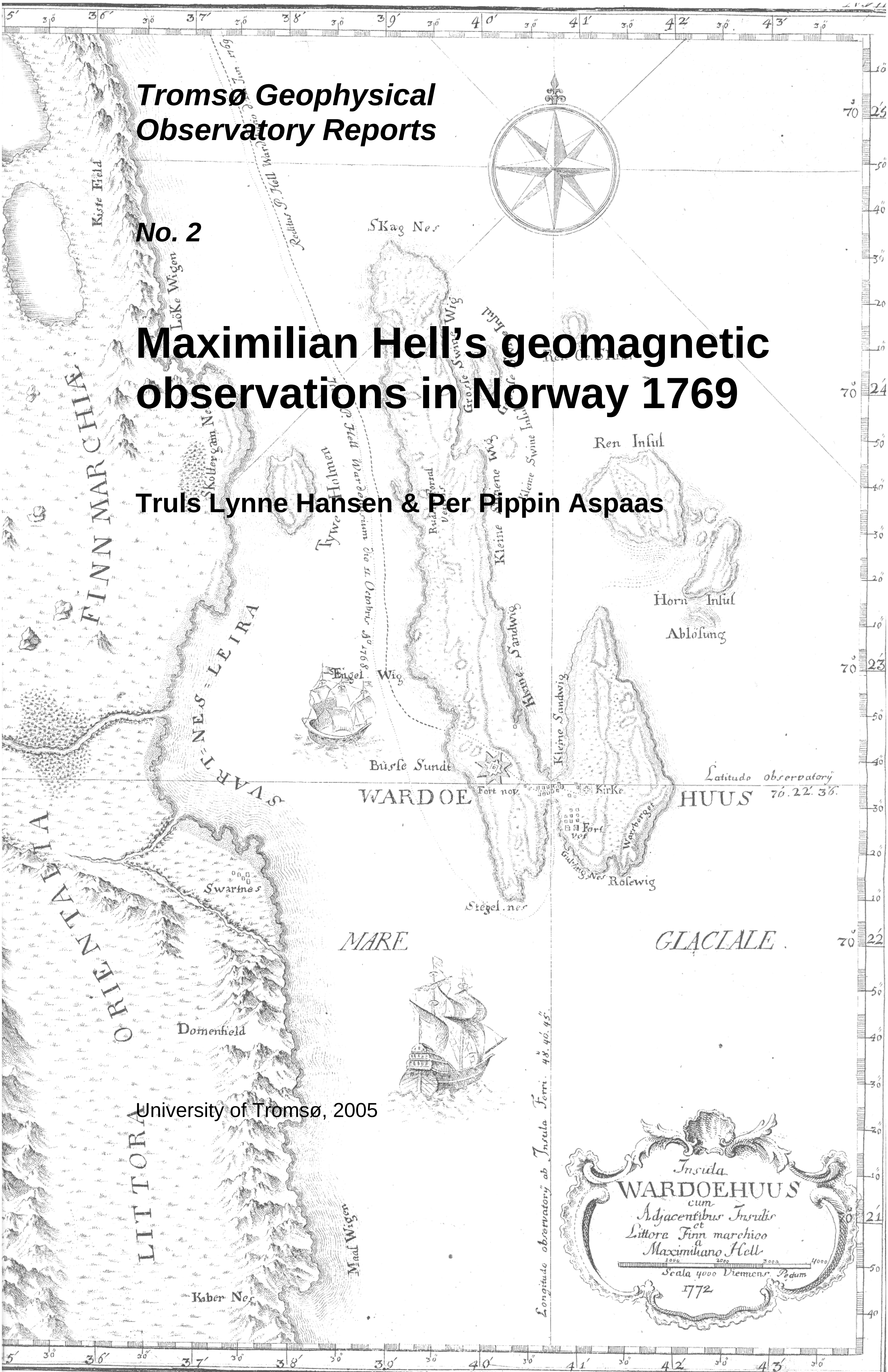


Tromsø Geophysical Observatory Reports

No. 2

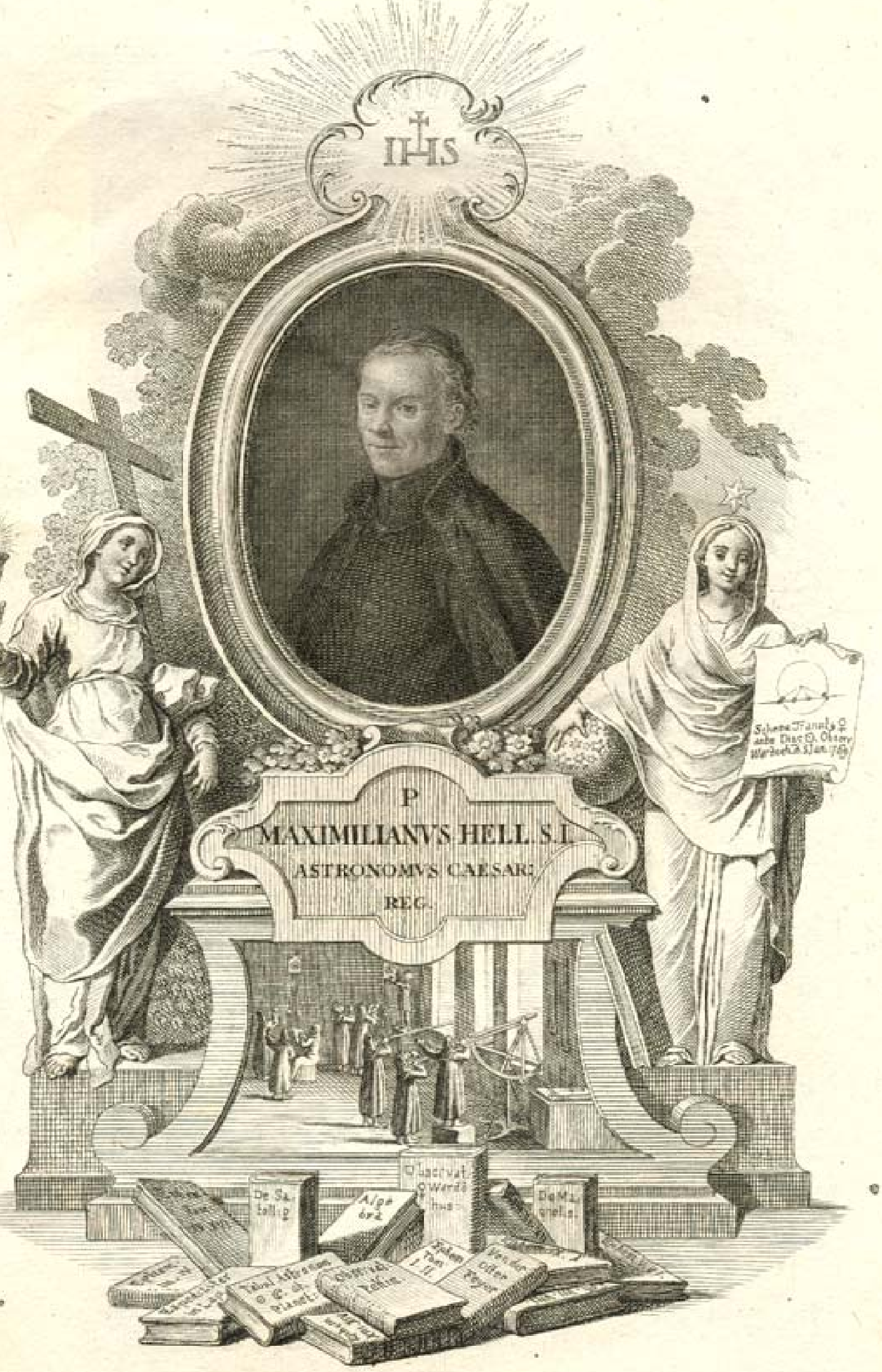
Maximilian Hell's geomagnetic observations in Norway 1769

Truls Lynne Hansen & Per Pippin Aspaas

University of Tromsø, 2005

Cover illustration: Maximilian Hell's map of his observing site Vardø with surroundings. From *Ephemerides Astronomicae ad Meridianum Vindobonensem Anni 1791* (Hell 1790).

Tromsø Geophysical Observatory Reports is a series intended as a medium for publishing documents that are not suited for publication in refereed journals, but that Tromsø Geophysical Observatory nevertheless wishes to make accessible to a wider readership than the local staff. The topics of the reports will be within, or at least related to, the disciplines of the Observatory: geomagnetism and upper atmosphere physics, the history of these included. The language will primarily be English.



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No. 2

Maximilian Hell's geomagnetic observations in Norway 1769

Truls Lynne Hansen
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&

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Europas Mathematiker haben seit Kepplers und Newtons Zeiten sämmtlich die Augen gen Himmel gekehrt, um die Planeten in ihren feinsten Bewegungen und gegenseitigen Störungen zu verfolgen; es wäre zu wünschen, dass sie jetzt eine Zeitlang den Blick hinab in den Mittelpunkt der Erde senken möchten, denn auch allda sind Merkwürdigkeiten zu schauen. Es spricht die Erde mittelst der stummen Sprache der Magnetnadel die Bewegungen in ihrem Innern aus, und verstünden wir des Polarlichtes Flammenschrift recht zu deuten, so würde sie für uns nicht weniger lehrreich seyn.

Christopher Hansteen 1819

University of Tromsø, 2005

Prologue

In 1819 Christopher Hansteen[1] issued the book *Untersuchungen über den Magnetismus der Erde*, today a classic in geomagnetism. While compiling data for his work, Hansteen came across an announcement by Maximilian Hell that magnetic observations carried out in Norway in 1769 were to be published. Hansteen did not find any such publication and remarked in a footnote in his book (p. 468):

I do not know whether this Expeditio litteraria *was ever printed. If that is not the case, it would be a valuable work to extract these observations from Father Hell's surviving manuscripts and publish them, since they probably will throw new light on the magnet theory.*

Expeditio litteraria was a grand exposition planned by Hell to describe the results from his Venus transit expedition to northern Norway in the years 1768-69. The work did, however, come to nothing. Fragments were published otherwise, but no magnetic observations.

We have followed the advice of Hansteen and present here what was found among Hell's unpublished manuscripts. Maximilian Hell's magnetic observations in Norway missed the opportunity to influence contemporary science, but even today, 236 years after they were recorded, they have not lost all their interest to geomagnetism, a science of large time scale. In a strictly geomagnetic perspective, their essential content could have been presented on a few pages. We have, however, chosen a wider perspective, included a historical framework, and let the voice of Hell himself be heard. It is our hope that this makes the story of the observations even more interesting to geomagneticians, as well as attracting a few readers among historians. Such a wider audience, however, inevitably leads to compromises in the exposition; we apologise to the geomagneticians and astronomers for explaining terms and technicalities obvious to them, and on the other hand, hope historians forgive us a few passages of mathematics.

This account is based on Hell's surviving manuscripts written in Latin. We have made extensive use of quotes from these manuscripts and several other 18th century writings. Acknowledging the position of English as the modern language of science, we have translated all of them to English. Hopefully not all scent of 18th century science has been lost in translation. In favour of those who wish to consult the Latin originals, reproduction of Hell's manuscript is also included.

We are pleased to express our gratitude to Professor Maria G. Firneis of Vienna who made this work possible by giving us access to Hell's manuscripts and providing the permission to reproduce them.

[1] Christopher Hansteen, 1784 – 1873, Norwegian geomagnetician and Professor of astronomy and mathematics at the University of Christiania (Oslo).

The magnet Earth

When the Austrian-Hungarian Jesuit Father Maximilian Hell in 1768 travelled to the small town of Vardø in the remote, sub-arctic northeast of Norway, his primary objective was to observe the transit of Venus the following year. His scientific programme did, however, encompass a wide range of secondary projects, one of them being geomagnetic observations, or as Hell put it, "observations of the magnetic needle". Geomagnetism attracted considerable interest in the 18th century, partly due to its importance to navigation, partly because terrestrial magnetism presented a range of puzzling phenomena. The opening words of the Swedish physicist Wilcke[2] in a paper of 1777 are illustrative:

The magnetic needle is a small and modest instrument, but it has provided us with great discoveries and presumably will reveal more to us in future. As the indispensable companion to the seafarers this needle has contributed to the improvement of trade and navigation. It has enhanced our knowledge of the Earth, and told us about the so far unexplained magnetic force completely surrounding our planet. The recent discovery of a relation between this force and atmospheric phenomena gives hope for more knowledge if we pay attention to the silent speech of the tiny movements of this needle.

The early history of geomagnetism is also the history of the mariner's compass. In Europe this remarkable instrument of navigation certainly was used as early as the 13th century. During the Middle Ages the magnetic needle was assumed to point exactly north-south. Some time early in the 15th century this view was modified. Portable sundials from this period are furnished with a compass for orientation, and the mark for geographic north is shifted from the magnetic north. This angle between the geographic north and the magnetic needle of the compass was referred to as the "variation" or "deviation" of the compass. In the science of geomagnetism the term magnetic *declination*[3] is commonly used.

When the Europeans started expanding world wide over the oceans in the 15th century knowledge of the magnetic declination became of great importance, and as a result we have a large number of observations dating from as far back as the first half of the 16th century. This practical application of geomagnetism has until recently been an important motivation for studies of the Earth's magnetic field, in particular among the major seafaring nations.

Towards the end of the 16th century another surprising property of the magnetic needle was discovered; when mounted on a horizontal axis (in contrast to the vertical axis in a compass) it came to rest in a position inclined to the horizontal. This "newe attractuie" - as its discoverer Robert Norman[4] put it – was announced in 1582, and gave William Gilbert[5] the clue he needed to assert that Earth itself was a magnet, a big one, but in principle not different from any other magnet. Gilbert published this far-reaching conclusion in his famous book *De magnete* in the year 1600. With this the Earth was ascribed a new property, and terrestrial magnetism as a discipline of science emerged. From now on the magnetic needle not only was a tool for navigation, but also an instrument used to explore Earth. A geophysicist should measure not only the horizontal angle of declination, but also the vertical dip or *inclination* of the magnetic needle.

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[2] Johan Carl Wilcke, 1732 – 1796, Swedish physicist working in Stockholm.
[3] Not to be confused with declination in astronomy.
[4] Robert Norman, flourished second half of 16th century, English sailor and instrument maker.
[5] William Gilbert, 1540 – 1603, English physician and scientist.

At Gilbert's terrestrial magnet the magnetic poles are shifted at some distance away from the geographic poles. This roughly explained the values of declination observed.[6] Furthermore, in accordance with Gilbert's theory an inclination needle would point vertically at the magnetic poles (inclination 90 degrees) and horizontally at magnetic equator (inclination 0 degrees). At an intermediate place like Europe the inclination would, as observed, be somewhere between these two extremes.

When *De magnete* appeared, magnetic declination and inclination were regarded as constant over time. However, around 1640 comparison of declinations measured at the same site over several decades made clear that the declination was slowly changing with time. To the scientists this so-called secular change remained a puzzle for 300 years. To the navigators of the oceans it implied that the task of mapping the variation of the compass was never-ending, since old values could not be trusted for more than a few decades.

The image of Earth as a slowly changing but otherwise stable magnet lasted for about a century. Around 1680, there appeared indications of variation also on shorter time scales, and in 1724 George Graham[7] demonstrated beyond doubt that the magnetic needle had a small diurnal variation as well as periods of irregular variations. During the next decades this was corroborated by several observers, and soon an even more mysterious and totally unexpected correlation between the irregular events and occurrence of Northern Lights also was discovered. Such was the situation of geomagnetic research as Father Hell set out for Vardø[8].

It should be kept in mind when studying 18th century geomagnetism that the convenient concept of "magnetic field" was very vague to the scientists of that century; it did not come into common use until far into the next century. At the time of Hell, both declination and inclination were conceived as results of an attraction by another magnet, not as the result of a magnetic field filling the space around the magnet, and was therefore referred to as the declination or inclination "of the needle".

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[6] Gilbert himself did not explain the declination by a displacement of the magnetic poles. Instead he sought the explanation in the asymmetries of Earth caused by the positions of continents and oceans.

[7] George Graham, 1673 – 1751, renowned English instrument maker, member of the Royal Society in London.

[8] Good summaries of the history of geomagnetism are given by among others Bartels and Chapman (1940), McConnell (1980) and Stern (2002). For a popular account see Hansen (1996).

The transits of Venus

The passages of Venus across the Sun's disc in 1761 and 1769 are highlights of 18th century science, the principle aim being to measure the scale of the solar system. The Newtonian theory of gravitation and mechanics of the previous century had greatly improved the methods to calculate the movements of the planets, but there were still large uncertainties about the actual distances from the Sun to the various planets. Transit of Venus was one way to solve the problem; observations of Venus crossing in front of the Sun from widely separated sites on Earth would reveal tiny shifts from which the distance between the Sun and Earth could be deduced.

The idea was first put forward in an elaborated form by the English astronomer Edmund Halley[9] in 1716. He pointed out the importance of taking advantage of the pair of forth-coming transits 6th June 1761 and 3rd June 1769, the next pair being as far away as 1874 and 1882. The subtle effects to be observed required as many observations as possible from sites ranging as far apart as possible. This clearly was an enterprise demanding international co-operation in science on a scale never seen before.

This project appealed to the 18th century mind of scientists as well as sovereigns. Despite rivalry and even wars between states on the political level, Great Powers such as Britain and France managed to co-operate. In the year 1761, according to the standard history on the Venus transits of the 18th century (Woolf 1959), about 124 trained observers, scattered around at least 65 places took part.

The 1761 results were, however, not satisfactory, and new expeditions with more grandiose ambitions were prepared for the forthcoming transit of 1769. As a consequence, data from more than 76 observational posts made their way to Lalande[10] in Paris who was to synthesize the results. In some cases, individual expeditions were given cross-disciplinary orders on a scale barely seen before. Notably, the principal justification for James Cook's[11] first circumnavigation of the globe in the years 1768-1771, was to observe the transit of Venus from the island Tahiti. With gifted painters, naturalists, and astronomers among the 96 men onboard, he not only succeeded in observing the transit itself, but also explored large parts of the southern seas.

In the northernmost parts of Europe (see map Figure 1), observers from several nations were involved in the Venus activities of 1769. The Swedish Academy of Sciences organised observations by Hellant[12], stationed at Torneå, Mallet[13], at Pello, and Planman[14], at Cajaneburg (modern Kajaani); the Royal Society of London sent the two observers Bayly[15] and Dixon[16] to Hammerfest and the Nordkapp (North Cape) area; the Russian Academy of Sciences sent their astronomer Rumovskiy[17] to the town Kola and invited the Swiss

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[9] Edmund Halley, 1656 – 1742, Astronomer Royal from 1720, most famous for his work on "Halley's comet".
[10] Joseph Jérôme Lefrançais de Lalande, 1732 – 1807, French astronomer.
[11] James Cook, 1728 – 1779, English sailor and explorer.
[12] Anders Hellant, 1719 – 1789, a member of the Swedish Academy of Sciences participating in a wide range of scientific activities. He lived in Torneå (thus, he was the only observer in these parts who did not need to travel in order to reach his destination).
[13] Fredrik Mallet, 1728 – 1797, Swedish astronomer.
[14] Anders Planman, 1724 – 1803, Swedish astronomer.
[15] William Bayly, 1737 – 1810, English astronomer.
[16] Jeremiah Dixon, 1733 – 1779, English surveyor and astronomer.
[17] Stepan Yakovlevich Rumovskiy, 1734 – 1812, Russian astronomer.

astronomers Mallet[18] and Pictet[19], who where to observe from the villages Ponoi and Umba on the Kola Peninsula. Geomagnetic observations were standard procedure at these expeditions like many of the others around the world.

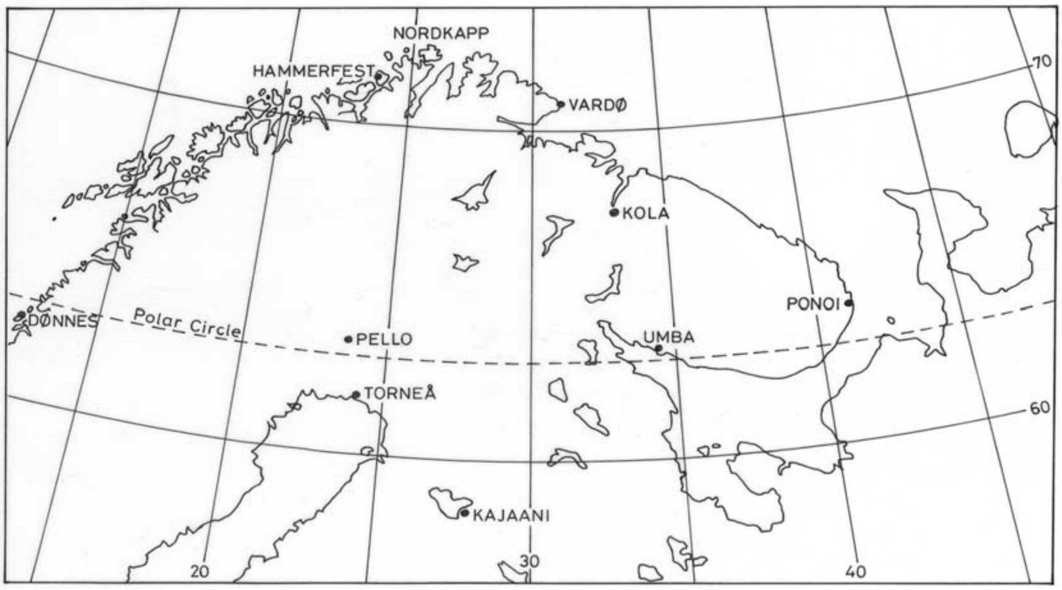

Figure 1 The observing sites for the 1769 transit in northern Fennoscandia and north-west Russia.

Although France and Britain played leading parts in the Venus-activities of the 1760s, comparatively smaller nations such as the kingdom of Denmark-Norway also wanted to make themselves heard. Observational attempts of 1761 in Trondheim and Copenhagen were, however, no success at all: At Trondheim, the weather was bad; in the capital, although the weather was perfect and the Astronomer Royal, Christian Horrebow[20], himself presided at the observations, the results were ridiculed due to the observers' inability to keep correct track of the time (Thykier *et al.* 1990, vol. II, pp. 251-252).

For the 1769 observations, Denmark-Norway needed help from abroad. Action was taken in the inner circles at court in order to engage a highly competent astronomer from Austria, the Jesuit and Royal-Caesarian Astronomer Maximilian Hell. On 5th September 1767, Father Hell was contacted by the Danish ambassador and presented with an invitation to travel to Vardø in the extreme northeast of Norway in order to observe the transit[21].

[18] Jacques-André Mallet, 1740 – 1790, Swiss astronomer.
[19] Jean-Louis Pictet, 1739 – 1781, Swiss astronomer and surveyor.
[20] Christian Pedersen Horrebow, 1718 – 1776, Astronomer Royal of Copenhagen from 1753.
[21] The Royal Society in Copenhagen did in fact organise two further expeditions to Norway the same year. Professor Kratzenstein (see note 37), who also had participated in the 1761 observations, was to observe the transit in Trondheim. Likewise, a brother of the Astronomer Royal, Peder Horrebow (1728 – 1812), and his assistant Ole N. Bützow (see note 69), went to Norway in spring with the intention of reaching Tromsø, but unfavourable winds forced them to station themselves further south at Dønnes. As it turned out, bad weather spoiled all the Copenhagen-sponsored transit observations apart from those of Maximilian Hell, who in any case led the most prestigious expedition.

Father Hell

Maximilian Hell (also called Max Höll, and in Hungarian, Hell Míksa) had been born in Schemnitz, or Banska Stiavnica in modern Slovakia, on 15th May 1720. As a Jesuit, Father Hell had received astronomical instruction at the highest level; a considerable number of the world's best observatories were in Jesuit hands at the time. The Empress Maria Theresa had in the year 1755 appointed him Royal-Caesarian Astronomer (*astronomus caesareo-regius*) and given him orders to erect a university observatory in addition to the Jesuit observatory already in existence in the capital. From the year 1756 onwards, Hell had published the Vienna Ephemeris (*Ephemerides Astronomicae ad Meridianum Vindobonensem*), every year including a wide range of scientific articles as appendices, most of them written by the editor himself. As a matter of course, Hell and his staff had participated in activities to observe the 1761 transit. And not only had he received distinguished guests from abroad on this occasion, he had also published a long critical article in which he summarised his own as well as other colleagues' observations (Hell 1761). Thus, Father Hell was a prestigious candidate for Denmark-Norway to employ[22].

To Hell, on the other hand, the offer to travel to the high north of Norway must have been a tempting one, from at least three perspectives:

- Hell had planned to observe once again from Vienna, although its geographical position precluded decisive results: The Venus transit on 3rd June 1769 was going to take place in the middle of the night at European longitudes, and one needed to travel to the land of the Midnight Sun in order to observe it in its entirety (a fact stressed already by Halley). This made the coast of Finnmark, and Vardø in particular, an obvious place for observations.

- The Protestant kingdom of Denmark-Norway laid strong restrictions on Catholics, especially Jesuits, who normally were not allowed to enter it at all[23]. With an invitation from the King himself, this was a unique opportunity not only for Father Hell himself, but so also for the whole order, to visit Scandinavia.

- In the international world of science, the region in question was virtually *terra incognita*. The Lapland travel of Carl Linnaeus[24] in 1732 and the geophysical expedition of Maupertuis[25] in 1736-37 both had gained international recognition, but they had not visited the area in question. So, with the King as sponsor, this was an opportunity to break new ground scientifically.

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[22] See Ferrari d'Occhieppo (1971, 1973) for more on Hell's background and career.

[23] See Kragemo (1960, 1968); Opsahl and Sogner (2003, vol. I, pp. 240-258).

[24] Carl Linnaeus (also named Carolus, later Carl von Linné), 1707 – 1778, famous botanist and author of the Systema Naturae.

[25] Pierre Louis Moreau de Maupertuis, 1698 – 1759. Led an expedition to the Torne valley in Northern Sweden (nowadays forming the border between Sweden and Finland) where theories on the shape of the Earth were tested by means of latitudinal measurements.

Preparations and travelling, 1767-1768

In the period between Hell's invitation on 5th September 1767 until he set off from Vienna on 28th April 1768, he prepared himself for an expedition of considerable scale. From the Jesuit milieu he invited the younger Joannes Sajnovics[26] to be his assistant. A trained astronomer as well, Sajnovics was to assist in the daily scientific work and take part in the 3rd June observations. He was also given instructions to investigate a possible linguistic link between the Hungarian and Sámi languages. Furthermore, he wrote an amusing diary during the whole expedition, which has survived in almost complete form as manuscript. Also a servant, Sebastian, and a dog, Apropos, took part in Hell's expedition from the start.

Meanwhile, preparations were being made in the scientific and administrative circles of Denmark-Norway. Johann Ernst Gunnerus[27], bishop of Nidaros and devoted naturalist, got his young assistant, Jens Finne Borchgrevink[28], attached to the expedition. Borchgrevink had travelled in northern Norway before and had relatives there. Furthermore, he had received education in Uppsala from Professor Linnaeus. He thus was to fill the triple role of scientific assistant, translator and "tour guide" to the company[29].

After leaving Vienna in late April, Hell and Sajnovics reached Travental in Holstein[30] on 30th May 1768. At the time, the Danish-Norwegian King Christian VII was residing in his castle here. They were given an audience and had occasion to discuss the expedition with the King in person[31].

From Travental they proceeded to Travemünde near Lübeck from where they sailed to Copenhagen. They stayed there for three weeks until 3rd July, supplementing their set of scientific instruments. Thereafter they crossed to Sweden, travelling on less than comfortable roads from Helsingborg via Christiania[32] to Trondheim, which they reached on 30th July. Here they were joined by Borchgrevink and the final preparations were made for the last part of their journey. On the ship *Anden* ("the Duck", Figure 2), they sailed along the coast for seven weeks until reaching the destination of Vardø on 11th October 1768.

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[26] Joannes (János) Sajnovics, 1733 – 1785, astronomer in Tyrnau, or Trnava in modern Slovakia (then part of Hungary). Sajnovics had previously been one of Hell's assistants at the observatory in Vienna.
[27] Johann Ernst Gunnerus, 1718 – 1773, bishop of Nidaros from 1758 and one of the initiators of the founding of the Royal Society in Trondheim, whose vice-president he was. The diocese Nidaros included the entire north of Norway.
[28] Jens Finne Borchgrevink, 1736 – 1819, studied under Linnaeus in 1766, became a priest in 1771.
[29] See Voje Johansen (2004) for more on his role in the expedition.
[30] In Holstein of northern Germany; the King of Denmark also was Duke of Holstein. When they met, the King was setting out for an 8 months' tour of Europe.
[31] Hell and Sajnovics both admired this King, whose posthumous reputation has been less than good. See the extracts of Sajnovics' diary in Littrow (1835, pp. 99-101).
[32] Now Oslo, capital of modern Norway.

The reports from the expedition

On 17th October 1769 Hell and Sajnovics again reached Copenhagen, after 15 months of scientific explorations in Norway. They stayed in the capital until 22nd May the next year. During this period they held lectures and started editing their results for printing. Not until 12th August 1770 did they return to Vienna.

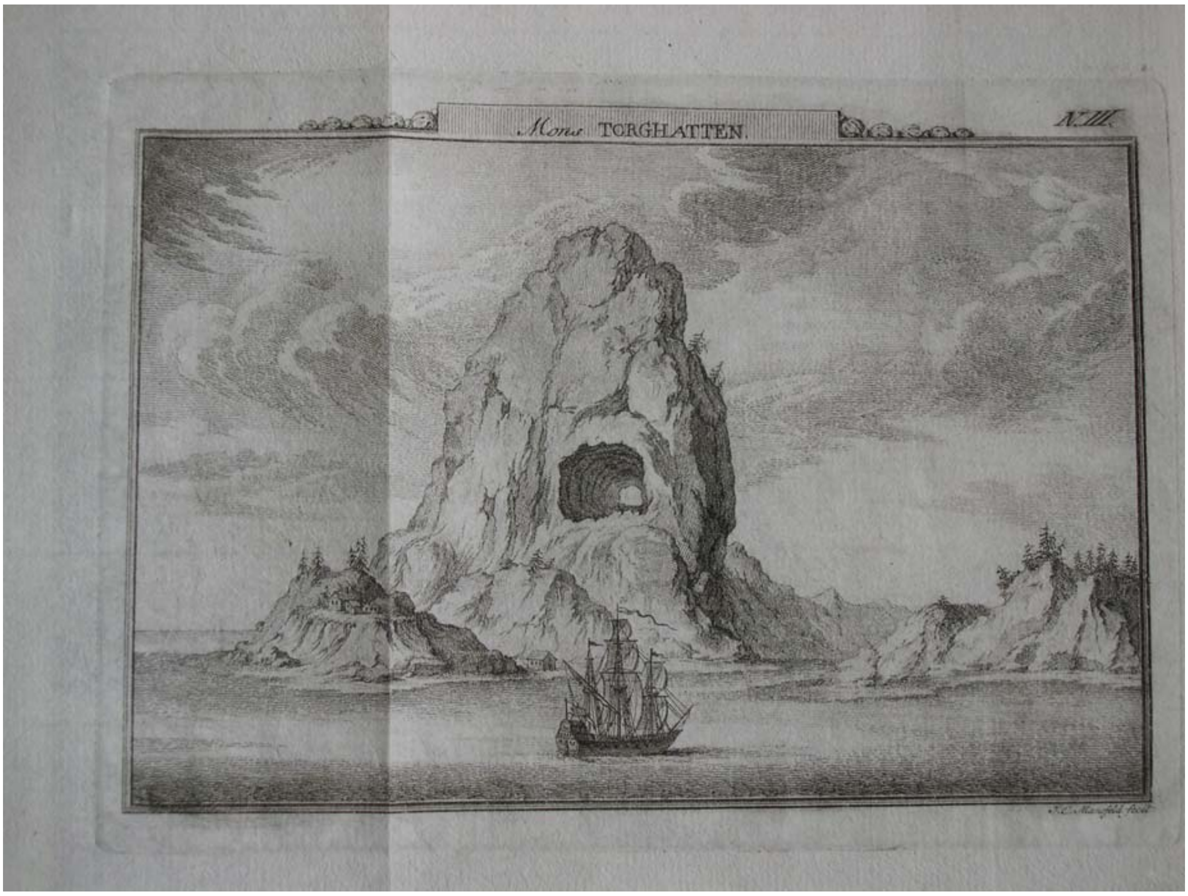

Figure 2 The expedition vessel "Anden" in front of the renowned island of Torghatten. From *Ephemerides Astronomicae ad Meridianum Vindobonensem Anni 1791* (Hell 1790).

Maximilian Hell had ambitious plans for publication of the expedition's results. He aimed on an integral presentation, in the form of three large volumes covering both the story of the expedition and a series of scientific articles on northern Norway. A large number of maps and other illustrations were supposed to ornate the work, which Hell planned to call *Expeditio litteraria ad Polum Arcticum* ("Literary Expedition by the North Pole"[33]).

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[33] It is tempting to translate *ad Polum Arcticum* as "to the North Pole", as is done both by Sarton (1944, p. 104) and Kragemo (1960, p. 122). However, the preposition *ad* was also a standard designation for "close to, near, by". Another common usage of *ad* was "towards, in the direction of". However, one of the manuscripts reproduced below (MS *Hell b* 1) has the heading: "The method used for observing the magnetic needle's declinations during the literary journey *ad Polum boreum*". Since this manuscript deals exclusively with observations on the *southbound* part of the journey, the translation "by the North Pole" seems most likely. Hell may intentionally have used a vague term, but he certainly did not boast at having reached the Pole!

Unfortunately, Hell never managed to publish these three volumes, but in a call for subscriptions, he laid out the contents of the work (Hell 1770*c*):

1. The first volume he called "historical" (*Historicus*). Here, he planned to explain the reasons why the expedition came about, and present a complete diary of the whole journey from the day they left Vienna in spring 1768 until they returned there more than two years later. The diary of Sajnovics mentioned above was apparently meant to fill up most of the opening part of volume I. Then, Sajnovics' work on the Sámi language would form the basis for the rest of this volume, in which ethnographical, linguistic and historical treatments on the Sámis were planned. Sajnovics did in fact publish a treatise on his findings of similarities between the Sámi and Hungarian languages (1770, 1771), which would have fitted well into this context.

2. The second volume was to be called "physical" (*Physicus*), a term covering a somewhat broader range of subjects in Hell's time than nowadays. The first part would treat the different species of animals, plants and algae found in the coastal areas of northern Norway. Then, Hell would discuss theories on whether the sea level was in decrease or increase. Furthermore, he would present his explanation of the phenomenon called "morild" (the nightly luminescence of the sea), which Hell rightly found to be caused by small shrimps now called *Metridia longa* or *M. lucens* (Johansson 2003). A treatise on the Northern Lights (*aurora borealis*) was also to be included here – a treatise which Hell did publish parts of in an appendix to his *Ephemerides* (Hell 1776). Finally, Hell planned to include weather observations, barometric measurements, and several comments on natural resources such as the fisheries, reindeer herding etc. in the northernmost region of Norway. Apart from his Northern Lights theory, only some weather reports were published of this whole volume (Hell 1792).

3. The third volume Hell called the "mathematical-astronomical volume" (*Mathematicus et Astronomicus*). The first part was to be devoted to a description of the observatory and instruments, as well as the observation of the Venus transit, which was to be compared to the observations made by other astronomers elsewhere and lead to a calculation of the solar parallax. All this was published in separate publications (Hell 1770*a*, 1772, 1773). The second part was to contain various geographical measurements, notably the longitude and latitude of Vardø, and latitudes observed along the journey from Copenhagen to Vardø and back. Most of this was published (Hell 1770*b*, 1790). In the fourth and last part of this volume, Hell was to discuss a theory on how to study the shape of the earth as well as the height of mountains etc. by the use of barometers. The third part of this third volume he devoted to the geomagnetic observations (1770*c*, p. 432):

Volume III, Part III. Observations pertaining to the theory of the magnetic needle's deviations. Chapter I: The instruments used in Vardø for magnetic observations are described. Chapter II: Observations of the magnetic needle's deviations, made day and night, at almost every hour, are laid out. Chapter III: The reason which apparently causes the magnetic needle to show deviations daily, almost every hour of the day, is discussed. Chapter IV: The method used in order to observe the magnetic needle's deviations during the journey is laid out. Chapter V: The magnetic observations made during the Arctic journey, at various latitudinal and longitudinal positions, are discussed.

As stated above, Professor Hell found himself incapable of publishing the *Expeditio litteraria.* The dissolution of the Jesuit order by Pope Clemens XIV in the summer of 1773, less than two years after Hell's return to Vienna, was no doubt an important reason for this. Apart from a serious blow to Father Hell personally, this meant that he lost the opportunity to make use of staff paid by the order to aid him in his daily work, so that he had to concentrate fully on his duties as Royal-Caesarian Astronomer. Realising the failure towards the end of his life, he started printing small fragments of the expedition material in the early 1790s. The magnetic observations were announced more than once. Finally, in the last *Ephemerides* he edited, Hell made the statement that (1792, p. 354):

The observations of the magnetic needle performed both in Vardø and during my literary journey, as well as the method by which a traveling astronomer may easily and exactly calculate the meridian line without knowing the time, nor using a horologe, but solely observe the altitude of the sun through the use of a traveler's quadrant, will be reserved for the third fragment [*of the* Expeditio litteraria]*, which is to be published in our Ephemerides.*

Father Hell died on 14th April 1792, leaving most of his manuscripts concerning the Vardø expedition unpublished.

The manuscripts and their history

The major collection of Father Hell's surviving manuscripts is still kept in the Vienna University Observatory[34]. These manuscripts were for some time in private hands (Firneis 2003), but made their way to the Vienna observatory in the first decades of the 19th century. We may say they then "returned home", since this observatory had been Professor Hell's main workplace for almost 40 years.

The young Carl Ludwig Littrow[35], son of the director of the Vienna observatory and later to become director there himself, set out to publish parts of Hell's surviving manuscripts in the early 1830s. His book *P. Hell's Reise nach Wardoe* (1835) is imbued with an exceptionally hostile attitude on the part of the editor. The compelling story of how Littrow doubted Hell's observations, and accused him of having forged them, and the vindication of Hell by Simon Newcombe 50 years later, is, unfortunately, beyond the scope of this report. Interested readers are referred to Newcombe (1883), Pinzger (1927)[36], Sarton (1944), Nielsen (1957), Kragemo (1960) or Aspaas and Voje Johansen (2004). None of these publications has been concerned with the geomagnetic observations, and to our knowledge, no work on them has so far been published.

Thanks to the helpfulness of Professor Maria G. Firneis we were given access to these manuscripts in the summer of 2003, when Per Pippin Aspaas along with Nils Voje Johansen from the Department of Mathematics at the University of Oslo visited the observatory. All writings concerning the geomagnetic measurements were selected for photographing, and are presented here.

Subsequent chapters of this report give a presentation and evaluation of the observations missed by Hansteen. They fall naturally in two parts: first, a time series of declinations recorded in Vardø from April to June 1769, and second, observations of declinations at several sites on his way back to Copenhagen during summer and autumn the same year. The Vardø observations are found in a set of sheets *in folio* (roughly our A3 format), including also Hell's description of his instruments and methods. These notes have probably been written in Vardø. The manuscript is reproduced on pages 45 to 59 as MS *Hell a* 1-14.

The observations from the return journey are found in a second set of sheets of the same format, but they are not devoted to geomagnetic measurements alone. What we are dealing with seems to be some sort of large format "notebook" in which Hell scribbled down notes during his voyage southwards to Trondheim as well as during his journey overland further south towards Copenhagen. Even here Hell has elaborated on his method of observation. As the company progresses south, the geomagnetic measurements become increasingly unsystematic and are in the end dropped entirely. We have nonetheless chosen to reproduce most of these pages as well. They have been numbered MS *Hell b* 1-52, and are found on pages 61 to 105.

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[34] Filed under "Chr 90. Manuscripte von Hell. Mappe 1-4" at the Institut für Astronomie der Universität Wien, Türkenschanzstraße 17.

[35] Carl Ludwig (later Karl Ludwig von) Littrow, 1811 – 1877, astronomer. From 1842 director of the Vienna University Observatory.

[36] This is the second part of a two-volume work from the years 1920-1927, commemorating Maximilian Hell and especially his Vardø-expedition. The main text is in Hungarian, though the second volume includes several letters and other texts written by, or addressed to, Professor Hell – in German, Latin, and French. There is also a German summary at the end of volume two.

Apart from these two main sources, the geomagnetic measurements of Father Hell are briefly mentioned in a few other texts also found among Hell's manuscripts in the Vienna University Observatory.

MS *Hell c* refers to Hell's "astronomical notebook", covering observations along his journey northward to Vardø as well as during his stay there. Hell's main concern in this notebook has been to describe purely astronomical activities (notably, the observation of the Venus transit on 3rd June). On one particular occasion, however, he also mentions his geomagnetic observations. The extract of interest is reproduced on pages 107 to 109.

MS *Hell Kratzenstein* 1-2 refers to an incomplete draft of a letter from Maximilian Hell to Professor Kratzenstein[37], written at Trondheim in August 1768. This letter was found among Hell's manuscripts in Vienna and is reproduced on pages 111 to 113.

We have also made use of the travel diary of Father Sajnovics, whose primary aim it was to give a popular account of the journey. Thus, the bulk of this text is concerned with extra-scientific matters[38]. However, he often mentions in brief whatever scientific activities were performed during the day, summarises details about the weather, and so on. We have referred to this diary as MS *Sajnovics* and date. A few important pages will be found at the end of this report.

[37] Christian Gottlieb Kratzenstein, 1723 – 1795, Born and educated in Germany, worked in St. Petersburg 1749-1753, thereafter professor of experimental physics at the University of Copenhagen.

[38] Extracts from this text have been printed in translations – in German by Littrow (1835) and in Norwegian by Daae (1895) and Kragemo (1960). There are also two Hungarian translations, based on Littrows text by František Tibenský (Bratislava: Tatran, 1977), and on the Latin manuscripts by András Deák (Budapest: ELTE Finnugor Nyelvtudományi Tanszék, 1990). Furthermore, a small extract of the Latin original appears in Pinzger (1927).

Note on translations

Maximilian Hell's handwriting is in general rather easy to read. Translating it is another matter. His Latin is of a technical kind, with terms and expressions peculiar to 18th century science. Moreover, some of Hell's notes, apparently scribbled down solely with the aim of aiding his own memory, serve as less than clear-cut explanations today. In our English versions we have tried to render the sense of Hell's sentences intelligible to the modern reader, partly by putting in stop marks, partly by explaining vocabulary in our comments. Sometimes extra words have been put into our translations in [brackets].

In the same vein, all quotations from printed texts in languages other than English have been translated. The original Latin, German, Swedish, Norwegian, or Danish wordings are found in the publications referred to.

The spelling of names of places has in many cases changed considerably since the 18th century, and for minor places the spelling also was somewhat haphazard. We have therefore used the modern versions even in quotes.

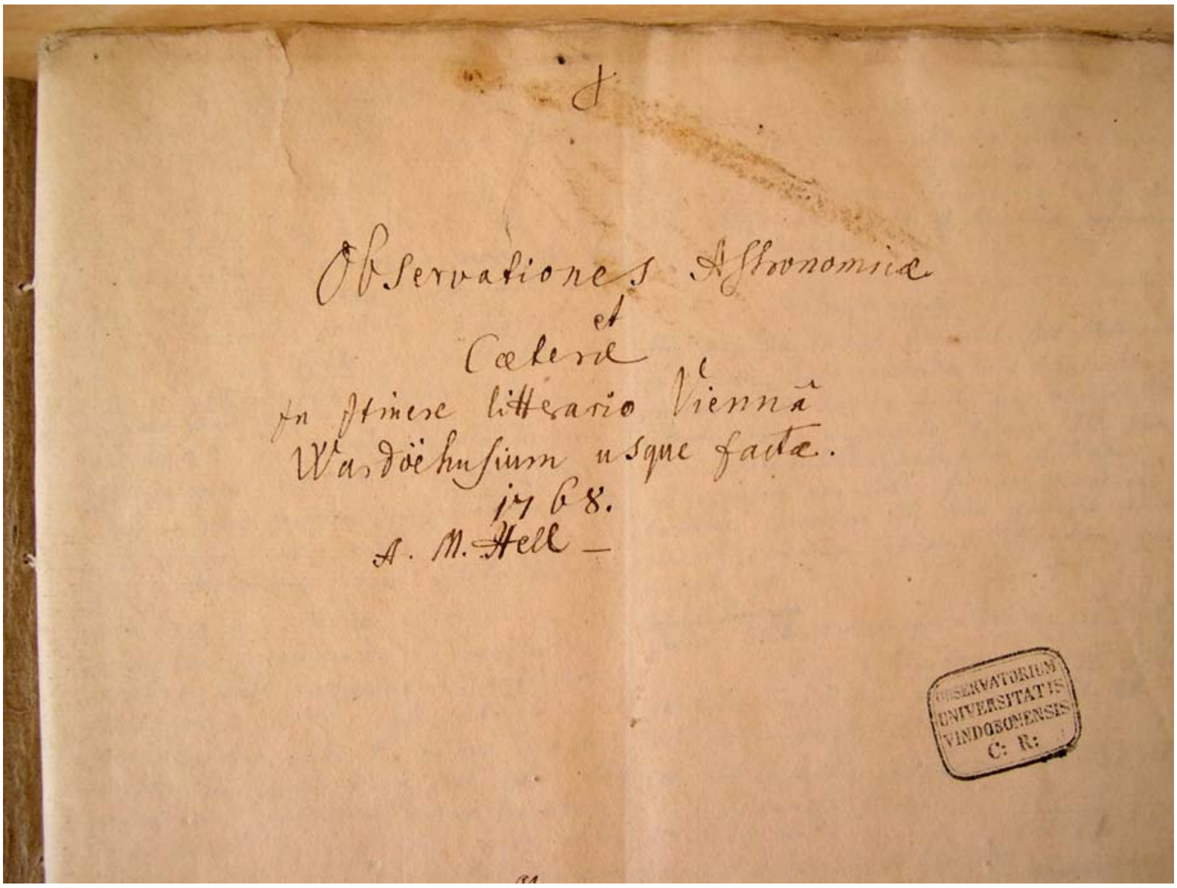

Figure 3 Title page of Hell's "astronomical notebook", the manuscript referred to as MS *Hell c* in this report.

The magnetic observations in Vardø

Hell measured the declination of the magnetic needle, i.e. the angle between the needle and geographic north. Traditionally this angle is denoted “west” when the needle is pointing west of north and “east” when it is on the other side. At Hell’s time the declination in northern Norway was westerly everywhere, and Hell in his manuscript usually skips the “west” designation. In modern geomagnetic terminology declination is reckoned positive towards east and negative towards west. In our tables and figures of Hell’s numbers this modern convention is used. His numbers therefore appear as negative. Today the declination in this region is positive (east).

Hell’s instrument for observing the declination is in principle a compass: a magnetic needle allowed to move freely on a vertical axis. However, the task of measuring declination is quite different from that of setting the course of a ship: Whereas the mariner’s compass tells the direction in a straightforward manner, measuring declination implies the double task of first finding north by astronomical methods, and then observing the deviation of the magnetic needle. The design of the instrument is therefore noticeably different from that of an ordinary compass, and the designation *declinometer* is used instead. This term was used also in the 18th century.

Observations of magnetic inclination probably was also on Hell’s scientific programme. His outline of the planned *Expeditio litteraria ad Polum Arcticum* has no reference to magnetic inclinations, but in a letter to Horrebow of 12th November 1768 (Pinzger 1927, p. 31) and in another to Schøller[39] of 1st January 1769 (ibid, p. 42), he expresses intention to measure inclination as well as declination. Finally, in a letter of 30th April 1769 to Count Thott[40] (ibid, p. 96) he explicitly states that such recordings were done routinely. An entry in the diary of Sajnovics seems to corroborate that they at least tried to observe inclination (MS *Sajnovics* 18th May 1769):

A tent was put up, and on a table inside the meridian line was drawn for the exploration of the magnet’s inclination. However, shortly afterwards it was overturned by a pig.

On 30th May Sajnovics makes the laconic remark that “determination of the magnetic needle’s determination began” (MS *Sajnovics* 27th May 1769 pt 2). Thus, it seems likely that they did, or at least had ambitions to, measure inclination as well as declination. However, there are no such data in the manuscripts we have had access to, nor have we found any information whatsoever about an inclinometer. Probably the magnetic inclination was given a low priority in Hell’s observing programme.

Upon his arrival in Vardø on 11th October 1768, Hell immediately started organising the construction of his astronomical observatory in the centre of the town. It was built in wood by local carpenters, and had several hatches in the roof and walls through which Hell and his assistants could observe the sky (Figure 4). It also served as one of two locations used for the geomagnetic observations. The observatory was completed on 10th January, and Hell then concentrated on the preparatory work for the Venus transit. In a letter of 12th

[39] Stig Tønsberg Schøller, 1700 – 1769, *Stiftsamtmann* (i.e., administrative governor for the entire diocese of Nidaros) in Trondheim and secretary of the Royal Society in Trondheim.
[40] Otto Thott, 1703 – 1785, Danish statesman and proponent of science.

November 1768 to his colleague Horrebow in Copenhagen he describes his astronomical programme thus (Pinzger 1927, p. 31):

First, accurately determine the pole height [i.e. geographical latitude] *by observations of vertical stars.*

Second, find the geographical longitude by means of stars occulted by the Moon, the total lunar eclipse 23rd December as well as by immersions of Jupiter's satellites (from which I expect to achieve very little due to the high southerly declination of Jupiter).

Third, construct a correct refraction table from observations of altitudes of the Sun and stars at culmination as well as at corresponding altitudes because I am of the opinion that the refraction must be much larger here than in Paris and other places closer to the equator. It is necessary for me to have such a table since the forthcoming transit of Venus will take place at low altitude.[41]

Fourth, measure the acceleration of the pendulum clocks which is dependent on gravity due to the shape of the Earth. Before such measurements are carried out I am not able to regulate the mean speed of either my own clock or the one I got in Copenhagen, nor make comparisons to the acceleration at the latitudes of Copenhagen and Vienna. For these observations I shall have a correct meridian where also two telescopes are fixed in the meridian plane. These telescopes are necessary here because the Sun is below the horizon for two months and I therefore have to rely on the stars for clock adjustment until end of February. Not until beginning of March will the Sun be at hand for such operation.

In our days of satellite navigation and precise clocks we shall keep in mind when reading this that finding the longitude and correctly keeping track of time were serious matters in 1768. Nevertheless, they were prerequisites to his observations of the transit. The time naturally used by Hell was local solar mean time (LMT), and we have kept that in this report (the longitude of Vardø, 31° 08' E, corresponds to $2^h\ 05^m$ east of Greenwich). In this system of time the clock is 12:00 when the mean Sun[42] is crossing the meridian. Thus, finding and marking in the observatory the meridian line or direction of south was crucial to his time keeping. The meridian serving as the mandatory reference direction for the magnetic needle, a careful determination of this line was crucial also to this part of his work. Details about the meridian are found in Hell's report about the Venus transit (1770*a*).

The difference in geographic longitude between two places is simply the difference in LMT for the places. One way of finding that difference is transporting a running clock between the places. The only clocks available to Hell were pendulum clocks, which cannot be transported while running. So the only way was using celestial events that could be

[41] The refraction of the atmosphere varies with the object's altitude, and thus a refraction table may be deduced by comparing observed and calculated altitudes. "Corresponding altitudes" means observations symmetric around the meridian. The common tables of refraction were calculated in Paris and quite naturally based on middle European atmospheric conditions. There was a widespread opinion that the atmosphere in polar region was thicker and accordingly the refraction larger. However, in his treatise on the Venus transit presented in Copenhagen upon his return there (Hell 1770*a*, p. 553 = Latin version, p. 19) he admits that this was not the case and that the Paris tables could be used.

[42] Due to the inclination of the Earth's axis of rotation and the fact that the orbit of Earth around the Sun is not quite circular, the true Sun does not move with constant speed and cannot be used for timekeeping. Instead a fictive mean sun moving uniformly is used. The time difference between the meridian transit for the true Sun and the mean Sun can be accurately calculated, a quantity designated "equation of time".

observed simultaneously at the two places. Such events were lunar eclipses and the other phenomena mentioned by Hell above.

After having described his programme of astronomy, Hell, being a genuine 18th century scientist, adds (Pinzger 1927, pp. 31-32):

Along with these astronomical tasks I shall not neglect work related to the realm of the physical, such as magnetic declination and inclination, observations with barometers and thermometers, northern lights, and the tides. That means everything I find useful for astronomy, navigation, geography, physics and understanding of Nature; all of this will contribute to my work.

The winter was dark and the weather inclement. The Moon was behind clouds on 23rd December, no suitable occultation was sighted, and the moons of Jupiter as anticipated yielded nothing. The critical longitude determination was finally saved by the solar eclipse of 4th June 1769.

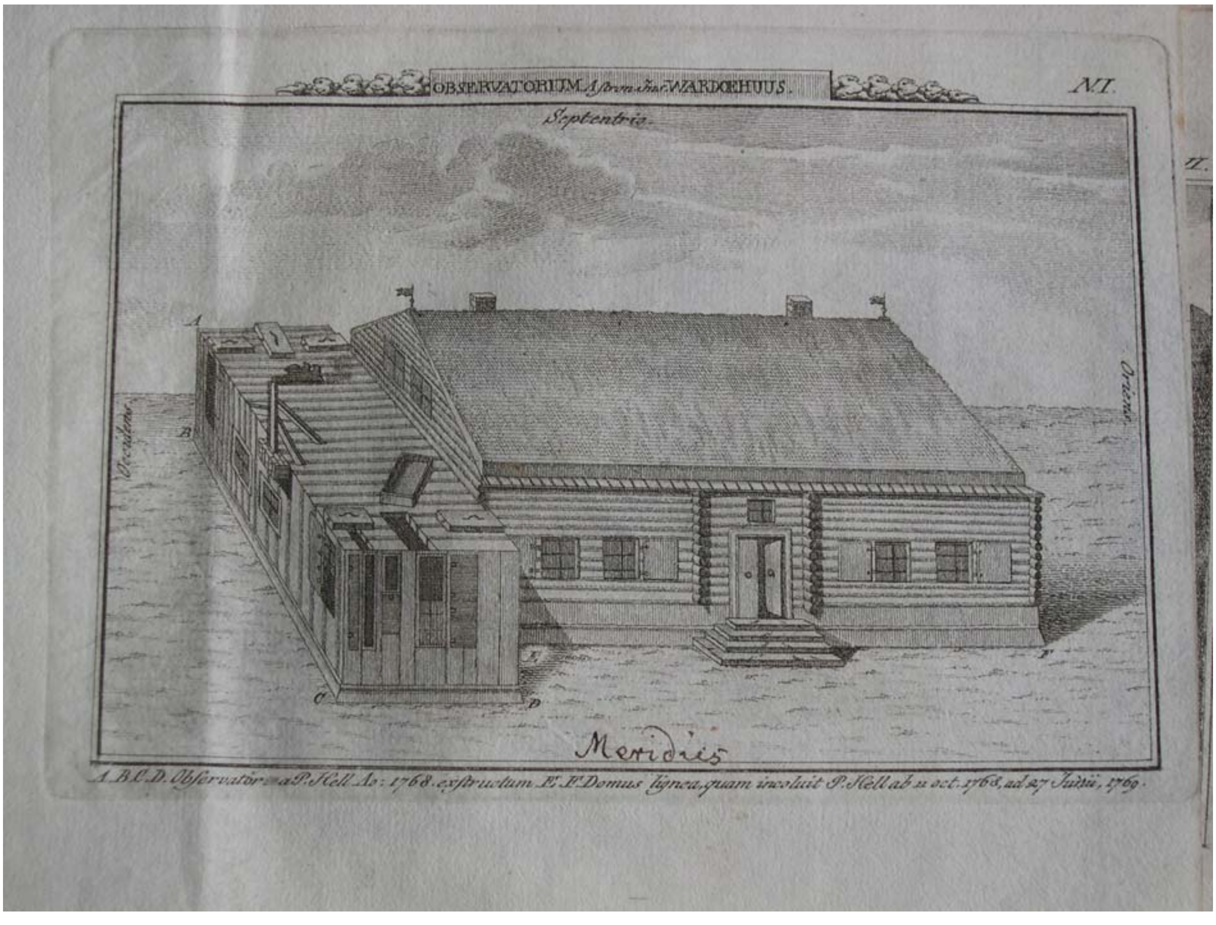

Figure 4 The Vardø observatory. From *Ephemerides Astronomicae ad Meridianum Vindobonensem Anni 1791* (Hell 1790).

Except for the annoying longitude, on 24th April 1769 everything was ready for the forthcoming transit of Venus as well as the magnetic observations. The first reading of the magnetic declination was noted on 27th April, and they were carried on at an irregular schedule until 18th June. Altogether 480 readings were recorded.

Hell describes his declinometer as follows (MS *Hell a* 1):

A magnetic needle, 7 digiti long, has been magnetised by Mr. Kratzenstein by an artificial magnet. After being carefully balanced this needle has been mounted in a square wooden box whose inner brass frame is accurately divided in degrees and 10s of minutes. The top of the box is precisely covered by a plane and polished glass glued tightly so that wind and other influence of the air are excluded. The readings are done by the use of a wooden microscope allowing every double minute to be clearly read.

This brief description leaves out several details which we would have liked to know, for example how parallax[43] was avoided when reading the position of the needle. Declinometer design was greatly improved in the 1720s by George Graham. His detailed description of his instrument is quite instructive and illustrates the delicacy of an 18th century declinometer, and Hell's instrument presumably had several features in common with Graham's not stated in the brief record above. We therefore quote Graham's description (Graham 1724):

The Figure of the three Needles [it was common to have more than one], *with which the Experiments were made, was prismatick; their Lengths were nearly 12,2 Inches* [305 mm]*; their Ends, which pointed to the Divisions, being filed to an Edge, which made a fine Line perpendicular to the Horizon. The Caps* [at the point of rotation] *of two were of Chrystal, the other of Glass; they were well polished on the Inside, in that Part which touched the Pin they moved upon. The Box was Brass, and of a Breadth sufficient to admit of 20° on each Side the middle Line, and covered with a piece of ground Glass. The circular Arches at the Ends were raised so much above the Bottom of the Box, as to have their upper Surfaces, upon which the Divisions were cut, lie in the same Plane with the needle, and at such a Distance from each other, that the Needle might play freely between them* [this way parallax during the reading was avoided]. *A few of the Degrees at the North End were divided into six equal Parts, each Division being 10'* [that means 0.45 mm between the engraved lines]. *It was easy, by the help of a Convex Glass, to determine the pointing of the Needle to less than a Quarter of these Divisions, or to about 2' of a Degree. The Pin, upon which the Needle moved, was of Steel hardned, and ground to a fine Point; and by a Spring placed in the Box, the Needle might be raised from off the Point, and let down again at Pleasure, without removing the Glass, or disturbing the Box. By this means both the sharpness of the point and polish of the Cap were better preserved from injury, when there was occasion to move the Box. A small piece of Brass was made to slide upon that End of the Needle which pointed to the South, for readily bringing it to an horizontal Position; for according to the different strength of the Touch, the North End of the Needle will dip more or less*.

One notes that Graham's needle was 305 mm long. By contrast, Hell states that the length of his needle was "7 digiti". The digitus is an old Roman measure equivalent to approximately 19 mm (the width of the index finger). That means Hell's needle was only 130 mm long, and the distance at the scale between the 10 minute engravings tiny 0.2 mm.

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[43] Parallax occurs when an object is viewed against a background farther away. The object then seems to change position relative to the background when the observer's position is shifted. Thus the reading of the position of the magnetic needle against a scale behind it will depend on the position of the observer's eye. The observations of the Venus transit were based on parallax on an astronomical scale; because Venus is between the Sun and Earth its position relative to the Sun would depend slightly on the observer's position on the Earth. So, while being a nuisance when reading the declinometer, parallax was also a tool to measure the Solar system.

In the late 1730s Graham made for Anders Celsius in Uppsala (Celsius 1740) a declinometer quite similar to the one described by Graham above, the scale divisions, however, being made at 5' intervals. Thus the separation of the engraved lines was only 0.22 mm. A declinometer of Wilcke made in 1765 was a little longer – 330 mm – and the line separations 0.24 mm (Wilcke 1777). So Hell's needle may well have been as short as the 19 mm digitus implies.

Nevertheless, a needle of only 130 mm is short by 18th century standards, as demonstrated for example by the declinometers in the instrument collection of the Royal Swedish Academy of Science (Pipping 1977). The needles of the eight declinometers in this collection, all made between 1740 and 1781 by various instrument makers, range from 175 to 642 mm in length. We therefore shall not rule out that the "digitus" of Hell in fact was an inch, a much more common unit of measure than the outdated digitus. Hell's needle would then be roughly 180 mm long. A third option is found in Stearn's *Botanical Latin* (1992, p. 111), where a digitus is said to be two Parisian inches or 55 mm (i.e., the length of the index finger). In that case the needle would be 385 mm. Unfortunately the instrument probably does not exist today. It has not been found at the astronomical observatory of Vienna (Firneis 2003), and if it belonged to Kratzenstein we must presume it was lost in the 1795 conflagration of Copenhagen when his house was destroyed along with his large collection of scientific instruments (Snorrason 1974, p. 135).

A possible clue to this digitus puzzle has been found in the Vienna Ephemeris for 1762, where Hell presents a summary of numerous observations made of the 1761 Venus transit, among them results from England. He writes (Hell 1761, p. 44):

[In Greenwich] this passage (because of Dr. Bradley[44] *being ill) was observed only by Mr. Bliss*[45]*, Professor of geometry from Oxford, as well as by Mr. Birch* [certainly a misspelling of *Bird*[46]]*, and by Mr. Green*[47]*, Mr. Bradley's assistant.* […] *The first mentioned observed with a 15 feet telescope magnifying 50x, the second used a telescope of 15 digiti with magnification 55x, and the last one a 2 feet telescope with magnification 120x.*

Hell continues:

Mr. Cantons [i.e., Canton[48]]*, member of the Royal Society in London, observed in the Spithal Square with a telescope of 18 digiti, magnifying 55x.*

Looking up the original English reports in *Philosophical Transactions* we find (Bliss 1762) Green using a "reflecting telescope, of 15 feet focal length", and Bliss an "excellent refracting telescope of 15 feet focal length", in accordance with Hell's account. About Bird's instrument the report tells:

We observed the internal contact of Venus with the Sun's limb, […] Mr. Bird, mathematical instrument-maker in the Strand, with a reflector of 18 inches focal length, of his own making, and myself with the refractor, the telescopes used by Mr. Bird and myself magnifying about 55 times, that by Mr. Green 120 times.

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[44] James Bradley, 1693 – 1762, English astronomer, Astronomer Royal from 1742.
[45] Nathaniel Bliss, 1700 – 1764, English astronomer.
[46] John Bird, 1709 – 1776, renowned English instrument-maker working in London.
[47] Charles Green, 1735 – 1771, English astronomer. Partook in Captain Cook's Venus observations in 1769.
[48] John Canton, 1718 – 1772, English physicist.

As for the observations of Canton we find (Canton 1762):

These observations were all made with a reflecting telescope of 18 inches focal length, which magnified about 55 times.

It seems like Hell has translated *inches* into *digiti*. Admittedly, there is a discrepancy with regard to the telescope used by Bird; Hell writes 15 digiti while Canton writes 18 inches. Hell did, however, get his information concerning the English observations not directly from the observers (the ongoing Seven Years' War made contacts with England complicate), but via colleagues in third countries. We therefore presume that "18" was changed to "15" by a mistake (note the similarity of the numbers 5 and 8 in handwriting), and we conclude that Hell's digitus very likely is equivalent to an inch.

This conclusion is corroborated by Hell's remark about observations from London by James Short[49]. Hell states that Short used a "telescope of 24 digiti, magnification 140x" (Hell 1761, p. 43). This corresponds to Short's own report, where he states that he used a "reflector of 2 feet focus, magnifying 140 times" (Short 1762). If 24 digiti were equivalent to 2 feet, then one digitus would indeed be an inch. The 55 mm digitus of Stearn, however, on such reasoning seems less probable.

In addition to the Kratzenstein declinometer, Hell also mentions using one borrowed from Carsten Niebuhr[50] in Copenhagen (see below). No details are known of this. And finally in MS *c* he talks about a magnetic needle made in Copenhagen by "Mr Aal"[51] (MS *Hell c* 23rd May 1769 pt 1):

3 digiti long and divided into semi-degrees, with a microscope placed above it, through which every 15' could be estimated fairly accurately.

The resolution of 15' does not make sense: it would simply mean the instrument could not serve its purpose. The length of this needle being roughly half of the Kratzenstein one, a resolution of say 5' would be reasonable.

Geomagnetic instruments require stable mounting in an environment devoid of other magnetic objects. Hell first made a pillar for the measurements in his astronomical observatory. He writes (MS *Hell a* 1):

In the southern observatory [i.e. the astronomical one] *was made a pillar of bricks. Atop of this was placed a polished, square piece of slate, which was covered with paper and levelled with a bubble tube. On this I drew the meridian in accordance with the main meridian I had determined. The pillar was placed at 6 feet's distance from all items of iron and ten feet away from an iron stove (which was the reason why I later made a new pillar at another place. More about that later).*

Care was taken to obtain uncontaminated observations (ibid):

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[49] James Short, 1710 – 1768, famous English instrument maker.

[50] Carsten Niebuhr, 1733 – 1815, German/Danish traveler and surveyor, famous for his expedition to the Middle East 1761 – 1767. Hell also borrowed the quadrant used by Niebuhr on the Middle East expedition and used it for latitude determinations when traveling.

[51] Certainly Johannes Ahl, 1729 – 1785, a Swedish instrument maker working in Copenhagen from 1762.

All possible precautions have been taken to secure good observations. In order to exclude draught all observations were carried out with doors and windows shut. At night candles without candlesticks or oil chambers were used, with keys, knives etc. having been removed from the pockets, so that there should be no doubt about the measurements.

On this pillar the observations were carried out until 19th May. There were, however, problems; the entry for 3rd May has the note (MS *Hell a* 2):

After 3 o'clock pm the quadrant was removed from the observatory. The magnetic needle then immediately showed 40 minutes less. That's why the last column for the observations so far has been reduced by 40 minutes. The subsequent observations are all made in the southern observatory with the quadrant removed.

Later he concluded that the iron oven also affected the observations. After the readings for 19th May he writes (MS *Hell a* 8):

The following three days' period (20th, 21st and 22nd) there are no entries. In the meantime the new observatory for observations of the magnetic needle's declinations was erected in the plank storage of the caretaker. This is placed about 100 steps from the astronomical observatory. At this site was made a solid pillar of brick. Atop of it a solid, horizontal table was placed and covered with white paper where the meridian line was reproduced in accordance with the observatory meridian. The reason for the construction of this new observatory was an iron oven in the laboratory of the astronomical observatory situated 10 feet from the pillar with the magnetic needle. I gradually became suspicious that the iron effected the magnetic observations, and got this confirmed when I started observing in the new observatory: the oven had caused an error of 20 minutes.

Another and supplementary description of this new magnetic observatory is found in Hell's "astronomical notebook" for 23rd May (MS *Hell c* 23rd May 1769, pt 1-2):

On this day the meridian was marked in the plank storage of the caretaker, situated west of the observatory. A solid pillar was raised, with sides of brick. On top of it a plate of solid wood was placed horizontally, with a sheet of paper upon it. This meridian line, corresponding to the one in the observatory, serves to determine the declination of the magnetic needle, because this plank storage is constructed from wooden stakes and only few iron spikes. But since the spikes are placed at 9 feet's distance from the pillar, there is no way they could have any effect on the needle. Moreover, the inside walls of this storage have been clad all over with my thick tent canvas against wind. This observatory is to be called The New Magnetic Observatory.

The fact that Hell initially ignored the magnetic effect of an iron oven only 3 meters away as well as the quadrant, make us suspect he had little previous experience with measurements of this kind. As a matter of fact, his interests in magnetism prior to the Vardø expedition seem to be limited to magnetic healing (Sarton 1944).

The declination recordings in Vardø may thus be subdivided into two series. In Figure 5 is presented the first series, taken in the astronomical observatory from 26th April to 19th May. The correction due to the quadrant is included and the numbers are also corrected by 20 minutes (see below) in order to render them comparable to the series from the new observatory.

Figure 6 displays the observations made in the new observatory. No correction is applied to these numbers. Hell introduces these observations with the note (MS *Hell a* 9):

Observations of the magnetic needle's variations performed in the above-described new observatory with Mr. Niebuhr's magnetic needle.

This may mean the two series have been observed with different instruments, the first one presumably with the Kratzenstein declinometer, the other with the one from Niebuhr.

Shifting the magnetic observation from one pillar to another meant the difference between them had to be measured in order to obtain consistent data. Hell did it this way (MS *Hell c* 23rd May 1769 pt 2):

At 3:30 pm the magnetic needle was moved into the new magnetic observatory, which is situated at fifty steps' distance west of the prior one. The magnetic needle situated in the old place of the astronomical observatory showed 2° 35' west at 3:30, but after it had been moved over to the new observatory, and had fallen to rest, the value it showed for almost the same point in time was 2° 55'. Hence we have a difference of 20', which in my opinion is likely to have been caused by the iron oven in the laboratory. Although this oven is situated 10 feet away, at an angle of about 45 degrees in northeast direction, it has pulled the needle 20 minutes from west towards east.

Hopefully this comparison was made during magnetically quiet conditions; otherwise the difference in time, presumably a few minutes, could have spoiled it. The two series of observations turn out to have virtually identical mean values, as they ought to have. We are therefore inclined to believe the 20′ correction is correct.

After the transition to the new observatory measurements were continued for a while in the old one for comparison. Along with the readings Hell made the following remark (MS *Hell a* 8):

These observations, from the 23rd of May until the end of the period [i.e., 31st May]*, were also carried out in the astronomical observatory on the old pillar only because I wanted to investigate if the difference between the old and the new observatory varied through the day. As is demonstrated by the corresponding observation in the new observatory, this was not the case.*

His own numbers contradict this statement. The overlapping data are plotted in Figure 7. In spite of the 20' correction being applied to the data from the old observatory, the two sets do not match. It may appear that they correspond for the first couple of days, but then they diverge. We have no good explanation for this. One possibility is that he used the inferior Copenhagen declinometer in the old observatory, as is in fact indicated by a sentence in his "astronomical notebook" (MS *Hell c* 23rd May 1769 pt 1), or some magnetic object was inadvertently introduced there. Whatever the reason, why does Hell insist on correspondence?

Geomagnetically, Vardø is in the auroral zone, the geomagnetic latitude[52] being 66.8°. For comparison we have included in Figure 8 a modern recording from the geomagnetic observatory in Tromsø, which is also an auroral station. Admittedly, the Earth's magnetic field has changed noticeably since the days of Hell and it is estimated that Vardø in 1769 was somewhat north of the auroral zone (Brekke and Egeland 1994). This difference is, however, not important for our qualitative comparison.

Both the series leave an impression of reasonable data:

- The stability throughout both periods is good, and the average declination is -3º 04' for both.

- The diurnal variation is discernable and of the right size. Comparing to the modern series from Tromsø, we see the general appearance is quite similar.

- We clearly see the magnetic field being rather quiet in the first part of series one. At 9th May this is abruptly interrupted by a moderate magnetic storm, and from then on the rest of the data is more or less disturbed as well, in particular around 10th June. This is what we would expect in the auroral zone where such disturbances are quite common.

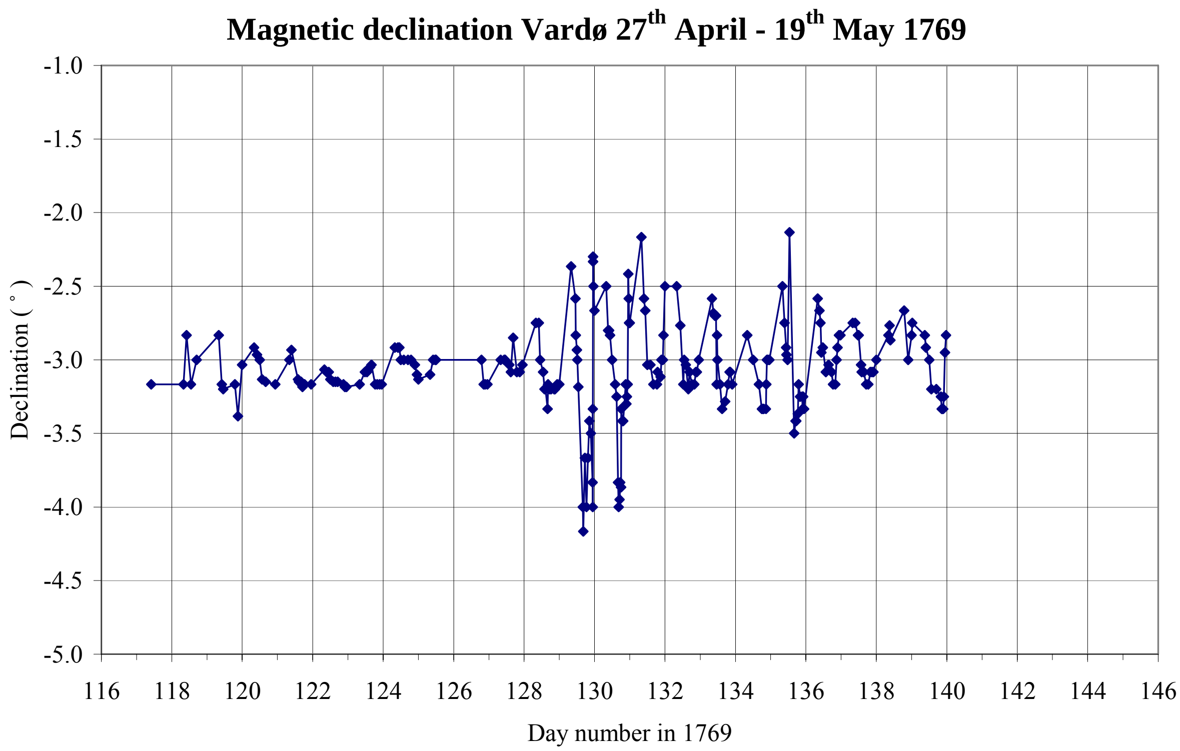

Figure 5 Declination series in the old observatory.

[52] Corrected geomagnetic latitude as calculated by the online service http://nssdc.nasa.gov/space/cgm/cgm.html.

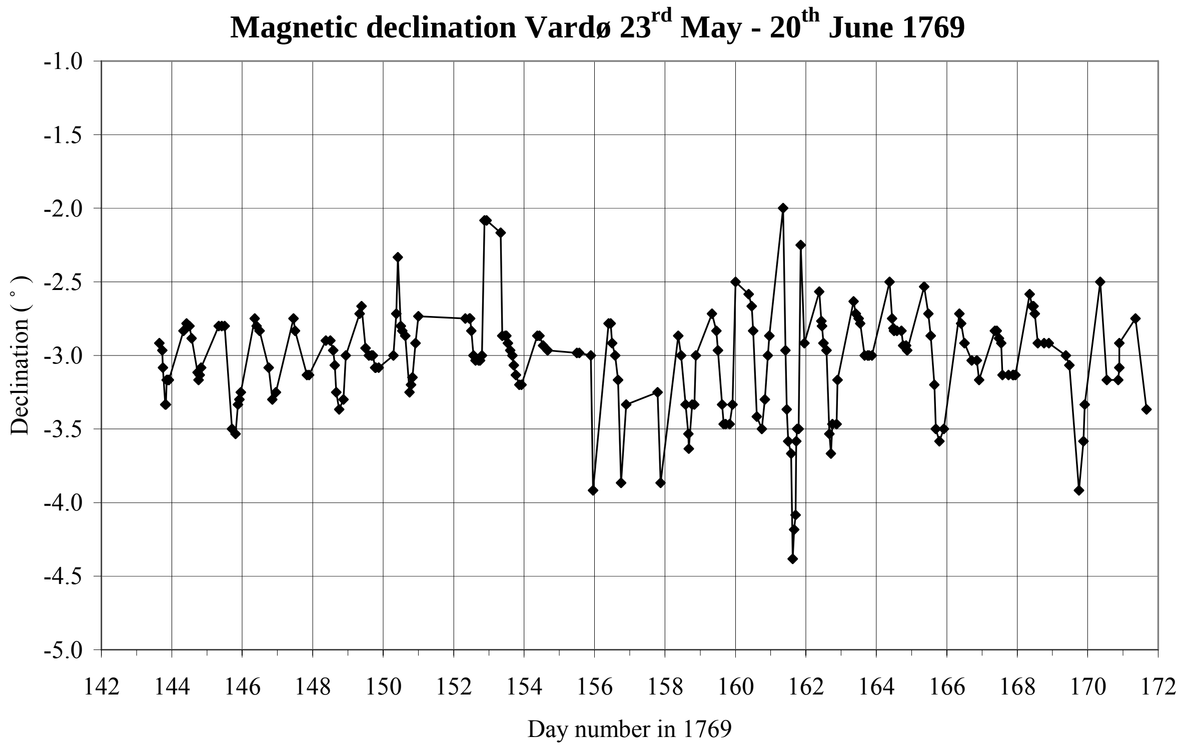

Figure 6 Declination series in the new observatory.

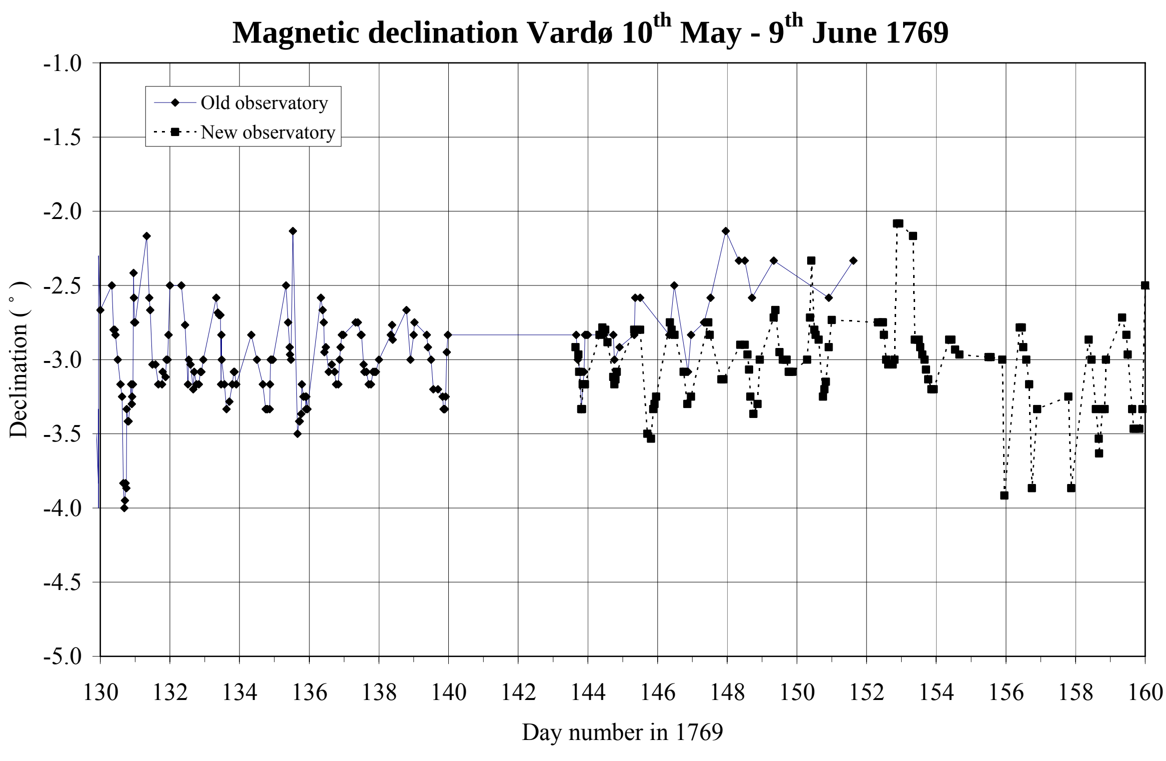

Figure 7 Transition between the old and the new observatory.

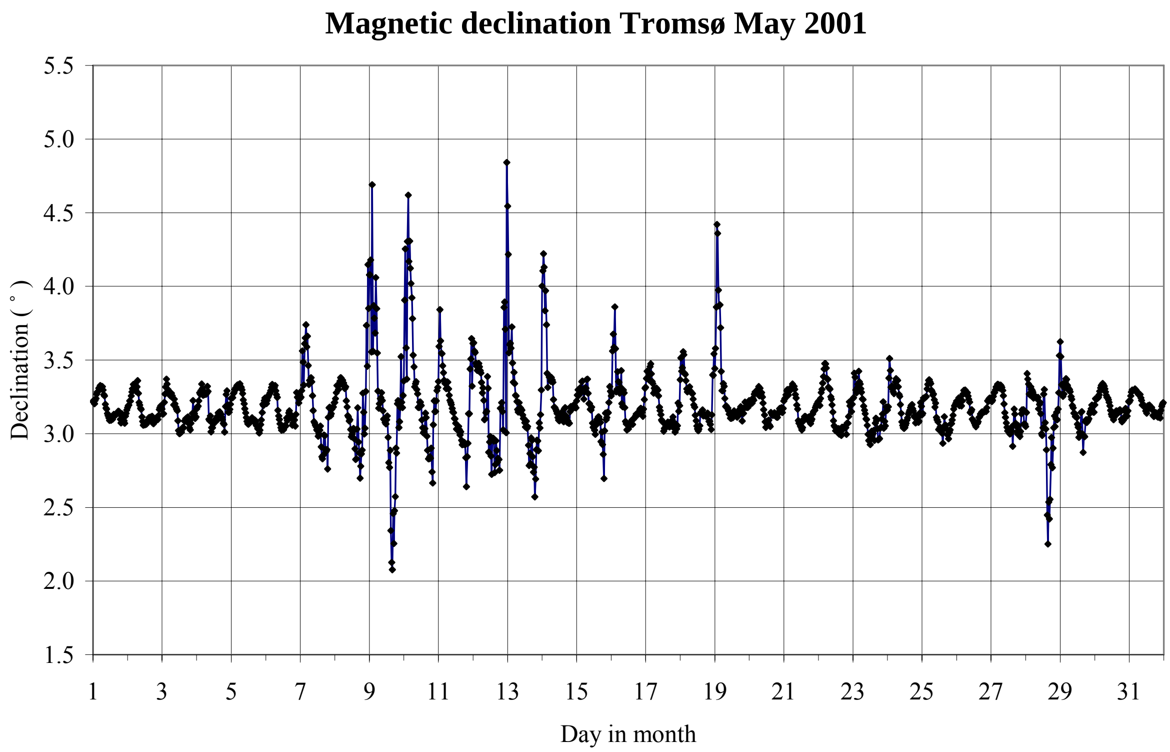

Figure 8 Modern series of declinations in the auroral zone.

The diurnal variation in the declination, discovered by Graham in the 1720s, was well confirmed when Hell made his observations[53]. We presume this phenomenon was well known to Hell, and that this explains why he does not comment on it.

The magnetic storm starting 9th May was, however, apparently quite a surprise to Hell. Noticing the rapid fluctuations of the needle he began reading with shorter intervals, as seen in the table of data, and at the end of it he leaves the note (MS *Hell a* 3):

These extraordinarily rapid variations confused me; I had prepared everything very thoroughly, I even ordered the servant to leave the room because I suspected him to carry with him keys or other objects of iron. Outside, there was a strong wind from east, but that could not possibly reach the needle. There were no Northern Lights, which by the way – as I later shall demonstrate – could not have had any influence on the magnetism. What caused these disturbances needs to be investigated.

The fact that the magnetic declination, apart from the rather regular diurnal variation, also exhibited short time irregular variations should not have been a surprise to Hell. The phenomenon was noted by Graham already in 1723. Convincing observations of strong, rapid variations were reported by Celsius[54] and Hiorter[55] in the 1740s (Hiorter 1747), and corroborated by among others Canton (1760) and Wargentin[56] (1750). The latter we know Hell was acquainted with (Nordenmark 1939, p. 434).

[53] See the overviews of Hansteen (1819) and Chapman and Bartels (1940).
[54] Anders Celsius, 1701 – 1744, Swedish physicist and astronomer.
[55] Olav Petr Hiorter, 1696 – 1750, Swedish physicist and astronomer.
[56] Pehr Wilhelm Wargentin, 1717 – 1783, Swedish astronomer.

The key to Hell's ostensible astonishment is the Northern Lights; he claims there were no Northern Lights while the magnetic disturbance took place. The immediate response to such an observation of Northern Lights is to reject it as nonsense. At the latitude of Vardø, the period of midnight sun starts around 15th May. Thus, at the 9th of May any observation of Northern Lights was totally excluded even at midnight because of the bright sky. However, Hell and Sajnovics do report of observations of daytime Northern Lights. In the diary of Sajnovics we find (MS *Sajnovics* 27th May 1769 pt 1-2):

In the afternoon the survey of the island [i.e., the Vardø island] *was continued. While doing this we saw a magnificent aurora borealis created by the Sun. The Sun was in northwest covered by a dense cloud with much snow high above the horizon. Another dense cloud was 30 degrees further to northeast, also high in the sky. The rest of the sky was clear. From the first cloud to the other splendid rays were stretching themselves out, long and numerous. They extended above the Sun's midnight point as luminous particles speedily drifted from the cloud in northwest to the one in northeast.*

This seems to be an observation of what we today call crepuscular rays, bundles of red rays occasionally seen when a low sun is illuminating particles in the air from behind a cloud. A similar observation is recorded a month later (MS *Sajnovics* 17th June 1769). The same observations are also mentioned in Hell's weather records from Vardø published in the *Ephemerides Astronomicae* for the year 1793 (Hell 1792). The concept of Northern Lights used by Hell and Sajnovics thus encompassed also crepuscular rays, and perhaps also other optical phenomena of the daytime sky. This is no surprise considering the predominating 18th century theories of the Northern Lights, which explained them as some sort of reflection of solar rays. As for the crepuscular rays, they do in fact resemble auroral rays.

Hell no doubt knew of the numerous reports of simultaneous occurrences of magnetic disturbances and Northern Lights. In a letter to Pilgram[57] of 5th April 1769 he even argues against them (Pinzger 1927, pp. 66-67). He knew, but was not willing to acknowledge the fact. During his stay in Vardø Father Hell had developed his own theory about the origin of the Northern Lights (Hell 1776) in which magnetic disturbances had no part. He became so preoccupied with his own theory that without further argument he excluded all other possibilities. Another letter to Pilgram of 30th April 1769 (Pinzger 1927, p. 94) illustrates this quite vividly:

The observers of the magnetic needle at times with aurora borealis still surprise me. I would wish – as I wrote recently – that these observers had done more observations of the needle at times without aurora. I shall now only maintain that the magnetic needle has as little relation to the aurora borealis as the rainbow of the sun or moon have with parhelion[58] *or paraselene*[59] *or halo around the moon. How embarrassing it will be to these meticulous observers of the magnetic needle when they learn about my unquestionable theory of the aurora borealis, and then read my extremely accurate observations of the magnetic needle, recorded almost every hour of the day. In other words, I think these observers of the needle would wish they never published their observations, exactly like the observers of that notorious "moon of Venus" do wish today.*

[57] Anton Pilgram, 1730 – 1793, astronomer and meteorologist. Replaced Hell at the observatory in Vienna during his absence.

[58] An atmospheric optics phenomenon; two bright spots, usually 22 degrees to each side of the Sun, caused by a reflection of sunlight in ice crystals. Commonly known as "sun dogs" or "mock suns".

[59] The same phenomenon as parhelion, but caused by moonlight.

According to Hell, the aurora borealis originated from minute particles of ice lit up by the Sun from below the horizon. It thus was to be considered a meteorological phenomenon, with no influence at all on the magnetic needle.

Observations of declination on the homeward journey

Hell and his fellow travellers left Vardø 27th June 1769, sailing along the coast of Norway to Trondheim where they arrived 30th August. Two weeks later they began retracing their route over land to Christania before proceeding via Sweden to Copenhagen.

On this southward journey Hell observed the astronomical latitude whenever weather permitted. The result of altogether 47 latitudes from Vardø to Copenhagen was presented to the Society of Sciences in Copenhagen and published in its proceedings (Hell 1770*b*). Along with the latitudes he frequently also measured the magnetic declination, but like the series in Vardø they never were published. Hell also observed latitudes on his way northwards to Vardø, and we can see from a letter to Kratzenstein (MS *Hell Kratzenstein* 2) that he had plans to perform magnetic observations as well. There is, however, no trace of such observations in his manuscripts. The northbound journey took place in the autumn and in unfavourable weather. They were in a hurry to reach Vardø before the winter, so presumably little time was left for science.

The section of Hell's manuscript dealing with the magnetic declination starts out with a description of the method used (MS *Hell b* 1):

We brought with us a little table without iron nails. This was placed under open sky at the observing site well away from the closest house so that all influence of iron in the house, wherever in the house it be, was eliminated. The table was mounted horizontally by means of a bubble tube. Atop of the table a white sheet of paper was fastened with soft wax. On the paper was a small circle precisely corresponding to the base of a wooden cone of a height of 2 digiti. The cone's shadow was distinctly visible on the sheet. Moreover, the table was placed not too far from a quadrant used for recording positions of the Sun's upper limb.

As the zenith distance of the Sun's upper limb was measured the assistant on signal marked the top of the cone's shadow on the paper. Various corresponding positions of the shadow and altitudes of the Sun's upper limb were recorded, and in this way several azimuth points were marked by means of which the meridian was fixed with certainty. As a rule, the [zenith] distance of the upper limb was recorded three, two or at least one hour before noon.

Thereafter the zenith distance of the Sun's upper limb at the culmination was recorded. From this recording, the Pole height at the site was calculated and the azimuths of the shadow calculated by means of Vlacq's trigonometric theorem XVI.

Vlacq's[60] theorem XVI (see for example Vlacq 1748, pp. 39-43) is used to compute azimuth A from astronomical latitude (pole height) φ, altitude h, and declination δ, thus:

$$\sin(\frac{A}{2}) = \sqrt{\frac{\sin(s-(90-\varphi))*\sin(s-(90-h))}{\sin(90-\varphi)*\sin(90-h)}}$$

where s is half the sum of the complemented angles:

[60] Adriaan Vlacq, 1600 – 1666(?), Dutch bookseller, publisher and mathematician. His tables of logarithms and formulas were published in several editions from 1628 to 1794.

$2s = (90\text{-}\varphi) + (90\text{-}\delta) + (90\text{-}h)$

This logarithmic formula makes the computation quite convenient:

$\text{logsin}(A/2) = ½[(\text{logsin}(s – (90\text{-}\varphi)) + \text{logsin}(s\text{-}(90\text{-}h)) – \text{logsin}(90\text{-}\varphi) – \text{logsin}(90\text{-}h)]$

Hell then gives the example of calculation shown below (MS *Hell b* 1-2). We have added some comments in [brackets] to facilitate the decoding. Note that 10 is added to all the logarithms, a practise maintained until our days, to make the manipulation of the numbers easier. This is equivalent to defining log 1 = 10. Correspondingly the expression “ + full sine” means adding 10 to the logarithm to prevent negative values, and correct offset of 10. A “full sine” is sin(90º), which has a logarithm equal to 10 in the notation above.

The observations carried out at the island of Bjørøy may serve as an example. The pole height of this island was by observation calculated to 64˚34′ 27″.

Distance to the Sun's upper limb	*62° 57′ 0″*	*Length of cone shadow = 3375 steps*		
Quadrant correction	*-1′ 30″*			
	62° 55′ 30″			[zenith distance ζ of upper limb]
complement	*27° 04′ 30″*			[$u = 90° - \zeta$]
Semi-diameter of sun	*15′ 53″*			[R]
Height of Sun's centre	*26° 48′ 37″*			[$h = u - R$]
complement	*63° 11′ 23″*	*declination= north 10° 37′ 52″*		[90 - h]
Thus				
complement pole height	*25° 25′ 33″*			[$90 - \varphi$]
compl. declination	*79° 22′ 08″*			[$90-\delta$]
compl. height	*63° 11′ 23″*			[90-h]
	167° 59′ 04″			[2s]
	83° 59′ 32″			[s]
compl. pole eight	*25° 25′ 33″*			[$90 - \varphi$]
	58° 33′ 59″	*I . log. diff.*	*9.93107*	[$L_1 = \text{logsin}(s-(90 - \varphi))$]
	83° 59′ 32″			[s]
	63°11′ 23″			[90 -h]
	20° 48′ 09″	*II. log.diff .*	*9.55040*	[$L_2 = \text{logsin}(s-(90 - h))$]
sum			*19.48147*	[$L_1 + L_2$]
compl. pole height	*25° 25′ 33″*	-	*9.63279*	[logsin($90 - \varphi$) subtracted]
+ full sine		+	*19.84868*	
compl. height	*63° 11′ 23″*	-	*9.95061*	[logsin(90 - h) subtracted]
+ full sine once more			*19.89807*	[2logsin(A/2)]
azimuth's half-angle	*27° 13′ 00″*	=	*9.94902*	[$A/2 = \text{logsin}^{-1}(A/2)$]
thus	*54° 26′ 00″*			[A]

There is no mention above of the refraction in the atmosphere. Truly, refraction does not affect azimuth, but it does alter both declination and altitude. So, when calculating azimuth by the method described, declination and altitude must both be either true (corrected for refraction), or both apparent (uncorrected). Applying one true and the other apparent will give a small error. It looks like Hell above has used apparent altitude and true declination. If so his azimuth is 6' too low; a small error, but not negligible.

Having calculated the azimuth, Hell finds the meridian by a simple geometric construction:

A rectangular triangle was then placed upon the table. The hypotenuse in this is the shadow of the cone AC and the angle BAC is the calculated azimuth and hence also ACB, which gives the sides AB and AC. In our example we found the hypotenuse AC=3375, and the azimuth angle BAC=54° 26' 00", which gave the sides BC=2745 and AB=1963.

The length CA was measured from C with a pair of compasses, and in the same manner an arc around A with radius AB was drawn. The point of intersection is B and the line BA is the meridian to which the declination of the needle is referred.

Three more observations at different azimuth were recorded and Hell concludes:

if the intersection points are all on the same line AB, everything is correct.

This procedure is reconstructed in Figure 9 using two of Hell's observations. The unit used by Hell when measuring the length of the shadow we have not been able to decode, but the figure is drawn to scale assuming a digitus of 19 mm (the Sun's altitude and the height of the cone gives the length of the shadow). As we see the drawing is small, so small that fixing the meridian with an accuracy better than ½º is very difficult. Again we therefore suspect the digitus of Hell was larger than 19 mm.

In his *Ephemerides* for the year 1791 Hell seems to claim this was his own method: "I made these observations with a special method of mine" (Hell 1790, p. 310). The method is, however, outlined by Vlacq (1748, p. 40), although not in such a detailed way.

From Vardø Hell's ship sailed along the inhospitable coast of East Finnmark. Not until they reached Kjelvik (Figure 10) close to Nordkapp did they make any observations (MS *Hell b* 11-12):

On the 6th day of July at 11 o'clock in the morning we arrived at Kjelvik after we with God's help had escaped being shipwrecked.

On the 7th in the morning a tent camp was set up at the north side of the harbour. A quadrant and a magnetic needle were brought ashore, but no observations were achieved due to overcast weather. In the meantime the small table was put up horizontally, and the box with the magnetic needle placed on it so that at 2 pm it showed a declination of 2° 05'. I did this only to be able to observe the variations in the declination: In absence of a meridian line because of the overcast sky, the true declination could not be obtained. The following values were recorded:

7th July	*2 pm*	*2° 05' west*
	2:30	*2 15*

	3:15	*2 15*
	4:30	*2 18*
	5:30	*2 18*
	7	*2 10*
	8:30	*2 10*
	12	*1 30*
8th July	*10 am*	*1 45*

The 8th July the meridian line was determined, and after the magnetic needle had been correctly adjusted the following observations were made:

8th July	*3 pm*	*8 02 west*
	8	*7 32*
	9:30	*7 27*
9th July	*10:30 am*	*7 17*
	10 pm	*7 12*
10th July	*10:30 am*	*7 14 mean value 7 38*

After the magnetic observation on this day - the 10th July - the assistant removed the upper part of the tent because the culmination of the Sun was to be observed. When opening it he nudged the table on which the magnetic needle rested and moved it out of position. This made the meridian line useless and the observations were interrupted.

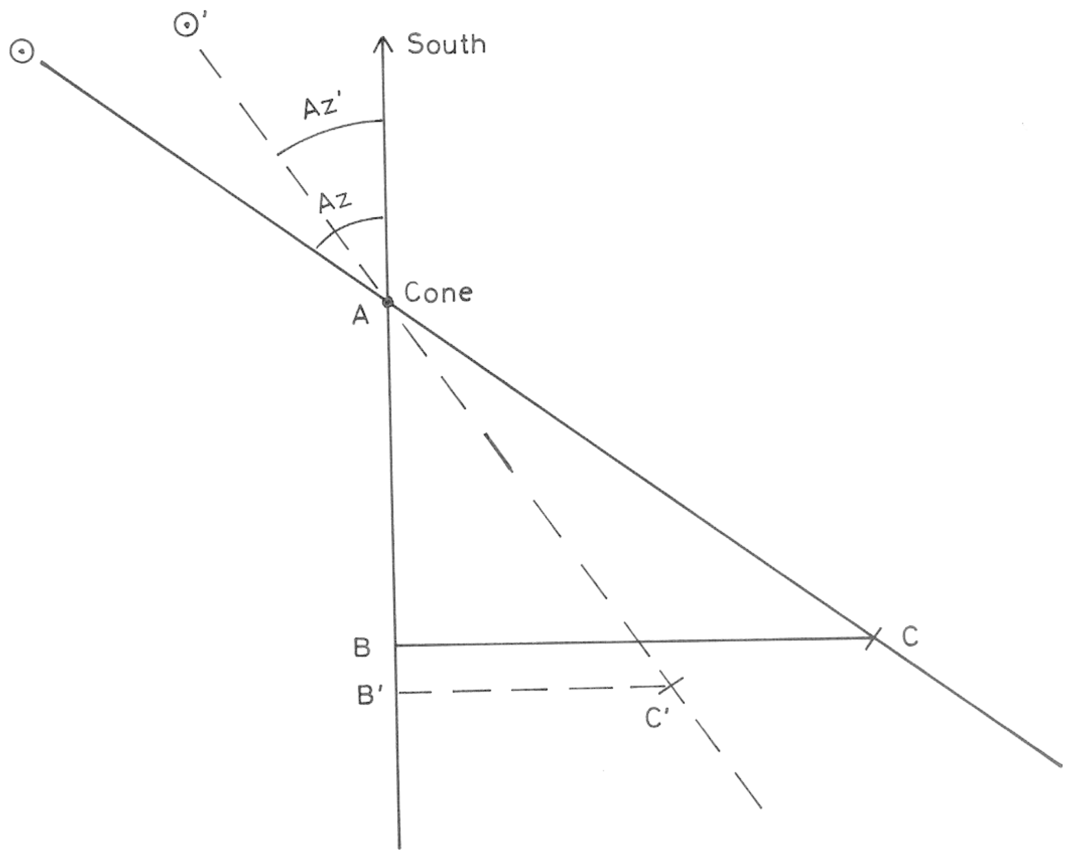

Figure 9 Geometry to find the meridian line (BA). The line AC is the Shadow of the cone, then CB=AC*cos(Az), AB=AC*sin(Az), and B is fixed by a simple geometric construction. To check the result the procedure is repeated with one or more different positions of the Sun.

Hell remarks that the meridian line was based on an observation of the latitude not entirely correct; because of clouds he read the solar zenith angle several minutes after culmination. The value used vas 71° 03' 00". On the 10th July he obtained a better value of 71° 00' 53". Apparently he did not correct his observed declination for the small error. We have estimated this error to be of the order of 3' (plus or minus), an error of little importance.

The variations in the two short time series above are not very much larger than can be attributed to the diurnal variation at summer time. At most observing sites Hell made similar series of observations and calculated the mean value. This procedure removes at least some of the uncertainty caused by irregular magnetic disturbances. We have not made any attempt to correct the observations, neither for the regular diurnal variation nor for the associated seasonal variation.

Hell continues with a description of barometric height measurements of the surrounding mountains and course directions to important points in the area. He also makes speculations on changes of the level of the sea, a phenomenon in which he also had shown interest during his stay in Vardø (Kragemo 1960).

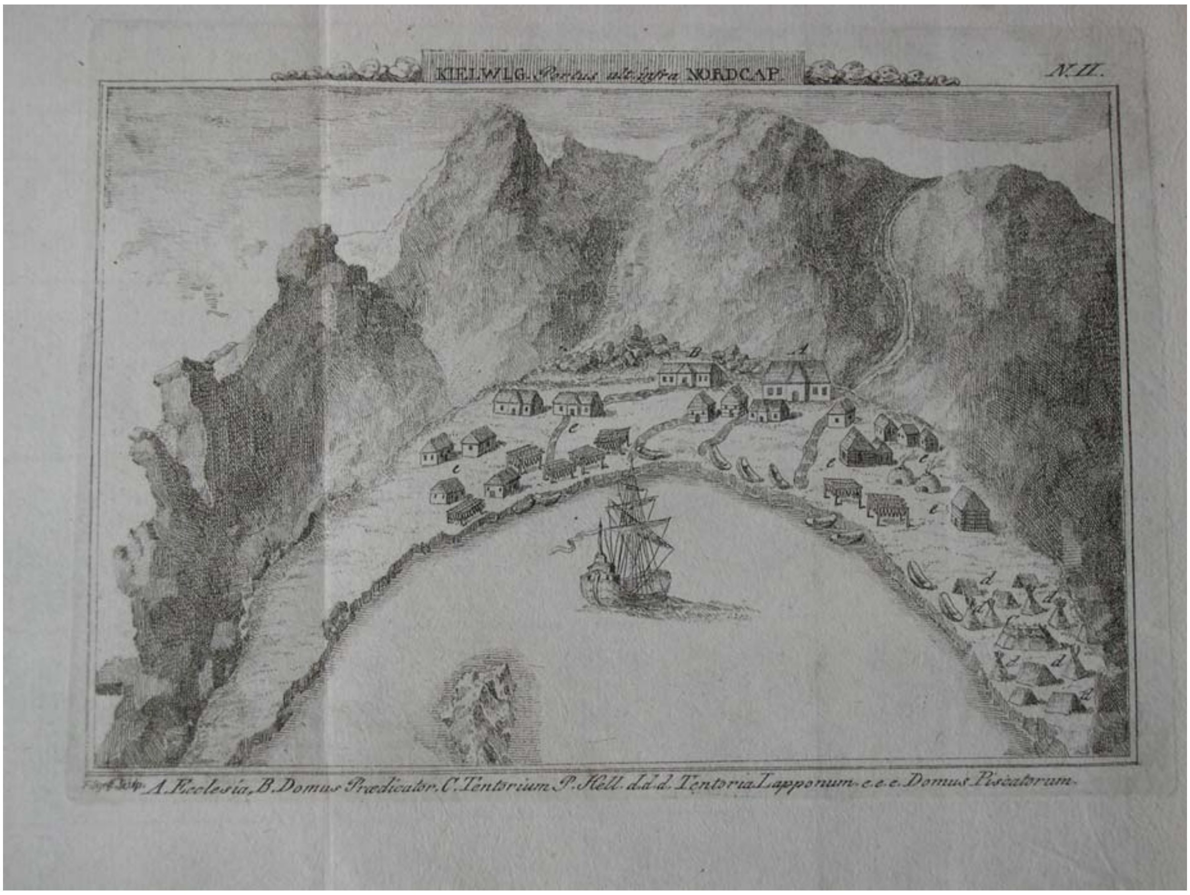

Figure 10 View of Kjelvik. From *Ephemerides Astronomicae ad Meridianum Vindobonensem Anni 1791* (Hell 1790).

Next stop was at Måsøy at the west side of North Cape on 19th July (MS *Hell b* 15):

Observed the pole height by the church at Måsøy on a very clear day, though with some wind. The zenith distance of the Sun's upper limb observed with Niebuhr's quadrant was 49° 56' 30, which after subtraction of the error of the quadrant gives a pole height of 71° 00' 26".

Thereafter, the magnetic declination was measured at 2 pm and 3 pm to 5° 10' and 5° 05' west respectively.

Diverting for a moment from geomagnetism we would like to draw attention to MS *Hell b* 16-18 in our appendix. Here Hell has left nice drawings of manets ("sea insects" in Hell's parlance) from Måsøy. They have been identified as *Staurophora martensia*, *Chrysora hyocella*, and *Beroë cucumis* (Johansson 2003). There is also an outline of the geography of the island, and an archeological item gives rise to further speculation on the sea level in former times.

Hammerfest was visited 21st July (MS *Hell b* 19):

By the church the zenith distance of the Sun's upper limb was recorded as 51° 23′ 30″ and 50° 09′ 00″ before noon. This gave azimuth half angles of 24° 06′ 00″ and 7° 52′ 00″ respectively, and when the magnetic needle was placed on the meridian line the declination was found to be 6° 50′ west.

Two days later – 23rd July – observations were made in Talvik (MS *Hell b* 19-20):

In the house of Mr. Magistrate Johannes Paus[61]*, a suitable place close to the same parallel as the Talvik church, the following observations were made:*

For the azimuth half angles the zenith distance of the Sun's upper limb was read before noon to be 51° 49′ 30″ and 50°06′ 15″. The first one gives an azimuth half angle of 29° 00′ 00″, the second 11° 32′ 00″.

The meridian line was drawn and the Copenhagen needle set up. Initially it showed a declination of 7° 40′ west, but because the table with the meridian line was in the garden just outside the house close to an iron oven only 8 feet away, I, in order to eliminate any doubt, set up a new table in the middle of the garden more than 80 feet from the house and drew a new meridian line corresponding to the first.

At these two tables I found after several agitations[62] *with a key the declinations as follows:*

1) At the table close to the house when the needle came to rest	*8° 30′ west*
after a new agitation and coming to rest again	*8° 50′*
and once more	*8° 55'*
with the Niebuhr needle at the same table	*8° 30′*
and a second reading	*8°20′*
2) At the table in the middle of the garden the Copenhagen instrument	*8° 00′*
once more	*7° 40′*
and another time	*6° 20′*
with the Niebuhr needle at the same table	*8° 00′*
and a second time	*7° 40′*

These observations were performed 23rd July from 12:30 to 2 pm. The uneven movements of the needles, and in particular the fact that they after being agitated came to rest quite suddenly after a few oscillations in an unexpected position, I assume is caused by the mountains in the neighbourhood. They do perhaps contain magnetic minerals. The fact that the third and small Copenhagen needle also showed such behaviour corroborates this opinion.

At the 25th and 26th July the needle at the table close to the house showed more regular movement. In most cases it came to rest at 7° 40′, 7° 20′ or 7° 10′.

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[61] Hans Paus, 1710-1770, jurist. *Sorenskriver* (district stipendiary magistrate) of Finnmark from 1753.

[62] Agitation here means moving a key or some other object of iron close to the needle, thereby disturbing the needle. When the object is removed the needle should return to its original position. The agitation is performed to be sure the movement of the needle is not obstructed by friction.

The zenith distance of the Sun's upper limb at culmination was the 23rd July read as 49° 45' 15". From this the Pole height was calculated to be 70° 02' 16".

The erratic behaviour of the magnetic needles may well be explained by a magnetic storm. Since the phenomenon occurred in the middle of the day the storm must have been a major one. The fact that Hell mentions and investigated this so much indicates it was not a normal behaviour of the declinometers. His conjecture of magnetic mountains can safely be rejected; that would not cause temporal variations.

The spell in Talvik apparently made an indelible impression on Hell. Towards the end of his life he writes in his *Ephemerides* (1790, p. 321):

[Talvik is] a harbour and also the residence of the magistrate of the entire Finnmark. There is hardly any place in the European part of the world surpassing it in beauty. Towards the end of July, when I visited this place surrounded by high mountains at roughly one mile's distance, I saw the most idyllic forests with various sorts of trees, luxuriant fields and gardens with blossoming plants belonging to the zone of temperate climate, among them carpets of flowering Linneas [Linnea borealis]. *The summits wrapped in snow, the hillsides covered with green trees, and Spring meeting Summer in the valleys, were a wonderful sight. Then, there was the most refreshing air, the sweetest of Zephyrs blowing, in a day that knows no night. Therefore this place, at the 70th latitude, is rightfully called the "Paradise of Finnmark" by its inhabitants. Bewildered, I found this to be what it really was – a paradise.*

We leave Hell and his manuscript here in his *Paradisus borealis*. The rest of his account of observations on the long journey towards Copenhagen is mainly repetitive listings of observed angles and holds little of additional interest. A complete list of observations is found in Table I, the locations of observation are shown on the map of Figure 11. South of Trondheim we find only two observations of declination; the weather is not the best, and he seems getting tired of measuring. The last trace of magnetic observation is a remark from southern Sweden stating that a peasant moved the table and spoiled the observation (MS *Hell b* 47).

Hell refers to his observing sites by the name of the place, often accompanied by a closer description of the exact location, and his observation of the geographic latitude. Observations of longitude were, for reasons explained earlier, not feasible during the short stops ashore. The lack of longitudes has not caused any problem when identifying Hell's sites on modern maps. The names, latitudes, and longitudes in Table I are all in the modern forms. The latitudes never deviate from Hell's values by more than 2'. For comparison of the declination values we have quoted from Hansteen's tables (1819) contemporary observations at the same places. Considering the frequent magnetic storms, diurnal variation, and measuring uncertainties, the correspondence is satisfactory.

Table I Hell's declinations along Norway 1769

Date	Site	Latitude	Longitude	Declination	Other observations
April-June	Vardø	70 22	31 08	- 3 04	
8, 9, 10 July	Kjelvik[63]	71 00	26 07	- 7 38	Holm[64] 1766: - 5 30
19 July	Måsøy	71 01	25 00	- 5 08	
21 July	Hammerfest	70 40	23 40	- 6 50	Holm 1765: - 6 50
25, 26 July	Talvik	70 03	22 57	- 7 35	Holm 1766: - 6 50
29 July	Loppa	70 20	21 27	- 9 25	
4 August	Tromsø	69 39	18 57	- 10 40	
8 August	Dyrøy	69 05	17 30	- 10 40	
10 August	Steigen	67 57	14 59	- 10 16	
12 August	Landegode	67 23	14 15	- 12 30	
14 August	Arnøy	67 09	14 00	- 12 35	
17 August	Rødøy	66 40	13 05	- 14 58	
18 August	Selsøy	66 35	12 59	- 15 05	
19 August	Dønnes	66 12	12 35	- 14 05	
21 August	Alstahaug	65 55	12 27	- 15 08	
22 August	Brønnøysund	65 28	12 12	- 14 07	
24 August	Nærøy	64 51	11 12	- 15 30	
25 August	Bjørøy	64 34	10 49	- 16 25	
28 August	Bessaker[65]	64 15	10 19	- 15 45	
29 August	Vallersund	63 52	9 45	- 15 30	
6,7 September	Trondheim	63 26	10 23	- 15 26	Berlin[66] 1770: - 15 30
21 September	Fåvang[67]	61 26	10 13	- 13 10	
28 September	Christiania	59 55	10 45	- 16 45	Holm 1769: -16 45

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[63] Close to present Honningsvåg.

[64] Jørgen Nielsen (Georgius Nicolai) Holm, 1727 – 1769, surveyor and Professor of mathematics in Copenhagen.

[65] Hell's Bokkelsund.

[66] Johan Daniel Berlin, 1711 – 1789, German/Danish/Norwegian musician and instrument maker, lived in Trondheim from 1737. According to Hell (MS *Hell b* 40), Berlin was present during the observations 7th September 1769. Berlin later made observations every year until 1783.

[67] Hell's Lösnes.

Figure 11 Points of magnetic observations on the southbound journey.

Epilogue

So, what would Hansteen have said had he gotten access to Hell's results? For sure he would have examined the time series of declinations from Vardø with great interest. This was the first of its kind from such high latitude (possibly with the exception of the unpublished observations of Anders Hellant in Torneå, mentioned by Hellant 1777, and by his biographer Tobé 1991, pp. 121-124). Hell's observations did give a hint of magnetic storms being frequent at high latitudes, but the series was too short for any definite conclusion to be drawn.

We know that Hell had ambitions of reading the magnetic needle regularly 24 hours a day. In a letter to Father Weiss[68] 24th May 1771 (Pinzger 1927, pp. 105-106) he wrote:

If my theory for the Northern Lights is correct – as I am indeed sure all future observers will confirm – then such variations of the magnetic needle that have been observed during outbreaks of Northern Lights, really have nothing to do with the Northern Lights, not any more than these are related to rainbow, halo, parhelion, or paraselene. In fact the cause of these variations is quite another, and I suspect I have found the relation in my Vardø observations which I carried out over a three months period at almost all hours, day and night. These observations all seem to point in one direction: that the variations of the magnetic needle are connected to the monthly motion of the Moon described by the Moon's apogeical and perigeical quadratures and declination, just like the regular variations of the barometer and the tides of the sea. I did in fact observe how almost exactly the same variations of the magnetic needle returned after a period of 30 days. I hope my Father Colleague [Weiss] *may take interest in becoming a diligent observer of this very useful phenomenon. However, the task of keeping records of the magnetic needle almost every hour, day and night, is not possible for one person only. It has to be shared between several observers, like the way I, Father Sajnovics and our servant* [Sebastian] *shared between us the nighttime and daytime observations. The preparations for such observations must be very careful in order to yield data of sufficient precision. I shall, however, elaborate on this in my work "Expeditio litteraria".*

We regret today that Hell was not able to cope with his ambitions with regard to the observing schedule. A more regular scheme might for example have made the data series suitable for the methods of Svalgaard *et al.* (2004) for deduction of the interplanetary magnetic field.

The letter to Weiss immediately raises the question: where are these nighttime observations? The data at hand are all between 08 and 24, and they are all in the handwriting of Hell. Possibly were they recorded in a separate and so far unknown notebook.

Hell's theory of a 30-day period is daring when we consider the irregularity of the series and the fact that it spans over less than three months. But in suggesting a period close to 30 days the synodical period of the Moon was an irresistible choice. A time series of longer duration would have demonstrated that the periodicity was more like 27 days, the rotation period of the Sun. A hundred years were to elapse until this solar-terrestrial relation was revealed.

[68] Ferenc Weiss, 1717 – 1785, Hell's colleague at the Observatory at Tyrnau (see note 26).

We are sure the value for the declination in Vardø would have pleased Hansteen very much. Taking the mean value of all observations in Vardø we arrive at a declination of -3° 04'. Considering the length of the series and his care to determine the meridian and eliminate artificial disturbances, this value stands out as quite reliable. According to the tables of Hansteen (1819) there were two additional observations of magnetic declination in Vardø not too distant from 1769 in time: Hellant measured -0º 15' in August 1748 and Bützow[69] got -5º 32' in March 1775. Allowing for the secular variation they both agree quite well with Hell's value.

The series of declination values along Norway certainly would also have been welcomed by Hansteen, who would have added the numbers to his comprehensive list of observations and thus improved his declination charts for this part of the world. Taking into account the inevitable uncertainties caused by magnetic storms and the fact that the observations were performed under open sky, they stand out as a good series. Probably there are not many of the kind in the 18th century.

As isolated numbers Hell's values may seem of little significance today, but in the time-consuming efforts still going on to map the Earth's magnetic field in space and time and thus increase our understanding of the interior of the Earth, they contribute along with thousands of other numbers.

[69] Ole Nicolai Bützow, 1742 – 1794, surveyor. Based at Hell's observatory in Vardø during 1774-1778.

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[70] At the title page of the paper the author's name is spelled *Bayley*, which we consider a misprint.

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