NORTH CIRCUMPOLAR MAPPING IN THE ATLAS OF CANADA

R. Eric Kramers
kramers@nrcan.gc.ca

Andrew Murray
amurray@nrcan.gc.ca

The Atlas of Canada Program
Natural Resources Canada
650 - 615 Booth Street
Ottawa, Canada K1A 0E9

Abstract

For over 100 years the Government of Canada's Atlas of Canada has told the story of Canada through geographical and historical maps reflecting the country's incredible social, environmental and economic diversity. The Atlas has always focused on small scale thematic and reference maps. Cartographic representation of the north circumpolar polar region has advanced considerably in the last decade. The use of data from advanced satellite sensors, new hydrographic and geodetic surveys and new data integration methods have offered Atlas of Canada cartographers many resources for creating and revising maps. The Atlas' newly revised North Circumpolar Region Map, released during the International Polar Year, is the beneficiary of all of these. The revision process brought together a range of challenges combined with innovative cartographic solutions, convention and judgement. This paper presents the objectives, challenges and methods used in creating this new and authoritative map of the north.

Introduction

The Northern Circumpolar Region is a spectacular environment, rich in Inuit culture, wildlife and diverse ecosystems. D'Arcy McGee, a great supporter of Canada's Confederation in 1867, spoke of Canada as a Northern nation, bounded by the blue rim of the ocean. Canadians view the North as a vital part of our nation and identity. The North fills us with a sense of awe, as a place of expansive and mighty landscapes, history and limitless potential.

Figure 1: Gerard Mercator's *Septentrionalium Terrarum descriptio* from 1595 and Willem Barentsz's *Deliniatio cartæ trium navigationum* published by Cornelis Claeszoon in 1599.

The first detailed maps of the circumpolar north (Figure 1) were published in the late 16th century. Mercator's was mostly pure fantasy with rivers flowing north between fictitious landmasses and ultimately into the earth at the North Pole (Ginsberg, 2006). These features were representative of myths and lore of an arctic paradise described by the ancient Greeks and maintained to the 20th century (McGee, 2004). The map by Barentsz took the opposite approach by leaving the unknown regions empty with the exception of some whales. Both maps are artistically beautiful, showing great cartographic skill and design. The goal, however, of both maps remained the same: to show the reality of the times using the most accurate available data and visualized using the best cartographic practices.

In response to the International Polar Year, 2007-2008, various new polar mapping initiatives have been undertaken around the world. This paper will focus on the revision and cartography of the Atlas of Canada's 2008 North Circumpolar Region Reference Map. The primary objectives of the map revision project were as follows:

- Produce an authoritative geo-political wall map of the north circumpolar region, with a 3 to 4 year lifespan, to replace the existing version of the map
- Emphasize Canada as a northern country
- Create a base map to be the source of three products with multiple delivery formats: printed and online viewable and downloadable vector and raster versions.
    - Revised North Circumpolar Region map
    - Promotional map/brochure for the Atlas of Canada containing the circumpolar map North of 55° and an equivalent circumpolar MODIS satellite image
    - North of 55° round wall or floor map graphic file scalable to 6 metres in diameter
- Support Government of Canada International Polar Year activities

Map Design

The design team discussed how the north could be defined and whether the extents of the map required changes (Figure 2) to reflect these definitions. The term "north" is subjective when referring to arctic latitudes. Most Canadian provinces consider their northern portions to be part of the "north". Canada has several indigenous Inuit populations whose traditional territories extend south into areas that are not considered to be arctic. Other boundaries, such as the tree line, permafrost and the Arctic Circle can be considered to be the boundary between north and south. Finally, a very common Canadian notion of the north is "north of 60°". While the earlier editions of the map mostly focused the extent north of 55° latitude, the new map would extend further south in Canada and Europe. In Canada, the increased coverage would show all of Hudson Bay and James Bay (including the islands belonging to the Territory of Nunavut), more of northern Ontario, the Inuit land areas of Nunavik in Northern Quebec and Nunatsiavut in Labrador, and a greater number of southern communities. In Europe, it would include more seaports – potential gateways for Arctic shipping. In short, the new extents would offer map users a greater number of visible connections with the North.

Figure 2: Conceptual draft of the 2008 map of the North Circumpolar Region.

Feedback from map distributors and retailers confirmed that a slightly larger map would be preferred. To accommodate this and the plan for increased map detail, it was decided to increase the physical dimensions of the map from 31.5 by 36 inches to 36 by 43 inches. The change resulted in an overall scale change from 1:10 000 000 to 1:9 000 000. This would still fit smaller 36 inch plotters used for printing the digital versions of the map to be made available on the Atlas of Canada website. Other design details included:

- Using a strong colour palette north of 55° and a subdued colour palette south of 55°
- A decreased level of detail south of 55°, except in Canada
- Updating bathymetric contours and polar sea ice extents
- Adding more polar undersea feature names
- Including terrestrial and undersea hillshading (also known as shaded relief)
- Adding the tree line to help define the north/south boundary
- Adding the North Magnetic Pole and its historical track of survey positions

Colour was a major aspect of the design of this map, and the challenges were different for the terrestrial and marine areas. The design required that all countries be distinct from their immediate neighbours, and that no country be unduly dominant. At the same time this is a Canadian publication, so Canada should be "front and centre". There were other factors to consider:

- To ensure the large volume of symbology and toponymy would be legible, a relatively light background was required.
- Tonal differences of the hillshading would darken the basic country colours so the "base" hues needed to be light.
- Hillshading works best with colours/inks that can support a wide range of opacity. Black, magenta and cyan inks, being relatively opaque, do this fairly well by varying the amount of ink: less for highlights, more for shading. But yellow requires the addition of black ink to show shading, which tends to change the hue to brown or green. (Theoretical reflectance values for 100% ink coverage on white paper: black 10%, magenta 33%, cyan 38%, yellow 90%.) (Robinson, et al, 1995).
- The convention of using blues for water features is so strong and obvious that it is difficult to use them for anything else.
- Larger areas of colour appear darker.
- "Warmer" colours (red, orange, yellow, and brown) appear to advance towards the viewer, while "cooler" colours (blue, green, perhaps violet) appear to recede.

These considerations influenced the assignment of colours. Russia, occupying a large area of the map, required a light, cool colour to prevent it from overwhelming the other countries. To place Canada in the foreground required a bright but not dominant warmer colour. Smaller countries needed to have greater-than-average contrast with their neighbours; similarly, countries with many small islands needed strong contrast against the ocean colour. Only countries with low relief could be shown in yellow.

Choice of colours for the marine areas was also a challenge. A light blue would be used in the ocean around the perimeter of the map south of 55°, and five more shades were required for the five ranges of depth. The darkest shade needed to be light enough that other, even darker blue symbols and text labels would still stand out well against it. Further, the tonal variations in the hillshading would create variations within each depth class colour which could potentially create confusion – ideally a shaded slope in one class still needs to be lighter than an illuminated slope in the next, darker class.

With the background colour in the deepest ocean depths being quite dark, the colour for water feature type was composed of 100% cyan ink and 75% magenta. While ocean type must be perceived as sitting on the water's surface, type for the undersea features had to be associated with the ocean floor, and so needed to appear "earthier" and "lower" than ocean labels. This was achieved with 100% cyan ink and 60% black.

Undersea Relief

In 1985 an Atlas of Canada cartographic artist used traditional artistic airbrush techniques to create a hillshading (also known as shaded relief) of the north circumpolar region, both terrestrial and undersea (McGarry, c1996). At the time much of the Arctic Ocean was not-surveyed or data was not available, and in some areas the undersea topography had to be interpolated from a minimal set of contours. Nevertheless it was the best at the time and was used for several early editions of the Atlas of Canada's North Circumpolar Region map. The original artwork was lost, but in 2007 a photographic reproduction of the hillshading was accidentally discovered; it was scanned and digitally archived.

Figure 3: Round north of 60° circumpolar maps at the Atlas of Canada's 100th Anniversary (2006), IPY exhibit in Paris (2007), and IPY launch event in Ottawa (2007).

In 2006, a round 2.5 metre floor version of the Atlas' North Circumpolar Region map was created for an exhibit celebrating the Atlas of Canada's 100th Anniversary (Siemonsen, 2006). This was so popular that in 2007, the newly scanned hillshade was incorporated into a larger round 6 metre "floor map" for the Government of Canada's International Polar Year (IPY) launch event in Ottawa. A few months later it was featured in the IPY exhibit at the Cité des Sciences et de l'Industrie in Paris along side a map of the Antarctic. The effect of the hillshading in a large map was dramatic and very well received (Figure 3). When it was decided to update the Atlas' North Circumpolar Region map there was no question that hillshading should be included.

Meanwhile, with continued survey activity, advances in technology, and access to previously classified data, the mapping of the Arctic Ocean had dramatically improved. Version 1 of the International Bathymetric Chart of the Arctic Ocean (IBCAO) was released in 2000; version 2 (Jakobsson, et al, 2008) was released just as planning for the new Circumpolar Map was getting underway. During the early stages of production a successful verification of the bathymetry in Canadian waters was done by the Canadian Hydrographic Service of Fisheries and Oceans Canada.

The IBCAO product is a digital elevation model (DEM), with a resolution of 2 km. It did not cover the entire marine area required for the revised map, so the IBCAO DEM was combined with another from the General Bathymetric Chart of the Oceans (GEBCO, 2003). The resulting DEM was re-projected and re-sampled to a resolution of 1524 metres to yield an image resolution of 150 pixels per inch (ppi) at the 1:9 000 000 map scale.

The combined DEM was hillshaded in ArcInfo using the standard parameters where illumination comes from the upper left of the map at 45 degrees from the surface. The level of detail visible in the ocean floor was impressive, but there were numerous artefacts such as terracing, banding, and traces of ship tracks and spot soundings (Figure 4). These were eliminated by manually editing in Adobe Photoshop.

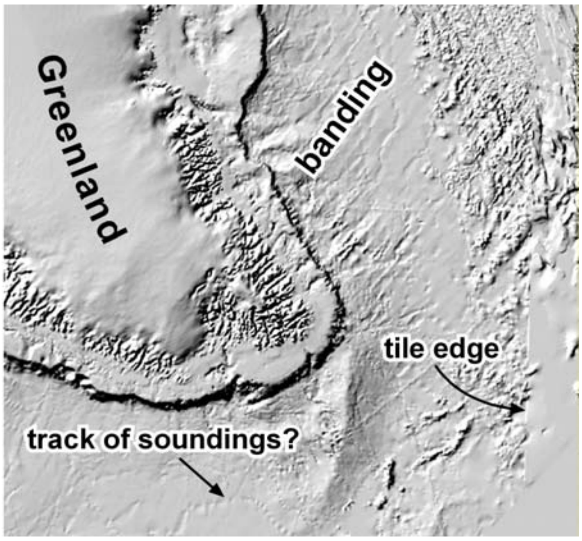


Figure 4: Artefacts in the IBCAO DEM

Once the artefacts were eliminated the hillshade was re-evaluated. Even with the addition of coloured depth classes (Figure 5, left image) the effect was not as dramatic as expected. The solution was to reprocess the DEM with a smoothing operator using a very high tolerance and hillshade the result with a low angle of illumination (20 degrees). The resulting hillshade was judiciously combined with the existing DEM hillshade to produce a satisfactory combination of visual depth and undersea topographic detail (Figure 5).

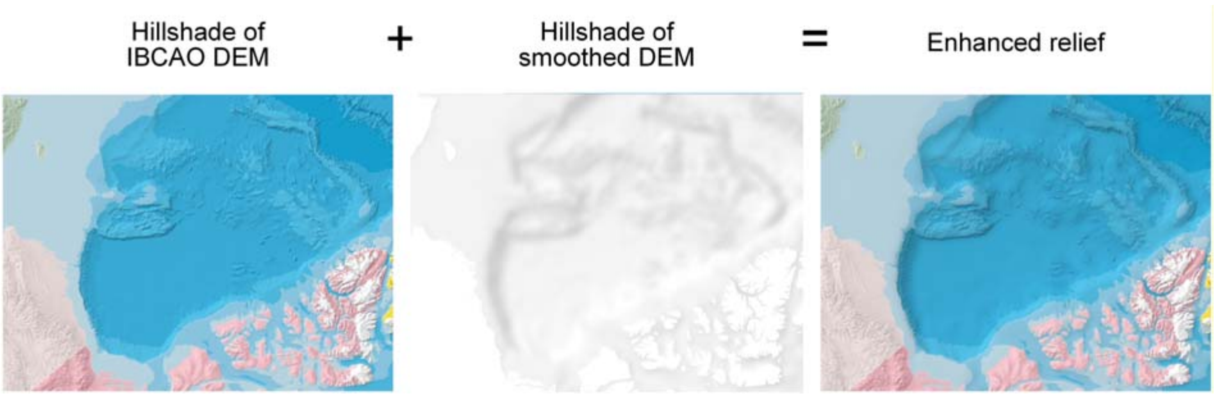


Figure 5: Enhancement of undersea relief.

Terrestrial Relief

The DEM distributed by the International Bathymetric Chart of the Arctic Ocean contains terrestrial elevation data which was taken from GTOPO30, a global 30 arc-second terrestrial DEM (USGS, 1996). For the production of this map it was necessary to supplement the IBCAO DEM with other elevation data because 1) the IBCAO DEM did not cover the full terrestrial extent of the map, and 2) a few regions of Canada are poorly depicted in GTOPO30. The extents of the map were filled by acquiring the missing portions from GTOPO30, and the Canadian region was replaced with data from CANADA3D, a Canadian DEM with the same resolution (GeoGratis, 2008). The resulting large-scale DEM is, however, very detailed for the scale of the map. Mountainous regions appear as masses of individual peaks, with little evidence of their relative heights or their organization into broader mountain ranges and subranges. The overall effect adversely affected the legibility of any overlying symbols (Figure 6).

Based on the experience with other Atlas of Canada maps the higher-resolution hillshaded DEM was combined with the older artistic hillshading to enhance the mountain ranges. The greyscale values of each layer were globally adjusted (using various contrast and brightness adjustments and layer blending modes) until the right balance of high and low resolution hillshading was achieved. At a later stage, local adjustments were made to refine the balance. For instance, shading in low-relief areas had been purposefully exaggerated in the traditional airbrushed hillshade, and some adjustment was required to preserve this enhancement in the final hillshade.

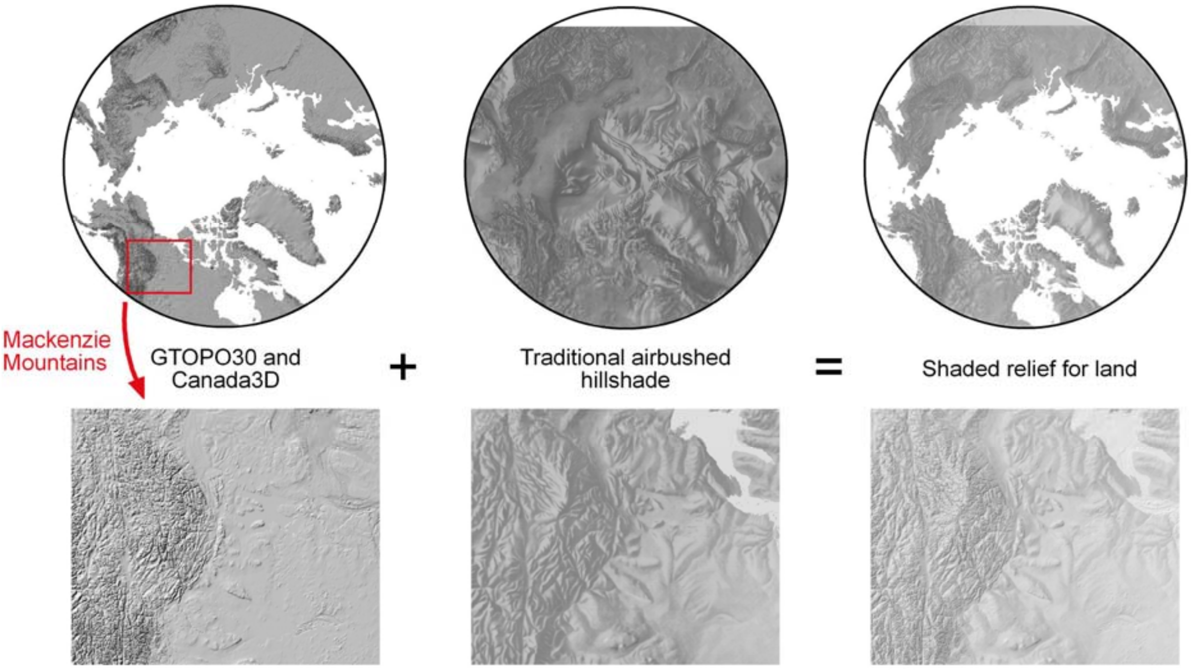
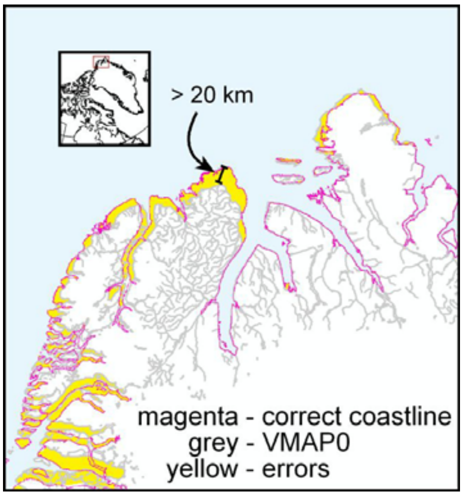


Figure 6: Combination of two different hillshaded images.

It should be noted that it is not currently possible, using computerized processes alone, to create generalized hillshading similar to the manually airbrushed product. This is a cartographic process requiring human interpretation of the landscape.

Drainage Features

Since the map's legacy drainage feature vectors (lakes, rivers, coastline) did not fit the more up-to-date DEM hillshading, it was decided that a thorough overhaul of them was required.



VMAP0, an improved version of the Digital Chart of the World, was used as a reference layer for updating the position of much of the drainage features in Europe and Asia (NIMA, 1998). VMAP0 is a venerable digital collection of 1:1 000 000 scale layers. By today's standards its horizontal accuracy is only fair but it provides a reasonable reference at 1:9 000 000 and is readily available in digital vector format. In certain areas, particularly in the north, MODIS satellite imagery at one kilometre resolution was a more helpful reference. The two kilometre IBCAO DEM provided the best locational reference for northern Greenland, since it incorporates the coastline from a recent survey by the Danish National Survey and Cadastre correcting some errors

Figure 7: Correction of the coastline of northern Greenland.

The drainage features for North America were replaced with an appropriate selection of drainage from the most recent version of the Atlas of Canada's 1:6-million base map. Finally, they had to be checked against the hillshading, to ensure that rivers followed valley floors and did not appear to cross mountain ranges.

Geographic Names

Toponymy provides the map reader with the names of features, but should also suggest a feature's relative importance, its extent and position in a hierarchy of features (showing, for example, that Lancaster Sound is part of Parry Channel). The volume of label editing required was significant – the finished map includes just over 3000 text objects, and due to the correction of large areas of drainage features, the majority of the labels had to be repositioned. New labels were required for the added features in the extended coverage of the map from 55° to 60° north and for the addition of undersea features such as basins and ridges. In order to expedite the interactive manipulation of text in ArcInfo, a number of short scripts were written. These helped with such functions as creating, resizing, and rotating text, fitting text to a path or modifying its position on the path, and automatically rotating text to follow the graticule/projection.

It is interesting to note how the labels across the map face were oriented so that they could all be easily read from one viewing position facing Canada. On the left and right quadrants they generally follow the lines of longitude, while the remainder follow the lines of latitude. Determining where to make the transition from one orientation to another was challenging. For example, there appears to be no "correct" orientation for "Kong Christian IX Land" on Greenland: rotating it 180 degrees does not help, and breaking the name into 3 or 4 lines is little better, given the awkward combination or long and short words. In the end, function, optimally showing the extent of the feature, was given precedence over aesthetics.

Undersea Feature Names

Undersea features in the Arctic Ocean have received considerable attention during the International Polar Year years due to the high level of research activity by circumpolar countries. It was a challenge to identify the correct and approved names for all the undersea features as well as their actual locations and extents. Natural Resources Canada's Geographical Names Board of Canada verified the undersea feature names using their own records for Canada and used established conventions for names in other international locations. Names for features completely in the territorial extent of another country would be in the language of that country (for example, Karskoye More for the Kara Sea). Names in all other areas would be shown in Canada’s two official languages, English and French (for example, Alpha Ridge/Dorsale Alpha). A primary source of input, on the advice of the Canadian Hydrographic Service, was the General Bathymetric Chart of the Oceans Sub-committee on Undersea Feature Names (SCUFN) list of approved names.

Glaciers and Ice Fields

To verify and update the glaciers and ice fields, a current, consistent source was needed with sufficient detail for the map’s 1:9 000 000 scale. The ideal source was a composite circumpolar MODIS (Moderate Resolution Imaging Spectroradiometer) satellite image (Figure 8, left) from Natural Resources Canada’s Canada Centre for Remote Sensing (Trishchenko, et al, 2009). A cloud-free composite image of 250 metre resolution from July to September 2007 was used. Optimally only data from late August to mid September should be used since the maximum snow and ice melt occurs at that time. However, some snow was found in the September data for some areas so to complete the composite, imagery from earlier in the summer was needed. In addition, a variant of this image was created classifying the surface reflectance/albedo for land, water, partial snow and ice and full snow and ice (Figure 8, right).

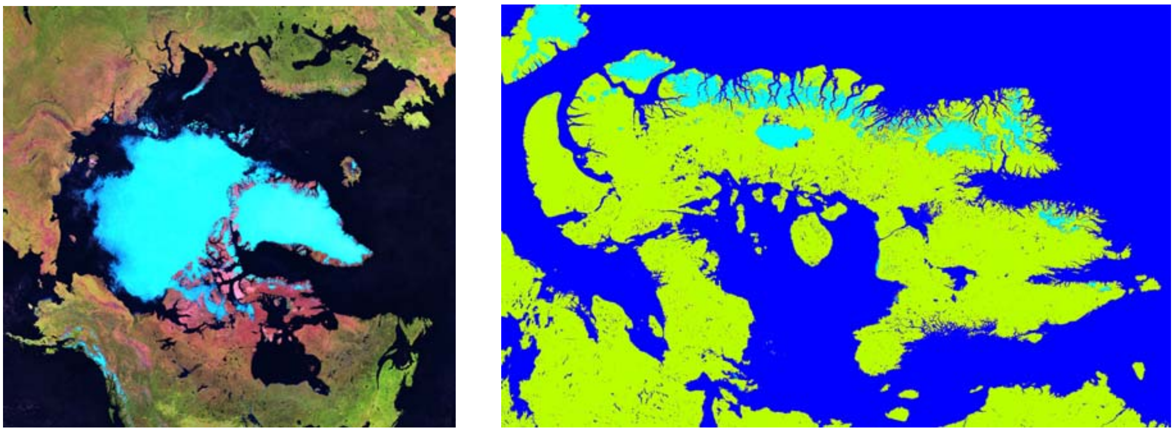


Figure 8: Composite MODIS imagery showing multi-band reflectance (left) and the snow/ice/land/water index, Baffin Island (right).

When comparing the old glacier and ice field polygons with the MODIS image, there were positional and extent differences requiring editing. These were most noticeable in Alaska, Russia, Norway and Iceland. A few prominent glaciers and small ice fields were missing, mostly in Iceland and Norway – these were added. Glacier and ice field names were added to the new map where reliable information was available. The source maps were produced by each country, and specific advice was taken from the Norwegian Polar Institute and other published sources (Weidick, 1995).

Sea Ice

Earlier versions of the circumpolar map showed three sea ice limits of unknown provenance. They were the limits of the minimum, median and maximum ice edges for an unknown multi-year period. New polar sea ice limits were supplied by the Canadian Ice Service (Chagnon, 2007) of Environment Canada (Figure 9). These reflected the maximum and the minimum (permanent) polar sea ice limits for the month of September from 1972 to 2004. In addition to these the minimum ice extent for September 10th, 2007 was made available.

When the initial proofs were produced, it became obvious that it was very confusing to show all three of these limits on top of the detailed bathymetry and dense toponymy. In the end, based on advice from the Canadian Ice Service, a single permanent polar ice limit was used, combining the 1972 to 2004 minimum with that from 2007. This produced the limit of permanent polar sea ice from 1972 to 2007. At printing, a varnish was used with a slight pattern mask to effectively highlight this area.

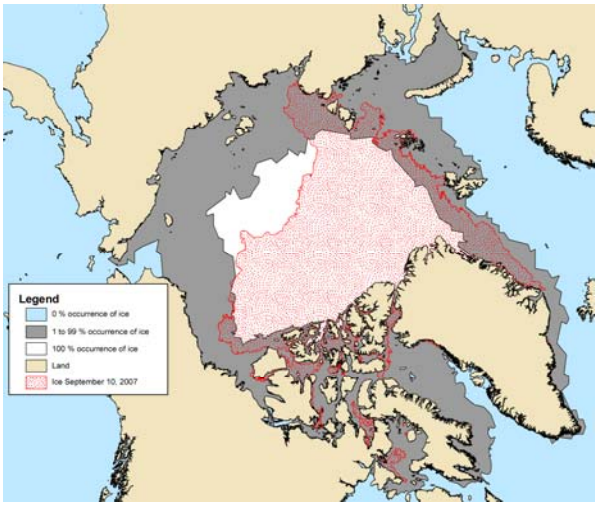


Figure 9: Graphic showing the initial polar sea ice limits for the revised map. The actual limit used was a combination of the 100% occurrence of ice and the September 10th, 2007 limits.

Ice Shelves

The ice shelves, along the north coast of Ellesmere Island, were a late addition to the map. Due to rapidly changing sea ice conditions in the polar region and the overall public interest in these changes, it was decided to show them. Ice shelves are a unique and quickly-disappearing feature in Canada's Arctic. More than 90% of Canada's ice shelves have disappeared during the last century. The ice shelves are now highly prone to breaking apart. In 2008, the entire 50 km^2 Markham ice shelf broke away and is now drifting in the Arctic Ocean within the sea ice. Two large sections of ice broke away from the Serson ice shelf, shrinking this ice feature by 122 km^2, about 60 % (Figure 10). Due to their small size and number they are shown on the map in a darker hue, and are also labelled.

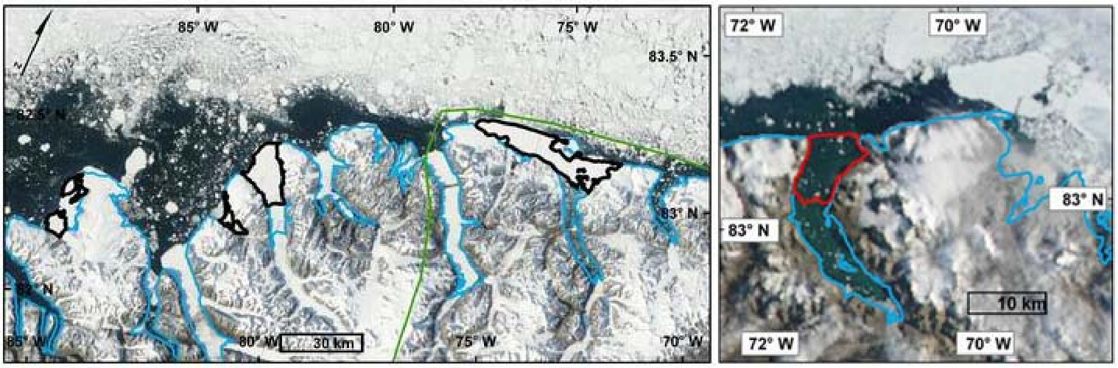


Figure 10: Ellesmere Island ice shelves, August 2008**.** Ice shelves are outlined in black, the former Markham Ice Shelf in red and Quttinirpaaq National Park in green (Mueller, 2008).

Conclusion

The revision of the Atlas of Canada's North Circumpolar Region map ended up going many steps beyond a simple revision of base map features and toponymy. The resultant map (Figure 11) achieved its objectives by offering map users, from the general public to scientist, a fresh and accurate view of the north. It shows Canada as a northern land – whose history, society, economy and future is linked to the circumpolar region. The three maps created: North Circumpolar Region, promotional Atlas of Canada map brochure and scalable round wall and floor version, will offer Canadians useful products in the years ahead. There were many technical challenges in working with and integrating legacy and current data. The software and computing platforms were varied from desktop image editing to geographic information systems. The tradition of mapping the north, from the earliest 16th Century maps to the present, shows that cartographic skill, art and ingenuity continue to be very much alive in the 21st Century.

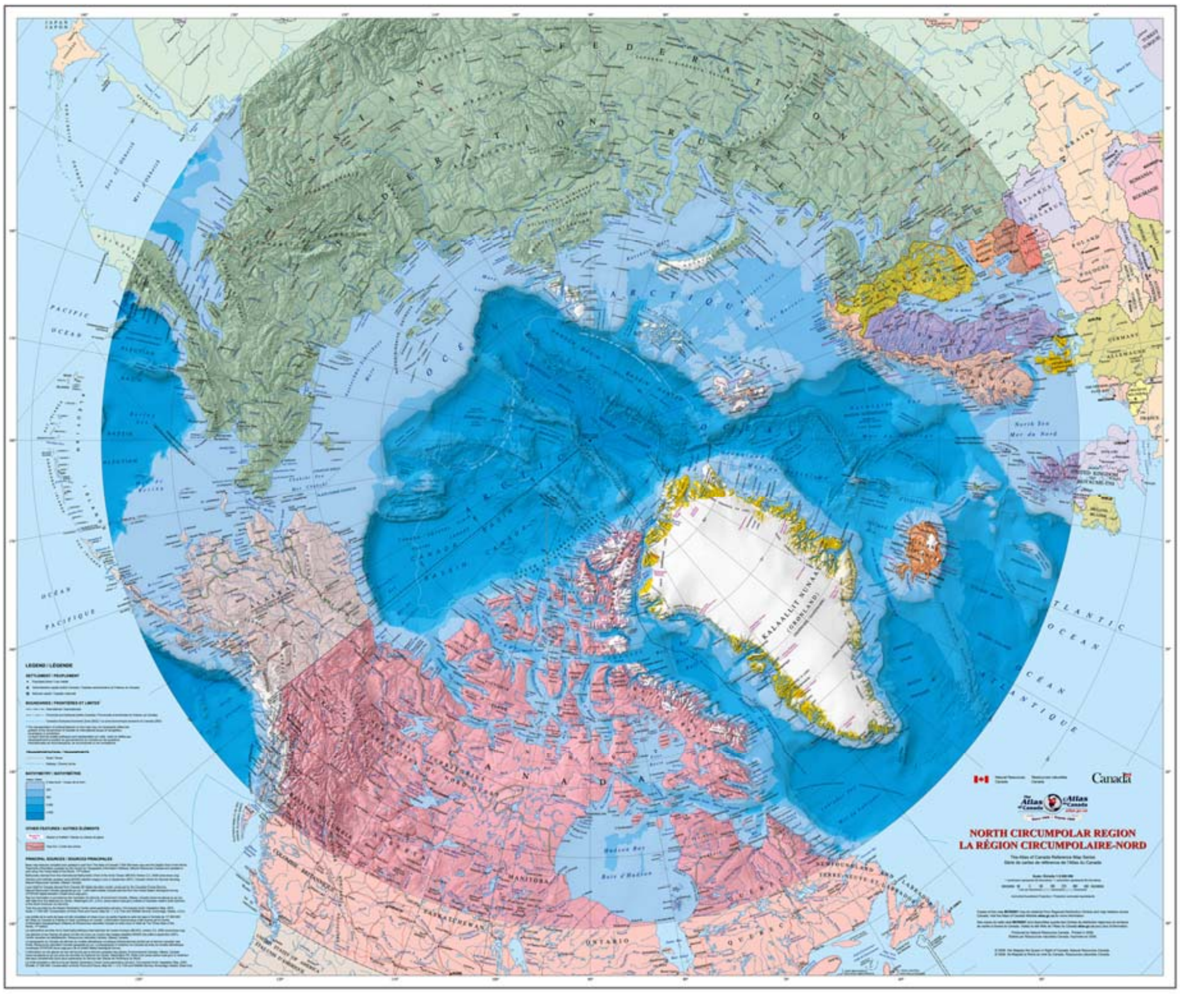


Figure 11: The Atlas of Canada's new North Circumpolar Region map, 2008.

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