The ice historians

TO TELL WHETHER GREENLAND'S GLACIAL CAP WILL MELT AWAY ANY TIME SOON, RESEARCHERS ARE PORING OVER OLD PHOTOGRAPHS AND DRAWINGS FOR CLUES TO ITS PAST BEHAVIOUR.

BY QUIRIN SCHIERMEIER

ARCTIC INSTITUTE

Danish geologist Lauge Koch (centre) and colleagues on the open-cockpit Heinkel plane that his team used to survey East Greenland in 1932.

Anders Bjørk could have stepped out from a painting of a nineteenth-century Arctic expedition. Tall, athletic and burning for outdoor action, he has been attracted to the wild fjords and glaciers of Greenland since his university days, when he took summer tourists on guided tours there. He still ventures to the island every summer to measure its waning ice sheet — and he doesn't always travel by air. In 2014, he retraced the route of early Danish explorers by sailing to Greenland in a three-masted wooden schooner built in the 1930s.

But on a pleasant spring day in Copenhagen, Bjørk is carrying out a much safer reconnaissance. In the belly of Denmark's national archive, he sifts through yellowed files filled with rows of daily weather and ocean-temperature measurements that Danish clergymen and village chiefs made decades ago along the Greenland coast.

"I get a kick out of sitting over old maps and documents," he says. "I somehow find that kind of stuff just as fascinating as doing field work." Bjørk has alternated expeditions to the archives and to distant glaciers for ten years, ever since he first came across tens of thousands of aerial photographs of Greenland from the 1930s, lying all but forgotten in a seventeenth-century fortress outside Copenhagen.

Bjørk and his colleagues at the Natural History Museum of Denmark in Copenhagen are ice historians. They are combing the old records to document how Greenland's ice sheet and glaciers have behaved since the nineteenth century — a crucial set of information for climate scientists trying to predict how it might change in the future.

With Arctic temperatures rising faster than anywhere else on Earth, Greenland is now losing about 200 billion tonnes of ice per year and raising ocean levels around the globe. Projections suggest that melting from the island might swell sea levels by 30 centimetres by the end of this century. If all Greenland's ice melted — a possibility over the next few centuries – it would push up sea level by more than 6 metres, enough to flood coastal megacities such as New York and Miami.

But the projections carry large uncertainties, in part because researchers lack basic information about Greenland's past. Satellite data only go back 40 years, which is why Bjørk and his colleagues are poring over 180,000 photographs and other data that record how glaciers have advanced and retreated during cold and warm spells in the recent past. Their first sets of findings suggest that Greenland ice has responded more strongly to past climate changes than was previously realized. Now, the researchers are trying to unravel what factors within the oceans, atmosphere and inside glaciers control their behaviour.

What sets Bjørk apart, say other scientists, is that he combines the heart of a seafarer with a strong sense of detail and creativity in research. The studies by him and his fellow ice historians are making key contributions to glacial science, says Beata Csatho, a glaciologist at the University at Buffalo in New York. "Collecting historical data sets is probably more important at this point than having yet another satellite do more of the same stuff," she says. "This is not incremental progress — it is a big advance in science."

EPIC ADVENTURES

Bjørk's fascination with Arctic exploration reaches back to his childhood. Like many Danes, he learned to sail at a young age and over the years he embarked on a series of increasingly epic voyages that blended science and adventure.

In Bjørk's most extreme expedition, he and a small crew of like-minded scientists sailed through the storm-tossed south Atlantic for two months in 2011. Svante Björck, a Quaternary geologist at the University of Lund in Sweden, had chartered a two-masted ship to sail from the Falkland Islands to Tristan da Cunha, the most remote inhabited island in the world. During the 13-day trip, Bjørk spent several nights awake on deck, tied to the mast during gales, helping the captain steer the ship through huge waves. "It was scary. I've never seen anything like this," he says. The return journey to Uruguay took 33 days against relentlessly unfavourable trade winds. Yet the rich yield in climate data and the unforgettable adventure was well worth the ordeal, he says.

The son of two school teachers, Bjørk grew up in Svendborg, a small harbour town in southern Denmark with a long seafaring tradition. Eager to explore the world, he studied geography and became enthralled with Greenland, which has been part of the kingdom of Denmark since the early 1800s. While serving as a student assistant to Quaternary geologist Kurt Kjær of the Natural History Museum of Denmark, Bjørk learned to mix traditional geology and expedition-era geography with modern high-tech data.

His interest in historic records was piqued ten years ago when he first heard tales of a cache somewhere in Copenhagen filled with aerial images of Greenland taken in the 1930s during mapping expeditions. He eventually discovered that the formerly classified images had been locked away in a ramshackle citadel outside the city. Bjørk sensed a unique research opportunity, but it took him years to sift through rows and rows of boxes filled with thousands of light-sensitive negatives and to work out which might be useful.

As he extended his search, he came across many more images taken

during Danish–US Greenland aerial surveys from the 1940s to the 1970s. Then came pictures from Danish mapping expeditions carried out from 1978 to 1987. Bjørk has now amassed a collection of 180,000 aerial photographs (see 'Flight lines'). But he has paid particular attention to the first images he acquired, from the 1930s, because they chronicle a warm period that shares some similarities with the present. The mapping expeditions, led by the explorer Knud Rasmussen, were partly motivated by a dispute with Norway about which country had sovereignty over Greenland — a legal battle that the international court in The Hague settled in 1933 in favour of Denmark. But the crews were aware of the scientific potential of their work. "The instantaneous record contained in the air and terrestrial photographs of the present state of the glaciers of the entire coast is in itself of great value for future researchers," the Danish captain Carl Gabel-Jørgensen wrote in a 1935 report.

"WITHOUT GPS OR OTHER PRECISION TOOLS THEY STILL MANAGED TO PRODUCE GLACIER DATA OF AMAZING QUALITY."

"These men were professionals," says Eric Rignot, a glaciologist at the University of California, Irvine, whose group Bjørk will join in the autumn as a postdoc. "Without GPS or other precision tools they still managed to produce glacier data of amazing quality."

The image collection from the 1930s includes 10,000 overlapping aerial photographs captured with a rotating camera flown in an open hydroplane at 4,000 metres altitude. Bjørk and his colleagues have used these images — alongside more recent aerial images and satellite observations — to produce an 80-year record of how 132 glaciers in southeast Greenland have waxed and waned[1]. They found that the glaciers retreated strongly during both warm periods but many have lost more ice during the record temperatures in recent decades.

Not all glaciers have responded to warming in the same way. It has hit low-elevation glaciers harder than ones higher up, and glaciers that terminate in the sea seem to be more vulnerable to the present rise in temperatures than those that end on land. Researchers are particularly concerned about how quickly these marine glaciers might shrink as they are attacked by the rapidly warming ocean. That may be a key factor in determining how quickly Greenland loses ice.

The signs are not good. Hundreds of outlet glaciers that drain the ice sheet are losing substantially more mass and are thinning more than they are gaining through snow accumulation. Jakobshavn, one of Greenland's largest glaciers, is moving faster than all the others and is the poster child for the fragile ice sheet, which some fear might approach a fatal tipping point as air temperatures continue to rise and the glaciers thin even more[2].

The findings from the historical studies released so far are a reminder that the current glacier retreat has lasted far longer and is more pronounced than the typical fluctuations over the past century. "It's that kind of long-term perspective that helps us understand that the rapid changes we are seeing now are definitely more than just noise," says Csatho, who has looked at satellite and aerial data to reconstruct how the surface elevation of the Greenland ice sheet changed at nearly 100,000 locations from 1993 to 2012 (ref. 3).

RECOVERED TREASURE

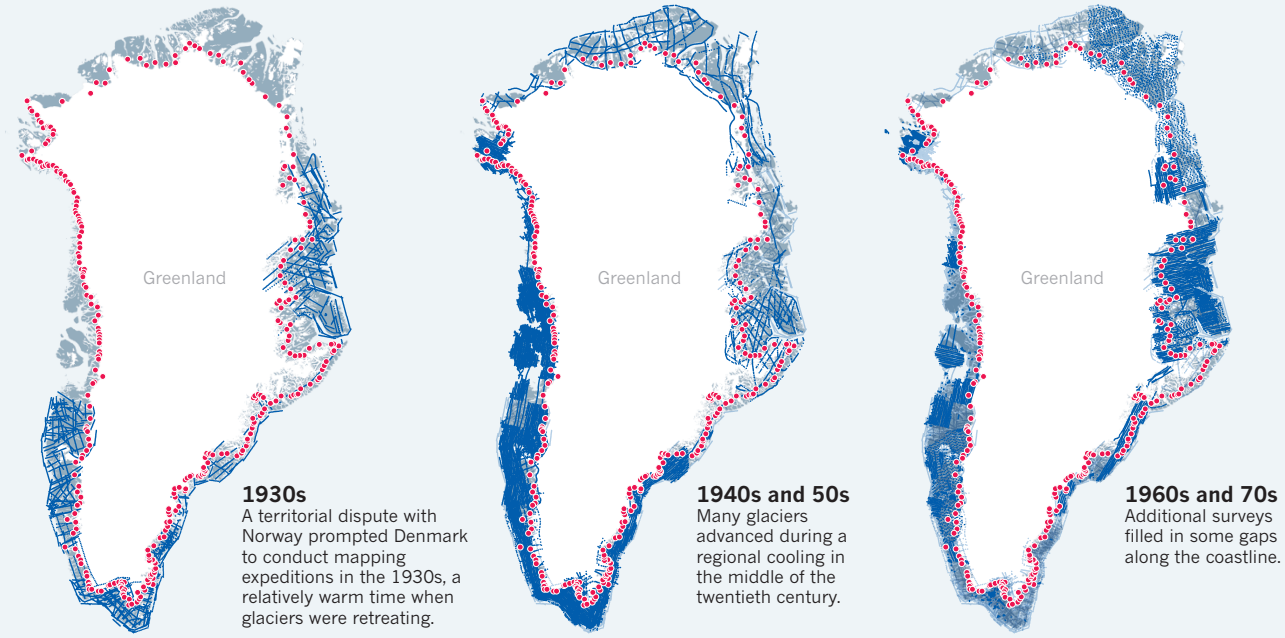
Bjørk's work at the Arctic Institute in Copenhagen is more sedate than his trips to Greenland, but no less rewarding. The centre's archives hold treasured documents and memorabilia of Denmark's Greenland expeditions, which are part of the Nordic kingdom's cultural DNA. Bjørk gleams with the delight of an art lover as he unrolls maps drawn by Danish explorer Hinrich Rink in 1851 of the mighty Jakobshavn. Carefully opening stitched albums, Bjørk passes by snapshots of Inuit villagers with sealskin boats, and heads for the pages that most interest him — the sketches and images depicting the shapes of glaciers and their thickness.

"Rink and later explorers documented very carefully where they were, and we can trust that what they painted is exactly what they saw," he says. "Their zeal and accuracy is a gift for us."

Bjørk has done much of his work with fellow geographer Kristian Kjedlsen, with whom he shares an office in the Natural History Museum plastered with Greenland maps and Arctic photography. In a second study, they and their colleagues carefully picked out geographical features on old photographs, such as moraines of rock or vegetation lines

FLIGHT LINES

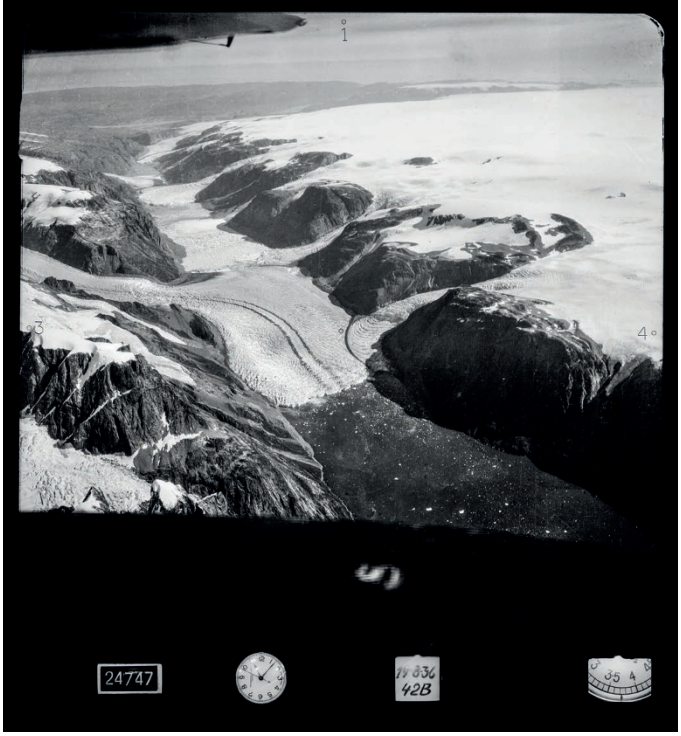
Anders Bjørk and his colleagues are using historical aerial surveys to assess Greenland's glaciers, including 309 major ones (•) that drain the ice sheet. Blue lines represent flight tracks.



1930s
A territorial dispute with Norway prompted Denmark to conduct mapping expeditions in the 1930s, a relatively warm time when glaciers were retreating.

1940s and 50s
Many glaciers advanced during a regional cooling in the middle of the twentieth century.

1960s and 70s
Additional surveys filled in some gaps along the coastline.



L: DANISH GEODATA AGENCY; HANS HENRIK THOLSTRUP/
R: NAT. HIST. MUS. DENMARK

Photographs of Ujaraannaq Valley in southwest Greenland in summer in 1936 (left) and in 2013 show that several glaciers have disappeared.

that mark the greatest extent of the glaciers during the Little Ice Age at the end of the nineteenth century.

They used these data, along with more recent aerial surveys, to determine how the height of the glaciers has shifted, which provides a way to track changes in the ice mass. Their results indicate that the mean annual rate of ice loss between 2003 and 2010 was more than double the average for the twentieth century[4]. Moreover, striking spatial differences seem to confirm that the ice sheet's response to changing climates is governed by the topography of the underlying bedrock and by the geometry of the fjords through which outlet glaciers are flowing towards the sea.

UNRULY ICE

Greenland's glaciers have been fickle over the past century, advancing in some places and retreating in others. By discovering when those changes happened and what kind of conditions prevailed at the time, Bjørk and his co-workers hope to shed light on the ice sheet's complicated mechanics — a missing piece in attempts to model its waxing and waning accurately.

But nailing the ice sheet's behaviour requires looking at as many individual glaciers as possible. This is just what Bjørk and his group are doing now. Using all available historic records from Greenland, including pictures of glaciers in the least-explored high north, alongside modern satellite imagery, he aims to reconstruct the history of the island's 309 biggest glaciers in unprecedented detail.

The work is in full swing. On most days, two of his students toil away in the basement of the museum in front of computers, clicking on boulders, cliffs and other recognizable features that can be spotted in photographs taken decades apart. These are control points, which allow the researchers to match pictures captured at different altitudes and angles. Most aerial pictures were not taken looking straight down and hence lack a single scale. All of these oblique pictures need to be converted, one by one, to vertical views so that they can be transferred onto a common coordinate system. Without doing this geo-rectification, the researchers could not accurately measure the glaciers' advances and retreats.

Photos are not the only source of information. In the Arctic Institute on a sunny afternoon, Bjørk looks at sketches that the German geologist Alfred Wegener produced during his last expedition, shortly before he died in November 1930 near an ice camp in central Greenland. Other albums hold illustrations of glaciers that scientists made during field trips in a cold spell in the late nineteenth century.

So far, he has discovered about 600 sketches and paintings that might help to tell the story of Greenland's glaciers before aerial photographs first became available. For some glaciers, official aerial pictures don't exist. To fill the gaps, he is also consulting privately held images that geologists have taken over the years. "New information is coming up from all sides," he says.

In 2014, the daughters of two pilots involved in the 1930s surveys offered Bjørk their large collections of photos and even an 8-millimetre film their fathers had taken during the campaigns.

The emerging story is that ice disappeared very fast in the early twentieth century in the warming that followed the end of the Little Ice Age. Then the subsequent cool spell brought widespread glacial advances. The profound switch between shrinking and surging suggests that the glaciers are more sensitive to warmings and coolings than researchers had previously thought, says Bjørk. But why some glaciers advanced forcefully at given periods and temperatures whereas others did not is still a puzzle.

NASA has launched the Oceans Melting Greenland (OMG) project, led by Rignot, to provide glaciologists and ice-sheet modellers with unprecedented base maps of fjord bathymetry and other information needed to determine how glaciers interact with the sea. That is where one of Bjørk's latest discoveries could prove useful. The historic records of sea-surface temperature that he unearthed can be combined with the individual histories of different glaciers to see how those that end in the ocean responded to changing marine conditions. The past behaviour of the ice, Rignot says, "matters a great lot when it comes to projecting its fate".

After all, the ultimate goal of this historical research is to look forward. Along with palaeoclimatic data from hundreds and thousands of years ago, the findings of Bjørk and his colleagues from the recent past promise to increase confidence in the projections of ice-sheet models, says Richard Alley, a glaciologist at Pennsylvania State University in University Park. "We need history as well as modern observations to build and test predictive models."

For Bjørk, the historical research goes well beyond science. It also connects him with the pioneering scientists and explorers he grew up admiring. He is grateful that their legacy is finally being dug out from the crypt. "It's part of Nordic history," he says, "and a real gift to modern science." ■

Quirin Schiermeier *writes for* Nature *from Munich, Germany.*

1. Bjørk, A. A. *et al. Nature Geosci.* **5,** 427–432 (2012).
2. Gregory, J. M., Huybrechts, P. & Raper, S. C. B. *Nature* **428,** 616 (2004).
3. Csatho, B. M. *et al. Proc. Natl Acad. Sci. USA* **111,** 18478–18483 (2014).
4. Kjeldsen, K. K. *et al. Nature* **528,** 396–400 (2015).