HOW STRUVE AND TENNER STARTED THE WORK OF THEIR LIFE

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Abstract. The great Russian-Scandinavian arc measurement was initiated by two men: F. G. W. Struve and C. F. Tenner. When they decided to join their endeavours, they both had obtained a substantial experience – Struve had completed the Livonia triangulation and he had measured the meridian arc from Jekabpils to Hogland, and Tenner had finished the triangulation for the Vilnius government and was continuing it for Kurland, Grodno and Minsk governments. In 1827 Tenner came forward with the idea to join their arcs, and during the meeting of both men in Tartu in 1828 they signed the respective agreement. The most difficult point in merging the projects was the use of measuring rods with different units of length: Struve used European toises and Tenner Russian sazhens. These rods had to be thoroughly compared, which they did and the results were checked independently by F. F. Schubert and F. W. Bessel who found them to be in a very good accordance. The later extension of the meridian arc northward to Fuglenes and to Stara-Nekrasivka in south allowed Struve to determine the preliminary result for the oblateness of the Earth with a great precision ($\alpha = 1:294.73$).

Key words: triangulation – geodetic measurements – geodetic instruments – Struve arc

1. INTRODUCTION

From the very beginning of time mankind has always wondered about the shape of the Earth. We know that Eratosthenes (276–195 BC) was among the first to understand that the Earth was approximately spherical. He proposed a method to measure the radius of the Earth and actually performed the measurements in nowadays Egypt. As far as we do not know the exact length of the “stadia” unit that Eratosthenes used we may only deduce that his result for the circumference of the Earth was about 46250 km or that the relative error was approximately 16%. Until the 16th century the attempts to measure the Earth were made outside Europe, and around 724 AD the Chinese measured it, using almost the same technique as Eratosthenes. And again the question arises about the length of the unit they used (Batten & Smith 2006). In 829 AD the seventh Abbasid Caliph...
of Bagdad, Al-Mamun kept astronomy in high regard, and according to his measurements one degree of an arc of meridian was about 111 km. This was very accurate, even according to our standards. The first European to measure the Earth was Jean Fernel of France in 1536. His result – one degree of arc equals 110.69 km was rather accurate. This result was the last before the triangulation age, which usually is associated with the names of Gemma Frisius and Gerardus Mercator around 1533 (Batten & Smith 2006). From Newton’s theory of gravitation it follows that the Earth is not a perfect sphere but an oblate spheroid. The French astronomers argued that the measurements of G. D. Cassini in 1701–1733 had shown that the length of one degree was shorter toward higher latitudes thus indicating a prolate Earth. To solve this controversy the French Academy of Sciences sent out two expeditions, one to a region in Peru (now mostly belonging to Ecuador) under Louis Godin and another to Lapland (Sweden) under Pierre Louis de Maupertuis (Tobé 1986). The results of both expeditions showed unambiguously that the Earth was oblate. Obviously, the next step was to ascertain as accurately as possible how oblate the Earth was. Though many attempts were made to measure the oblateness of the Earth in 19th century but one of the most successful was that by Friedrich Georg Wilhelm Struve and Carl Friedrich Tenner. There is a huge number of papers describing the big Russian-Scandinavian arc measurement as Struve himself named it but not much is known how they started their careers as geodesists (Kaptüg 2007). In the following we describe the paths they both took.

2. F. G. W. STRUVE’S MEASUREMENTS

Even when Struve studied in Tartu university, he was interested in geodesy, since when he was a private tutor of Count Berg’s sons in Sangaste (Sagnitz) he bought a sextant which he used during his excursions on horseback around Sangaste. It was just a lucky coincidence that at that time the Livonian Public Utility and Economic Society was looking for a good surveyor because they planned to compile a topographic map of Livonia (approximately 44000 square kilometres between the latitudes of 56°32’ and 59°), and the society applied to the university for support. The university entered into a contract with Struve who was then the extraordinary professor of mathematics and astronomy. He was allowed to spend only three to four summer months for this work. The contract foresaw that all the expenses should be covered by the Society – approximately 3000 silver roubles, as planned. Struve was even given a horse and a wagon (Struve 1844)!

2.1. Instruments

There were two sets of instruments – as a main instrument for measuring the horizontal angles, azimuths and latitudes Struve used a 10-inch Troughton mirror sextant which was given to him by the Society. Besides of that Struve used a telescope with a focal length of 2 feet to find the far-away trigonometric signals, Arnolds pocket chronometer, Baumanns artificial horizon and a horizontal sector (with the objective diameter of 50 mm, focal length of 480 mm and magnification of 30x) to measure vertical angles. It allowed to measure vertical angles up and down to 10 degrees with the accuracy of 4 arcseconds. This instrument was constructed by Struve himself and made in the workshop of the university. In the beginning Struve used an elevation measurer – “Höheninstrument” borrowed from prof. Moritz Engelhardt but evidently this was not accurate enough. The second
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set consisted of a smaller sextant, artificial horizon, made of thick black polished glass and a pocket-watch, able to measure seconds. Carl Friedrich Knorre, the son of the former extraordinary professor of astronomy in Tartu University Ernst Christopher Knorre and later to become the astronomer of the Imperial Black Sea Navy (Levitskij 1899; Héral & Pinigin 2010), operated the second set (Torim 1994). To measure the baseline he had designed an instrument consisting of five wooden rods, each 1 toise long (one toise is 1.949 m), they were compared against an iron rod in the university observatory which was one toise long and which was certified in Paris on April 6, 1784 at 14 degrees R. Two identical sets of rods were made, each set was connected with pin joints, making the total length of 9.75 m. These rods were made of fir-tree, boiled in linseed varnish and lacquered. The terminal rods had silvered scales. This set of instruments was hardly appropriate for high-accuracy measurements.

2.2. The baseline measurements

For the measuring of the baseline in February 1819 Struve decided to use the flat surface of ice on lake Võrtsjärv. This elegant approach was not new – it has been used by Joseph-Nicolas Delisle in 1737 when he started to measure the meridian arc through St. Petersburg (this work was never completed). The triangulation network was constructed on the 13.34 km baseline between villages Uniküla and Rannaküla, both on the eastern shore. The base was measured only once and in one direction – there was no time to make two passages. The temperature was taken into account, the thermal expansion of iron was known, and the expansion of fir-tree was measured experimentally. The base-line of 600 toise = 1169 m for the triangulation in the western part of Livonia was measured with a steel chain along the ice of river Daugava at the end of the winter of 1818 (this measurement was done by Wilhelm Friedrich Keussler, a headmaster of one of the schools in Riga). A similar instrument was used to measure the baseline for the Pärnu triangulation (it is not clear whether this was the same chain that was used in Riga). This time the measurement took place not on the ice but along the flat coastal meadow near Pärnu, and it was found to be 2158.43 m. The steel chain was repeatedly checked before and after the measurements along the brass ruler on the wooden floor of the Audru church at the temperature of 15.75 degrees Réaumur. For the astronomical source of the geodetic network Struve chose the university observatory whose geographical coordinates he had measured for his doctoral thesis, and the cathedral in Riga.

2.3. Triangulation in eastern and southern Livonia

As far as the landscape in these parts was (and still is) rather open, Struve chose as main triangle points the local buildings. The list includes 2 observatories, 74 church spires, 73 windmills, 1 lighthouse, 113 other buildings, like factories, manor houses, etc. There were also 6 single fir-trees. Altogether 292 points were used, including 63 geodetic signals and marks that were built during the triangulation. None of those signals and marks are preserved. The triangulation network was divided into three categories according to the accuracy. In the first category of 90 triangles only for 53 all three angles were measured. For the remaining 37 only two angles were measured and the third was assumed to be $\pi$ minus the sum of the other two angles. For the triangles of the second category mostly two angles were measured. The average length of the sides of the triangles was around 25 km.
the longest was 60 km.

2.4. Astronomical-trigonometrical survey from Riga to Pärnu

The landscape in this part of Livonia was (and still is) rather closed. This prevented Struve to use the approach he had so successfully exploited in eastern and southern parts. So he established a chain of astronomical points from Riga to Pärnu where he measured the azimuths and partly also geographical latitudes. This method, later developed further by Struve himself, was to become known as parallactic polygonometry. The traverse between Riga and Pärnu ran mostly along the meridian and its length is 186 km. This network was connected with the inland triangulation with only one point (Cathedral in Riga) thus making the accuracy of the whole project much worse.

2.5. Trigonometric measurement of elevation

In measuring the elevations above the sea level Struve used the method of trigonometric levelling. Since he had neither a Borda circle nor Ramsden nor Reichenbach theodolites, he had to cope first with Engelhardt's "elevation measurer" and later with the horizontal sector. The elevations were measured altogether in 280 points, so some of the points were left unmeasured. According to Torim (1994), for the zero point of his elevation measurement was taken the average sea level in the estuary of the river Daugava (at that time the systematic zero level was not introduced – only in 1870s the Kronstadt zero point was defined). Using this data Struve was able to calculate the refraction coefficient of the Earth atmosphere, which he found to be 0.2137, thus only slightly less than the result by Gauss – 0.3106. Both of these results differed seriously from that by Delambre – 0.1678 (Woodhouse 1821).

2.6. Accuracy of triangulation

As a genuine representative of the exact sciences, Struve always considered the possible errors during the measurements. First of all you have to know the accuracy of the instruments available. In three consecutive years he checked his main instrument – the Troughton sextant – by measuring horizontal angles over the horizon. He found the errors to be in the range from 2′53″ to 3′21″. Since he did not reduce the horizontal angle measurements to true horizon he made an error that, according to Estonian geodesist Vuuk (1968), was up to 3″. For quite a few points the angles were measured eccentrically, the instrument being shifted up to 4.5 m. Due to the fact that he could use only the summer months free of lectures, he had to make measurements even at 10:00 in July mornings which definitely did not add to accuracy. Vuuk (1968) has estimated the mean square errors in measurement of angles and found them to be 15 arcseconds. The length of the main baseline on the ice of the lake Võrtsjärv was not reduced to the sea-level because Struve assumed the respective error to be very small. He estimated the accuracy of the baseline to be 1:40000. Nothing is said about the accuracy in baseline measurements in Riga and Audru. According to Torim (1994) the average mean square errors were large, and depending on the distances between points (from 5 to 50 km), reached from 0.19 to 7.60 meters.

2.7. Results

The triangulation of Livonia was meant as a basic network for compiling a map
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of Livonia (Struve 1844). The map was to be drawn up by a Livonian nobleman Carl Gottlieb Rücker, who was the adjured surveyor of the Livonian Knighthood. Due to some resistance of the local landowners, the map was ready only in 1839 – 23 years after Struve finished his triangulation. F. G. W. Struve intended to remeasure at least a part of the Livonian triangulation network, but instead of that he started a much bigger project – measuring the meridian arc of 25° 20′ – what can be considered as one part of his lifework. In conclusion we may say that the triangulation of Livonia – a big and exacting task for young and unexperienced Struve – was carried out with flying colours. The experience accumulated during this work laid a solid basis for an enormous future project of measuring the big arc.

3. C. F. TENNER’S MEASUREMENTS

3.1. C. F. Tenner’s origin and maturing

Struve was born into a family of a rather well-off high-school teacher in Altona, but the life-story of Carl Friedrich Tenner – not so well documented – was different. He was born on July 22nd, 1783 (old style) in Vaivara parish (Estonia) in the family of the manager of Auvere manor (Rootsmäe 1984). A long time Tenner was thought to be a Baltic-German. In 1983 the Estonian historian Traat (1983) expressed a cautious opinion that Tenner might have been an Estonian. In his opinion he relied mainly on a work by Baltic-German doctor and writer G. J. Schultz-Bertram “Wagien” (Bertram 1868), where the author asserted that Lieutenant-General Tenner was of Estonian origin (Vassiljev 1983). But only the study by Rootsmäe (1984), based on archive materials, proved this statement convincingly. Tenner’s parents were not able to give their children systematic education, thus they sometimes hired the travelling teachers. But the life of little Carl changed drastically when in the nineties of the 18th century the landlord invited two surveyors to Saare manor. The surveyors acquainted the boy with technical drawing and some methods of topography. Carl quickly understood the explanations and he could soon draw some simple maps and copy the paintings and engravings in the manor (Vassiljev 1983). The son-in-law of the landlord, the landlord of Rõngu manor Count Gotthard Andreas von Manteuffel noticed the drawings of this talented boy while visiting Saare manor. He immediately understood Carl’s intelligence and he asked Carl’s father to give the boy under his tutoring in Rõngu manor. During five years spent at Rõngu he studied German, French and Latin languages, to say nothing about mathematics and other general subjects. Approximately at the same time the Count Manteuffel was about to finish his book on Siberia and Tenner drew the maps which were necessary to illustrate it. When it was required to obtain additional material, the Count travelled to St Petersburg and took Tenner with him. The materials were obtained from the Map Depot of the Quartermaster department of the military headquarters where General Jan-Peter van Suchtelen was the chief. As a result of this meeting Tenner began his studies of topography and astronomy in the Map Depot. After graduating from the courses Tenner was promoted an officer. He worked under Suchtelen (Novokshanova 1957), executing different topographic tasks until 1805 when he was sent with a diplomatic delegation to China. However, the delegation never reached their objective because of political reasons but on the way back Tenner, together with two other officers, was sent from Kjahta to Nertshinsk area.
to map these regions by eye, up to the Amur river. When they returned from this trip to Irkutsk they were sent once more to map the regions from Kolován through Barnaul up to the Ust-Buhtarma stronghold. The leader of the delegation Count Golovkin characterized the work done under leadership of Tenner as brilliant (Rothstein 1862). All the year of 1807 Tenner spent in different campaigns against Napoleon in a guard division.

3.2. Working as a geodesist

In 1809 Tenner together with two other officers was given a task to map the area of St Petersburg and then the regions close to the southern coast of the Gulf of Finland and the islands in it. They started by measuring a baseline on Vassili island in St. Petersburg using the Ramsden chain made of iron. The angles were measured by the fifteen-inch Troughton repeating theodolite and the six-inch Ramsden theodolite. This St Petersburg triangulation was the first Russian triangulation that had a real practical value. The work continued to Narva in 1810 and to Tallinn and Tartu in spring of 1811. They built signals and measured one more baseline on Kotlin island. They also compiled a map of coastal triangles. Like all Tenner’s later geodetic works this one was highly accurate, too. In 1812 the Patriotic war began, in which Tenner took part, campaigning in battles of Vitebsk, Smolensk and Borodino. He was decorated with three orders for chivalry, and with a golden sword with the inscript “For bravery”. In 1810 Prince Volkonski was named the quartermaster-general and later the Head of the General Headquarters and the Depot of Military topography (Viik 2007). In 1815 he ordered the performance of the trigonometric and topographic measurements in Vilnius (Vilno) government. The direction of this task was given to Tenner who from the very beginning planned to measure a meridian arc as a by-product of this work. The triangulation in the Vilnius government was one of the biggest trigonometric works, which consisted of Drisvjata, Ponedelski and Palanga baselines, of 11 closed polygons, consisting of 119 triangles (part of them was compiled in 1832 when this net was joined with the Prussian net) and of 100 reference points. These consisted of 71 signals (from 10 to 30 meters high), of 21 pyramids (from 4 to 8 meters high) and of 8 towers (Novokshanova 1957).

3.3. The instruments

How did the Tenner measuring rod look like? At first he planned to use the 10-sazhen Ramsden chain. However, he argued against it because it was impossible to measure the temperature of chain-links accurately enough. Taking into account these arguments Volkonski ordered a new instrument from the mechanical shop of the Military Headquarters, which was made after the Delambre instrument but which was improved by Tenner. This instrument remained in use for 30 years. It consisted of four iron rods each 13 feet 11.94 inches long (426.57 cm), 0.85 inches (2.16 cm) wide and 0.3 inches (0.76 cm) thick. Each rod lied freely on a base of redwood and was fixed to the base at one point. Later Tenner changed the redwood base by a base made of pine because the redwood tended to bend. For measuring the distance between the two rods along the baseline Tenner used 4 inches long silver-covered brass pins which protruded from the rods. These pins had a scale of accuracy of one hundredth of an inch, and also a nonius which helped to read the distances with an accuracy of one thousandth of an inch, provided that a magnifying glass with an optical power of 8 dioptres was used. To arrange the
rods in the direction of the baseline, Tenner used a theodolite. In order to measure horizontal declination they used a level, the accuracy of which was checked during each measurement (Novokshanova 1957). One of the important improvements Tenner started to use was the quicksilver thermometers with Réaumur scale. Before that everybody used metal thermometers. The thermal expansion of the rods was measured with a pyrometric device which was made in the mechanical shop of the Military Headquarters in 1818. Differently from Struve, Tenner paid very much attention to marking the ends of the baselines on terrain. For this a hole about two cubic meters was dug which was filled in with stones and lime. A granite cube with sides of 25 cm was placed in the hole. In the cube there was a cylinder-shaped hollow filled in with lead. The center of the cylinder was the initial or the final point, respectively. Together with the measurement tools, the Goldbach normal sazhen and the Ramsden callipers were sent to Vilnius expedition. Later the pyrometric device, the passage instrument on three legs, two theodolites and an 18-inch Ertel vertical circle were added. Tenner made all the length measurements with his instrument, the length of which was compared with the so-called normal measure, which was the normal sazhen No 1 sent to Tenner from the mechanical shop of the Military Headquarters in 1816. This sazhen was made by mechanic Yuryev from Moscow under the leadership of professor of astronomy Goldbach who determined the length of sazhen using the toise of Lenoir, which was 6 Paris feet long (the Russian sazhen was 7 London feet long). This comparison length was in use until 1822 when Tenner carried it over to normal sazhen No 10, using the Ramsden callipers. Since the length of the normal sazhen No 1 was measured at the temperature 14 R (17.5 C) then forthwith Tenner tried to compare lengths at the same temperature. In 1823 he compared the lengths of sazhen and Lennel’s French toise at the same temperature and found that one toise is 76.735276 inches or 0.9135152 sazhens. As already pointed out, Tenner paid very much attention to securing the endpoints of baselines and to strong construction of signals: at the turn of the 19–20th centuries, K. V. Scharnhorst from the Department of Military topography calculated anew all the geodetical measurements done in Russia, and he had to conclude that one could trust only Tenner’s measurements. Tenner’s work has been used in new triangulations in 1910–1916 and also during the Soviet rule. Tenner contributed hugely to the development of Russian topography, especially when we keep in mind the accuracy of his work. As a good example of Tenner’s work we may bring the maps of the Vilnius government which were done in scale of 1:21000 (half inch to one verst). In 1824 Tenner introduced universal instruments, vertical circles and astronomical theodolites instead of earlier used repeating theodolites. Four years later Tenner introduced yet another new element – for measuring angles he started to use a method used by Struve – the method of measuring the angles in sets (Novokshanova 1957).

3.4. Merging the projects

Already in 1816 when Tenner was on the reconnaissance tour in the Vilnius government, he made a proposition to Prince Volkonski (Head of the Military Headquarters) to measure the meridian arc through Vilnius observatory. Volkonski, who always had supported scientific initiative, agreed upon, so Tenner always had in mind the way how to use his first class triangles for that purpose. The situation became worse when Prince Volkonski left the post. Tenner could not count on the help of the Head of the Depot of Military topography F.F. Shubert, who was of the opinion that the triangulation had only military dimension.
In order to continue the arc measurement Tenner had to debit the finances allocated to topographic triangulation. At last Tenner wrote a letter to the Head of the Military Headquarters H.K.Fr.A. von Diebitsch and Norden (in Russian Diebitsch-Zabalkanski) in which he explained that knowing the exact shape of the Earth was very important for drawing up the topographic maps, and asked for permission to carry on with the respective measurements (Kaptität 2000). Having got the permission, Tenner started the astronomical observations for measuring the Lithuanian part of the arc. At one of the endpoints of the arc which was situated in Bristen – approximately 30 km from Jekabpils (Jacobstadt), Tenner observed in 1826 and in Belin, where a new observatory was built, in 1827. In November 1827 Tenner, who closely followed all the geodetic works in Russia and abroad, came forward with an idea to join the Lithuanian arc with that of Livonia, which was measured by Struve on the appointment of Tartu University. He was given the permission, and in January 1828 Tenner came to Tartu to meet Struve. The negotiations were successful and on February 23rd the protocol was signed for joining the arc measurements. It declared that: “In order that the merging of the two projects would have the effect of independent correlation as to precision, neither party will share his results with the other. A third party shall receive both sets of results in a sealed envelope, and shall open them simultaneously, in order to pronounce judgment as to their coincidence. Both parties share the wish that these third parties would be Major General von Schubert, head of the Map Depot of the Imperial Central Headquarters, and Professor Bessel, professor of astronomy at Königsberg University and director of the University observatory from Königsberg.” Signed on 23/11 February 1828 by Major General Tenner and W. Struve, Professor of Astronomy Tartu (Batten 1988).

Tenner had to trigonometrically join the southernmost point of Struve with the northernmost point of his net. Struve had to provide the joining of both nets astronomically. Struve promised to find the relation between the units of length of both measurements, i.e., compare the Lennel toise that had been used by Struve with the Jean Nicolas Fortin toise – Tenner had already compared hissazhen No 10 with the Fortin toise (Bessel 1841). According to the agreement and to be quite sure in the results they did not inform each other of the results but sent the data to Schubert and Bessel. They made the final comparison and agreed upon the very good accordance of the results and the brilliant accuracy of the measurements. In January 1832 both great men met again in Tartu. They discussed about the too large difference between Struve’s observed azimuth in the direction Krustpils (Kreutzburg) – Taborskalns (Daborskaln) and Tenner’s calculations reaching 26.01′′. Struve thought that this error was caused by the fact that Tenner used inaccurate instruments. Tenner decided to repeat the observations in Vilnius observatory with its good instruments but the difference persisted. Struve and Tenner agreed that there should be some local influence on the determination of the vertical direction. The importance of the Lithuania–Livonia arc measurement was appraised so highly that the St Petersburg Academy of Sciences elected Tenner its honorary member on December 22nd, 1832. In 1834 Tenner recommended Bessel to calculate the dimensions of the Earth and its oblateness. Bessel did it and took into account all the results of the arc measurements known at that time. These elements of the spheroid found by Bessel were in use close to 100 years! According to Bessel the big half-axis of the Earth was \( a = 6377.096 \) m, the small half-axis \( b = 6356.015 \) m and the polar oblateness \( c = 1 : 302.5 \) (Struve 1860). In 1844 Struve and Tenner decided to continue the arc measurements up to
the estuary of the Danube in such a way making it longer by 3 degrees and 25 minutes. All the huge undertaking – the arc measurement from Fuglenes in Norway to Stara-Nekrasivka in Ukraine – altogether 25 degrees and 20 minutes or 2822 km – ended in 1852. The part of Tenner in it was 11 degrees 10 minutes and the Struve part 9 degrees 38 minutes. This means that we are not making a mistake when suggesting to name this project the Struve-Tenner arc measurement. As we have already mentioned here, Tenner scores for having marked the centers of his signal points in a lasting way while Struve did not do it (Novokshanova 1957).

4. SUMMARY

We have described the cooperation of two great man that resulted in measuring a huge arc of a meridian – 25 degrees 20 minutes – thus helping to determine the exact shape of the Earth. Though H. J. Walbeck from Finland, D. G. Lindhagen from Sweden and Chr. Hansteen from Norway took active part in measuring the northern part of the arc, Struve and Tenner were the major operators. They both started their smaller projects but soon they understood the possibilities hidden in these projects and when joining their efforts they reached brilliant results. There is no doubt that we may use the names of Struve and Tenner side by side in this endeavour. And the name of the big arc measurement, inscribed in the World Heritage List as Struve Geodetic Arc, should be “The Struve-Tenner Geodetic Arc”.

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REFERENCES

Bertram, Dr. (Schultz G. J.) 1868, Baltische Studien und Erinnerungen, Dorpat
Bessel F. W. 1841, AN, 19, 438, 97
Kaptäg V. 2000, in “QUO VADIS” International Conference, FIG Working Week, 21
Kaptäg V. 2007, Vestnik Sankt-Peterburgskogo obsshhestva geodezii i kartografi, 6, 11
Levitskij G. 1899, Astronomers of the Yuryev (Tartu) University (from 1802 to 1894), Yuryev
Novokshanova Z. 1957, Karl Ivanovich Tenner, Izdatelstvo geodezii i kartografi, Moskva
Rootsmäe L. 1984, Eesti Loodus, 3, 181
Rothstein 1862, Zapiski Voyenno-topograficheskogo, part XXIII, St. Petersburg
Struve W. 1844, Resultate der in den Jahren 1816 bis 1819 ausgeführten astronomisch trigonometrischen Vermessung Livlands, St.-Petersburg
Struve F. G. W. 1860, Arc du méridien de 25°20' entre le Danube et la Mer
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Glaciale, St. Petersbourg
Tobé E. 1986, Fransysk visit i Tornedalen 1736–1737, I-Tryck AB, Luleå
Torim A. 1994, Geodeet, 6 (30), 31
Traat A. 1983, Eesti Loodus, 8, 513
Vassiljev L. 1983, Eesti Loodus, 8, 509
Viik T. 2007, Geodeet, 35, 74
Vuuk A. 1968, Geodetic works in Tartu University, 1–90, Tartu
Woodhouse R. 1821, A Treatise on Astronomy, Theoretical and Practical, J. Deighton & sons