Introduction - Measuring the Earth. Jarno Niskala

Introduction: Size and shape of the Earth has been an interesting question for humans for a long time. Scientists in several countries were working with measuring the Earth and developed science and research. Triangulation was the method to measure the length of the meridian arc on the surface of the Earth. The Struve Geodetic Arc was one of the largest observation projects in measuring the globe. The Northern part of the triangle chain had a special role in the work.

This story works as background information with other background texts. Stories of measurements in different areas and villages in the North can be read together with related background info.

Keywords: History, Earth, triangulation, Europe, North

Triangulation

Lengths and distances on Earth's surface were possible to measure by triangulation. Triangulation as a method to measure distances dates back to antiquity. ”It is based on the laws of plane trigonometry, which states that, if one side and two angles of a triangle are known, the other two sides and angle can be readily calculated. One side of the selected triangle is measured; this is the baseline.” [1]

Scientists like astronomers and surveyors were creating these triangles on Earth, travelling in woods, hills and mountains. They used theodolites in measuring angles and tried to see measuring points from one mountain to another.

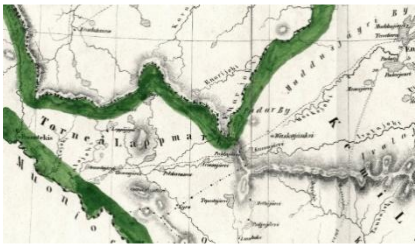

Photo 1. The Norwegian-Finnish border. Lindeman Berndt Adolf, 1846. Jyväskylän yliopisto.

Getting to know lengths of triangle sides, one needs first to measure a specific distance very precisely from A to B. This line is also called a baseline. The Baseline's length is extended by an expansion net that is also built by triangulation. The Expansion network extends from the baseline to a line between two points in the main network. Then scientists knew the length between 2 points that would have been basically impossible to measure directly. Baselines are measured in flat or even areas, which helps in getting an exact length.

Astronomical observations were closely connected to triangulation. Most of the leading scientists in triangulations actually were astronomers. Astronomical observations were mainly used to determine

[1] Britannica, T. Editors of Encyclopaedia (2011, April 14). *Triangulation. Encyclopedia Britannica*. https://www.britannica.com/science/triangulation-trigonometry

latitude and azimuth (a horizontal angle measured from meridian) in geodetic arc measurements. Pole star measurements are very convenient because the star's movement seen from the earth is within one degree.

Along the Struve Geodetic Arc, special astronomic stations were built in certain parts of the chain. Astronomic stations were often small buildings, some may have even been light constructions like tents. For instance, in the northern section, astronomic stations were located at both ends of the chain, in Tornio and Hammerfest. There was also a station in the middle, in Stuorrahanoaivi.

As Per-Christian Bratheim from the Norwegian Mapping Authority says, triangulation has become obsolete in modern geodesy. All modern reference frames are based on satellite geodesy. Triangulation as a method is still in use for detailed measurements in the construction industry.

Shape of the Earth

About 2500 years ago, astronomers concluded that the Earth was spherical, not flat. Then people didn't know yet the size of the Earth. Aristotle, the Greek philosopher, thought the Earth must be round because some stars were visible in Egypt and Cyprus, but never in Greece.[2] He listed several arguments for the spherical Earth, for instance ships disappear hull first when they sail over the horizon. Aristotle (384-322 BC) was possibly the first who proposed actual physical evidence of a spherical Earth.[3] In general, people started to think the Earth was fully round until the end of the 1600s.[4]

In the early 1700's, French and British scientists disputed whether the earth was flattened at the poles like a mandarin, or narrowing around the equator like a lemon. The True shape was established after the arc measurements to Peru and Tornio valley in the 1730's, but the degree of flattening at the poles was still uncertain in the early 1800's.[5]

It is possible to know the shape of the Earth by concentrating on certain measures. For instance, because the poles are flattened, gravitation is smaller at the equator compared to the poles. Meridian is an imaginary arc on the Earth's surface from the North Pole to the South Pole. The Idea to measure the meridian also goes far back in history. Meridian arc measuring developed after triangulation was introduced in the 1600s. An Important method is measuring a part of the meridian near the pole and comparing it to a similar measure near the equator. If there are differences in measures, the Earth is not fully spherical. The Distance of one degree of arc is longer near the poles compared to near the equator. (Smith 2005; Kakkuri.)

The Idea to measure close to the Pole area was why triangulations were done in the northern hemisphere. Also knowing exact lengths between geographical points would certainly be applicable information for many purposes.

European development

---

[2] URSA. https://www.ursa.fi/

[3] American Physical Society. June 2006, Vol 15, nr 6.

[4] Kakkuri, J. Ote tekstistä Maupertuisin retkikunnan merkitys geodesialle. https://www.maupertuis.fi/tieteelliset-mittaukset/geodesia/

[5] Smith, J.R. (2005). "The Struve Geodetic Arc." International Institution for History of Surveying & Measurement.

At first the mandarin theory with flattened poles was favoured in England while the French trusted on lemon shape. France and England were also competing in a wider range of sciences. Both were trying to develop better maps and equipment than the other one. Scientific development in geodesy and astronomy was an important element in the competition to be the strongest naval power. A good example of this competition was deciding the right place for the main Meridian. Should it go through Paris or Greenwich? [6]

Photo 2. The Telescope in the old Tartu observatory. Photo: Jarno Niskala

One of the scientists who worked with measuring the meridian was the French Pierre Louis Maupertuis. Maupertuis chose Tornio valley as the place to measure the meridian arc in the 1730s. Similar observations were done in the South at the equator by the expedition to Peru. The Idea was to compare the lengths of the Tornio valley arc with the arc in Peru in order to settle the French/British dispute on the shape of the earth. (Smith 2005.) In Sweden, astronomer Anders Celsius was promoting these observations as well as the general development of astronomy in Sweden. In Sweden science also started to become more independent from religious demands. The Science Academy was established in 1739. Scientific applications started to become more common in terms of practical and economic benefits.[7]

Political and religious relationships between states like Sweden, France, England, Prussia and Russia were influential to science. The Great French Revolution affected Europe in many ways. For instance, a new metric system was adopted. Lack of detailed mapping was felt back then, especially in Russia. (Smith 2005.) In the 1800s there was considerable tension between these states, but still it was possible to measure and tie people together within the distance of almost 3000 km in Europe. This was the approximate length of the Struve Geodetic Arc that was measured 1816-1855.

Largest meridian observation

German astronomer, geodesist, F.G.W. Struve was working in Dorpat (Tarto) University when he made triangle measurements in Livonia (a historical region on the eastern shore of the Baltic Sea) 1816-1818. At the same time the Russians were measuring in Lithuania, Belarussia and Courland (in western Latvia). General Karl Tenner was leading this Russian work. Struve and Tenner realized that if they combined and extended their projects, they were able to build a geodetic arc and determine the size and shape of the Earth. Struve wanted to link new triangles with the existing

[6] Outhier, R. & Itkonen-Kaila, M. (2011). Matka Pohjan perille 1736-1737 (2. tark. ja täyd. laitos.). [Pello]: Maupertuis-säätiö: Väylä-yhtiöt.
[7] MARKKANEN, T., DONNER, K. J. t., LINNALUOTO, S. t. & POUTANEN, M. t. (1984). TÄHTITIETEEN VAIHEITA HELSINGIN YLIOPISTOSSA: OBSERVATORIO 150 VUOTTA. [HKI]: HELSINGIN YLIOPISTO. OBSERVATORIO.

triangle chain in Tornio valley. Tenner, for his part, continued measurements in the southern part of the arc.[8]

Photo 3. The Struve statue in Tarto. Photo: Jarno Niskala.

This became true when Struve started to work for the Pulkovo observatory. Then the Russian Academy of Science started to proceed with triangle measurements. The Russian army needed to map their border areas with Austria and Turkey. The Triangle chain between the Black Sea and the Baltic Sea was serving mainly military purposes and scientific interests came from behind. Continuation of the chain to the North was introduced to the emperor by the minister of public education, and there were no ongoing militarily oriented mapping projects that required triangulation in Finland. The Program was clearly also serving military interests in the North, but supposedly not as clearly as it was in southern regions. The Chain reached Tornio in 1842. In 1844 Struve suggested to the Swedes and Norwegians to continue measurements to Nordkapp – the North Cape. (Strang 2014.)

The Northern part

The Struve Geodetic Arc was measured and observed 1816-1855. It contains several phases and parts that were combined into one long triangle chain. The Northern part was carried out in Sweden, Norway and the Finnish Tornio-Muonio valley in 1844-1852.[9] In order to get trigonometrical measurements carried out properly, Russian and Swedish academies as well as Norwegian scientists were cooperating closely. The Science academies cooperated by exchanging knowledge, information and instruments. Scientists wanted to get as reliable results as possible regardless of which country they represented. Astromer F. Woldstedt was leading the work from the southern direction towards Alatornio. Astronomer N.H. Selander was in charge of observations in Lapland to Kautokeino and astronomer C. Hansteen in Finnmark.

In this Russian-Scandinavian work, scientists were aiming to use already existing observation points in Tornio valley. These were inherited from the Maupertuis's 1700s triangle chain that was built between Tornio and Kittisvaara in Pello. Jöns Svanberg had measured a slightly larger area in 1801-1803. After Struve negotiated with the Swedes and Norwegians in 1844, they joined the

[8] Strang, J. (2014). Venäjän Suomi-kuva – Venäjä Suomen kartoittajana 1710–1942. – Helsinki: Antiikki-Kirja.
[9] (2004). *The Struve Geodetic Arc: Submission to the World Heritage Committee for inscription on the World Heritage list*.

measurement work and started observations in their areas as well. Preparations for measurements started in Lapland and Finnmark already next year in 1845.

Compared to older observations, measurement technique was greatly improved during the 1800's. The Work under Struve was done carefully and by using the best equipment. Cooperation between the states was one important factor that made this possible. That was seen for instance when the Russian academy helped the Swedes and Norwegians to build baselines and measure them in Alta and Ylitornio. In general, the results of these measurements were used as a basis for topographical mapping well into the 20th century. New triangulation projects were based on the Struve arc during this time period. Afterwards the states were able to conquer and map new areas by extending triangulation. (Strang 2014.)

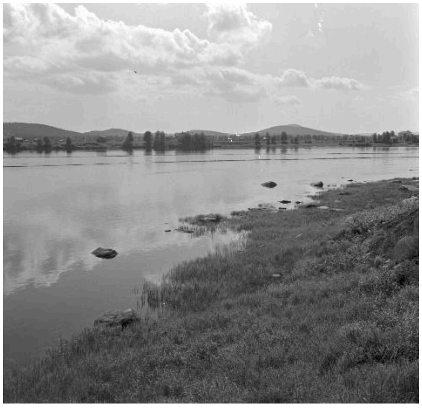

Photo 4. The Tornio river. Photo: Walther Seved 1960. Järnvägsmuseet.

For observations in the mid-1800s the north had distinctive and special circumstances compared to southern areas. To many explorers and scientists, Tornio valley had been a well-known route to "the wild north". Older travel descriptions were read and heard in Europe, so explorers knew, to some extent, what to expect. Routes along rivers, roads and paths did follow inhabited villages that were important places of comfort and necessities for travellers. Still, there were wide areas where explorers and surveyors had to endure swamps, dense woods and mountains without roads.

The Alatornio church was one of those rare measuring points that was set up in the building. From the church tower, scientists were pointing along triangle sides to visual marks, signals that were built in Kaakamavaara and Perävaara. Some of the measuring lines were new, for instance the Perävaara point was established now as a new point. Aavasaksa, Huitaperi and Pullinki for instance were known as good sighting places and were close to the routes along the Tornio river. In Pello, the old Kittisvaara point, where Maupertuis' observatory was located in the 1730s, was also in use and offered advantages for scientists even if it was a lower mountain compared to other ones nearby.

Lengths of triangle sides depend on visibility between points. In the South, the distance from the church to Kaakamavaara is about 35 km, but further north, the landscape opens up, allowing for longer triangle sides. Kiuaskero and Olostunturi points in Lapland are good examples of that.

The Struve Geodetic Arc extends further from Enontekiö to Kautokeino, Alta and Hammerfest in the North. Besides existing knowledge from earlier expeditions, scientists learned recent information regarding observation conditions that were experienced during the French La

Recherche -expedition. That expedition was carried out in Finnmark and Tornio-Muonio valley in 1838-1839.

Photo 5. Astronomers expedition to Tornio Lapland at the end of the 1800s. Photo: The National Museum of Finland.

Most of the planning of the Norwegian part of the arc was done in 1845. First, F. Klouman and C.A.B. Lundh travelled by ship along the coast. From Alta, they went on an overland expedition to Karesuando where they selected suitable points for the triangulation the following years. Most of the triangulation work was done in 1846-47. The Work was very challenging due to the harsh climate and long travel distances in difficult terrain. Bad weather was continuously hampering the work. The Point at Seilandstuva was particularly demanding; several attempts were required before the work was completed. [10]

The Original plan was to re-use a coastal triangulation chain and establish an end point near the North cape. However, it was found that the outline of the triangles was unsuitable for the purpose, and they decided to locate the end point of the arc at Fuglenes near Hammerfest. Besides, this location was considered more suitable for the astronomical observations. (Valen 2016.) The Monument of the arc at Fuglenes is reminding us of this huge achievement. Especially in the north, the Struve Geodetic Arc is in close relation with nature and offers nature and science experiences for people also today.

[10] Valen, G. (2016), The Art of Survey of the Earth from Finnmark. Expeditions in Finnmark for «Struve's geodetic arc» 1845-1850.