

Workshop on GNSS for Policy and Decision Makers 21st January 2022

Low-Cost and Smart-Phone Receiver Systems

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High-End Survey Grade Receivers

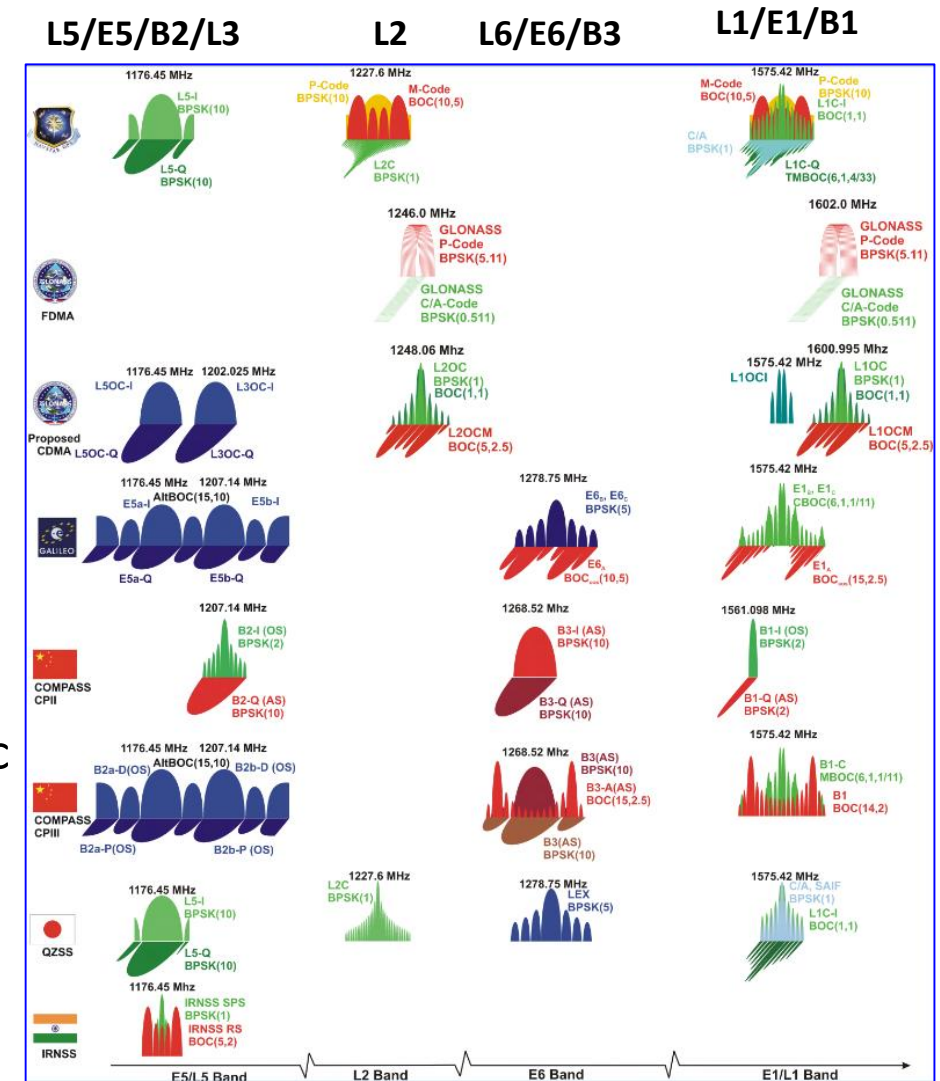
- Multi-frequency

- GPS : L1/L2/L5
- GLONASS : L1/L2/L3
- GALILEO : E1/E5/E6
- BDS : B1/B2/B3
- QZSS : L1/L2/L5/L6
- NAVIC : L5/S

- Multi-system

- GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc

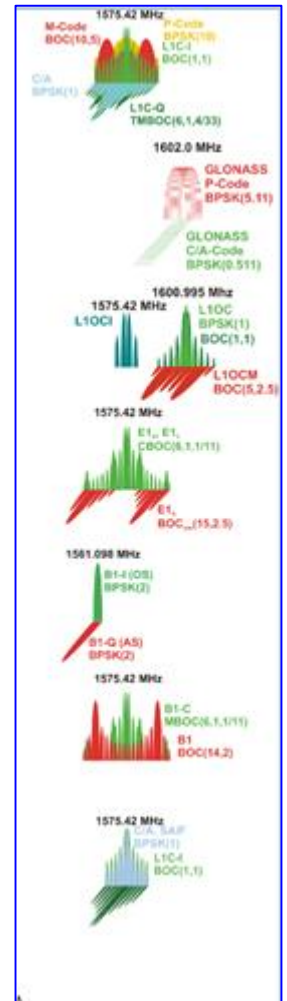
- Price varies from \$3,000 to \$30,000 or more (including antenna)



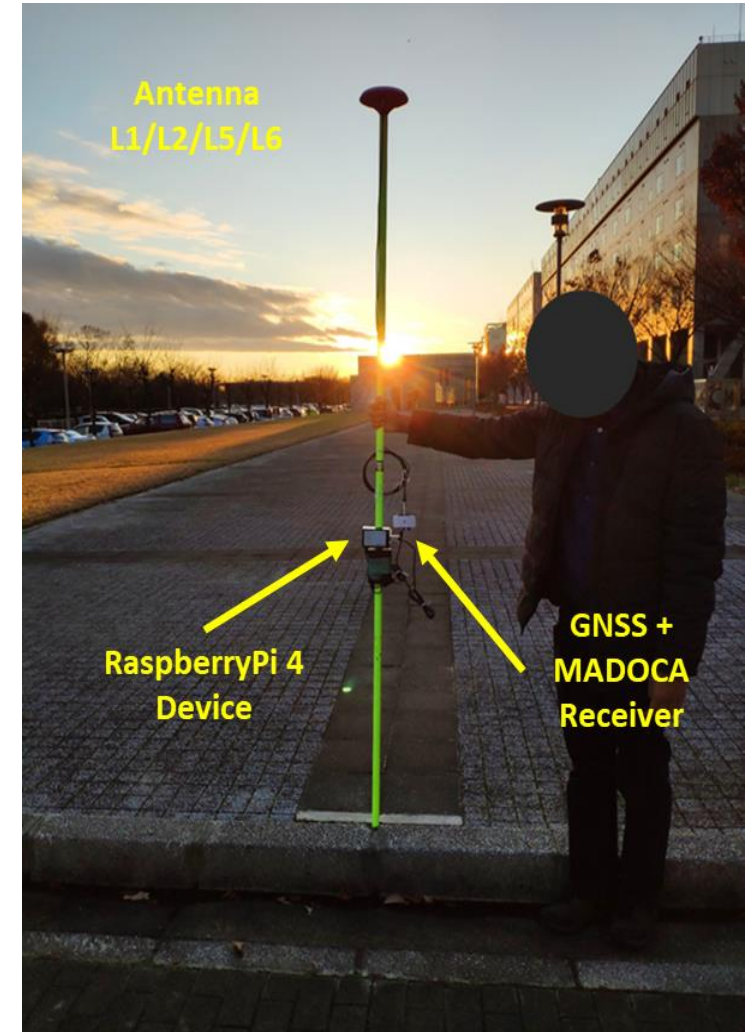
Low-Cost Receivers

- Multi-System
 - GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
- Basically Single Frequency
 - L1/E1/B1-Band
 - Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
 - Future trend for Mass Market System will be L1/L5
 - Some chip makers have already announced Multi-System, Multi-Frequency GNSS Chips for Mass Market
- Low Cost:
 - Less than \$1,000
 - Our Target: \$100 including everything. (L1 band only receiver)
 - But, currently about \$300 including Antenna and all necessary Hardware, Software
 - This is using Dual-Band Receiver and Antenna
 - In future, dual band low-cost receivers based on L1/L2 and L1/L5 will be available

L1/E1/B1*



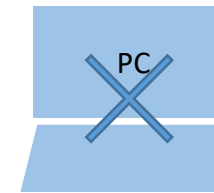
Low-Cost High-Accuracy Receiver Systems RTKDROID, MADROID, MAD-WIN, MAD- π



Objectives

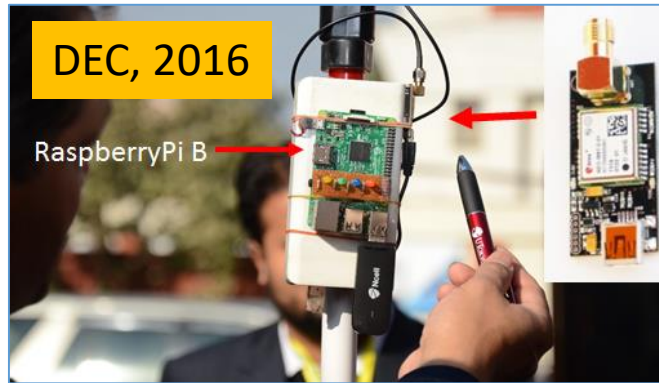
- Develop Low-Cost High-Accuracy Positioning Systems (L-CHAPS)
 - System Integration of commercially available receiver or module
 - For RTK and MADOCA
 - Avoid use of computer to minimize the cost
 - Use Single Board Computer (SBC)
 - RaspberryPi, Arduino, Spresense
 - Use Tablet or Smart-Phone
 - Android devices are quite flexible and easier to use
- Develop Easy to Use System in Field
 - A user without GNSS knowledge shall be able to use
 - Self-understanding interface
 - Suitable for remote operation and data logging
 - Operate with mobile power-banks
- Promote GNSS and MADOCA Technologies Abroad through
 - Lectures, Trainings, Seminars, Workshops and Events
 - Joint Research and Joint Projects

RTKDROID
MAD- π
RTKLIB
MADROID
MAD-WIN



We have no intention to prefer any brand names mentioned in these slides. They are used only for reference.

Low-Cost High-Accuracy Receiver system Development Cycle

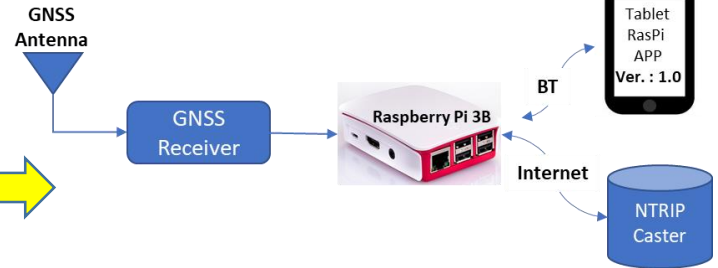


DEC, 2016

RaspberryPi B

MAY, 2017

Low-Cost RTK

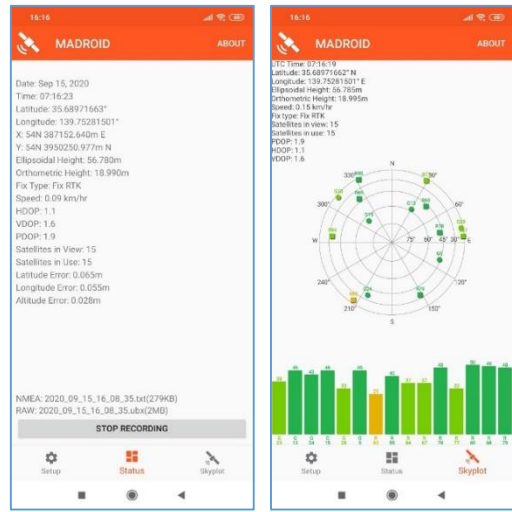


MAR, 2018

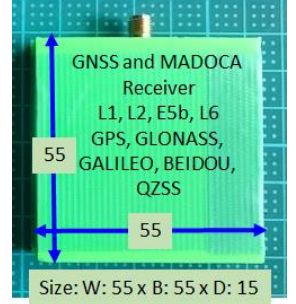
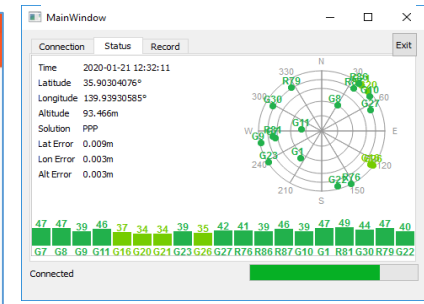


Android Device
RTK / MADOCA / EWS / SAR
System
2022

Enhancement of
MADOCA System
2021



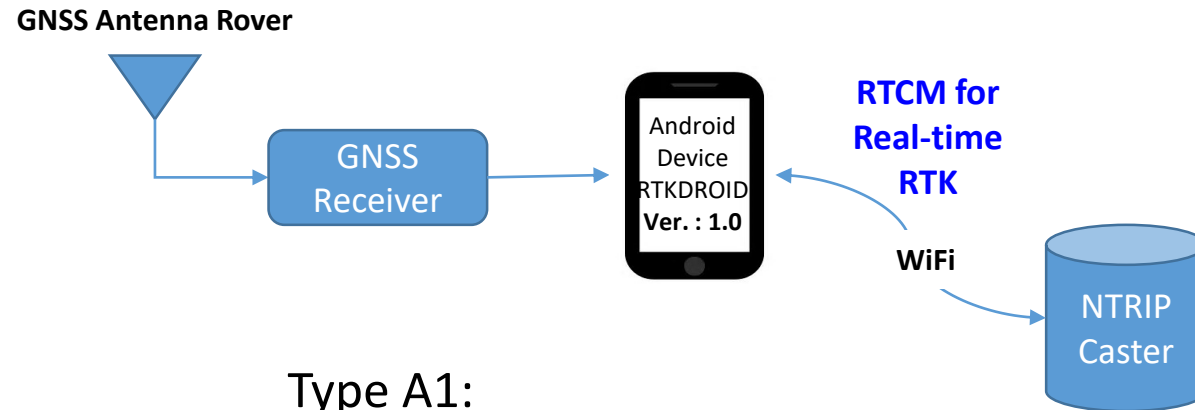
Low-Cost MADOCA



DEC, 2019

What type of smart-phone
will emerge by 2025 ?

Type – A1: GNSS Receiver with Android Device



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



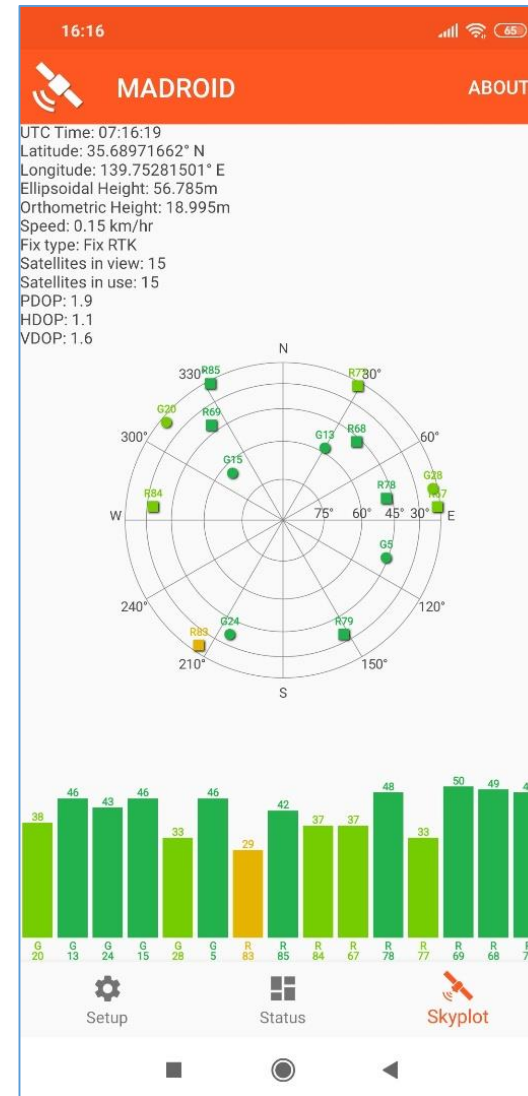
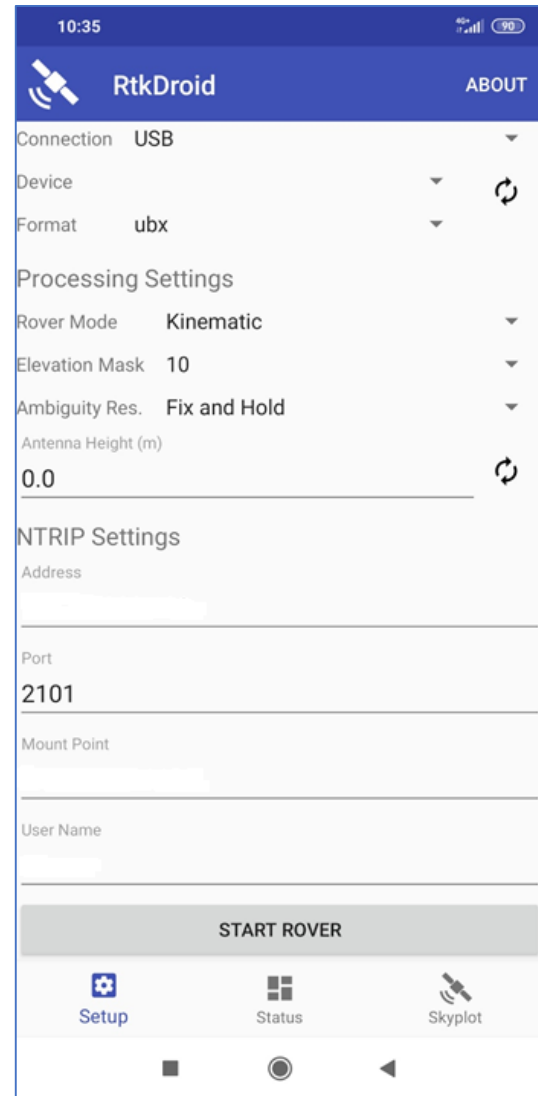
GNSS Receiver Module

Screen Shots of RTKDROID and MADROID

Connect GNSS receiver to Android device

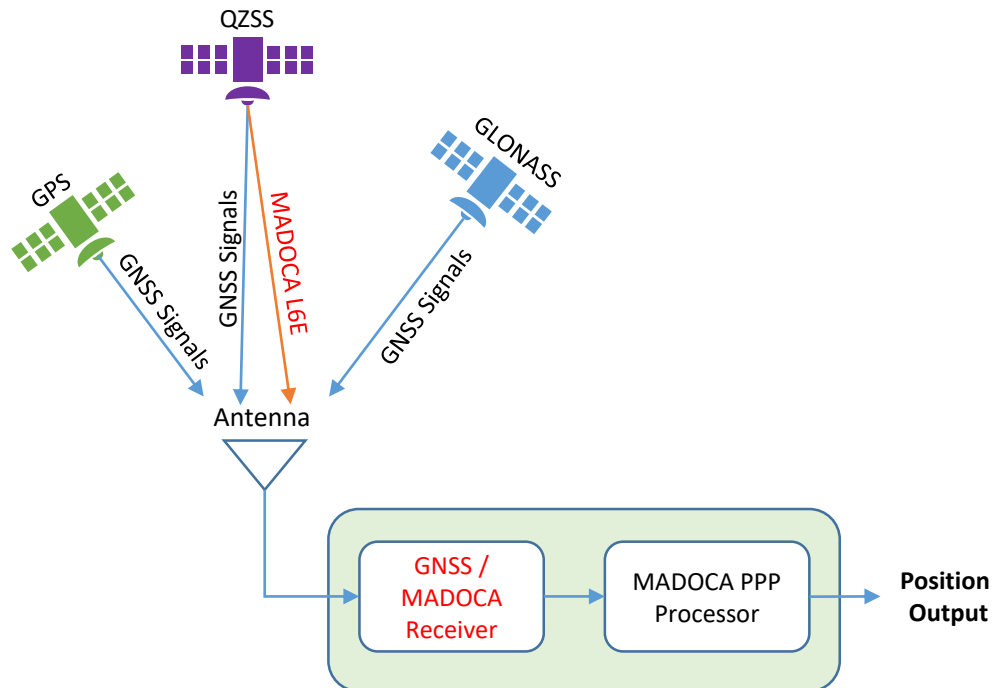
(1) RTKDROID :
For RTK or PPK

(2) MADROID:
for MADOCA-PPP,
MADOCA-PPP/AR (future)

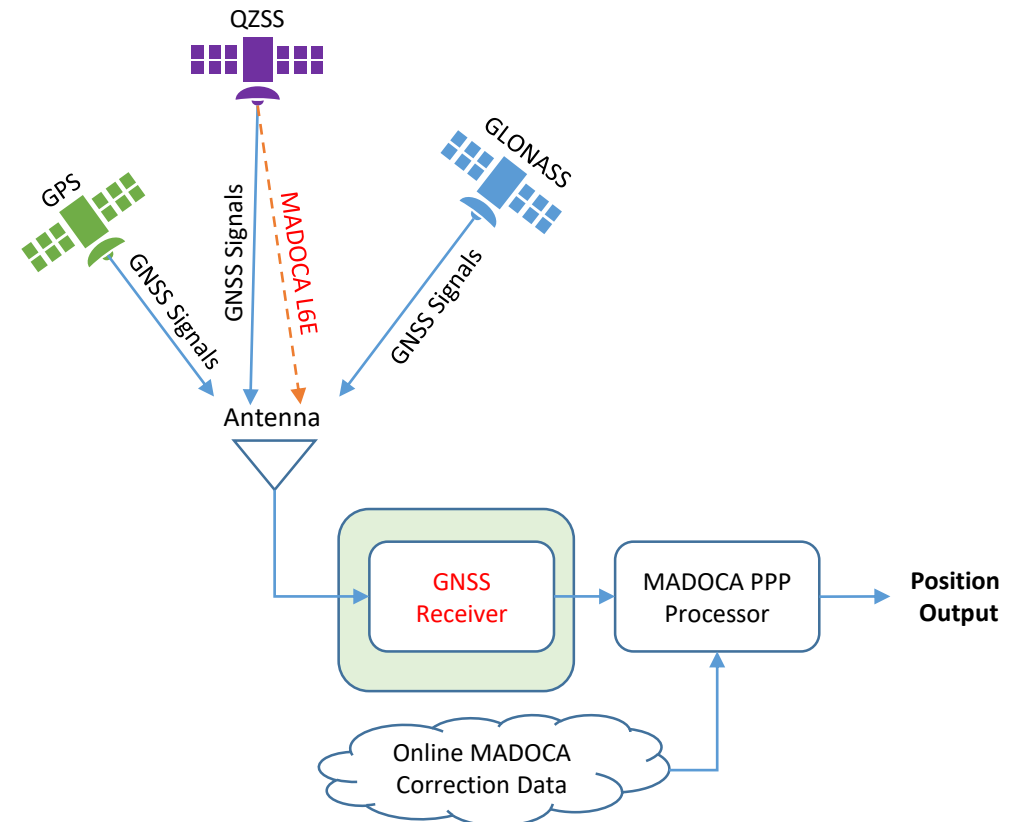


MADOCA System: Direct from QZSS or Online Correction Data

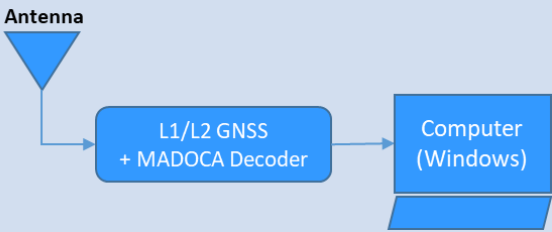
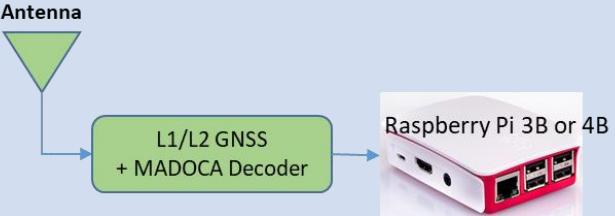
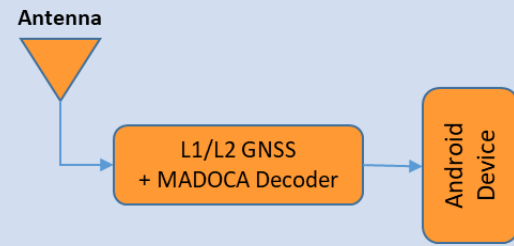
GNSS Receiver + MADOCA Decoder



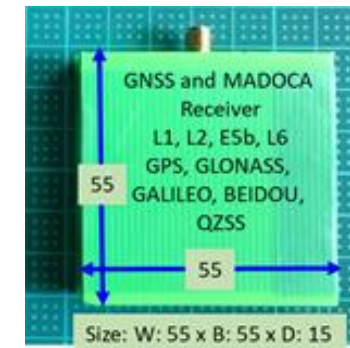
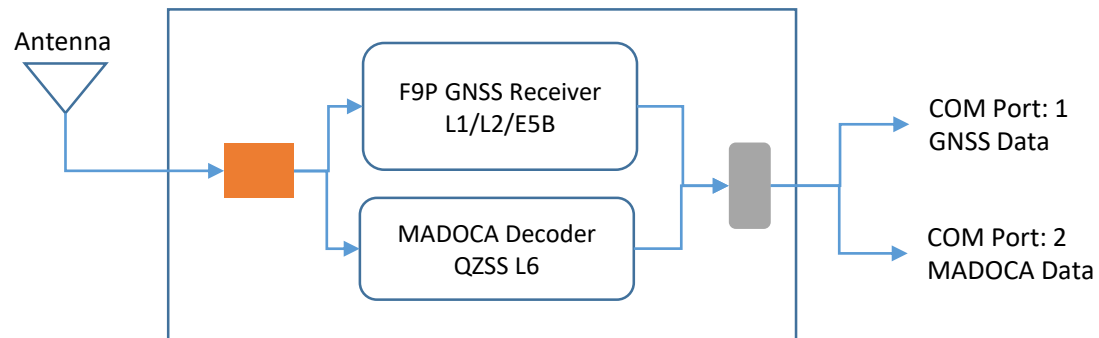
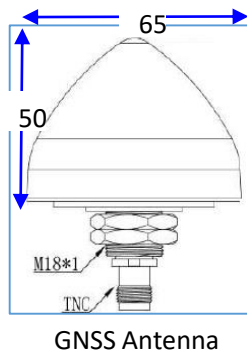
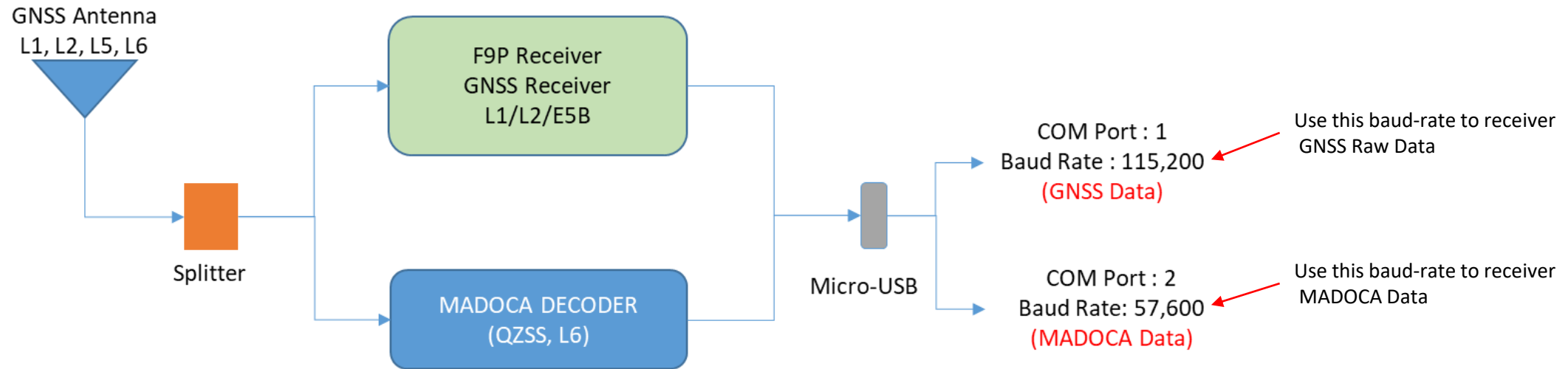
GNSS Receiver Only



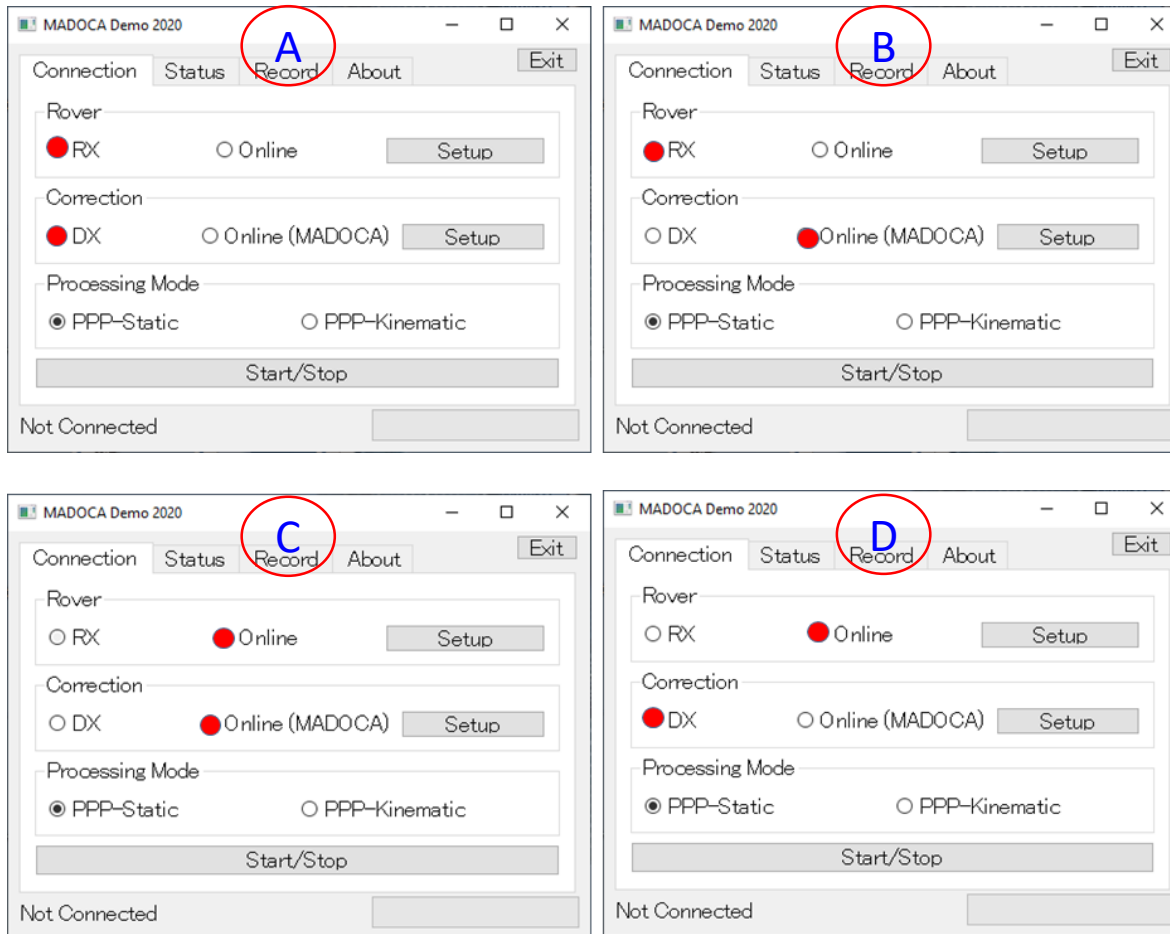
Low-Cost MADOCA Receiver Systems: Product Types

	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction Data only)
GNSS Receiver Data Format	UBX, SBF, RTCM3	UBX SBF, RTCM3 (For online GNSS data)	UBX
MADOCA Correction Data Format (Satellite)	UBX only	UBX only	NA
MADOCA Correction Data Format (Online)	Online Services from GPAS, UTokyo (Test Level) UBX or RTCM3	Online Services from GPAS, UTokyo (Test Level) Online Services UBX or RTCM3	GPAS Services, RTCM3 UTokyo Online Service in the next release
System Architecture			

MADOCA PPP Receiver System



MAD-WIN / MAD-PI User Interface



Cases	GNSS Receiver	MADOCA Correction Data	Selection Setting in the Program
Case A	Connect Receiver Directly	Connect MADOCA Receiver Directly	RX and DX
Case B	Connect Receiver Directly	Get MADOCA correction data through NTRIP	RX and Online (MADOCA)
Case C	Connect Receiver though NTRIP	Get MADOCA correction data through NTRIP	Online and Online (MADOCA)
Case D	Connect Receiver though NTRIP	Connect MADOCA Receiver Directly	Online and DX

MAD-WIN / MAD-PI User Interface

The image displays three screenshots of the MADOCA Demo 2020 software interface, showing different views of the user interface.

Left Screenshot: Connection and Processing Mode

- Connection: RX (selected), Online
- Correction: DX (selected), Online (MADOCA)
- Processing Mode: PPP-Static (selected), PPP-Kinematic
- Buttons: Setup, Start/Stop, Exit
- Status: Connected (indicated by a green bar)

Middle Screenshot: Real-time Data and Constellation Diagram

Time: 2020-09-30 01:12:24
 Latitude: 35.68970411°
 Longitude: 139.75278573°
 Altitude: 57.353m
 Solution: PPP
 Lat Error: 0.074m
 Lon Error: 0.132m
 Alt Error: 0.075m

The constellation diagram shows satellites G1 through G17 and R6 through R8. Below the diagram, a bar chart displays signal strength for various satellites: G2 (49), G6 (45), G9 (42), G12 (41), G17 (45), G19 (48), R65 (47), R66 (53), R72 (52), R81 (47), R87 (49), R88 (51), G5 (44).

Status: Connected (indicated by a green bar)

Right Screenshot: Recording and Device Information

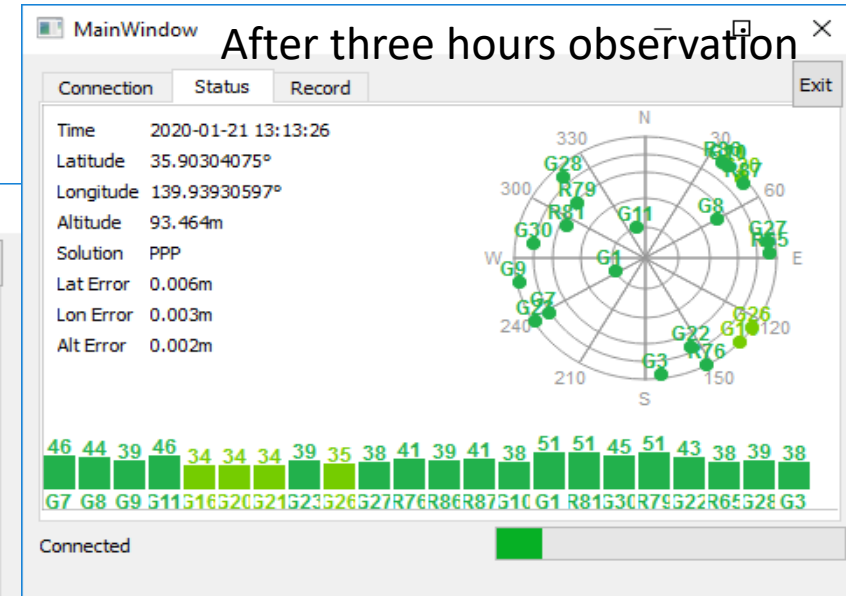
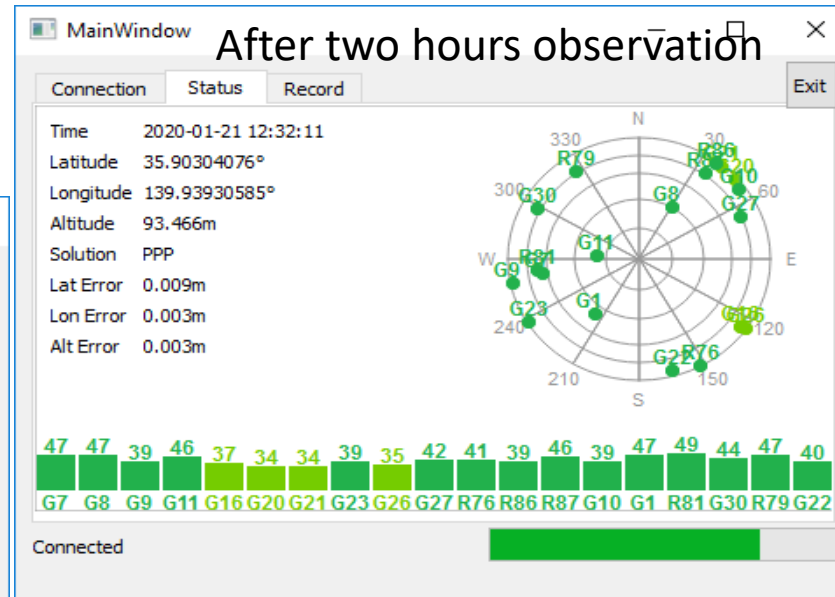
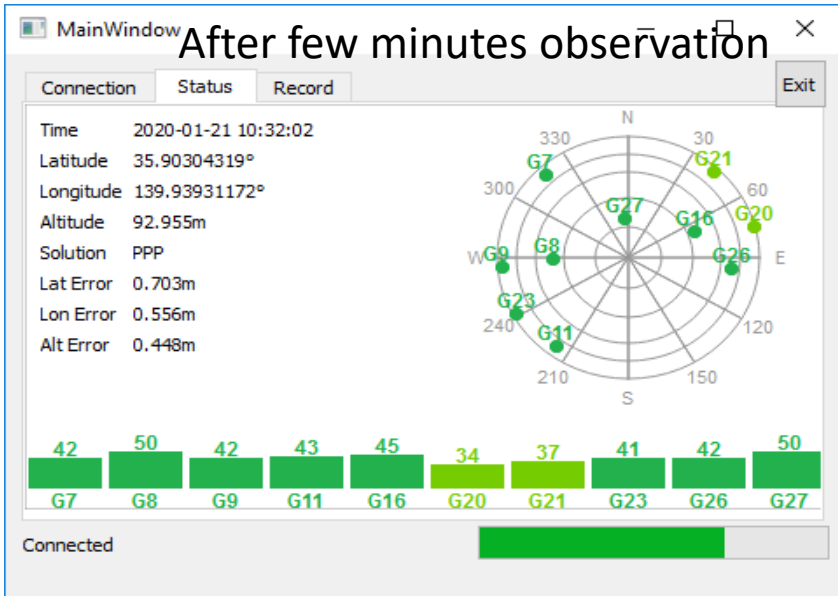
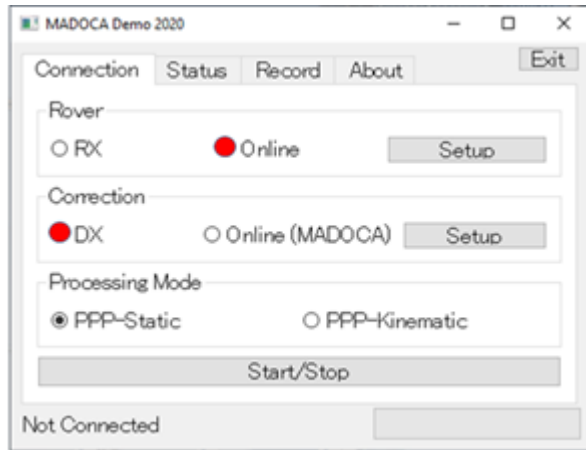
- Device: Windows
- Solution: 2020-09-30_010212.nmea(365568)
- Rover: 2020-09-30_010212.ubx(2855936)
- Correction: 2020-09-30_010212.ubx(345088)
- Buttons: Record On/Off, Exit
- Status: Connected (indicated by a green bar)

Log Files:

1. Solution: MADOCA PPP Solution in NEMA format
2. Rover: Rover RAW Data in receiver's proprietary format
Can be used for PPK (Post-Processing Kinematic) Solution or Post-Processing PPP
3. Correction: MADOCA PPP Correction Data in receiver's proprietary format
Can be used for Post-Processing MADOCA

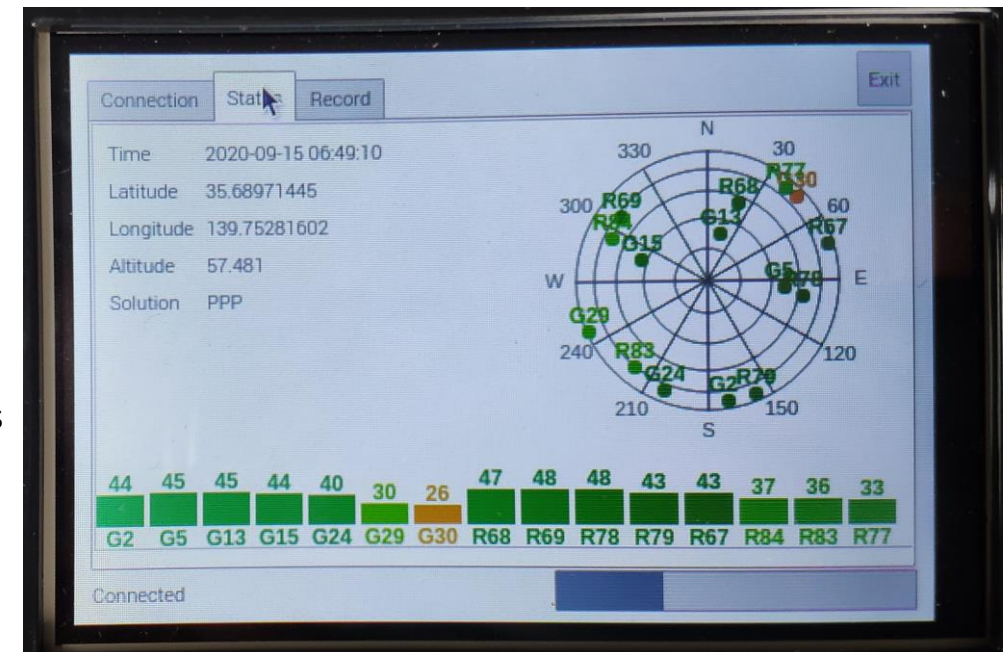
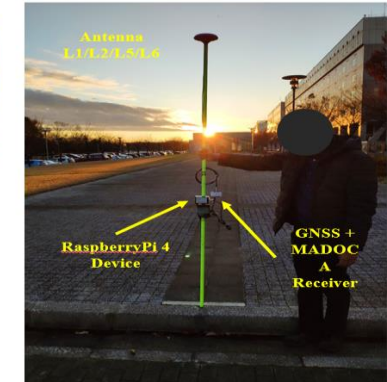
MAD-WIN Data Observation

Receiver: Online receiver access in Kashiwa / Correction Data: MADOCA Receiver in Bali



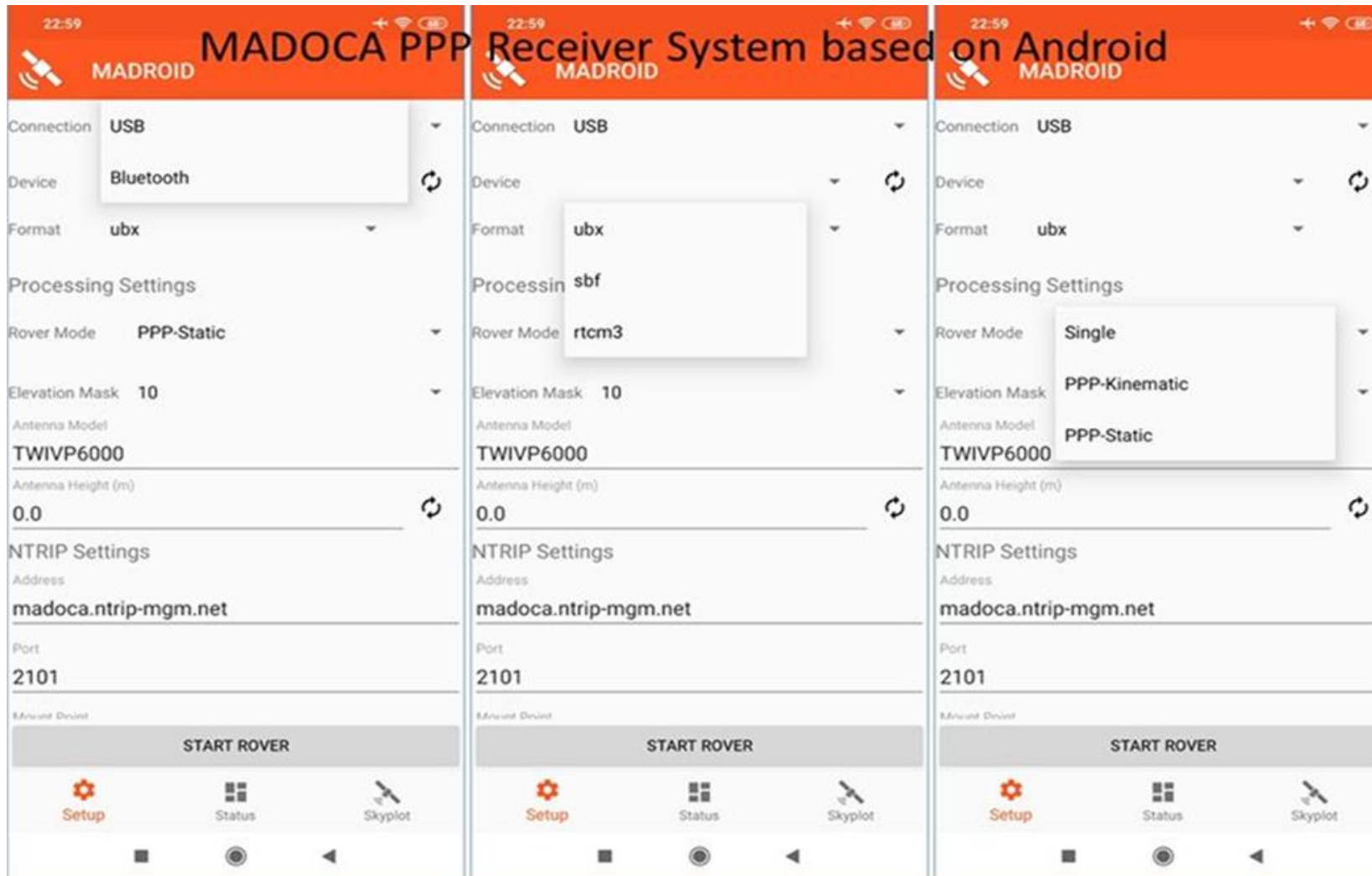
MAD-PI:MADOCA with RaspberryPi Device

- MAD-Pi has been tested with RaspberryPi-3B device
 - It also works with RaspberryPi-4B
 - If the device does not work, please try with a different USB port
- Do not remove and insert SD Card several times. It may get damaged.
- Observation data can be logged to an external USB memory disk. Memory drive of upto 64GB is supported.
 - Files are created at 6-hour interval with Date/Time based filename.
- Ras-Pi 4 device consumes more power than Ras-Pi 3 device. Continuous operation of the device will generate heat. Keep the device in well ventilated area
 - Do not keep the device in a closed box
- We have set both Ras-Pi 3 and Ras-Pi 4 devices with touch screens for easy operation.
 - Mouse and External keyboard can be connected either via BT or USB ports
- Ras-Pi device can be connected by an Android device using BT



Raspberry-Pi device with Touch Screen

MADROID: MADOCA with Android Device



MADROID: MADOCA with Android Device

The image displays three sequential screenshots of the MADROID application interface on an Android device. The top bar of each screen is orange and contains the text 'MADROID' and a satellite icon.

- Left Screenshot (14:34):** Shows the configuration screen. It includes sections for 'Connection' (USB), 'Device' (u-blox GNSS receiver), 'Format' (ubx), 'Processing Settings' (Rover Mode: PPP-Static, Elevation Mask: 10, Antenna Model: TWIVP6000), and 'NTRIP Settings' (Address: madoca.ntrip-mgm.net, Port: 2101, Mount Point: MDC0). A 'START ROVER' button is at the bottom.
- Middle Screenshot (14:27):** Shows the real-time data and skyplot screen. It displays UTC Time (05:27:17), coordinates (Latitude: 35.90202657° N, Longitude: 139.93857286° E), and various DOP values. A skyplot shows satellite positions, and a bar chart at the bottom shows signal strength for satellites G20 through G29.
- Right Screenshot (14:34):** Shows the status screen. It displays Date (Dec 25, 2019), Time (05:34:17), coordinates, X and Y coordinates, Ellipsoidal and Orthometric Heights, Fix Type (PPP), Speed (0.11 km/hr), and error values (Latitude Error: 0.191m, Longitude Error: 0.171m, Altitude Error: 0.104m). A 'STOP RECORDING' button is at the bottom.

GNSS Data from Android Device

GNSS Data from Android Smart-Phone

- Android device can output GNSS only position data
 - Since it uses multiple satellite systems and some device also uses L1 and L5 bands – Accuracy is much better
- Many Android devices with OS 7.0 or higher can output Raw Data
 - These data are used for High-Accuracy data processing such as RTK
- Some devices have Multi-Frequency (L1/L5) GNSS receiver
 - Multi-System (GPS, GLONASS, GALILEO, BEIDOU, QZSS, NavIC)
 - Multi-Frequency (L1/E1/B1, L5/E5)
 - Outputs more than 40 channels
 - Some devices output NAV BIT Data, AGC values and Antenna Phase Center
- Google APIs are available to process GNSS raw data from a smart-phone

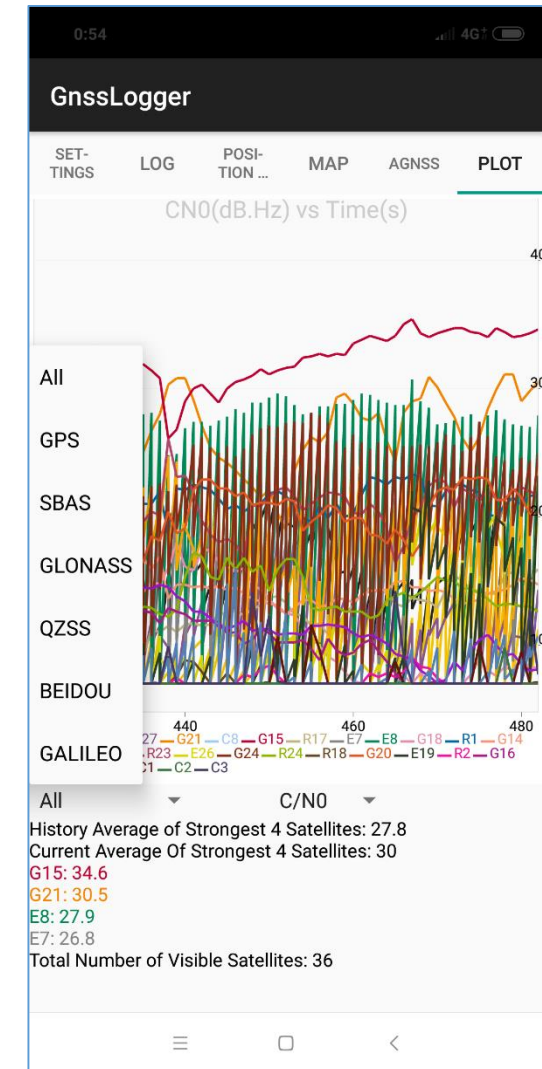
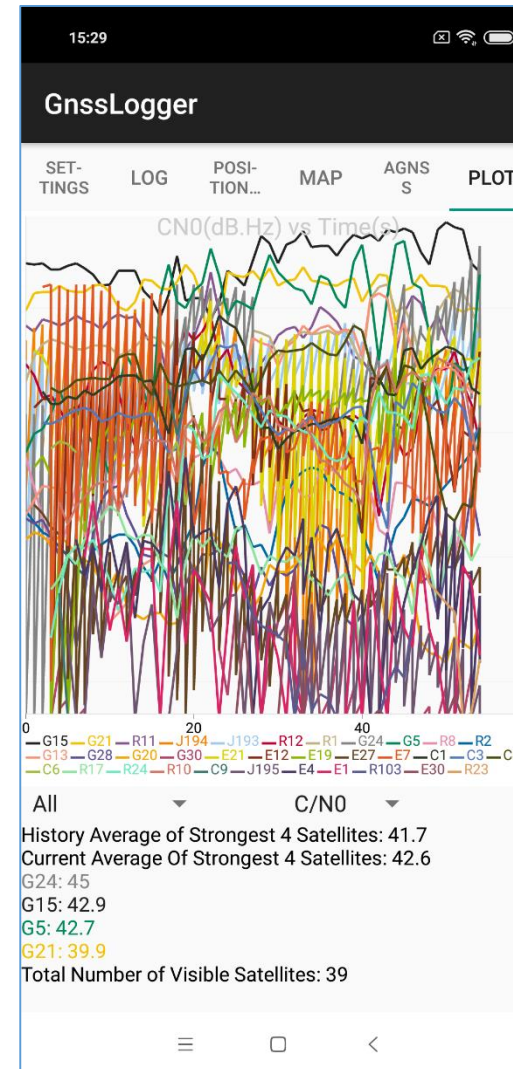
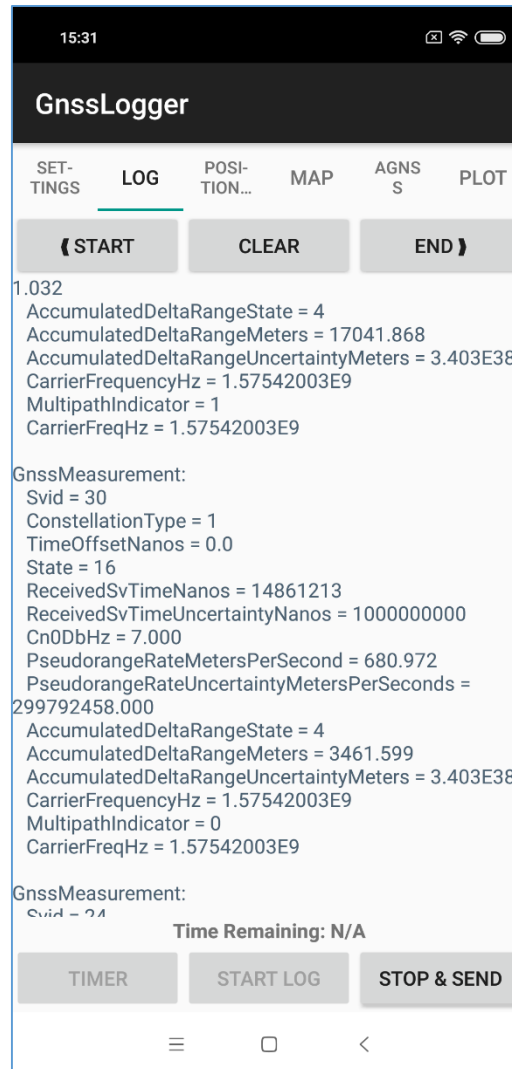
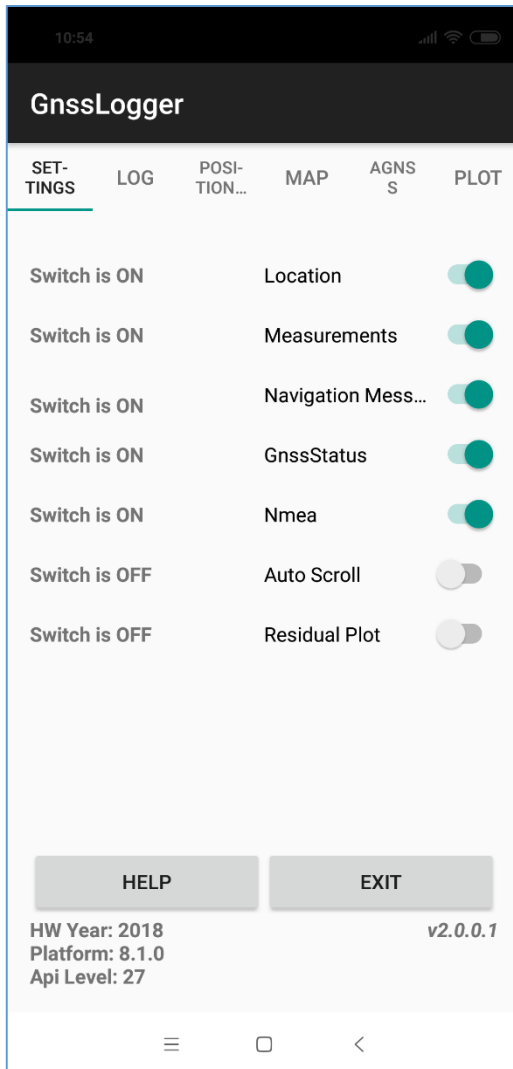
GNSS Raw Data Compatible Smart-Phones

This List is Old. Please check for New List

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

Check → <https://developer.android.com/guide/topics/sensors/gnss> for Latest Updates

Android Raw Data Logging Tool – 1: GnsLogger



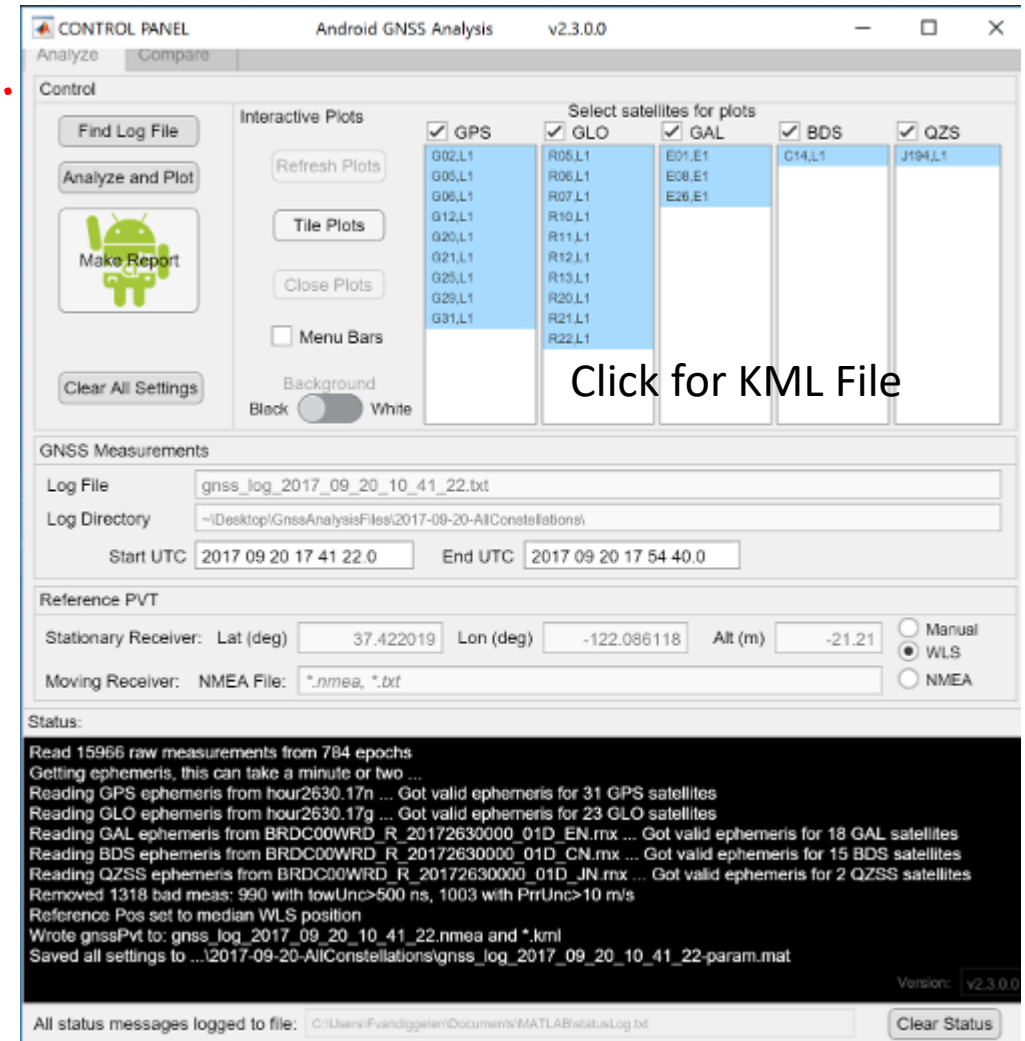
GNSS Raw Data Analysis Tool for GnsLogger

• 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)

<https://developer.android.com/guide/topics/sensors/gnss#releaseGNSS> Analysis app v2.6.3.0 release notes.

New Version V4.0.0.0 is available.
Download new version



The GNSS Analysis app is built on [MATLAB](https://www.mathworks.com/), 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.

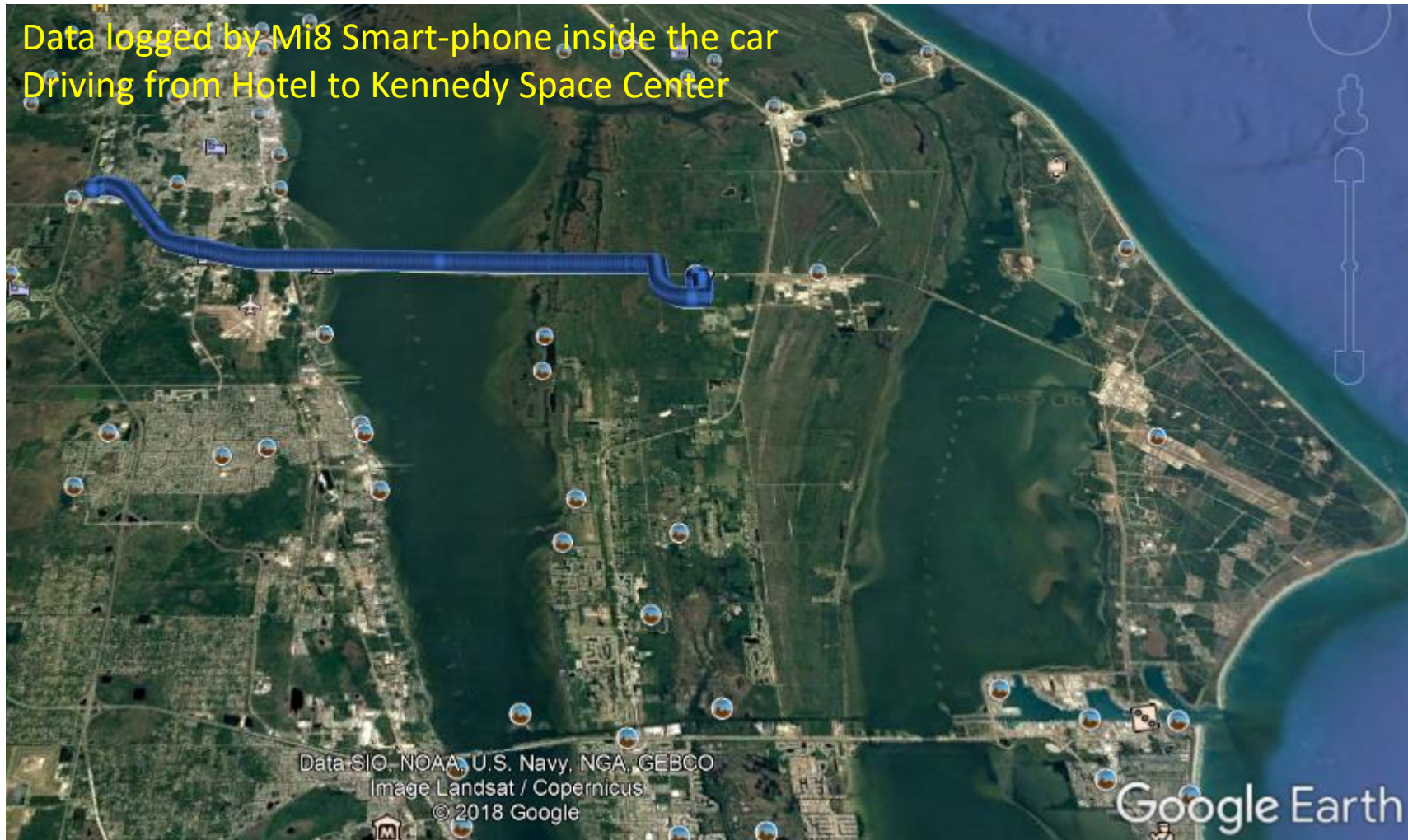
Position Output from Android GNSS Receiver, Tokyo University, Komaba Campus

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



Output from GNSS Analysis Tool, Data Logged by GNSSLogger

Location:
Kennedy Space Center
Florida



Output from GNSS Analysis Tool, Data Logged by GNSSLogger



Xiaomi Mi11 Lite 5G Screen Shots

13:38

Status

Lat: 35.85
Long: 139.8
Alt (MSL): 8.3 m
Speed: 0.0 m/s
S. Acc: 0.1 m/s
PDOP: 0.5

Time: 13:38:26
TTFF: 2 sec
E/H/V Acc: 3.8/2.5 m
Sats: 43/55/64
Bearing: B. Acc:
H/V DOP: 0.3/0.4

ID	GNSS	CF	C/N0	Flags	Elev	Azim
10	L1	43.0	AEU	39°	220°	
12	L1	37.0	AE	39°	220°	
10	L1	33.3	AEU	48°	48°	
23	L1	46.2	AEU	19°	188°	
23	L5	40.2	AEU	19°	188°	
24	L1	32.5	AEU	20°	74°	
24	L5	32.4	AEU	20°	74°	
25	L1	30.8	AEU	82°	106°	
25	L5	32.6	AEU	82°	106°	
26	L1	24.4	AE	3°	221°	
26	L5	20.2	AE	3°	221°	
29	L1	30.9	AEU	18°	142°	
31	L1	41.4	AEU	26°	277°	
32	L1	37.1	AEU	60°	319°	
32	L5	29.2	AEU	60°	319°	
2	L1	A	A	2°	154°	
3	L1	46.0	AEU	52°	164°	
4	L1	35.9	AEU	68°	313°	
5	L1	33.7	AEU	16°	329°	
13	L1	20.1	A U	32°	33°	
14	L1-C	38.6	AE	66°	306°	
15	L1	41.1	AEU	26°	246°	
22	L1	A	A	2°	29°	
23	L1	21.7	A	2°	85°	
2	E5a	26.3	AE	88°	260°	
3	E1	40.2	AEU	54°	136°	
3	E5a	33.5	AEU	54°	136°	
5	E1	18.4	A	3°	135°	
5	E5a	16.8	A	3°	135°	
7	E1	21.6	A U	16°	314°	

13:38

Status

2	E5a	28.2	AE	88°	260°
3	E5a	35.5	AE	54°	136°
5	E1	17.0	A	3°	135°
7	E1	25.6	A U	16°	314°
7	E5a	15.4	A	16°	314°
8	E1	37.2	AEU	68°	313°
8	E5a	34.2	AEU	68°	313°
25	E1	31.6	AEU	36°	43°
25	E5a	27.7	AEU	36°	43°
30	E1	38.0	AEU	35°	224°
30	E5a	40.0	AEU	35°	224°
193	L1	39.9	AEU	66°	177°
193	L5	34.2	AE	66°	177°
194	L1	33.2	AEU	76°	183°
194	L5	25.5	AE	76°	183°
195	L5	24.4	AEU	7°	174°
1	B1	35.4	AEU	47°	172°
2	B1	33.6	A U	19°	248°
3	B1	41.2	AEU	37°	223°
4	B1	A	A	42°	148°
6	B1	33.1	AEU	52°	315°
7	B1	37.6	A	19°	206°
8	B1	A	AE	8°	226°
9	B1	31.7	AEU	41°	308°
10	B1	26.0	AEU	8°	210°
12	B1	23.9	A U	9°	109°
13	B1	41.3	AEU	9°	233°
14	B1	31.7	AEU	29°	168°
16	B1	36.7	AEU	60°	325°
23	B1	30.2	AE	19°	252°
23	B2a	22.7	AE	19°	252°
23	B2a	33.6	AE	19°	252°
24	B1	32.8	AEU	43°	46°
24	B2a	22.1	AE	43°	46°
24	B2a	29.7	AE	43°	46°
25	B1	35.8	AEU	64°	288°
25	B2a	32.5	AEU	64°	288°
25	B1C	33.2	AEU	64°	288°
26	B1	A	A	1°	62°

13:38

Status

26	B2a	A	1°	62°	
32	B1	A	7°	323°	
32	B2a	19.8	A	7°	323°
32	B1C	27.4	A	7°	323°
33	B1	47.0	AEU	52°	189°
33	B2a	40.2	AE	52°	189°
33	B1C	50.5	AEU	52°	189°
34	B1	A	6°	135°	
34	B2a	20.5	A U	6°	135°
34	B1C	20.7	A	6°	135°
35	B1	A	A	A	A
35	B2a	18.5	A	A	A
38	B1	A	4°	210°	
38	B2a	22.4	A	4°	210°
39	B1	36.3	AEU	66°	334°
39	B2a	24.3	AEU	66°	334°
39	B1C	34.0	AEU	66°	334°
40	B1	43.0	AEU	27°	192°
40	B2a	41.1	AEU	27°	192°
40	B1C	41.2	AEU	27°	192°
41	B1	40.0	AEU	52°	291°
41	B2a	34.4	AEU	52°	291°
41	B1C	43.7	AEU	52°	291°
42	B1	28.2	A U	8°	158°
42	B2a	23.3	A U	8°	158°
42	B1C	31.5	A	8°	158°
44	B1	A	A U	11°	85°
44	B2a	21.9	A U	11°	85°
44	B1C	35.1	A U	11°	85°
56	B1	A	A	12°	210°
59	1602.000	47.1	A	49°	179°
60	1602.000	44.0	AE	14°	249°
61	B1	A	A	37°	223°
62	B1	A	A	48°	171°
4	L5	30.1	AEU	39°	222°
9	L5	15.8	A	12°	288°

ID	SBAS	CF	C/N0	Flags	Elev	Azim
128	L1	42.0				
137	L1	38.2				

13:39

Sky

Avg C/N0 (dB-Hz): 10 18 27 36 45

Legend

- - NAVSTAR GPS (USA)
- - GLONASS (Russia)
- ▲ - Galileo (European Union)
- ◆ - BeiDou/COMPASS (China)
- - QZSS (Japan)
- - IRNSS/NavIC (India)

13:39

Sky

Avg C/N0 (dB-Hz): 10 18 27 36 45

Legend

Global Navigation Satellite Systems (GNSS)

- - NAVSTAR GPS (USA)
- - GLONASS (Russia)
- ▲ - Galileo (European Union)
- ◆ - BeiDou/COMPASS (China)
- - QZSS (Japan)
- - IRNSS/NavIC (India)

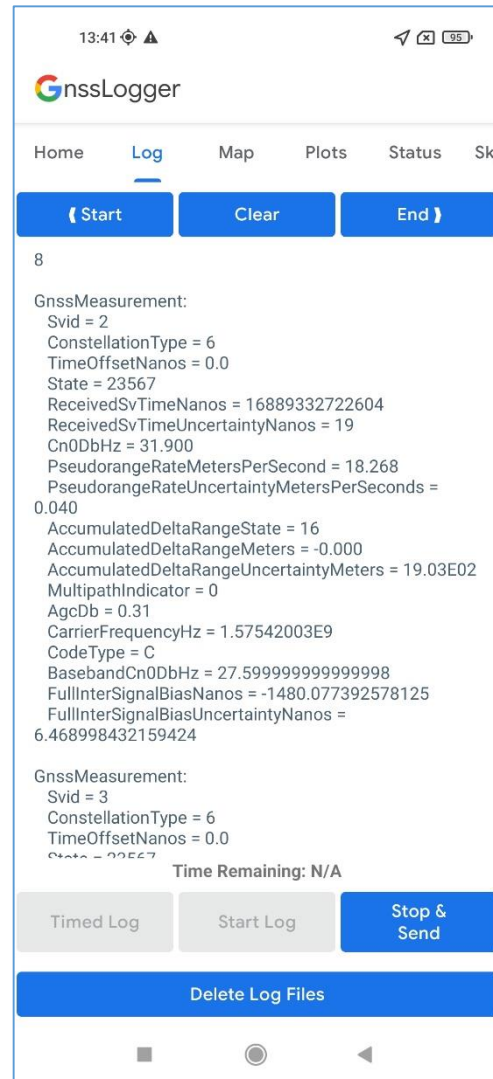
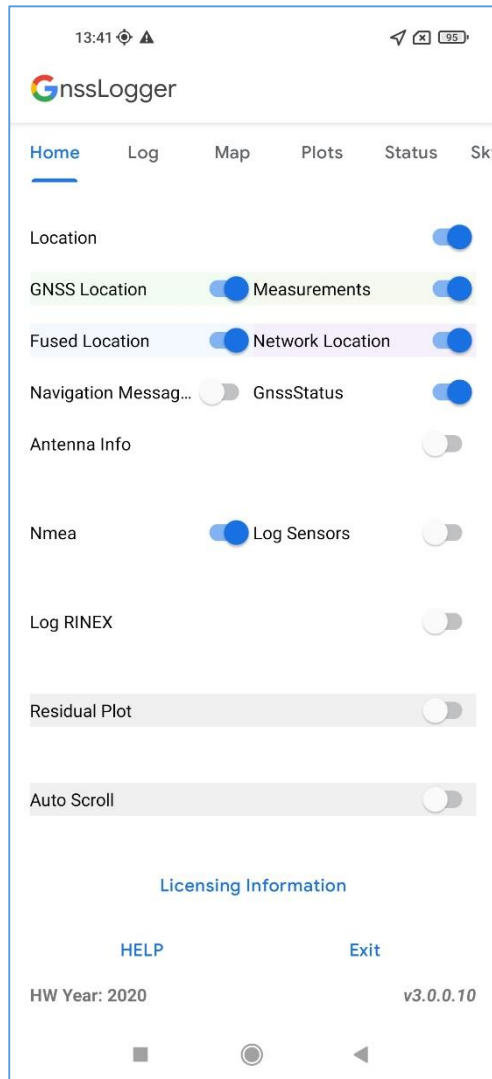
Satellite-based Augmentation Systems (SBAS)

- ◆ - WAAS (USA)
- ◆ - EGNOS (European Union)
- ◆ - GAGAN (India)
- ◆ - MSAS (Japan)
- ◆ - SDCM (Russia)
- ◆ - BDSBAS/SNAs (China)
- ◆ - SACCSSA (ICAO)

Signal Availability

- - Not in view of device
- - In view
- - Used in fix

Xiaomi Mi11 Lite 5G Screen Shots



Sample GNSS Raw Data from Mi11 Lite 5G

Sample GNSS raw data can be downloaded from the following website:

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

Data were taken at the same time by using 4 or 5 different types of devices.

This will help to compare accuracy from different devices as well.

	Smart-Phone Data					
	Xiaomi Mi8 (a)	Xiaomi Mi8 (b)	Xiaomi Mi8 (c)	Xiaomi Mi11 Lite 5G	OppoReno 3 A	
Day 1	Data 01	Data 02	Data 03	Data 08 Data 09	Data 10	
Day 2	Data 04	Data 05 Data 06	Data 07			

GNSS Raw Data from android devices open new opportunities to develop location based applications with high accuracy that were not possible before.