LOW-COST GNSS RECEIVER SYSTEM FOR HIGH-PRECISION GNSS DATA PROCESSING

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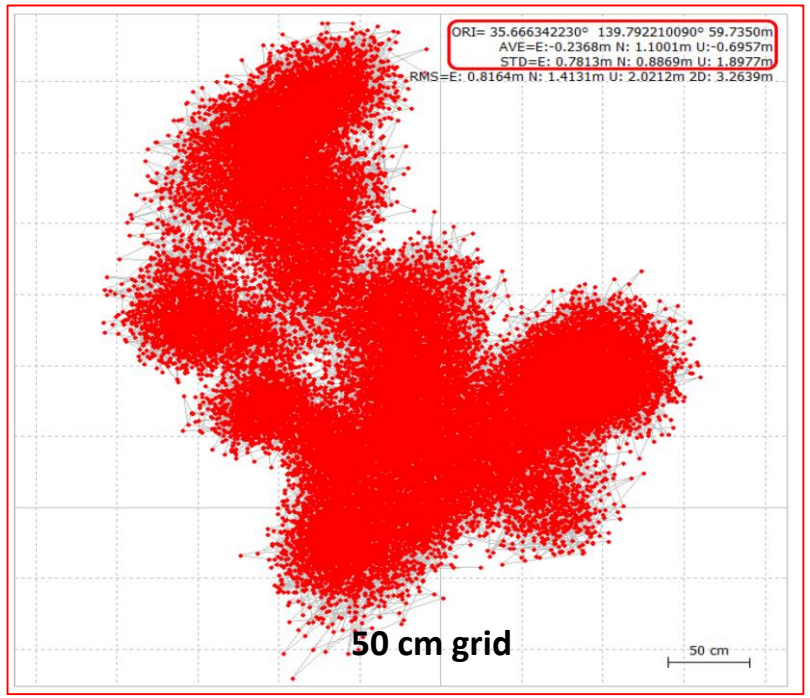
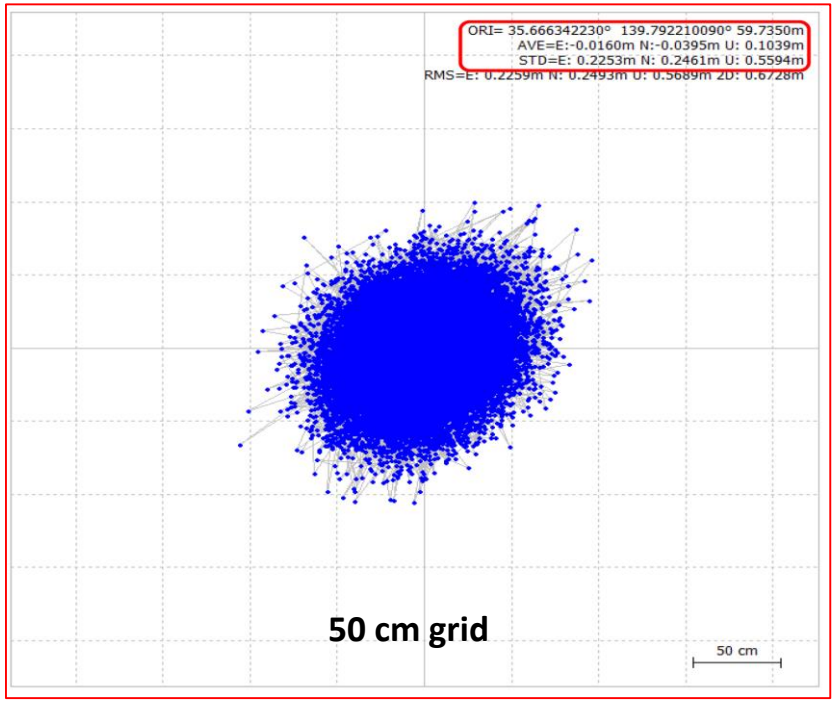
High Accuracy Receivers are Expensive

- High-Accuracy Survey Grade Receivers are multi-frequency and multi-system receivers
  - L1/L2/L5, G1/G2, B1/B2/B3 etc
  - GPS, GLONASS, BGALILEO, BeiDou, QZSS etc
  - Price varies from $3, 000 to $30,000 or more.
- However, Low Cost Receivers are also capable of
  - Multi-System: GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
  - Basically only in L1-Band Frequency
  - Low Cost: $300 (Multi-GNSS, L1 Only)
  - Low-cost Multi-System, Multi Frequency GNSS Receivers are already available
    - Broadcom, u-Blox chips and modules already available for Mass Market applications
    - Other companies like Qualcomm, ST Micro have already announced Multi-System, Multi-Band GNSS Chips for Mass Market
    - More products coming-up by the end of this year

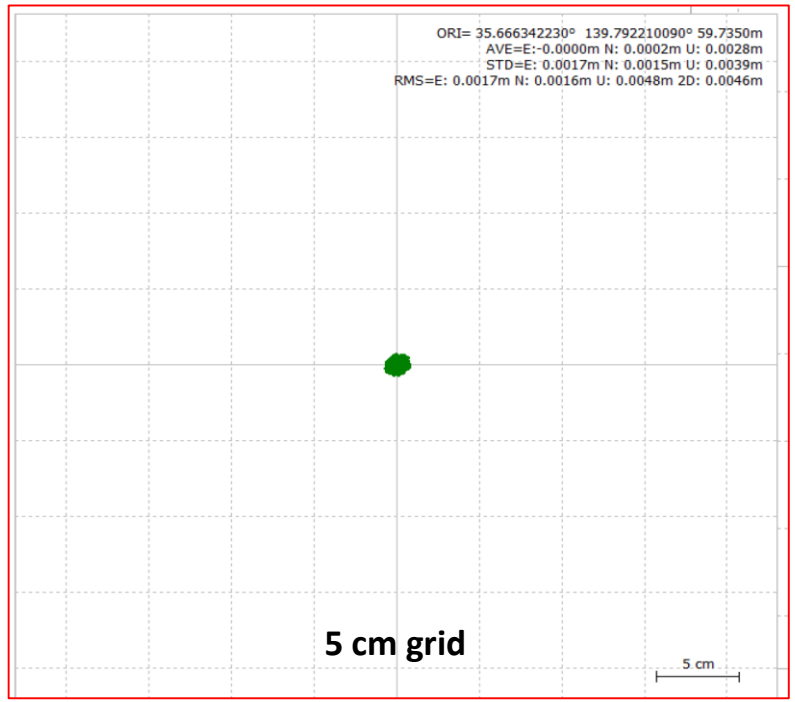
How accurate is GPS Position?



SPP (Single Point Position)



DGPS (Differential GPS)



RTK (Real Time Kinematic)

Errors in GPS Observation (L1C/A Signal)

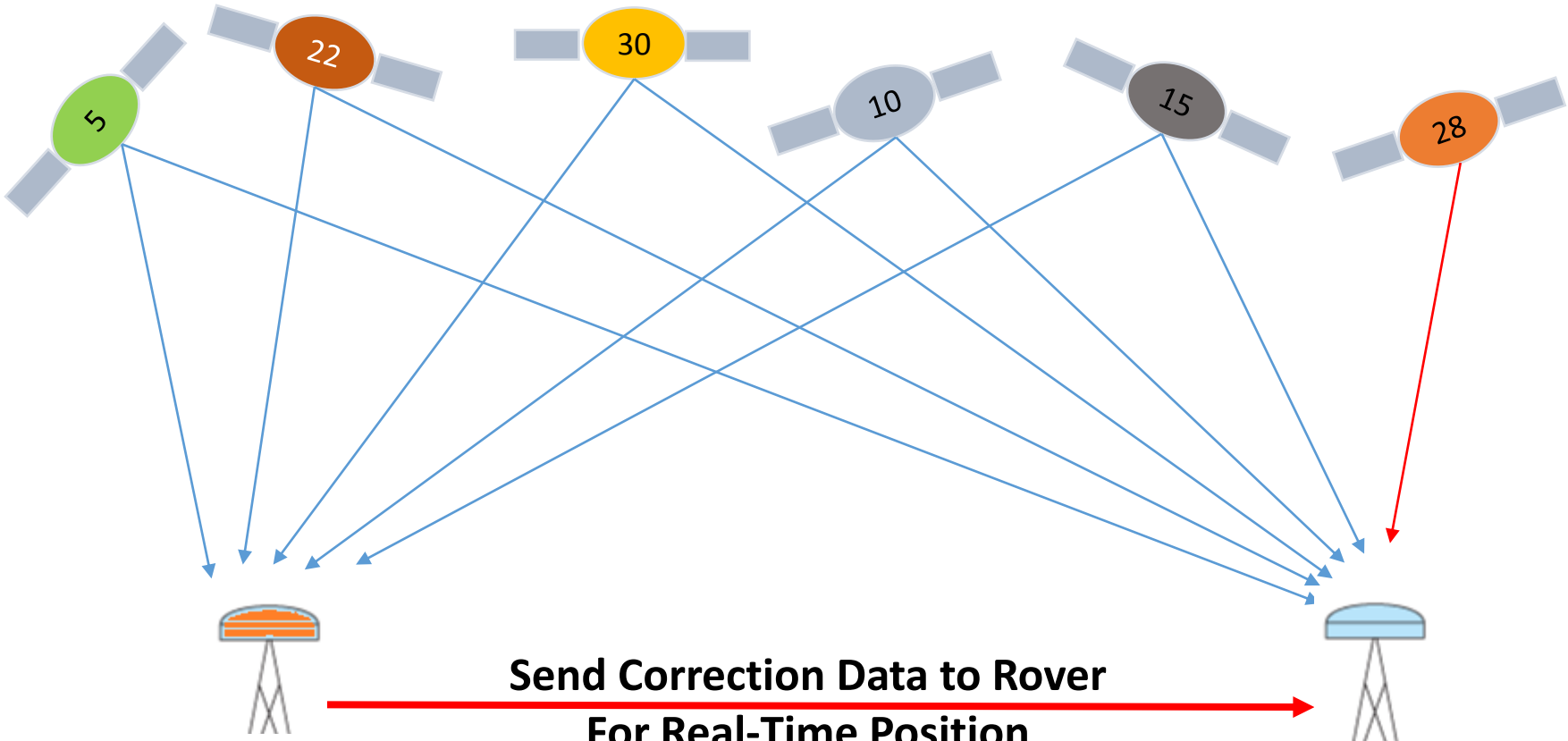
Error Sources	One-Sigma Error , m		Comments
	Total	DGPS	
Satellite Orbit	2.1	0.0	Common errors are removed
Satellite Clock	2.1	0.0	
Ionosphere Error	4.0	0.4	Common errors are reduced
Troposphere Error	0.7	0.2	
Multipath	1.4	1.4	
Receiver Circuits	0.5	0.5	

If we can remove common errors, position accuracy can be increased.

Common errors are: <u>Satellite Orbit Errors, Clock Errors and Atmospheric Errors (within few km)</u>

Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath

Principle of Differential Correction



Base-Station

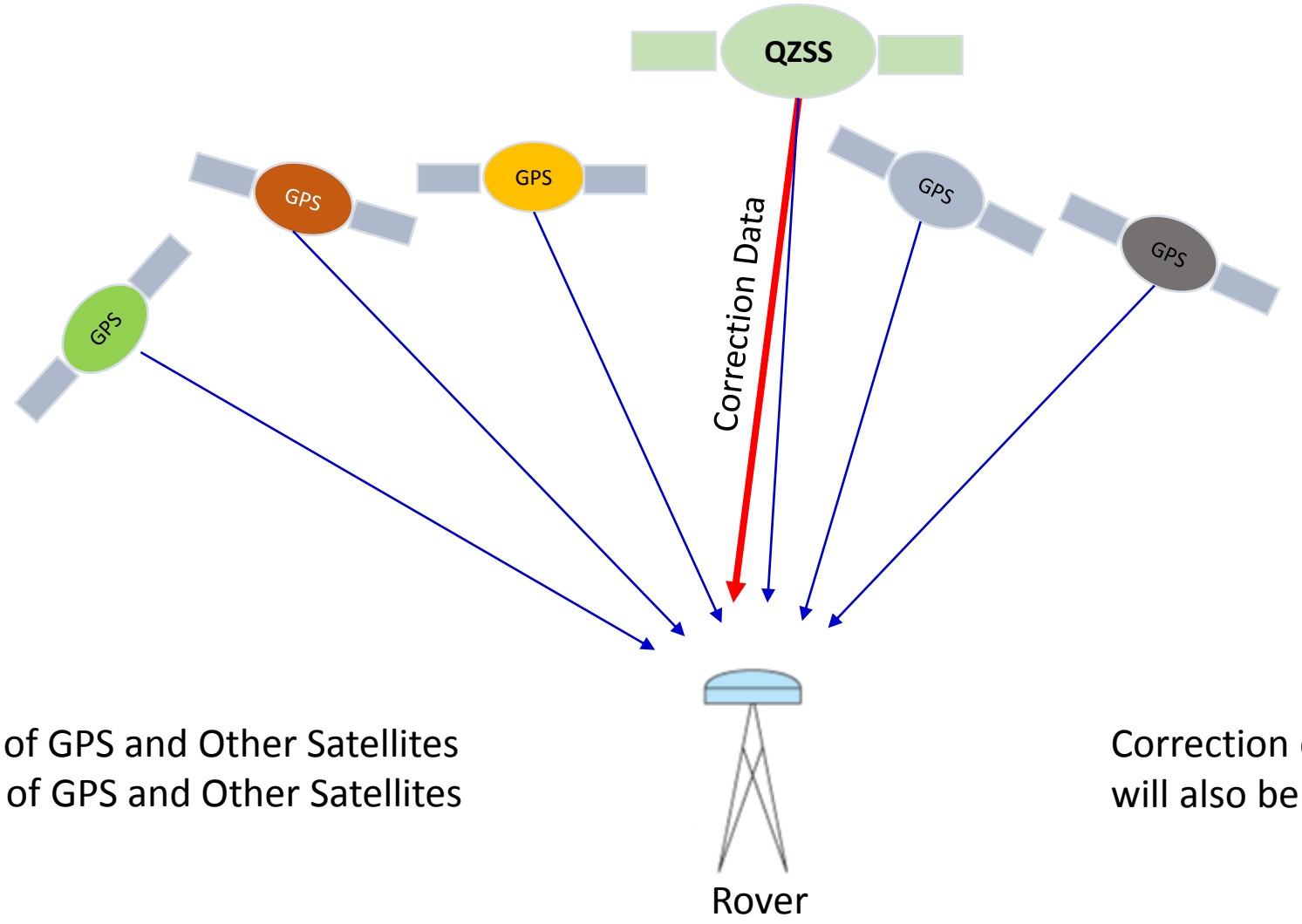
Antenna is installed at a known-position

Rover

User in the Field

(Either fixed or moving)

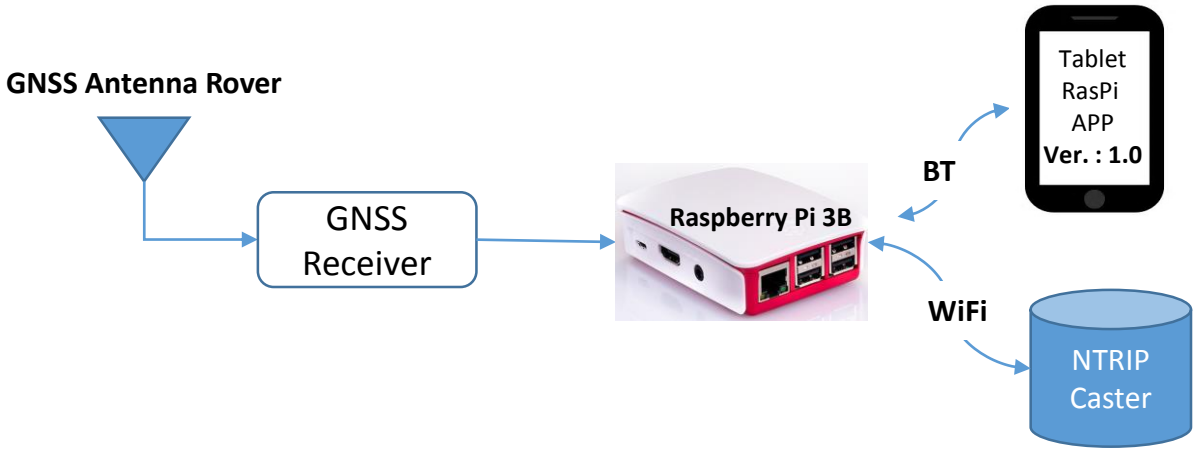
Principle of QZSS MADOCA and CLAS Services



Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

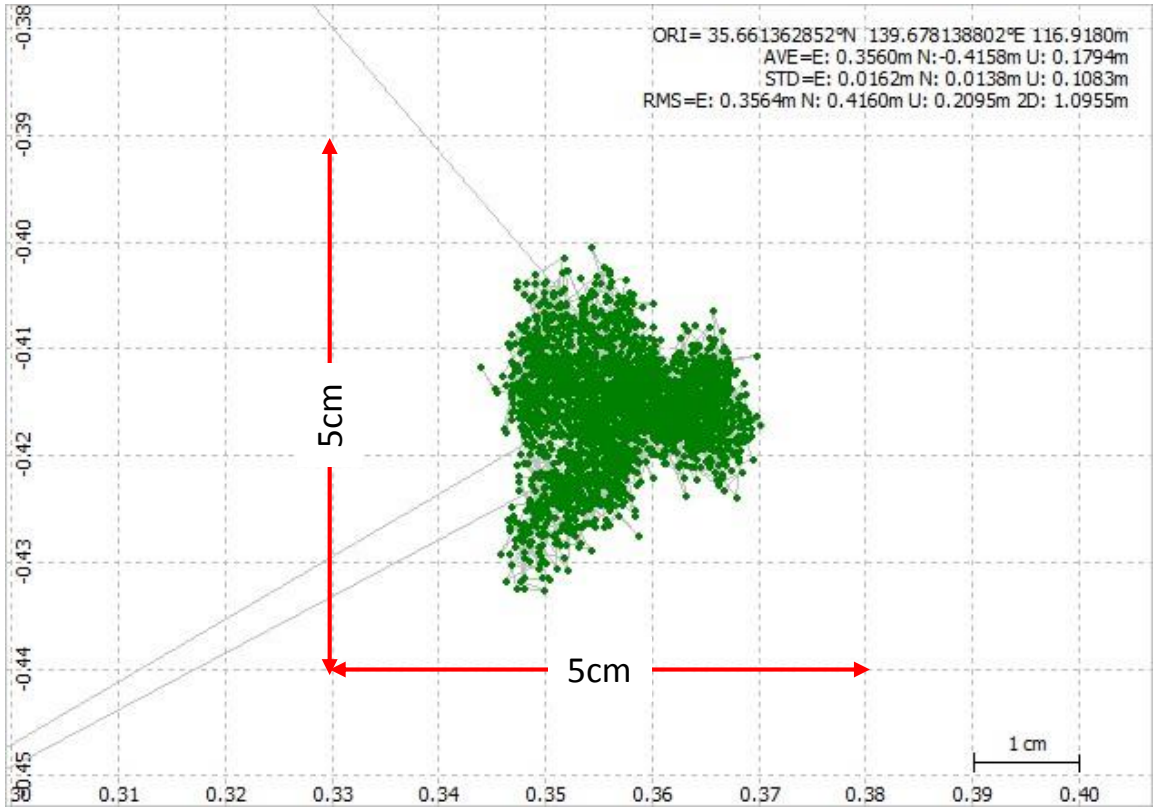
Correction data for other satellites will also be provided

Accuracy from Low-Cost RTK System

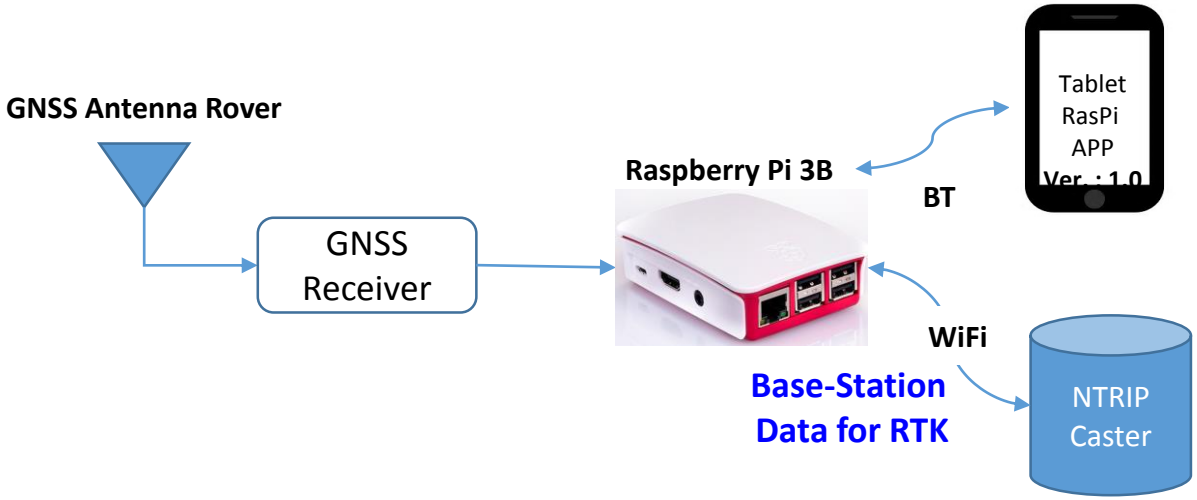


Rover-Station:
Receiver: u-blox M8T
Antenna: Zephyr 2
Computer: RaspberryPi 3B+
Distance between Base and Rover : about 12Km

Base-Station:
Receiver: Trimble NetR9
Antenna: Zephyr 2

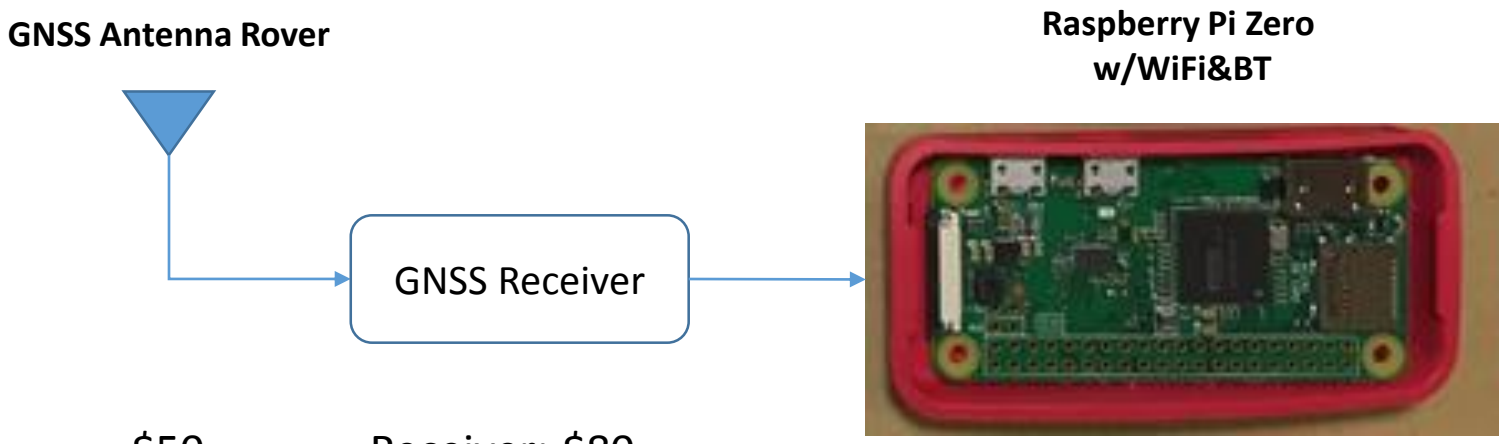


Type – R1: GNSS Receiver with RaspberryPi-3 For RTK, NRTK (based on VRS Correction Data) or PPK



Type R1:
Base or Rover Mode
Real-Time and Post-Processing RTK
Based on RTKLIB Engine

Type – R2: GNSS Receiver with RaspberryPi-Zero/W For PPK with or without Camera



$50

Receiver: $80
Case: $10

PiZero Board: $12
Case: $12
Camera: $25

Type R2:
Rover Mode
SPS + Post-Processing RTK
Log Necessary Raw Data for Post-processing RTK
Based on RTKLIB Engine

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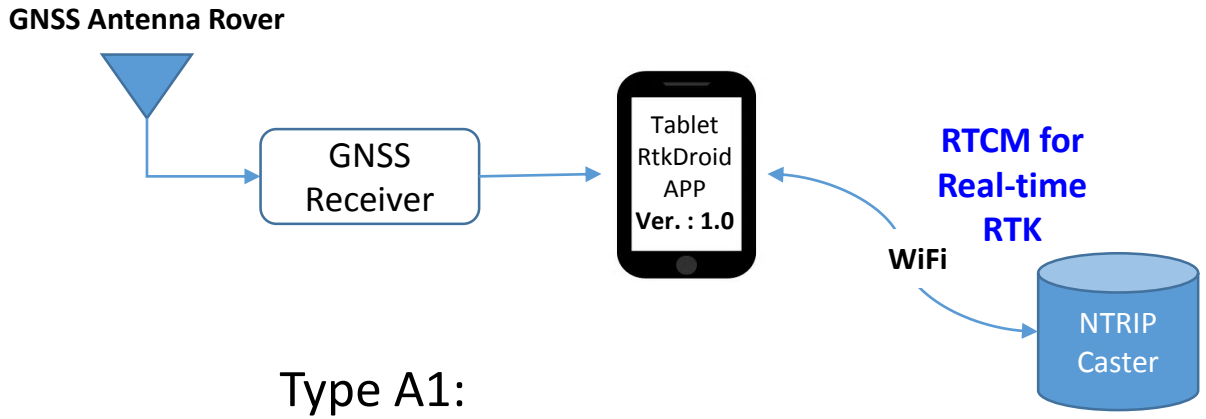
Type – A1: GNSS Receiver with Android Device

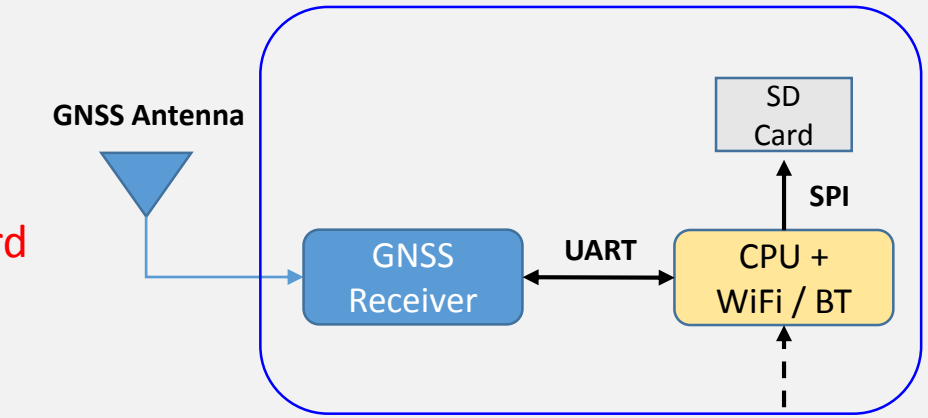


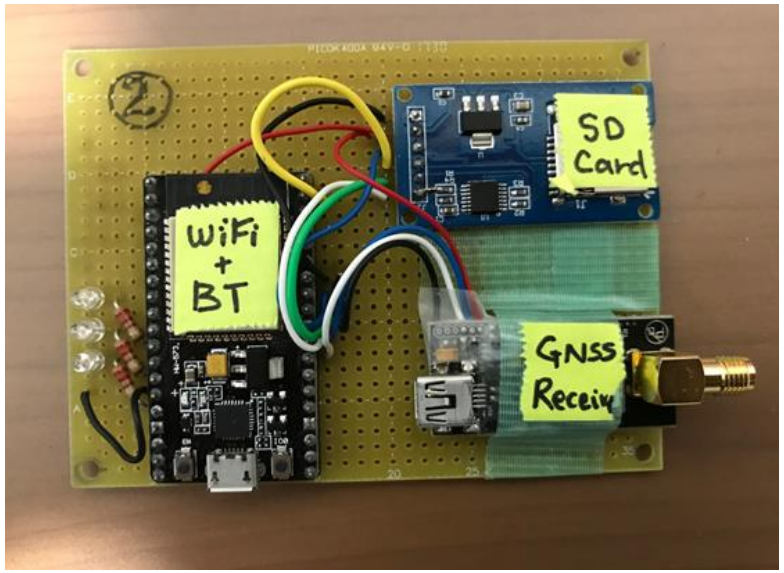
Type A1:
Rover Mode
Real-Time or/and Post-Processing RTK
Based on RTKLIB Engine
Real-time processing in Android Device
APP: RTKDroid

GNSS Receiver Module

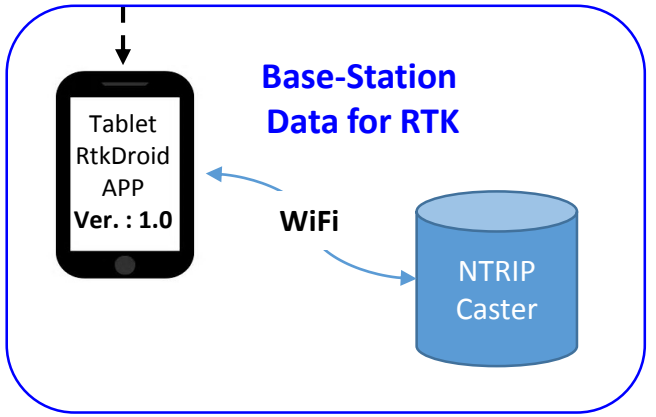
Type – W1: GNSS Receiver + WiFi + BT
Easy to Use GNSS Data Logger for PPK

For Post-Processing
Just power-on the device
Data will be logged to SD Card

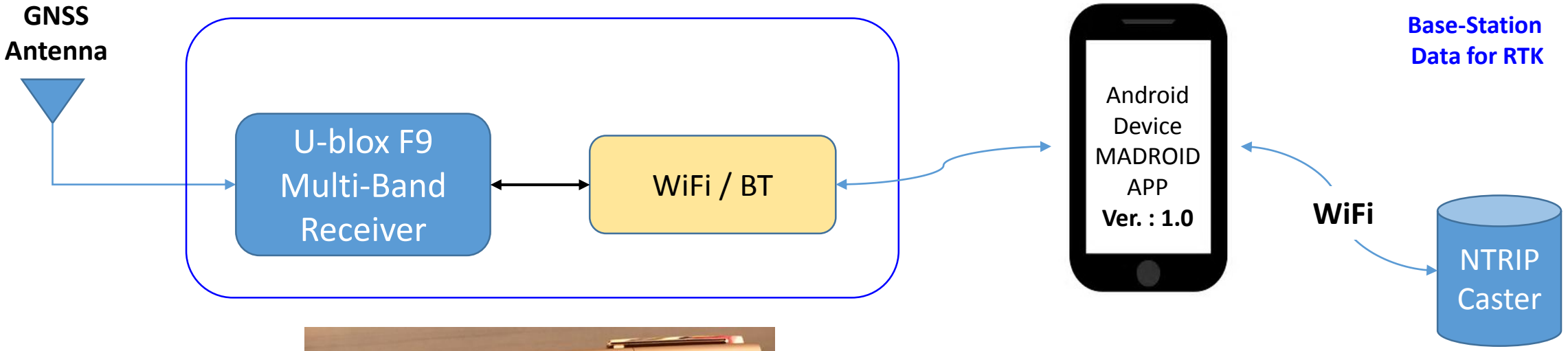




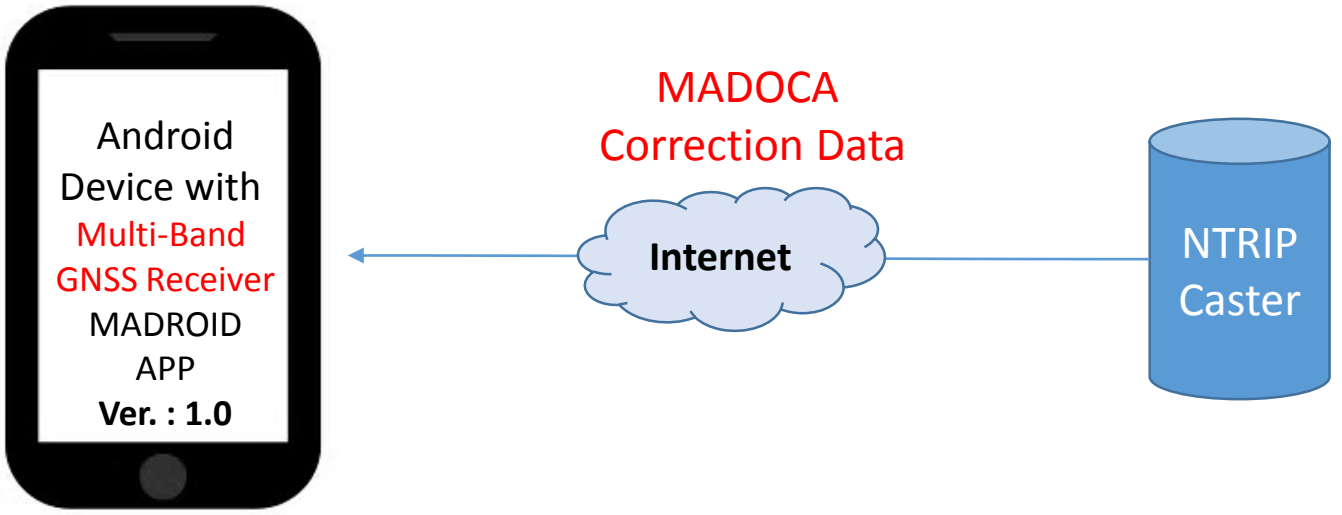
For Real-Time Processing
Connect to an Android Device via BT



Type: MC-F: F9 Board + Android Device
Low-Cost Multi-Frequency GNSS Receiver with Built-In RTK



Type: MA: Android Device with Multi-Band GNSS Receiver



GNSS L1, L5
e. g. Xiomi Mi8

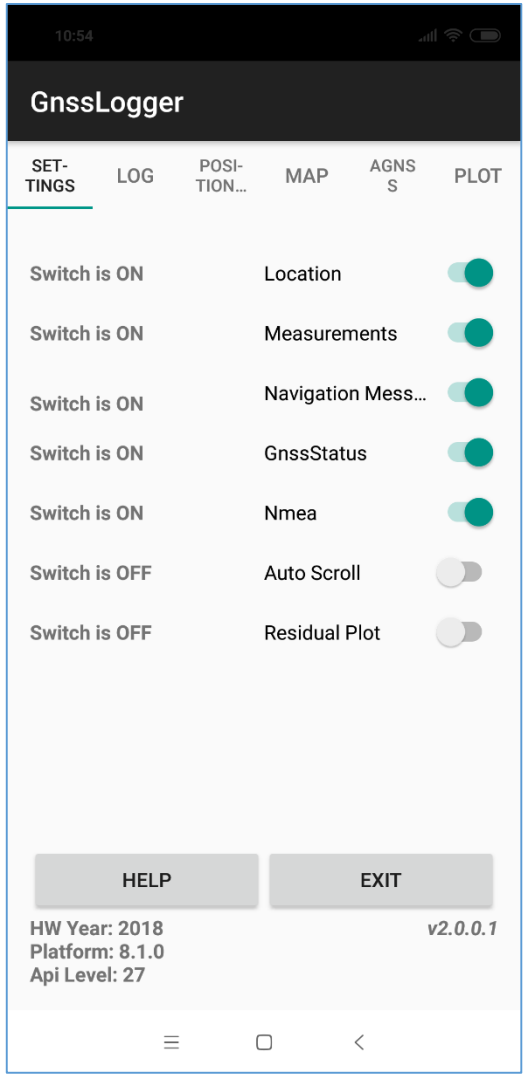
GNSS Raw Data from Smart-Phone

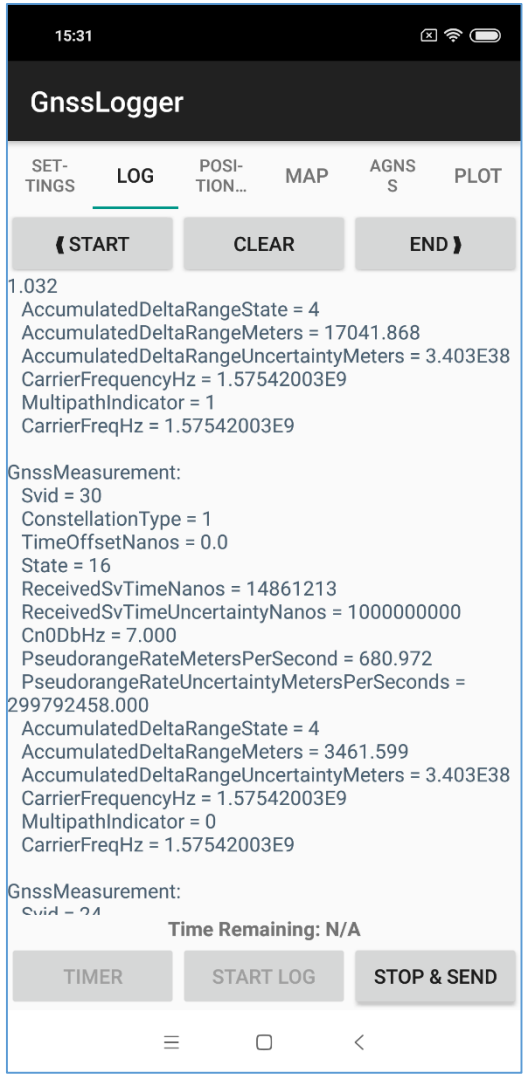
- Many Android devices with OS 8.0 or higher can output GNSS Raw Data
  - These data can be used for RTK post-processing
- Some devices have Multi-Frequency (L1/L5) GNSS receiver
  - Multi-System (GPS, GLONASS, GALILEO, BEIDOU, QZSS)
  - Multi-Frequency (L1/E1/B1, L5/E5)
  - Outputs more than 40 channels
  - Some devices output NAV BIT Data and/or AGC values

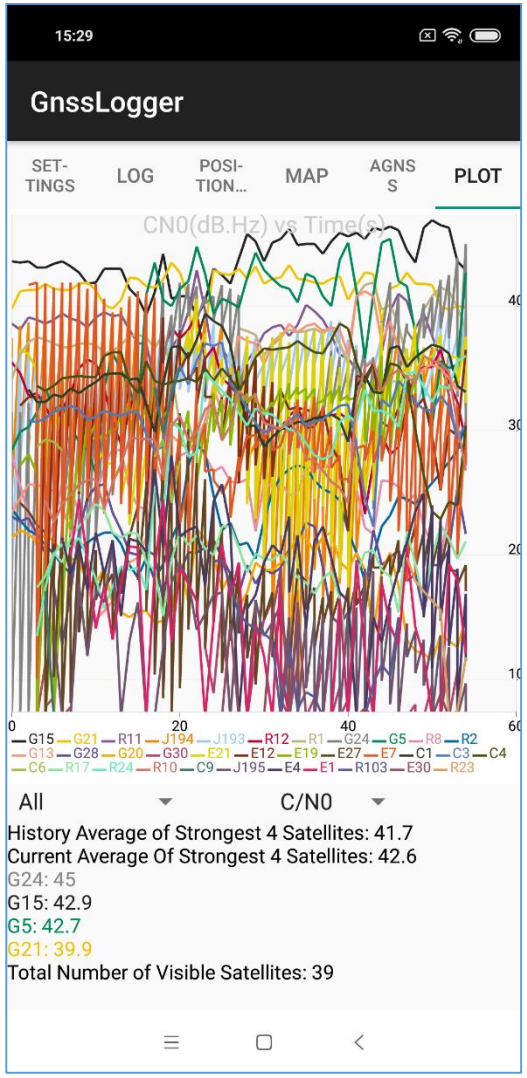
Android Devices capable to output GNSS Raw Data

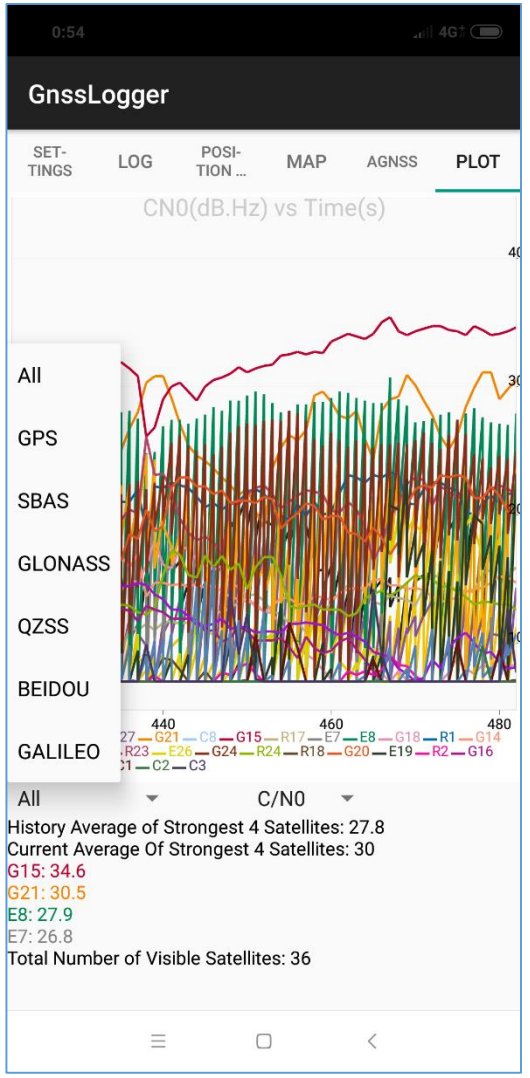
						Raw Data output used in System Score					Satellite Systems used in System Score					
S. No.	Model	Android version	System Score Max: 6 (D)	Function Score Max: 5 (E)	Total Score (D + E)	AGC	NAV MSG	Accumulated delta range	HW clock	L5 Support	GPS	GLO	GAL	BDS	QZSS	SBAS
4	Xiaomi Mi 8	8.1	5	4	9	no	yes	yes	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



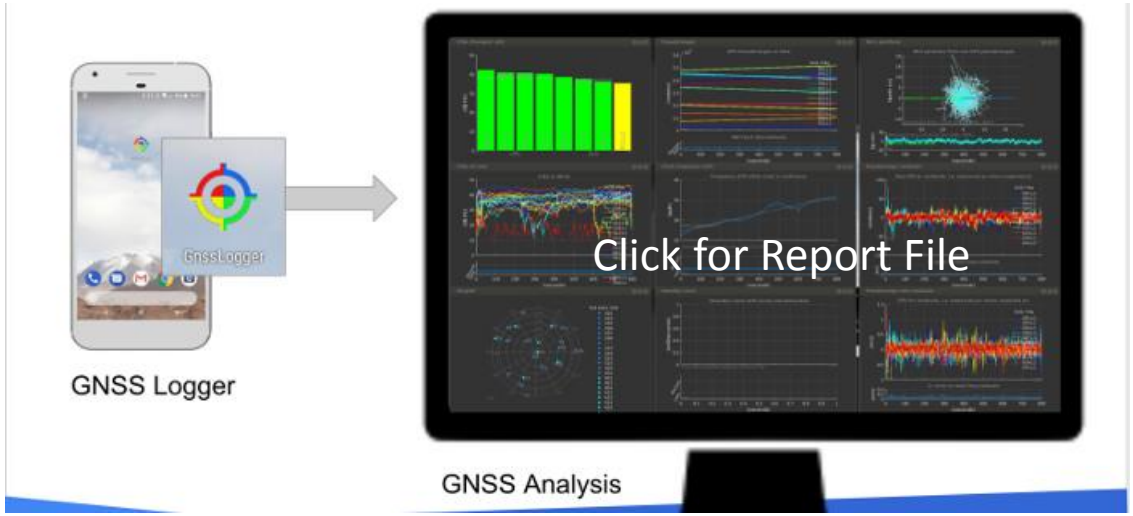


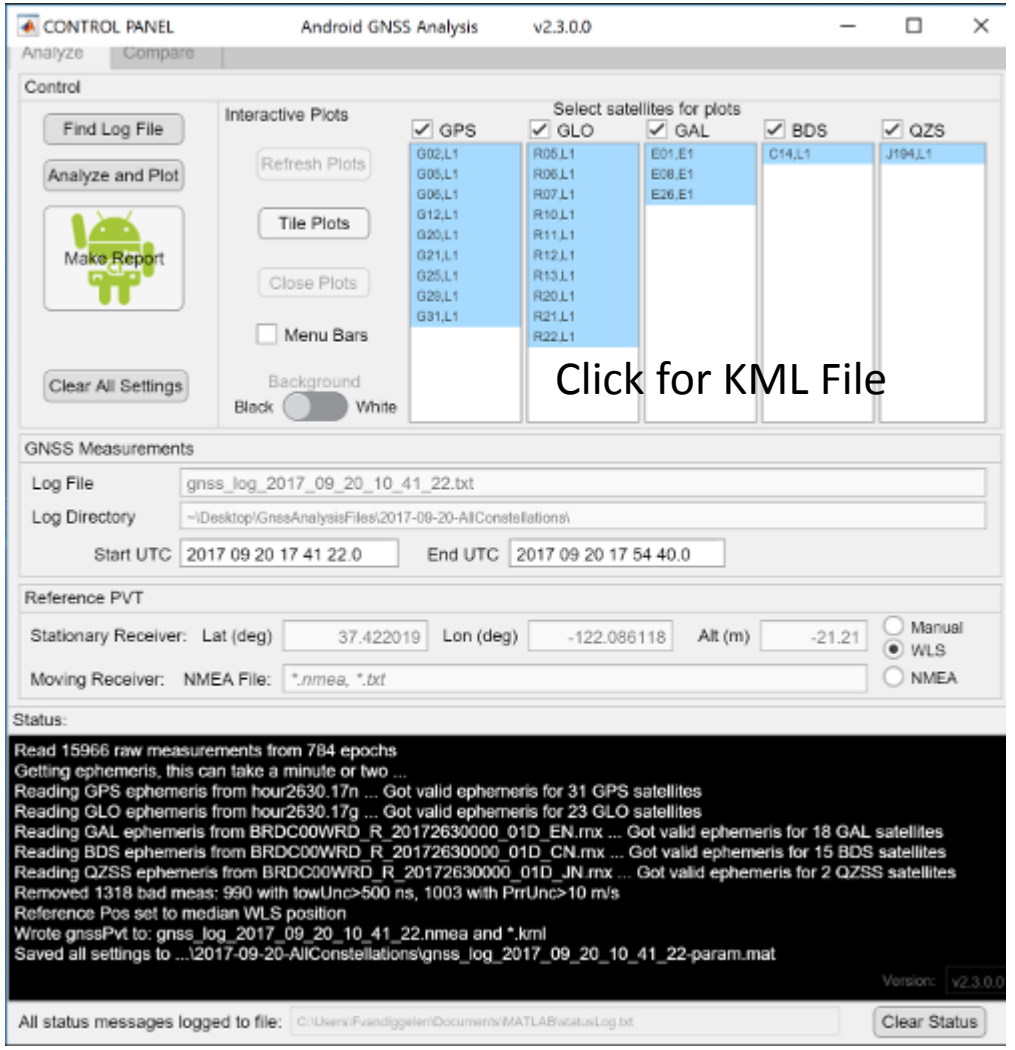




GNSS Raw Data Analysis Tool for GnssLogger

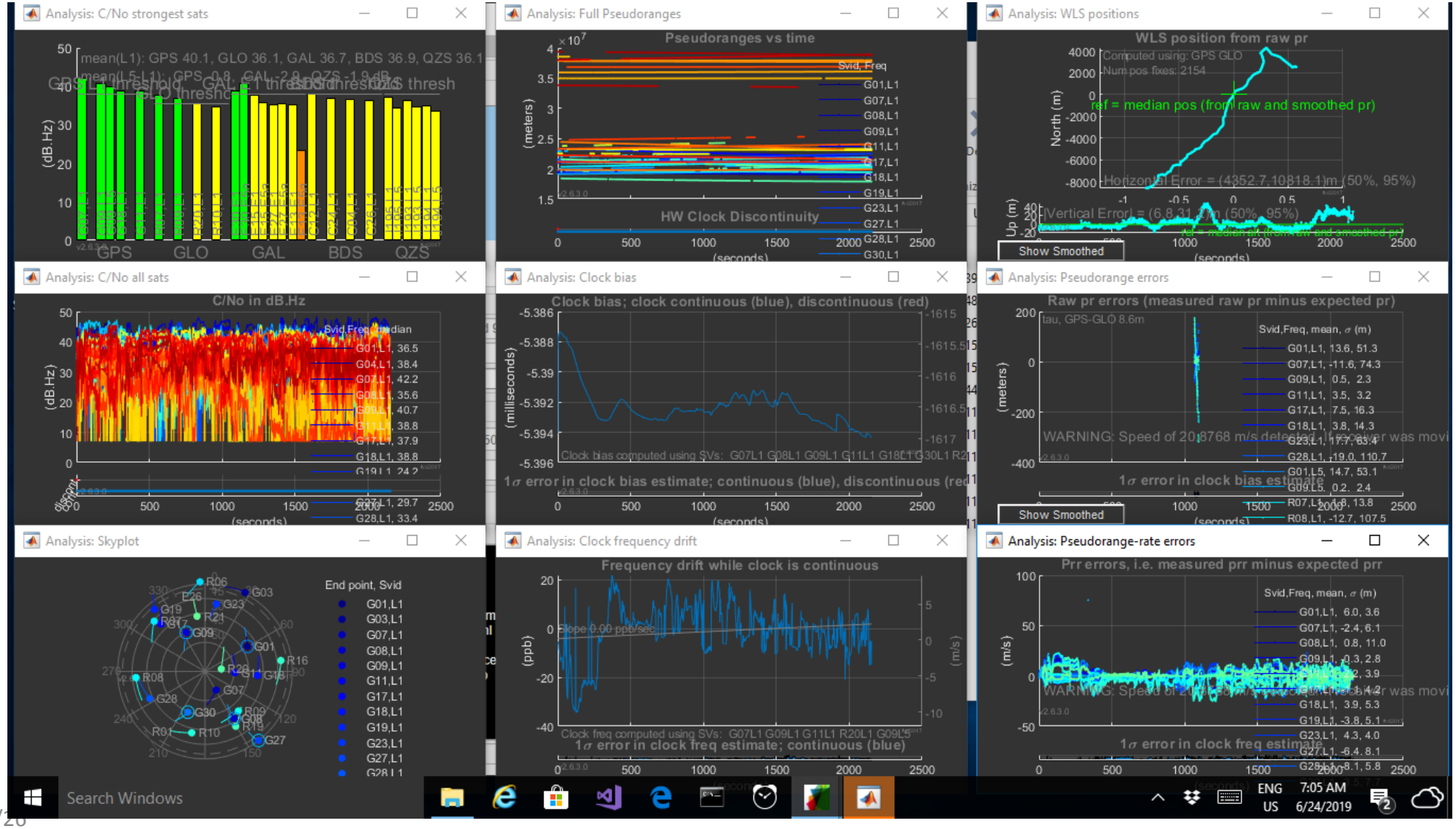
- GNSS Analysis APP
  - Matlab-based Tool
  - Linux, Windows, MacOS
  - Version 2.6.3.0
  - Release Notes: https://developer.android.com/guide/topics/sensors/gnss#releaseGNSS Analysis app v2.6.3.0 release notes.



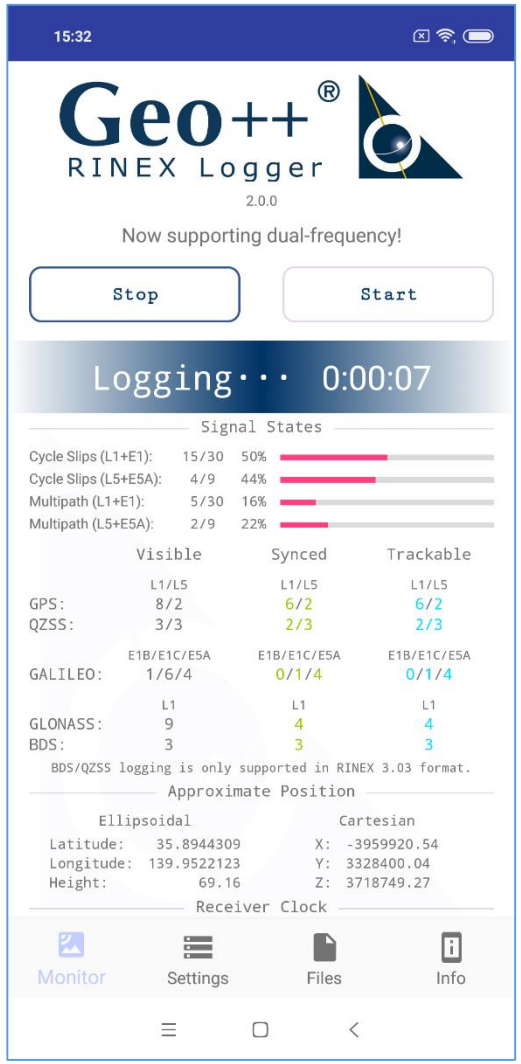


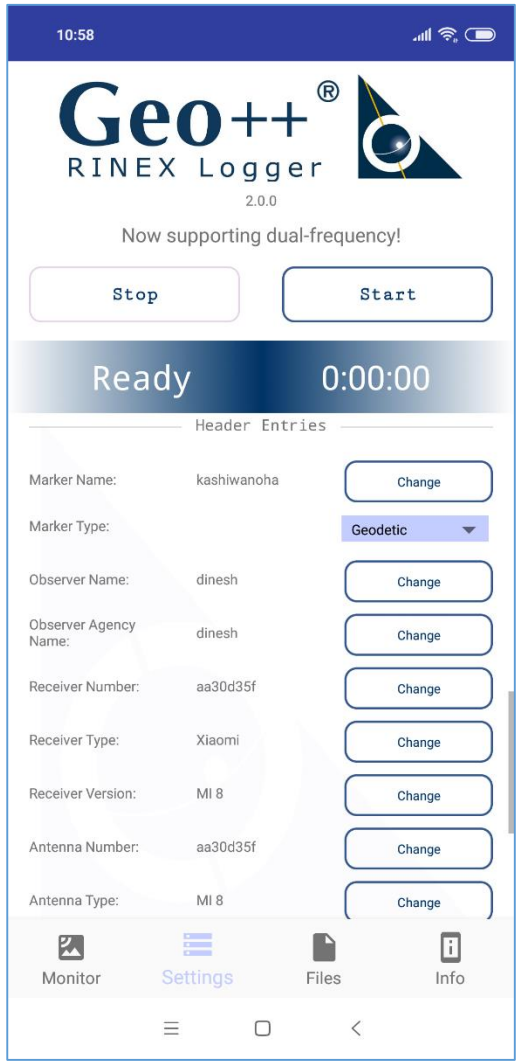
The GNSS Analysis app is built on MATLAB, but you don't need to have MATLAB to run it. The app is compiled into an executable that installs a copy of the MATLAB Runtime.

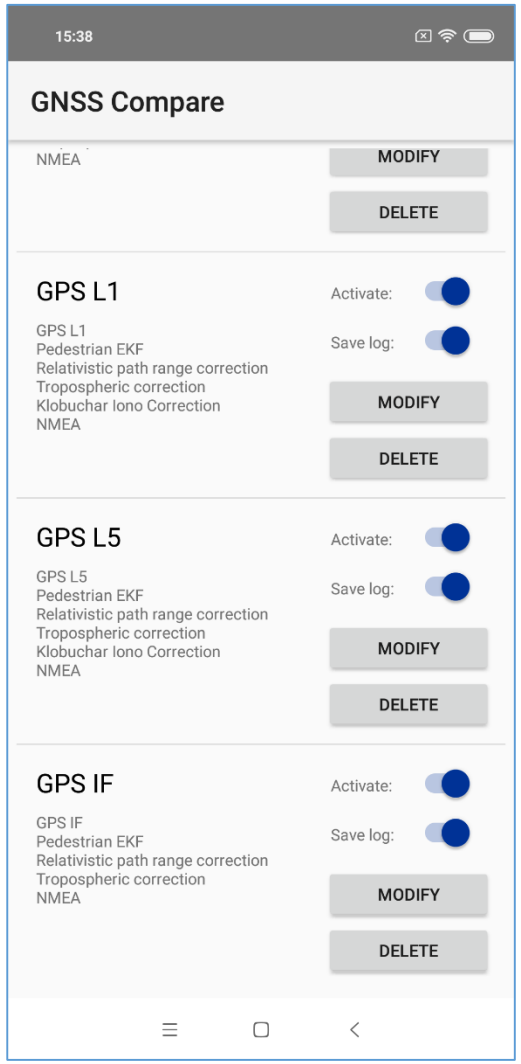
Output of GNSS Raw Data from SUVA Airport to Hotel Peninsula

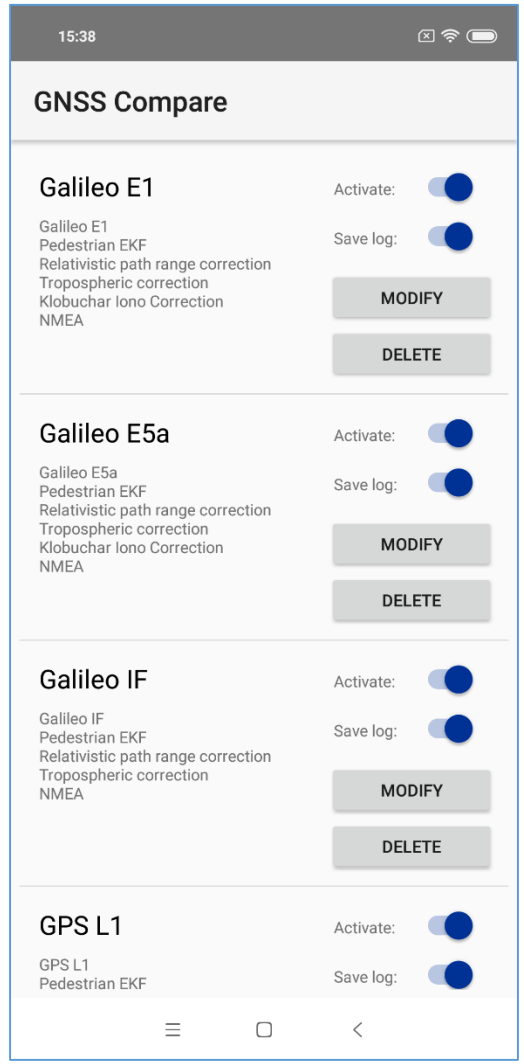


Android Raw Data Logging Tool – 2: Geo++ RINEX Logger







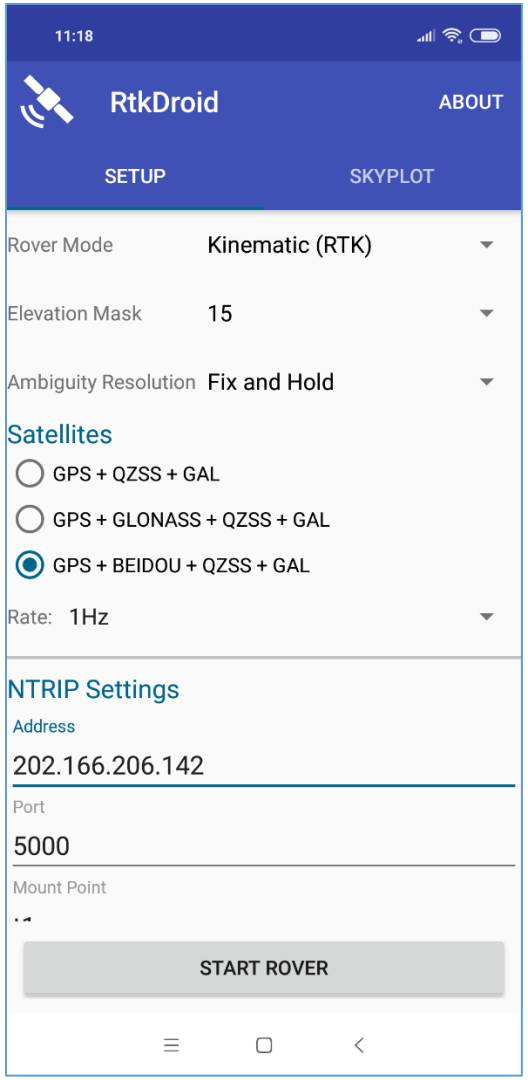


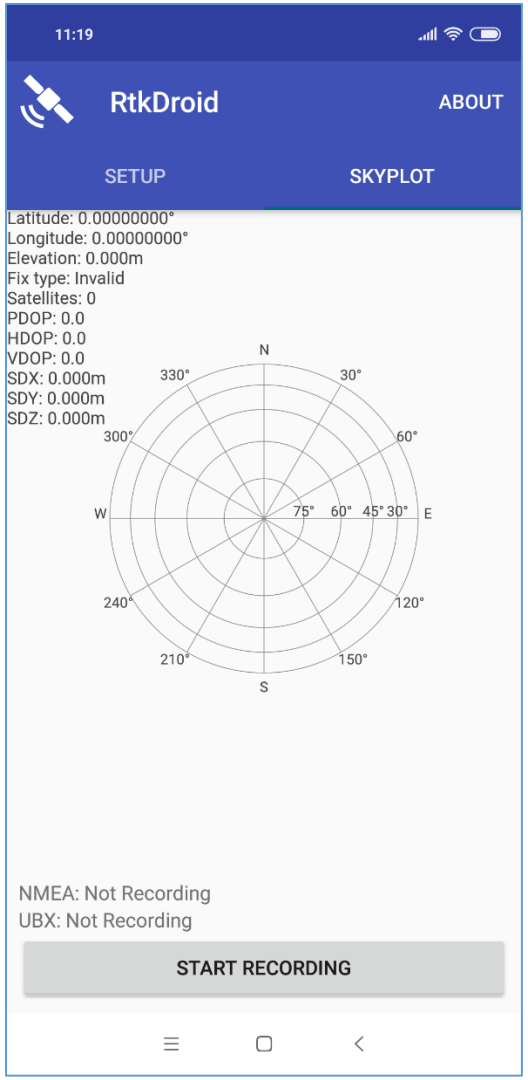
GNSS Raw Data Output in RINEX Format, Observation File Header

```
     3.03           OBSERVATION DATA    M: Mixed            RINEX VERSION / TYPE
Geo++ RINEX Logger  Geo++                20181108 104519 UTC PGM / RUN BY / DATE
************************************************************COMMENT
This file was generated by the Geo++ RINEX Logger App       COMMENT
for Android devices (Version 2.0.1). If you encounter       COMMENT
any issues, please send an email to android@geopp.de        COMMENT
************************************************************COMMENT
Geo++                                                       MARKER NAME
GEODETIC                                                    MARKER TYPE
RINEX Logger user   Geo++                                   OBSERVER / AGENCY
bf643821            Xiaomi              MI 8                REC # / TYPE / VERS
bf643821            MI 8                                    ANT # / TYPE
 -3961916.4382  3348991.6513  3698200.7630                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
G    8 C1C L1C D1C S1C C5Q L5Q D5Q S5Q                       SYS / # / OBS TYPES
R    4 C1C L1C D1C S1C                                      SYS / # / OBS TYPES
E   12 C1B L1B D1B S1B C1C L1C D1C S1C C5Q L5Q D5Q S5Q      SYS / # / OBS TYPES
C    4 C2I L2I D2I S2I                                      SYS / # / OBS TYPES
J    8 C1C L1C D1C S1C C5Q L5Q D5Q S5Q                      SYS / # / OBS TYPES
  2018    11     8    10    45   37.0000732     GPS         TIME OF FIRST OBS
 24 R01  1 R02 -4 R03  5 R04  6 R05  1 R06 -4 R07  5 R08  6 GLONASS SLOT / FRQ #
    R09 -2 R10 -7 R11  0 R12 -1 R13 -2 R14 -7 R15  0 R16 -1 GLONASS SLOT / FRQ #
    R17  4 R18 -3 R19  3 R20  2 R21  4 R22 -3 R23  3 R24  2 GLONASS SLOT / FRQ #
G L1C                                                       SYS / PHASE SHIFTS
G L5Q -0.25000                                              SYS / PHASE SHIFTS
R L1C                                                       SYS / PHASE SHIFTS
E L1B                                                       SYS / PHASE SHIFTS
E L1C +0.50000                                              SYS / PHASE SHIFTS
E L5Q -0.25000                                              SYS / PHASE SHIFTS
C L2I                                                       SYS / PHASE SHIFTS
J L1C                                                       SYS / PHASE SHIFTS
J L5Q -0.25000                                              SYS / PHASE SHIFTS
 C1C    0.000 C1P    0.000 C2C    0.000 C2P    0.000       GLONASS COD/PHS/BIS
                                                            END OF HEADER
```

Android Raw Data Logging Tool – 3: RTKDROID

- External GNSS Receiver can be connected to Android Device
- Base-Station is connected via NTRIP Address
- VRS Correction also supported
- Supported File Format
  - ubx (u-blox)
  - Other formats will be included if requested
    - SBF (Septentrio) will be included in near future
- Real-Time RTK
- Raw Data can be logged for Post-Processing
- Output from RTKDROID can be send to other APKs in the device



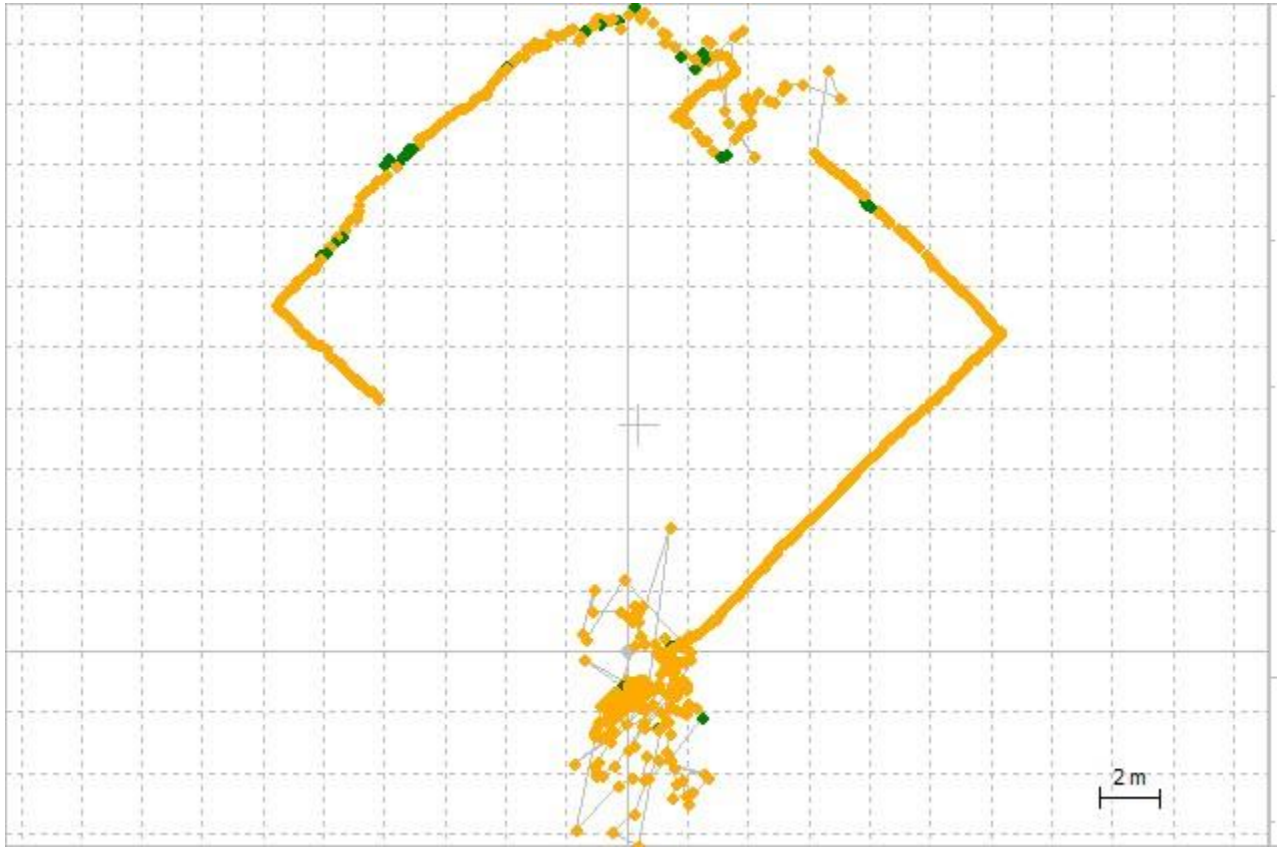


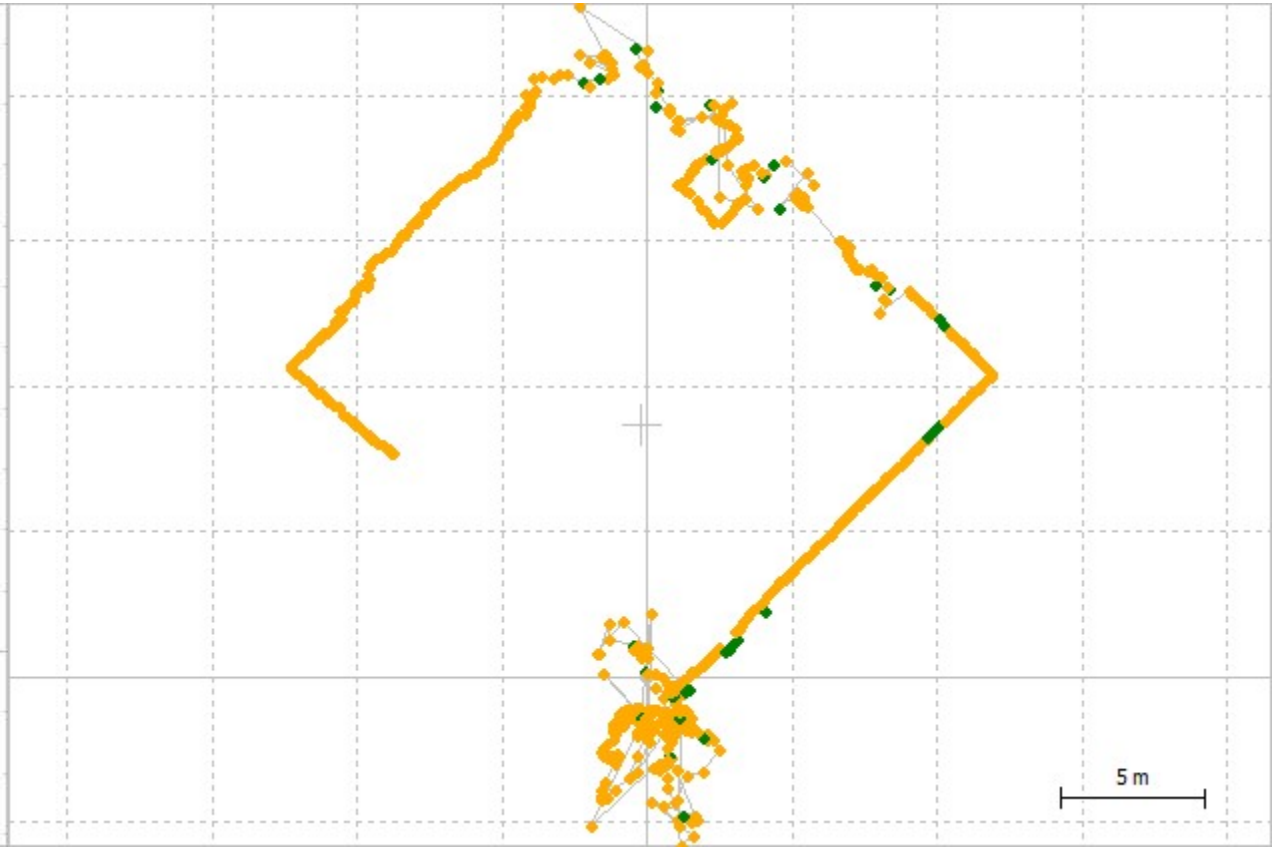
Position Output from Android GNSS Receiver 海洋大学 (TUMSAT)

- 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

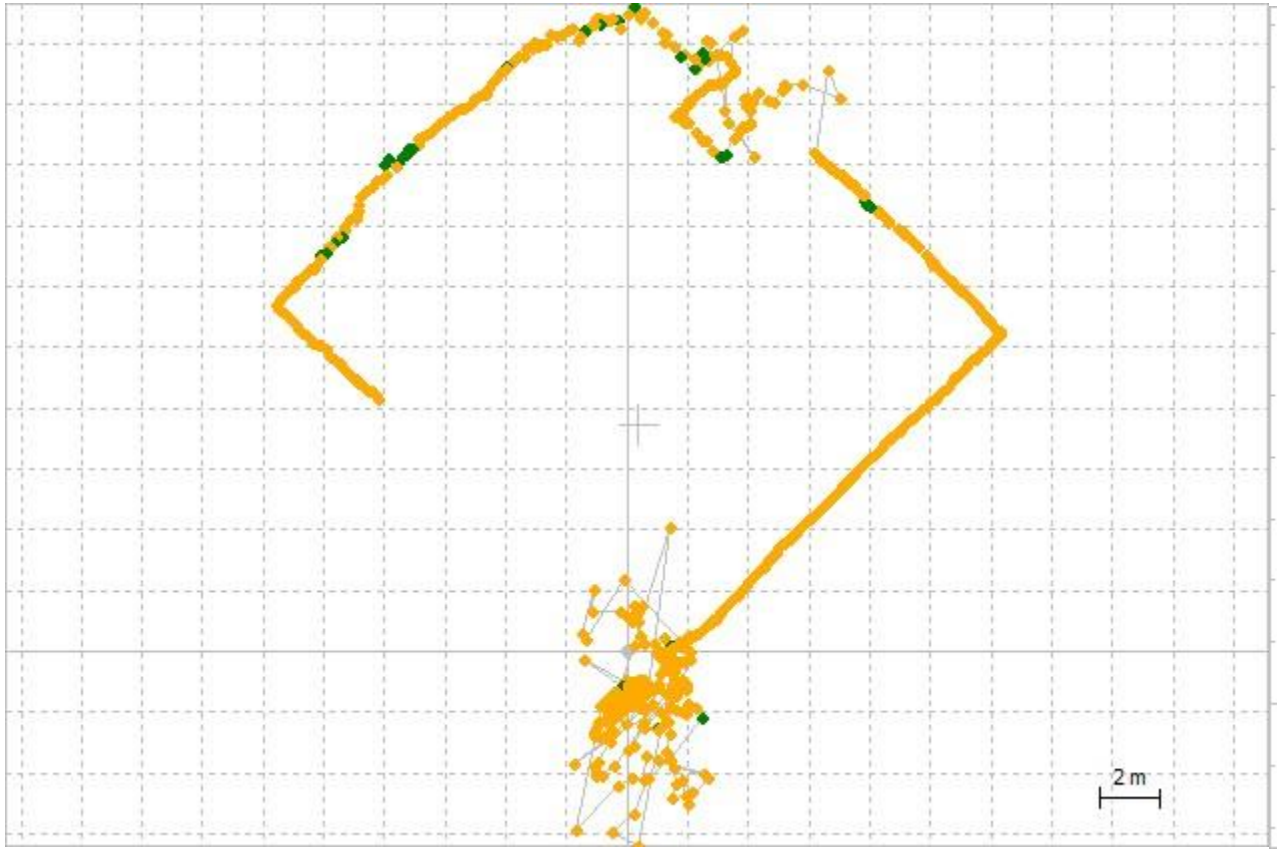
Post-Processing Output: GPS L1 vs GPS L1/L5

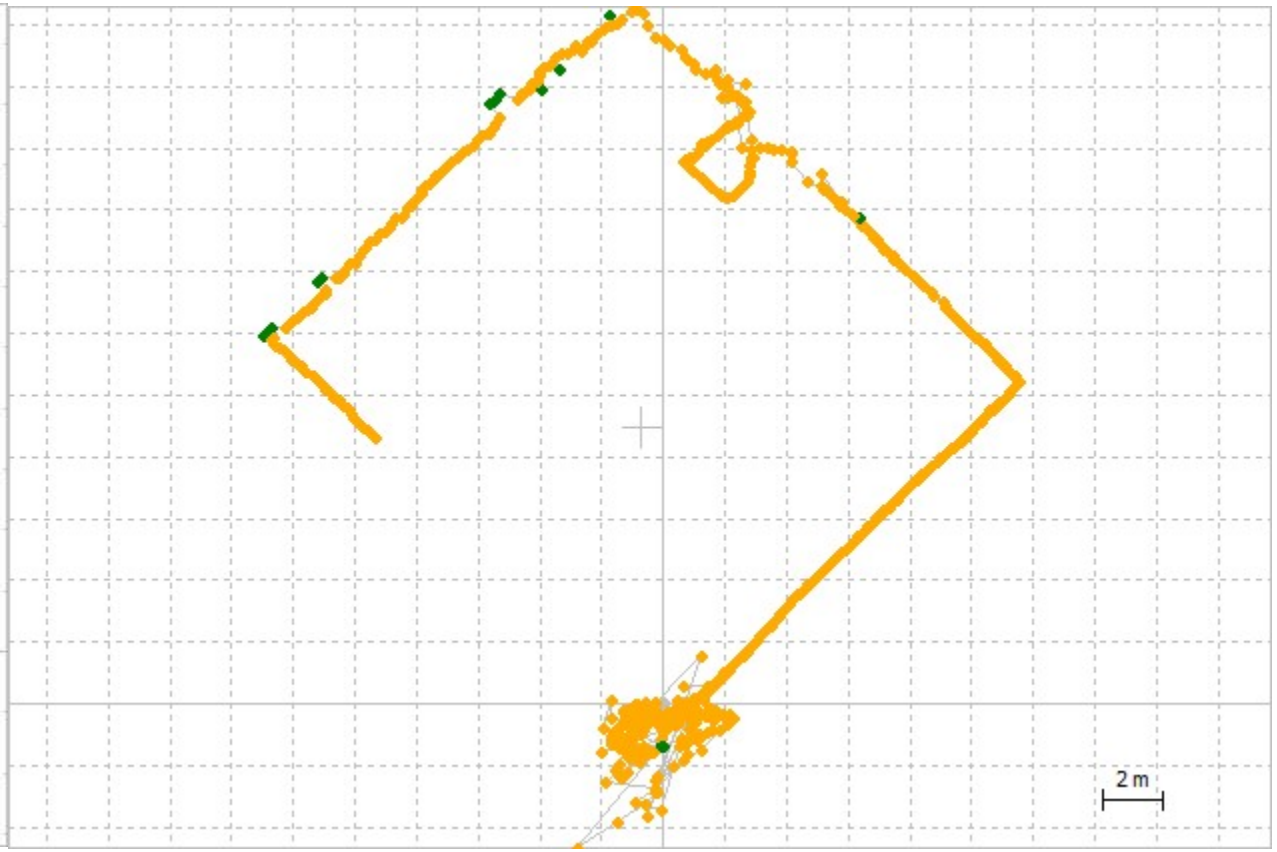




Data logged by Mi8 Smart-phone

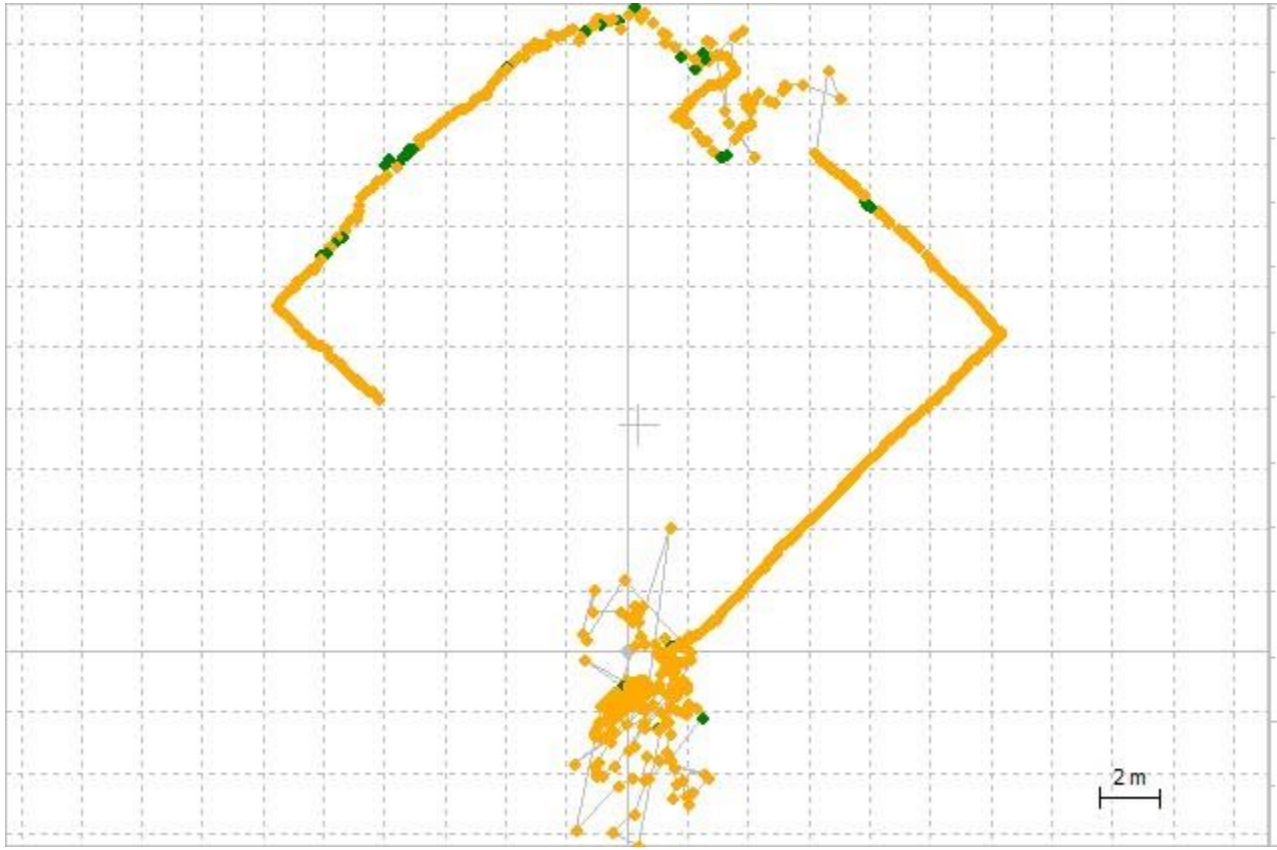
Post-Processing Output: GPS L1 vs GPS + QZS L1

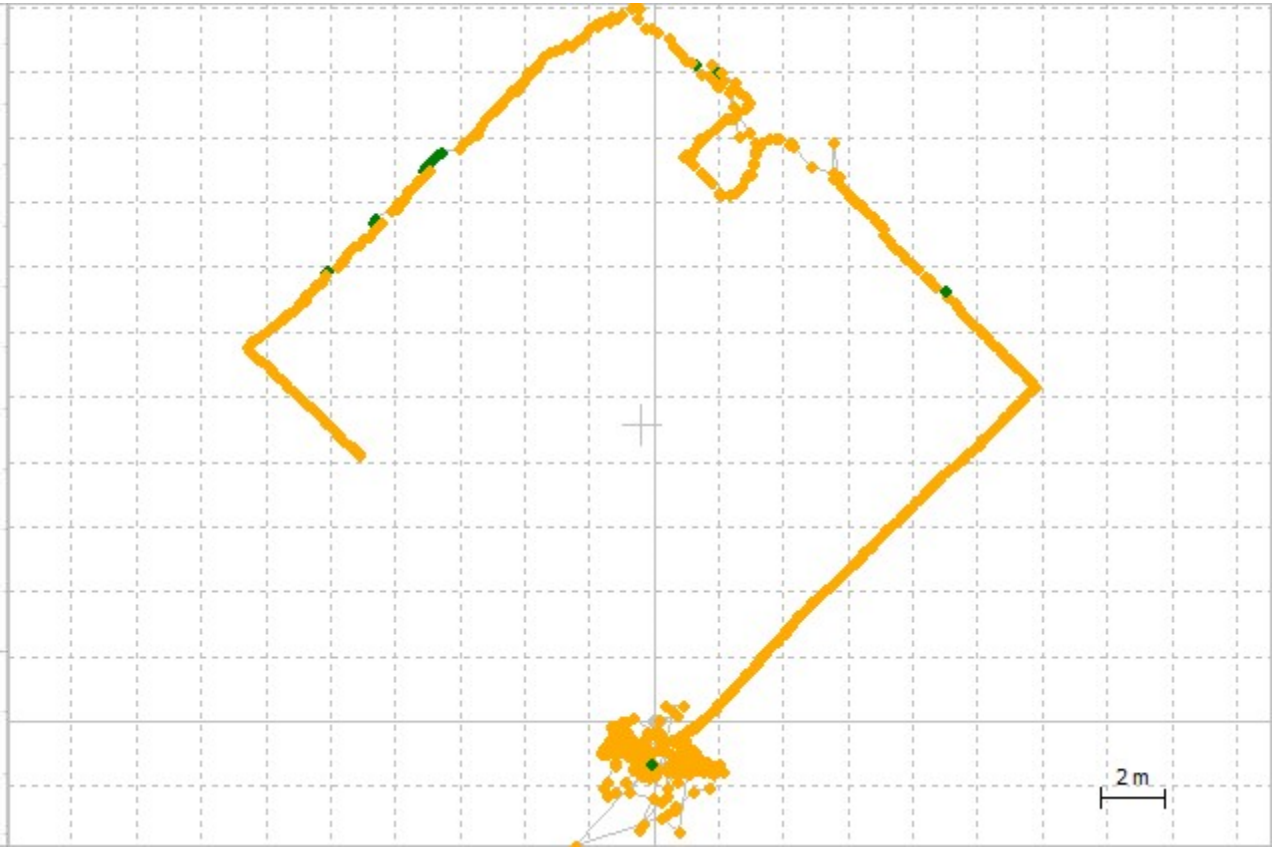




Data logged by Mi8 Smart-phone

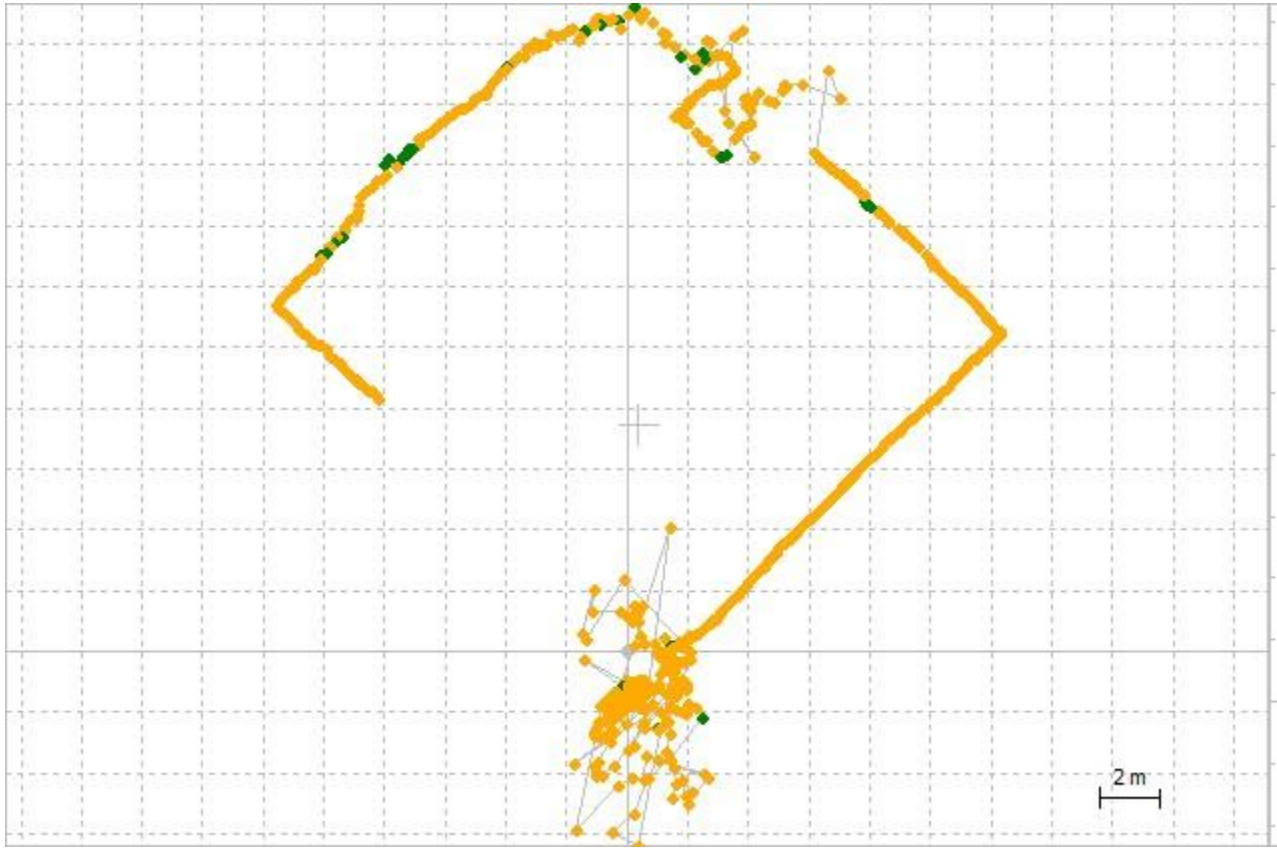
Post-Processing Output: GPS L1 vs GPS + QZS L1/L5

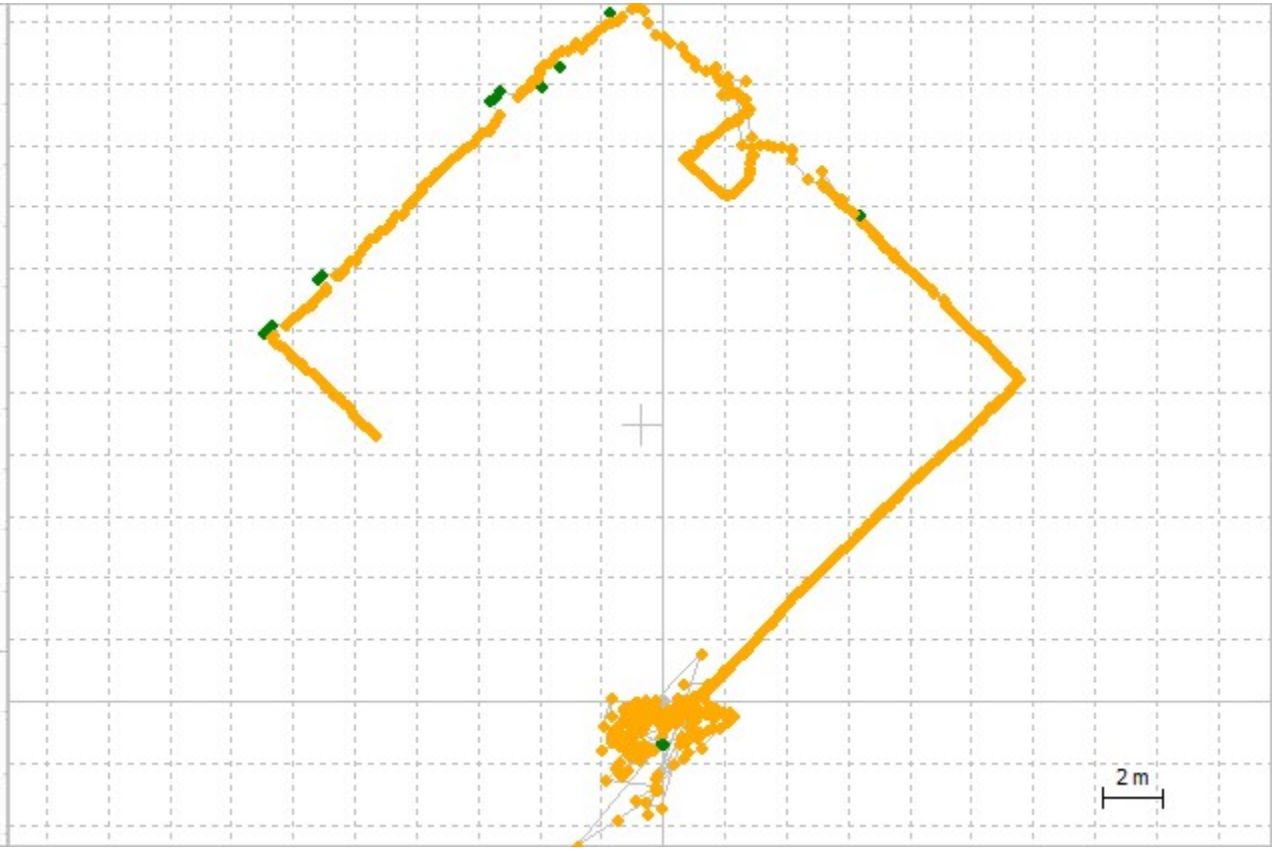




Data logged by Mi8 Smart-phone

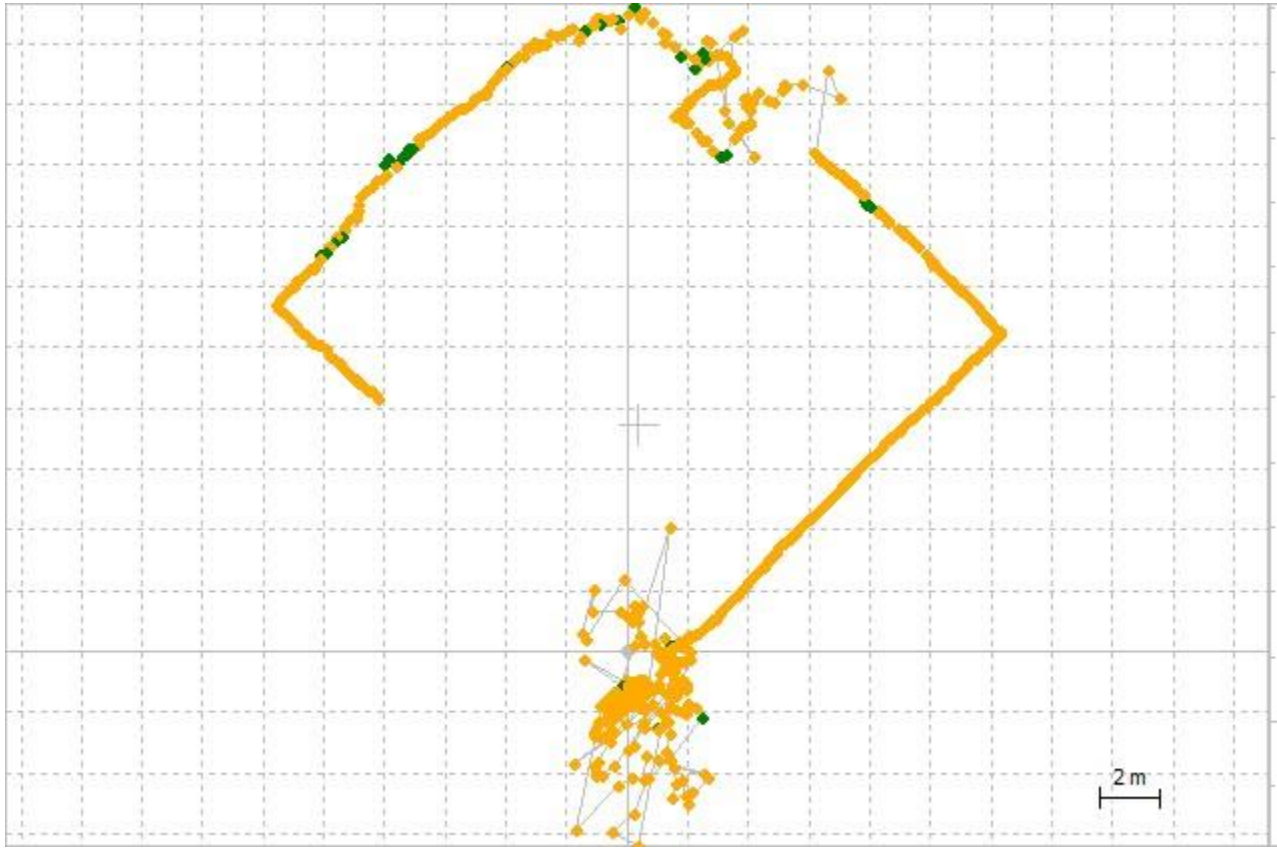
Post-Processing Output: GPS L1 vs GPS + QZS + BDS L1

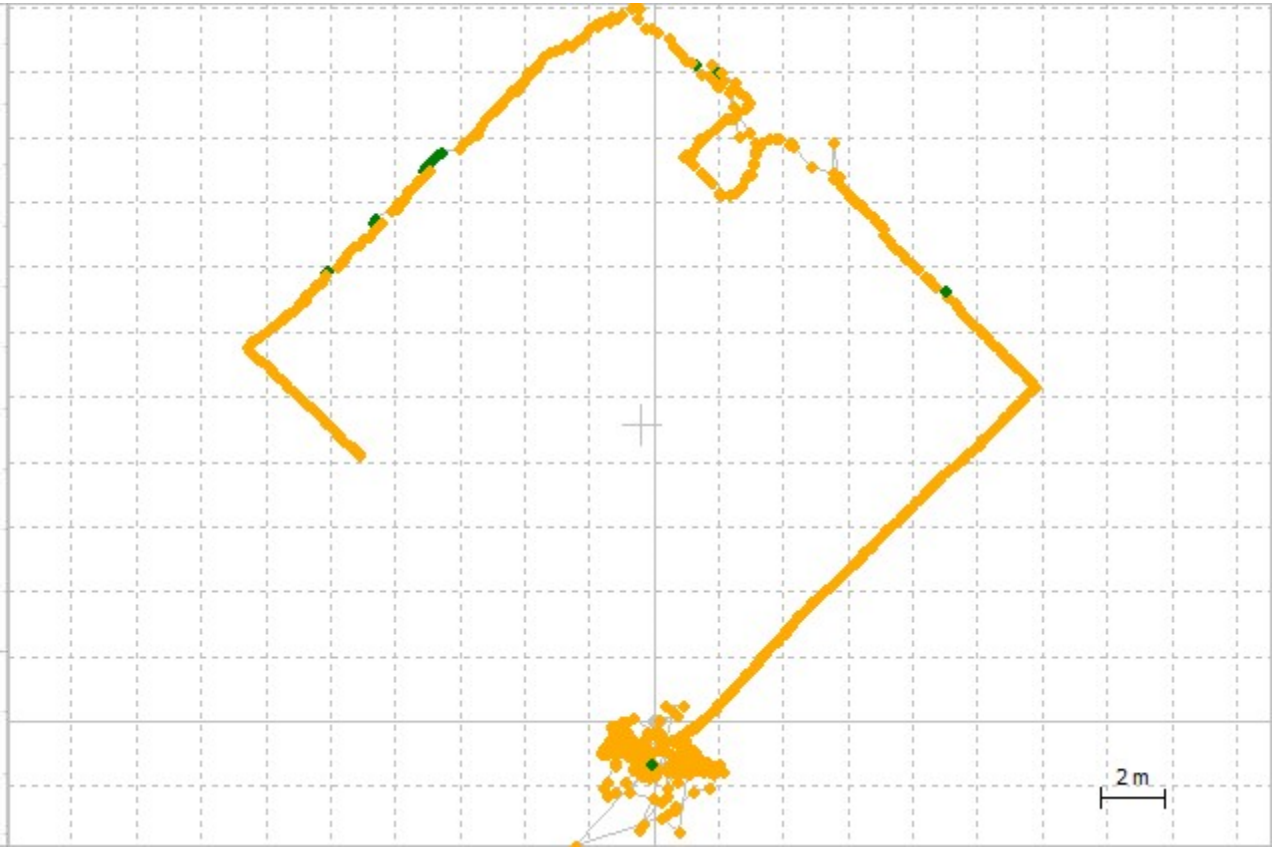




Data logged by Mi8 Smart-phone

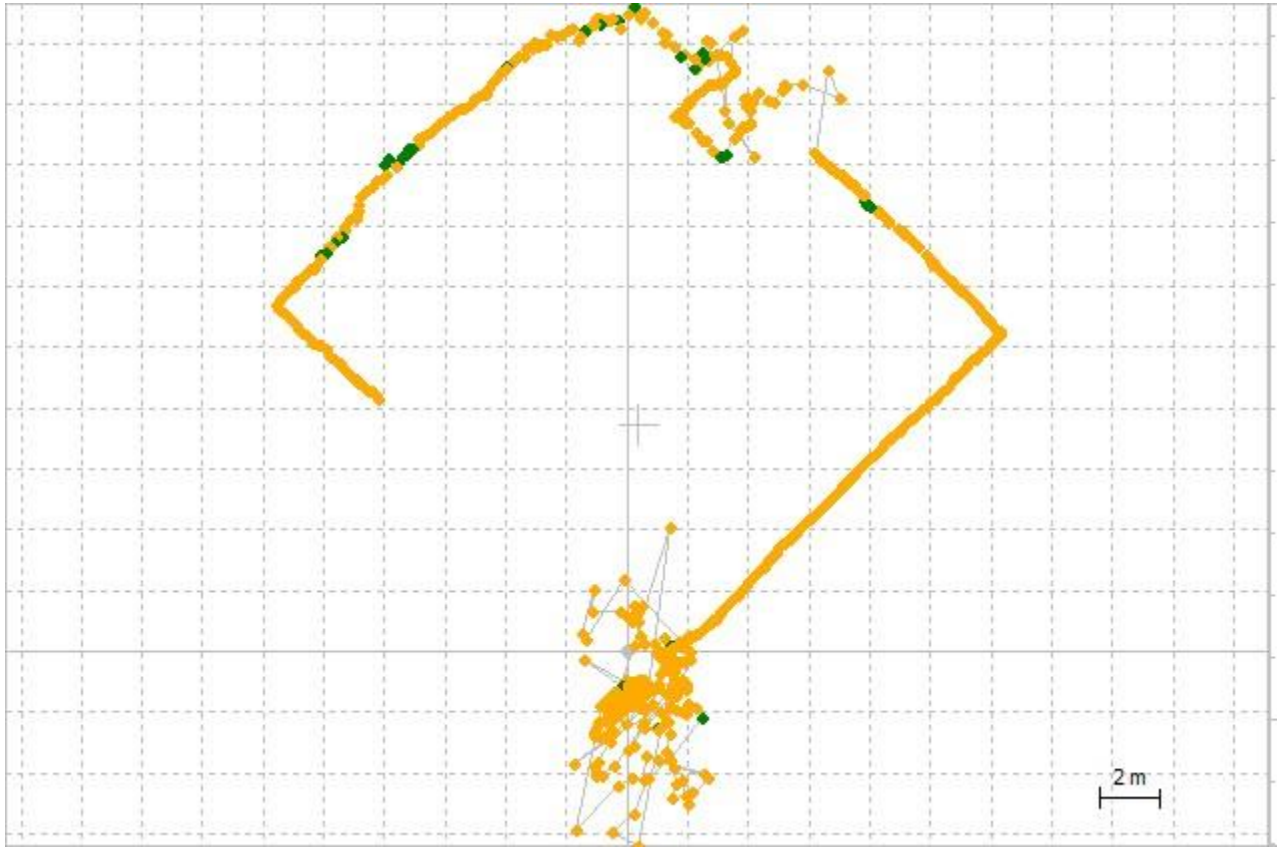
Post-Processing Output: GPS L1 vs GPS + BDS + QZS L1/L5

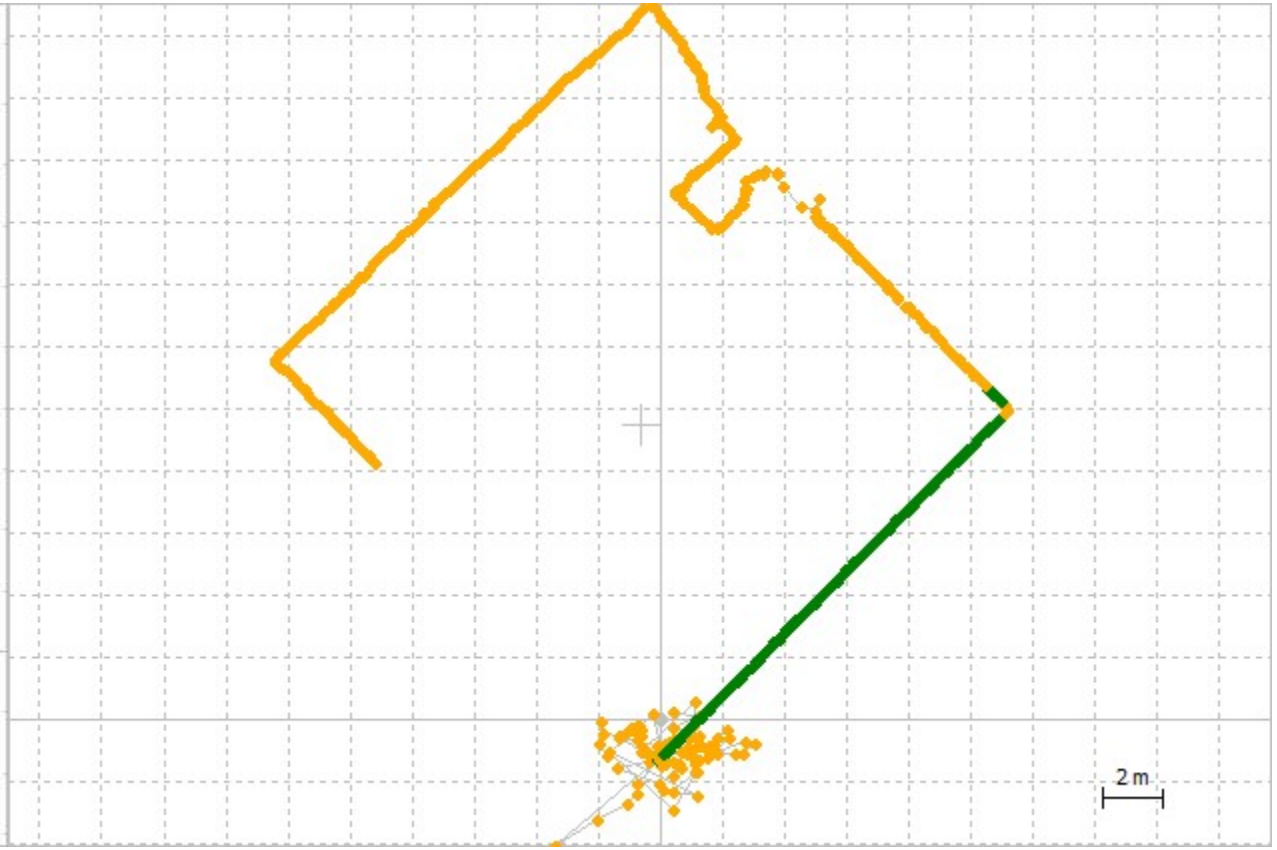




Data logged by Mi8 Smart-phone

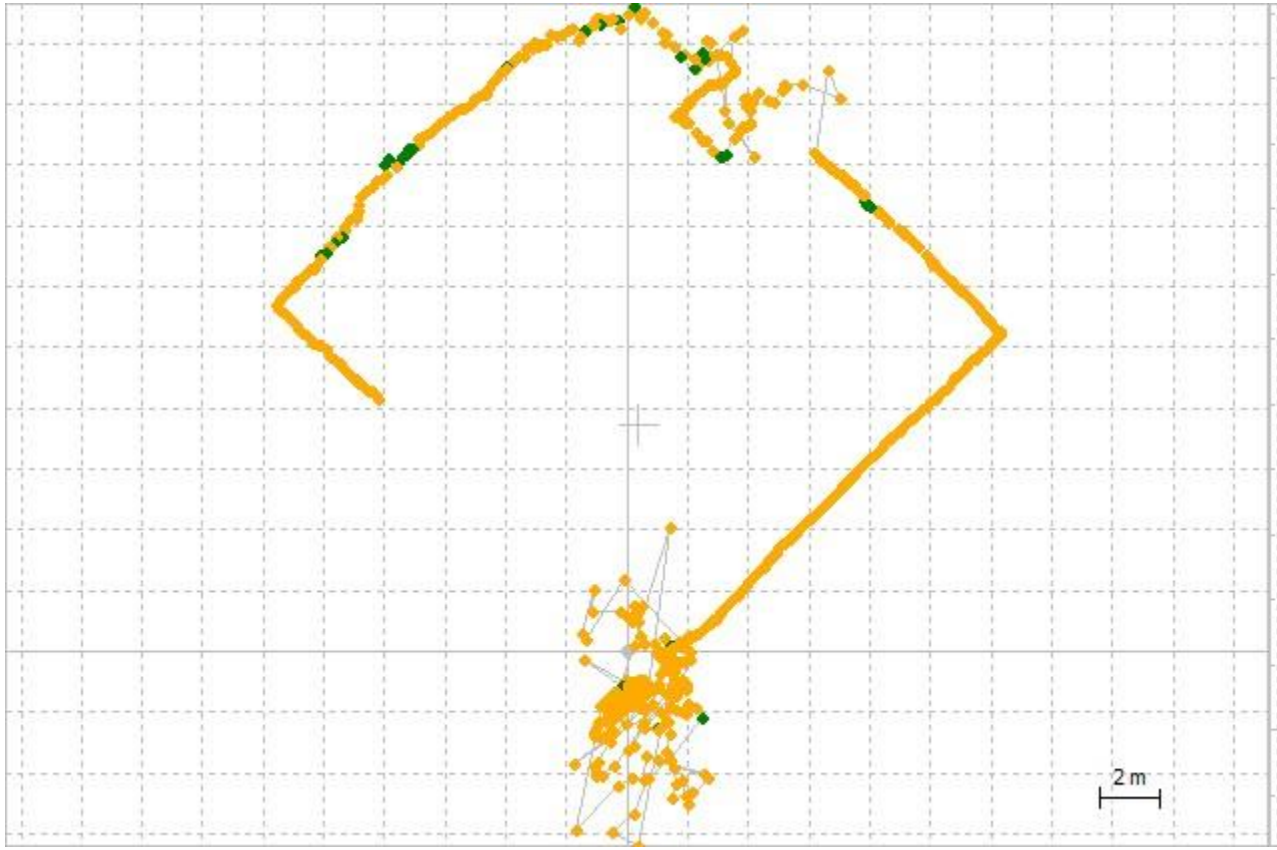
Post-Processing Output: GPS L1 vs GPS + GAL+ BDS + QZS L1

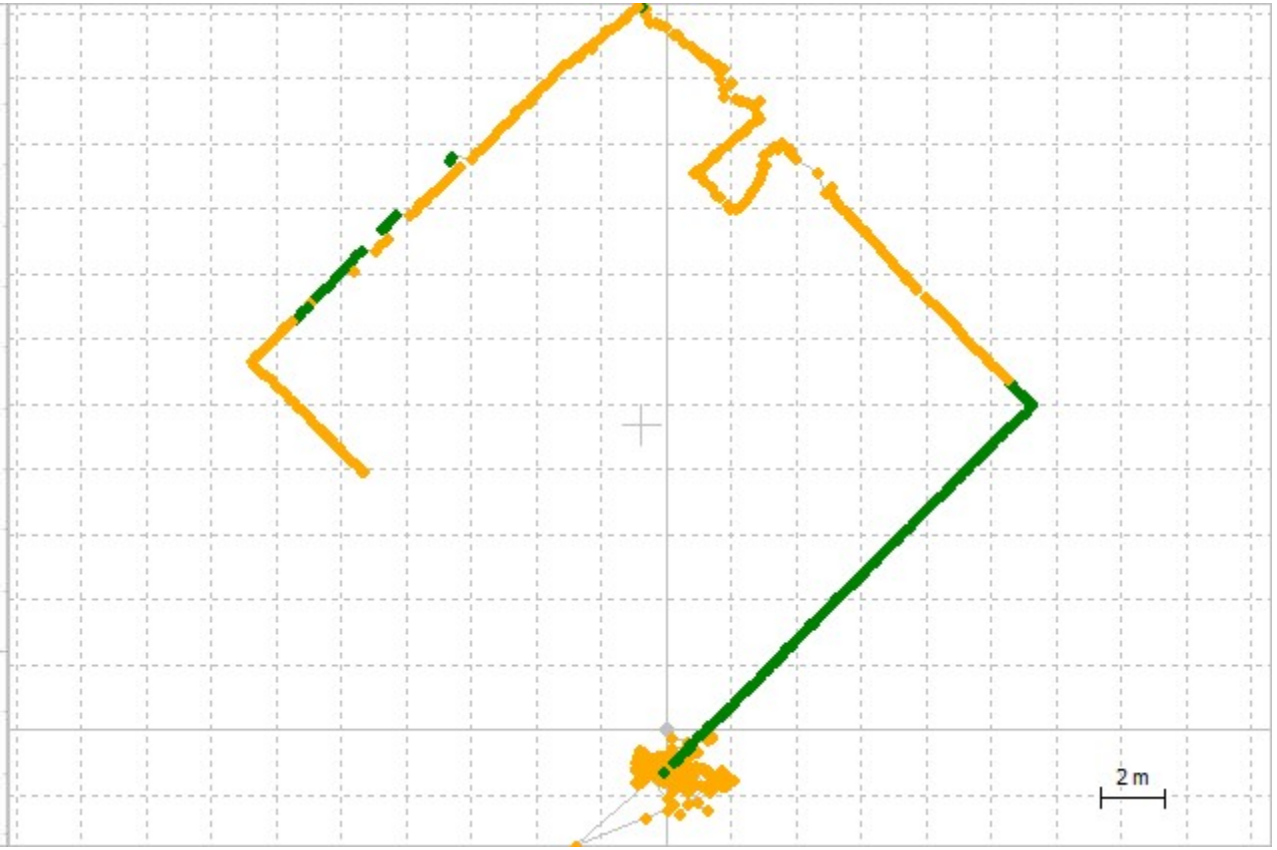




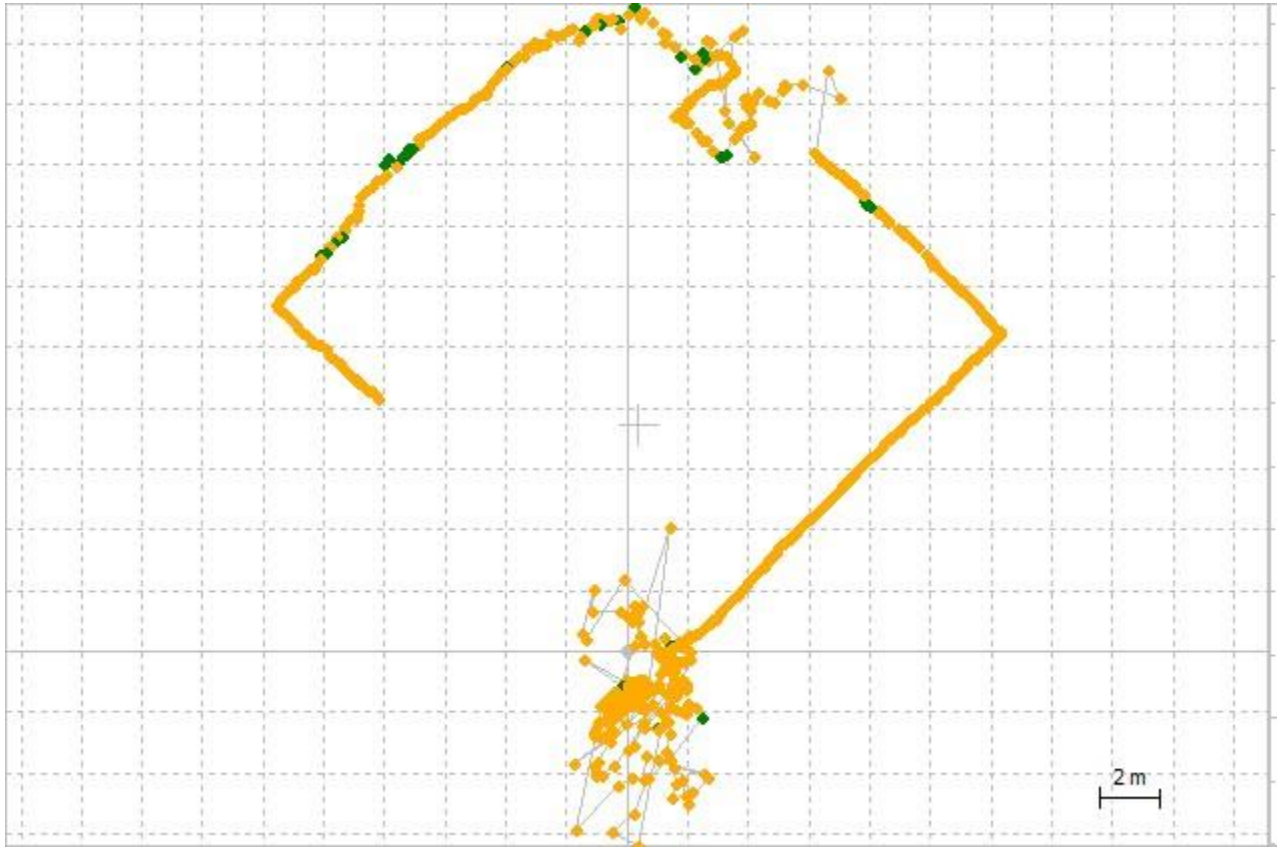
Data logged by Mi8 Smart-phone

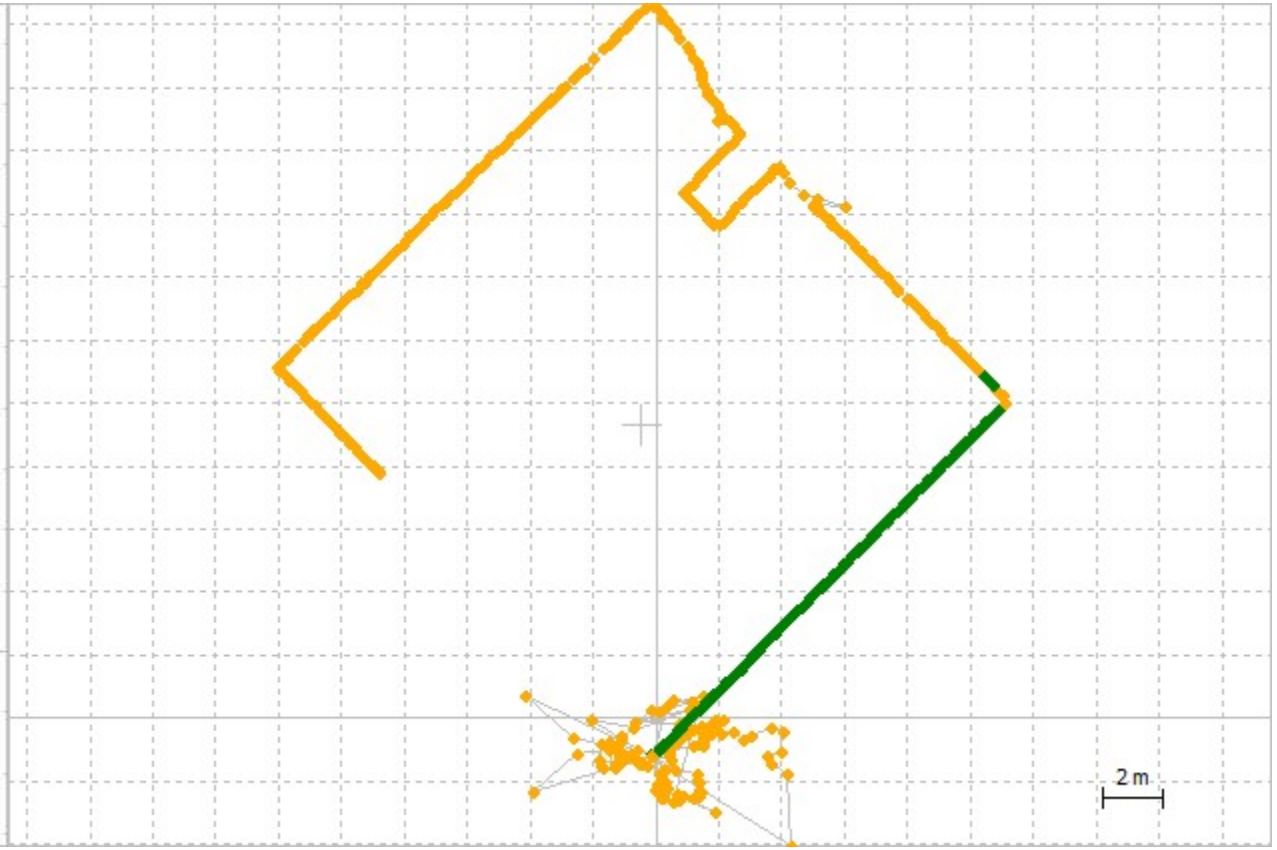
Post-Processing Output: GPS L1 vs GPS + GAL+ BDS + QZS L1/L5





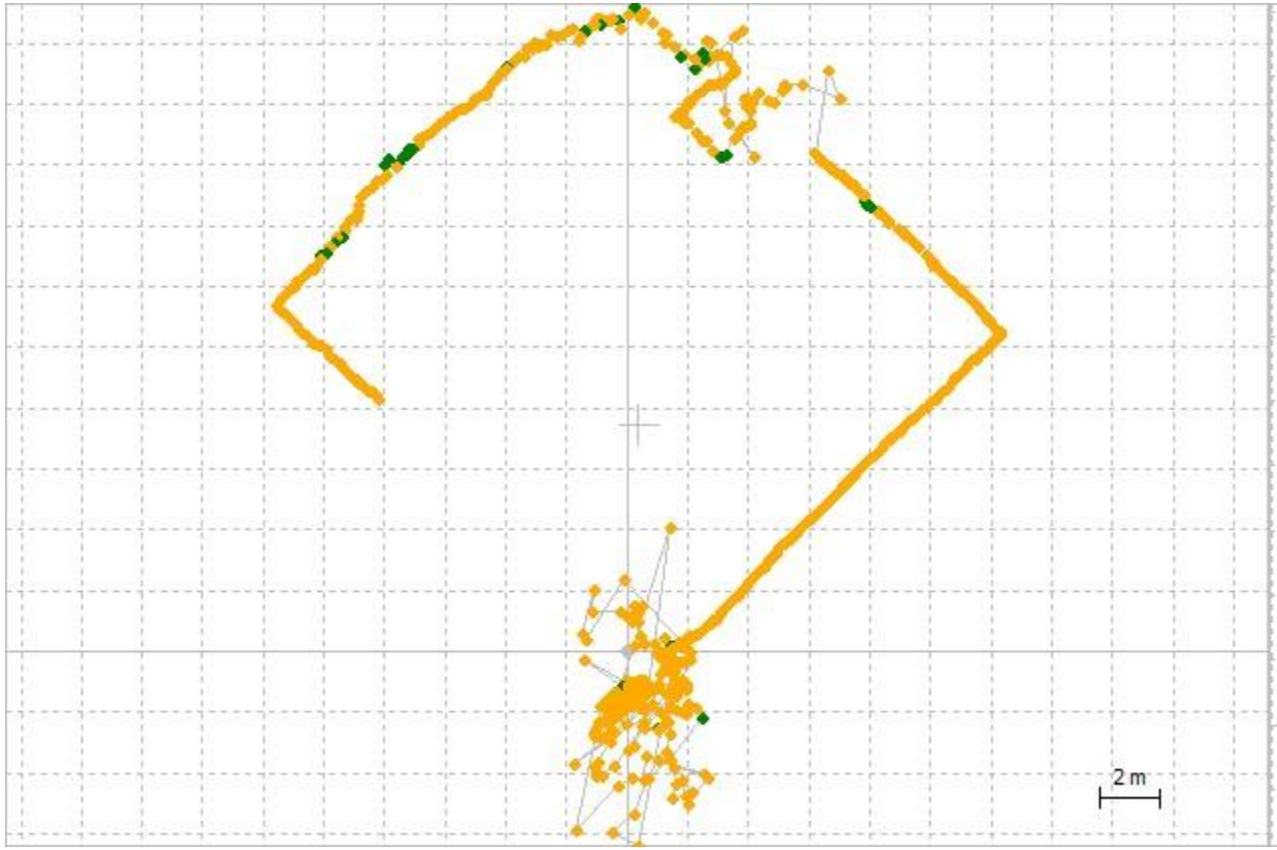
Post-Processing Output: GPS L1 vs GPS + GLO + GAL+ BDS + QZS L1

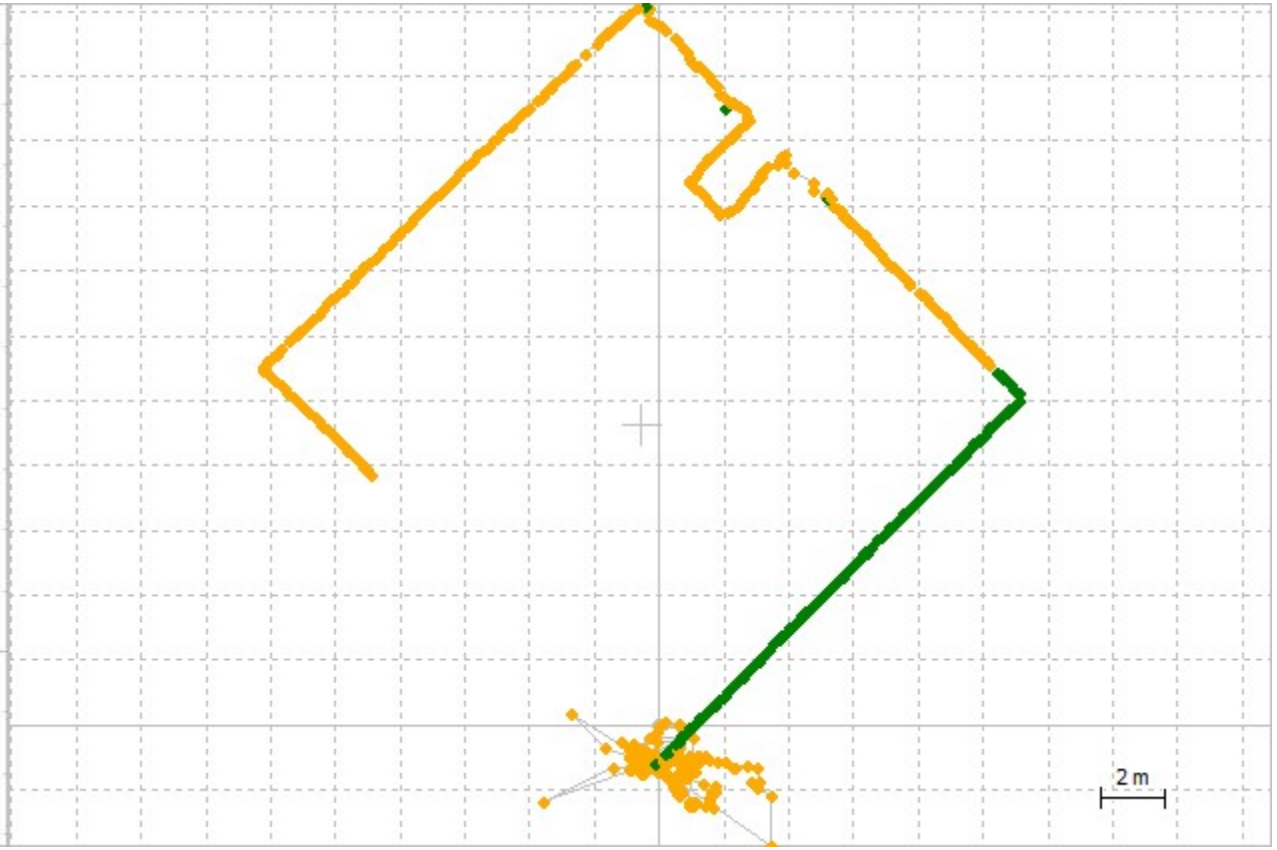




Data logged by Mi8 Smart-phone

Post-Processing Output: 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

Additional Information

Please visit website at

https://home.csis.u-tokyo.ac.jp/~dinesh/index.htm

Contact:

dinesh@csis.u-tokyo.ac.jp

Sample Raw Data can be downloaded to Check Accuracy of RTK Processing

1. High-End Base (NetR9) Data vs Low-End Rover (u-blox M8T) Data
2. Low-End Base (u-blox M8T) Data vs Low-End Rover (u-Blox M8T) Data