Community Cadastres

Using Dual-Frequency GNSS Modules for Land Rights in Dar es Salaam, Tanzania

EthicalGEO Final Report

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Table of Contents

Executive Summary	**3**
Introduction	**4**
Problem Statement	**5**
Cadastre Processes	**6**
Goal and Objectives	**7**
The Team	**8**
The Technology	**9**
Community Cadastres	**10**
Outputs	**12**
Positive Externalities	**13**
Conclusion and Lessons Learned	**15**
Annex: NRCan PPP Report	**16**

Executive Summary

The following report tells the story of my EthicalGEO Project, from October 1st 2019 through August 31st 2020. The American Geographical Society (AGS) selected me, and six other EthicalGEO Fellows[1], to shine a light on the best ideas about ethical challenges and the opportunities posed by the many geospatial technologies and data sources that are shaping our society. We seek to engage thinkers, innovators, entrepreneurs, policymakers, practitioners, students, as well as everyday citizens in a global dialogue on these issues.

My project was unique insofar as it was one of the only projects to engage in activities outside of the United States. Though an American citizen myself, I have worked closely with a local team of Tanzanians over the last years to use community mapping as both a tool and methodology for improving resilience and development in East Africa. As a manager with Humanitarian OpenStreetMap Team (HOT)[2], we believe that open data can fundamentally address both humanitarian and development challenges.

With this in mind, I will correct myself and continue by speaking about *our* project, because although I was personally selected as a Fellow, I have collaborated extensively with a brilliant Tanzanian organization named OpenMap Development Tanzania (OMDTZ).[3] They have been with me every step of the way, from identifying land rights as a critical issue facing the developing world, to engaging communities in Swahili, to training field mappers, to doing the actual data collection and analysis.

The major “ethicalgeo” challenge our project sought to address was the fact that across the world nearly a billion people live without legal title to their land. Recognizing this, the project itself sought to answer one primary question—how can we make land rights accessible to the urban poor in Tanzania, with an eye to creating a model for the rest of the developing world? Our answer, as you will read in the report, is community cadastres.

This report includes useful sections from our original proposal, detailing the problem, goals, and context. It then goes on to the story of the project, the barriers we faced, outputs, positive externalities, and concludes with a reflection on lessons learned. *We do not claim to have solved the puzzle of land rights for all, but we may have solved one critical piece of the much larger picture.*

Thank you to the organizations who supported us (AGS, HOT, OMDTZ), and the individuals who made it happen: Imma, Iddy, Innocent, Kassano, Digna, Bornlove, Deo, Hessel and Ivan 🙏.

[1] https://ethicalgeo.org/
[2] https://www.hotosm.org/
[3] https://www.omdtz.or.tz/

Introduction

On the Eastern coast of Tanzania lies Dar es Salaam, one of Africa's fastest-growing urban centers. Experts project that it will achieve 'megacity' status in the next decade, with ten million residents or more. Of this population it is estimated that 70% live in informal, unplanned settlements, subsisting on roughly a dollar per day.

What this means is that these millions of residents do not have access to their land or property rights, depriving them of social stability. To put it bluntly, "A property without a land title is worthless," says Tanzania's Housing Minister, William Lukuvi. Obtaining a formal land title grants the owner access to credit, and provides essential protection to the urban poor.

Herein lies the ethical challenge: How can Tanzanians living in informal settlements gain essential access to land tenure? This is just one piece of a much larger problem, as nearly a billion people worldwide live without legal title to their land. This is both a political as well as a technical challenge, where bureaucracy, as well as precise surveying, can be barriers.

A key part of the solution is the use of new geospatial technology, in particular, dual-frequency receivers and open-source signal processing with mobile devices. This tech has only recently become affordable for the average citizen, and can help bridge the divide between the urban poor (who can't afford surveys) and their land rights. Estimates show that this can drastically reduce the cost to families paying for their land titles, which become over a hundred times cheaper.

What we have done in our EthicalGEO Project, is to use Real-Time Kinematics surveying with a newly released, low-cost, high-accuracy, dual-frequency sensor, to pave the way forward for land rights for the urban poor in Tanzania. Harnessing the power of this tech has been a local team of Tanzanian geographic information system (GIS) experts, who have conducted a pilot project in Dar es Salaam.

Before we go on to explain the cadastral mapping, it is helpful to further understand the many obstacles preventing land tenure as well as the history of land allocation in Tanzania.

Problem Statement

At least 70% of Dar es Salaam's residents live in informal settlements with no access to their land rights. Rapid unplanned urbanization means the problem will only get worse in the years ahead. People are becoming increasingly vulnerable to health and environmental hazards such as dengue fever and annual flooding.

The scale of the problem is huge, and in spite of efforts to address the problem, Tanzania is still listed as the 146th most difficult country to register property, with 8 different procedures and a wait time of 67 days, according to World Bank data[4] collected in 2018.

Informal Settlements in Makangira Subward, Dar es Salaam, Tanzania

Besides these statistics, the reality is that most families cannot afford to pay the cost of mapping each plot, which the Minister of Lands reduced to 150,000 Tanzanian Shillings, or approximately $65. This price is still *far* too high for the vast majority of informal residents. In addition, the

[4] https://data.worldbank.org/indicator/IC.PRP.DURS

professional surveyors who work in this field cannot afford to go through the process and create the survey for any less.

There have been different policies, strategies, and programs initiated by the Government of Tanzania to ensure all plots are surveyed and provided with title deeds through lowering the cost for plots survey, cost-sharing public housing programs, and slums upgrading among others—but still these strategies could not address the scale of plot surveys needed, which is colossal, and is speeding up while informal settlements are expanding.

In effect, this results in a Nash equilibrium[5] whereby neither side can unilaterally succeed if the other remains unchanged. The transformative power of new geospatial technology can begin to solve the problem. We have proposed introducing it in a way that works hand in hand with communities directly, as well as existing surveyors.

Cadastre Processes

The history of cadastral surveys in Tanzania goes back to when it was under colonial rule—by Germany from 1890-1914, and then Britain from 1919-1961. Surveys served the colonial settlers by securing their land boundaries, whereas following independence the primary objective was to provide geometric descriptions for equitable access to land and the registration of land rights.[6]

The basic unit of cadastral surveys is the land parcel—mapping of these land parcels provides a foundation to the cadastral survey system. Chapter 324 of the Land Survey Act of Tanzania, Part I (2) states “cadastral survey means any survey the purpose of which is to obtain information for recording the position of the boundaries of lands in separate ownership or intended to be the subject of any disposition or partition, or re-establishing such boundaries on the ground or setting out new boundaries on the ground”.

[5] The Nash equilibrium is named after the mathematician John Forbes Nash (popularized by the film, A Beautiful Mind) and is a proposed solution of a non-cooperative game involving two or more actors in which each actor is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only their own strategy. Thus, residents are unable to afford surveying their land, and the surveyors themselves are not economically incentivized to survey informal settlements because there is not a large enough base of customers able to pay for their expertise and equipment.
[6] An Overview of the Cadastral System in Tanzania, by Joseph Mango 2015.

In urban areas these are known as town plans. The three basic steps to conducting a cadastral survey in Tanzania are the request, execution, and submission—taken together these represent at least 8 different steps from the start to the end of the process.

The importance of cadastral surveys cannot be understated—it is among the primary sources of land and resource property rights. They are meant to be, “simple, quick and affordable to speed up official access to secure land tenure by many citizens.” However, this goal is difficult to achieve when the cost of surveying is known to be high, and the amount of town plans needed is vast.

All of the above has compounded the problem for the 70% of people in Dar es Salaam that live in informal settlements. Some of the main challenges are lack of funding, the time required to create a town plan, and bureaucracy. Professional surveyors are using Real-Time Kinematics tools, which allow the user to obtain highly accurate (centimeter-level) positioning in real time. Still, the sensors they are using are significantly more expensive than the sensor being introduced for the first time in this project.

The complexities inherent in the current cadastral surveying system in Tanzania make it such that poor people can rarely, if ever, obtain proper land rights. By bringing communities together and using some affordable dual-frequency receivers, we propose to change that.

Goal and Objectives

Main Goal: Make land rights accessible to the urban poor in Tanzania.

Specific Objectives:

1. Conduct a pilot exercise in an informal subward of Dar es Salaam that provides cadastral surveys to one hundred community members

2. Demonstrate the use of dual-frequency RTK and open source tools for reducing the cost of surveying

3. Show the benefit of providing land rights to a single community, with a clear pathway to scale the project for the entire city

The Team

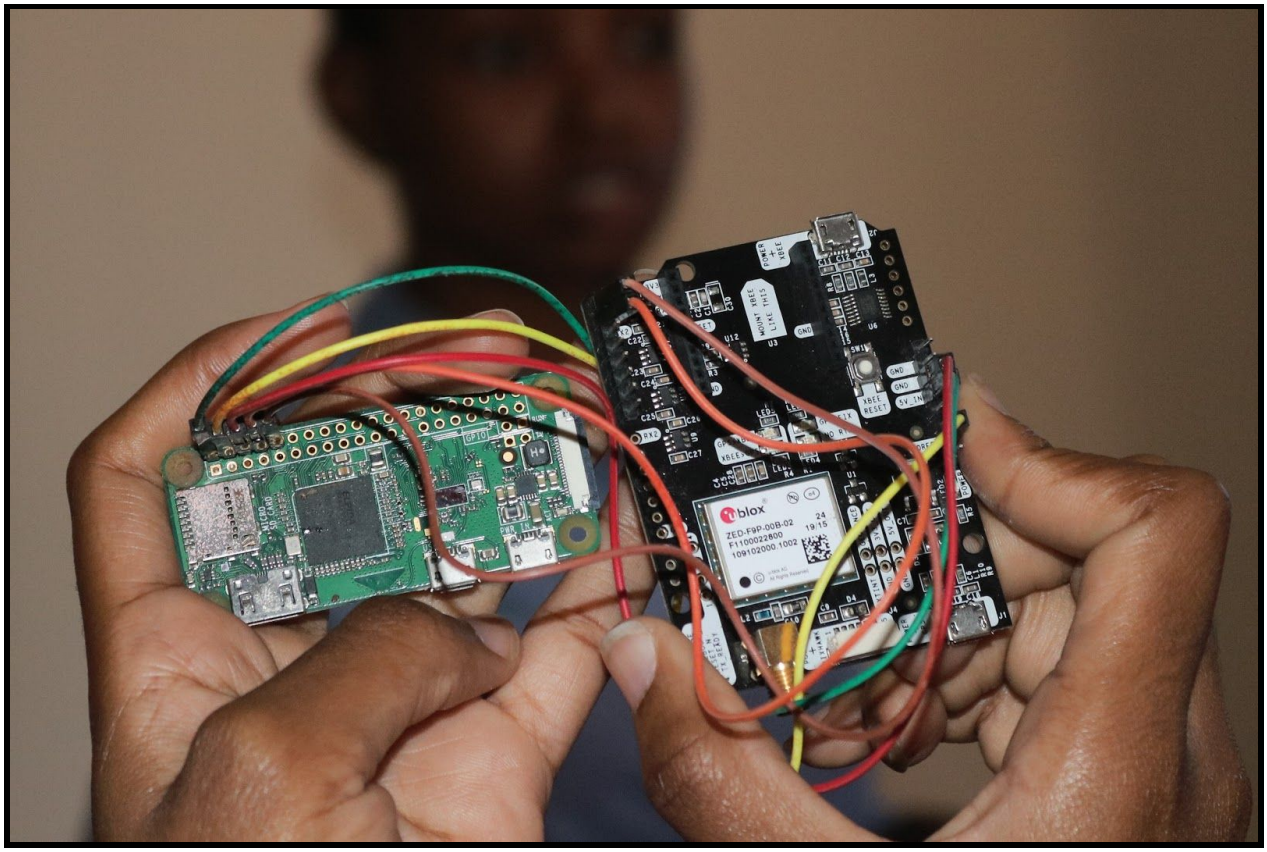
The Surveying Team, Kiwalani, Dar es Salaam, Tanzania

The team behind most of the fieldwork is OpenMap Development Tanzania (OMDTZ). This is a registered non-governmental organization based in Mikocheni, Dar es Salaam, and operating across the entire country. Their mission is to provide services for all of Tanzania to improve maps for humanitarian response and development. Three of their main pillars include: 1) Community Mapping 2) Data for Urban Resilience and 3) Innovation, GIS, and Open Source Technology.

OMDTZ has partnered with the Humanitarian OpenStreetMap Team over the years to conduct a variety of projects—digitizing building footprints, mapping drainage, soil sampling, flood extents, trash mapping, asset and threats, and doing flood responses. Focusing on community cadastres is a first, but the same tools and processes involved in the EthicalGEO Project have successfully been used in other OMDTZ projects, for instance, creating a digital terrain model from aerial imagery and ground control points across the Msimbazi River. The expertise and evidence gathered in these other projects, directly flows into EthicalGEO.

The Technology

A sensor has recently come to the market that allows its users to establish affordable, centimeter-precision location. The Swiss company u-blox[7] has released a dual frequency GPS sensor, along with a dual frequency antenna, for under $300. Tests done in August 2019 show an accuracy of 2cm within Dar es Salaam.



SimpleRTK2B Standalone Board with RTK GNSS technology, based on u-blox ZED-F9P

The RTK system (rover and base) works in combination with a simple Arduino and local Android phones. It is not without challenges, as the next section will illustrate. However, the output we have seen is astounding, and we believe it may not only empower Tanzanians, but potentially communities around the world who are living without land rights.

[7] https://www.u-blox.com/en

Community Cadastres

Let's begin with a simple definition: community cadastres are registers of the ownership and extent of property, generated by communities themselves. It is a combination of community mapping, with the official system of defining the dimensions and location of land parcels. The second word comes to English through French from Greek, which means 'organized line by line'.

Our approach uses geospatial technology and works together with communities to map out their plots. The innovation is twofold—on the one hand we are using the latest dual band RTK GNSS tech (which is orders of magnitude cheaper than traditional equipment), and on the other hand, we are encouraging whole communities to come together at once, reducing the time and cost of surveying.

As such, the story begins with community. The first person we engaged in October 2019 was named Susan, a former Sub-Ward Leader in Makangira. She has lived in this community since 1986 and has been a leader for 35 years, in particular representing women within the current ruling party in Tanzania. We visited her at her house and spoke of many things, foremost among them the question, "Do the residents in Makangira want this project?" Her answer was that "Yes, almost all residents in Makangira who have license to their lands want to have title deeds and this project can be one way of achieving that."

At the same time we were meeting with local authorities, namely the Chief Surveyor of Kinondoni Municipal Council. This surveyor informed us that we would need to be involved with a registered survey firm, in order to align with the Ministry of Lands legal requirements. He also advised us to start having meetings with the community members to sensitize and educate the residents about what we wanted to do.

As these processes were moving forward we sought to educate ourselves better about the complexities of land registration, so we set up a meeting with the Landesa[8] Tanzania office, which was launched in 2018 by the Minister of Lands. We learned about their work areas, and their main goal of providing women with secure land rights as evidence shows this increases income by 150%, reduces teen marriages, and increases school participation. We decided that this was such an important element to include that we invited one of their staff to the community meeting in Makangira to explain the importance of women having land rights.

[8] https://www.landesa.org/

After much patient waiting and organizing we finally joined a large community meeting held by the newly elected leader, seen in the image below making remarks. After normal business, we introduced ourselves to the community, as well as the project we were hoping to conduct. We also benefited from the participation of Landesa, who outlined the importance of gender equality in land rights. We also listened to the community's concerns, and explored all of the dimensions (pros and cons) of doing the project. At the end of the discussion, the community members were asked if they were ready to have their lands surveyed and they gave a resounding "yes!"

Community Meeting held in Makangira Subward, Dar es Salaam, Tanzania

After this major milestone in our project, we hit a number of barriers. The invitation letter from one of the community leaders was delayed by a month. Then, the District Executive Director in Kinondoni took another two months to get us the official permission letter to begin surveying. By that time, in March, the Minister of Health had confirmed the first COVID-19 case, and we shifted to remote work.

Yet, in spite of these challenges we pressed ahead. We made the difficult decision to begin piloting in different communities, as Makangira's was slow to respond. We visited three separate communities with ongoing regularization projects to test our tools and processes, overcoming

both technical as well as political hurdles along the way. In the end, we managed to survey 20 plots in Segerea Ward, while at the same time obtaining the cadastral data from a professional survey company that had mapped the same plots before. This has allowed us to follow through with our first two goals, namely conducting a pilot exercise in an informal subward, and then demonstrating the accuracy of our inexpensive dual-frequency receivers.

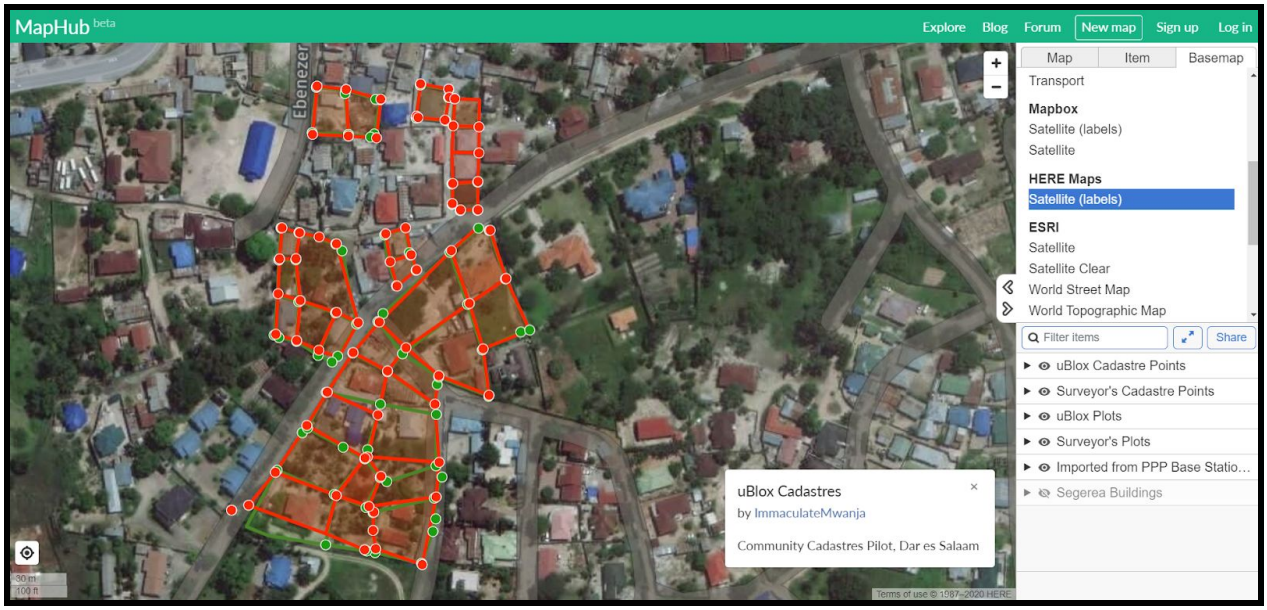
Outputs

The below image captures the incredible results from this pilot project. In total, we mapped out 20 plots using the $300 u-blox ZED-F9P GNSS Receiver, which shows the same degree of accuracy as $10,000 GPS receivers.

The best scientific evidence that we can present for the accuracy of this data comes from a method known as Precise Point Positioning (PPP). PPP is a positioning technique that removes or models GNSS system errors to provide an extremely high level of position accuracy. It can deliver an accuracy up to 3 centimeters, and requires a longer period of time coverage to resolve local biases such as the atmospheric conditions, multipath environment and satellite geometry. This is the global gold standard.

While some of our comparative analysis is ongoing, we are confident that the data show clear evidence of accuracy, and are produced by the Natural Resource Canada (NRCan), which is the government agency of Canada responsible for mapping and remote sensing. We are attaching the report generated from this fieldwork as an annex.

Additionally, we have created an online interactive map to play with the data, and observe the differences up close: https://maphub.net/ImmaculateMwanja/gnss_plots



Online Interactive Map of Cadastral Surveys using a Low-Cost Sensor

The red points and polygons represent the cadastral surveys conducted with our inexpensive u-blox receivers, whereas the green are taken from the professional survey company data. If you would like to view with satellite imagery, just select this option under the Basemap tab.

Positive Externalities

Throughout the course of the project there were a number of additional benefits that arose from our work, that are just as consequential as the outputs themselves:

- HOT and OMDTZ formed a partnership with Spatial Collective, an organization that has a track record of using community mapping for land rights in Zanzibar. We are currently working together on the next iteration of Ramani Huria in northern Tanzania.

- HOT, OMDTZ and Uhurulabs[9] (a Tanzanian drone company) are in the final stages of a grant application with Fondation Botnar.[10] The project we have put forward is called Open Skies Fellows: African Tech for African Data, and is a fellowship program for young Africans to learn skills in technology for social good—we have taken direct inspiration from the EthicalGEO Fellowship and believe that providing the time, resources, and guidance to young Africans is profoundly impactful.
- We now have a number of our Tanzanian staff trained on how to use this equipment!
- In addition to this final report, we are working on some useful open documentation so that others can benefit from our knowledge and replicate our efforts in their own communities. Specifically we hope to provide a How To Guide, a Video Tutorial, and a PowerPoint video lesson on GNSS.
- We have developed a relationship with Landesa, and even participated with them together in a local conference called Innovation Week, in Dar es Salaam, to speak about the importance of land rights.

Speaking with Landesa During Innovation Week 2020, Dar es Salaam

[9] http://website.uhurulabs.org/
[10] https://www.fondationbotnar.org/

Conclusion and Lessons Learned

We will be the first to admit we did not reach our moonshot of delivering title deeds to residents, which, after all, is the ultimate aim of this project. In spite of this shortcoming, we are thrilled with the results we have been able to achieve—namely, that **we now have strong, scientific evidence that our tools and methods can democratize land rights for poor people.**

The challenges remaining are many. Our experience taught us several valuable lessons, about the technology, politics involved, and agonizing bureaucracy of land tenure:

1. Technology can sometimes break down in the simplest of ways. We spent a full day in the field once, puzzled at why we could not get a fix on the satellites, only to realize later that the coaxial cable wiring our equipment had a broken connection.

2. The community needs to lead the way. Land rights are so sensitive, and a key component of our approach is the idea that neighbors come together to reduce the time and cost of surveying, working together to agree on their boundaries. It also takes leadership from the authorities, and when this is in short supply surveying can hit a wall.

3. The bureaucracy is just as bad as our research tells us. The fundamental barrier for informal settlements receiving their title deeds is no longer technological, it is political. Innovations such as ours must be parallel to legal and bureaucratic reforms.

None of this is to suggest that there is *one* way to go about the process of providing land rights to people, or even that the provision of title deeds is the only solution for insecurity of land tenure. It even occurred to us that ground surveying may not be the most effective means for accomplishing the ultimate goal of land rights for all. Fit-for-purpose land administration[11] suggests other ways, such as using drones to capture high resolution aerial imagery and using this to digitize the cadastres with the help of communities and local leaders, like in Rwanda.[12]

What we do claim, is that we have found a viable, low-cost, highly-accurate, solution for mapping properties—and we have no doubt that with political will, community cadastres can change a billion lives.

[11] Fit-for-purpose land administration: Guiding Principles for Country Implementation, UN-Habitat
[12] Land reform: Lessons from Rwanda (Video)

Annex: NRCan PPP Report

CSRS-PPP 2.32.0 (2020-03-31)

BASE00TZN_R_20202260700_01D_01S_MO.rnx
base_log_2020_08_13_08_05.ubx

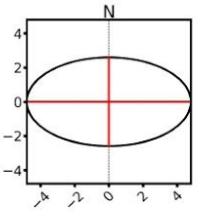
Data Start	Data End	Duration of Observations
2020-08-13 07:05:46.00	2020-08-13 11:06:35.01	4:00:49.010
Processing Time		**Product Type**
15:36:20 UTC 2020/08/17		NRCan Rapid
Observations	**Frequency**	**Mode**
Phase and Code	Double	Static
Elevation Cut-Off	**Rejected Epochs**	**Estimation Steps**
7.5 degrees	0.00 %	1.00 sec
Antenna Model	**APC to ARP**	**ARP to Marker**
UNKNOWN NONE	Unknown	H:0.000m / E:0.000m / N:0.000m

(APC = antenna phase center; ARP = antenna reference point)

Estimated Position for BASE00TZN_R_20202260700_01D_01S_MO.rnx

	Latitude (+n)	Longitude (+e)	Ell. Height
ITRF14 (2020.6)	-6° 50' 41.80658"	39° 11' 14.88276"	41.282 m
Sigmas(95%)	0.021 m	0.038 m	0.103 m
A priori*	-6° 50' 41.79471"	39° 11' 14.89504"	42.166 m
Estimated − A priori	-0.365 m	-0.377 m	-0.885 m

95% Error Ellipse (cm)
semi-major: 4.8 cm
semi-minor: 2.6 cm
semi-major azimuth: 89° 59' 55.94"



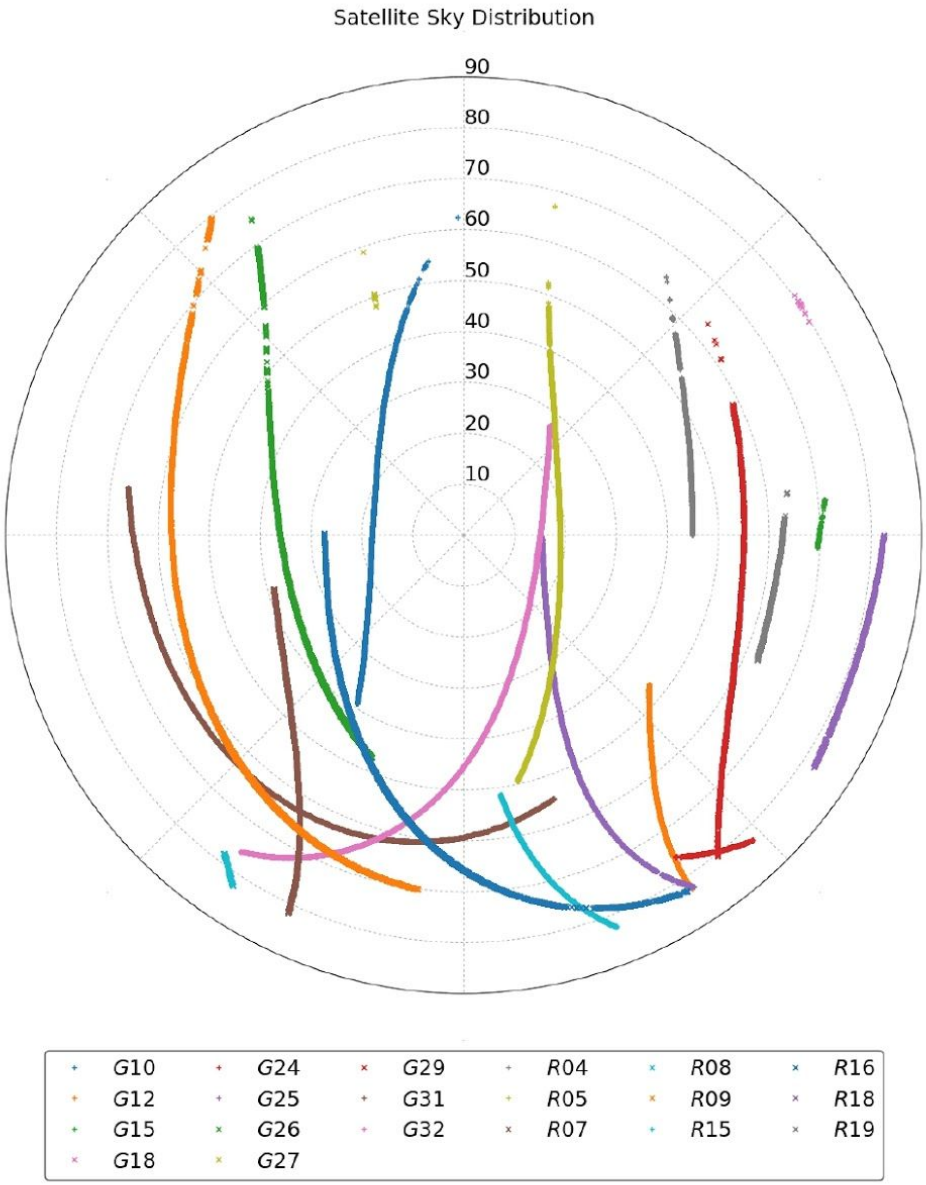
UTM (South)
Zone 37

9243387.692 m (N)
520712.766 m (E)

Scale Factors
0.99960531 (point)
0.99959882 (combined)

*(Coordinates from a code solution used as a priori position)

1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70
60
50
40
30
20
10
G10
G12
G15
G18
G24
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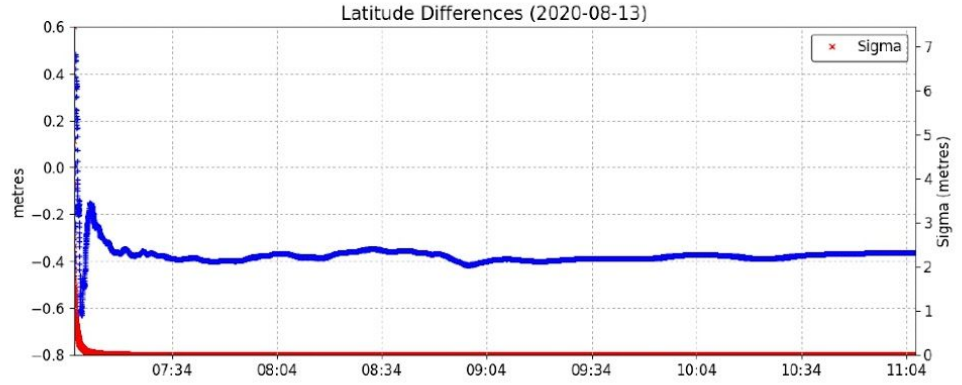
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Sigma (metres)
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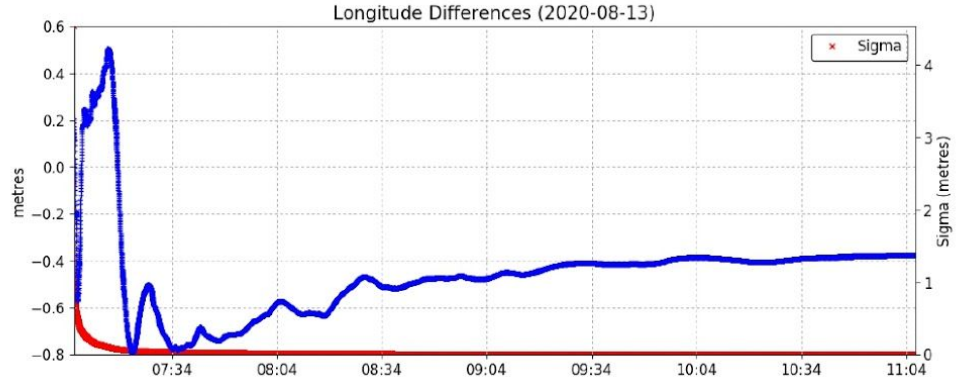
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metres
Sigma (metres)
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−0.6
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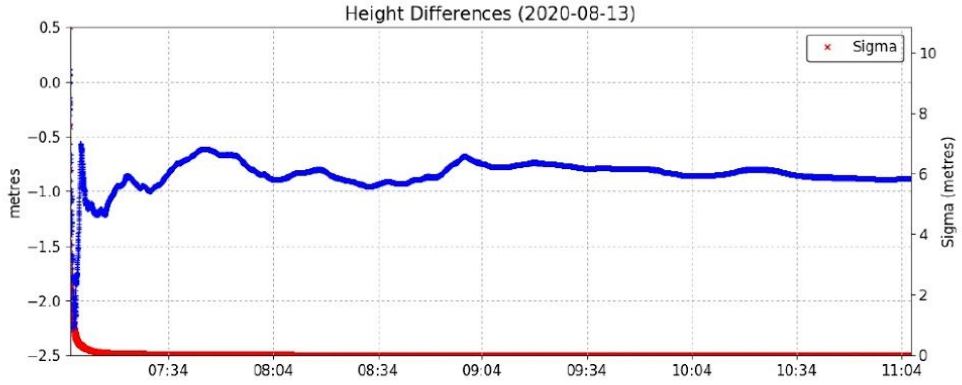
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metres
Sigma (metres)
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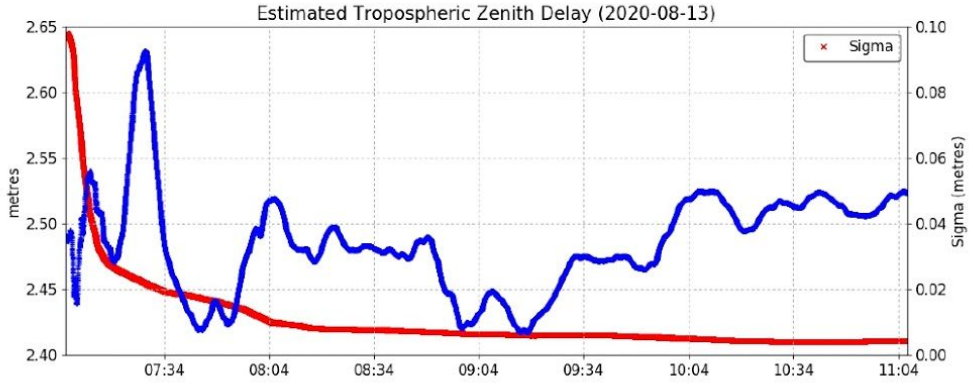
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Sigma (metres)
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2.40
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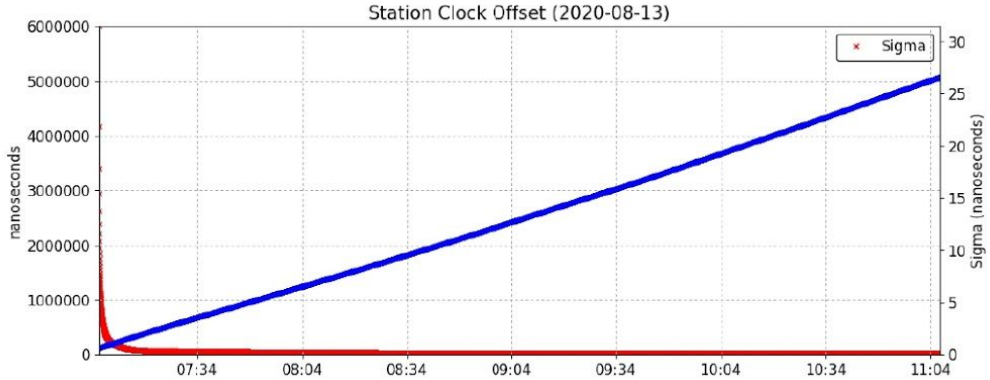
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Sigma (nanoseconds)
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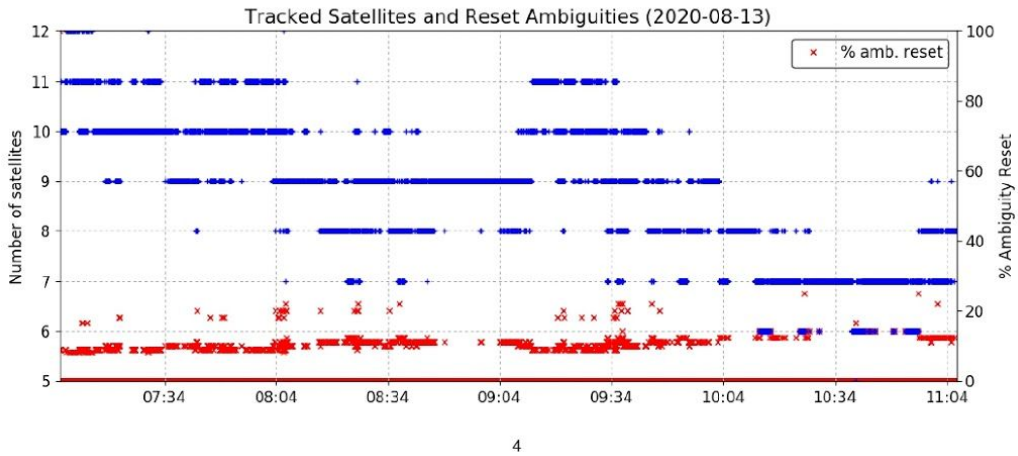
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% amb. reset
Number of satellites
% Ambiguity Reset
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11
10
9
8
7
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5
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08:04
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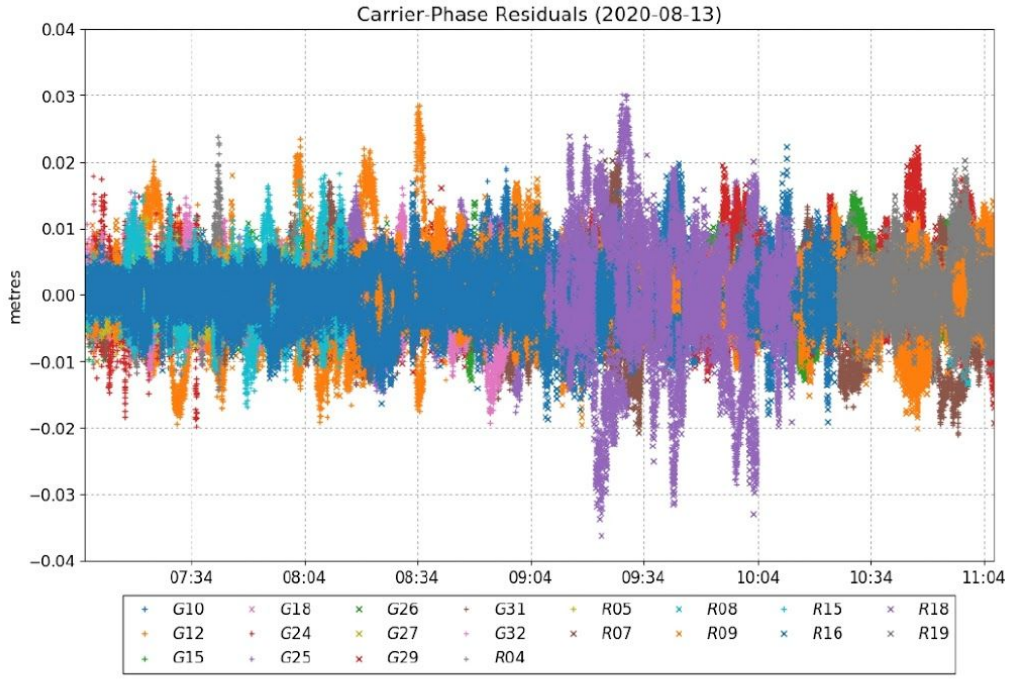
10:34
11:04

4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0.02
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−0.03
−0.04
07:34
08:04
08:34
09:04
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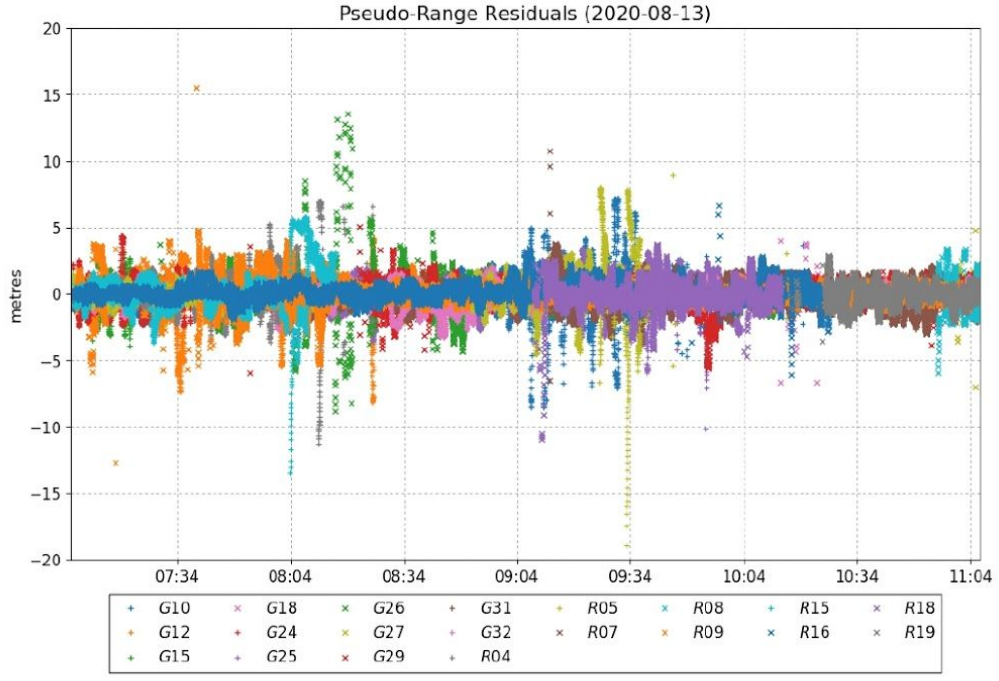
10:04
10:34
11:04
G10 G18 G26 G31 R05 R08 R15 R18
G12 G24 G27 G32 R07 R09 R16 R19
G15 G25 G29 R04


Pseudo-Range Residuals (2020-08-13)
metres
20
15
10
5
0
−5
−10
−15
−20
07:34
08:04
08:34
09:04
09:34
10:04
10:34
11:04
G10 G18 G26 G31 R05 R08 R15 R18
G12 G24 G27 G32 R07 R09 R16 R19
G15 G25 G29 R04

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