RTK GNSS

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RTK GNSS

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Abstract

RTK GNSS is a way of deciding the position of a GNSS receiver with high precision. It should theoretically be possible to determine the position with the precision of a couple of centimeters. Traditionally the RTK GNSS system consists of a base station and a rover. The base station knows its position and compares that to the information it gets from the satellites in order to calculate the error. The rover is the mobile unit that does not know its exact position but calculates it from satellites in ordinary fashion. The base station sends correction data based on the error to the rover, that then gets a precise position. Networked Transport of RTCM via Internet Protocol (NTRIP) is a way of transmitting the correction data to a rover. There are NTRIP service providers that makes it possible to receive correction data to a rover without a dedicated base station.

Anything from the choice of GNSS receiver to the choice of antenna can affect the precision. This thesis investigates how different choices of antenna can affect the precision, using three different antennas in four ways, by measuring at two different benchmarks.

The conclusion was that the largest antenna with ground plate was the best. However, if reducing the size of the antenna is important, it is better to use a larger ceramic patch antenna than an antenna without the ground plate.

Acknowledgements

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Chapter 1
Introduction

Global Navigation Satellite System (GNSS) is the general term for all satellite navigation systems. There are different constellations from different regions, for example Global Positioning System (GPS) from the USA, Galileo from the EU, and Globalnaja navigatsionnaja sputnikovaja Sistema (GLONASS) from Russia. The basic principle of GNSS is that at least four satellites need to be seen by the receiver in order to determine the position, this is in order to solve the four unknowns - longitude, latitude, height and the clock error of the receiver. The determined position is usually done so with an accuracy of around two meters. There are several sources of error that affect the accuracy of the position; atmospheric interference, clock errors in both the satellite and the receiver, ephemeris (orbital path) data errors, and multi-path effects. Real Time Kinematic (RTK) is a way to correct those errors and it can theoretically reach an accuracy at centimeter level. The most basic setup is a base station that transmits correction data (RTCM) to a rover (a moving GNSS receiver), usually over radio. RTCM data can also be transmitted over the internet, this is called Networked Transport of RTCM via Internet Protocol (NTRIP). There are subscription services offering RTK over NTRIP, opening the possibilities of having a rover without a dedicated base station.

1.1 Background and Motivation

GNSS receivers are notorious for not being the most accurate, and while they work fine in certain conditions like open landscapes, they can quickly lose accuracy. RTK hardware has gotten cheaper, and physically smaller, with time, simultaneously as mobile internet coverage has gotten better, and NTRIP providers are promising higher accuracy when using their services. This adds up to the possibility of making a small, high accuracy, portable RTK GNSS unit that is financially accessible.

The main motivation of this thesis is to create a high precision GNSS rover that receives the correction data via NTRIP and achieves centimeter level accuracy.

Some immediate challenges with this thesis are firstly to achieve centimeter level accuracy, since anything from the choice of GNSS receiver to the choice of antenna will affect the possible accuracy. Another challenge is the fact that anything disturbing the signal from any of the four needed satellites to get a position can result in lower accuracy.

1.2 Previous work

There are a lot of resources online when it comes to RTK GNSS, especially since the hardware has become readily available for the average consumer. For example, Wayne Baswell demonstrates how to set up a base station and a rover using u-blox C099-F9P High Precision GNSS RTK Development Kit [1], SparkFun has guides on how to use their development boards to set up RTK GNSS units [2], and Toji Takasu with Akio Yasuda developed a RTK GNSS receiver for approximately $400 [3]. Companies are also already using this technology for example in navigation of drones.

Chapter 2

Background and Theory

Classic GNSS receivers needs at least four satellites' signals in order to estimate their position. This still leaves a lot of margin of error due to the sources of error that exists; atmospheric interference, clock errors in both the satellite and the receiver, ephemeris (orbital path) data errors, and multi-path effects. A way to combat these errors is to have a receiver that knows its position, a base station, that calculates the error from the signal by comparing it to its own known position, and then send this difference to the rover.

2.1 GNSS positioning

There are several constellations of satellites orbiting Earth. These include, but are not limited to, GPS, Galileo, GLONASS, and BeiDou. Each of them has at least 24 satellites orbiting Earth.

As mentioned, in order to calculate the position of a GNSS receiver, signals from at least four satellites are needed. The distances to the satellites are calculated by measuring the time it took for the signal to be received and multiplying that with the speed of light. This means that the range of each satellite can be represented as a sphere, with the distance as the radius and the satellite in origin. The position of the satellite is known, which means that with only one satellite the receiver can be anywhere on the surface of the satellite's sphere. If a second satellite is added the receiver can be anywhere where these spheres intersect. Add a third satellite and the receiver is at one of two points of intersection, as visualized in Figure 2.1. Technically a fourth satellite is needed to solve the uncertainty, however one of the two points of intersection is usually unreasonable due to it not being placed at the surface of the earth or the velocity being too high. This means that the fourth satellite signal is used to correct the clock error of the receiver.

In order to get a good position, the circumstances need to be optimal. This means open sky conditions, with as many satellites visible for the GNSS receiver as possible, and a clear view to the horizon. In Sweden not many satellites fly to the north, so having a clear view to the south is of higher importance.

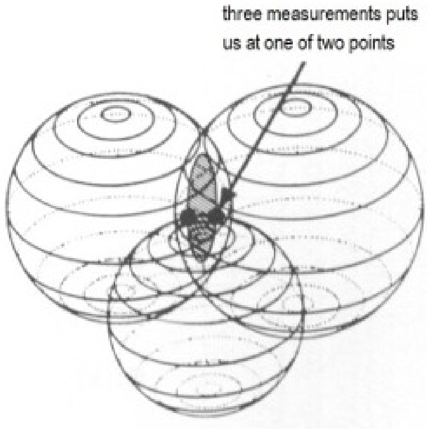

Figure 2.1: Illustration of position determination
[4]

2.2 Sources of Error

Errors caused by atmospheric interference are when the signal from satellites gets delayed or deflected by the atmosphere. Most of these occur in the ionosphere (50-1000 kilometers above the surface) because its density varies and therefore are some signals more delayed than others. Due to the delay also depending on how close the satellite is to being overhead, some of the ionospheric conditions can be modelled and corrected in the satellite signals. However, it is only possible to remove approximately three quarters of the bias [5].

The lower atmosphere also contributes to some error in the form of delays. Especially close to the horizon since there is more atmosphere to pass through. The atmosphere, due to its density, delays the signal, adding slightly to the calculated distances between the satellites and the receivers.

Clocks are another source of error. Even though satellites use atomic clocks they can drift up to a millisecond, which is enough to make a noticeable difference in accuracy, this is minimized by regularly correcting them. GNSS receivers are equipped with clocks as well, and these are less stable than the atomic clocks in the satellites, but they too are regularly corrected through comparing the times of arrival of two different satellite signals.

The ephemeris (orbital path) data error comes from an uncertainty in the shape of the satellite orbit and the velocity of the satellite. This is a source of error due to the fact that the satellite needs to know where it is in order for the GNSS receiver to estimate the position of itself. The locations of satellites are continuously monitored, and the orbital irregularities are calculated and documented. This data is sent to the GNSS receiver and applied.

Another source of error is multipath. Multipath occurs when the signals from the satellites bounce off different objects around us, like buildings, trees, and even the ground, before reaching the antenna of the GNSS receiver. Ideally the only

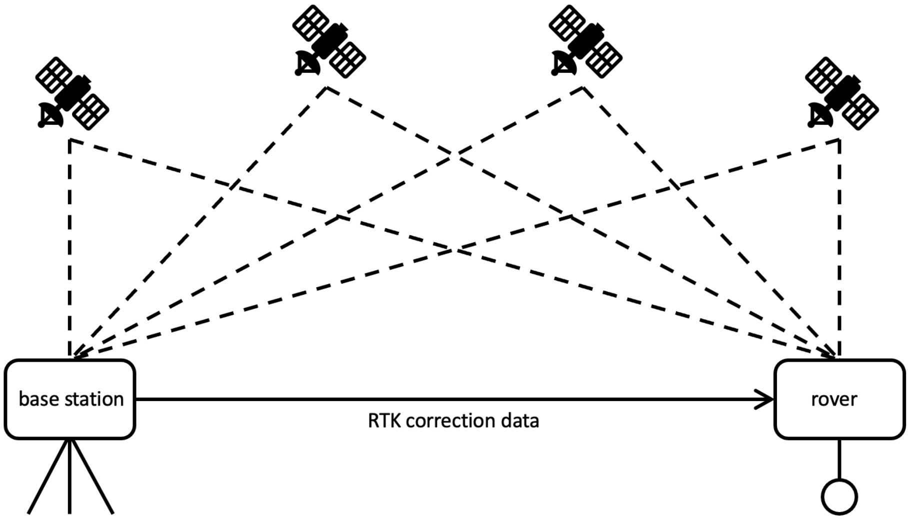

Figure 2.2: Basic setup of base station and rover

signals reaching the GNSS receiver should come directly from the satellites. Some of the reflected signals are eliminated since antennas are designed to minimize interference from signals reflected from below.

2.3 RTK

RTK is a way to correct in real time the position of a GNSS unit. As mentioned in previous sections, the most basic setup of an RTK system is a base station with a rover, where the base station is stationary, and the rover is a mobile receiver. The base station is placed at a known location, so when it computes its location from the satellite signals, it can calculate how wrong its position is, and send correction data (Radio Technical Commissions for Maritime Services, RTCM) to the rover, commonly over radio or internet, see figure Figure 2.2. The correction data is sent in RTCM format, which is a recommended standard developed by Radio Technical Commissions for Maritime Services. Due to the atmospheric conditions changing based on location and time, the rover cannot be too far away from the base station for this to work, and the corrections cannot be too old either.

Network-RTK is a way to determine the position of the rover without having to set up a dedicated base station. Network-RTK providers have several base stations set out that work together to create virtual base stations. Rovers then calculate their positions with the correction data from the virtual base stations. One of the benefits of network-RTK is that less hardware is used, since the only needed equipment is the rover. That however also means that there is a need for continuous internet connection in order to receive the RTCM data. Another thing that is important to keep track of when using network-RTK is which reference system the rover is operating in and which the base stations are operating in, since it otherwise can result in constant errors in positioning. With a classic RTK setup both the base station and rover use the same reference system.

When a rover receives RTCM data, that it recognizes as RTCM data, it can go into something called RTK float or RTK fixed. RTK fixed is achieved when phase ambiguities are fixed to an integer number, if the phase ambiguities are fixed to a float number RTK float is achieved. In order to achieve the accuracy promised by the RTK technology RTK fix is needed. This means that RTK fix results in higher accuracy than RTK float.

As mentioned earlier in this section, the distance from a base station to a rover matters in accuracy, and this also applies when there is a network of base stations. Depending on the distances between the base stations and the distance from the rover to the base stations the expected uncertainty of measurement differs. This means that the further away from the three closest base stations the rover is, and the further apart the base stations are from one another, the worse the expected uncertainty of measurement is. In Sweden, the network of base stations are located 70, 35, and 10 kilometers apart, and Latmäteriet has a template for how to look up the expected uncertainty of measurement [6]. For example, if the network of base stations has 70 kilometers between every base station, and the average distance from the rover to the three closest base stations is less than 10 kilometers, the expected uncertainty is 1.2 centimeters.

2.4 Reference systems

The Earth is not exactly spherical, so in order to determine a position, geodetic reference systems are needed. In the geodetic systems the Earth is described in three basic surfaces [7]; the surface of the Earth, including the sea surface, which is the surface we live on; the geoid which represents the mean sea level if the only factor that affected its shape was the Earth's gravitational field [8], and where the sea continues through the continents; the Earth ellipsoid, which is a smooth representation of the Earth.

Given a geodetic reference system based on the three surfaces, their internal relations, and their changes over time, a position on the surface of the Earth can be determined.

Reference systems that are relevant for this thesis are:

- International Terrestrial Reference Frame (ITRF), which is the reference system with the lowest level of uncertainty since it gets updated multiple times per year.
- World Geodetic System (WGS), which is a reference system based on ITRF, the latest version is WGS84, and it updates once a year.
- European Terrestrial Reference Frame 1989 (ETRS89), the European definition of how Europe joins ITRF.
- Swedish Reference Frame 1999 (SWEREF99) is a Swedish realization of ETRS89.

There is a difference in the reference systems, a position in WGS84 does not have the same coordinates in SWEREF99. Currently, because SWEREF99 is based on ETRS89, which has not been updated since 1989, there is a noticeable difference in the systems and the difference is approximately 70-80 centimeters [9].

The biggest difference between WGS84 and ETRS89 is that ETRS89 is not subject to the drift of the Eurasian continental plate. This means that ETRS89 moves in relation to WGS84 along with the Eurasian continental plate. The same thing applies to SWEREF99.

Local reference systems are needed because a global one is not nearly precise enough for high accuracy applications such as mapping.

Chapter 3

Design and Test Case

This chapter covers how the final design of the rover came to be, as well as how the tests were conducted.

3.1 Rover design

Initially the idea was to try different means of connecting to the NTRIP provider, meaning Bluetooth, Wi-Fi, and LTE. However, it quickly became obvious that it would not make any difference in the grand scope of things, so the idea was dismissed.

The first iteration of the rover was an Arduino MKR NB 1500, with a SparkFun GPS RTK2. The idea behind the choice of the Arduino was that it has an LTE modem, so the only unit needed out on the field was the rover. The library for Arduino MKR NB 1500 is MKRNB, and the version used was 1.5.1. The library for the SparkFun GPS RTK2 is SparkFun_u-blox_GNSS_Arduino_Library, and the version was 2.0.7.

Making the Arduino communicate with the NTRIP service provider was the first step. Once that was working, the second step was making the Arduino control the SparkFun GPS RTK2, using SparkFun's GNSS library. After that came the issue of putting it together.

SparkFun's GNSS library wanted to communicate with the GPS RTK2 over I_2C, however there were issues in transmitting the RTCM data over I_2C. It just would not work. When asking in the SparkFun forum how to send RTCM data over I_2C the answer was to do it over Serial. Thus, the RTCM data was transmitted over Serial, while the other data communication happened over I_2C. Initially it seemed promising, the setup achieved momentary RTK float multiple times, but it later froze. It kept freezing, not crashing, more and more quickly even after doing a cold reboot. The setup always seemed to freeze when doing anything with the modem. The SparkFun GPS RTK2 kept outputting data as normal, it was always the Arduino MKR NB 1500 that was freezing.

A forum post discussed a similar issue with the Arduino MKR NB 1500 freezing [10] and it said that the reason was a breaking fault in the MKRNB library that not only did not reset the memory properly, but it could also permanently damage the u-blox module on the Arduino MKR NB 1500. The forum was locked in 2020 and the last post was someone asking if anyone had any updates, and that even

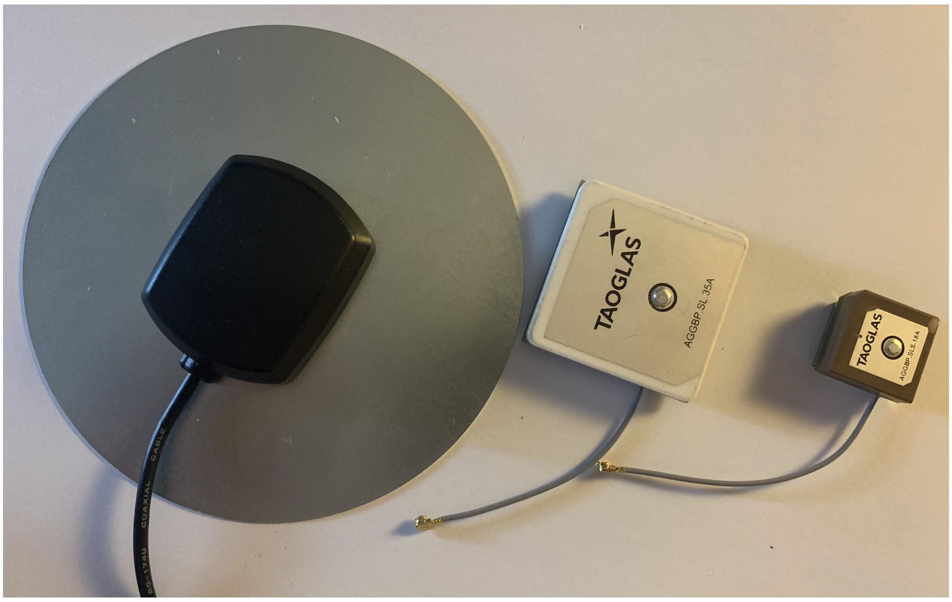

Figure 3.1: The antennas used in this project. To the left is the larger antenna that is used with and without the ground plate, in the middle is the larger ceramic patch antenna, and to the right is the small ceramic patch antenna.

though the developers had solved the issue that could permanently break the Arduino MKR NB 1500 they still had issues with the board freezing.

As a result, the decision to change the Arduino MKR NB 1500 to an Arduino MKR WIFI 1010 was made. As the name suggests, the Arduino MKR WIFI 1010 connects to internet via Wi-Fi. The Arduino MKR WIFI 1010 communicated with the SparkFun GPS RTK2 only over Serial, and the usage of SparkFun's GNSS library was omitted. Instead PUBX commands were used. This solution was a lot more stable. Essentially, read the NMEA messages the SparkFun GPS RTK2 outputs, send those to the NTRIP server, and push in the RTCM data recieved from the NTRIP server in to the SparkFun GPS RTK2.

There were three different antennas used in four ways for the rover, see Figure 3.1. The first was a generic, larger, active antenna. This was used with and without a ground plate that was 10 centimeters in diameter. The two other antennas were ceramic patch antennas of two different sizes, one 18x18 millimeters [11] and the other 35x35 millimeters [12].

3.2 Testing

Since the goal was to test and observe the differences between the antennas, and whether RTK fix is truly 1-2 centimeters off target using these types of modules, a benchmark (a point whose exact coordinates are known) was needed. Malmö city

Figure 3.2: Selected benchmarks are circled.

has a network of benchmarks in SWEREF99. The ones whose coordinates were retrieved was in Västra Hamnen, and two of them were selected, see Figure 3.2.

The most optimal point to get a good fix should be FIX1212, since it does not really have any obstacles to the south, and there is a clear view of the horizon almost 270°, see Figures 3.3, 3.4, 3.5. FIX1211 has some difficulties, but overall should not be impossible to achieve good positioning, see Figures 3.6, 3.7. Both the benchmarks are studs in a wall, pictured in Figures 3.8 and 3.9.

The tests consisted of placing the rover at a benchmark, on top of the wall, cold booting the rover, and logging its outputs for 15 minutes. Since the rover determines its position once every second it means that there are approximately 900 positions. This was done for all four ways of using the antennas, with and without RTK. In order to make sure that the antenna was not moved around, the selected antenna was tested with and without RTK before moving onto the next antenna. The placement of the rover with the antenna is pictured in Figures 3.10, 3.11, 3.12, 3.13. Since the benchmarks are far down on the side of the walls, and the rover with the antenna was placed on top the wall, there is an error that it adds. At FIX1211 the added error should be no more than 5 centimeters to the south, and at FIX1212 it should not be any more than 5 centimeters to the north.

After the data was collected the coordinates of the benchmark was compared

Figure 3.3: Photo 1 from FIX1212.

Figure 3.4: Photo 2 from FIX1212.

Figure 3.5: Photo 3 from FIX1212.

Figure 3.6: Photo 1 from FIX1211.

Figure 3.7: Photo 2 of FIX1211.

Figure 3.8: FIX1212 circled in red.

Figure 3.9: FIX1211 circled in red.

to the measured coordinates in scatter plots, and the distance between the benchmark and the measured coordinates was calculated using the haversine formula, Equation 3.1. In Equation 3.1 d is the shortest distance between two points, ϕ_1, ϕ_2 are the latitude of point 1 and 2 in radians, λ_1, λ_2 are the longitude of point 1 and 2 in radians, and r is the radius of the Earth.

$$d = 2r\ arcsin\left(\sqrt{sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) + cos(\phi_1)cos(\phi_2)sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right) \tag{3.1}$$

Figure 3.10: Large antenna with ground plate at benchmark.

Figure 3.11: Large antenna with no ground plate at benchmark.

Figure 3.12: Large ceramic patch antenna at benchmark.

Figure 3.13: Small ceramic patch antenna at benchmark.

Chapter 4
Result

In this section some the figures where the distances are displayed can be seen, the rest can be found in Appendix B. In these figures the blue lines are before the rover entered RTK mode, the green lines are with RTK float, and the red lines are with RTK fix. The x-axis of the figures are the samples, and the y-axis are the distances.

In the tables in this section the average distance (mean) from the benchmark, as well as the standard deviation (std), for traditional GNSS, RTK float, and RTK fix can be seen.

In Appendix A scatter plots of coordinates can be seen.

4.1 FIX1212

Below, in table 4.1, mean distances and standard deviations can be found from measurement made at benchmark FIX1212 at 2021.06.02. The figures, Figure B.1, B.2, B.3, B.4, B.5, B.6, B.7, and B.8, displaying the distances over time can be found in Appendix B.

FIX1212 21.06.02	Mean [m] GNSS	Std [m] GNSS	Mean [m] RTK float	Std [m] RTK float	Mean [m] RTK fix	Std [m] RTK fix
Large antenna with ground plate	1.6002	0.1599	1.3014	0.9196	5.6795	1.5603
Large antenna without ground plate	1.3245	0.1739	0.7656	0.2900	0.5741	$2.4 \cdot 10^{-15}$
Larger ceramic patch	0.7681	0.0782	0.5739	0.1695	0.5730	0.0108
Smaller ceramic patch	0.7677	0.2853	0.4189	0.3609	-	-

Table 4.1: Mean distances from FIX1212.

Distances from measurement 2021.06.08 at FIX1212 can be found below in Figures 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, and table 4.2 shows the mean distances and standard deviations from the benchmark.

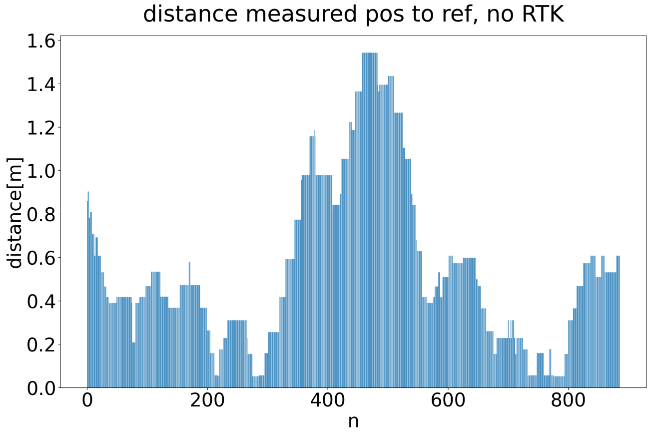

Figure 4.1: FIX1212, 2021.06.08. Large antenna with ground plate, no RTK, distance from benchmark in meters.

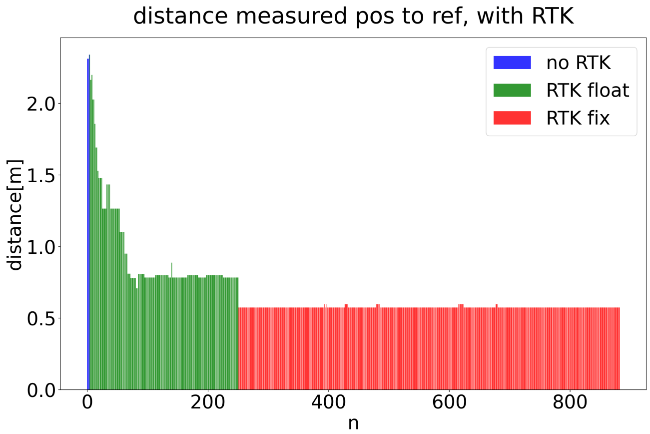

Figure 4.2: FIX1212, 2021.06.08. Large antenna with ground plate, RTK, distance from benchmark in meters.

FIX1212 21.06.08	Mean [m] GNSS	Std [m] GNSS	Mean [m] RTK float	Std [m] RTK float	Mean [m] RTK fix	Std [m] RTK fix
Large antenna with ground plate	0.5530	0.3828	0.9510	0.3223	0.5751	0.0048
Large antenna without ground plate	0.9240	0.4583	0.4246	0.1164	-	-
Larger ceramic patch	0.6338	0.4159	0.5686	0.3757	0.5738	0.0054
Smaller ceramic patch	0.7880	0.6693	0.7217	0.2850	0.5669	0.0265

Table 4.2: Mean distances from FIX1212.

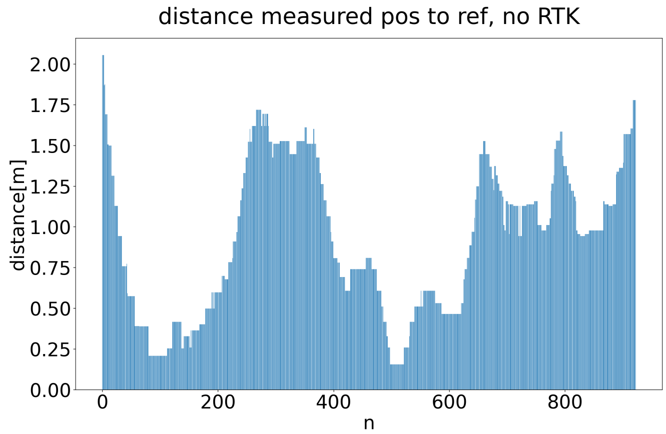

Figure 4.3: FIX1212, 2021.06.08. Large antenna no ground plate, no RTK, distance from benchmark in meters.

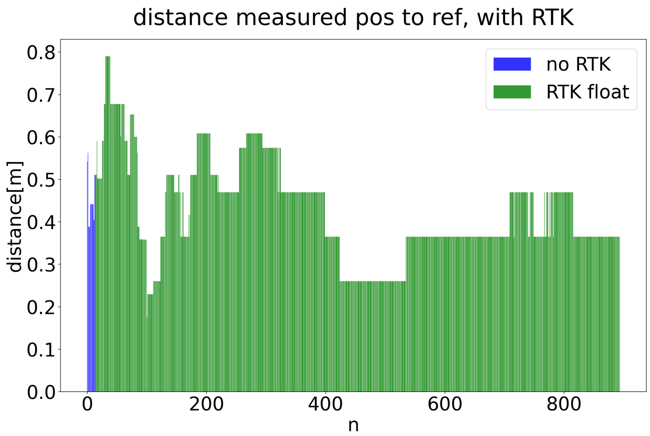

Figure 4.4: FIX1212, 2021.06.08. Large antenna no ground plate, RTK, distance from benchmark in meters.

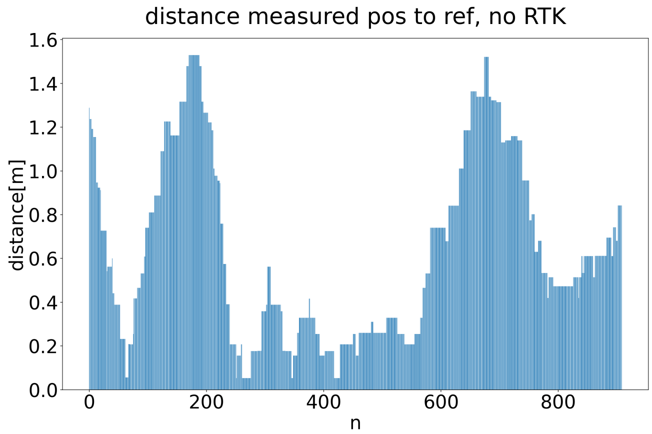

Figure 4.5: FIX1212, 2021.06.08. Larger ceramic patch, no RTK, distance from benchmark in meters.

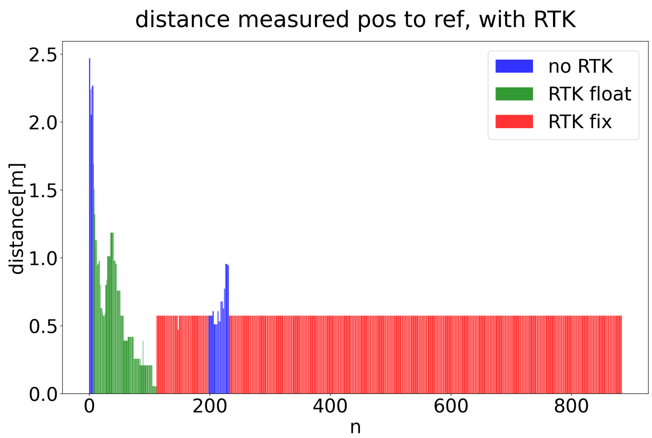

Figure 4.6: FIX1212, 2021.06.08. Larger ceramic patch, RTK, distance from benchmark in meters.

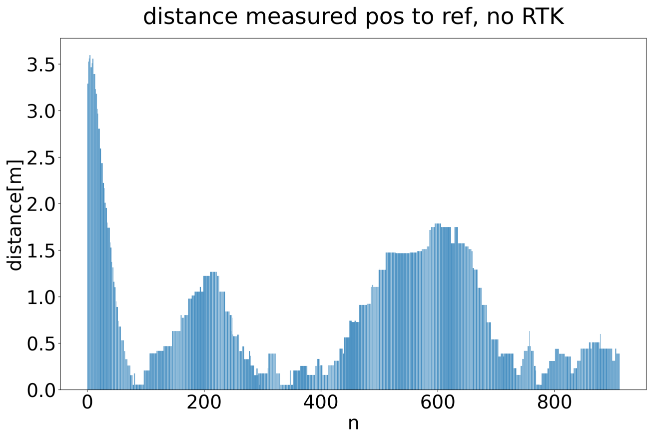

Figure 4.7: FIX1212, 2021.06.08. Smaller ceramic patch, no RTK, distance from benchmark in meters.

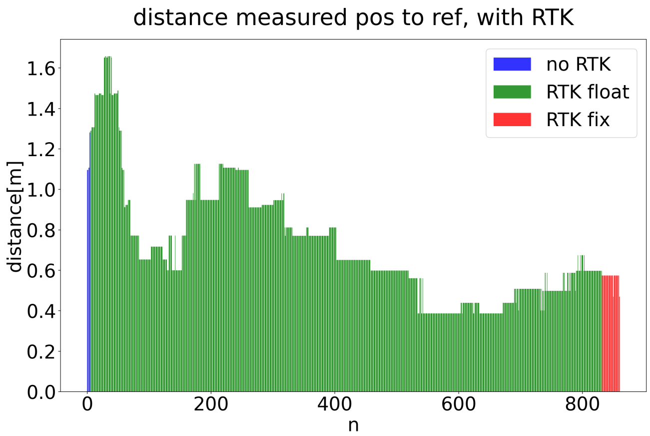

Figure 4.8: FIX1212, 2021.06.08. Smaller ceramic patch, RTK, distance from benchmark in meters.

4.2 FIX1211

Below, in table 4.3, mean distances and standard deviations can be found from measurement made at benchmark FIX1211 at 2021.05.30. The figures, figure B.9, B.10, B.11, B.12, B.13, B.14, B.15, and B.16, displaying the distances over time can be found in Appendix B.

FIX1211 21.05.30	Mean [m] GNSS	Std [m] GNSS	Mean [m] RTK float	Std [m] RTK float	Mean [m] RTK fix	Std [m] RTK fix
Large antenna with ground plate	1.0415	0.2963	1.1550	0.8279	1.4275	0.0590
Large antenna without ground plate	1.2709	0.3748	0.5792	0.4339	0.5890	0.0010
Larger ceramic patch	1.5675	0.8963	0.7955	0.8506	0.6043	$2.4 \cdot 10^{-15}$
Smaller ceramic patch	3.5187	0.9235	1.5989	0.9561	0.7148	0.6829

Table 4.3: Mean distances from FIX1211.

Distances from measurement 2021.06.09 at FIX1211 can be found below in Figures 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, and table 4.4 shows the mean distances and standard deviations from the benchmark.

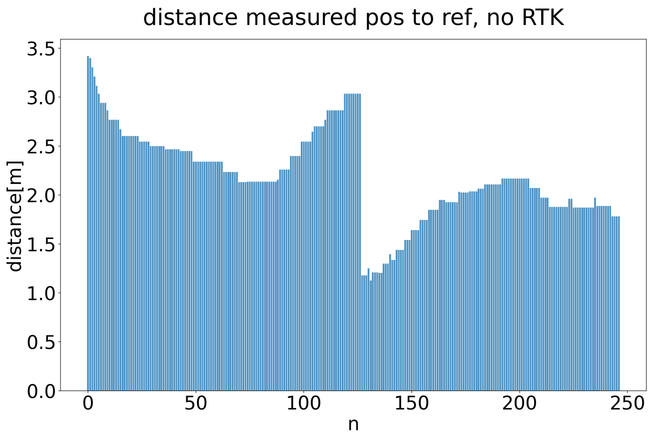

Figure 4.9: FIX1211, 2021.06.09. Large antenna with ground plate, no RTK, distance from benchmark in meters.

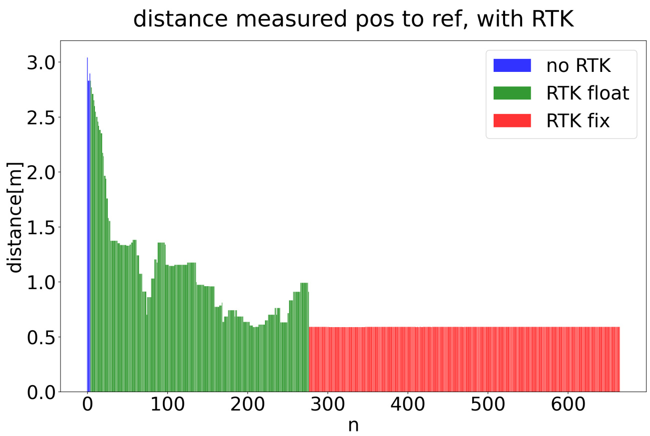

Figure 4.10: FIX1211, 2021.06.09. Large antenna with ground plate, RTK, distance from benchmark in meters.

FIX1211 21.06.09	Mean [m] GNSS	Std [m] GNSS	Mean [m] RTK float	Std [m] RTK float	Mean [m] RTK fix	Std [m] RTK fix
Large antenna with ground plate	2.1941	0.4586	1.0775	0.4657	0.5910	0.0009
Large antenna without ground plate	1.4391	0.6626	0.7743	0.3746	0.2272	$2.5 \cdot 10^{-16}$
Larger ceramic patch	2.6179	1.3438	0.5342	0.2691	-	-
Smaller ceramic patch	6.0404	1.3170	8.0249	1.7431	-	-

Table 4.4: Mean distances from FIX1211.

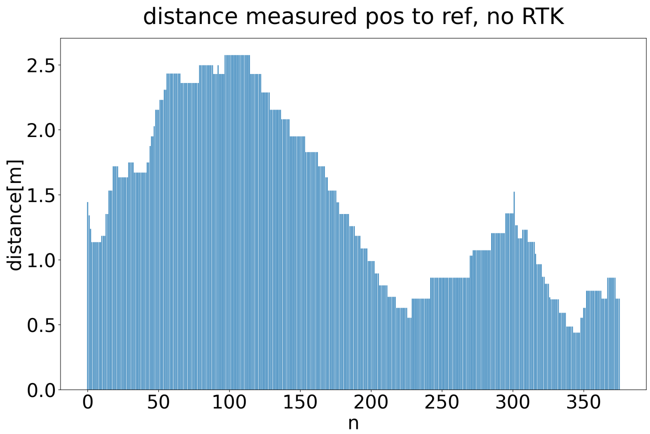

Figure 4.11: FIX1211, 2021.06.09. Large antenna no ground plate, no RTK, distance from benchmark in meters.

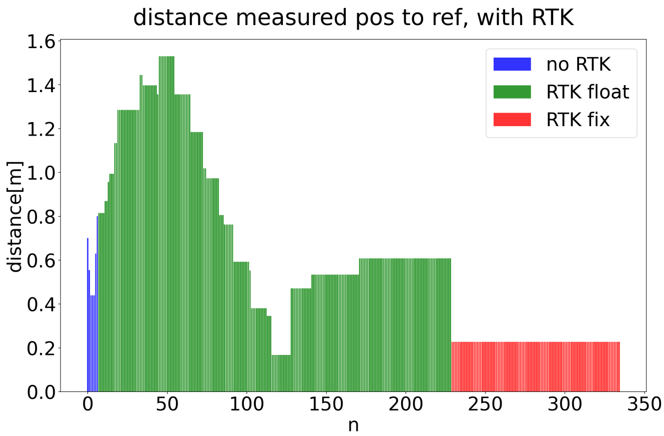

Figure 4.12: FIX1211, 2021.06.09. Large antenna no ground plate, RTK, distance from benchmark in meters.

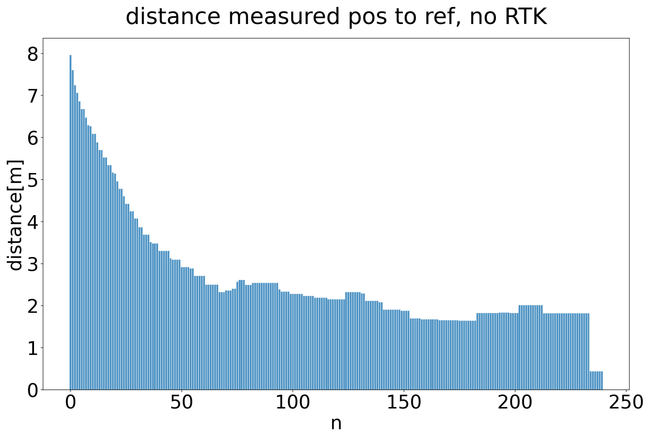

Figure 4.13: FIX1211, 2021.06.09. Larger ceramic patch, no RTK, distance from benchmark in meters.

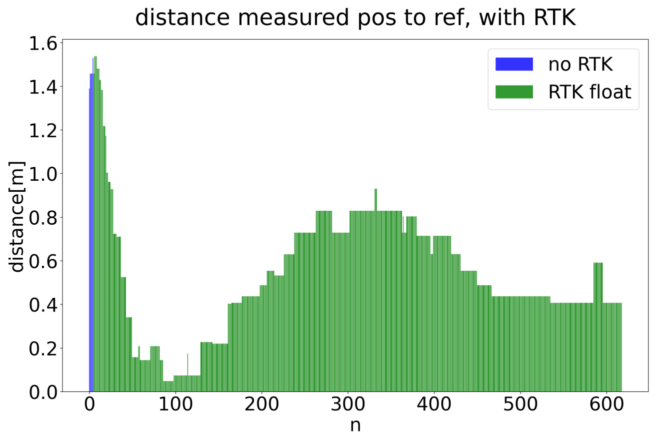

Figure 4.14: FIX1211, 2021.06.09. Larger ceramic patch, RTK, distance from benchmark in meters.

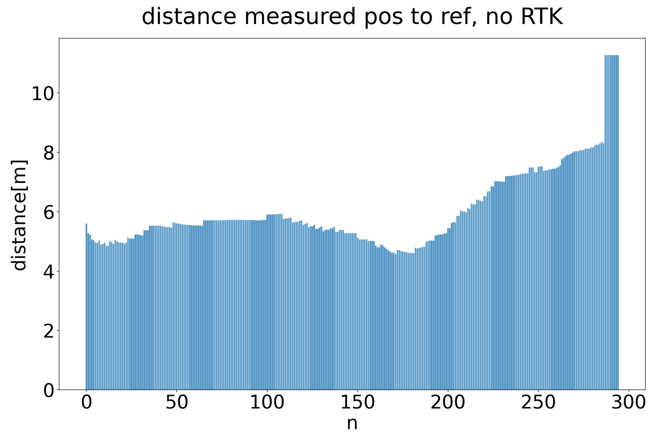

Figure 4.15: FIX1211, 2021.06.09. Smaller ceramic patch, no RTK, distance from benchmark in meters.

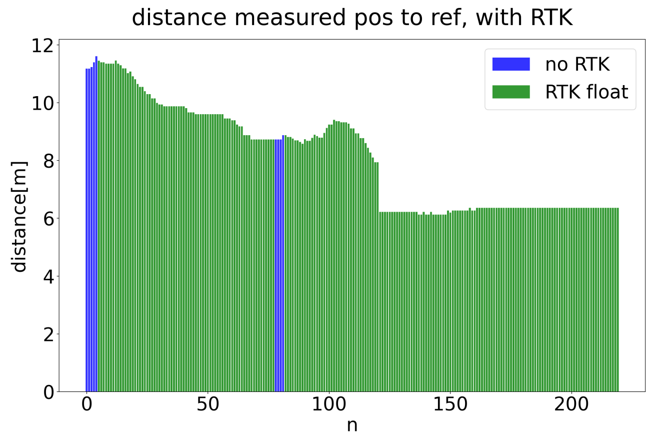

Figure 4.16: FIX1211, 2021.06.09. Smaller ceramic patch, RTK, distance from benchmark in meters.

Chapter 5

Conclusion

The first thing of note is the fact that even when the rover is in RTK fix there is still an error, usually it is around 57 centimeters. This error is most likely because the coordinates of the benchmark was in SWEREF99, and the reference system the rover was using was WGS84. As stated in section 2.4 Reference systems, SWEREF99 uses a solution from 1989 while WGS84 updates once a year. This means that there is a constant error because of that the continental plates on earth moves. If on average a continental plate moves around 1-10 centimeters per year, and Sweden in located on a continental plate that does not move a lot, it is fair to assume around 2 centimeters of drift per year. 2 centimeters per year for 30 years is 60 centimeters.

There are other times when there is a larger error when the rover is in RTK fix, see figures B.2 and B.16. This is probably due to the rover locking on a wrong integer. Since the rover achieves RTK fix when it finds a solution to phase ambiguities using an integer number, it is possible to choose the wrong integer number, and when doing that the accuracy drastically worsens. This occurrence could possibly be because of multipathing.

Another thing of note is in the scatter plots (figures A.1, A.2, A.3, A.4, A.5, A.6, A.7, A.8, A.9, A.10, A.11, A.12, A.13, A.14, A.15, and A.16) there seems to be a constant distance between the points. Since the latitude and longitude values are in the format ddmm.mmmmm (d is degree and m is minute) there is a limit here as well in how precise the rover could have gotten. The distance between two points in latitude is 1.853 centimeters, while the distance between two points longitude is 1.047 centimeters. In this exact instance this does not really matter since there is a greater error affecting the accuracy more. There is also a setting for the ZED-F9P to increase the resolution, however it is not clear how many decimal places there are in those positions.

When comparing the results of traditional GNSS with the results using RTK technology, the traditional GNSS may at times have better mean values, but the standard deviations are a lot larger than the standard deviations using RTK. Since there was the issue with the reference systems, the mean distance does not really give much indication of accuracy, and standard deviation is really the only empirical measurement available given these circumstances. Thus there was a definite improvement using RTK.

When looking more closely at the results for the large antenna with ground plate, it almost immediately achieves RTK float. Twice the rover went into RTK fix within five minutes and stayed in RTK fix for the duration of the measurement. Once it locked on the wrong integer, figure B.2 (FIX1212), where it later lost RTK fix and went into float, but it quickly went into RTK fix again, that time with the right integer. During one of the measurements at FIX1211, figure B.10, it had issues to maintain RTK float and getting RTK fix. If looking more closely at figure 4.10 (FIX1211) and 4.2 (FIX1212) one can see that in the instance that figure 4.2 is demonstrating the rover entered RTK fix faster.

Turning the focus on the large antenna without the ground plate, the results show that it still does not take a long time for the rover to achieve RTK float. In figure B.4, at FIX1212, it is visible that the rover had some issues maintaining RTK float and fix, but it locked on the same solution every time since the standard deviation is 10^{-15} meters. The second measurement at FIX1212, figure 4.4, the rover did not reach RTK fix at all. In figure B.12, FIX1211, there was only a short period of time that the rover was in RTK fix, it also lost RTK float several times during the time of measurement, even if it was only momentarily. In figure 4.12, FIX1211, the rover achieved RTK fix only in the end.

When looking at the larger ceramic patch antenna, it too goes in to RTK float quickly. When looking at figure B.6, FIX1212, it achieves RTK fix fast, and maintains it throughout the measurement. The solution varied slightly, but the standard deviation was approximately 1 centimeter. In figure 4.6, FIX1212, the rover once again reaches RTK fix relatively fast. It does not hold it the entirety of the time, however the standard deviation is about 0.5 centimeters. At FIX1211, figure B.14 and 4.14, the rover only shortly at one point achieved RTK fix, the majority of the time it held RTK float.

With the smaller ceramic patch antenna, the rover enters RTK float quickly. In figure B.8, FIX1212, there are some issues to maintain RTK float, and no RTK fix is achieved. Figure 4.8, FIX1212, there are some measurements with RTK fix at the end, but only right at the end. In figure B.16, FIX1211, the rover achieves RTK fix twice, but loses it shortly after, and the second round of RTK fix the rover locked into the wrong solution. Figure 4.16, FIX1211, shows that the rover had issues maintaining RTK float, and it did not reach RTK fix at all.

When comparing the benchmarks, they indicate better results being achieved in FIX1212 than in FIX1211, this in how quickly a solution for RTK fix was achieved and how long RTK fix was maintained. This aligns with the theory, since FIX1212 had better sight of the horizon, had less buildings around it, and more or less a clear view to the south. When comparing the antennas with one another, they indicate the large antenna with ground plate being better, which once again aligns with the theory. The larger ceramic patch antenna is in some cases better than the large antenna without ground plate. This could be because of the fact that the ceramic patch antenna is made to be used without a ground plate, something the large antenna is not. The small ceramic patch antenna was the worst antenna, there was difficulties for it to reach RTK fix even at FIX1212.

If a RTK GNSS rover were to be built by someone, the conclusion that can be drawn from the given data is that a good antenna is of higher prioritization, that is if the rover will be in any areas that might have some difficulties. If optimal conditions for the rover can be guaranteed a smaller antenna can be used.

There was quite an uphill climb to get the rover to just work. The documentation from u-blox is not the easiest to read, when I asked for help in forums the answers were quite often cryptic – when I asked in SparkFun's forum how to send RTCM data over I_2C they just answered to use Serial instead, or from u-blox they liked to give answers in how to achieve the goal in u-center which is a separate program. Also there are a lot more things to keep track of that no one in these forums for the enthusiasts ever mention, for example the reference systems. There are local reference systems in several places on earth, and those local reference points are going to be better locally than the global reference system, and thus the local organizations are likely to keep track of any benchmark or anything of those sorts in the local reference system. It is peculiar that no one has motioned it. To be fair, the official major organizations mention it, but that information must be specifically inquired.

Chapter 6

Future Work

The first thing that should be done it take more measurements. Two data collections per benchmark is not nearly enough to truly come to any definite conclusions. Another thing that should be done is add more benchmarks, more difficult and easier points to measure at to see the differences. It could also be interesting to test with an antenna with a properly sized ground plate, meaning at least 19 centimeters in diameter.

Further, finding benchmarks in the same reference system as that of the rover is another step to take. If a proper comparison with a ground truth should be made this is needed. Since it is not possible to change the reference system in the SparkFun GPS RTK2 in the present day, it has to be done by finding the reference points in the reference system of SparkFun GPS RTK2. The positions should be able to be found with an arbitrarily accurate representation by leaving a GNSS receiver at the points for an extended period of time. In that time the GNSS receiver should have been able to estimate its position.

In the absence of the benchmarks in the desired reference system, the displacement of the rover is another angle to explore. Moving the rover a specific distance and seeing if the rover actually registers it is a way to see how precise it is. Since the claims around RTK is that the accuracy is a couple of centimeters it should be enough to move it 10 centimeters.

Another avenue to explore is trying different NTRIP service providers. If the different providers are placing their base stations themselves at different points, their solutions could theoretically be different, and that could affect the overall accuracy.

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[12] https://cdn3.taoglas.com/datasheets/AGGBP.SL.35A.07.0060A.pdf

Appendix A

Scatter plots

In this section the scatter plots from the measurements are presented. The gradients in the plots are to show the timeline of the samples. In the figures in this section the x-axis is latitude, y-axis is longitude, blue-to-green dots are traditional GNSS, red-to-yellow dots are with RTK turned on, and the green dot is benchmark.

A.1 FIX1212

A.1.1 2021.06.02

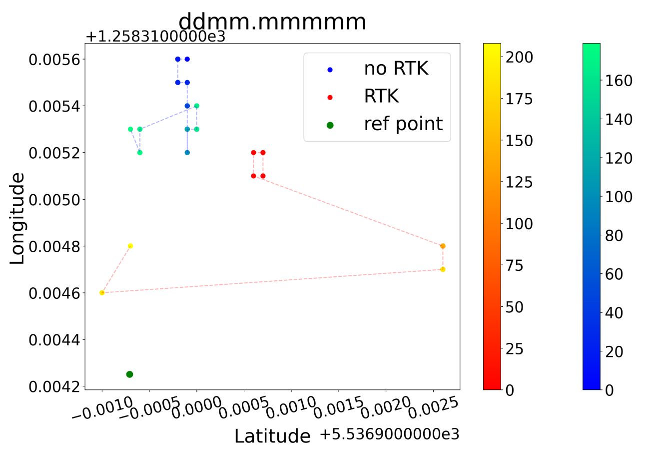

Figure A.1: FIX1212, 2021.06.02. Large antenna with ground plate. Long/lat in ddmm.mm.

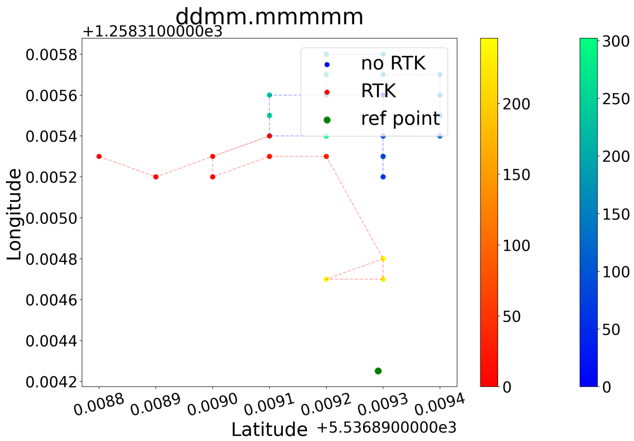

Figure A.2: FIX1212, 2021.06.02. Large antenna no ground plate. Long/lat in ddmm.mm.

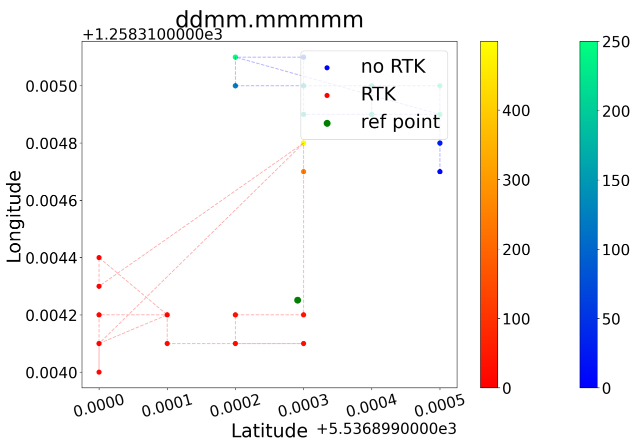

Figure A.3: FIX1212, 2021.06.02. Larger ceramic patch antenna. Long/lat in ddmm.mm.

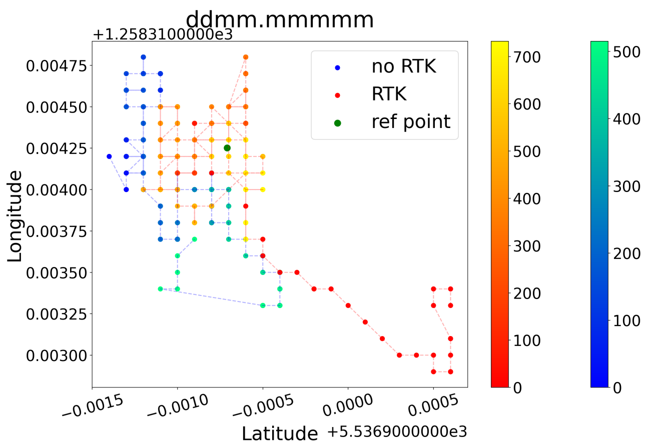

Figure A.4: FIX1212, 2021.06.02. Smaller ceramic patch antenna. Long/lat in ddmm.mm.

A.1.2 2021.06.08

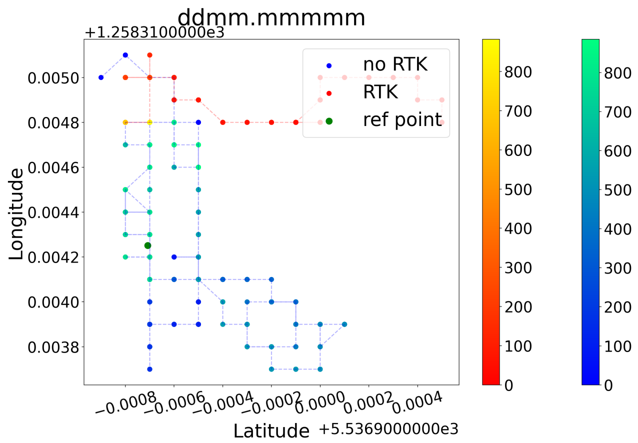

Figure A.5: FIX1212, 2021.06.08. Large antenna with ground plate. Long/lat in ddmm.mm.

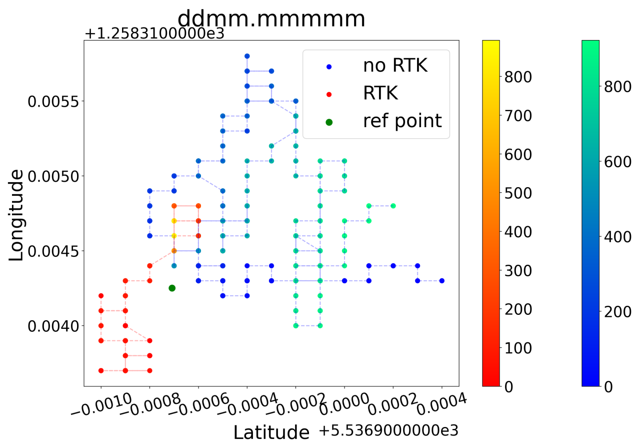

Figure A.6: FIX1212, 2021.06.08. Large antenna no ground plate. Long/lat in ddmm.mm.

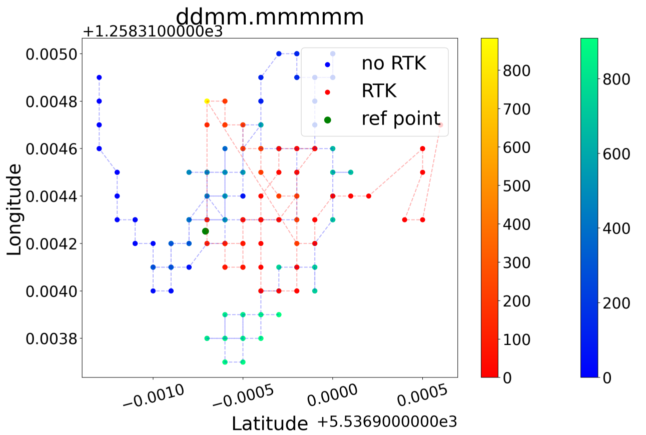

Figure A.7: FIX1212, 2021.06.08. Larger ceramic patch antenna. Long/lat in ddmm.mm.

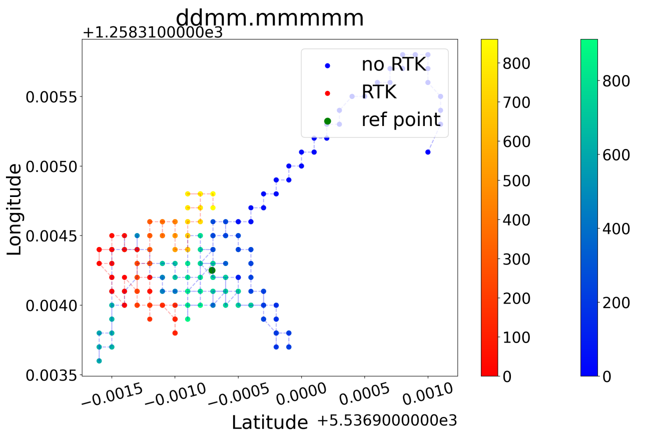

Figure A.8: FIX1212, 2021.06.08. Smaller ceramic patch antenna. Long/lat in ddmm.mm.

A.2 FIX1211

A.2.1 2021.05.30

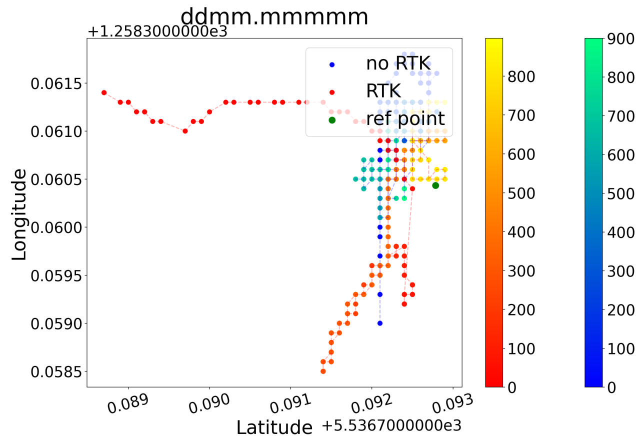

Figure A.9: FIX1211, 2021.05.30. Large antenna with ground plate. Long/lat in ddmm.mm.

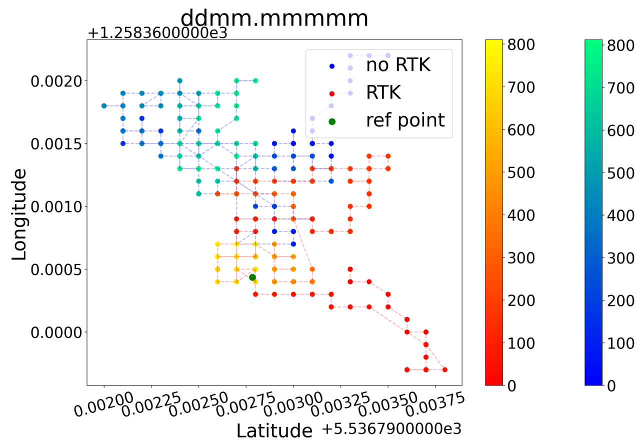

Figure A.10: FIX1211, 2021.05.30. Large antenna no ground plate. Long/lat in ddmm.mm.

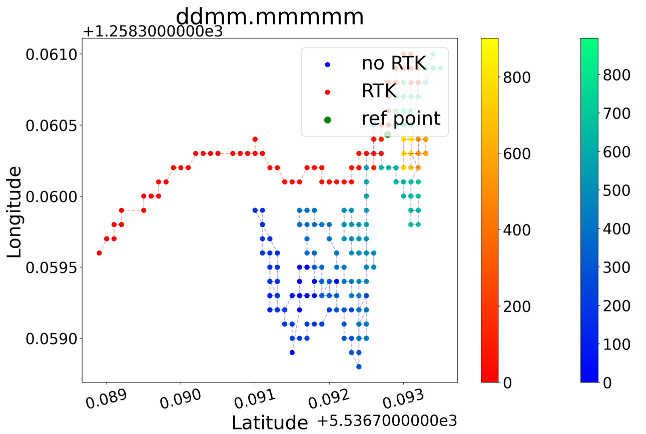

Figure A.11: FIX1211, 2021.05.30. Larger ceramic patch antenna. Long/lat in ddmm.mm.

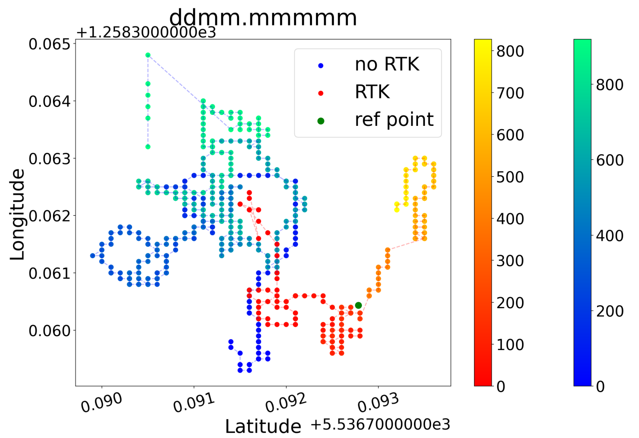

Figure A.12: FIX1211, 2021.05.30. Smaller ceramic patch antenna. Long/lat in ddmm.mm.

A.2.2 2021.06.09

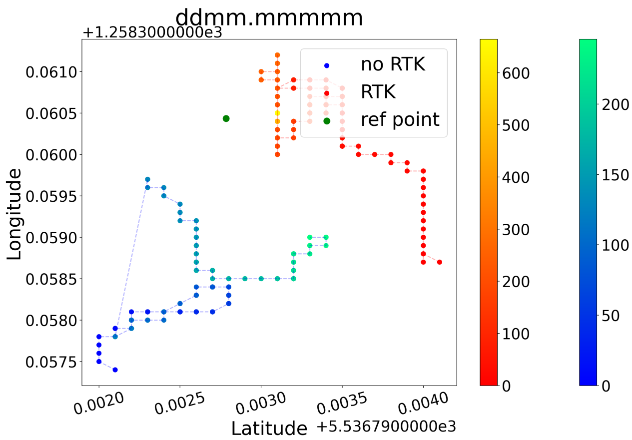

Figure A.13: FIX1211, 2021.06.09. Large antenna with ground plate. Long/lat in ddmm.mm.

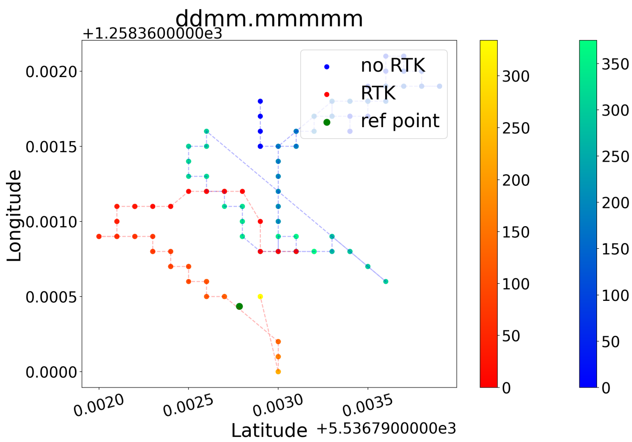

Figure A.14: FIX1211, 2021.06.09. Large antenna no ground plate. Long/lat in ddmm.mm.

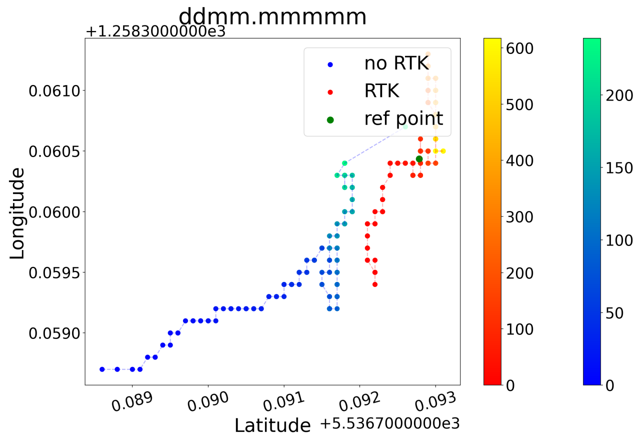

Figure A.15: FIX1211, 2021.06.09. Larger ceramic patch antenna. Long/lat in ddmm.mm.

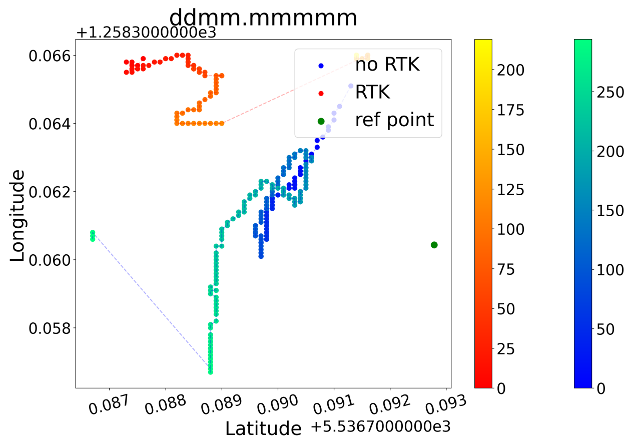

Figure A.16: FIX1211, 2021.06.09. Smaller ceramic patch antenna. Long/lat in ddmm.mm.

Appendix B

More results

In these figures the distances are represented. With RTK the blue lines are before the rover entered RTK mode, the green lines are with RTK float, and the red lines are with RTK fix. The x-axis of the figures are the samples, and the y-axis are the distances.

B.1 FIX1212

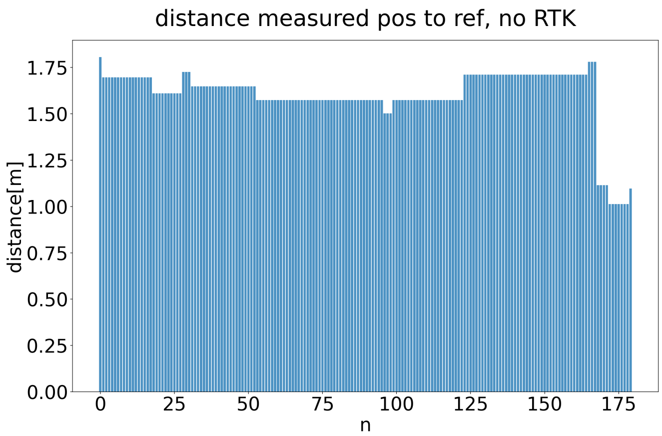

Figure B.1: FIX1212, 2021.06.02. Large antenna with ground plate, no RTK, distance from benchmark in meters.

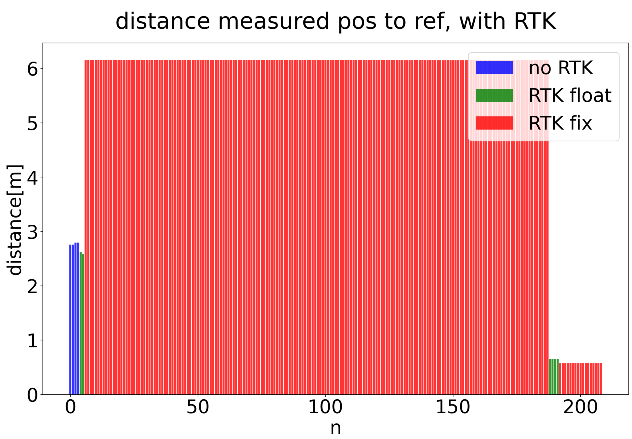

Figure B.2: FIX1212, 2021.06.02. Large antenna with ground plate, RTK, distance from benchmark in meters.

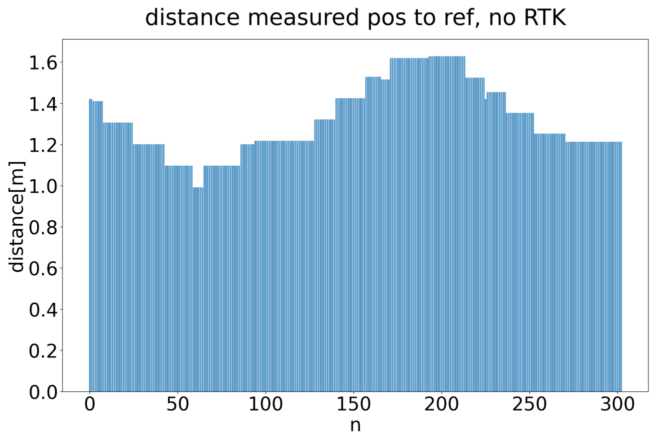

Figure B.3: FIX1212, 2021.06.02. Large antenna no ground plate, no RTK, distance from benchmark in meters.

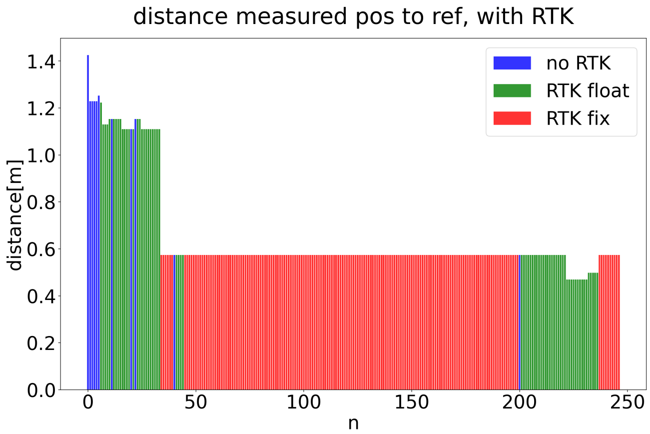

Figure B.4: FIX1212, 2021.06.02. Large antenna no ground plate, RTK, distance from benchmark in meters.

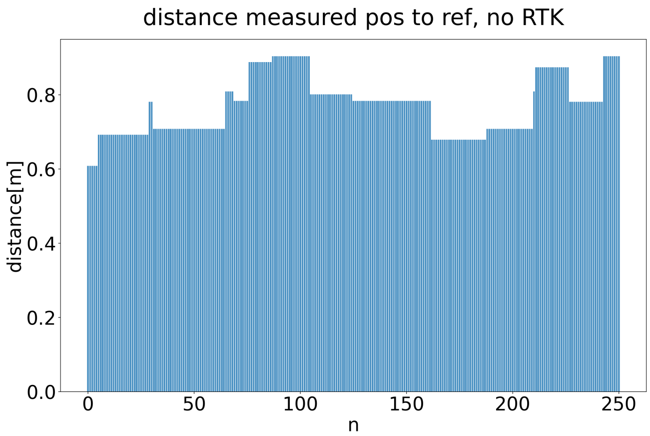

Figure B.5: FIX1212, 2021.06.02. Larger ceramic patch, no RTK, distance from benchmark in meters.

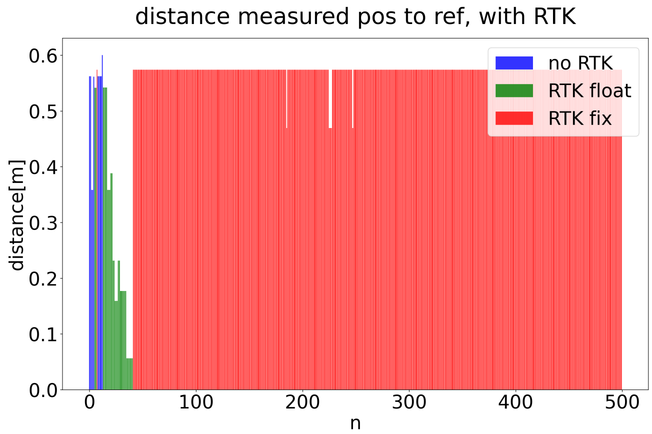

Figure B.6: FIX1212, 2021.06.02. Larger ceramic patch, RTK, distance from benchmark in meters.

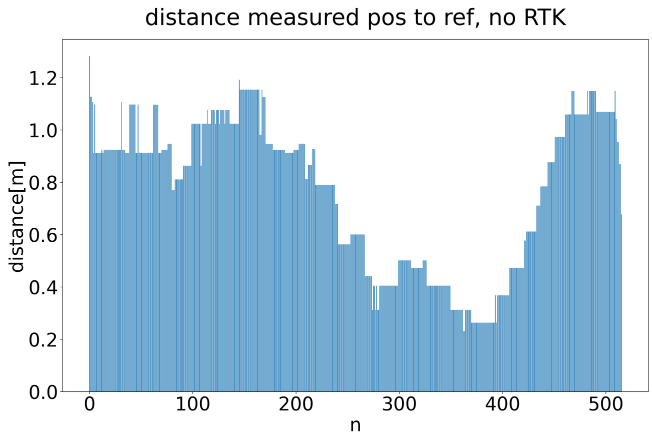

Figure B.7: FIX1212, 2021.06.02. Smaller ceramic patch, no RTK, distance from benchmark in meters.

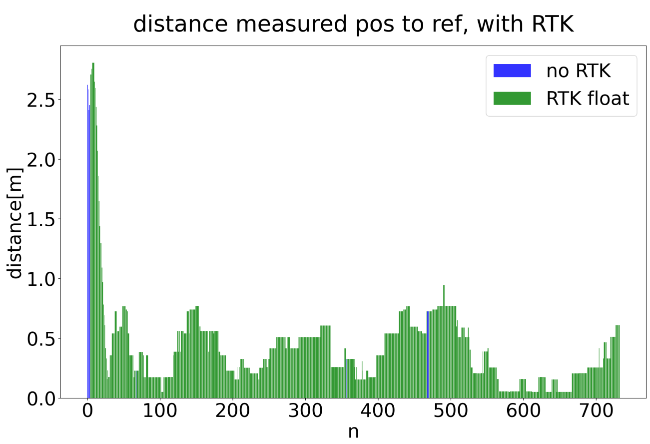

Figure B.8: FIX1212, 2021.06.02. Smaller ceramic patch, RTK, distance from benchmark in meters.

B.2 FIX1211

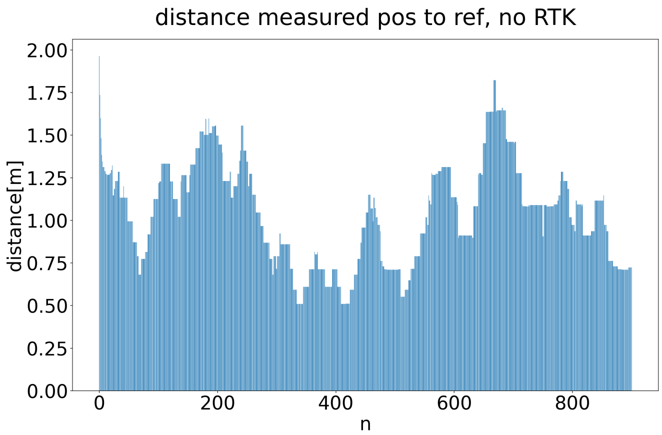

Figure B.9: FIX1211, 2021.05.30. Large antenna with ground plate, no RTK, distance from benchmark in meters.

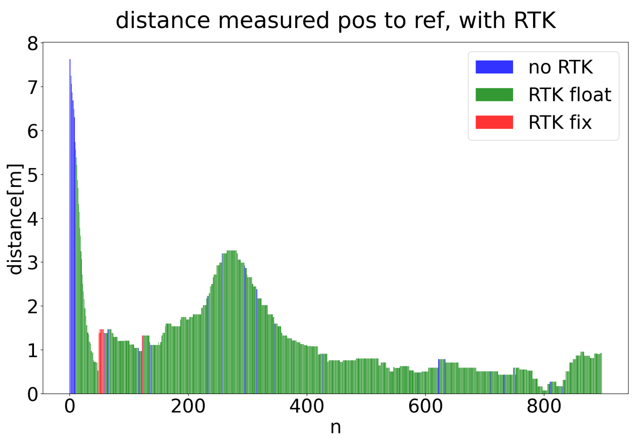

Figure B.10: FIX1211, 2021.05.30. Large antenna with ground plate, RTK, distance from benchmark in meters.

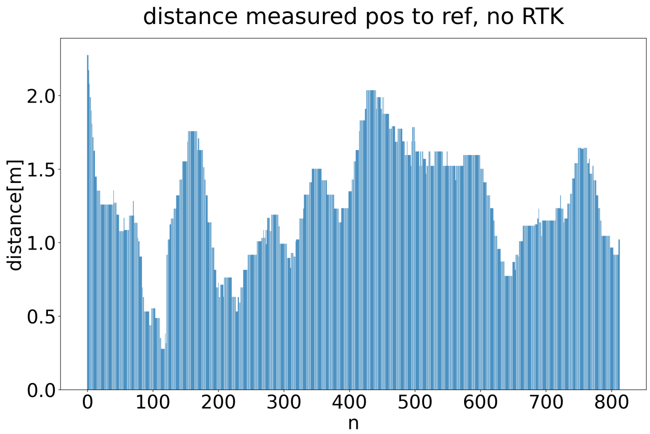

Figure B.11: FIX1211, 2021.05.30. Large antenna no ground plate, no RTK, distance from benchmark in meters.

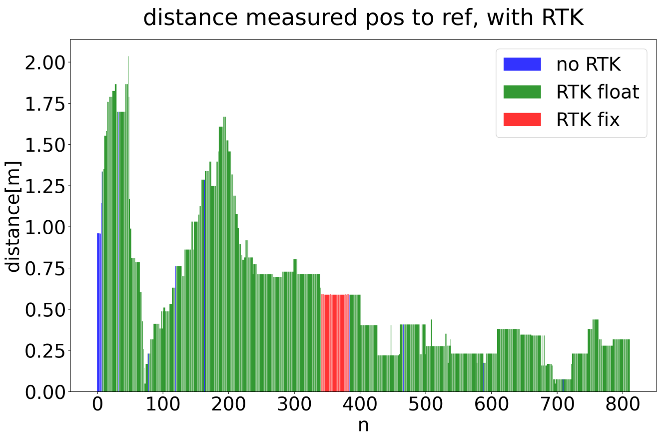

Figure B.12: FIX1211, 2021.05.30. Large antenna no ground plate, RTK, distance from benchmark in meters.

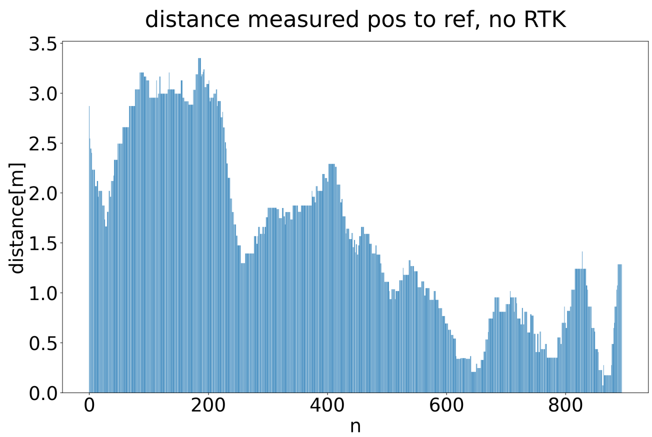

Figure B.13: FIX1211, 2021.05.30. Larger ceramic patch, no RTK, distance from benchmark in meters.

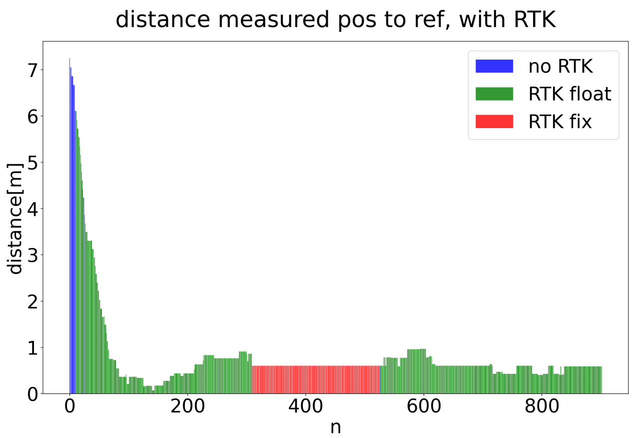

Figure B.14: FIX1211, 2021.05.30. Larger ceramic patch, RTK, distance from benchmark in meters.

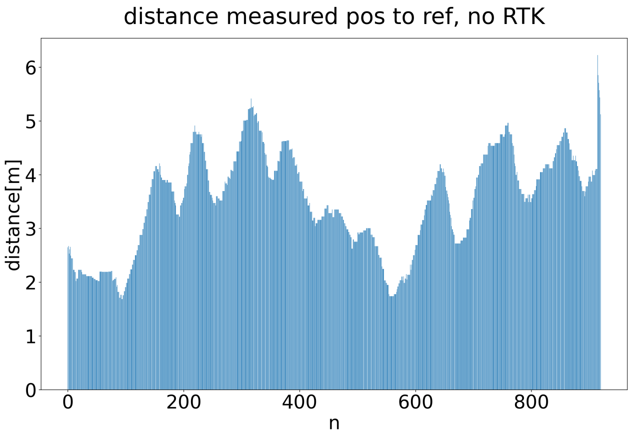

Figure B.15: FIX1211, 2021.05.30. Smaller ceramic patch, no RTK, distance from benchmark in meters.

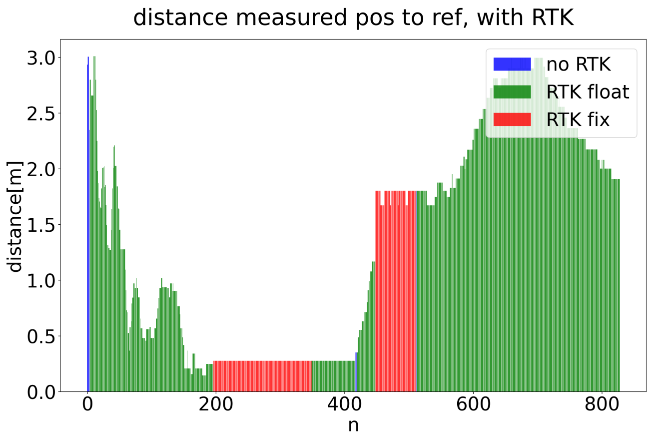

Figure B.16: FIX1211, 2021.05.30. Smaller ceramic patch, RTK, distance from benchmark in meters.

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