Low-Cost High-Accuracy GNSS Receiver System based on QZSS MADOCA Signal

MAD-WIN, MAD-π and MADROID

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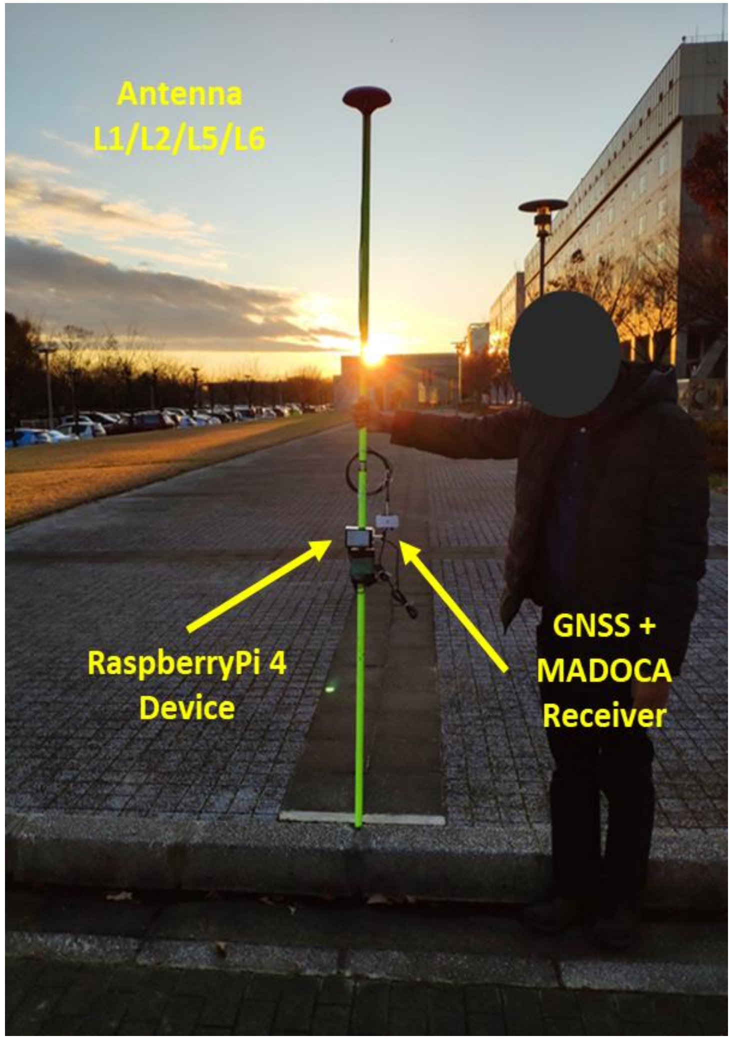
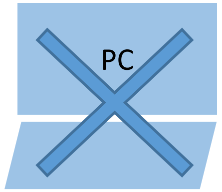
26th October 2021



Objectives

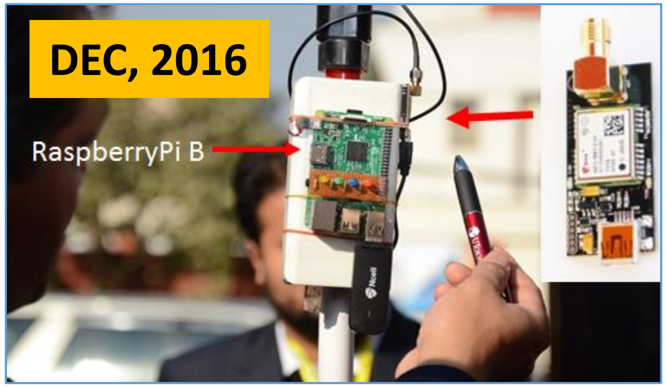
- Develop Low-Cost High-Accuracy Positioning Systems (L-CHAPS)
  - System Integration of commercially available receiver or module
    - For RTK and MADOCA
  - Avoid use of computer to minimize the cost
    - Use Single Board Computer (SBC)
      - RaspberryPi, Arduino, Spresense
    - Use Tablet or 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



Low-Cost GNSS Receivers are necessary for promotion of GNSS technology to conduct lectures, trainings and pilot projects

Low-Cost Receiver System Development Cycle



UN-NEPAL GNSS Workshop

MAY, 2017

Low-Cost RTK

GNSS Antenna → GNSS Receiver → 

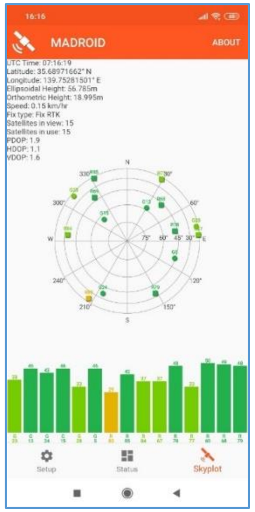
BT — Tablet RasPi APP Ver. : 1.0

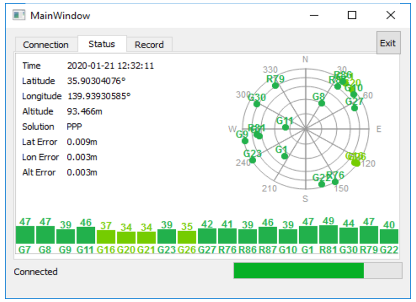
Internet — NTRIP Caster

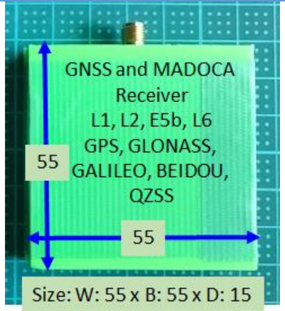
MAR, 2018

GNSS Antenna → GNSS Receiver → Tablet RTKDROID APP Ver. : 1.0 ← Internet — NTRIP Caster

Low-Cost MADOCA







DEC, 2019

Enhancement of MADOCA System 2021

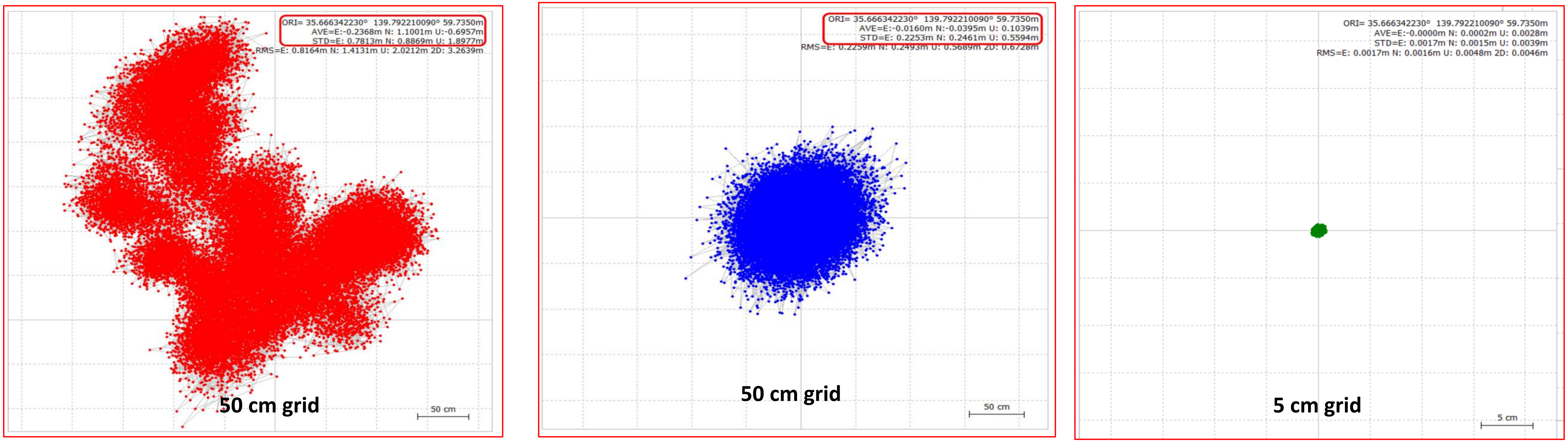
Android Device Only RTK / MADOCA / EWS / SAR System 2022

What type of smart-phone will emerge by 2025 ?

GPS Position Accuracy

How to achieve accuracy from few meters to few centimeters?

meter → centimeter

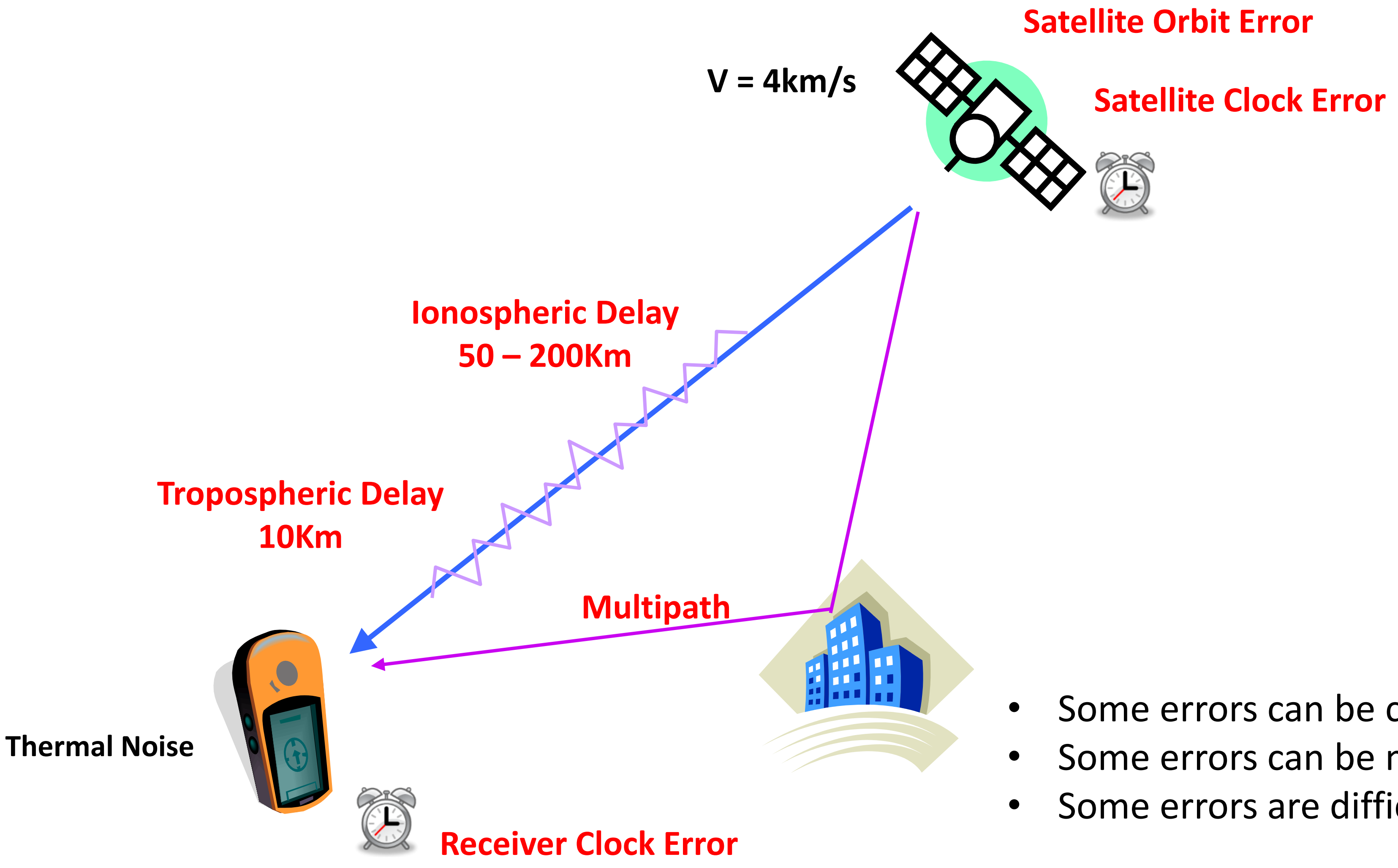


SPP (Single Point Position)

DGPS (Differential GPS)
Code-phase observation

RTK (Real Time Kinematic)
Carrier-phase observation

How to Improve Accuracy?
Need to Know Error sources



- Some errors can be completely removed
- Some errors can be minimized
- Some errors are difficult to remove

Errors in GPS Observation (L1C/A Signal)

Error Sources	One-Sigma Error , m		Comments
	Total	DGPS	
Satellite Orbit	2.0	0.0	Common errors are removed
Satellite Clock	2.0	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: Satellite Orbit Errors, Satellite Clock Errors and Atmospheric Errors (within few km)

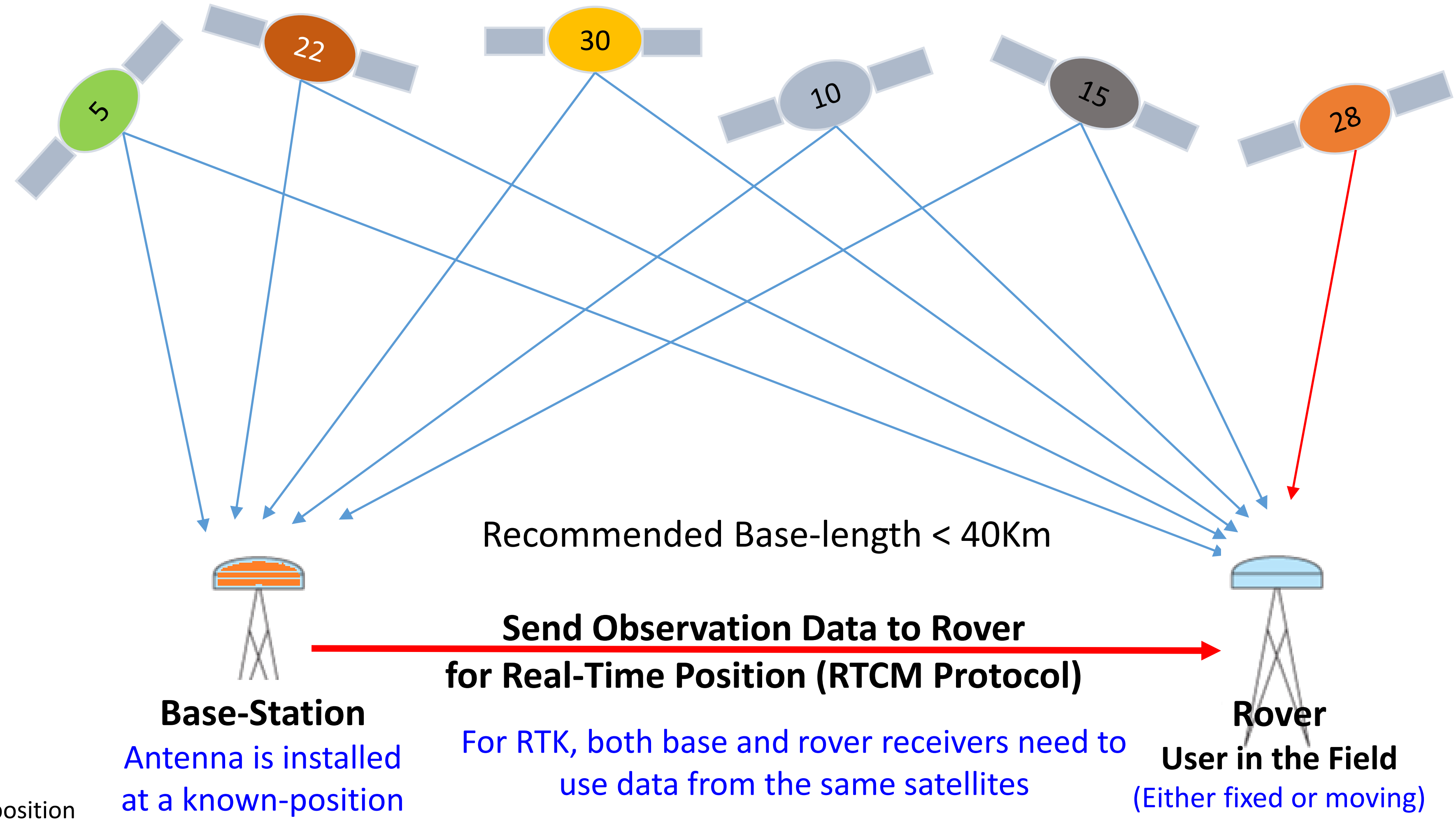
Values in the Table are just for illustrative purpose, not the exact measured values.
Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath

Observation Methods for High-Accuracy

- Basically three types of Observation
  - DGPS (Differential GPS)
    - Code-phase observation
    - Requires Base-station (Reference Station)
  - RTK (Real Time Kinematic)
    - Code-phase and Carrier-Phase Observation
    - Requires Base-station (Reference Station)
  - PPP (Precise Point Positioning)
    - Code-phase and Carrier-phase observation
    - Does not require base-station

How to Remove or Minimize Common Errors?

Use Differential Correction



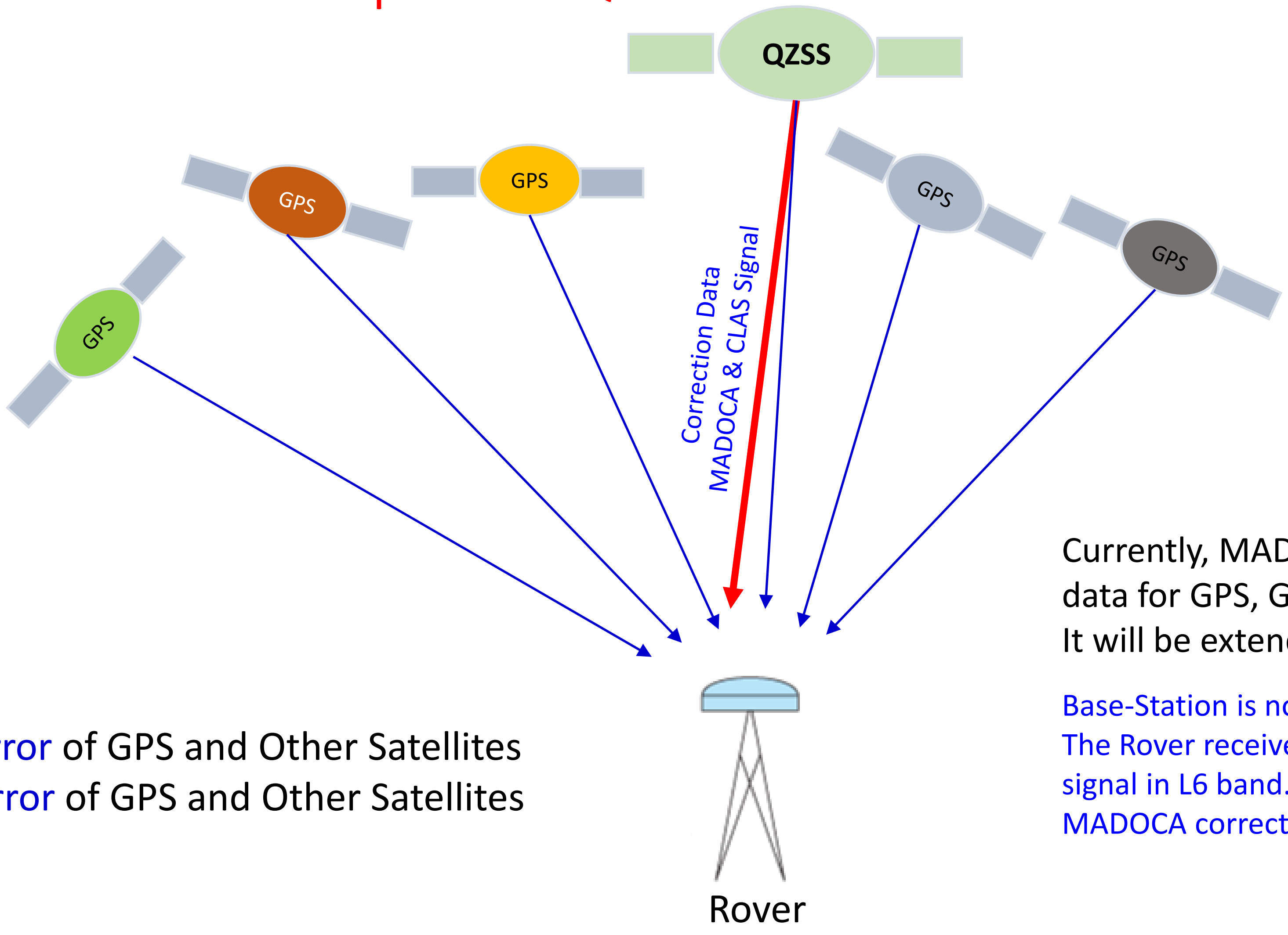
For RTK, both base and rover receivers need to use data from the same satellites

Base-station Antenna position shall be known in advance

Use RINEX data for post-processing

How to Remove or Minimize Common Errors?

Principle of QZSS MADOCA Services



Currently, MADOCA provides correction data for GPS, GLONASS and QZSS.
It will be extended for Galileo in future.

Base-Station is not required.
The Rover receiver should be able to receiver MADOCA signal in L6 band.
MADOCA correction data is also available online.

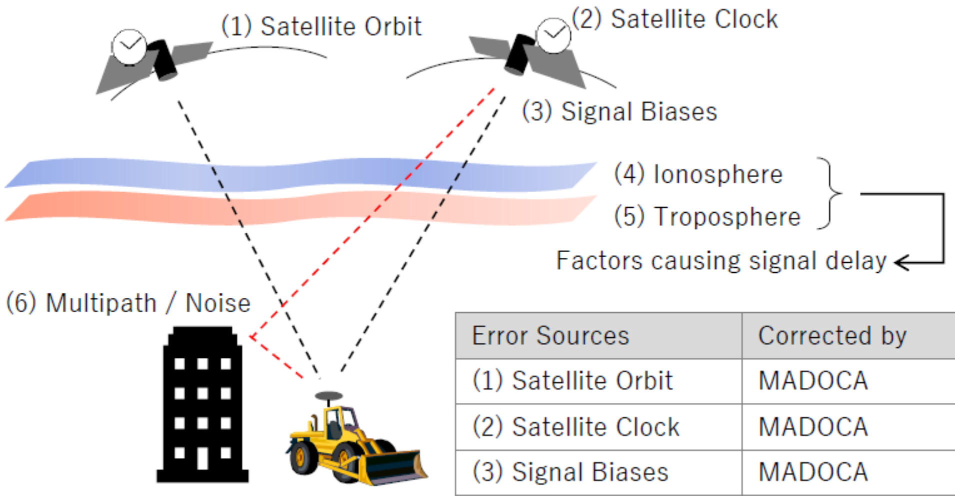
Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

How does MADOCA Work?

- MADOCA
  - Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis
- Provides an accuracy of 10cm
- MADOCA signal broadcasts the following correction data:
  - Satellite Orbit, Satellite Clock, Signal Biases
- Currently, correction data are broadcasted for GPS, GLOANSS and QZSS satellites

product	Interval	RTCM Message			
	Estimate	Provide	GPS	GLONASS	QZSS
Orbit correction	30	1	1057	1063	1246
Clock correction	1	1	1058	1064	1247
HR-Clock correction	1	1	1062	1068	1251
URA	1	1	1061	1067	1250

Table Source: https://www.gpas.co.jp/service_madoca.php

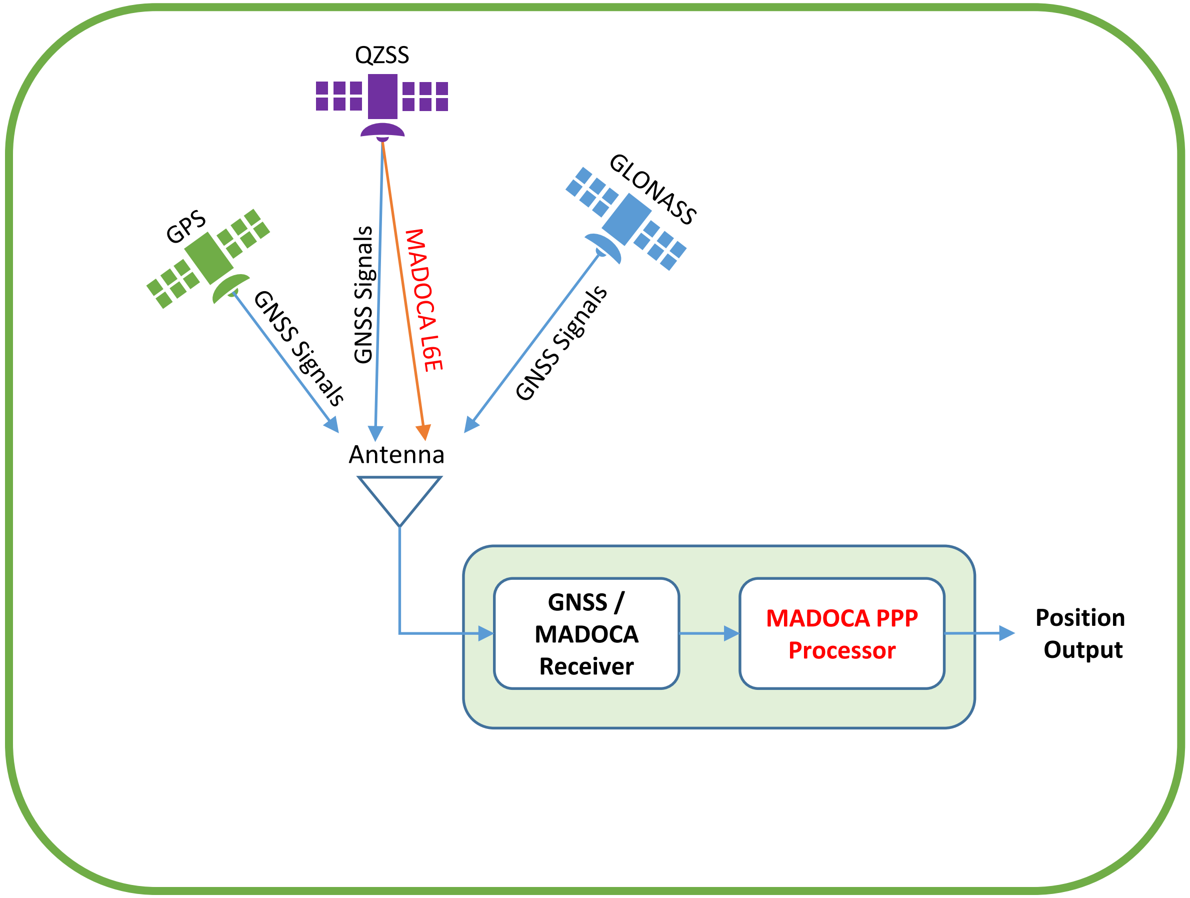


Error Sources	Corrected by
(1) Satellite Orbit	MADOCA
(2) Satellite Clock	MADOCA
(3) Signal Biases	MADOCA
(4) Ionosphere	Positioning Process
(5) Troposphere	Positioning Process
(6) Multipath / Noise	N/A

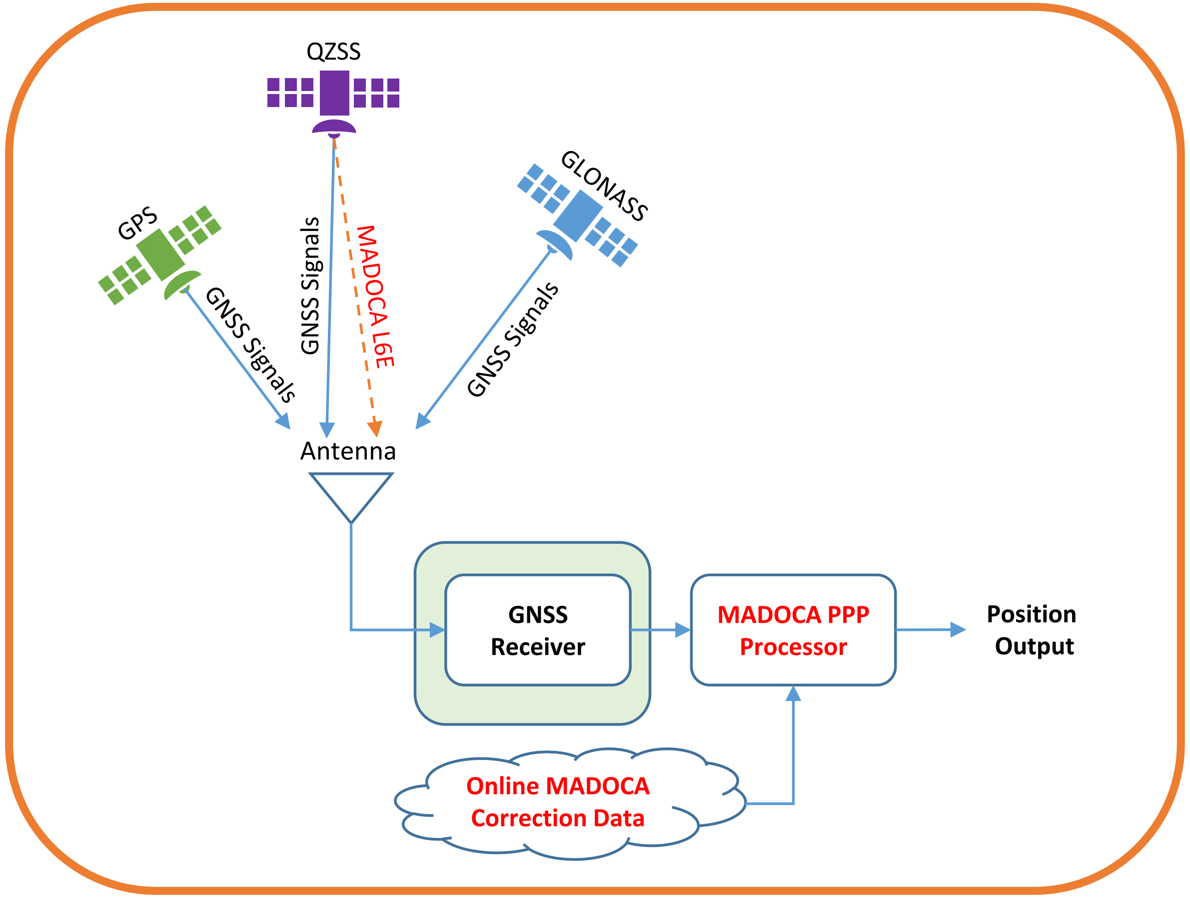
Image from presentation file: Introduction to MADOCA by H. Kakimoto, GPAS Company

MADOCA System: Direct from QZSS or Online Correction Data

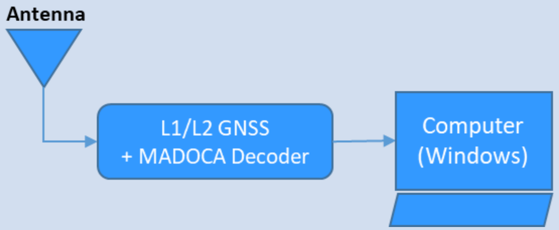
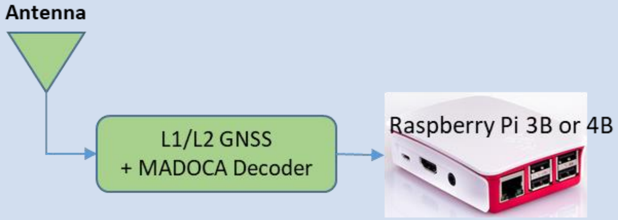
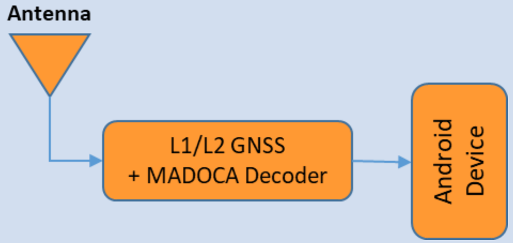
If you have GNSS Receiver and MADOCA Decoder



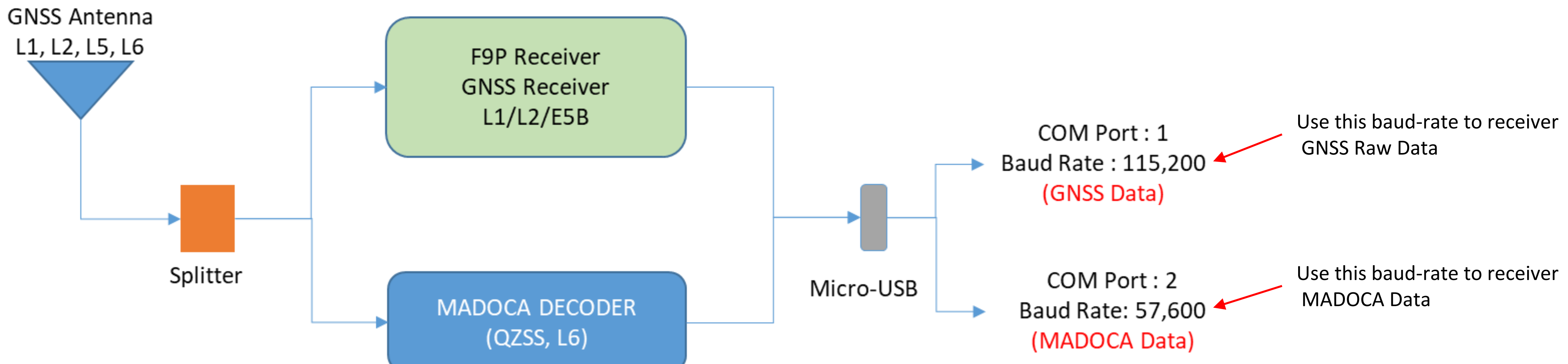
If you have only GNSS Receiver

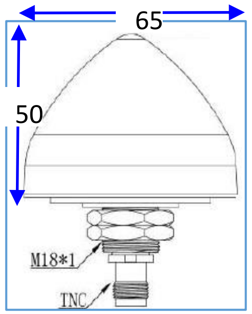


Low-Cost MADOCA Receiver Systems: Product Types

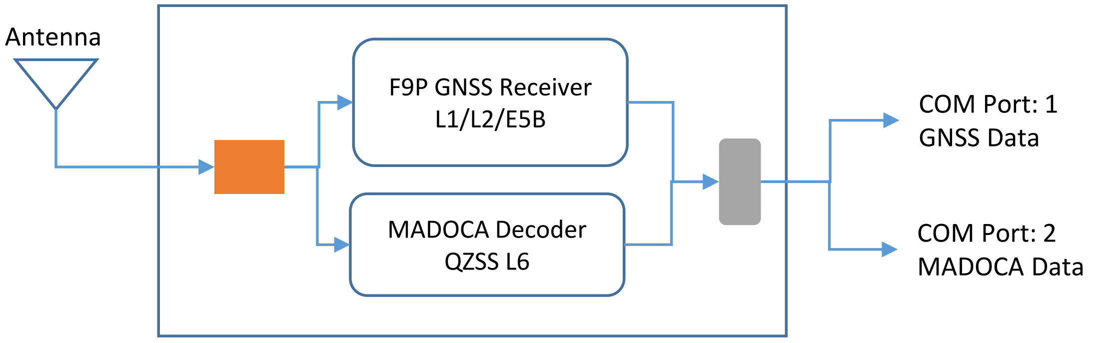
	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction 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			

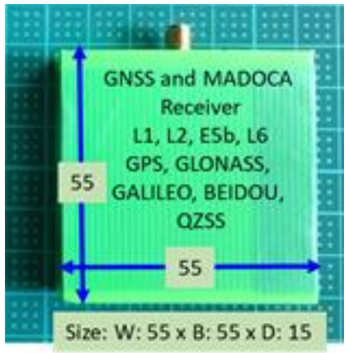
System Architecture



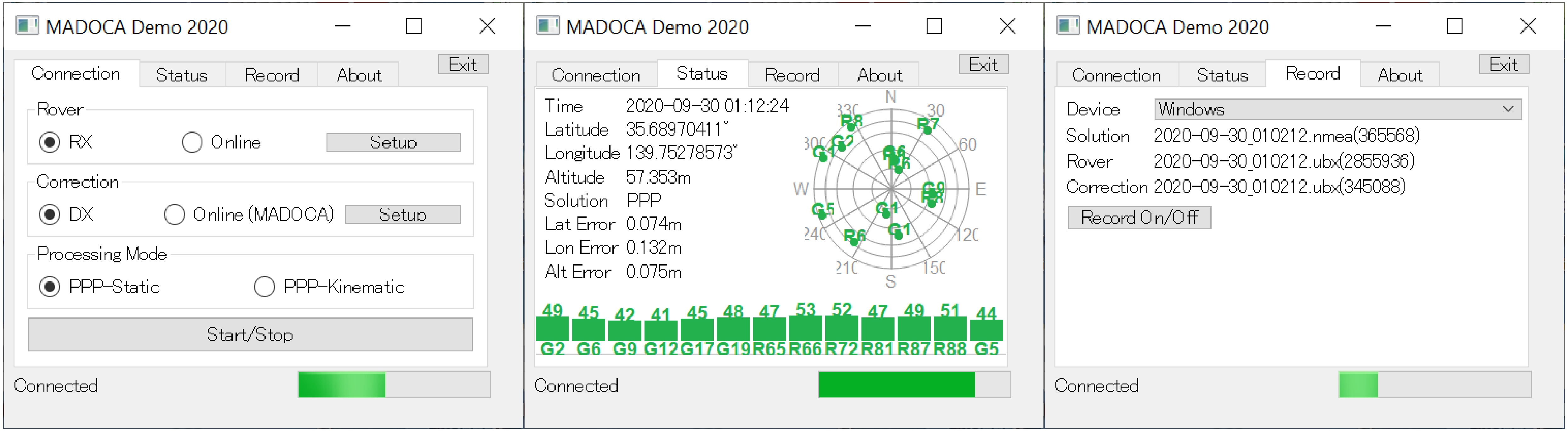


GNSS Antenna





MAD-WIN / MAD-PI User Interface



Log Files:

1. Solution: MADOCA PPP Solution in NEMA format
2. Rover: Rover RAW Data in receiver's proprietary format

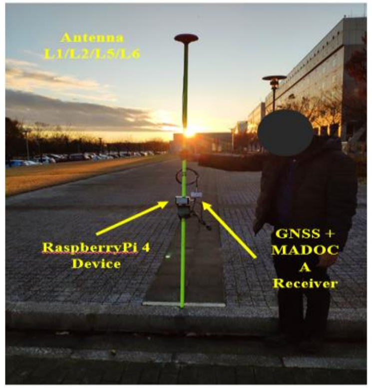
Can be used for PPK (Post-Processing Kinematic) Solution or Post-Processing PPP

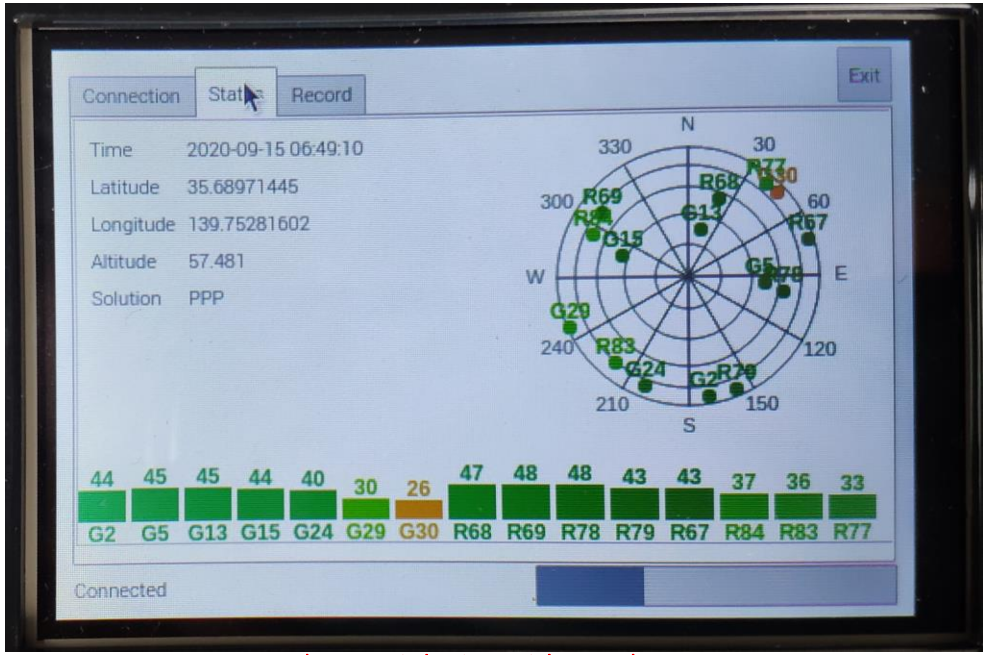
3. Correction: MADOCA PPP Correction Data in receiver's proprietary format

Can be used for Post-Processing MADOCA

MAD-PI:MADOCA with RaspberryPi Device

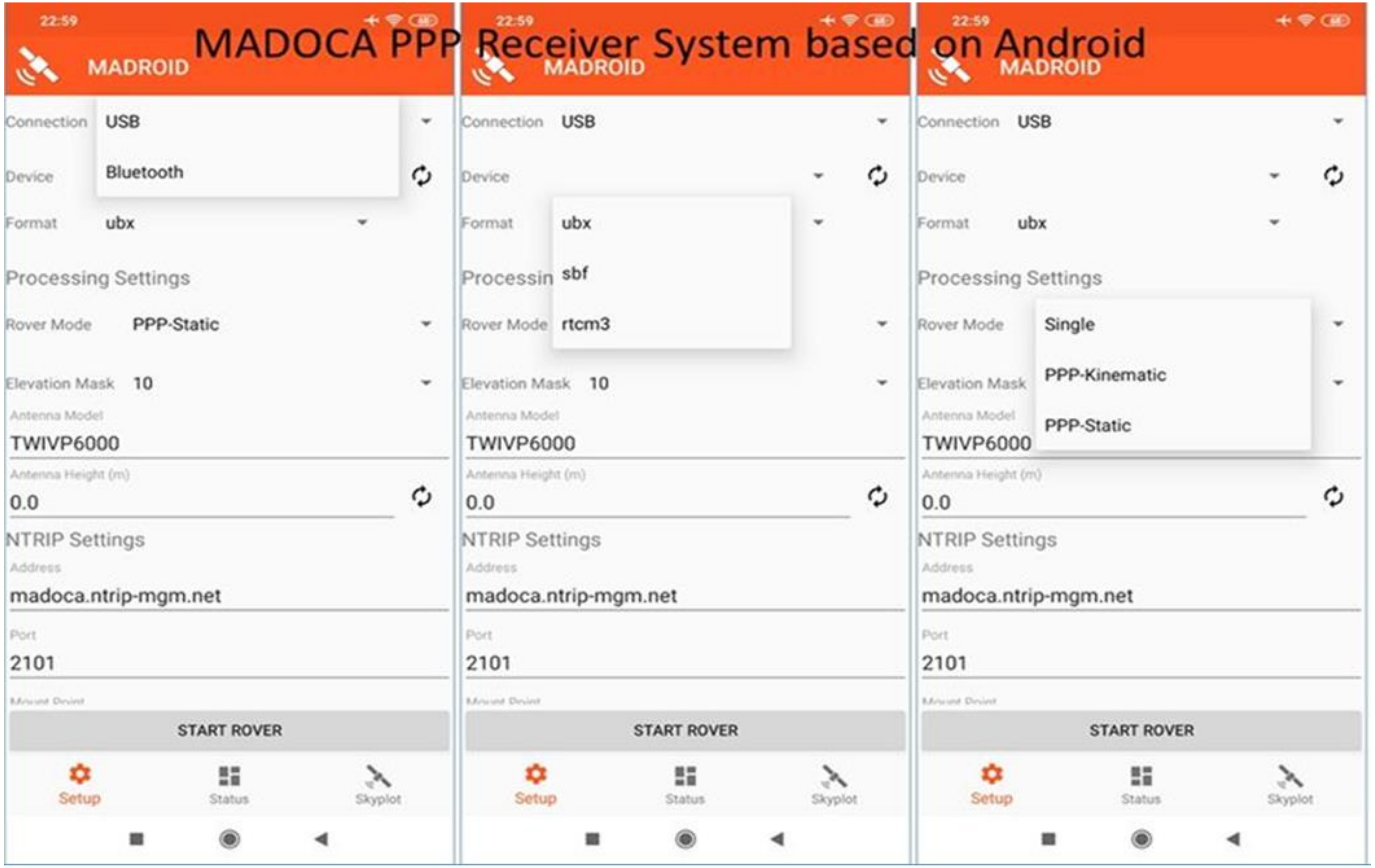
- MAD-Pi has been tested with RaspberryPi-3B device
  - It also works with RaspberryPi-4B
  - If the device does not work, please try with a different USB port
- Do not remove and insert SD Card several times. It may get damaged.
- Observation data can be logged to an external USB memory disk. Memory 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



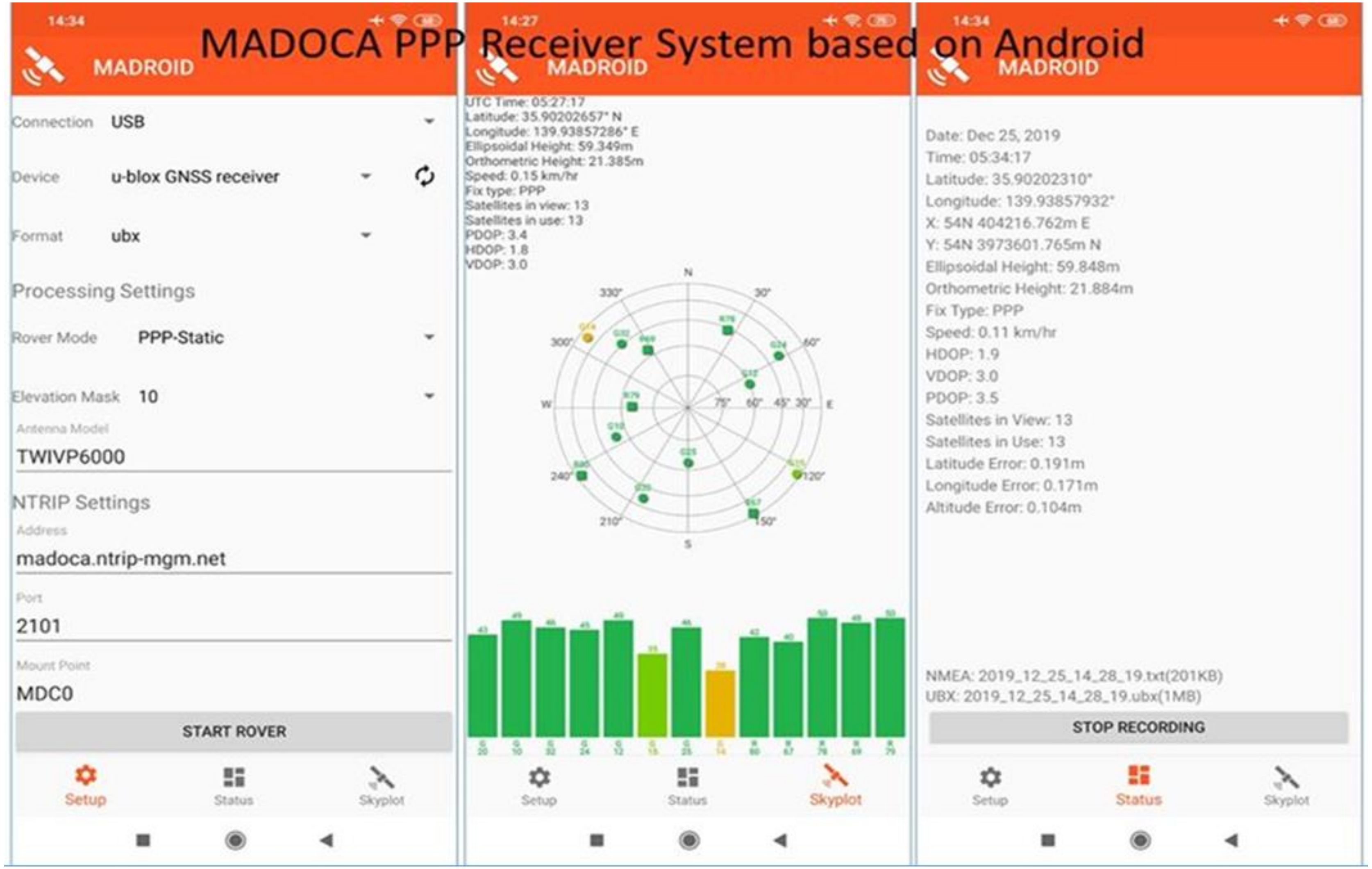


Raspberry-Pi device with Touch Screen

MADROID: MADOCA with Android Device

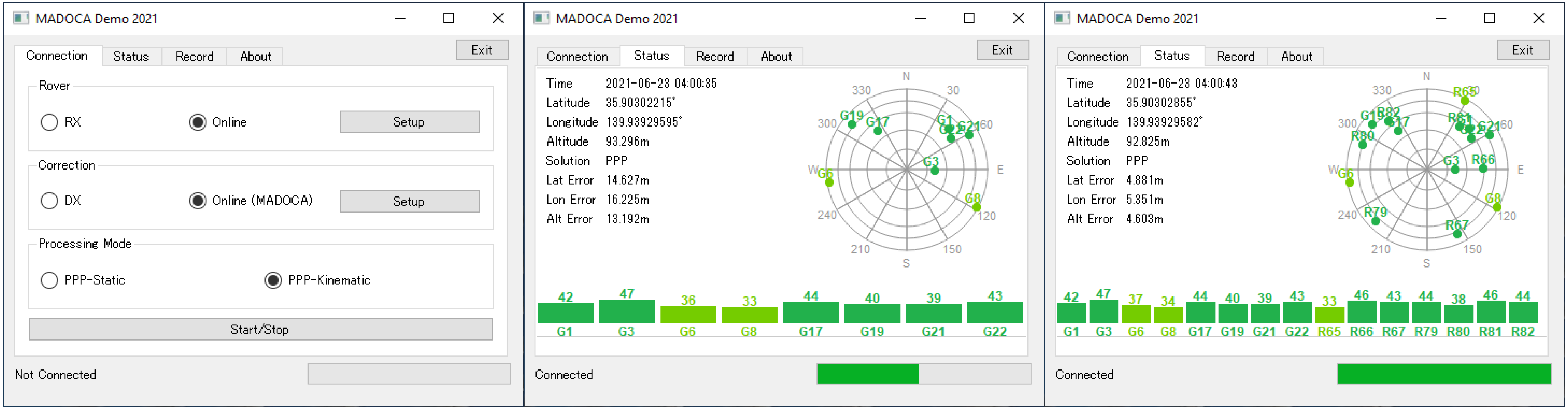


MADROID: MADOCA with Android Device

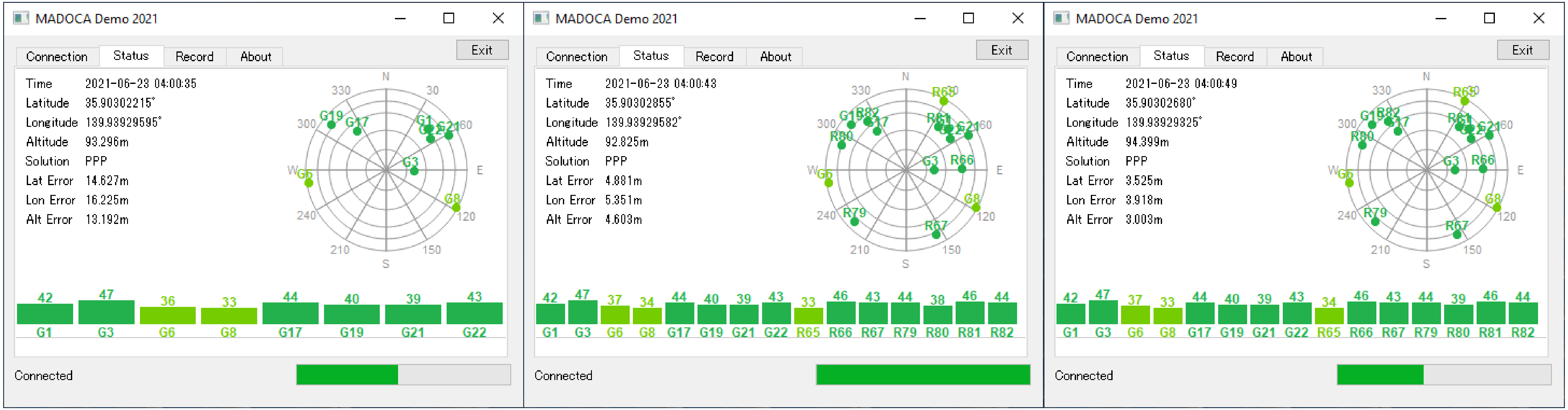


MADOCA Observation

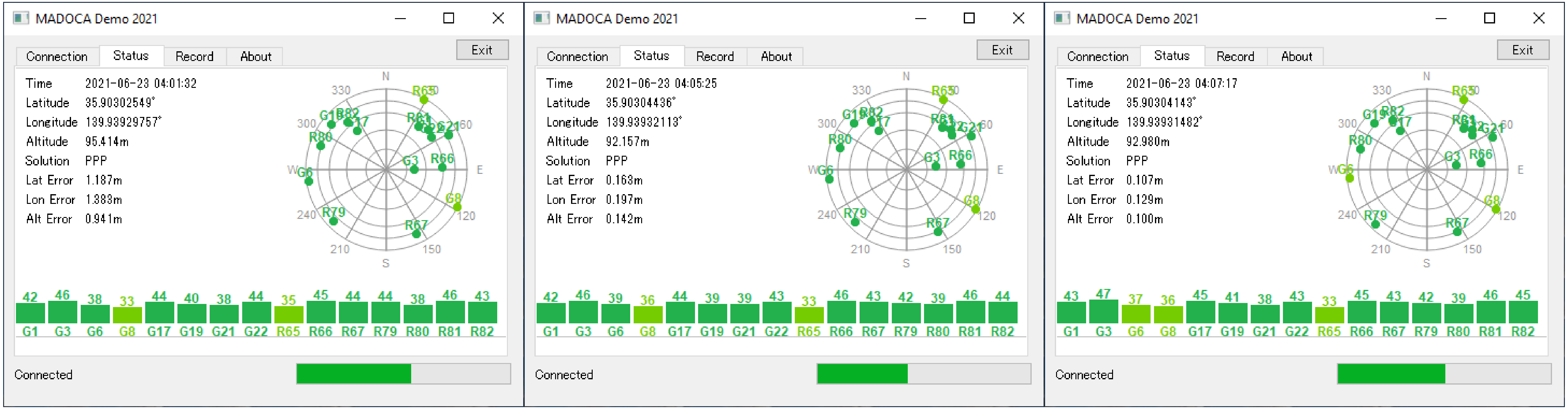
MADOCA PPP Test Results



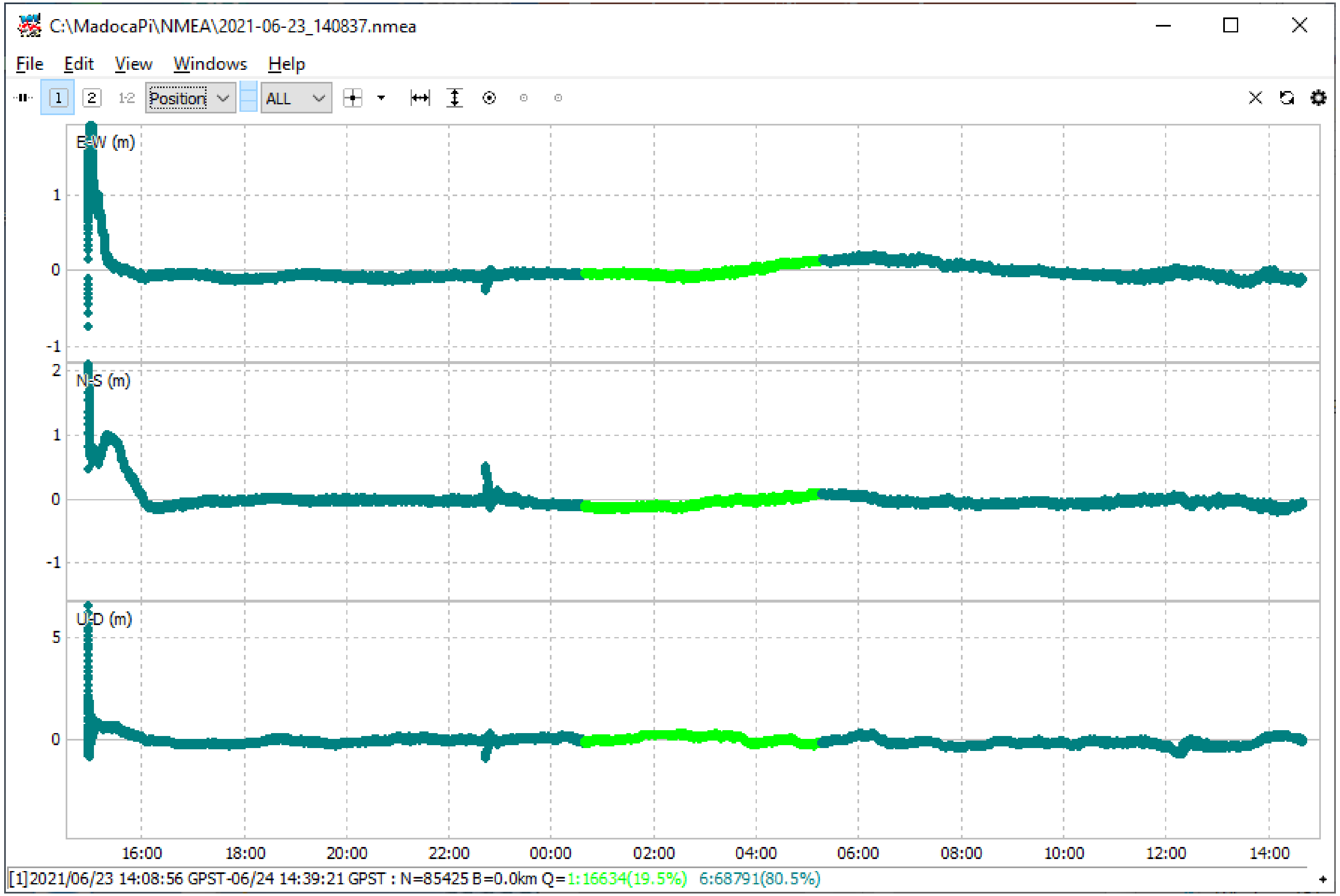
MADOCA PPP Test Results



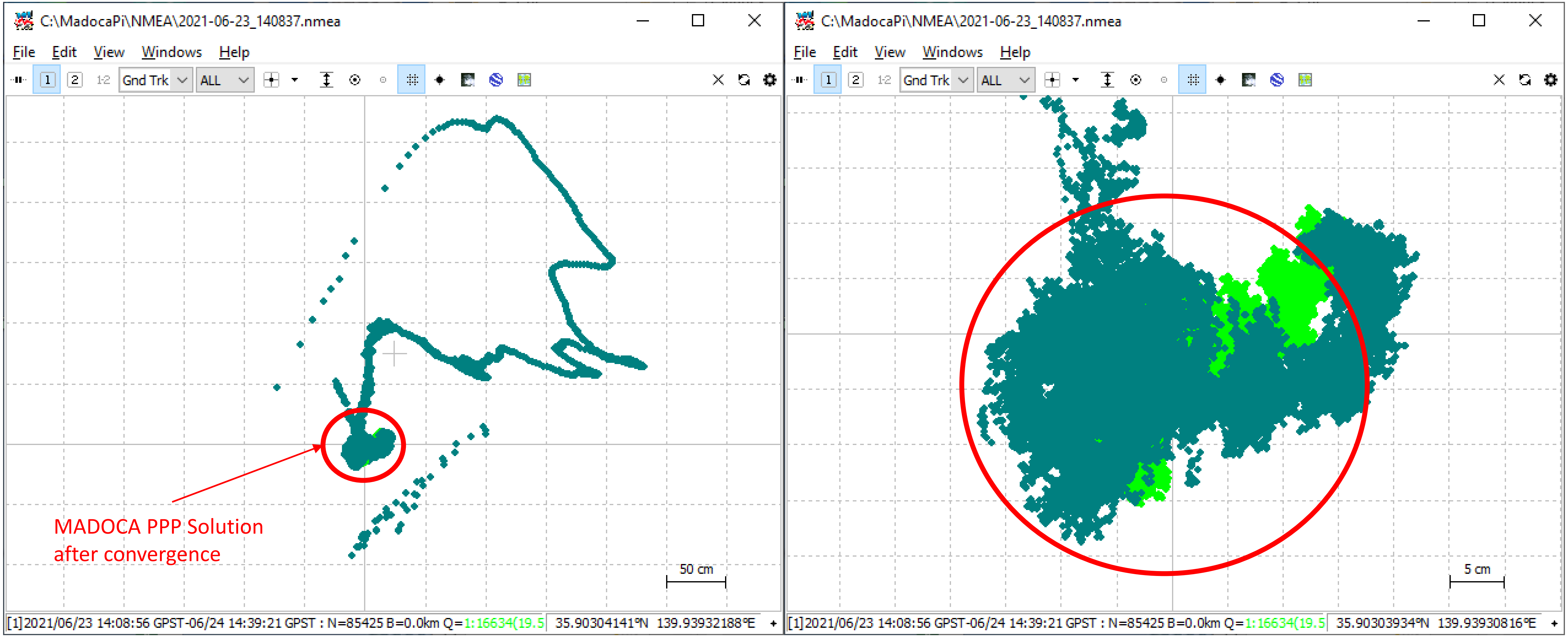
MADOCA PPP Test Results



MADOCA PPP Test Results (24 hours)



MADOCA PPP Test Results (24 hours)

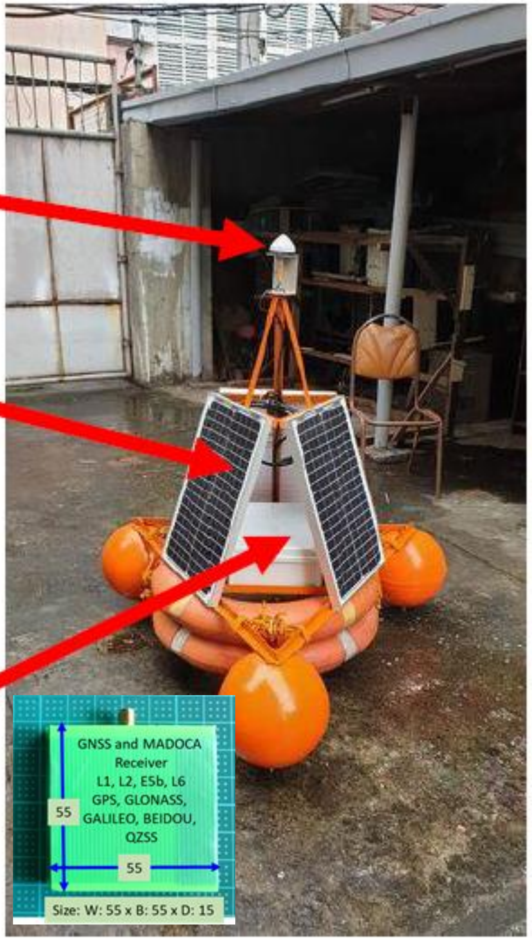


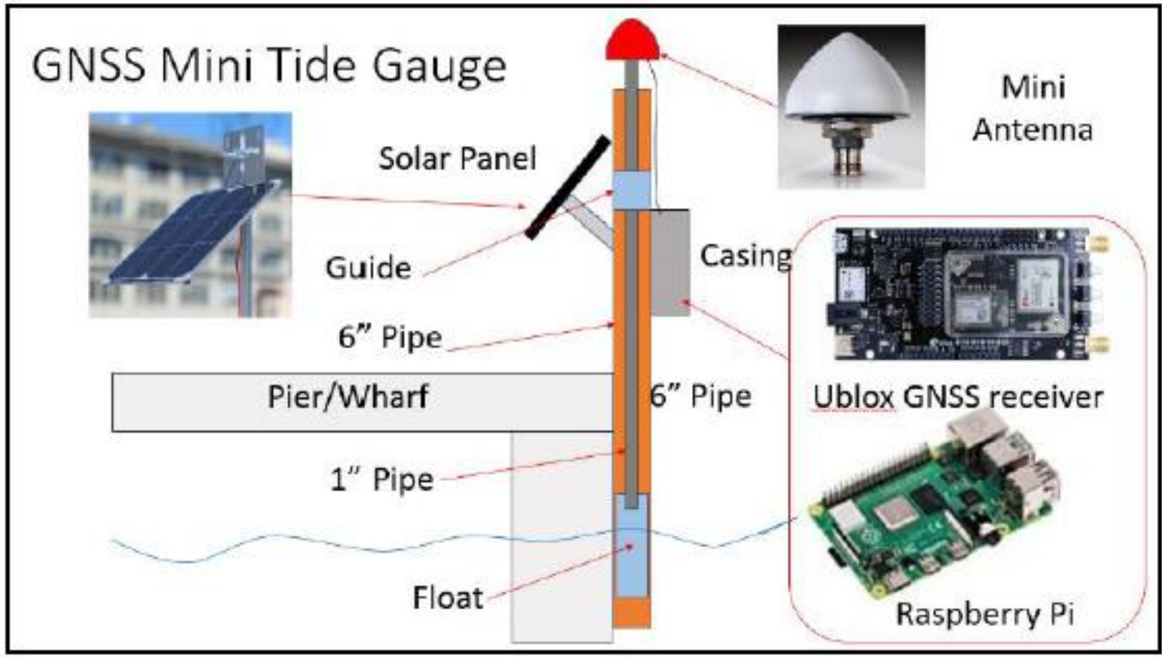
Low-Cost MADOCA Receiver for Sea-Level Rise Measurement

GNSS antenna

Solar power

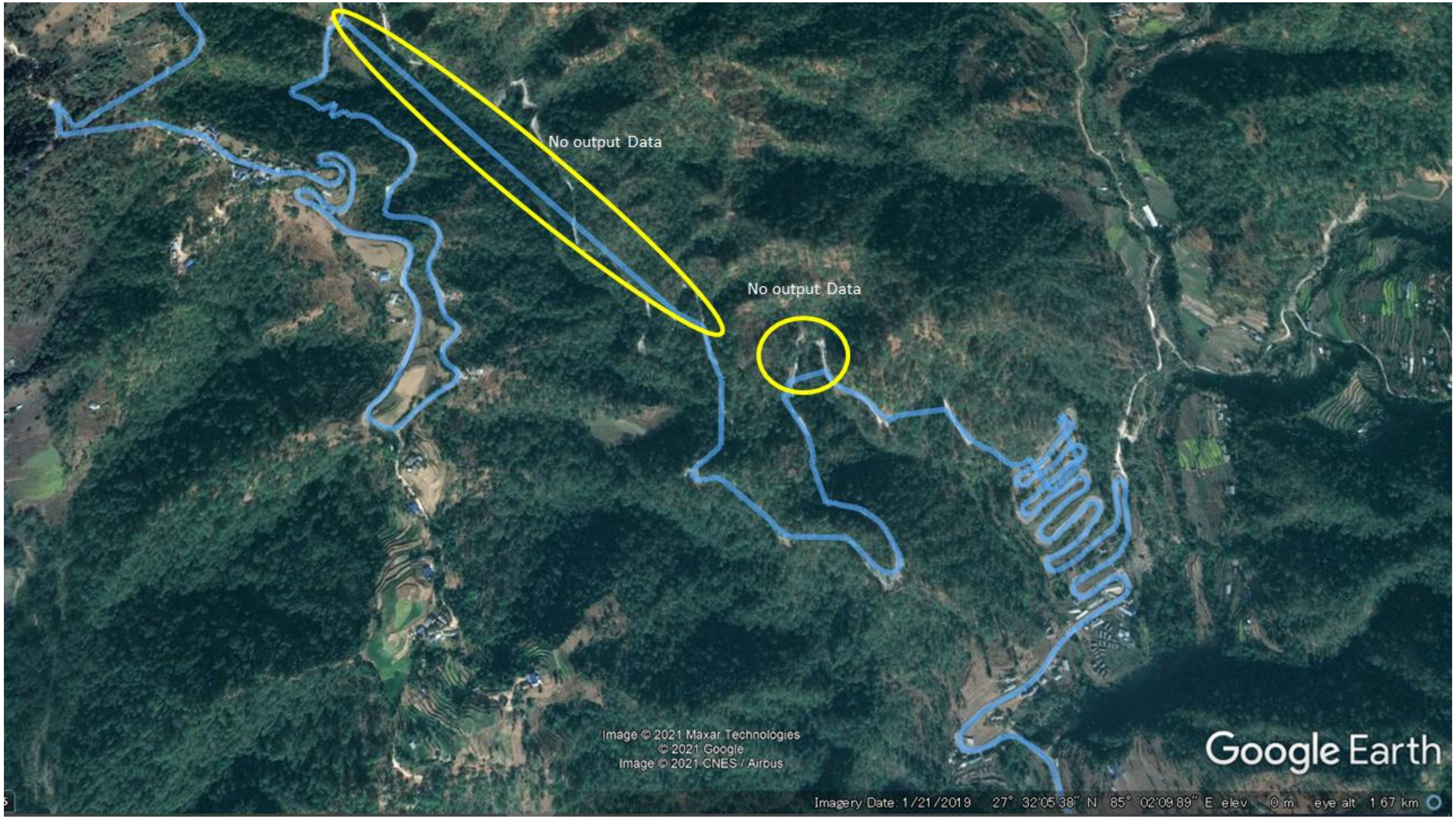
TiBox enclosure containing the battery, raspberry pi and Ublox and MADOCA decoder





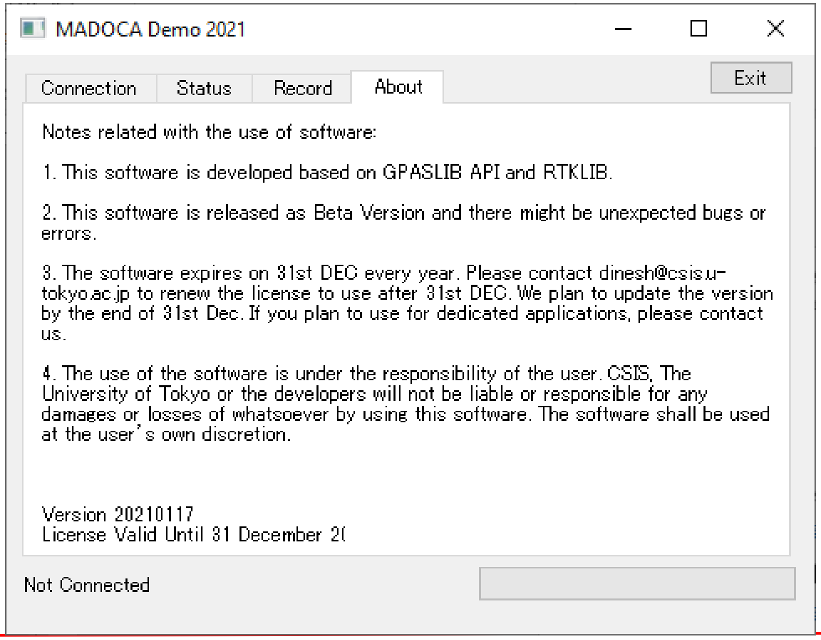
Source: Technical Report, GNSS/QZSS MADOCA PPP Data Acquisition for Sea Level Rise Measurement, DR. ROSALIE B. REYES, UP DGE and Project Leader, CLSR-Phil Project

MADOCA PPP Test in Mountain Area



Request for HW/SW

- MADOCA Receiver Systems are distributed to overseas universities for joint research and pilot projects
  - Includes HW and SW
  - Signing of MTA (Material Transfer Agreement) Document is necessary for HW
  - If only SW is required, please send request through
    - https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
  - SW is provided under the understanding that the recipients provide feedbacks and some sample data
  - Feedbacks are necessary to improve and debug the products



Go To MAIN PAGE

Low-Cost High-Accuracy Receiver Systems

Receiver Systems: Type A, Type B, Type C, Type D

Note: APKs can be downloaded from the following links:
Please send e-mail to dinesh{@}csis.u-tokyo.ac.jp for password.
Following information are necessary:
1. Name
2. Affiliation (Organization Name)
3. Purpose (Optional)

	APK Name	Description
1	RTKDROID (click to download) - Register for Password and Updates	**RTK based on RTKLIB 2.4.3** Receiver Type: Single or Dual Frequency Receiver Receiver and Data Compatibility: u-blox: M8T, M8P, F9P in UBX Format Septentrio in SBF Format Other Receivers in RTCM3 Format Connection: (1) USB using OTG cable with Android Device (2) Bluetooth
2	MADROID We will provide software for joint research and pilot projects based on MADOCA. Please contact me if your institute or organization is interested. Register here for MADOCA PPP Software	**PPP with MADOCA Correction Data** Receiver Type: Dual Frequency Receiver Receiver and Data Compatibility: u-blox: F9P in UBX Format Septentrio in SBF Format Other Receivers in RTCM3 Format Connection: USB using OTG cable with Android Device Download Presentation File

Summary and Future Plans

- Three types of Low-Cost MADOCA receiver systems are developed.
  - MAD-WIN, MAD-PI and MADROID
- MAD-PI will be improved for remote data logging.
- MADROID will be improved for using MADOCA data directly.
- Integration of current system with other systems
  - Traffic monitoring, EWS Application, GIS data collection tool, ……..
- Detail field tests will be conducted in this fiscal year.
- Trainings, Seminars, Workshops and Joint Projects with foreign universities will be conducted
  - With support from MELCO, GPAS, TUMSAT and CAO

We are planning to conduct online webinars on GNSS Data Processing and MADOCA for Mongolia.

We would like to request the concerned authorities to organize the webinars.

References

- Main Page
  - https://home.csis.u-tokyo.ac.jp/~dinesh/
- Request for Low-Cost Receiver System
  - https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
- Other Training Materials
  - https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
- Webinar Links
  - https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm
- Link to MADOCA Information at GPAS
  - https://www.gpas.co.jp/service_madoca.php
- QZSS Main Page
  - https://qzss.go.jp/en/

Additional Slides

Our Definition of Low-Cost High-Accuracy

	Type	Target Cost	Current Cost	Description	Remarks
Cost	RTK	$100	$300 - $500	Single or Dual Frequency Receiver Dual Frequency Antenna RaspberryPi Device	
	MADOCA	$300	$500 - $800	Dual Frequency GNSS Receiver Triple Frequency GNSS Antenna RaspberryPi Device	Antenna Cost Factor

- Cost of accessories, cables, connectors and power supply unit are not included

Pseudorange equation

Ideal Case: $\rho_0 = c(t_r - t_s)$

Real Case: $\rho = \rho_0 + c(\delta t_r - \delta t_s) + Iono + Tropo + Multipath + \xi$

Receiver Clock Error

Satellite Clock Error

Ionospheric Delay

Tropospheric Delay

Multipath Error

Thermal Noise

Simplified Equation: $\rho = \rho_0 + c(\delta t_r - \delta t_s) + \varepsilon$

How to Improve Accuracy?

- Both Code-Phase and Carrier-Phase observations are necessary
  - Carrier-phase provides centimeter level resolution
- Need to remove or minimize the following errors:
  - Satellite Related Error
    - Satellite orbit errors
    - Satellite clock errors
  - Space Related Errors
    - Ionospheric errors
    - Tropospheric erros
  - Receiver Related Errors
    - Receiver clock error
    - Receiver circuit related