What did the Viking discoverers of America know of the North Atlantic Environment?

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In discovering and colonizing Iceland, Greenland and Atlantic Canada, Norse explorers displayed remarkable resilience to the harsh North Atlantic environment 500 years before Columbus reached the New World. Given such widespread exploration of the subpolar North Atlantic Ocean and such close exposure to the environment, it is interesting to speculate about Norse knowledge of oceanography, meteorology and climate. Is it possible that they possessed a relatively advanced knowledge of their environment, albeit without any basic understanding? This article addresses this question.

Leif Eriksson's arrival in Newfoundland in AD1000 marked the culmination of Viking expansion west from Scandinavia that began two centuries before (Figure 1). The early eighth- and ninth-century voyages from the homeland fjords of south-west Norway left permanent Viking settlements in northern France and the British Isles. Settlers arrived in the Faeroe Islands around AD825 and reached Iceland by around AD870; the oldest archaeological remains there lie immediately above the tephra from the large AD871 volcanic eruption of the Vatnaoldur fissure in southern Iceland. These farmers established permanent settlements that survived to the modern era.

Colonial occupation of south-west Greenland began in AD985 when Erik the Red Thorvaldsson led an expedition of 25 ships from Iceland to the vast new territory he had optimistically named himself. The total population of the two primary Greenland settlements peaked at a few thousand, but eventually disappeared in the fifteenth century and European knowledge of their existence was lost for many decades.

Two important written accounts of oral history describe exploration further west to what the Norse called *Helluland, Markland* and *Vinland* (see Figure 2, which shows a medieval map of the North Atlantic, and, for orientation, the modern view in Figure 3). These Icelandic sagas about Erik the Red, his family and followers (principally *Erik the Red's Saga* and *Greenlander's Saga*) explain how Leif Eriksson, Erik the Red's son, established a settlement in *Vinland* in AD1000. Although the Norse only stayed a few years, unequivocal evidence for their presence in North America was discovered at present-day L'Anse aux Meadows (Newfoundland) in 1961.

The sagas provide unique insight into details of the Norse activities, the places they visited and their contact with the indigenous Indians (the 'skraelings', with whom they skirmished). There are only occasional and indirect references to their environmental knowledge. The uncontroversial evidence is therefore meagre, but there are hints that the Norse did indeed appreciate many facets of North Atlantic oceanography, meteorology and climate. In particular, consider the following phenomena and what Norse observers may have known about them.

Navigation and seamanship

The Norse pioneers relied on a critical piece of technology – the Viking *knörr* (cargo ship) – and the knowledge required to operate it. Several well-preserved examples of these sailing ships have been excavated and many details of their design and construction are now known. The vessel shown in Figure 4, for example, was built using designs and methods typical of ninth-century Norwegian shipwrights. She sailed from Iceland to Greenland then North America in 2000 to retrace the course of the *Vinland* explorers a millennium before and now stands in Reykjanesbaer, south-west Iceland. At the time of the Norse colonization of Greenland, ships like this one would carry up to 70 people as well as livestock and an open fire. The ship was rowed and sailed when possible, but could not step her mast or tack. Steering was accomplished by use of the *stjornbordi* paddle on the right hand side (*stjornbordi* means 'side on which a vessel is steered' and gave rise to the modern words *stern* and *starboard*).

Much less is understood about how Viking ships were navigated, however, especially in the open ocean where fog and calm could bring on the dangerous state of *hafvilla* ('loss of one's course at sea'; Marcus (1955)). One early explorer of Iceland, Floki Vilgerdarson, sailed with three ravens which he released periodically. The last bird flew purposefully to the north-west and land was spotted there soon after. Magnetic compasses, sea charts, and record-keeping were unknown, however. Debate exists over the sophistication of Norse astronomy and celestial navigation. The Pole Star was named (*Leidarstjarna*) and comments on the length of the *Vinland* day, as well as reference to cardinal points, exist in the *Greenlander's Saga*. The Norse may also have known of latitude and its significance for navigation, but the first records of crude sailing directions do not appear until the thirteenth century *Landnamabok* (Book of Settlements; Palsson and Edwards (1972)).

Figure 1. Leif Eriksson, Norse discoverer of America. Eriksson's father, Erik the Red Thorvaldsson colonized Greenland from Iceland in AD985. This statue by Alexander Stirling Calder stands outside the Hallgrimskirkja church in Reykjavik, Iceland.

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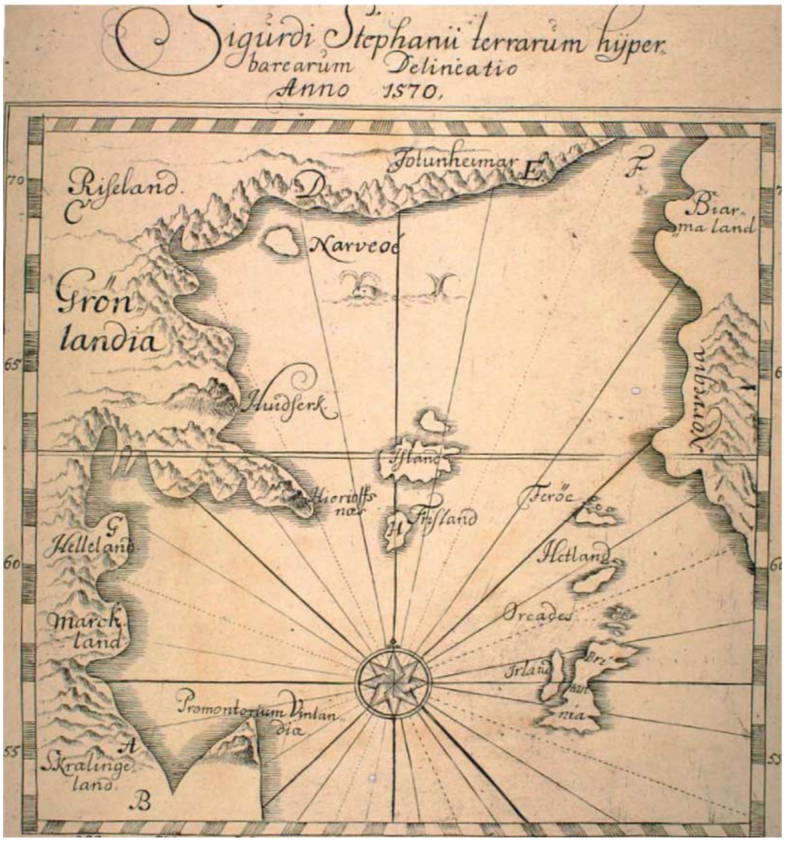

Figure 2. Medieval map of the North Atlantic drawn in 1570 by Sigurdur Stefannsson. There is, as yet, no unambiguous identification of the places the Norse called Helluland *('Stone Slab Land'),* Markland *('Wooded Land'), and, especially,* Vinland *('Wine Land'). The archaeological evidence from L'Anse aux Meadows, Newfoundland, clearly proves the Norse presence in America around* AD*1000, however. (© The National and University Library of Iceland.)*

Some people assert 'sunstones' were known (perhaps a polaroid mineral, such as feldspar, that could be used to locate the sun in fog) and 'sun compasses' (also called 'bearing dials') or 'shadow compasses' may have been available to steer by. The evidence for widespread use of instruments in navigation is very weak, however. Within sight of land, sailing was relatively straightforward and simply required an excellent visual memory to identify coastlines from the sea. Sailing out of sight of land was a much riskier proposition and presumably the losses were heavy. Nevertheless, the occasional serendipitous discoveries must have made the proposition attractive; Bjarni Herjolfsson apparently sighted *Vinland* or *Markland* in AD985, fifteen years before Leif Eriksson arrived there, after being blown off course from Iceland, for example.

Tides

Knowing the tidal cycle in water level and current velocity is critical to safe and effective seamanship, and there is no doubt the Norse knew this, too. There are several references to the tide in the Sagas. In *Erik's Saga*, Thorfinn Karlsefni describes reaching a *Vinland* river mouth that could only be entered at high water. He called the estuary *Hop* (Tidal Lake) and caught halibut stranded in trenches there as the tide ebbed. *Erik's Saga* also describes *Straumsey* and *Straumfjord,* which mean 'Current Island' and 'Current Fjord', respectively. It is possible that *Straumfjord* coincides with the *Leifsbudir* settlement described in the *Greenlander's Saga*, that is, the settlement at L'Anse aux Meadows. But, interestingly, the tidal range along the northern Newfoundland peninsula, near L'Anse aux Meadows, is only around 1 m and hardly worthy of special mention in the Sagas. The non-tidal flow through the Strait of Belle Isle, which separates the northern Newfoundland peninsula from Labrador, is also weak (about 6–34 cm s^{-1} according to Garrett and Petrie ((1981), (their Figure 15). Remarkably large tidal ranges do exist along the Canadian Atlantic coast. In particular, the two greatest tidal ranges in the world are at Ungava Bay and the Bay of Fundy where the ranges often exceed 10 m and the associat-

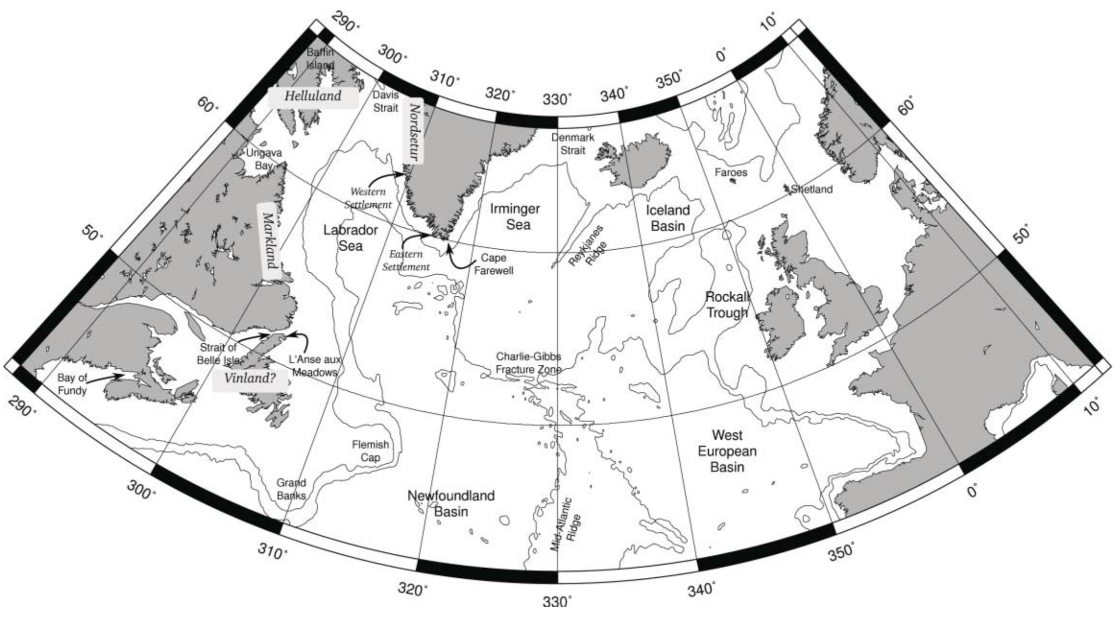

Figure 3. Modern map of the subpolar North Atlantic with Norse place names (italics) included where possible (1250 m and 3250 m depth contours are shown). It is salutary to see the accuracy of the medieval map (Figure 2), made without sophisticated instruments, despite the obvious distortions.

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ed currents would easily overwhelm a Viking ship. Some uncertainty therefore still exists about the true locations of *Hop*, *Straumsey* and *Straumfjord*.

There is unambiguous evidence from the thirteenth century about the Norse understanding of tides: an extensive discussion exists in the *King's Mirror* (Chapter 6) – a revealing Norwegian document written around AD1250 in the form of a father's advice to his son (Larson, 1917) – including reference to the fortnightly beat of the tide.

Non-tidal ocean currents

There are no direct references to ocean currents, apart from tides, in *Erik's Saga* or the *Greenlander's Saga*. Nevertheless, various lines of evidence suggest that the Norse were knowledgeable of the gross features of the upper ocean circulation. Sea-ice motion at subtidal frequencies would have been clear to any seasoned observer as explained above. Driftwood in Greenland was also very valuable and clearly did not originate locally (see Figure 5). The most highly prized species were larch (also called tamarack) and spruce from Siberia, northern Scandinavia or North America. (Interestingly, Fridtjof Nansen used the presence of Siberian driftwood east and west of Greenland as strong evidence of a trans-polar current in his 1890 address to the Christiania Geographical Society when he first proposed the famous *Fram* expedition.) Experience gained by a Norse sailor travelling from Norway to Iceland and Greenland and then on forays to Canada would reinforce a consistent picture. Drifting in the East Greenland, West Greenland and Labrador Currents, a Viking ship might make 30 nautical miles a day, maybe half or a third of the rate under sail (based on four weeks to reach *Vinland* from Greenland; 3200 km = 1750 nautical miles). This would have been clearly discernable and awareness of these currents would have been an important factor in route planning and navigation. Moreover, the unambiguous hydrographic character of the subpolar boundary circulation must have also helped; typical salinities and temperatures increase by 5 psu and 5 degC, or more, when crossing the continental shelves, and their associated jets, into deep water. These hydrographic variations are readily apparent to the careful observer by taste and touch and the Norse must have known of them. So, it seems likely that the existence and basic structure of the surface circulation of the western subpolar Atlantic Ocean, and the boundary current system in particular, were known 1000 years ago.

Sea ice

Sea ice played a critical role in the lives of the Greenland Norse and it is likely that they were keen observers of it. The two main settlements in Greenland – the Western Settlement, near modern Nuuk , and the Eastern Settlement, centred at Narssarsuaq – were influenced by sea ice in somewhat different ways. The Eastern Settlement consisted of farms of grazing animals with few crops grown for human consumption. For these people, sea ice prevented access to the open sea. Residents of the Western Settlement endured a harsher climate and relied more on hunting land and marine game, often travelling long distances across the rich *Nordsetur* hunting grounds around Disko Bay. For these people, land-fast sea ice was present for longer periods each year than at the Eastern Settlement and allowed important opportunities to hunt and travel easily. The Inuit operating in the *Nordsetur* knew these facts, but the Norse did not adopt their successful methods and it is unclear whether they exploited land-fast ice or not. For both Settlements, trade with the Norwegian homelands was obstructed by heavy ice. Penetration of driftwood may also have been blocked by coastal ice, and driftwood was the sole source of lumber for building construction and ship repair in Greenland. Sea-ice concentration and its prevailing drift must have been closely monitored by Norse observers waiting for ships to return or to put to sea (and is discussed in the *King's Mirror*). Similarly, the seal and walrus hunters would be aware of these factors when stalking their prey. Indeed, they may well have glimpsed Baffin

Figure 4. The 80-ton Viking ship Islendingur *launched in 1996 to celebrate the 1000th anniversary of the Norse discovery of North America. (© Hakluyt Society, London.)*

Figure 5. There are no natural sources of lumber for construction or ship repair in Greenland, so the Norse colonists relied on trade or driftwood. This woodcut shows floating wood and ship wreckage drifting past dwellings that appear to be partly constructed from whale bones (evidence for this practice exists from excavated Greenland Norse farms). The driftwood obviously has a non-local origin, and supports the idea that the Norse were aware of the existence and character of non-tidal ocean currents.
From the 1555 work of Olaus (Magnus, 1996).

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Island across Davis Strait when far out on the ice and returned with stories of *Helluland*.

Marine meteorology

Norse seafarers would have been obsessively interested in the weather at sea and the Sagas contain abundant references to storms – presumably, mesoscale polar lows – and their sometimes devastating consequences. Of particular interest is the reference to *hafgerdingar* (e.g., in the *Greenlander's Saga* and in the *King's Mirror*), a term that has an obscure and controversial meaning. Literally, *hafgerdingar* (*hillingar* in Icelandic) means 'sea hedges' or 'sea fences' and it indicates some gross calamity at sea. Erik the Red's emigration from Iceland to Greenland in AD985 began with 25 ships, but only fourteen managed to reach their destination, apparently due to such a disaster. *Hafgerdingar* has been traditionally translated as a 'submarine earthquake' although this is a very unlikely explanation.

Instead, *hafgerdingar* probably means an Arctic (superior) mirage, that is, an optical illusion. The superior mirage occurs in clear, anticyclonic conditions when there is a strong temperature inversion in the marine boundary layer. When the vertical *in-situ* temperature gradient exceeds about 0.11 degC m^{-1} (increasing upwards) the variation of refractive index with air density is strong enough for light rays to bend more strongly than the Earth's curvature. This effect allows objects below the horizon to become visible. In extreme cases, the horizon appears to loom up and one appears to be sailing on a concave sea with rising edges like a saucer. These conditions must have unnerved Norse sailors and great courage would have been needed not to steer away from the apparently colossal wall of water ahead. Actually, temperature inversions often precede cyclonic storms (Lehn and Schroeder, 2003) so *hafgerdingar* may well signal deteriorating weather and therefore a genuine threat.

The medieval northern European view of the world, perpetuated by the Church until the Renaissance, held that the Earth was flat or saucer-shaped (Sawatzky and Lehn, 1976). Greek astronomers and philosophers had believed the Earth to be spherical since about the fourth century BC, however. A key observation in support of their view was that ships departing from port would sink below the horizon. Temperature inversions strong enough to cause superior mirages do not occur in the Mediterranean and so would not contradict this evidence. Another reason is the Earth's circular shadow on the face of the moon during lunar eclipses, although, good viewing conditions in the eastern Mediterranean are much more common than in northern Europe because of the clearer skies. Evidently, marine meteorology had a profound and lasting impact on the world views of these two societies.

In one sense, *hafgerdingar* probably helped Norse sailors; under superior mirage conditions, viewing distances are no longer limited by rectilinear paths to the horizon. Rather, light from extremely distant objects that are well below the horizon can be refracted by the temperature inversion to become visible. In some cases, land 300–500 km distant may come into sight. Therefore, it seems possible that the Norse would have occasionally seen the Shetland Islands from Norwegian mountains, the Faeroes from Shetland, Iceland from the Faeroes, the East Greenland ice cap from Iceland and Baffin Island from West Greenland. That is, in their exploration of the subpolar Atlantic they would sometimes, literally, have seen the way ahead.

Climate variability: the North Atlantic Oscillation

The dominant natural mode of variability of the North Atlantic climate system is the well-known North Atlantic Oscillation (NAO). The principal effect of the NAO is on the storm track of cyclones that cross the North Atlantic Ocean towards Europe. During high NAO phases the westerly winds tend to be stronger, causing mild, wet winters in western Europe and cool summers; during low phases Western Europe tends to experience colder, drier winters and warmer summers. The NAO influences many other environmental parameters, too, including East Greenland sea ice, North Atlantic plankton and fish populations and West Greenland winter temperatures and precipitation. There is no reason to suspect the NAO operated in fundamentally different ways 1000 years ago, and so its significant impact on the North Atlantic environment presumably influenced the Greenland Norse, too.

The first unequivocal evidence of the NAO's existence appeared in the writings of the eighteenth-century Danish missionary to Greenland, Hans Egede Saabye. His diary, published in 1745, clearly points to the anti-correlation in the severity of Danish and Greenland winters. There are also interesting earlier remarks about Greenland climate in the *King's Mirror* which clearly reveal an appreciation for *climate* as distinct from *weather*. Indeed, Stephenson *et al.* (2003) conclude from the *King's Mirror* that:

> ''*the Norse knew from their observations that colder than normal conditions in Greenland were associated with more storminess elsewhere – an important aspect of the North Atlantic Oscillation*''.

Nevertheless, it seems rather far-fetched to assert that the Norse knew of the non-local relationships between weather in different parts of the North Atlantic. After all, the NAO is, essentially, a phenomenon that emerges from statistical treatment of climate time series from widely separated stations. (Even with the modern pespective, this author finds it very hard to estimate the phase of the NAO from personal observation because one's memories are unreliable and dominated by extreme events!) Presumably, the Norse were aware of interannual variations in climate, such as winter temperatures, which are partly associated with the NAO (see Figure 7 and the discussion below). And perhaps there is fragmentary, anecdotal evidence of NAO-related environmental changes among the writings that do exist: most likely in qualitative observations of sea ice. But the Norse had no tradition of scientific record-keeping, empirical data analysis, or thermometers and it therefore seems unlikely that they possessed anything close to the modern notion of the NAO.

Climate change

The slow demise of the Norse settlements in Greenland is well-established, but poorly understood. Many reasons have been proposed including successive crop failures caused by a large volcanic eruption in the Pacific in 1453, disease, genetic deterioration, chronic malnutrition, soil erosion, hostility with, or assimilation into, the Inuit population, loss of economic markets, and piracy (Figure 6). Likely no single factor can explain what happened, but climate change is an enduring theme and, at the very least, it appears to have exacerbated an already grim situation. Failure to adapt to changing conditions by modifying traditional farming practices in favour of Inuit technology and expertise was another factor (McGovern, 1981). Norse construction of large elaborate stone churches actually increased in the thirteenth and fourteenth centuries, for example, at the expense of essential subsistence activity. Meanwhile the Inuit, who survived the changing climate, migrated south to explore better territory.

Erik the Red and his followers established their farms in Greenland during the relatively benign Medieval Warm Period (AD600–1150). At this time, raising animals in pastures was possible alongside a few sheltered fjords. Sea-ice conditions were relatively light and permitted safe access for commerce and administration. It appears that for 300 years after the Medieval Warm Period, the climate became colder with shorter growing seasons, greater sea ice, more extensive permafrost and advancing glaciers. For example, sea ice crossed the Denmark Strait in 1306, 1319, 1320, 1321, 1350, 1374 and many times in the 1400s, yet summer sea ice at the Eastern Settlement was probably rare or absent in Erik the Red's

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day. Encroaching ice cut off the Greenland settlements from Iceland and Norway, and prohibited expeditions to *Markland* to collect lumber. Oxygen isotope evidence from the teeth of Norse skeletons clearly shows declining temperatures over several generations (Fricke *et al.,* 1995) and some excavated Eastern Settlement skeletons lay in graves that are now in permanently frozen ground.

Figure 7 shows climate data relevant to this story. The main panel shows a recent reconstruction of the Northern-Hemisphere temperature anomaly over the last 2000 years (Moberg, *et al*., 2005). The Medieval Warm Period, Little Ice Age and Anthropocene clearly stand out. The Norse settled in Greenland when the hemispheric-average temperature was 0.6 ± 0.4 degC warmer than when they disappeared 500 years later. This change is small compared to both the seasonal cycle and the recent interannual variability at Narssarsuaq in the former Eastern Settlement (lower panels). Moreover, the very notion of labelling discrete events, such as the Medieval Warm Period and the Little Ice Age can obscure the true nature of climate variability, which is much

Figure 6. The faces of Greenland. This granite sculpture stands in Qaqortoq, Greenland, in the former Eastern Settlement. It shows on one side a Norse face (left) and on the other a traditional Inuit design of a pagan face. The disappearance of the Greenland Norse settlers in the fifteenth century is well established, but the reasons are unclear. Climate change is a likely factor although assimilation and/or conflict with the Inuit is another possibility. In any case, the Norse farmers died out while the Inuit adapted and survived.

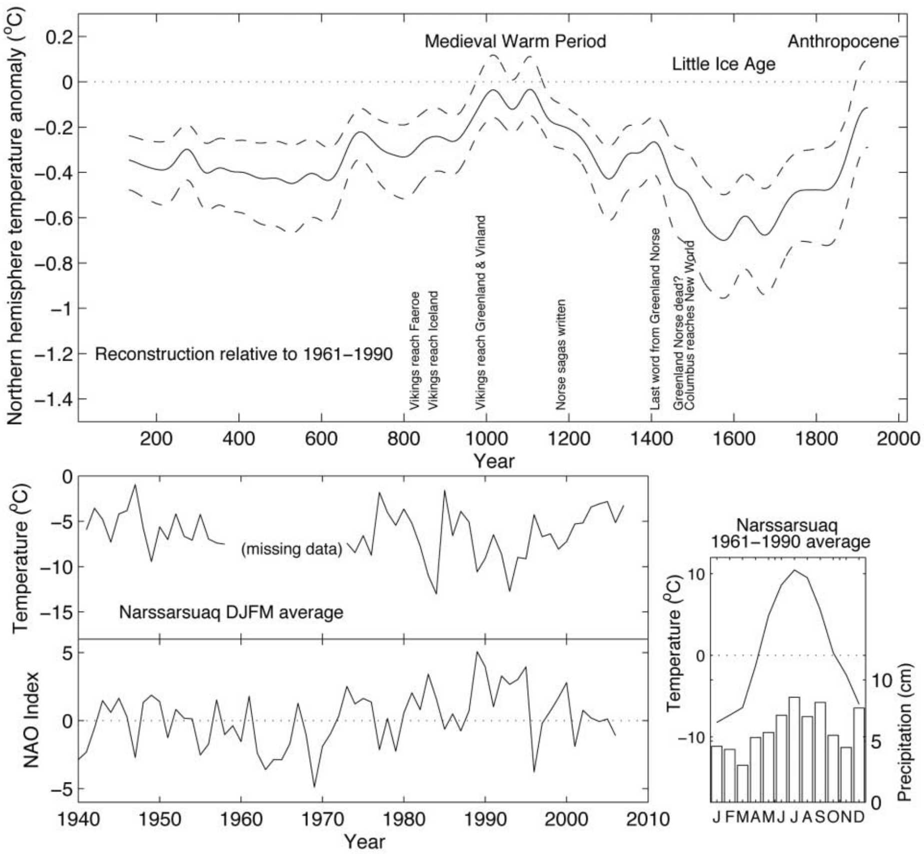

Figure 7. Climate data relevant to the Greenland Norse. The main panel shows the Northern-Hemisphere temperature anomaly reconstruction over the last 2000 years by Moberg et al., *2005 (relative to 1961–1990, with confidence limits). The Medieval Warm Period and the Little Ice Age clearly stand out. The lower left hand panels show Narssarsuaq DJFM average temperatures (upper) and the North Atlantic Oscillation Index since 1940 (lower; from the Climate Analysis Section, NCAR, Boulder, USA; Hurrell, (1995)). The lower right hand panel shows the 1961–1990 monthly average temperature and precipitation data for Narssarsuaq. Present-day Narssarsuaq is in the former Eastern Settlement next to the site of Erik the Red's farm. (All Narssarsuaq data are from the US National Climatic Data Center.)*

more complex (Ogilvie and Jónsson, 2001). Nevertheless, the tendency for increased sea ice, the expansion of Greenland glaciers, changes in precipitation, and the shorter growing seasons presumably had a cumulative detrimental effect on the Greenland Norse. The stress would have been greatest during periods of positive NAO, which is reasonably well correlated with Narssarsuaq DJFM temperatures in the figure (coefficient of –0.63). Times of high NAO during the fifteenth century would presumably have caused cold winter anomalies of 5–6 degC . A period of successive hard winters like those of the late 1980s and early 1990s, on top of the Little Ice Age conditions, would have caused a serious crisis.

A few people in Iceland and Norway were aware of the changing climate, and especially the worse ice conditions in the fourteenth and fifteenth centuries. The Pope complained in 1492 that the Bishopric at Gardar, Eastern Settlement, had not been relieved for 80 years due to the ice, for instance. Most Greenland Norse were coping with the increased challenges of their day-to-day survival, however, and were probably unaware of how the climate was slowly changing around them.

Conclusions

In conclusion, the Greenland Norse knew of tides, ocean currents, sea ice, and weather. They were exposed to decadal and centennial climate variations, but probably without realizing it. Their knowledge was at best semi-quantitative and existed in the context of an epistemology that seems primitive today. Yet, their knowledge was essentially robust and through exploitation of their technologies they achieved great discoveries in adverse conditions.

At the dawn of the third millennium, and the fourth International Polar Year, it is sobering to think how these statements may equally apply to our own efforts one day. In expanding our knowledge of the North Atlantic environment, and learning to live in it, there is much about the Norse explorers to inspire us.

Further reading and acknowledgements

I highly recommend the encyclopaedic *Vikings: The North Atlantic Saga* by W. W. Fitzhugh and E. I. Ward (Smithsonian Books, Washington, 2000) and *The Vinland Sagas: The Norse Discovery of America* by M. Magnusson and H. Palsson (Penguin Books, London, 1965) as fascinating and accessible introductions to the Norse story. I have used information from these sources freely here. Figure 2 is from the Map Collection of The National and University Library of Iceland: (http://kort.bok.hi.is/index.php). Figure 5 is shown with permission of the Hakluyt Society, London (established in 1846), which seeks to advance knowledge and education by the publication of scholarly editions of primary records of voyages, travels and other geographical material (http://www.hakluyt.com/index.htm). All photographs are by the author.

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