

International GNSS Summer School 2019

Organized by Tokyo University of Marine Science and Technology

Course

Module A: GNSS Signal Security

Module B: Spoofing & GNSS Signal Authentication

Module C: Android GNSS Raw Data Processing

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- **Member, ICAO/NSP, DFMC/SBAS Signal Authentication**

Outline of the Lecture

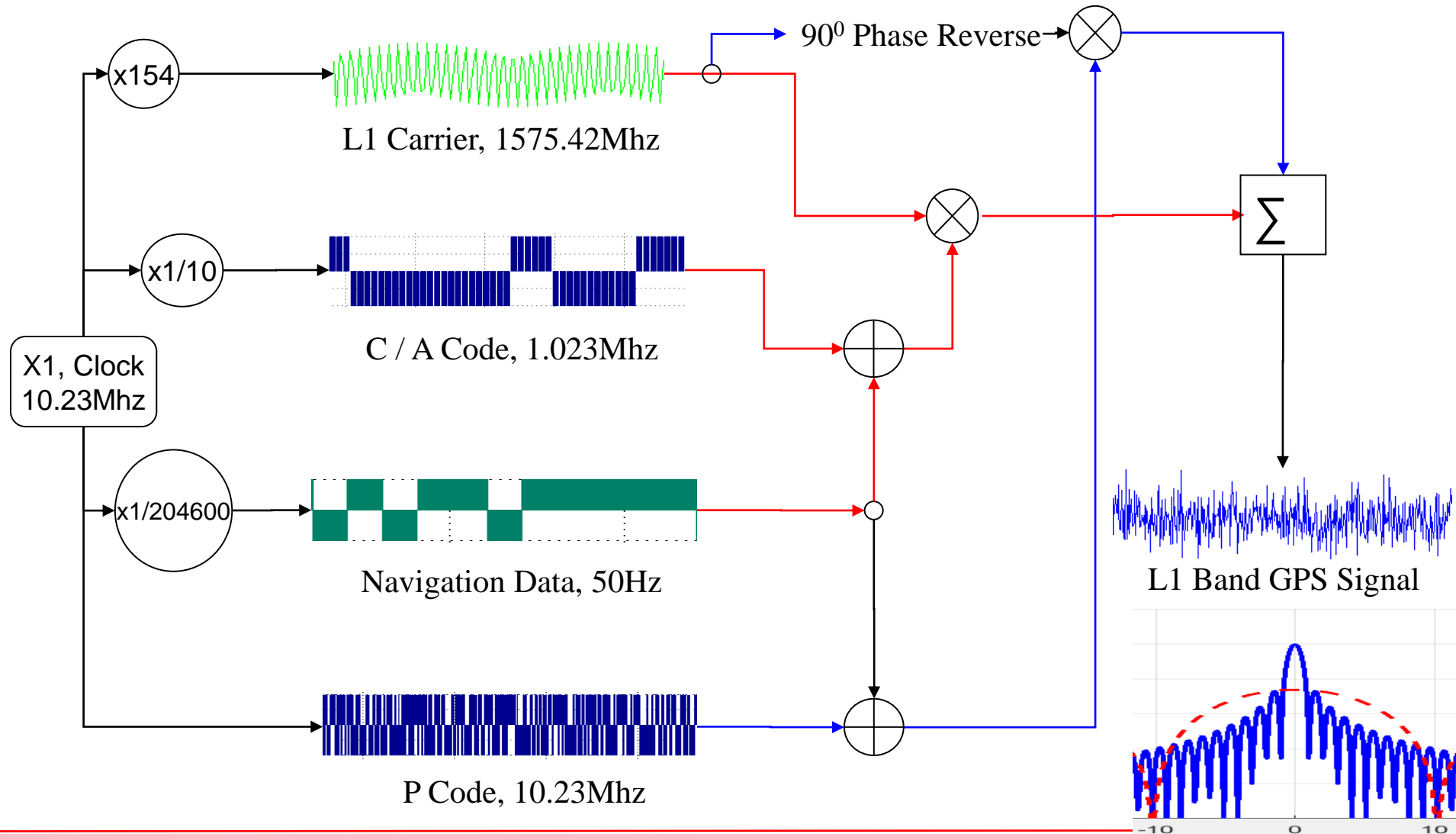
- **Module A: GNSS Signal Security**
 - Introduction to GNSS Vulnerabilities
 - Interference
 - Jamming
 - Spoofing
- **Module B: Spoofing and GNSS Signal Authentication**
 - Detail discussions on Spoofing
 - Demonstration of Spoofing
 - Anti-Spoofing Methods
 - Demonstration of Anti-Spoofing Method
- **Module C: Android GNSS Raw Data Processing**
 - Introduction
 - Android Devices
 - Data Logging Tools
 - Data Processing Tools
 - Data Processing Outputs
 - Innovative and Challenging Applications

Module: C-I

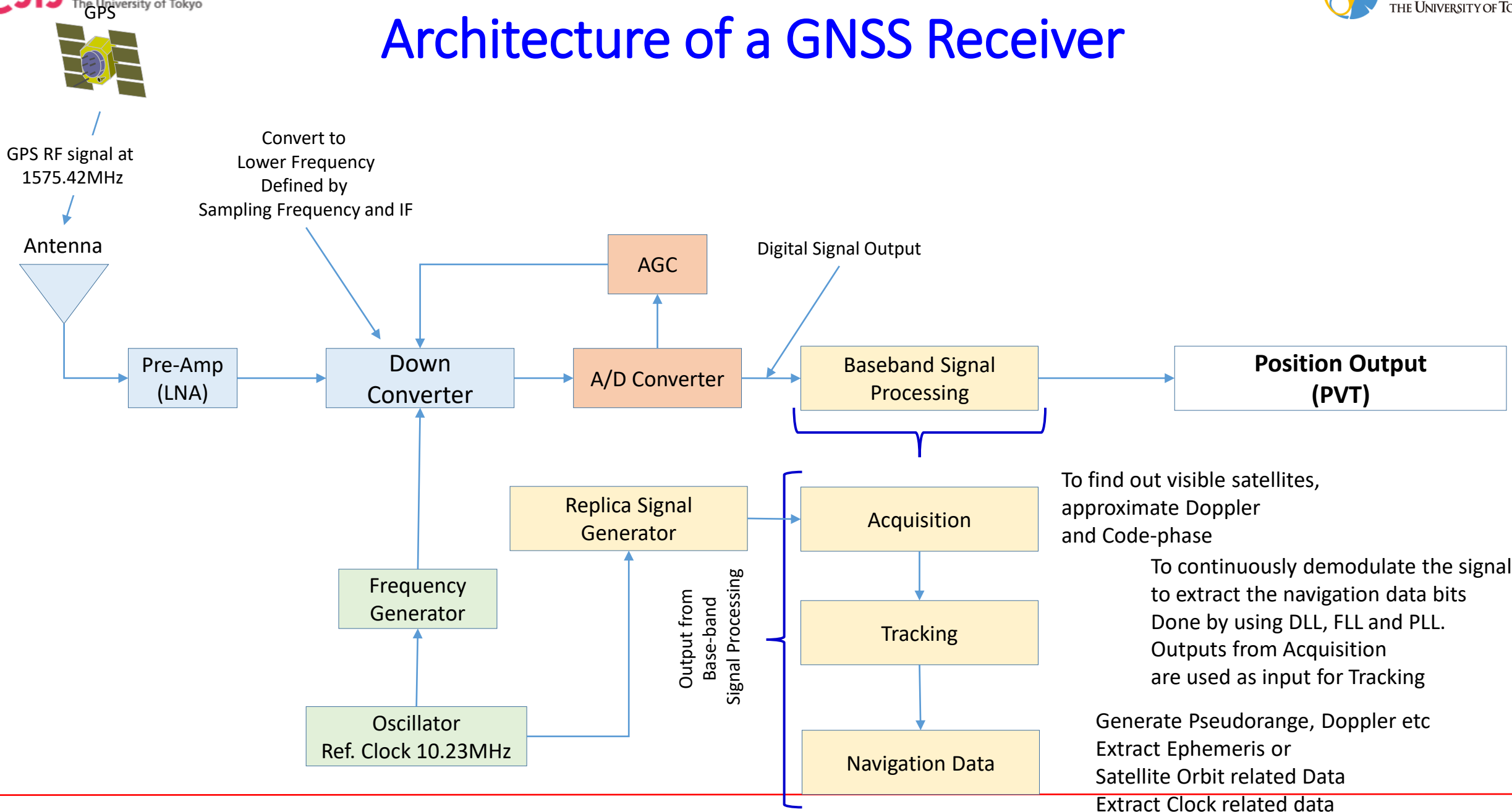
Background on

GNSS Raw Data Measurement

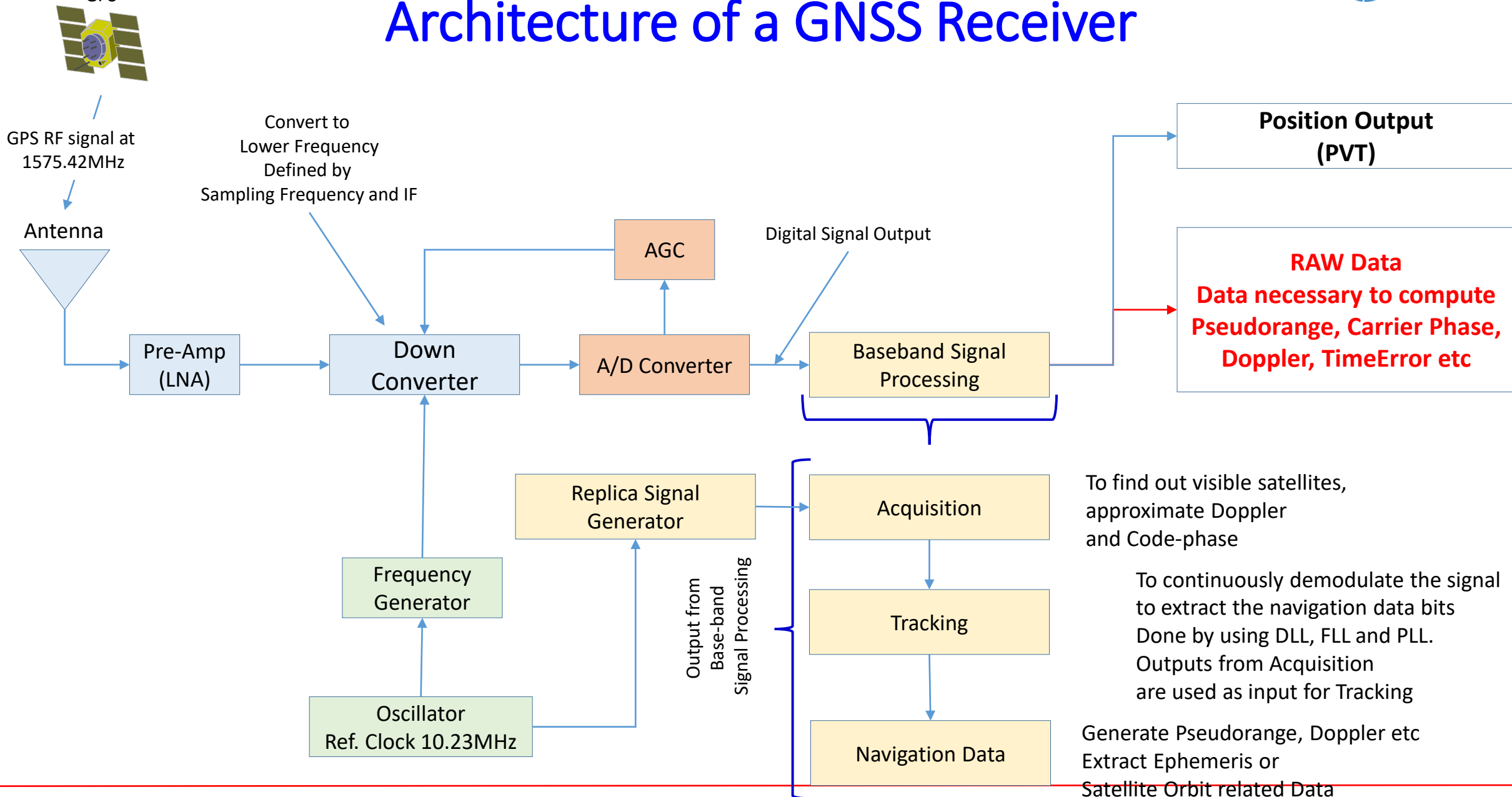
Background Information : GPS Signal Structure



Architecture of a GNSS Receiver



Architecture of a GNSS Receiver



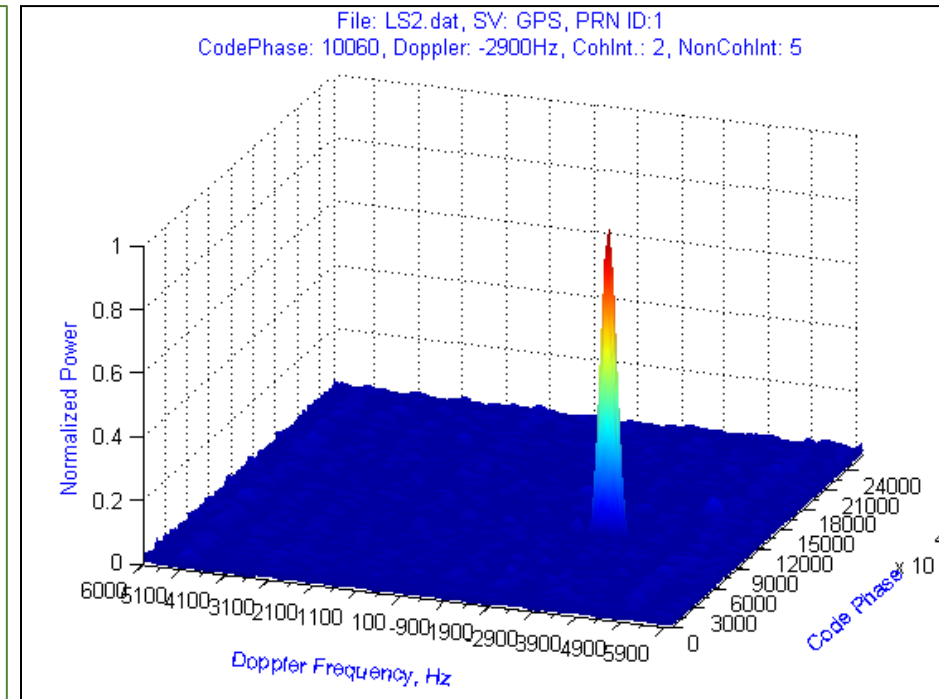
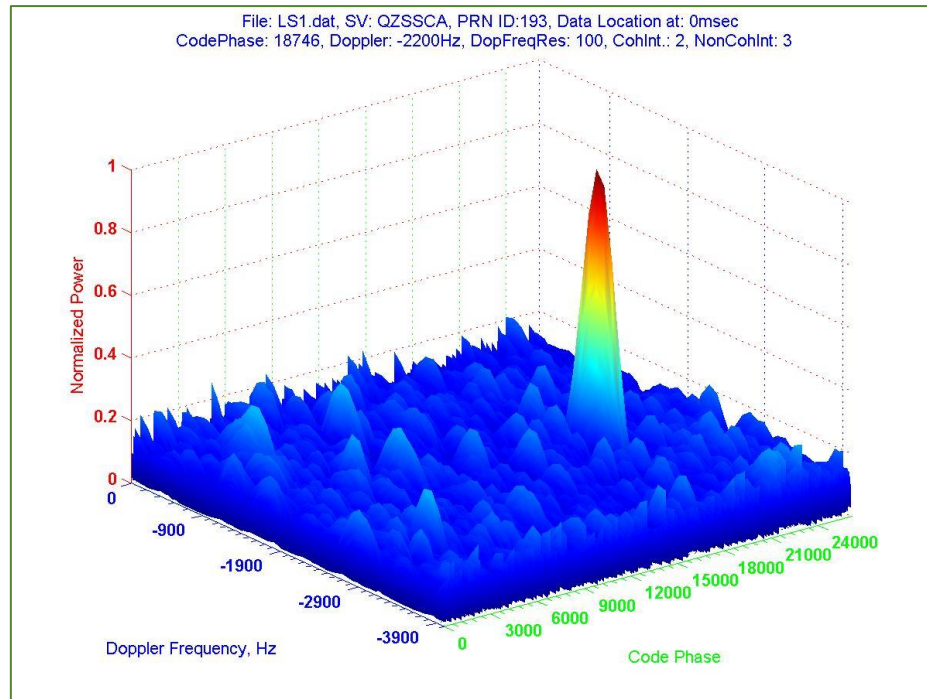
To find out visible satellites, approximate Doppler and Code-phase

To continuously demodulate the signal to extract the navigation data bits Done by using DLL, FLL and PLL. Outputs from Acquisition are used as input for Tracking

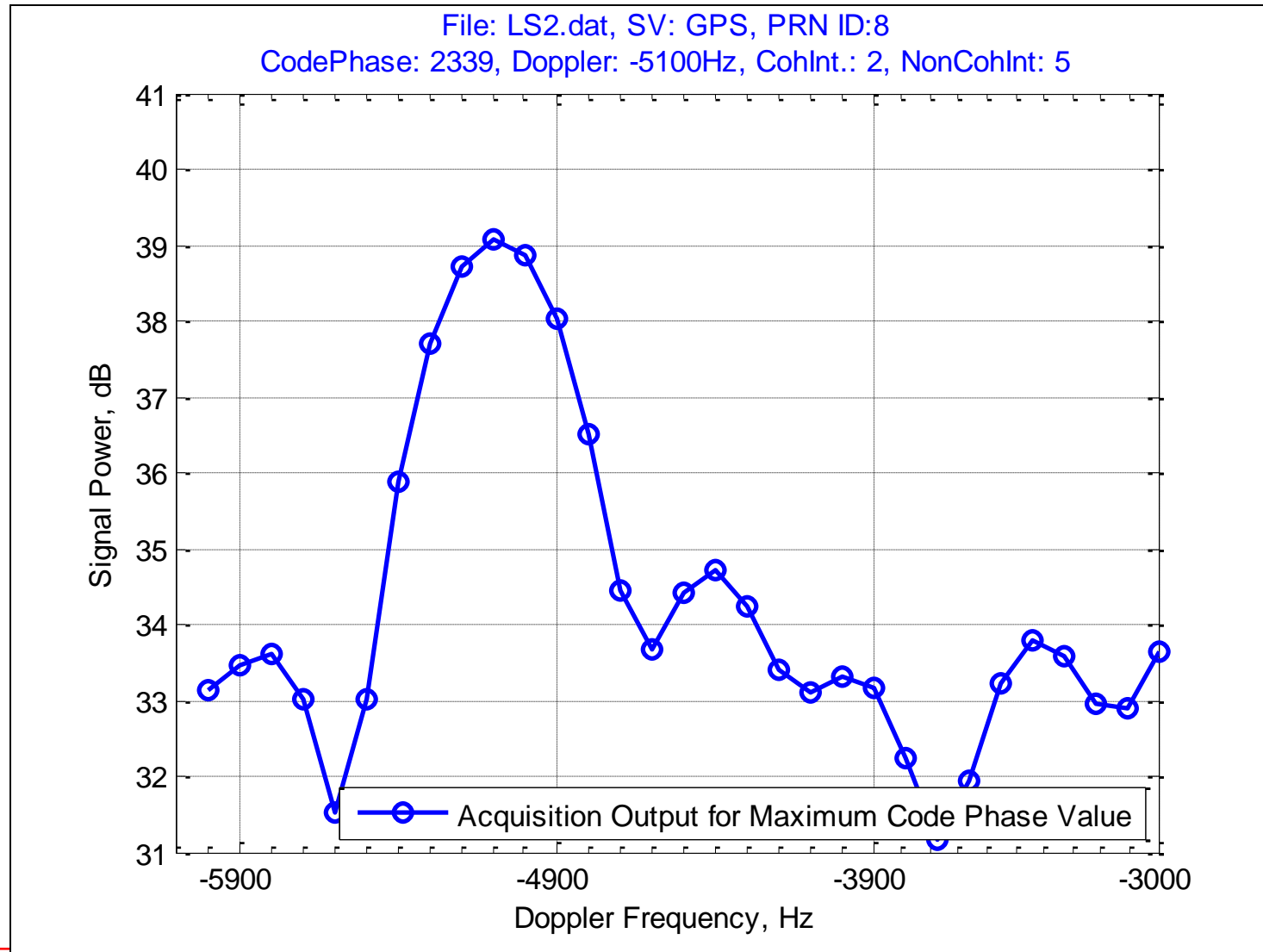
Generate Pseudorange, Doppler etc Extract Ephemeris or Satellite Orbit related Data

Extract Clock related data

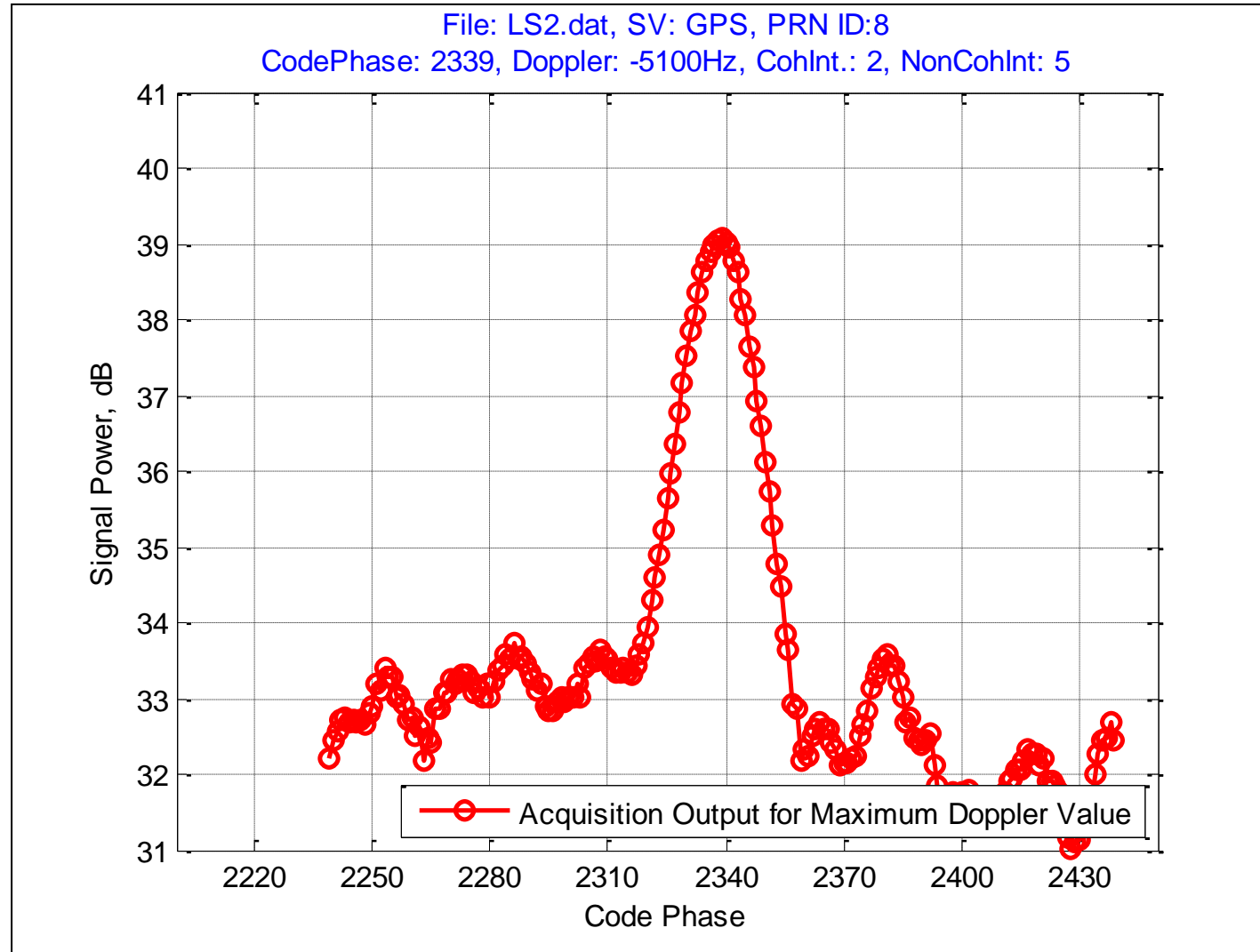
Acquisition of GPS L1C/A Signal



Acquisition Output shown for Doppler Frequency



Acquisition Output shown for Code Phase (PRN Code Chip Delay)

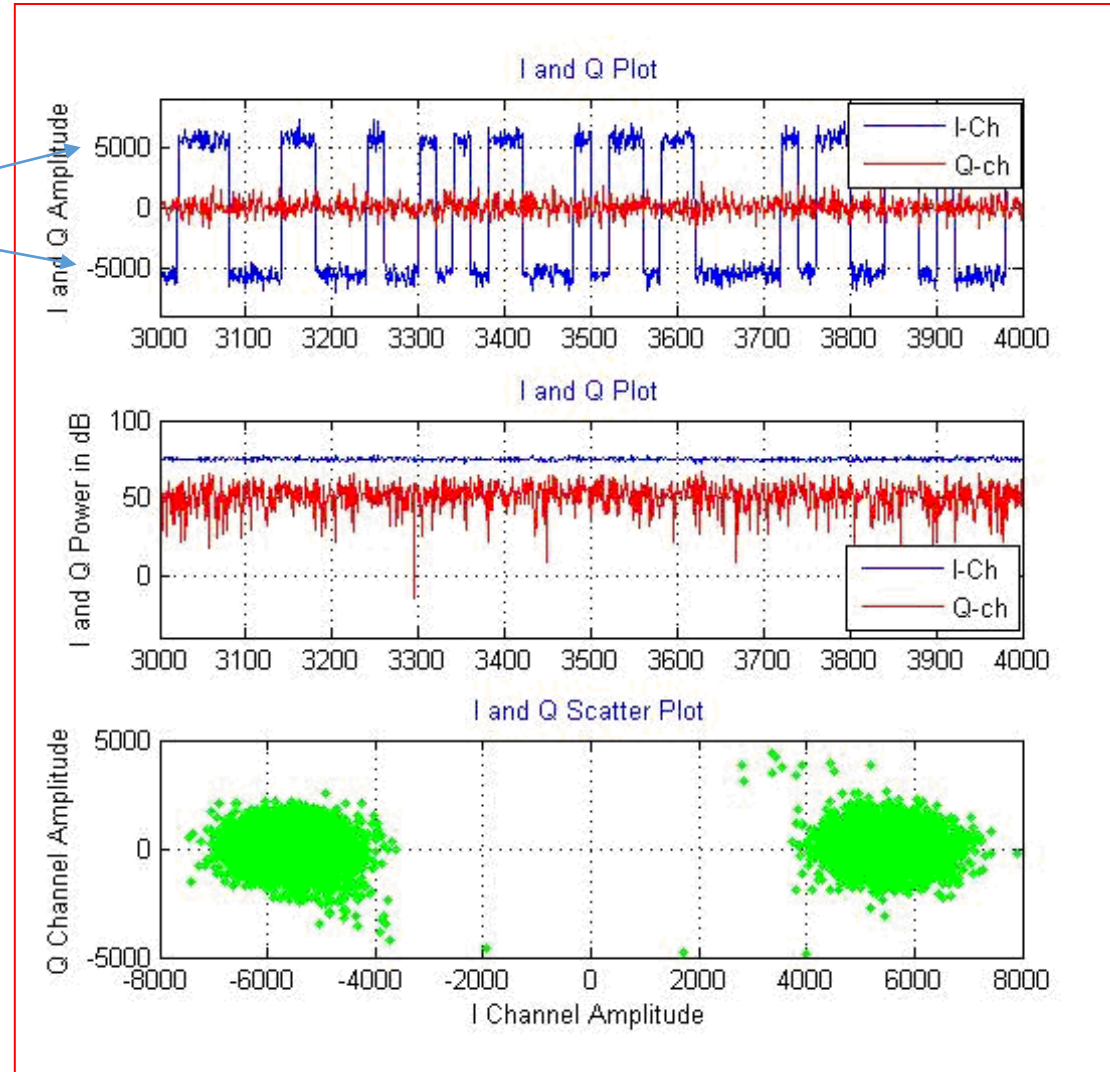


GPS Signal Tracking

- **Tracking Loops (PLL & DLL) are used to continuously lock the incoming signal and demodulate it by using the carrier frequency and code phase values detected in Acquisition.**
- **PLL**
 - Phase Lock Loop
 - To Track the Carrier Frequency
- **DLL**
 - Delay Lock Loop
 - To Track the Code Phase (PRN Code Delays)

GPS Signal Tracking Output

Navigation Data Bits
1's and 0's



SNR & C/No

- **SNR**
 - Signal to Noise Ratio, unit is dB
 - S: Signal Power in dBm or dBW
 - N: Noise power in a given bandwidth in dBm or dBW
- **C/No**
 - Carrier to Noise Density, unit is dB-Hz
 - C: Carrier power in dBm or dBW
 - No: Noise power density in dBm-Hz or dBW-Hz
- **SNR = C/No-BW (BW = bandwidth of the Front End)**
 - If BW = 4Mhz = $10 \cdot \log_{10}(4000000) = 66\text{dB}$
 - If C/No = 48dB-Hz
 - SNR = C/No-BW = 45-66 = -21dB
- **Noise Density (No) at Room Temperature (290K): -204dBW/Hz**
- **Received Power (GPS L1C/A Signal) at Antenna: -158.5dBW**
- **C/No = -158.5-(-204) = 45.5dB-Hz**

Module: C-II

Android GNSS Raw Data Processing

Purpose

- **Provide updates related with Android GNSS Raw Data**
 - **Results from Raw Data Processing**
 - Tokyo, Japan
 - Suva, Fiji
 - Melbourne, Australia
 - Florida, USA
 - **Sharing of Raw Data to practice**
- **Please refer MGA Webinar #8 for additional information**
 - <https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm>

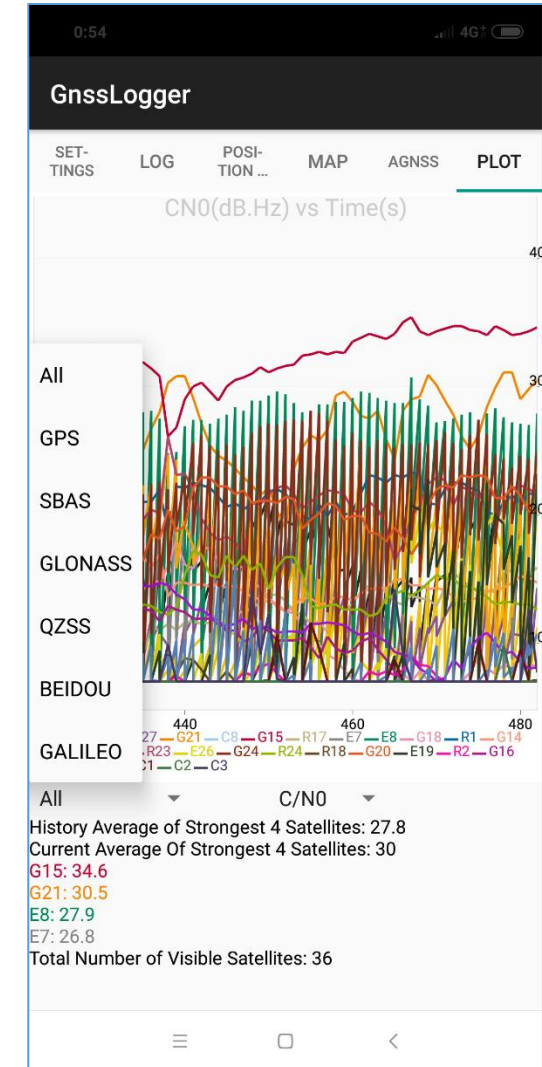
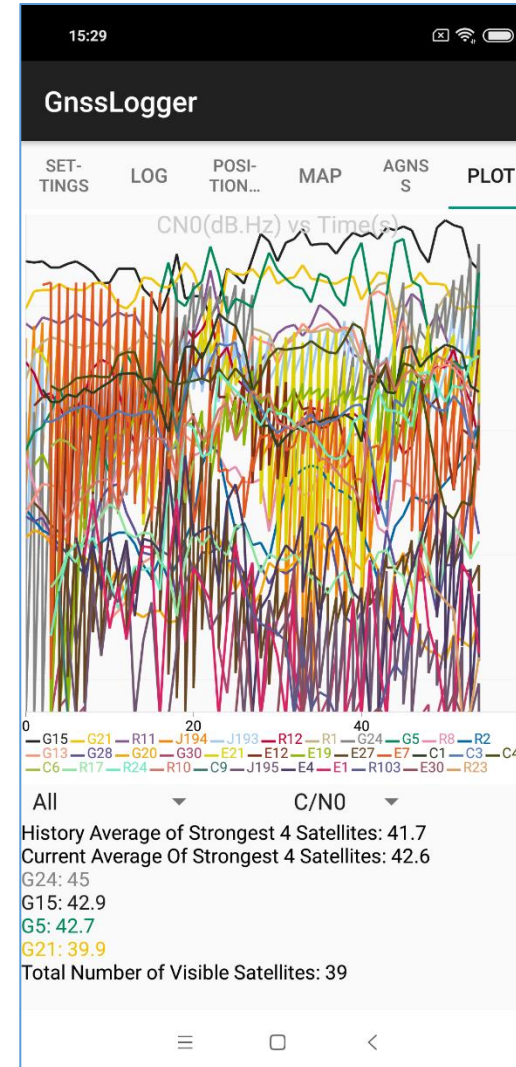
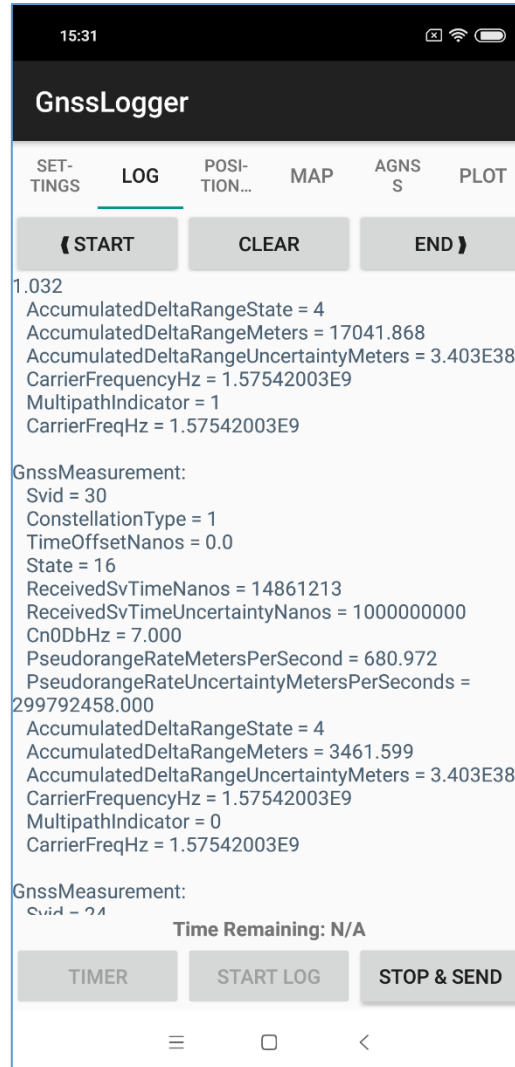
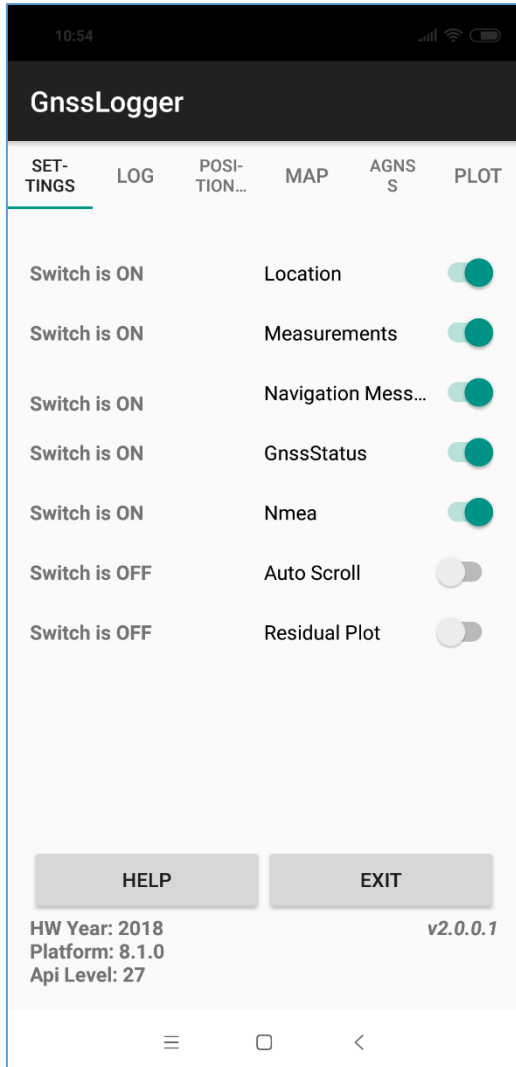
Android Device for GNSS Raw Data

- **Many Android devices with OS 7.0 or higher can output GNSS Raw Data**
 - These data can be used for RTK post-processing
- **Some devices have Multi-Frequency (L1/L5) GNSS receiver**
 - Multi-System (GPS, GLONASS, GALILEO, BEIDOU, QZSS)
 - Multi-Frequency (L1/E1/B1, L5/E5)
 - Outputs more than 40 channels
 - Some devices output NAV BIT Data and/or AGC values

GNSS Raw Data Compatible Smart-Phones

S. No.	Model	Android version	System Score Max: 6 (D)	Function Score Max: 5 (E)	Total Score (D + E)	Raw Data output used in System Score					Satellite Systems used in System Score					
						AGC	NAV MSG	Accumulated delta range	HW clock	L5 Support	GPS	GLO	GAL	BDS	QZSS	SBAS
4	Xiaomi Mi 8	8.1	5	4	9	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	no
31	Samsung S8	7	5	3	8	no	yes	yes	yes	no	yes	yes	yes	yes	yes	no
33	Huawei P10	7	5	3	8	no	yes	yes	yes	no	yes	yes	yes	yes	yes	no
42	Huawei Mate 20 X	9	4	4	8	no	yes	yes	yes	yes	yes	yes	yes	no	yes	no
19	Google Pixel 2 XL	8	5	2	7	yes	no	no	yes	no	yes	yes	yes	yes	yes	no
20	Google Pixel 2	8	5	2	7	yes	no	no	yes	no	yes	yes	yes	yes	yes	no
22	Samsung Note 8	7.1	4	3	7	no	yes	yes	yes	no	yes	yes	yes	yes	no	no
1	Pixel 3 XL	9	4	3	7	yes	no	yes	yes	no	yes	yes	yes	yes	no	no
2	Pixel 3	9	4	3	7	yes	no	yes	yes	no	yes	yes	yes	yes	no	no
43	Huawei Mate 20 RS	9	4	3	7	no	no	yes	yes	yes	yes	yes	yes	yes	no	no
44	Huawei Mate 20 Pro	9	4	3	7	no	no	yes	yes	yes	yes	yes	yes	yes	no	no
45	Huawei Mate 20	9	4	3	7	no	no	yes	yes	yes	yes	yes	yes	yes	no	no
10	Huawei P20	8.1	3	3	6	no	yes	yes	yes	no	yes	yes	no	no	yes	no
11	Samsung Galaxy S9	8	3	3	6	no	yes	yes	yes	no	yes	yes	no	no	yes	no
18	Huawei Mate 10 Pro	8	3	3	6	no	yes	yes	yes	no	yes	yes	no	no	yes	no

Android Raw Data Logging Tool – 1: GnssLogger



GNSS Raw Data Output Format from Smart Phone Device

- #
- # Header Description:
- # Version: v2.0.0.1 Platform: 9 Manufacturer: Xiaomi Model: MI 8
- # Raw,
 - ElapsedRealtimeMillis,TimeNanos,LeapSecond,TimeUncertaintyNanos,FullBiasNanos,
 - BiasNanos,BiasUncertaintyNanos,DriftNanosPerSecond,DriftUncertaintyNanosPerSecond,
 - HardwareClockDiscontinuityCount,Svid,TimeOffsetNanos,State,ReceivedSvTimeNanos,
 - ReceivedSvTimeUncertaintyNanos,Cn0DbHz,PseudorangeRateMetersPerSecond,
 - PseudorangeRateUncertaintyMetersPerSecond,AccumulatedDeltaRangeState,
 - AccumulatedDeltaRangeMeters,AccumulatedDeltaRangeUncertaintyMeters,CarrierFrequencyHz,
 - CarrierCycles,CarrierPhase,CarrierPhaseUncertainty,MultipathIndicator,
 - SnrInDb,ConstellationType,AgcDb,CarrierFrequencyHz
- # Fix,
 - Provider,Latitude,Longitude,Altitude,Speed,Accuracy,(UTC)TimeInMs
- # Nav,
 - Svid,Type,Status,MessageId,Sub-messageId,Data(Bytes)

Sample GNSS Raw Data Output

```

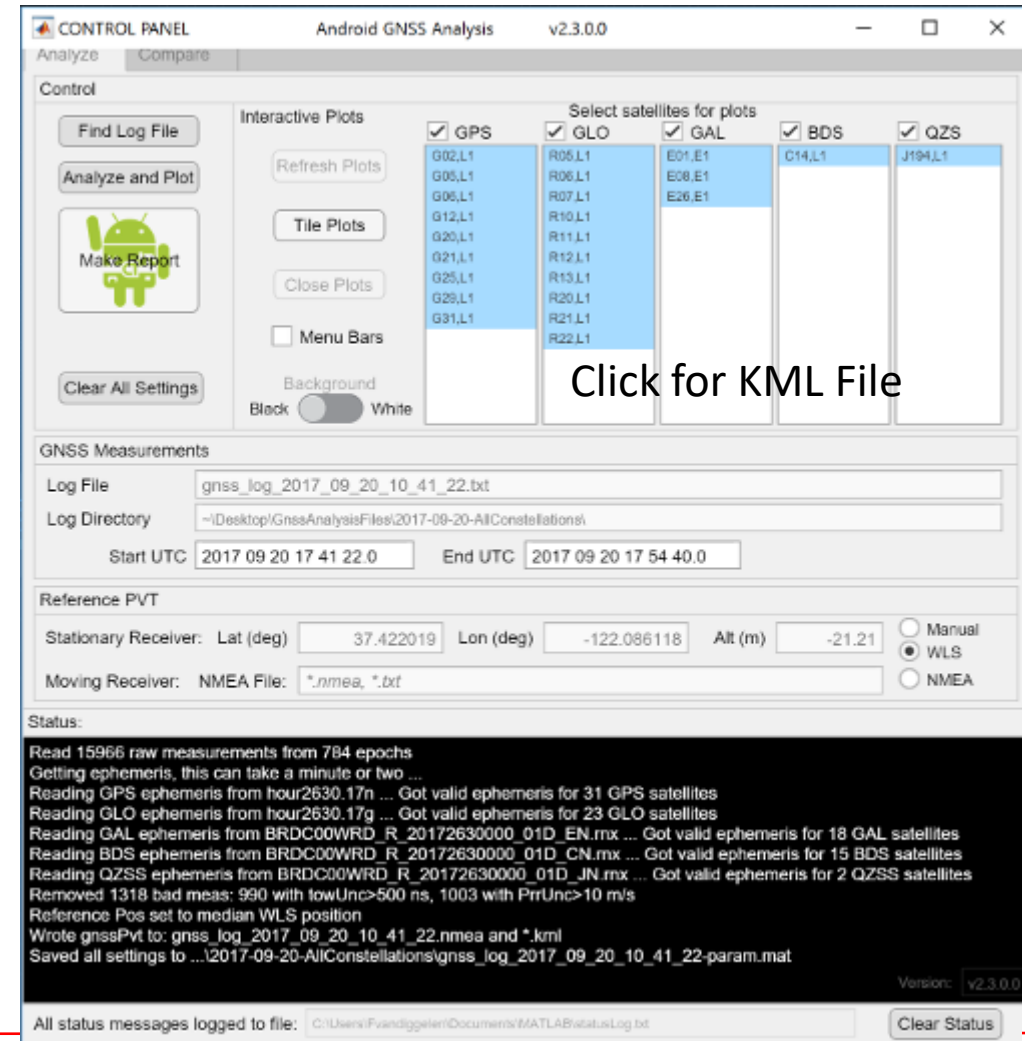
13 # Nav,Svid,Type,Status,MessageId,Sub-messageId,Data (Bytes)
14
15 Nav,96,769,1,-1,13,110,121,9,58,-100,116,-65,-32,-96,100,32
16
17 Raw,86394315,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,1,0.0,16431,303193919524422,20,33.86
18 Raw,86394315,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,3,0.0,16431,303193916939667,33,27.52
19 Raw,86394315,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,10,0.0,16431,303193928480980,27,29.8
20 Raw,86394315,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,11,0.0,16392,303193914305357,1000000
21 Raw,86394315,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,12,0.0,16431,303193918153504,44,23.9
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25 Raw,86394316,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,22,0.0,16431,303193921837227,16,36.6
26 Raw,86394316,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,25,0.0,16431,303193926177270,14,38.1
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32 Raw,86394317,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,25,0.0,16393,303193926177261,8,33.51
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49 Raw,86394319,73386000000,,,-1238933520614358644,0.0,6.103678716954078,,0,26,0.0,19498,303193910514372,39,25.8

```

GNSS Raw Data Analysis Tool for GnssLogger

• GNSS Analysis APP

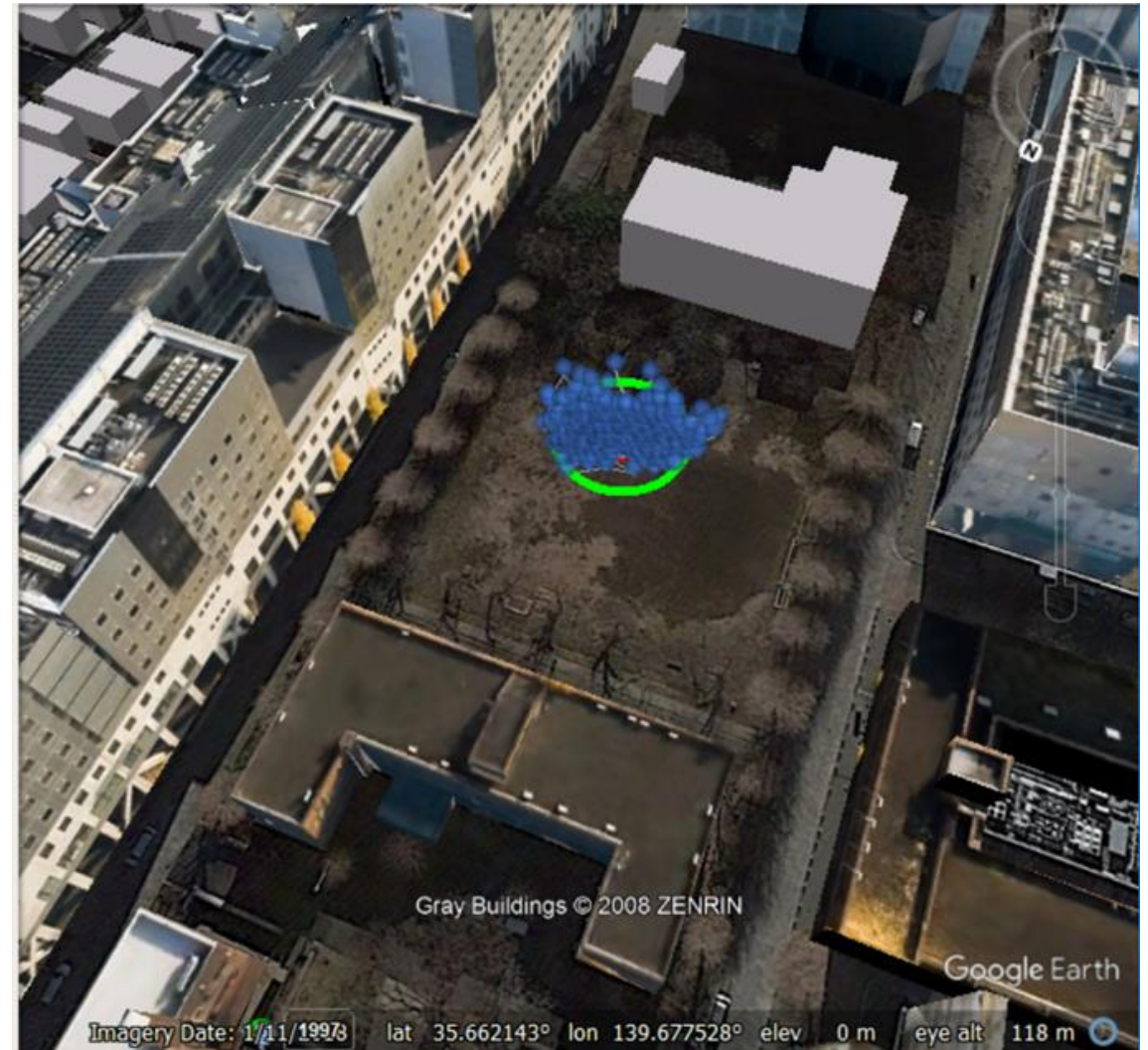
- Matlab-based Tool
- Linux, Windows, MacOS
- Version 2.6.3.0
- [Release Notes:](https://developer.android.com/guide/topics/sensors/gnss#releaseGNSS%20Analysis%20app%20v2.6.3.0)
<https://developer.android.com/guide/topics/sensors/gnss#releaseGNSS Analysis app v2.6.3.0> release notes.



The GNSS Analysis app is built on [MATLAB](#), but you don't need to have MATLAB to run it. The app is compiled into an executable that installs a copy of the MATLAB Runtime.

Position Output from Android GNSS Receiver, Komaba

- **Standard Position Computation**
 - No DGPS or RTK Corrections
 - All visible GNSS Satellites are used
 - Frequency : L1/L5/E5
 - Surrounding : Tall Buildings around



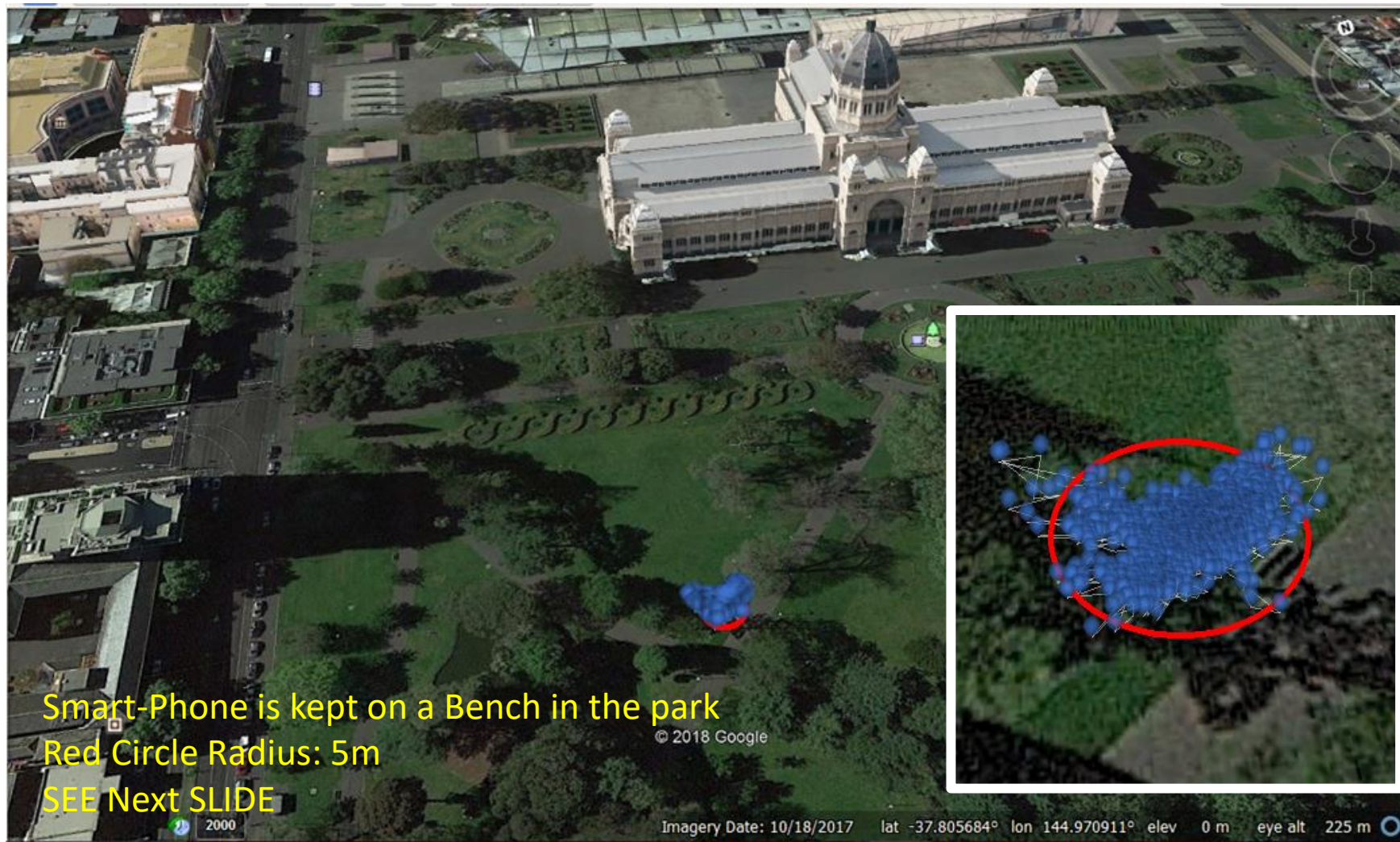
Position Output from Android GNSS Receiver, Hongo



Position Output from Android GNSS Receiver



Position Output from Android GNSS Receiver, Melbourne



Smart-Phone is kept on a Bench in the park
Red Circle Radius: 5m
SEE Next SLIDE



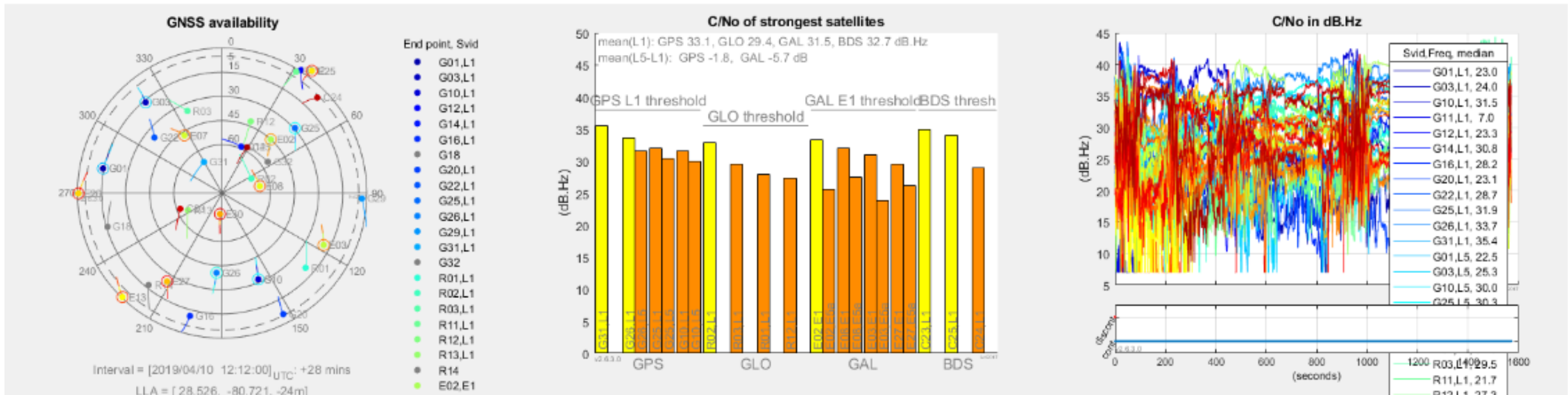
Smart-Phone is kept on a Bench in the park
Red Circle Radius: 5m

© 2018 Google
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Google Earth

Imagery Date: 8/2014 lat -37.806114° lon 144.970363° elev 0 m eye alt 3 m

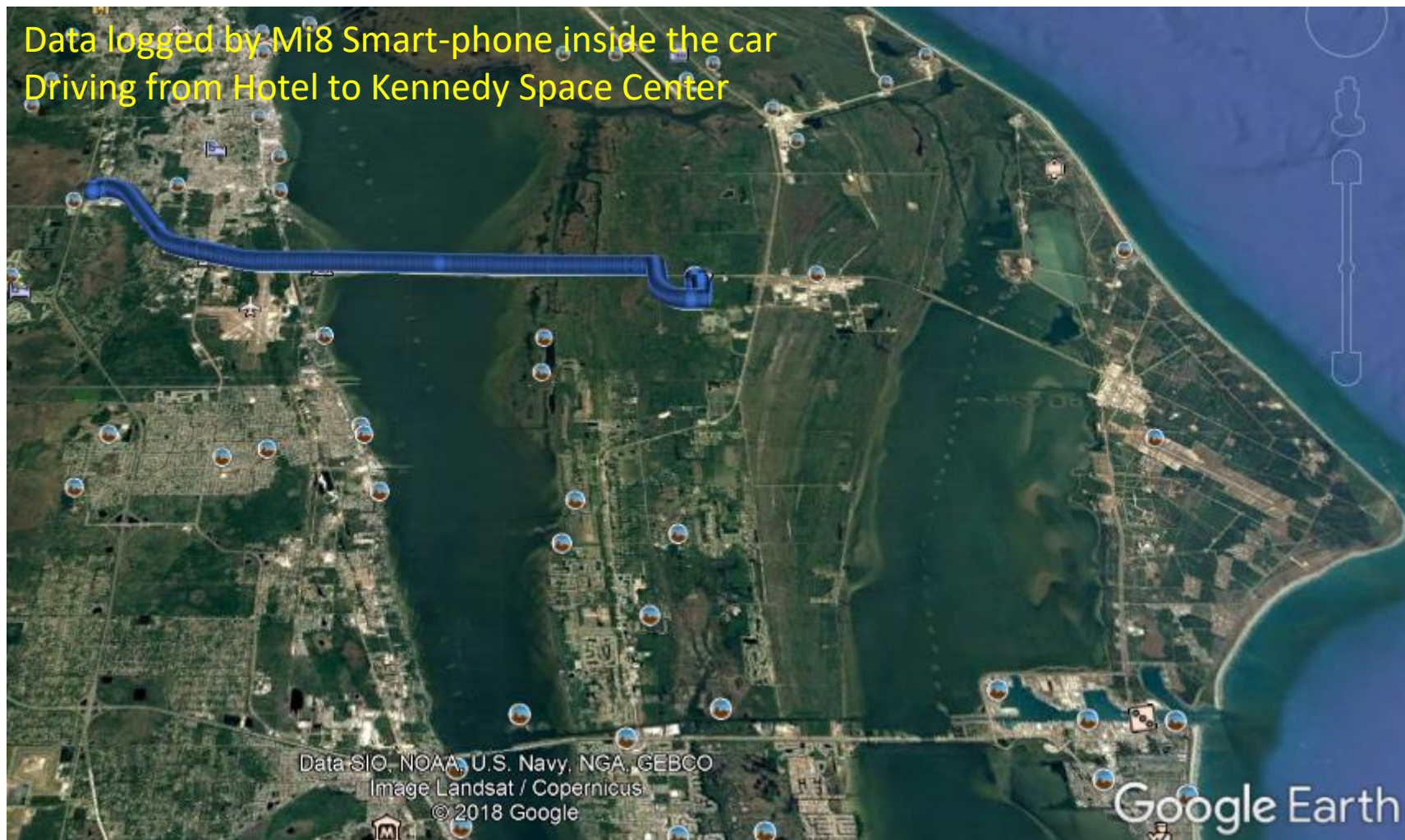
Output from GNSS Analysis Tool, Data Logged by GNSSLogger



Data logged by Mi8 Smart-phone inside the car

Output from GNSS Analysis Tool, Data Logged by GNSSLogger

Location:
Kennedy Space Center
Florida



Output from GNSS Analysis Tool, Data Logged by GNSSLogger



GNSS Position Data from Mi8 Android Device

Yellow Circles : Mi8 Device
White Circle : 5m Radius



Location: SUVA, FIJI

GNSS Position Data from P20 Android Device

Red Circles : P20 Device
White Circle : 5m Radius



Location: SUVA, FIJI

GNSS Position Data from Mi8 & P20 Android Devices

Red Circles : P20 Device
Yellow Circles : Mi8 Device
White Circle : 5m Radius

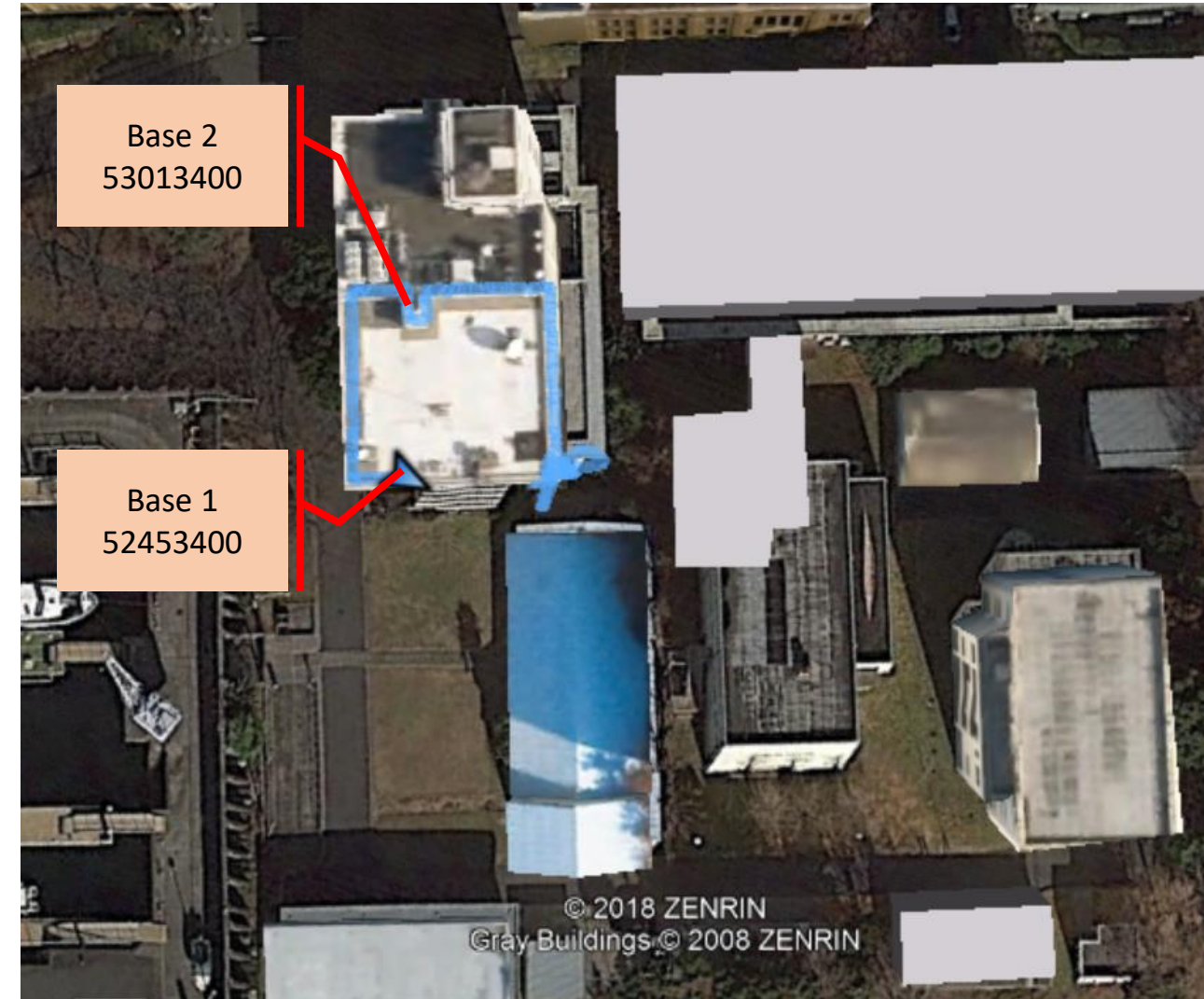


Location: SUVA, FIJI

Position Output from Android GNSS Receiver 海洋大学 (TUMSAT)

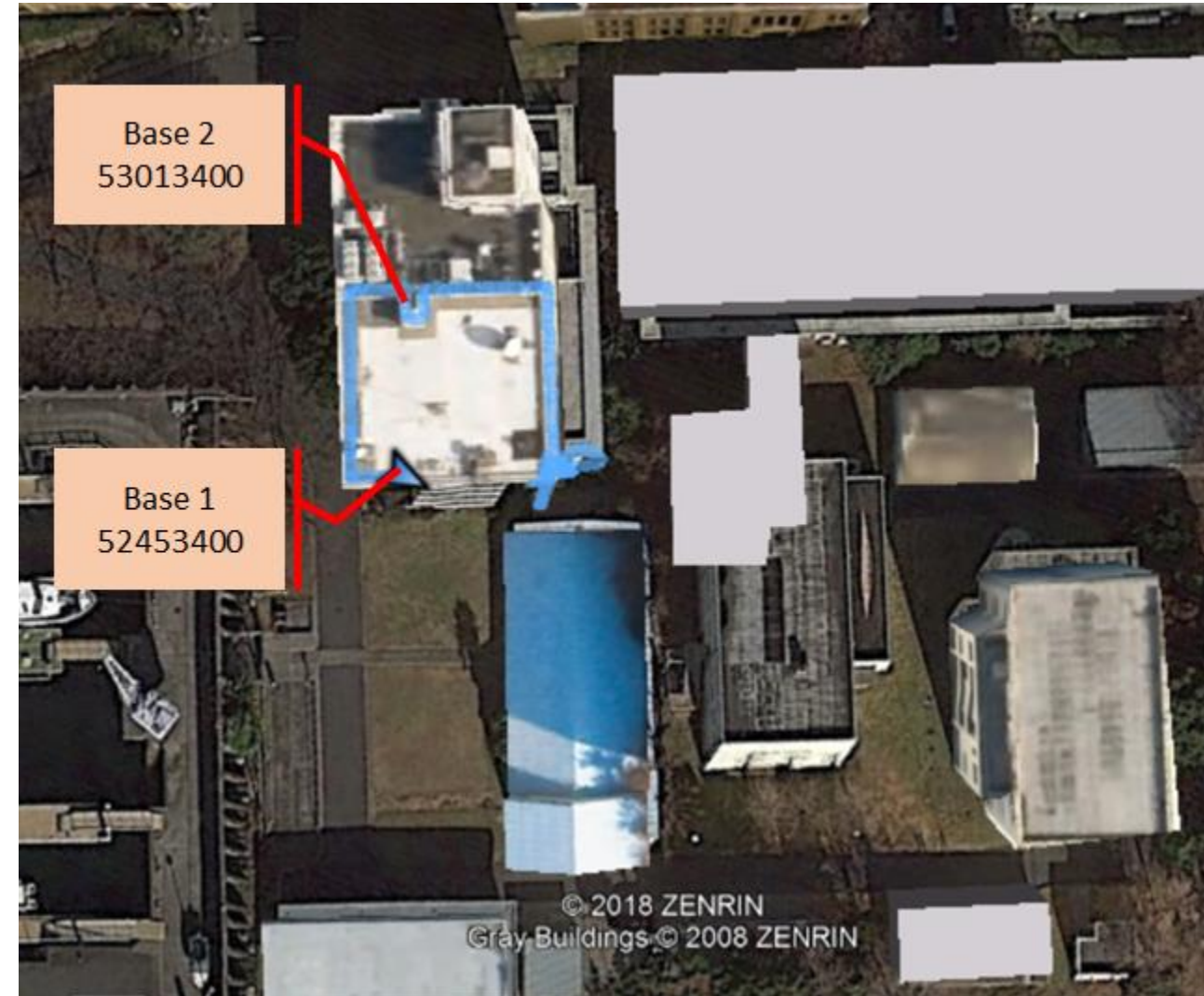
- Mobile-phone is kept static for about 60min then moved around the roof.
- A GNSS base-station (Trimble NetR9) on the roof is used to collect correction data.

These data were logged at TUMST, Dr. Yize

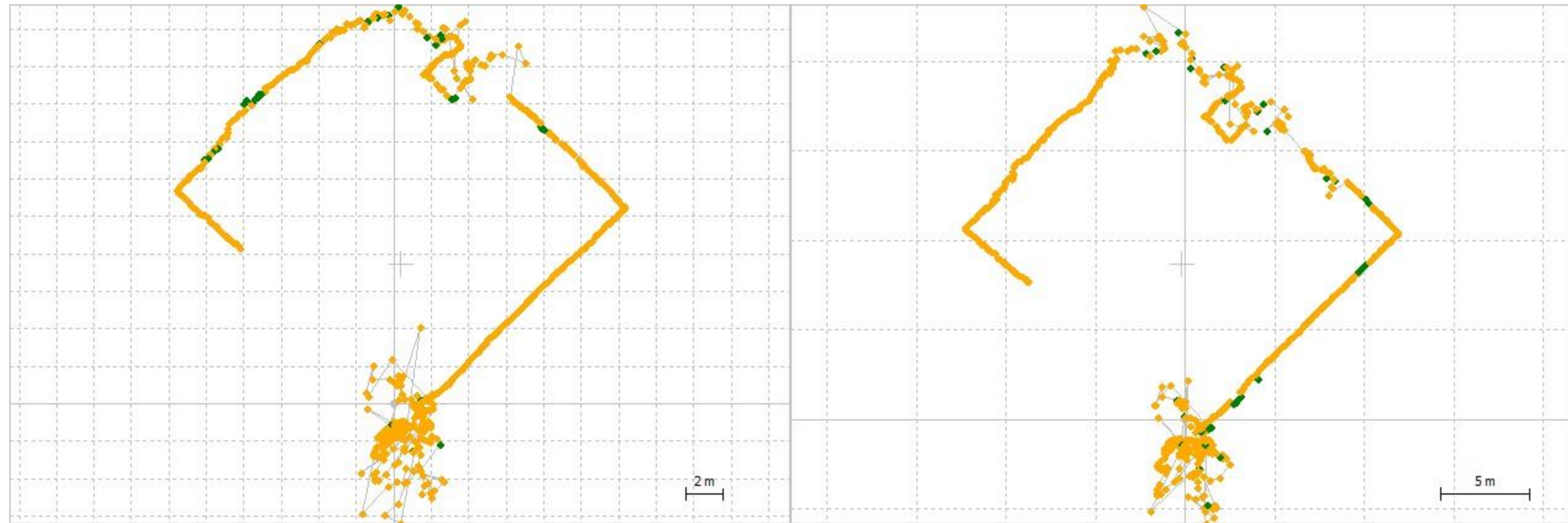


Android GNSS Raw Data Information

1	Base-Station File 1	53013400.18o	Trimble NetR9
2	Base-Station File 2	52453400.18o	Trimble NetR9
3	Android GNSS Data	GEOP3400	Device Mi8 Logger: Geop++
4	RINEX NAV File	brdm3400.18p	

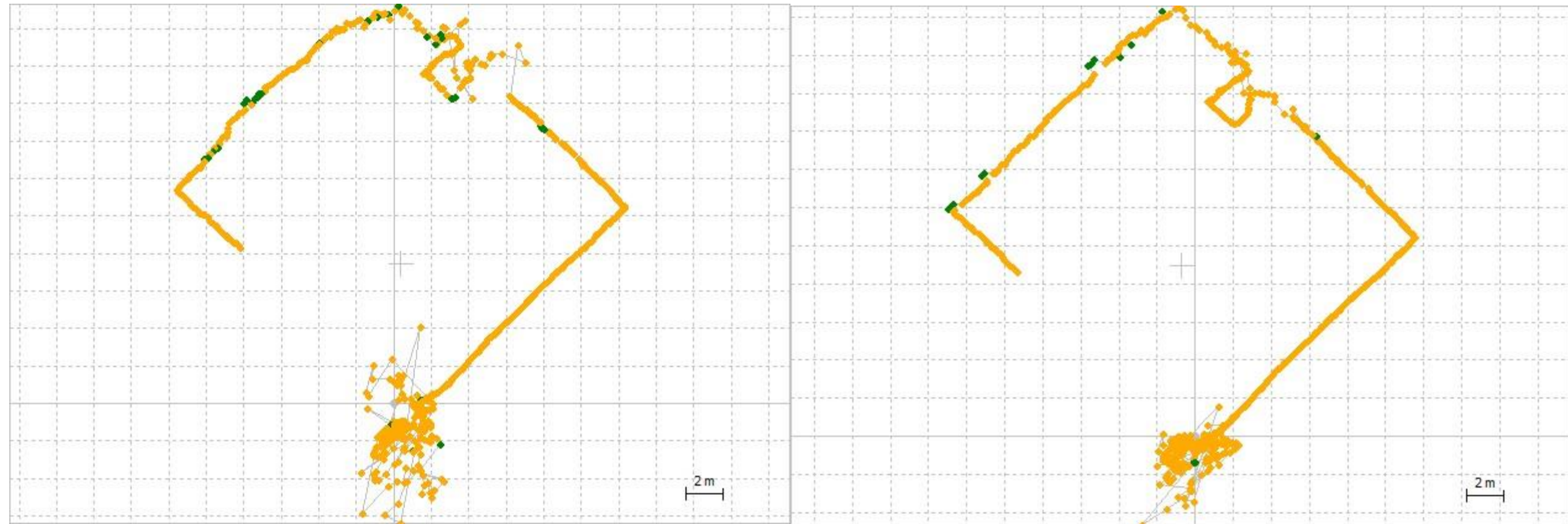


GPS L1 vs GPS L1/L5



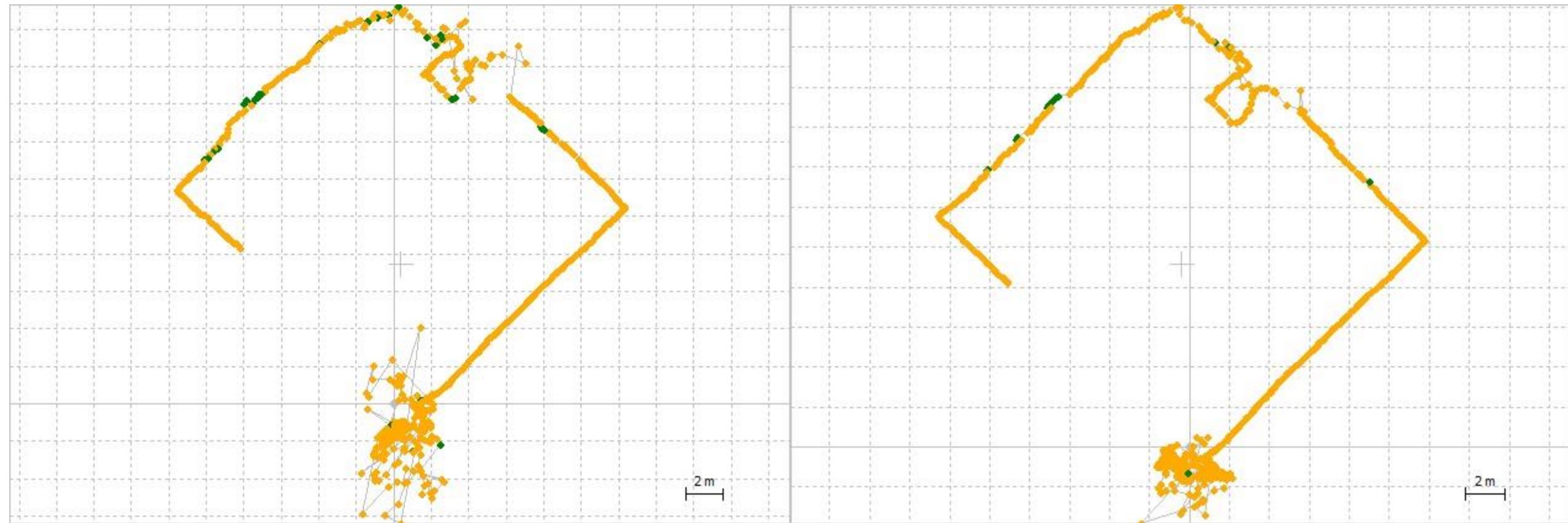
Data logged by Mi8 Smart-phone

GPS L1 vs GPS + QZS L1



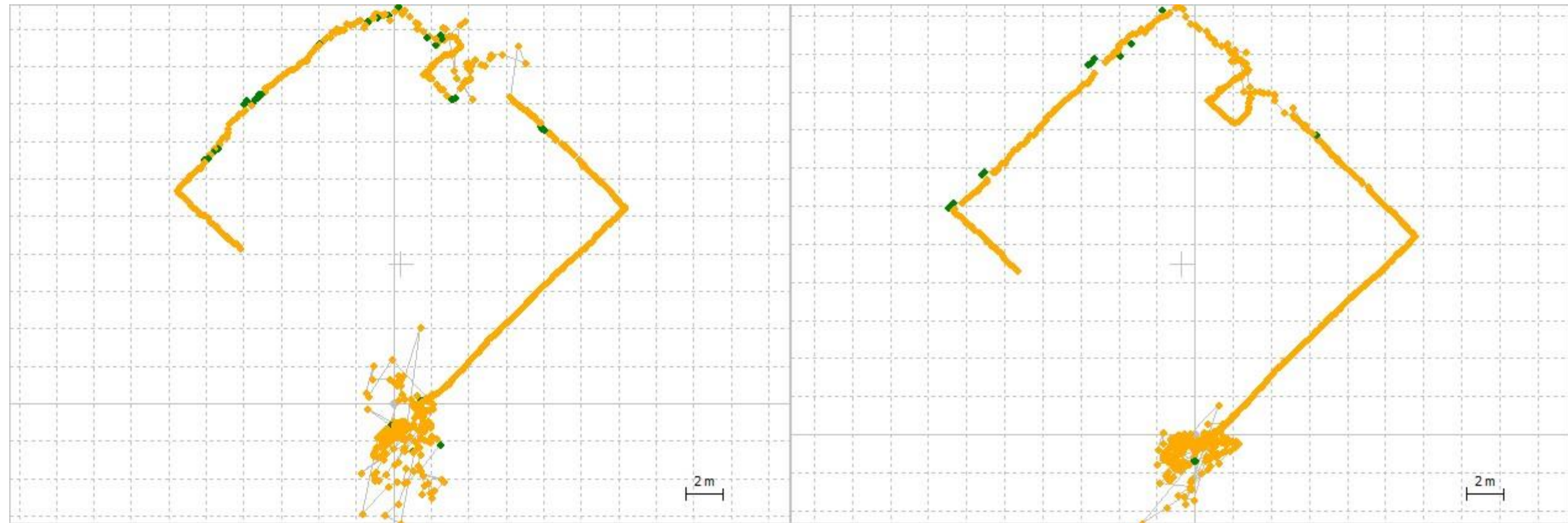
Data logged by Mi8 Smart-phone

GPS L1 vs GPS + QZS L1/L5



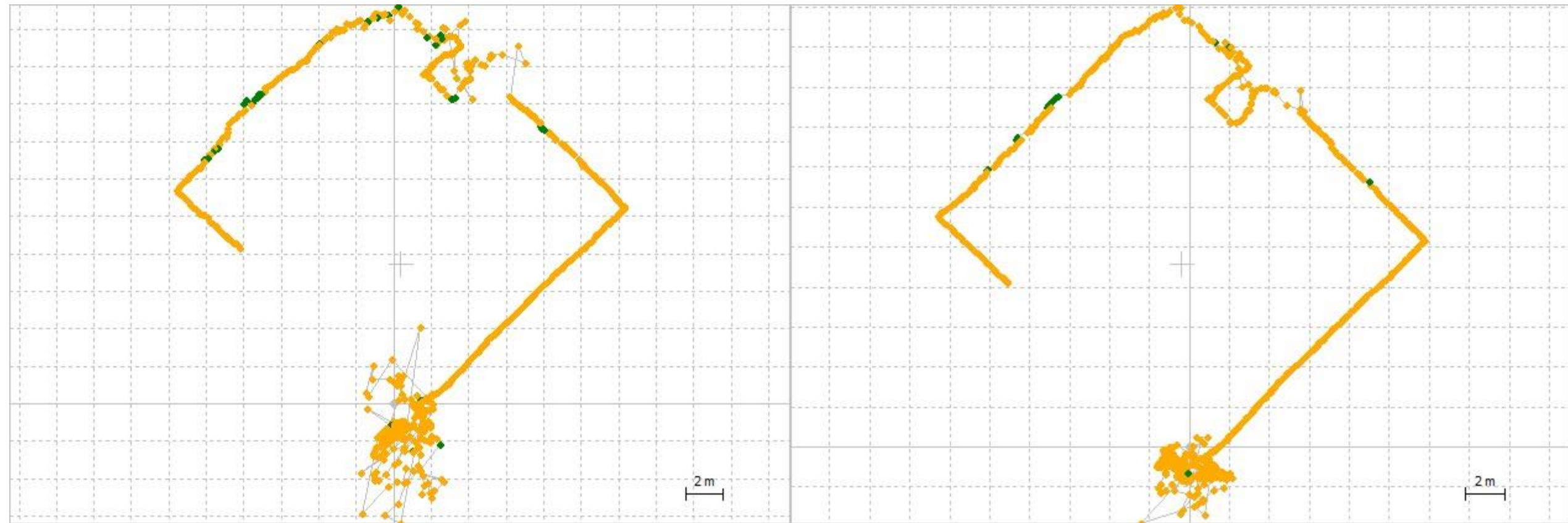
Data logged by Mi8 Smart-phone

GPS L1 vs GPS + QZS + BDS L1



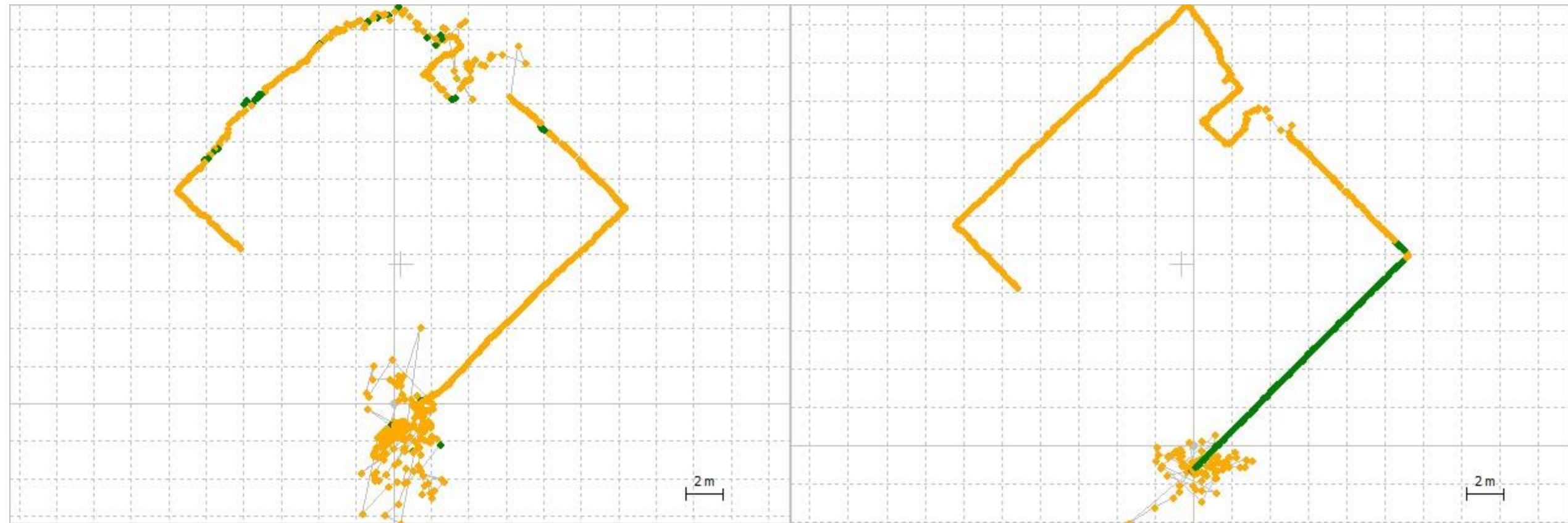
Data logged by Mi8 Smart-phone

GPS L1 vs GPS + BDS + QZS L1/L5



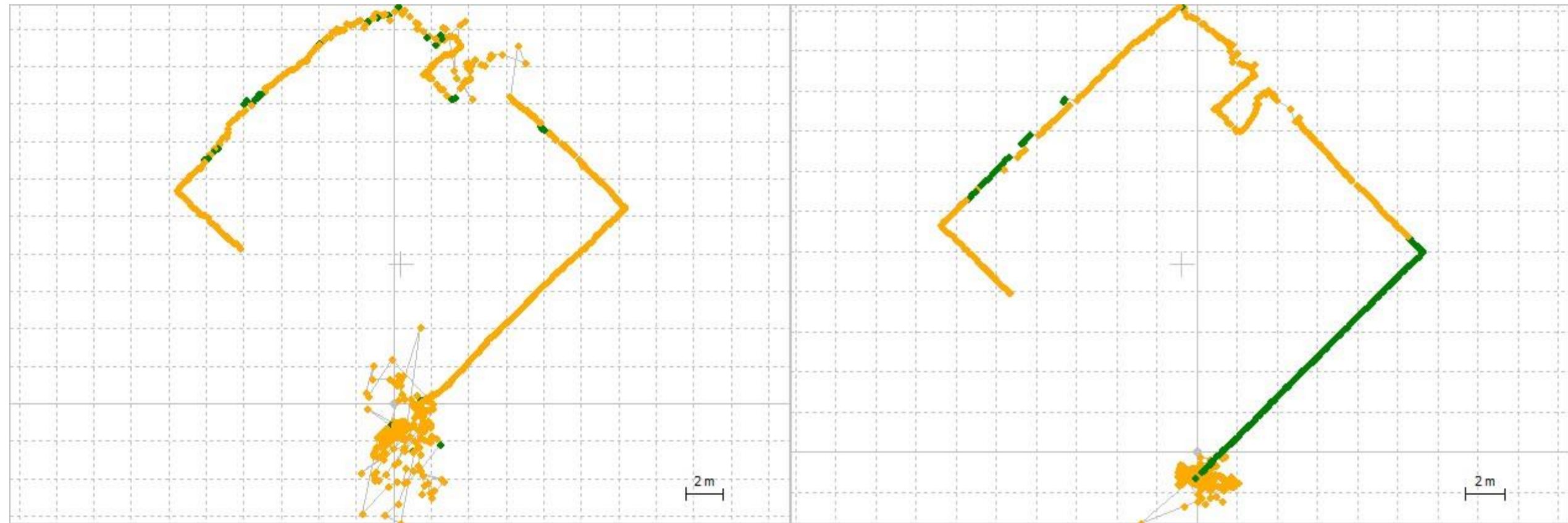
Data logged by Mi8 Smart-phone

GPS L1 vs GPS + GAL+ BDS + QZS L1

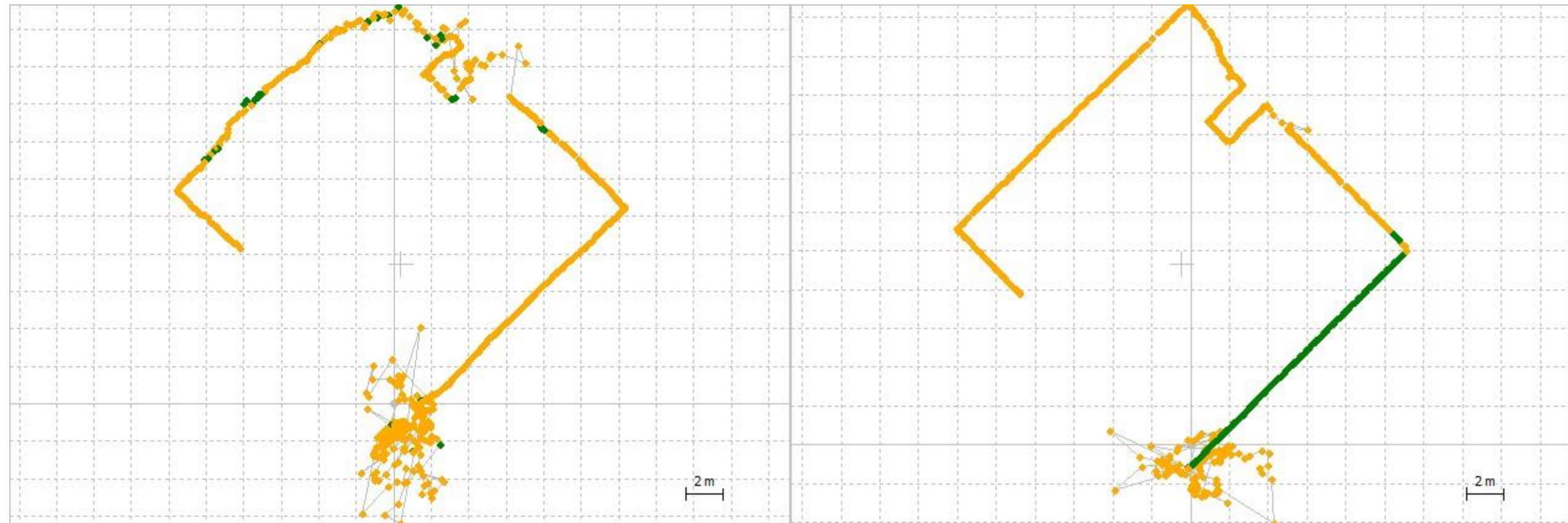


Data logged by Mi8 Smart-phone

GPS L1 vs GPS + GAL+ BDS + QZS L1/L2/L5

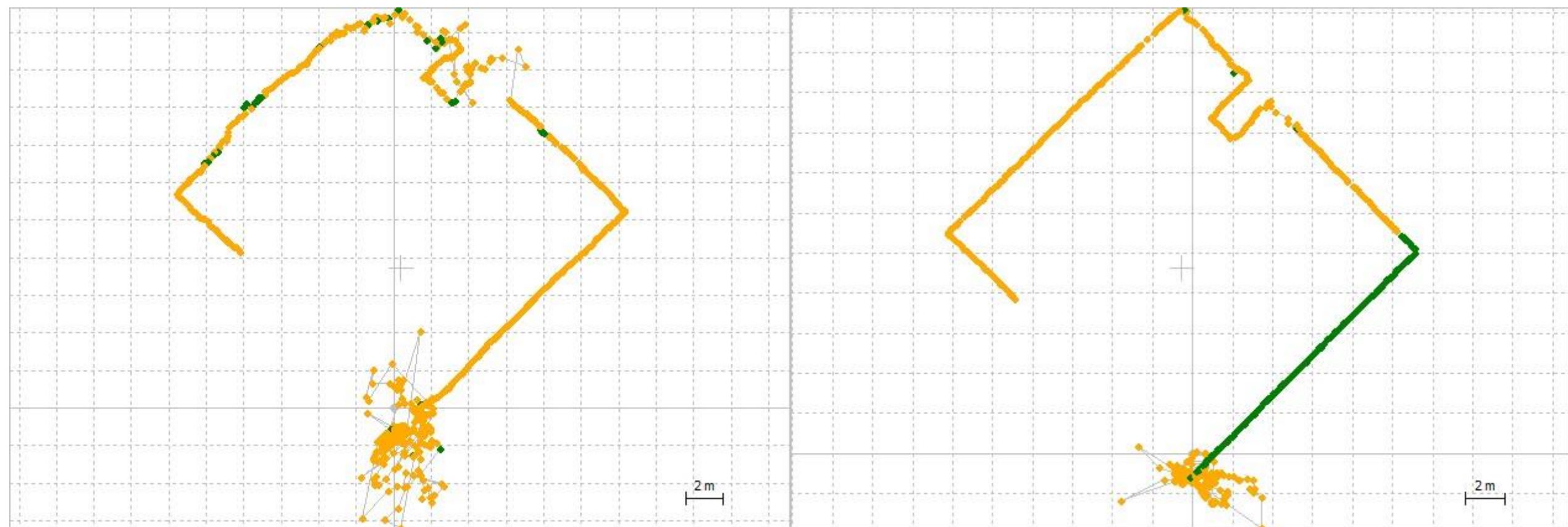


GPS L1 vs GPS + GLO + GAL+ BDS + QZS L1



Data logged by Mi8 Smart-phone

GPS L1 vs GPS + GAL+ BDS + QZS L1/L5

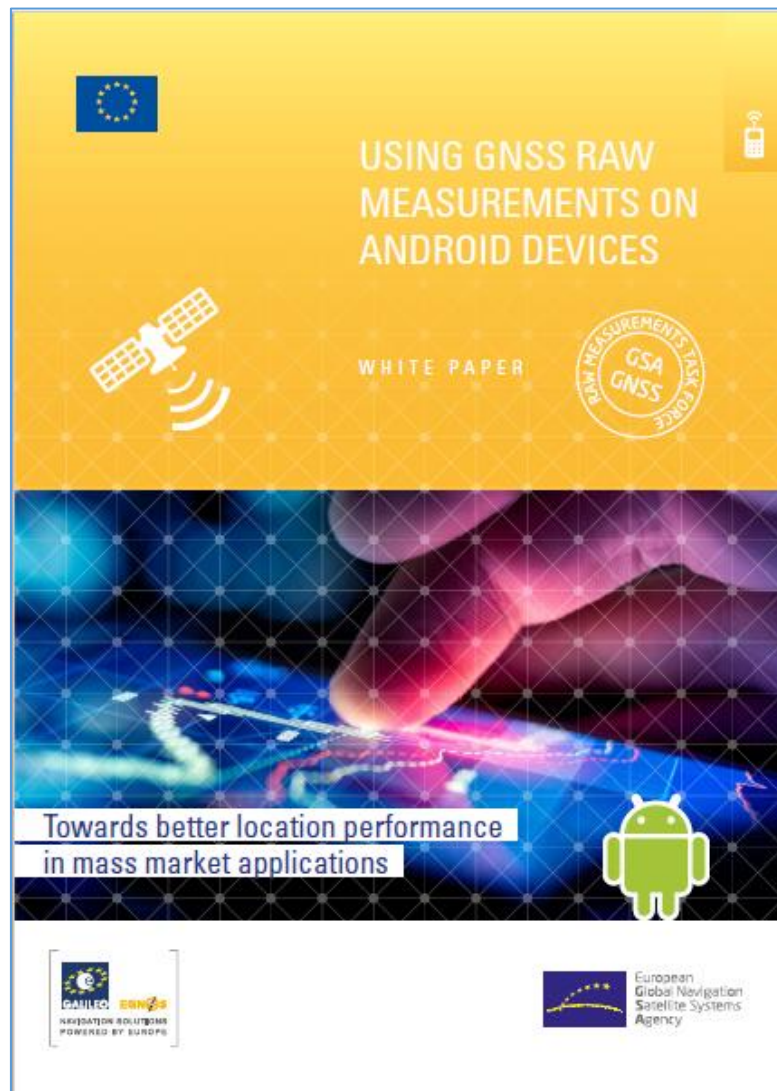


Data logged by Mi8 Smart-phone

(Possible) Applications of Android GNSS Raw Data

- **High-Accuracy Positioning**
 - Multi-System, Multi-Frequency
- **Interference and Jamming Detection**
 - Crowd Sourcing
- **Spoofing Detection**
- **Signal Authentication**
- **Atmospheric Parameter Estimations**
 - Ionosphere and Troposphere
- **Space Weather**
- **Scientific Applications**

White Paper on GNSS Raw Data Measurement



USING GNSS RAW MEASUREMENTS ON ANDROID DEVICES 3

TABLE OF CONTENTS

TABLE OF CONTENTS	3
EXECUTIVE SUMMARY	5
DOCUMENT STRUCTURE	6
1 GNSS BASICS NEEDED FOR UNDERSTANDING RAW MEASUREMENTS	7
1.1 Introduction	7
1.2 Global Navigation Satellite System	7
1.3 GNSS Receiver Architecture	8
1.4 Time	8
1.4.1 Introduction	8
1.4.2 Reference times	9
1.5 Navigation Message and Tracking Status	10
1.6 Pseudorange Generation	13
1.7 Position Estimation	14
1.7.1 Single-GNSS constellation	14
1.7.2 Multi-GNSS constellation	15
2 HOW TO ACCESS GNSS RAW MEASUREMENTS USING ANDROID APIS	16
2.1 Introduction	16
2.2 Location API Before Android 7 - <i>android.gsm.Location</i>	16
2.3 Location API in Android 7	17
2.4 Using GNSS Raw Measurements	18
2.4.1 GPS time generation	20
2.4.2 Pseudorange generation	20
2.4.3 Carrier phase measurements	22
2.4.4 Doppler	23
2.4.5 Satellite ID	24
2.4.6 Constellation	24
2.5 Raw Data Architecture	24
2.6 Existing Applications and Devices	26
3 OPPORTUNITIES AND PRACTICAL USE OF GNSS RAW MEASUREMENTS	27
3.1 Mobile A-GNSS Chipsets Overview	28
3.2 Baseline Performance - Code Positioning	29
3.3 Improving Position	30
3.3.1 Multiple constellations	30
3.3.2 Using information inside chipsets - Doppler smoothing of the code observables	31
3.4 Taking It Beyond The Phone - Differential Observations	33
3.4.1 Duty cycle	34
3.4.2 Sensor fusion	37
3.5 Educational and Scientific Applications	37
3.6 High Integrity Solutions	38

USING GNSS RAW MEASUREMENTS ON ANDROID DEVICES 4

4 THE NEED AND USE CASES FOR HIGHER ACCURACY IN THE MASS MARKET	39
4.1 Main Application Areas to Benefit from Improved Location Accuracy	39
4.1.1 Mobile applications	40
4.1.2 Safety-related applications	40
4.1.3 Semi-professional applications	41
LIST OF FIGURES	42
LIST OF TABLES	43
ACRONYMS	44
REFERENCE DOCUMENTS	45

<http://galileognss.eu/wp-content/uploads/2018/05/Using-GNSS-Raw-Measurements-on-Android-devices.pdf>

GNSS Raw Measurements Taskforce Workshop

GNSS Raw Measurements Taskforce Workshop was held on
26th June 2019, Prague, *GSA European Agency* Headquarters

Refer <https://www.gsa.europa.eu/gnss-raw-measurements-taskforce-workshop> for more information

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 - https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Raw_files/GNSS%20102%20Measurements%20from%20Phones%20Short%20Course%20Slides.pdf
- **GPS Receiver Signal Processing background information file:**
 - https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR_files/MGA_W08_RawDataMeasurement_Background.pdf
- **Video record of GNSS Raw Signal Measurement MGA WEBINAR held on 6th DEC 2018.**
 - https://www.youtube.com/watch?v=S217xg--O_Q&feature=youtu.be
- **Sample Data**
 - **Sample GNSS Raw Data from Android Device**
 - <https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm>

Additional Information

- **Main Page**

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- **Webinar Page**

- <http://www.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm>
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- **GNSS Training Courses**

- http://www.csis.u-tokyo.ac.jp/~dinesh/T141_30.htm

- **MGA 2018 GNSS Conference**

- <http://www.csis.u-tokyo.ac.jp/~dinesh/mga2018.htm>

- **Contact : dinesh@iis.u-tokyo.ac.jp**

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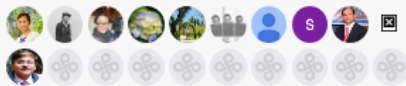
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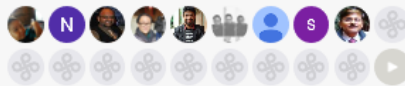
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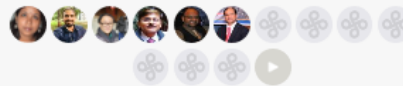
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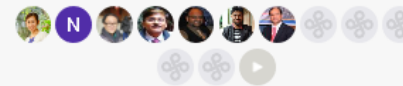
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