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French Geodetic and Scientific Expedition to Lapland

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Abstract. The paper describes surveying a part of the meridian arc in Lapland (border of Sweden and Finland). The field team had great difficulty with the climate and terrain configuration. However, they managed to prove that the Earth is roughly shaped as a rotational ellipsoid and confirm theoretical assumptions on Newton and Huygens that the arc length of one meridian degree near a pole is greater than at smaller latitudes.

Keywords: triangulation chain, length of baseline, astronomic observations, difference in latitudes, zenith sector, quadrant, length of meridian arc degree, Lapland, rotational ellipsoid

1 Introduction

A dispute over the Earth's shape arose at the beginning of the 18th century – is its equator flattened or are its poles flattened? There were two sides of the argument:

- Newton (1642–1727) and Huygens (1629–1695) reached a conclusion that the Earth's poles were flattened and its equator bulging out due to the Earth's rotation around its axis,
- Cassinis argued the Earth's poles were bulging out based on surveys of the Paris meridian.

In order to resolve this scientific dispute, French King Louis XV and the French Academy of Sciences in Paris decided to send an expedition of scientists close to the equator (Peru) and another close to the polar circle, Lapland.

2 Geodetic and Scientific Expedition to Lapland

We first provide brief biographic data on the main participants of the geodetic and scientific expedition to Lapland (now the border between Sweden and Finland).

Pierre-Louis Moreau de Maupertuis (1698–1759), (Fig. 1, URL 1 and 2) was a French mathematician, philosopher, geodesist and writer. His parents sent him to study philosophy at the Collège de la Marche in Paris in 1714. However, his mother insisted he return to Sant Malo in 1717 and study music, but he soon developed an interest in mathematics. He was a cavalry officer and lived in Paris until 1722. His early interest in mathematics flourished and he became respected and started working for the French Academy of Sciences in 1723. He produced his first paper *Sur la forme des instrumenata de musique* in 1724. In order to expand his knowledge of mathematics and other fields, he went to study with Johann Bernoulli in Basel. There he obtained an outstanding education and learned about Newton's physics from Bernoulli, who accepted the results of universal gravitation. On his return to Paris in July 1730, Moreau de Maupertuis started writing about mathematics, and he wrote his first paper on astronomy in 1731. He supported Newton's theory of gravity and in November 1732 published *Discours sur les differentes figures des astres*, in which he presented his attitude on one of the greatest issues of his period, that of the Earth's shape.

In May 1735, French King Louis XV and the French Academy of Sciences sent a geodetic scientific expedition to Peru to survey the length of one degree of meridian arc near the equator and another expedition to Lapland, near the polar circle. For the latter of which Maupertuis was invited to be the leader.

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Francuska geodetska znanstvena ekspedicija u Lapland

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Sažetak. U radu je opisano mjerenje duljine dijela meridijanskog luka u Laplandu (danas na granici Švedske i Finske). Ekipa je na terenu imala velike poteškoće u radu zbog klimatskih uvjeta i svladavanja konfiguracija terena. Međutim, uspjeli su dokazati da Zemlja približno ima oblik rotacijskog elipsoida te potvrditi Newtonova i Huygensova teorijska predviđanja da je duljina luka jednog stupnja meridijana u blizini pola veća nego na manjim geografskim širinama.

Ključne riječi: triangulacijski lanac, duljina baze triangulacijskog lanca, astronomska mjerenja, razlika geografskih širina, sekstant, kvadrant, duljina jednog stupnja meridijanskog luka, Lapland, rotacijski elipsoid

1. Uvod

Početkom 18. stoljeća nastao je znanstveni spor o Zemljinu obliku – je li ona spljoštena na ekvatoru ili na polovima. Na jednoj strani bili su:

- Newton (1642–1727) i Huygens (1629–1695), koji su teorijskim razmatranjem došli do zaključka da je Zemlja zbog svoje rotacije oko vlastite osi spljoštena na polovima i ispupčena na ekvatoru, a na drugoj strani
- Cassiniji, koji su tvrdili da je Zemlja ispupčena na polovima na osnovi mjerenja na Pariškom meridijanu.

Da bi se konačno riješio taj spor, francuski kralj Luj XV. i Kraljevska akademija znanosti iz Pariza odlučili su poslati jednu skupinu znanstvenika u blizinu ekvatora, točnije u Peru, a drugu skupinu u blizinu polarnoga kruga, u Lapland.

2. Geodetska znanstvena ekspedicija u Lapland

Na početku rada navode se kratki biografski podaci o glavnim sudionicima geodetske znanstvene ekspedicije u Lapland (na današnjoj granici Švedske i Finske).

Pierre-Louis Moreau de Maupertuis (1698–1759) (sl. 1, URL 1 i 2) bio je francuski matematičar, filozof, geodet i pisac. Roditelji su ga 1714. godine poslali u Collège de la Marche u Pariz, gdje je studirao filozofiju. Međutim, na inzistiranje majke vratio se 1717. u Sant Malo i počeo studirati glazbu, ali je ubrzo razvio snažan interes za matematiku. Do 1722. godine bio je konjički časnik i živio je u Parizu. Njegov rani interes za matematiku tada je procvjetao, te je stekao poštovanje sredine, a uz Kraljevsku akademiju znanosti je od 1723. godine. Sljedeće godine izradio je svoj prvi rad *Sur la forme des instrumenata de musique*. Da bi proširio svoje znanje iz matematike i ostalih područja otišao je u Basel na studij kod Johanna Bernoullija. Ondje je stekao izvanredno obrazovanje i učio o Newtonovoj fizici od Bernoullija, koji je prihvatio rezultate univerzalne gravitacije. Po povratku u Pariz u srpnju 1730. počeo je pisati radove iz mehanike, a 1731. godine napisao je svoj prvi rad iz astronomije. U Francuskoj je u studenome 1732. podupro Newtonovu teoriju gravitacije i objavio djelo *Discours sur les differentes figures des astres*, te je tako najavio svoje gledište o jednom od najvećih problema tih godina, Zemljinu obliku.

U svibnju 1735. francuski kralj Luj XV. i Kraljevska akademija znanosti poslali su iz Pariza geodetsku znanstvenu ekspediciju u Peru da bi izmjerila duljinu jednog stupnja luka meridijana u blizini ekvatora, a drugu, na čelu s Maupertuisom, u Lapland blizu polarnoga kruga.

Fig. 1. Pierre Louis Maupertuis (1698–1759) (URL 1)
Slika 1. Pierre Louis Maupertuis (1698–1759) (URL 1)

Fig. 2. Alexis Clairaut (1713–1765) (URL 5)
Slika 2. Alexis Clairaut (1713–1765) (URL 5)

Alexis Claude Clairaut (1713–1765) (Fig. 2, URL 5 and 6) was a French mathematician and intellectual. He was born in Paris, where his father taught him at home and reached an unbelievably high education standard. He read his first paper in the French Academy of Sciences when he was only 13 years old. He became a member of that prestigious institution at 18 years of age, in 1731. He joined a small group headed by Maupertuis who supported Newton's theory of natural philosophy. The two of them visited Johann Bernoulli in Bassel in 1734, which helped Clairaut's development as a scientist. He participated in the geodetic expedition to Lapland from April 20, 1736 to August 20, 1737.

Pierre Charles Le Monnier (1715–1799) (Fig. 3, URL 7 and 8) was a French astronomer. He was born in Paris, where his father was a professor at Collége d'Harcourt. He conducted his first astronomic surveys when he was only 15 years old, and his detailed presentation of the Moon's map helped him to enter the French Academy of Sciences in 1736 when he was 20 years old. He participated in the geodetic expedition to Lapland. He is often referred to as Lemonnier in literature.

Charles Étienne Louis Camus (1699–1768) was a little known French scientist. He was first a watchmaker and later an administrator in the French Academy of Sciences. He had the lowest status among the Lapland expedition scientists. He published *Course de Mathématique*, 3 parts, 1749–51, and *Éléments d'arithmétique*, 1753.

Anders Celsius (1701–1744) (Fig. 4, URL 9) was a Swedish physicist and astronomer. As a young man, he was a talented mathematician and studied in Uppsala. He was a professor of astronomy in Uppsala from 1730 to 1744. He visited astronomic observatories in Germany, Italy and France from 1732 to 1735 in order to gain knowledge necessary to establish an astronomic observatory in Uppsala. He observed variations of magnetic (compass) needle and was the first to notice its large deviations in polar light (auroral activity). He supported surveying of the part of meridian arc near the polar circle in Lapland and personally participated in the survey. He is famous for introducing the division of the temperature scale into 100 degrees. Celsius first called them centigrads, which is Latin for "hundred degrees". Namely, he proposed the boiling point of water be 0° and freezing point 100° when the air pressure was 760 mm of mercury. However, Linné and Strömer introduced the contemporary temperature scale with freezing point at 0 °C and boiling point at 100 °C in 1750. In honour of Celsius, they called it the Celsius temperature scale and they called the division the degrees of Celsius.

2.1 Departure of the geodetic expedition to Lapland

A group of scientists departed from Paris at the end of April, and from Dunkerque on May 2, 1736 (Smith 2002, URL 2), i.e. a year after the Peruvian geodetic expedition. Preparations for the expedition included Maupertuis dispatching Celsius to London to obtain two zenith sectors for astronomic observation from famous instrument producer George Graham. Members of the expedition were presented in Stockholm to the king

Fig. 3. Pierre Charles Le Monnier (1715–1799) (URL 8)
Slika 3. Pierre Charles Le Monnier (1715–1799) (URL 8)

Fig. 4. Anders Celsius (1701–1744) (URL 9)
Slika 4. Anders Celsius (1701–1744) (URL 9)

Alexis Claude Clairaut (1713–1765) (sl. 2, URL 5 i 6) bio je francuski matematičar i intelektualac. Rođen je u Parizu, gdje ga je otac kod kuće podučavao i pritom je postigao nevjerojatno visok standard obrazovanja. Svoj prvi rad u Kraljevskoj akademiji znanosti pročitao je u dobi od samo 13 godina. U članstvo te ugledne ustanove primljen je 1731. u svojoj 18. godini. Ondje se pridružio maloj skupini na čelu s Maupertuisom, koji su bili pristaše Newtonove teorije prirodne filozofije. S Maupertuisom je 1734. posjetio Johanna Bernoullija u Basselu, što mu je pomoglo u znanstvenom razvoju. Od 20. travnja 1736. do 20. kolovoza 1737. sudjelovao je u geodetskoj ekspediciji u Lapland.

Pierre Charles Le Monnier (1715–1799) (sl. 3, URL 7 i 8) bio je francuski astronom. Rođen je u Parizu, gdje je njegov otac bio profesor na Collége d'Harcourt. Prva astronomska mjerenja obavio je kad je imao samo petnaest godina, a detaljno prezentiranje Mjesečeve karte pripomoglo mu je da bude primljen u Kraljevsku akademiju znanosti 1736. godine u njegovoj 20. godini života. Sudjelovao je u geodetskoj ekspediciji na Lapland. U literaturi se često navodi kao Lemonnier.

Charles Étienne Louis Camus (1699–1768) malo je poznati francuski znanstvenik. Na početku je bio urar, a poslije administrator u Kraljevskoj akademiji znanosti. Bio je znanstvenik s najnižim statusom u ekspediciji u Laplandu. Objavio je *Course de Mathématique*, 3 dijela, 1749–51, i *Éléments d'arithmétique*, 1753.

Anders Celsius (1701–1744) (sl. 4, URL 9) švedski je fizičar i astronom. Već u mladosti bio je talentirani matematičar. Studirao je u Uppsali, gdje je bio profesor astronomije od 1730. do 1744. godine. Od 1732. do 1735. posjetio je astronomske opservatorije u Njemačkoj, Italiji i Francuskoj kako bi stekao znanje potrebno za osnivanje astronomskog opservatorija u Uppsali. Opažao je varijacije magnetske (kompasne) igle i prvi je otkrio da velika odstupanja nastaju kod velikih pojava polarne svjetlosti (auroralnih aktivnosti). U Parizu je bio zagovornik mjerenja duljine dijela meridijanskog luka u blizini polarnoga kruga u Laplandu i osobno je sudjelovao u toj izmjeri. Danas ga spominjemo po tome što je uveo podjelu temperaturne ljestvice na 100 stupnjeva. Celsius je te stupnjeve najprije nazvao centigrad prema latinskom "sto stupnjeva". Naime, prema njegovu prijedlogu vrelište vode je kod 0°, a ledište kod 100° pri tlaku zraka od 760 mm stupca žive. Međutim, Linné i Strömer su 1750. godine uveli današnju temperaturnu ljestvicu s ledištem na 0 °C i vrelištem na 100 °C. Nju su u počast Celsiusu nazvali Celzijevom ljestvicom, a podjelu u njoj Celzijevim stupnjevima.

2.1. Polazak geodetske ekspedicije u Lapland

Skupina znanstvenika krenula je na put iz Pariza potkraj mjeseca travnja, a iz Dunkerquea 2. svibnja 1736. (Smith 2002 i URL 2), tj. godinu dana nakon peruanske geodetske ekspedicije. Prije polaska učinjene su pripreme pa je Maupertuis poslao Celsiusa u London da kod poznatog izrađivača instrumenata Georgea Grahama nabavi dva zenitna sektora za astronomska opažanja.

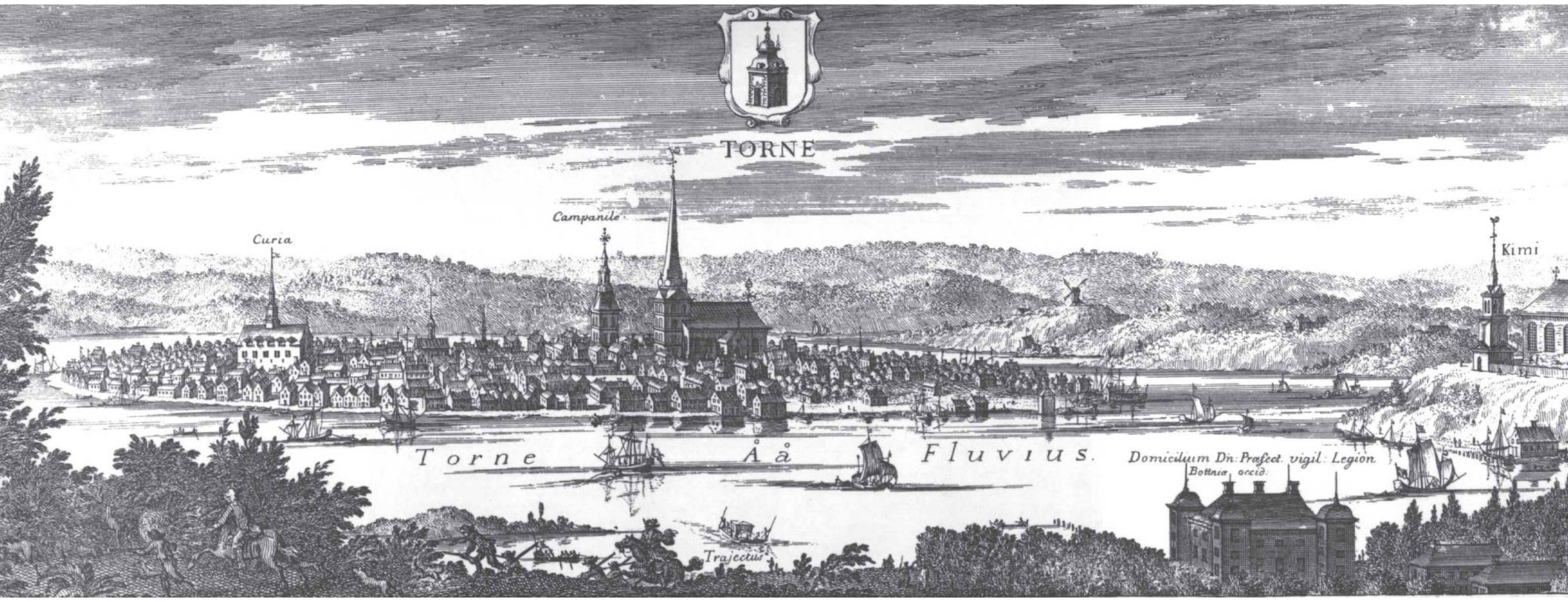

Fig. 5. City of Torneå (now Tornio) which belonged to Sweden at the time of the Lapland expedition and which now belongs to Finland; copper-engraving produced between 1690 and 1710 (URL 12)

Slika 5. Slika grada Torneå (danas Tornio), koji je u vrijeme laplandske ekspedicije pripadao Švedskoj, a danas je u Finskoj; bakrorez izrađen 1690–1710 (URL 12)

and a group of scientists from the Swedish map office (Murdin 2009, page 57). After stopping in Stockholm for several days, the expedition travelled to Tornio, where they arrived on June 19, 1736 (URL 12).

The team consisted of 36 people, headed by Pierre-Louis Moreau de Maupertuis and French scientists Alexis Claude Clairaut, Charles Le Monnier and Charles Etienne Louis Camus. Swedish astronomer and physicist Anders Celsius (URL 3) was also a part of the expedition, and he had an additional task of serving as a liaison with the Swedish authority in Tornio (Murdin 2009, page 56). Priest Réginald Outhier was interested in astronomy, and he was also a doctor and keeper of the work diary. He was the only person knowledgeable in surveying, with experience from helping Cassini II in the geodetic survey of France (Normandy) (Murdin 2009, page 59).

Swedish scientist Anders Helant (1717–1789) served as a translator who spoke Finnish, French, Swedish and Latin, while the other translator was mayor of Tornio Petter Johan Pipping, who spoke Swedish, Finnish and Latin. M. Sommeraux worked as a secretary and a cashier, and M. d'Herbelot was a draftsman. Lieutenant colonel Du Rietz commanded soldiers who secured transport for Maupertius's team, carried instruments and did other physical work (URL 3 and 11). The team had a total of 8 scientists, 2 translators, 5 servants and as many as 21 rowers. Namely, they had 3 rowers for each of the 7 boats they had.

2.2 Arrival of the geodetic expedition in Lapland

The geodetic expedition arrived in Tornio (Fig. 5) on June 19, 1736, which means two days prior to June 21, which has the longest daylight in the northern hemisphere and on which the Sun does not go below the horizon during the entire day (24 hours) within the polar circle at latitudes greater 66.5°. These are the so-called "white nights". Tornio is located at 65°51' latitude, which means the Sun was partially below the horizon only briefly at the time the expedition arrived. However, light could be seen the same as prior to dawn, meaning one was able to read. Tornio is located on a peninsula near the mouth of the river Torneo into the Gulf of Bothnia, where they took the belfry (Fig. 6) as the starting point of surveying the meridian arc length.

2.3 Selection of trigonometric points

Maupertuis first planned to make a chain of triangles in the Gulf of Bothnia archipelago. However, scouting the field showed the islands were not elevated enough for trigonometric points. Wegelius, Tornio school principal, proposed the river Tornea and surrounding hills for the chain along the meridian. Maupertuis accepted the idea. Nowadays, the river Tornea in the southern part is a natural border between Sweden and Finland, but it was a part of Sweden at the time of the expedition.

Članovi ekspedicije predstavljeni su u Stockholmu kralju i skupini znanstvenika iz švedskog ureda za karte (Murdin 2009, str. 57). Nakon zaustavljanja na nekoliko dana u Stockholmu, ekspedicija je otputovala u Tornio gdje su stigli 19. 6. 1736. (URL 12).

U ekipi je bilo 36 osoba na čelu s vođom ekspedicije Pierre-Louisom Moreauom de Maupertuisom i francuskim znanstvenicima Alexisom Claudeom Clairautom, Charlesom Le Monnierom i Charlesom Etienneom Louisom Camusom. U nju je bio uključen i švedski astronom i fizičar Anders Celsius (URL 3), a njegov zadatak bio je da osim rada u ekipi kao znanstvenik služi i kao veza sa švedskim vlastima. Naime, tada je Tornio bio pod švedskom nadležnošću (Murdin 2009, str. 56). Svećenik Réginald Outhier bio je zainteresiran za astronomiju, a u ekipi je radio i kao liječnik i čuvao je radni dnevnik. Bio je jedina osoba koja je imala iskustvo u mjerenju, jer je pomagao Cassiniju II. na geodetskoj izmjeri u Francuskoj (Normandiji) (Murdin 2009, str. 59).

Švedski znanstvenik Anders Helant (1717–1789) bio je i prevoditelj, koji je govorio finski, francuski, švedski i latinski, a drugi prevoditelj bio je gradonačelnik Tornia Petter Johan Pipping, koji je govorio švedski, finski i latinski. M. Sommeraux radio je kao tajnik i blagajnik, a M. d'Herbelot bio je crtač. Potpukovnik Du Rietz zapovijedao je vojnicima koji su Maupertuisovoj ekipi osiguravali transport, prenosili instrumente i izvodili ostale fizičke poslove (URL 3 i 11). U ekipi je bilo ukupno: 8 znanstvenika, 2 prevoditelja, 5 poslužitelja i čak 21 veslač. Naime, imali su 7 čamaca, a u svakom čamcu po 3 veslača.

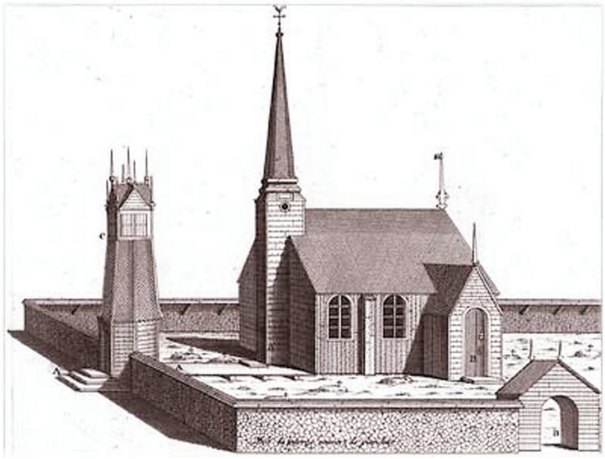

Fig. 6. The belfry in Tornio was the first point in the triangulation chain of the Lapland expedition (drawing by Réginald Outhier, URL 11)

Slika 6. Zvonik crkve u Torniu bila je prva točka u trigonometrijskom lancu laplandske ekspedicije (crtež Réginald Outhier URL 11)

2.2. Dolazak geodetske ekspedicije u Lapland

Geodetska ekspedicija stigla je u grad Tornio (sl. 5) 19. lipnja 1736., a to znači dva dana prije 21. lipnja, kada je na sjevernoj Zemljinoj hemisferi najduža obdanica u godini i unutar polarnoga kruga na geografskim širinama većim od 66,5° tijekom čitavoga dana (24 sata) Sunce ne zalazi za horizont. Ondje su nastupile tzv. "bijele noći". Grad Tornio nalazi se na geografskoj širini 65°51' tako da je u to doba ljeta kad je stigla ekspedicija Sunce bilo vrlo kratko vrijeme djelomično pod horizontom. Međutim, i tada se vidjela svjetlost kao pred zoru, tako da se moglo čitati. Inače grad Tornio smješten je na poluotoku blizu ušća rijeke Torneo u Botnički zaljev, gdje su crkveni toranj (sl. 6) uzeli kao početnu točku mjerenja duljine meridijanskog luka.

2.3. Izbor položaja trigonometrijskih točaka

Maupertuis je najprije planirao izvesti trigonometrijski lanac u arhipelagu Botničkog zaljeva. Međutim, rekognosciranjem terena ustanovljeno je da su ti otoci preniski i nepogodni za postavljanje trigonometrijskih točaka, koje se obično postavljaju na veće uzvisine. Tada je Wegelius, ravnatelj škole u Torniu, sugerirao da bi za postavljanje trigonometrijskog lanca uzduž meridijana mogla dobro poslužiti rijeka Tornea i okolna brda. Maupertuis je tu ideju prihvatio i proveo u djelo. Danas je rijeka Tornea u južnom dijelu prirodna granica između Švedske i Finske, ali u vrijeme ekspedicije to je područje pripadalo Švedskoj.

Posljednja trigonometrijska točka na mjerenom dijelu duljine meridijanskog luka nalazila se oko 110 km sjevernije od Tornia, na brijegu Kittisvaara (sl. 7). To je viši dio, malo brdovit, a do njega su mogli doći ljeti po uzburkanoj vodi, u laponskim čamcima s plitkim dnom izrađenim od tankih dasaka, dovoljno fleksibilnim da se ne oštete pri čestim sudarima s potopljenim stijenama.

Preko ljeta su članovi ekspedicije i njihovi pomagači morali izdržati ubode rojeva komaraca i drugih insekata. Da bi se zaštitili, morali su pokrivati lice velom, a sličnih problem imali su i s hranom.

Krećući se rijekom na sjever, mjernici su susretali domorodačke stanovnike Laponce, koji su sebe nazivali Sabme, ruski Saami, prije Lopj (Šentija 1979, str. 32). Oni su podmirivali sve svoje životne potrebe brinući se za krdo sobova, a od njihove kože izrađivali su šatore. Maupertuis ih je opisivao ružnima, a njihove šatore bijednima. Međutim, i članovi ekspedicije mogli su nešto naučiti od Laponaca. Tako su naučili da rojeve insekata

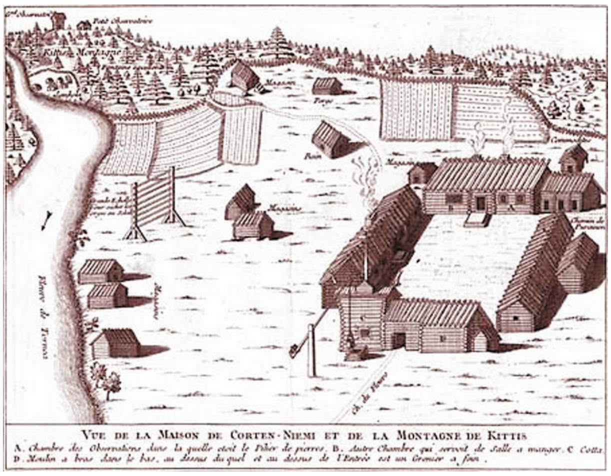

Fig. 7. Korteniemi house and Kittisvaara hill with large and small observatories, with the last point of the chain; the river Tornea is to the left (drawing by Réginald Outhier; URL 11)

Slika 7. Kuća Korteniemi i brijeg Kittisvaara s velikim i malim opservatorijem, gdje je bila posljednja točka trigonometrijskog lanca; lijevo rijeka Tornea (crtež Réginald Outhier, URL 11)

The last trigonometric point on the surveyed part of the meridian arc was located about 110 km north from Tornio on the Kittisvara hill (Fig. 7). It is a higher, hilly part which could be reached in summer by Lapplanders with shallow bottom boats made out of thin boards, which were flexible enough not to be damaged in frequent crashes with submerged rocks.

Expedition members and their aides had to endure stings of swarms of mosquitoes and other insects over the summer. They had to cover their faces with veils in order to protect themselves, and they also had issues with food.

Following the river northward, surveyors met the native inhabitants Lapps, who referred to themselves as Sabme, Russian Saami, earlier Lopj (Šentija 1979, page 32). They met all their needs by taking care of reindeers and used their hide to produce tents. Maupertuis did not like them; he described them as ugly and their tents as miserable. However, members of the expedition were able to learn from the Lapps. For example, they learned to repel swarms of insects using smoke. In order to avoid getting bitten by insects during night, they wrapped their heads with *Lappmudes* (long dresses made from reindeer hide) and covered themselves with fir branches (Murdin 2009, page 58).

The River Tornea flows approximately along the meridian, so points Nivavaara, Kaakarnavaara, Huitaperi, Luppiovaara, Polki-Torni, Aavasaksa, Horilankero, Niemivaara and Pullinki (Fig. 8) were placed between Tornio and Kittisvaara. Maupertuis planned surveying the base for the chain in winter along the frozen river Torneo between points Luppiovaara and Polki-Torni (URL 11). In winter, the expedition employed some kind of skis or sledge-carriages with reindeers (Fig. 9). The sledge-carriage was similar to boats and could be stopped using wooden bats.

The advantage of the selected points in Lapland was that there were no large differences in altitude, in contrast to Peru, where some trigonometric points were placed on mountain peaks with altitudes of more than 4000 m. This meant the Peru expedition had to exert great physical effort and time.

2.4. Surveying instruments and tools

Quadrants

Quadrants were used to survey angles in the triangles of the chain. They consisted of two quadrants produced by famous royal instrument maker Claude Langlois in Paris. The largest had a radius of 0.66 m. Maupertuis donated the copies used in the Lapland expedition to the observatory in Potsdam – Babelberg in Germany, where they are preserved as historical copies (URL 11). An inscription reads they were used to definitely prove Earth is flattened at poles.

Zenith sectors

A zenith sector was used for astronomic surveys in order to determine the difference in latitudes between the first and the last point in the chain. It was produced by leading English instrument maker George Graham. Zenith distances were surveyed on the same star at the beginning and end of the chain. The radius of the zenith sector was equal to 3.66 m and had the graduated limb of arc of the sector covered only 5°30' (URL 11).

Measuring rods

Claude Langlois, royal engineer for astronomic instruments produced two iron standard toises based on the *Chatelet toise* sample in 1735. One was taken to Peru (now Ecuador) and called *Toise du Pérou*, while the other one was taken to Lapland and called *Toise du Nord* (URL 14). The Lapland expedition produced eight spruce measuring rods each of five *Toise du Nord* (9.745 m) in length (Murdin 2009, page 60 and URL 11).

Signals for pointing

Wooden signals on which surveyors pointed their angle measuring instruments were placed on each of the selected positions of the stations of the trigonometric chain points. Maupertuis constructed pyramids in such a way that trunks connected at the top of pyramid.

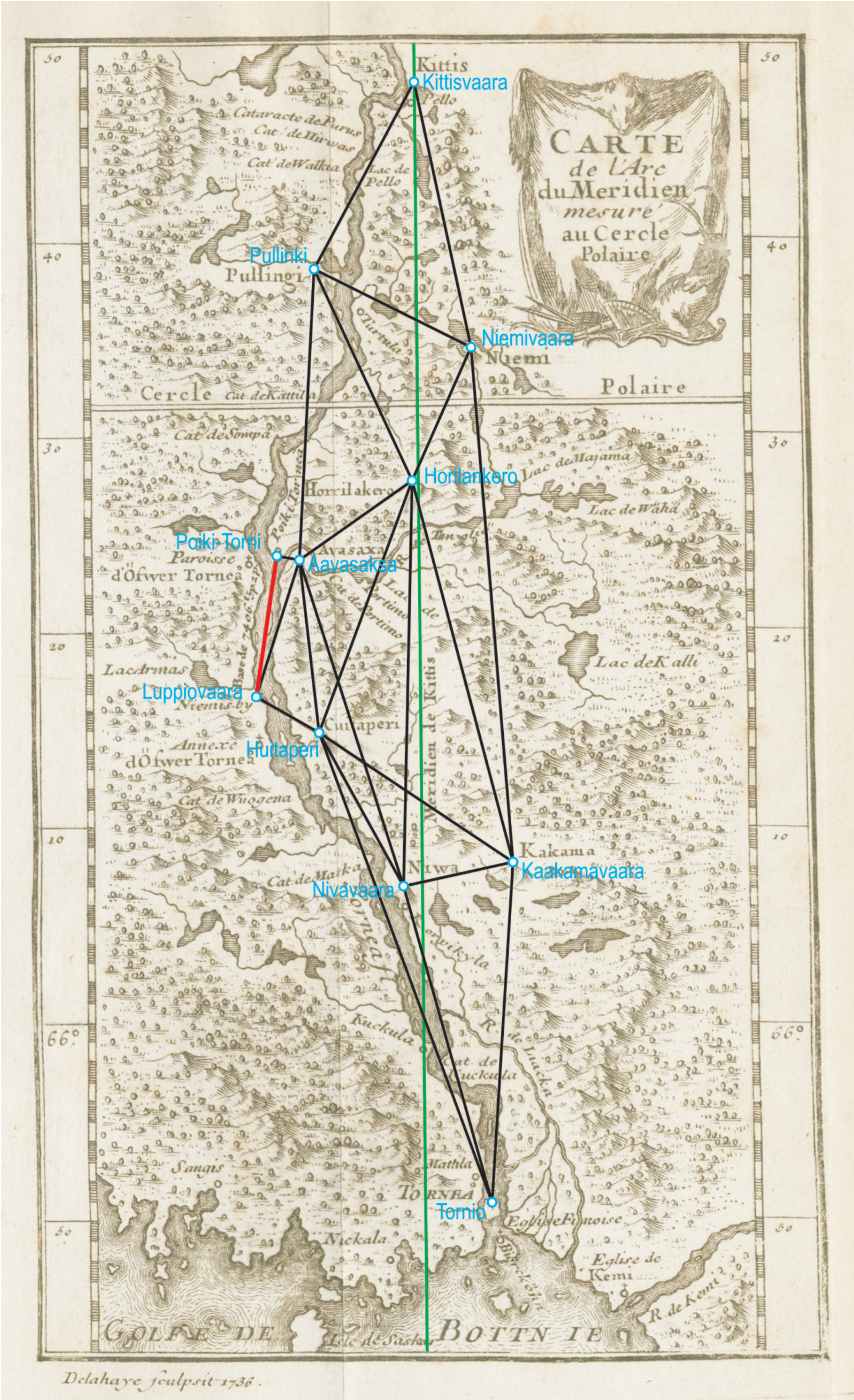

Fig. 8. Triangulation chain from Tornio to Kittisvaara (from the book of Maupertuis and others: *La Figure de la Terre*, Copyright Max Planck Institute for the History of Science, Library, http://echo.mpiwg-berlin.mpg.de/MPIWG:R44MEPRB)

Slika 8. Trigonometrijski lanac od Tornia do Kittisvaara (iz knjige Maupertuis i drugi: *La Figure de la Terre*, izvornik Max Planck Institute for the History of Science, Library, http://echo.mpiwg-berlin.mpg.de/MPIWG:R44MEPRB)

Fig. 9. Maupertuis used sledges-carriages with reindeers. They were similar to boats and could be stopped using a bat. He also employed skis, but with less skill (drawing by Réginald Outhier, URL 11)

Slika 9. Maupertuis se koristio saonicama sa zapregnutim poludivljim sobom. Saonice su bile poput čamca, a palicom se služilo za kočenje. Putovao je i s pomoću skija, ali s manje vještine (crtež Réginald Outhier URL 11)

The top of the pyramid was used to view from a large distance, with surveyors placing an instrument for measuring angles in the pyramid's centre. Such a procedure avoided computing the reduction of angles to the centre of the trigonometric point.

2.5 Measuring angles in the trigonometric chain

They had visited all the trigonometric points on several occasions. In order to start measuring angles in the trigonometric chain, they first had to place pyramids as signals for viewing on neighbouring points and they also served as shelters for instruments.

All three angles were measured in all the triangles, and measurements lasted two months during summer of 1736 (URL 11). They were measured with quadrants produced by Claude Langlois in Paris. The same angles were measured by several people on several occasions, and they also checked the sum of angles in triangles. This was done only to verify that the sum did not significantly deviate from 180°, otherwise it would have been sufficient to know only two angles in each triangle. However, nothing was said about spherical excess, i.e. deviation of the sum of angles in larger spherical triangles from 180°, which was calculated for the first time in the geodetic expedition in Peru.

It is very cold in the mountainous part of Lapland throughout the year. The team had to visit many of the points three or four times, and they had to camp at one site for ten days and wait for the atmosphere, i.e. the fog, to clear. The team forgot to conduct some important measurements during the summer, and therefore Maupertuis had to supplement the measurements during winter (Murdin 2009, page 60).

2.6 Measuring the base length

The measuring site was selected practically on the river Tornea, because that part naturally has the smaller difference in altitude. Selected points were Luppiovaara on the ice of the river Tornea and Poiki-Torni on the bank of the river Tornea in Aavasaksa. The distance between the two points was about 7400 toise, i.e. about 14.5 km.

In order to measure the base length, the team had to wait until the river froze and they could walk on it. Therefore, they carried out this procedure in December 1736, when the temperature was extremely low. Prior to starting to measure, it was necessary to remove drifts of snow and some obstructive blocks between the first and last points of the base (Murdin 2009, page 60).

The shortest day on the northern hemisphere is 21st December, which means the entire day (24 hours) is a night within the Arctic Circle. This is why the base could only have been measured during twilight or illumination from aurora or other source.

The surveyors were divided into two groups of four. They did not trust native helpers or their officials, so each surveyor had a pencil and paper fixed to a plate around his neck and marked each measuring rod. The temperature was low, 18° R below the freezing point (URL 11).

8 measuring rods were produced from spruce and they were made to be exactly 5 toise (9.745 m) long according to Murdin (2009, page 60). In fact there were 8 wooden measuring rods and 5 metal bars each about one toise long. First the five bars were calibrated against the *Toise du Nord* so that when laid end to end they measured exactly 5 toises. Then 8 rods were each made equal to the length covered by the 5 toise bars end to end, i.e. each was of 5 toises length. These were then put into two groups of 4 rods. The rods were heavy and were supported by helpers to facilitate carrying them. Surveyors paid special attention to the accuracy of touching nails on the ends of rods. In order to roughly control their measurements, they stretched a 50 toise (97.45 m) long rope (Bialas 1982, page 127) along the entire length of the base. Namely, fewer mistakes could be made using a rope than in numerous counting of measuring pole lengths, which there were as many as 1480 if they were 5 toise long each. We have not been able to find data on taking into account the stretching or shortening coefficient for the iron *Toise du Nord*, which was produced in

oko hrane odbija dim tinjajuće vatre. Da bi preko noći izbjegli ugrize insekata, zamatali su glave u *lappmudes* (vrstu duge haljine načinjene od sobovske kože) i pokrili se granama jela (Murdin 2009, str. 58).

Rijeka Torneo teče približno po pravcu meridijana tako da su između Tornia i Kittisvaara na okolna brda postavljene trigonometrijske točke Nivavaara, Kaakarnavaara, Huitaperi, Luppiovaara, Polki-Torni, Aavasaksa, Horilankero, Niemivaara i Pullinki (sl. 8). Pritom je Maupertuis planirao mjerenje duljine baze trigonometrijskog lanca po zimi uzduž zaleđene rijeke Torneo između točaka Luppiovaara i Polki-Torni (URL 11). Po zimi su se kretali na nekoj vrsti tamošnjih skija ili na sanjkama sa zapregnutim poludivljim sobom (sl. 9). Saonice su bile poput čamca, a zaustavljale su se drvenim palicama.

Prednost odabranih položaja trigonometrijskih točaka u Laplandu bila je u tome što nije bilo velikih visinskih razlika, kao na primjer u Peruu, gdje su neke trigonometrijske točke bile postavljene na planinske vrhove s nadmorskom visinom iznad 4000 m. Zbog toga su u Peruu članovi ekspedicije trebali uložiti velike fizičke napore i bilo je potrebno više vremena za savladavanje uspona.

2.4. Mjerni instrumenti i pomagala

Kvadranti

Kvadranti su služili za mjerenje kutova u trokutima trigonometrijskoga lanca. U laplandskoj ekspediciji imali su dva kvadranta, koje je izradio poznati kraljev izrađivač instrumenata Claude Langlois u Parizu. Najveći je imao radijus 0,66 m. Te primjerke poklonio je Maupertuis opservatoriju u Potsdamu – Babelberg u Njemačkoj, gdje se čuvaju kao povijesni primjerci (URL 11). Na njima piše da je tim kvadrantima definitivno dokazano da je Zemlja spljoštena na polovima.

Zenitni sektori

Zenitni sektor korišten je za astronomska mjerenja za određivanje razlike geografskih širina između prve i posljednje točke u trigonometrijskom lancu. Izradio ga je vodeći engleski izrađivač instrumenata George Graham. Mjerene su zenitne udaljenosti na iste zvijezde na početku i kraju trigonometrijskog lanca. Radijus zenitnog sektora bio je 3,66 m, a limb je bio podijeljen u luku od samo 5°30' (URL 11).

Mjerne motke

Claude Langlois, kraljev inženjer za astronomske instrumente, izradio je 1735. godine dva željezna standardna toisea na temelju uzorka *Chatelet toise*. Jedan je ponijela ekspedicija u Peru (današnji Ekvador) te je nazvan *Toise du Pérou*, a drugi, koji je nazvan *Toise du Nord*, ekspedicija u Lapland (URL 14). U Laplandu su za stvarno mjerenje duljine baze trigonometrijskog lanca na terenu izradili osam mjernih motki od drveta omorike, dugih 5 *Toise du Nord* (9,745 m) (Murdin 2009, str. 60, URL 11).

Signali za viziranje

Signale izrađene od drveta na koje su mjeritelji vizirali postavljali su na izabrane položaje točaka trigonometrijskoga lanca. Maupertuis je konstruirao piramide tako da su se debla spajala na njezinu vrhu, koji je služio za viziranje iz velike udaljenosti, a opažač je postavljao instrument za mjerenje kutova u sredinu piramide. Na taj način izbjegnuto je izvođenje redukcije kutova na središte trigonometrijske točke računskim putem.

2.5. Mjerenje kutova u trigonometrijskom lancu

Na sve trigonometrijske točke morali su dolaziti više puta. Da bi počeli mjeriti kutove u trigonometrijskom lancu morali su prethodno postaviti piramide kao signale za viziranje na susjedne točke, koje su im ujedno služile i kao skloništa za instrumente.

Sva tri kuta mjerena su u svima trokutima, a mjerenja su trajala dva mjeseca u ljetu 1736. godine (URL 11). Kutove su mjerili kvadrantima koje je izradio Claude Langlois u Parizu. Pritome je iste kutove mjerilo više osoba i s više ponavljanja, a izvršena je i kontrola zbroja kutova u trokutima. Naime, to je bila samo kontrola da zbroj izmjerenih kutova u trokutu ne odstupa znatno od 180°, jer inače bi bilo dovoljno izmjeriti samo dva kuta u svakom trokutu. Međutim, nije bilo ništa rečeno o sfernom ekscesu, tj. odstupanju zbroja kutova u većim sfernim trokutima od 180°, što su prvi put računali u geodetskoj ekspediciji u Peruu.

U planinskom dijelu Laplanda vrlo je hladno tijekom godine. Na mnoge trigonometrijske točke morali su dolaziti 3–4 puta, a na jednom su mjestu morali i kampirati deset dana i čekati da se atmosfera pročisti, tj. da nestane magla. Za vrijeme ljeta zaboravili su obaviti neka važna mjerenja, stoga je Maupertuis po zimi morao dopuniti mjerenja (Murdin 2009, str. 60).

2.6. Mjerenje duljine baze trigonometrijskog lanca

Mjesto za izmjeru duljine baze trigonometrijskog lanca izabrano je praktički na samoj rijeci Tornea, jer taj dio ima najmanju visinsku razliku. Izabrane su točke Luppiovaara kod obale rijeke Tornea i točka Poiki-Torni na obali rijeke Tornea u Aavasaksi. Udaljenost između tih dviju točaka iznosila je oko 7400 toisea, tj. oko 14,5 km.

Paris at +14°, probably according to the Réaumur scale (URL 11). It is also unknown whether the surveyors took into account stretching and shortening coefficients for the wooden measuring rods.

The base length was measured with the rods twice in the same direction, with the difference between them being only 4 pouces (11 cm).

2.7 Astronomic measurements

The difference in latitudes between Tornio and Kittisvaara using the zenith sector was measured in October and November 1736 (Murdin 2009, page 59). Elevation angles were measured of stars δ and α in the Dragon constellation (Bialas 1982, page 127) when the stars passed through the meridian, i.e. when their elevation heights were the greatest (URL 11). Three observers usually worked on this task and never the same three people:

- one was in charge of the plumb
- another read the micrometer and
- the third observer moved the telescope and followed the star without looking into the micrometer.

Astronomic measurement established the difference in latitudes between Tornio and Kittisvaara: 57'30.42'', very close to one degree (Vykutil 1982, page 418). The measurement was repeated in March and April 1737 with the following result: 57'26.93'' (Vykutil 1982, page 418). They took the average of the two measurements for subsequent calculations: 57'28.67'' (Bialas 1982, page 129).

In addition, they measured azimuths from Tornio and Kittisvaara astronomically toward some of the triangulation points (URL 11). Using these measured azimuths and the triangulation chain, they calculated the position of the meridian passing through the Kittisvaara point (Fig. 8).

2.8 Measurement using a second pendulum

The Lapland geodetic expedition also employed the pendulum in 1736 and 1737. They noticed that a second pendulum showing the correct time in Paris accelerated 59 seconds a day in Lapland (Murdin 2009, page 63). They determined the variations by astronomically observing the positions of stars.

Let us mention that in 1673, Jean Richer was the first to measure the change in length of a seconds pendulum in French Guyana which showed the correct time in Paris. A second pendulum from Paris was two and a half minutes late in French Guyana.

By comparing these results according to the mathematical pendulum formula

$$t = 2\pi\sqrt{\frac{l}{g}}$$

where t – time, l – length of mathematical pendulum, and g – acceleration of gravity, it is clear that:

- acceleration of gravity g is greater in Paris than in French Guyana near the equator at +5° because the second pendulum had to be shortened and,
- acceleration of gravity g is greater in Lapland than in Paris because the second pendulum had to be extended.

These results show the Earth is flattened at poles because acceleration of gravity is greater in Paris than near the equator, while it is greater near poles than in Paris. Therefore, measurement of second pendulum length in Lapland indicated Earth was flattened at poles.

2.9 Processing of field measurement results

Angle measurements in the chain were conducted from July 6 to September 6, 1736. The first astronomic measurements were carried out in October and November, and the base length was measured in December of the same year. Therefore, it can be said the field measurements without subsequent measurements were completed in half a year. Field measurements were numerically processed during winter, from January to March 1737 (Vykutil 1982, page 418). Previous results indicated the length of one degree of meridian arc in Lapland was significantly larger than the one determined by Picard in France. Thus Maupertuis felt the need to verify some measurements in the spring (Murdin 2010, page 63), so they repeated the measurement of the difference between latitudes in March and April of 1737 and continued calculating with the average of the two results, 57'28.67''.

By numerical processing, reducing to the meridian straight line passing through the Kittisvaara trigonometric point, reducing lengths to sea level, as well as other necessary reductions of conducted measurements in the chain, it was determined that the length of the meridian chain from Tornio to Kittisvaara equals 55 023.47 toise (107 240.74 m), i.e. that the length of one degree of meridian arc in Lapland equals 57 437.94 toise (111 946.47 m) (Bialas 1982, page 129).

2.10 Return and publishing of the result of determining the length of one degree of meridian arc

The Lapland expedition had great difficulty in conducting measurements in a very unfavourable climate and their return was not simple, but extremely dangerous. Le Monnier became ill during winter and Maupertuis was constantly in poor health. In addition, the expedition had a shipwreck in the Baltic Sea. They had to save their papers with recorded measurements and the instruments. Still, they continued their voyage for

Da bi mogli mjeriti duljinu baze trigonometrijskog lanca morali su pričekati veću hladnoću, kad se voda u rijeci zaledila, tako da su mogli hodati po ledu. Zato su izmjeru duljine baze organizirali u prosincu 1736. kad su bile ekstremno niske temperature. Prije početka mjerenja duljine baze bilo je potrebno ukloniti zapuhe snijega i neke opstruktivne blokove po čitavom dijelu baze između njezine početne i završne točke (Murdin 2009, str. 60).

Dana 21. prosinca najkraći je dan na sjevernoj Zemljinoj hemisferi, a to znači da unutar arktičkoga kruga nastupa noć kroz čitav dan (tj. kroz 24 sata). Zato se duljina baze mogla mjeriti samo u sumrak, uz slabu polarnu svjetlost ili svjetlost iz drugih izvora.

Mjernici su se razdijelili u dvije grupe, tako da su u svakoj grupi bila četiri mjeritelja. Nisu imali povjerenje u domaće pomagače, ali ni u svoje službenike pa je svaki mjeritelj imao olovku i papir, učvršćene na ploču obješenu o vrat, i upisivao crtice za svaku položenu mjernu motku. Zapisano je da je temperatura bila niska i iznosila je 18° R ispod točke ledišta (URL 11).

Mjerne motke izradili su od drveta smreke i bile su duge 5 toisea (9,745 m) prema Murdinu (2009, str. 60). U stvarnosti bilo je 8 drvenih mjernih motki i 5 metalnih šipki dugih oko 1 toise. Najprije su kalibrirali 5 metalnih mjernih šipki prema *Toise du Nord*. Zatim su položili 5 mjernih šipki jednu do druge i tako dobili duljinu od 8 drvenih motki dugih 5 toisea. Njih su zatim podijelili u dvije grupe po 4 drvene mjerne motke. Motke su bile teške te su pomoćni radnici podupirali jedan kraj i pomagali ih nositi. Mjeritelji su posebnu pozornost posvećivali točnosti dodirivanja čavlića koji su se nalazili na krajevima letvi. Da bi grublje kontrolirali svoja mjerenja, natezali su uže dugo 50 toisea (97,45 m) (Bialas 1982, str. 127) po čitavoj dužini baze, kojem su prethodno odredili duljinu. Naime, s užetom su mogli manje grubo pogriješiti nego mnogobrojnim brojenjem duljina mjernih letvi, kojih je bilo čak oko 1480 ako su bile duge 5 toisea. U literaturi nismo našli podatak o uzimanju u račun koeficijenta rastezanja, odnosno skraćivanja za željezni *Toise du Nord*, koji je u Parizu izrađen na temperaturi +14°, vjerojatno prema Réaumurovoj ljestvici (URL 11). Također nije poznato jesu li uzimali temperaturne koeficijente rastezanja, odnosno stezanja za izrađene drvene mjerne motke.

Duljina baze trigonometrijskog lanca mjerena je u dva puta, a razlika između tih dvaju mjerenja bila je samo 4 pouces (11 cm).

2.7. Astronomska mjerenja

U listopadu i studenome 1736. mjerena je razlika geografskih širina između Tornia i Kittisvaara s pomoću zenitnoga sektora (Murdin 2009, str. 59). Mjereni su elevacijski kutovi zvijezda δ i α u zviježđu Zmaja (Dragon) (Bialas 1982, str. 127), i to kada su zvijezde prolazile kroz meridijan, tj. kada su imale najveće elevacijske visine (URL 11). Obično su istodobno radila trojica opažača, i to svaki dan tri različite osobe:

- jedan je pazio na visak
- drugi je očitavao mikrometar
- treći je opažač pomicao teleskop prateći zvijezdu naprijed ili natrag, ali pritom nije gledao u mikrometar.

Astronomskim mjerenjem utvrđeno je da razlika geografskih širina između Tornia i Kittisvaara iznosi 57'30,42'', dakle vrlo blizu jednog stupnja (Vykutil 1982, str. 418). U ožujku i travnju 1737. mjerili su ponovno astronomskim načinom razliku geografskih širina između Tornia i Kittisvaara i dobili da ona iznosi 57'26,93'' (Vykutil 1982, str. 418). Zatim su uzeli sredinu tih dvaju mjerenja te dalje računali s razlikom geografskih širina 57'28,67'' (Bialas 1982, str. 129).

Osim toga astronomskim načinom izmjerili su azimute iz Tornia i Kittisvaara prema nekim trigonometrijskim točkama (URL 11). S pomoću tih izmjerenih azimuta i izmjerenoga trigonometrijskog lanca izračunali su položaj meridijana položen kroz točku Kittisvaara (sl. 8).

2.8 Mjerenje sekundnim njihalom

Laplandska geodetska ekspedicija je zimi 1736/37. mjerila i njihalom. Uočili su da je sekundno njihalo, koje je pokazivalo točno vrijeme u Parizu, na geografskoj širini u Laplandu ubrzavalo za 59 sekundi na dan (Murdin 2009, str. 63). To odstupanje odredili su s pomoću astronomskih opažanja položaja zvijezda.

Spomenimo da je Jean Richer 1673. godine prvi izmjerio promjenu duljine sekundnog njihala u Francuskoj Gvajani, koje je pokazivalo točno vrijeme u Parizu. Izmjereno je da sekundno njihalo iz Pariza kasni dvije i pol minute u Francuskoj Gvajani.

Usporede li se ti rezultati prema formuli za matematičko njihalo

$$t = 2\pi\sqrt{\frac{l}{g}}$$

gdje je t – vrijeme, l – duljina matematičkog njihala, a g – ubrzanje sile teže, očito je:

- da je u Francuskoj Gvajani u blizini ekvatora na geografskoj širini +5° ubrzanje sile teže g manje nego u Parizu jer se morala skratiti duljina sekundnog njihala i
- da je u Laplandu ubrzanje sile teže g veće nego u Parizu jer se morala produžiti duljina sekundnog njihala.


LA FIGURE
DE
LA TERRE,
DE'TERMINE'E
PAR LES OBSERVATIONS
De Meſſieurs DE MAUPERTUIS, CLAIRAUT, CAMUS, LE MONNIER, de l'Académie Royale des Sciences, & de M. l'Abbé OUTHIER, Correſpondant de la même Académie,
Accompagnés de M. CELSIUS, Profeſſeur d'Aſtronomie à Upſal,
FAITES PAR ORDRE DU ROY
AU CERCLE POLAIRE.
Par M. DE MAUPERTUIS.
A PARIS,
DE L'IMPRIMERIE ROYALE.
M. DCCXXXVIII.

Fig. 10. Cover of the book *La Figure de la Terre* by Maupertuis, Clairaut, Camus, Le Monnier, Outhier and Celsius from 1738 (URL 13)

Slika 10. Korice knjige *La Figure de la Terre* Maupertuisa, Clairauta, Camusa, Le Monniera, Outhiera i Celsiusa iz 1738. godine (URL 13)

Fig. 11. Jöns Svanberg (1771–1851), Swedish priest and mathematician (URL 10)

Slika 11. Jöns Svanberg (1771–1851), švedski svećenik i matematičar (URL 10)

Denmark and finally arrived in France (Murdin 2009, page 63).

Maupertuis presented members of the French Academy of Sciences with the measurement results in Paris on August 28, 1737 and concluded that the Earth was flattened at the poles, as stated by Newton and Huygens. Cassini and his supporters attacked Maupertuis and his colleagues. Cassini claimed that:

- Maupertuis took a too short distance on the meridian arc, a difference smaller than one degree in latitudes,
- Maupertuis measured the length of a base only on the south of the trigonometric chain and did not control the north end of the chain with a second base and that,
- Maupertuis did not recalibrate astronomic measurements.

In reality, results of the Lapland expedition were too large, i.e. it was determined that the length of one degree of meridian arc in Lapland was much larger than predicted in France. It was also greater than calculated theoretically by Newton. Therefore, all parties were eager to find out the results of the Peru expedition, which would confirm the Lapland expedition results.

Expedition participants Maupertuis, Clairaut, Camus, Le Monnier, Outhier and Celsius published their results in *La Figure de la Terre* (Fig. 10) in Paris in 1738. King Louis XV rewarded all Lapland expedition members with an annual reward of 1200 livres[1] (URL 11). M. Outhier published his *Journal d'un voyage au Nord* in 1744 in Paris. This publication is in some ways perhaps better than that of Maupertuis.

2.11 Repeated measurements of the meridian arc length from Tornio to Kittisvaara

The Royal Swedish Academy of Sciences planned to repeat the measurement of the meridian arc length as early as 1740. However, this was not done until much later

[1] Livres was a unit of mass (roughly the same as contemporary British and American pound) of about half a kilogram. It was also currency based on one pound of silver, which gradually changed (Murdin 2009, p. 12).

Ti rezultati za sekundno njihalo pokazuju da je Zemlja spljoštena na polovima jer je ubrzanje sile teže u blizini ekvatora manje nego u Parizu, a u blizini pola je veće. Dakle, rezultat mjerenja duljine sekundnog njihala u Laplandu upućivao je na to da je Zemlja spljoštena na polovima.

2.9. Obrada rezultata terenskih mjerenja

Mjerenja kutova u trigonometrijskom lancu trajala su od 6. srpnja do 6. rujna 1736., prva astronomska mjerenja bila su u listopadu i studenome, a izmjera duljine baze trigonometrijskog lanca u prosincu iste godine. Dakle, može se reći da su terenska mjerenja bez naknadnih mjerenja završila za pola godine. Tijekom zime od siječnja do ožujka 1737. godine terenska mjerenja su se numerički obrađivala (Vykutil 1982, str. 418). Prethodni rezultati upućivali su na to da je duljina jednog stupnja luka meridijana u Laplandu znatno veća od one što ju je odredio Picard u Francuskoj. Stoga je Maupertuis zaključio da neka opažanja treba provjeriti na proljeće (Murdin 2010, str. 63) pa su ponovno u ožujku i travnju 1737. astronomskim načinom mjerili razliku geografskih širina pri čemu su uzeli u račun sredinu iz prethodnog i toga, ponovljenoga mjerenja 57' 28,67''.

Numeričkom obradom, svođenjem na pravac meridijana postavljen kroz trigonometrijsku točku Kittisvaara, svođenjem duljina na razinu mora te ostalim potrebnim redukcijama izvedenih mjerenja u trigonometrijskom lancu određeno je da duljina meridijanskog luka od Tornia do Kittisvaara iznosi 55 023,47 toisea (107 240,74 m), odnosno da duljina jednog stupnja luka meridijana u Laplandu iznosi 57 437,94 toisea (111 946,47 m) (Bialas 1982, str. 129).

2.10. Povratak i objavljivanje rezultata određivanja duljine jednog stupnja luka meridijana

Laplandskoj ekspediciji nije bilo lako izvoditi mjerenja u više nego nepovoljnim klimatskim uvjetima, a i njihov povratak je bio ekstremno opasan. Le Monnier je već po zimi bio bolestan, a Maupertuisovo zdravlje bilo je stalno oštećeno. Osim toga ekspedicija je na povratku doživjela brodolom u Baltičkome moru. Morali su spašavati papire sa zapisima mjerenja i instrumente. Ipak su nastavili putovanje za Dansku i konačno stigli u Francusku (Murdin 2009, str. 63).

Maupertuis je u Parizu 28. kolovoza 1737. upoznao članove Kraljevske akademije znanosti s rezultatima mjerenja u Laplandu i zaključkom da je Zemlja spljoštena na polovima kako su to tvrdili Newton i Huygens. Slijedio je napad Cassinija i njegovih pristaša na rezultate mjerenja Maupertuisa i njegovih suradnika, ali i osobno na Maupertuisa. Cassini je tvrdio:

- da je Maupertuis uzeo prekratku udaljenost na luku meridijana, čak ni jedan stupanj po razlici geografskih širina
- da je mjerio duljinu baze trigonometrijskog lanca samo na jugu trigonometrijskog lanca, a da nije mjerio duljinu baze na kraju trigonometrijskog lanca za kontrolu
- da na kraju nije ponovno kalibrirao astronomska mjerenja.

U stvarnosti su rezultati ekspedicije u Laplandu bili preveliki, tj. utvrđeno je da je duljina jednog stupnja luka meridijana u Laplandu puno veća nego što se to predviđalo prema mjerenjima u Francuskoj. To je bilo također više nego što je Newton teorijski izračunao. Zbog toga se sve nestrpljivije očekivao rezultat mjerenja peruanske ekspedicije, koja bi potvrdila izmjeru laplandske ekspedicije.

Sudionici ekspedicije Maupertuis, Clairaut, Camus, Le Monnier, Outhier i Celsius objavili su svoje rezultate u djelu *La Figure de la Terre* (sl. 10) u Parizu 1738. godine. Kralj Luj XV. nagradio je sve članove ekspedicije u Laplandu godišnjom nagradom od 1200 livresa[1] (URL 11). M. Outhier objavio je prikaz ekspedicije 1744. u Parizu pod naslovom *Journal d'un voyage au Nord* koji se može smatrati i boljim od Maupertuisovog.

2.11. Ponovna mjerenja duljine luka meridijana od Tornia do Kittisvaara

Švedska akademija znanosti planirala je već 1740-ih godina ponoviti mjerenja duljine luka meridijana. Međutim, to je učinio švedski svećenik i matematičar Jöns Svanberg (sl. 11) tek 1801–1803. godine. Svanberg je pritom imao čak 22 trigonometrijske točke, a Maupertuis samo 11 (URL 11). Svanberg je izmjerio da duljina jednog stupnja meridijanskog luka u Laplandu iznosi 57 196 toisea (111 475,0 m), tj. da je kraća za 242 toisea (oko 471 m) od Maupertuisova rezultata (Murdin 2009, str. 65).

Mjerenja je ponovio i finski znanstvenik Yrjö Leinberg 1928. godine, koji je uzeo u račun i utjecaj otklona vertikala do kojeg dolazi zbog različitih podzemnih masa. Prema njemu, Maupertuisov preveliki rezultat bio je posljedica pogreške u trigonometrijskoj mreži koja je ekvivalentna 45 m u udaljenosti između Tornia i Kittisvaara zbog utjecaja otklona vertikala. Osim toga

[1] Livres je bila jedinica za masu (grubo isto kao danas britanski i američki pound) od oko pola kilograma. To je ujedno bila novčana jedinica osnovana na vrijednosti mase srebra od jednog pounda, koja je tijekom vremena mijenjana (Murdin 2009, str. 12).

by Swedish priest and mathematician Jöns Svanberg (Fig. 11) between 1801 and 1803. Svanberg had as many as 22 triangulation points, while Maupertuis had only 11 (URL 11). Svanberg determined the length of one meridian arc degree in Lapland was 57 196 toise (111 475.0 m), i.e. 242 toise (about 471 m) shorter than Maupertuis's result (Murdin 2009, page 65).

The measurement was repeated by Finnish scientist Yrjö Leinberg in 1928. He took into account the effect of vertical deviation of the plumb line due to different subterranean masses. According to him, Maupertuis's result was caused by an error in the trigonometric network which was equivalent to 45 m in distance between Tornio and Kittisvaara due to vertical deviation effect. In addition, he concluded the greatest error was in the sector instrument, which changed during transport and in the difficult field and weather conditions (Murdin 2009, page 65).

3 Conclusion

Even though the geodetic scientific expedition to Lapland started a year after the Peru expedition, it reached its result as early as 1737. The result indicated that length of one meridian arc degree near the polar circle was significantly larger than the one obtained by Cassini in France and that it was equal to 57 437.94 toise (119 946 m). It confirmed that the Earth was flattened at the poles (i.e. was oblate) and that Newton-Huygens's theory on the Earth's shape was correct. The theory was also supported by measurements in Lapland with pendulums. However, Cassini's supporters had certain remarks. It is true there was doubt that Maupertuis's result was too large and the Swedish government decided to repeat the procedure in 1740. The result of the geodetic expedition to Peru was thus highly anticipated.

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konstatirao je da je najveća pogreška bila u sektorskom instrumentu, koji je promijenio svoja svojstva za vrijeme transporta u teškim terenskim i vremenskim uvjetima (Murdin 2009, str. 65).

3. Zaključak

Unatoč tome što je pošla na put godinu dana nakon ekspedicije u Peru, geodetska znanstvena ekspedicija u Lapland došla je do rezultata određivanja duljine jednog stupnja meridijana već 1737. godine. Njihov je rezultat pokazivao da je duljina jednog stupnja luka meridijana u blizini polarnoga kruga dosta veća od one što ju je Cassini izmjerio u Francuskoj i da iznosi 57 437,94 toisea (119 946 m). To je potvrđivalo da je Zemlja spljoštena na polovima i da je Newton-Huygensova teorija o Zemljinu obliku ispravna. U prilog toj teoriji išla su i mjerenja izvedena u Laplandu i njihalima. Unatoč tome Cassinijevi pristaše imali su izvjesne primjedbe. Istina je da se pojavila sumnja da je Maupertuisov rezultat za iznos duljine jednog stupnja luka meridijana prevelik te je već 1740. godine švedska vlada odlučila ponoviti mjerenje. Zato se s posebnom znatiželjom očekivao i rezultat geodetske ekspedicije u Peru.

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