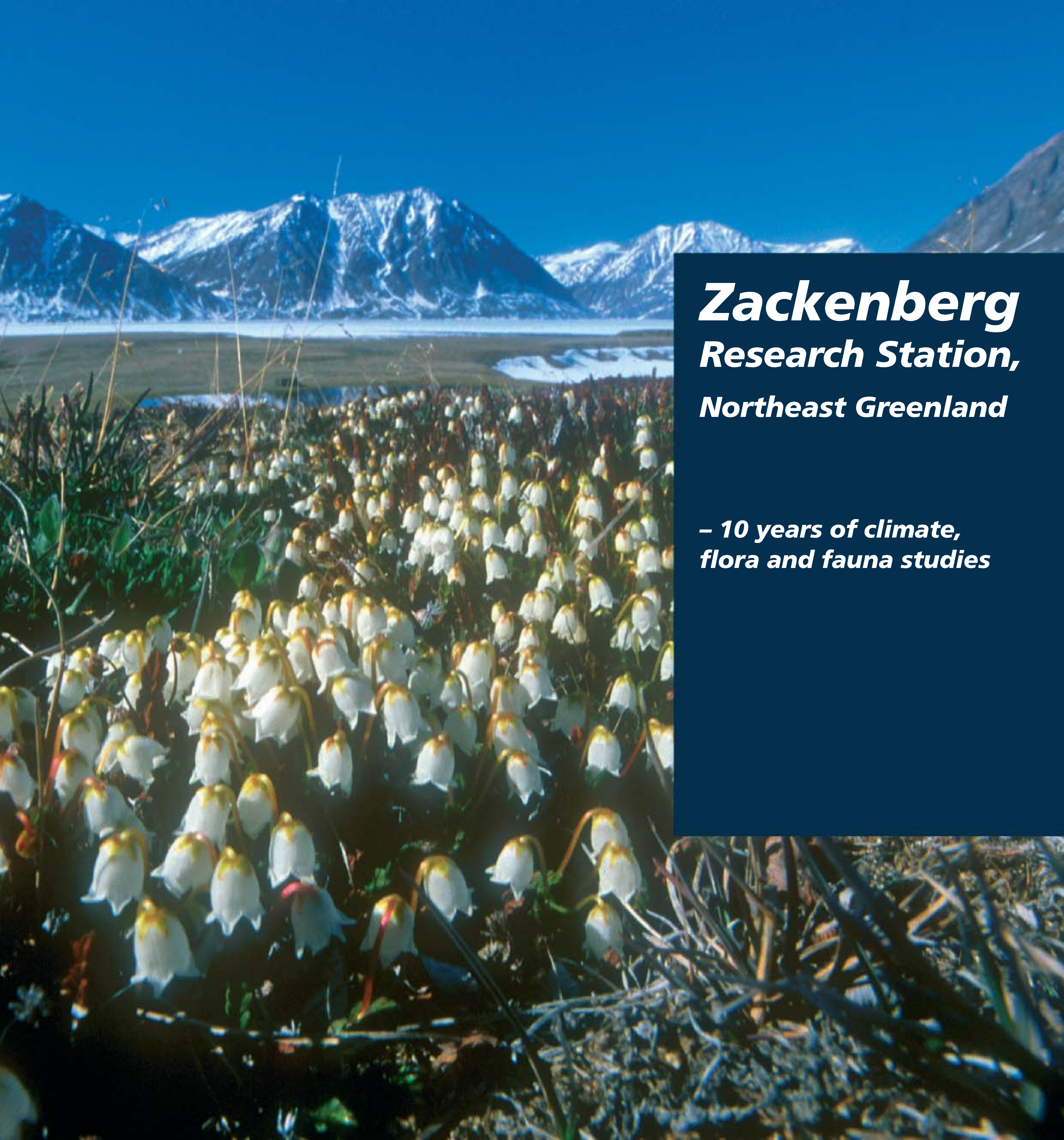

Zackenberg Research Station,

Northeast Greenland

– 10 years of climate, flora and fauna studies

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Zackenberg Research Station

The area north of Scoresby Sound is uninhabited except for the people at the few weather stations and military bases. Together with a large part of the Greenland Ice Sheet, northeast and northern Greenland comprise the world's largest national park. Whereas the fauna had been monitored for many years in the inhabited western part of Greenland, systematic monitoring was not performed in northeast Greenland until Zackenberg Research Station was established in 1995, and little was thus known about the interannual variation in the ecosystems and fauna of northeast Greenland before then. Neither did we know the effects of the more long-term changes in the climate that have always occurred, and which are expected to become marked in northeast Greenland in the future.

When the anthropogenic climate change became known during the 1980s, a group of scientists developed the idea to establish a research station in the national park. The former Danish Polar Center took up the idea and made such a research station one of its key tasks. Zackenberg near the SIRIUS Sledge Patrol base at Daneborg was selected as the best location. With support from the Commission for Scientific Research in Greenland, the Danish Environmental Protection Agency, the Greenland Home Rule, the University of Copenhagen, the National Environmental Research Institute, Asiaq and others, Zackenberg Research Station has now been in operation for more than 10 years.

Each year more than 1,500 ecosystem parameters are monitored, encompassing everything from water flow and sediment transport in the streams to flowering of the plants, the time of egg laying among the birds and calving among the musk oxen. In addition, a large number of more specific research projects have been conducted. The results have been collated in a 560-page book released by Academic Press in 2008. This booklet summarises the most important findings.

Northeast Greenland's place in the *High Arctic*

The name Arctic derives from the Greek word *Artikos* meaning "pertaining to the north", which in turn derives from the Greek word *Arkos* meaning bear, and used to denote the northerly constellation known as the Great Bear (Ursa Major). It is the land north of the tree line, where there is tundra. Tundra derives from the Sami (Lappish) word Tundar and is related to the Finnish word Tunturi, both of which refer to treeless uplands. Here the average temperature during the warmest month is less than 10–12 degrees Celsius.

The Arctic is subdivided into the high arctic zone and the low arctic zone. The low arctic zone is often lushly vegetated with bushes and other knee-high plants, whereas the vegetation in the high artic zone is restricted to ankle-high plants, and here the average temperature during the warmest month rarely exceeds 6 degrees Celsius. Moreover, far less snow falls in the high arctic zone. Thus 100 times as much snow falls on the southern tip of Greenland as in northern Greenland, where the climate is desert-like with only 25 mm of precipitation each year.

The whole of West Greenland lies in the low arctic zone, whereas northern and northeast Greenland and hence the whole of the national park lie in the high arctic zone. The reason why northeast Greenland lies within the high arctic zone is that the sea ice often lies in a several hundred kilometre wide belt off the coast. During periods with much sea ice, the climate of northeast Greenland is dry continental. When there is less sea ice, in contrast, the climate is maritime, with more snow during winter and fog during summer. The amount of sea ice that drifts down along the coast of East Greenland is thus the main determinant of the climate in northeast Greenland.

High arctic *flora and fauna*

Not only is the vegetation in northeast Greenland exclusively comprised of low plants, but there are also large areas where the snow blows away in winter and which are so dry that there is almost no vegetation at all. These are barren gravel and stone covered areas and slopes. The remainder is mountain heath, often with a beautiful flora of mountain aven, arctic bell heather, arctic poppy and purple saxifrage. In the valleys and on slopes fed all summer by trickling water from large melting snow drifts, one finds fens and grassland.

Thanks to the stable continental climate, both lemmings and musk oxen are found in the high arctic areas of Greenland. Whereas the musk oxen in West Greenland were introduced by man, the musk oxen in the high arctic areas of Greenland migrated in from Canada. Both lemmings and musk oxen are completely dependent on a stable winter climate devoid of prolonged periods of thawing. If the snow melts and freezes again, a layer of solid ice forms in the snow and on the vegetation, thereby preventing the lemmings and musk oxen from getting at the plants upon which they feed. Musk oxen have therefore become extinct in large areas on many occasions in the past.

Apart from these two species the fauna is mainly dominated by the waders (shorebirds) that inhabit the tundra, as well as geese, long-tailed skuas and snow buntings. These are all migrants that depart during the winter, leaving behind only the ptarmigans, ravens and snowy owls in the cold winter darkness, where the temperature often reaches minus 25–35 degrees Celsius.

The Zackenberg *climate* – present and future

Ninety percent of the precipitation at Zackenberg falls as snow during the winter snow storms, and the amount of precipitation has increased over the past 50 years. The temperature has also increased, with the five warmest years during the past 100-year period all having occurred during the past decade.

In the future the temperature and precipitation are expected to increase even further because the extent of the coastal sea ice is diminishing under the warmer climate. As a result, the climate in northeast Greenland might become low arctic with much milder winters like those in southeast Greenland. The temperature during the few summer months is unlikely to change very much, however. All in all, the number of days with a positive average temperature is expected to increase from c. 80 at present to c. 110 after the year 2050, and the precipitation is expected to increase by around 60 percent. This will completely change living conditions for the flora and fauna in northeast Greenland.

The combination of more snow and higher spring temperature will result in a largely unchanged average onset of the snow melt, but the interannual variation will be considerably greater. In areas where the wind causes snow to accumulate, the snow melt will occur 2–3 weeks later than at present. As the timing of the snow melt is one of the most important determinants of many natural processes in the high arctic environment, it will contribute to the change in living conditions for the flora and fauna.

The expected changes in the climate are so great that it is very difficult to predict how the individual species and ecosystems will react. Thus we only dare tell about what we think might happen during the next few decades.

Several hundred metre thick *permafrost*

According to our calculations – since no one has yet drilled at Zackenberg – the ground is frozen to a depth of 200–400 metres. Only the upper 45–80 cm – the so-called active layer – thaws during the summer. The depth to which the ground thaws each summer has increased since we began investigations in 1995, however. In future the ground will thaw to even greater depths, probably leading to more mountain slides and other erosion. At present the Zackenberg river transports as much as 40,000 tonnes of sediment out into Young Sound each year. In some years, though, just as much can be washed out in a few days as is washed out during the whole summer in other years. One reason for such extreme water and sediment transport could be the bursting of ice-dammed glacial lakes in the hinterland, whereby all the water escapes at once.

Changed distribution of the plant communities

Deeper thawing of the permafrost in the summer will give the plants access to more nutrients in the soil, which in combination with more precipitation could lead to a more lush vegetation and more widespread plant cover. The increase in the amount of snow will probably also result in changed distribution of the plant communities with larger areas of sparse vegetation under late melting snow. New plant species can also be expected to colonise from the south in step with the increasingly mild spring climate, while other species can be expected to disappear.

In contrast to the southern latitudes, where many plants only live for a single summer and reproduce by means of seeds, nearly all the plants in the Arctic are perennials, many of which live for several hundred years. The brevity of the arctic summer, which can often be so harsh that the plants are unable to produce seeds, means that many years may pass before the plants reproduce. The seeds are also vital if the plants are to be able to disperse and colonise new areas.

The timing of the spring thaw and the temperature determine when plant growth starts and hence when flowering takes place. As the snow does not melt until June, when the sun is highest in the sky, the timing of the onset of plant growth is of great significance. The earlier they start growing and flowering, the more they can benefit from the peak in solar energy. And the earlier they can flower, the earlier the seeds can develop. In years with a late snow melt, many plants fail to complete seed development.

Plant growth and flowering is controlled by the snow melt

As the high arctic growing season is so short, the plants develop their flower buds the year before flowering so that they are ready to blossom as soon as the snow has gone. The summer temperature the preceding year is therefore a major determinant of how many flowers the individual plant species produce. In some years the tundra heaths can be coloured white by the flowers of arctic bell heather, whereas in other years there are very few flowers.

Mosquitoes are a well-known plague throughout the Arctic, but there are other insects that occur in far greater numbers. This particularly applies to midges, which do not bite, but which thrive everywhere there is enough moisture to allow their larvae to thrive among dead plant remains on the tundra. Spiders also occur in very large numbers.

The appearance of flying insects in the spring and their culmination in the summer is completely dependent on the timing of the snow melt, as is the case for plant growth and flowering. The appearance of the insects in the different areas thus differs markedly depending on when the snow disappears.

If the climate change follows predictions, the occurrence of insects and other arthropods will change considerably in the future as the timing of the snow melt will become much more variable. In the areas where the thickness of the snow will increase, many species will probably disappear. On the other hand, the vegetation will colonise other areas where the snow will disappear earlier than at present, thus providing the insects with new habitats.

The insects

are also markedly dependent on the snow melt

The lakes

are very sensitive to changes in snow and ice cover

The timing of the snow melt and the duration of the ice-free period are also decisive determinants of life in the lakes. The amount of all the microscopic algae and the many crustaceans in the lakes depends on how early the ice disappears and the amount of nutrients washed into the lakes during the snow melt. If the increase in the amount of snow that is expected to accompany climate change results in the lakes becoming ice free later than at present, productivity in the lakes will diminish. An increase in snow fall will also result in greater nutrient loading of the lakes, however, so the net result is unclear.

The lemmings are at risk in the future

More plant growth and deeper snow in the winter will benefit the lemmings, which build their winter nests under the snow to better protect themselves from arctic foxes. The duration of the period of actual snow cover is thus an important determinant of lemming prosperity and is one of the explanations for the extreme interannual variation in the number of lemmings seen almost everywhere in the Arctic. The number of ermine is also an important determinant of lemming number in northeast Greenland. The ermine is a specialist in hunting lemmings and is just as dependent on the winter snow as its prey. It is small enough to be able to follow the lemmings into their burrows under the snow, and an ermine often moves into a lemming nest after it has eaten all the inhabitants.

The marked future increase in the number of thaw days will have the opposite effect of the increase in the amount of snow. During winters characterised by periods of thawing the lemmings thus risk dying out in large areas due to loss of the protective snow cover and because the formation of solid ice in the snow and on the ground will prevent them from getting at the vegetation.

If the lemmings disappear, the predators that depend on them will also disappear or will considerably diminish in number. In addition to the ermine, this also applies to the long-tailed skua, which almost only reproduces in years with many lemmings. The skuas faithfully arrive each spring from their overwintering sites in the southern Atlantic. Like the snowy owl, though, they only lay eggs in years with sufficient lemmings to allow them to maintain their body weight and raise their young.

The musk oxen are also threatened

The musk oxen will also benefit from the future increase in plant growth, but as with the lemmings, an increase in the number of winter thaw days will pose a serious threat to the population. During the period for which we have information about conditions in northeast Greenland, the musk ox population has almost been wiped out several times in large parts of the country when meltwater has "glazed" the landscape and vegetation with ice, thereby preventing the musk oxen from reaching their food such that they died of starvation.

The birds' breeding success

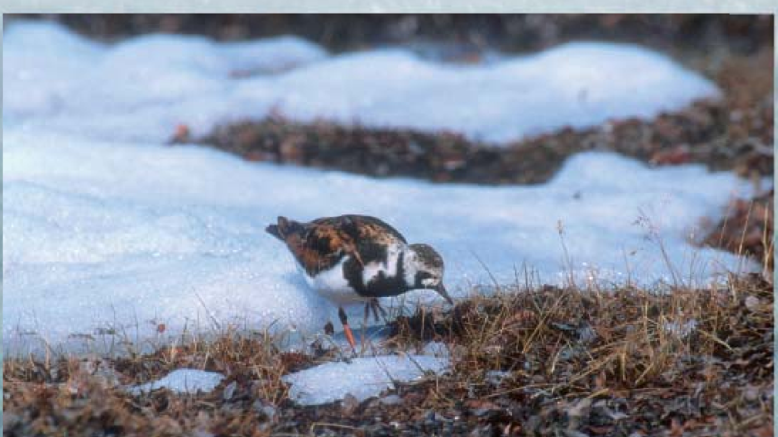
is controlled by insects, the snow melt and predation

Waders (shorebirds) are the dominant bird group on the tundra with respect to both the number of species and the number of individuals. After the long migration from their overwintering sites in western Europe and West Africa – which can consist of a several thousand kilometre long non-stop flight at a height of 2–4 kilometres – they arrive around 1st June to a tundra where only small patches may be snow free. Here the females are completely dependent on the number of insects and spiders to build up the body resources needed to lay a clutch of eggs that will often weigh as much as the bird itself. The amount of food available thus determines how rapidly after their arrival they are able to lay eggs. In years with widespread snow cover, however, the timing of egg laying is mainly determined by the snow. Thus in years with much snow, egg laying can be delayed by as much as 2–3 weeks. In such years the young hatch correspondingly later and therefore have less time to grow big and strong before at the tender age of 6–10 weeks having to make the long trek to the overwintering sites.

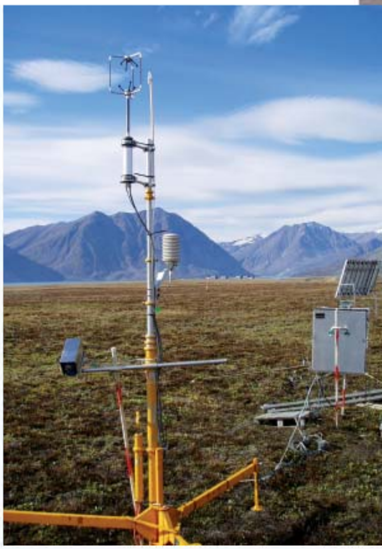
Before then the predators – especially the arctic foxes – will have eaten at least half of the eggs, and the foxes and skuas will have taken a corresponding proportion of the chicks. Thus in years with many foxes, fewer wader eggs and chicks survive.

The snow cover is also a major determinant of total population size as the amount of snow-free vegetation determines the amount of invertebrate food and hence the number of birds that can breed in a given area.

The situation for all the birds is that the future climate changes will markedly affect many of the factors upon which they depend. The marked interannual variation in the snow melt in particular will result in far more varied breeding success than at present.



Does the tundra take up or release *carbon dioxide?*



Carbon dioxide (CO_2) is responsible for most of the man-made greenhouse effect. Combustion of coal, oil and natural gas releases considerable amounts of CO_2 into the atmosphere. Here it acts in the same way as the glass in a greenhouse, allowing shortwave solar radiation to pass through the atmosphere to the Earth's surface but preventing much of the long-wave heat radiation from the Earth from escaping into space.

There are other sources of CO_2 than combustion of fossil fuels, however. Around 20 percent of the organically bound carbon in the Earth's surface (i.e. the carbon in living and dead plants, etc.) occurs in the peat layers in arctic areas. Due to the low temperature the dead plants do not decompose, but instead accumulate in increasingly thicker layers of peat in the mires and fens. With the higher temperatures expected in the future, these layers could start to decompose, thereby releasing the carbon in the form of CO_2 and methane (CH_4). However, higher temperatures will also mean increased plant growth, during which the plants take up CO_2. The question then is what the resultant balance will be between the release of CO_2 during decomposition and the uptake of CO_2 during plant growth.

The amount of carbon bound in living plants often culminates in July, which is also the time that the tundra takes up most CO_2. Since the snow melt is a decisive determinant of timing of plant growth, it also determines whether the tundra takes up more CO_2 than is released through biological processes in the soil. Under present conditions the tundra in northeast Greenland takes up more CO_2 than it releases, but the situation could well reverse in the future.

Most scientists arrive in the Arctic when the snow has melted and the plants are in full bloom. At that time, though, many of the most important processes in arctic nature have already taken place. Our investigations at Zackenberg over the past 10 years show that the timing of the snow melt is by far the most important factor affecting the high arctic ecosystem. The timing and course of the snow melt are determined by a combination of the amount of winter snow, the redistribution of the snow by storms, and the spring temperature. All three factors will change markedly in the future in that they are affected by both the North Atlantic Oscillation and the extent of the sea ice off the coast of northeast Greenland.

Spring snow cover and temperature are *key factors*

The amount of winter precipitation and hence the thickness of the snow cover will increase considerably in the future. At the same time, though, the spring temperature and hence the thaw will increase. These two factors may therefore balance each other out. It is very likely that the interannual variation in snow cover, etc. will increase considerably such that there will be markedly greater differences between years in which the snow melt occurs early and those in which it occurs extremely late. The effect of prolonged thaws in the winter and in the spring is a particularly unknown factor as the snow may disappear in periods even before the start of spring. Conversely, years with a large amount of snow and a cold spring could result in an almost total lack of reproduction in many plants and animals. The overall result is that the nature of northeast Greenland – and hence that of the national park – will face considerable change in the future.

The whole ecosystem at Zackenberg will change with the climate

On the preceding pages we have seen that climate change will affect many different parts of the ecosystem at Zackenberg. This means that the whole ecosystem will change because the climate does not just affect one organism in isolation, but all the other organisms that inhabit the same environment. One can say that the climate can affect the same organism in several ways – both directly, for example via temperature and precipitation, and indirectly, via other species, for example those that it lives off.

Changes in climate affect the interplay between predators, prey and plants

From findings made at Zackenberg we know that this is correct. The studies performed over the past 10 years have shown that much snow in winter means that more musk oxen will die and that they will give birth to fewer calves because they have difficulty in getting at their food under the snow. Because a higher winter snow fall also shortens the plant growing season, however, these changes will also have a negative effect on the musk oxen. In that way the climate can thus affect the same organism both directly and for example indirectly via its food.

This applies not just to musk oxen and their plant food, but to many organisms in the ecosystem at Zackenberg that live off or with each other. Moreover, because the climate does not just affect a single organism, but everything around it, an ecosystem will not only end up looking different, but will also function completely differently.

Many scientists are working to describe and understand this, and because it is necessary to keep track on so many things at the same time, Zackenberg is the best place to conduct such research.

In order to be able to determine the effects of climate change on the flora and fauna of Greenland it is necessary to collect long time series of data on many different elements of the ecosystem. Two ecosystem observatories have therefore been established – one at Zackenberg in high arctic northeast Greenland and one at Kobberfjorden near Nuuk in low arctic Greenland. Each summer, 4–6 scientists work at each observatory monitoring the ecosystem while other scientists perform detailed studies of specific aspects of the local nature.

Zackenberg is the oldest of the two observatories, and so much information is now available from Zackenberg that we can begin to describe the factors that are of greatest significance for the well-being of the ecosystems, the flora and the fauna.

This publication presents the most important findings concerning the changes that the nature in the world's largest national park may undergo as a result of climate change, which is likely to be particularly severe in eastern Greenland.