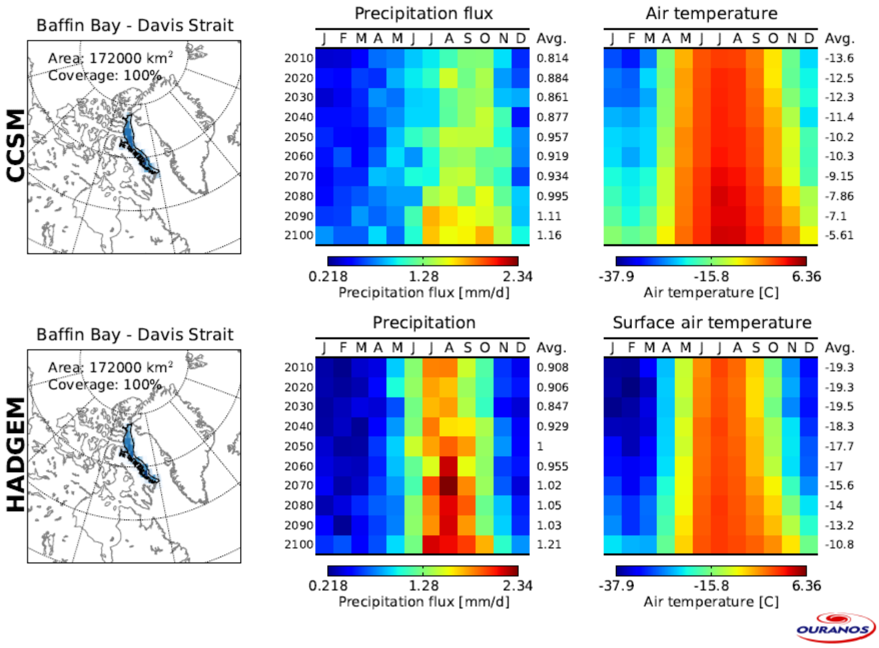

CNRM
Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 75%
Sea surface temperature
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
-0.586 -0.648 -0.766 -0.643 -0.26 -0.225 -0.057 -0.00666 0.322 0.515
-1.88 2.33 6.55
Sea surface temperature [C]
Salinity
J F M A M J J A S O N D Avg.
32.5 32.3 32.2 31.3 31.2 30.8 30 29.5 28.7 28.3
26.3 30.6 35
Sea water salinity [1e⁻³]
ECHO
Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 83%
Sea surface temperature
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
-1.26 -1.12 -1.1 -0.938 -0.988 -0.719 -0.313 -0.391 -0.267 -0.678
-1.88 2.33 6.55
Sea surface temperature [C]
Salinity
J F M A M J J A S O N D Avg.
34.3 34.3 34.3 34.2 34.4 34.1 34.2 34.2 34 33.3
26.3 30.6 35
Sea water salinity [1e⁻³]


CCSM
Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 89%
Sea surface temperature
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
-1.44 -1.29 -1.22 -1.19 -1.07 -1.07 -0.824 -0.514 -0.598 -0.3
-1.88 2.33 6.55
Sea surface temperature [C]
Sea water salinity
J F M A M J J A S O N D Avg.
29.3 29 29 28.6 28.4 28.2 27.9 27.8 27.5 27.3
26.3 30.6 35
Sea water salinity [1e⁻³]
HADGEM
Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 92%
Sea surface temperature
J F M A M J J A S O N D Avg.
2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
-1.65 -1.65 -1.66 -1.65 -1.64 -1.63 -1.58 -1.54 -1.45 -1.23
-1.88 2.33 6.55
Sea surface temperature [C]


Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 75%
CNRM
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 0.644
2020 0.658
2030 0.715
2040 0.67
2050 0.59
2060 0.553
2070 0.492
2080 0.492
2090 0.422
2100 0.42
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
J F M A M J J A S O N D Avg.
68.8
69.9
71.4
70.1
65
64.5
63
62.1
57.3
56.2
0 50 100
Sea ice area fraction [%]
Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 83%
ECHO
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 0.917
2020 0.816
2030 0.799
2040 0.734
2050 0.742
2060 0.678
2070 0.529
2080 0.566
2090 0.54
2100 0.628
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
J F M A M J J A S O N D Avg.
70.4
64.7
64.5
62.3
62.1
57.8
50.9
52.6
50.4
55.3
0 50 100
Sea ice area fraction [%]
OURANOS


Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 89%
CCSM
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 1.6
2020 1.25
2030 1.11
2040 1.13
2050 0.98
2060 0.937
2070 0.789
2080 0.687
2090 0.672
2100 0.437
0 2.5 5
Sea ice thickness [m]
Sea ice area fraction
J F M A M J J A S O N D Avg.
76
71.9
69.7
68.4
64.8
65.3
60.7
55.3
53.9
46.9
0 50 100
Sea ice area fraction [%]
Baffin Bay - Davis Strait
Area: 172000 km²
Coverage: 92%
HADGEM
Sea ice thickness
J F M A M J J A S O N D Avg.
2010 3.08
2020 2.85
2030 2.95
2040 2.94
2050 2.74
2060 2.63
2070 2.28
2080 2.16
2090 2.05
2100 1.62
0 2.5 5
Sea ice thickness [m]
Sea ice concentration
J F M A M J J A S O N D Avg.
89.3
88.6
89.7
88.7
87.5
87.6
84.2
82
78.6
70.6
0 50 100
Sea ice area fraction [%]
OURANOS





Trend: Sea surface temperature – Increasing; Salinity – Decreasing; Sea ice thickness – decreasing; Sea ice concentration – Decreasing; Precipitation – Increasing; Surface air temperature – Increasing.