

# GNSS Low-Cost Receiver Systems

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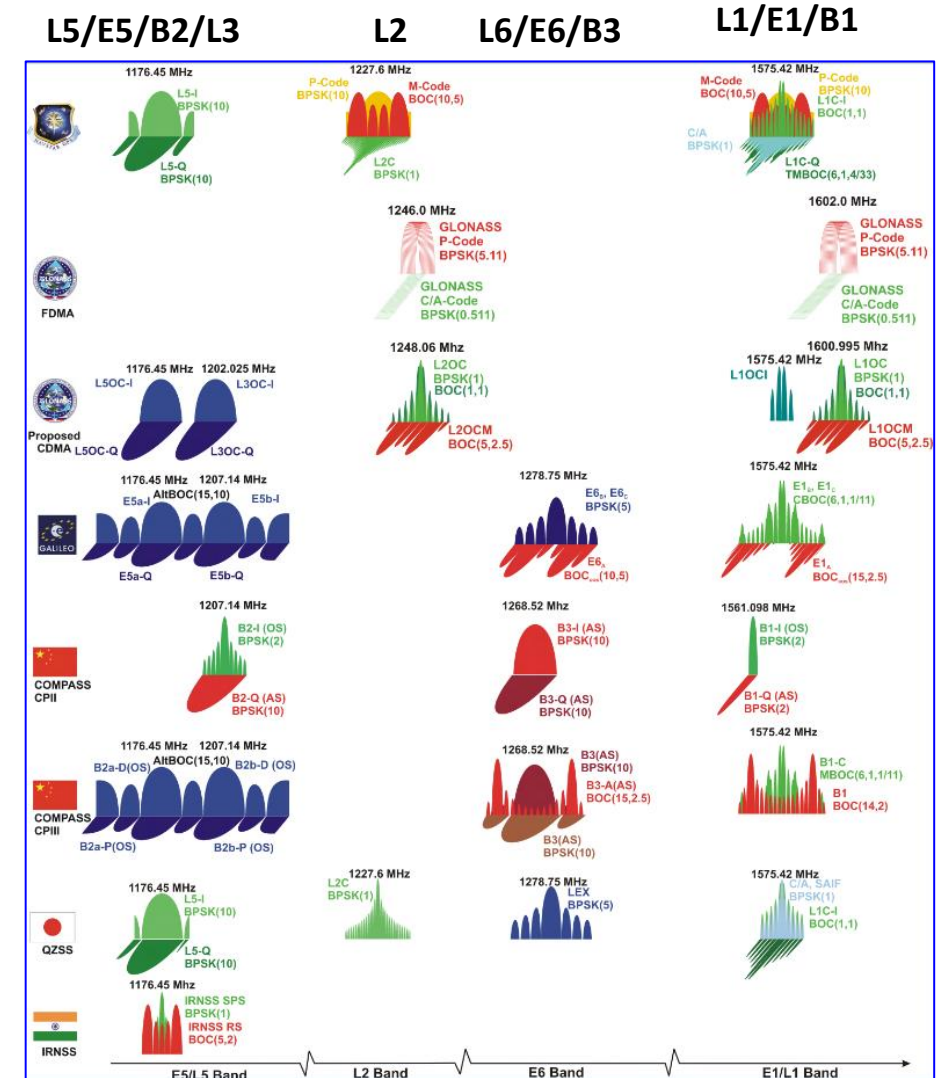
Contact Information: [dinesh@csis.u-tokyo.ac.jp](mailto:dinesh@csis.u-tokyo.ac.jp)

# Quiz

- What is the Price of a GNSS Receiver?
  - \$10? \$100? \$500 \$1,000 \$3,000 \$10,000 or more?
- What is the Accuracy that you can get from a GNSS receiver?
  - mm, cm, dm, few meters or 10 – 30m
- But,
  - What is your budget?
  - What Accuracy do you need?
  - What type of applications are you using?
  - How do you log the data?
    - Static Mode on a Tripod
    - Dynamic Mode on a Car?
  - Real-Time or Post-Processing

# High-End Survey Grade Receivers

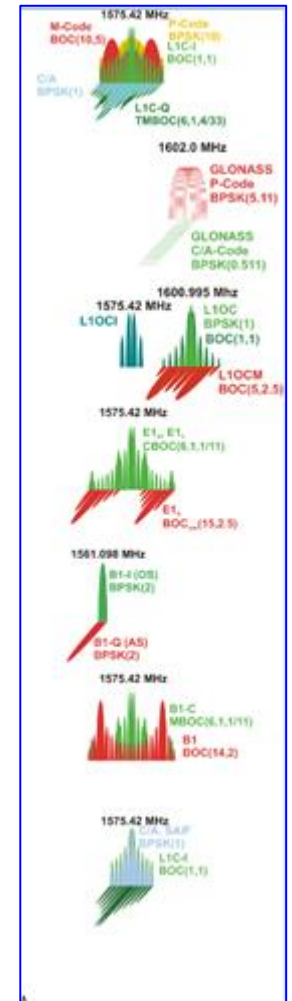
- Multi-frequency
  - L1/L2/L5/L6
  - G1/G2
  - E1/E5/E6
  - B1/B2/B3
- Multi-system
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc
- Price varies from \$3, 000 to \$30,000 or more



# Low-Cost Receivers

- Multi-System
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
- Basically Single Band
  - L1-Band
  - Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
  - Some chip makers have already announced Multi-System, Multi-Frequency GNSS Chips for Mass Market
- Low Cost:
  - Less than \$300 (Multi-GNSS, L1 Only) including Antenna and all necessary Hardware, Software
  - The price of module itself is less than \$100

L1/E1/B1\*



\*Note: Only one signal type from each system is processed  
e.g. GPS has L1C/A and L1C in L1, ,but only L1C/A is used in Low-Cost Receiver

# Our Definition of Low-Cost Receiver

- Price : \$100 or less
- Accuracy : Better than 100cm
- Weight : Within 100gm

**\$100x100cmx100gm**

# New Emerging Applications

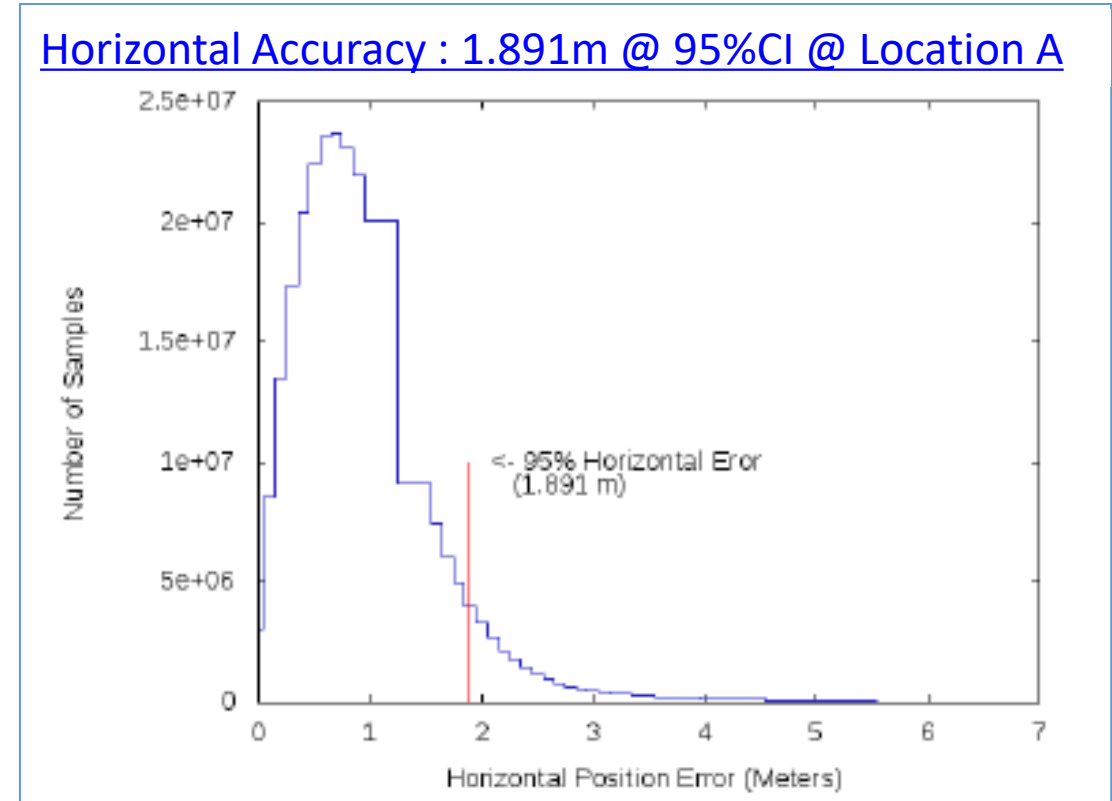
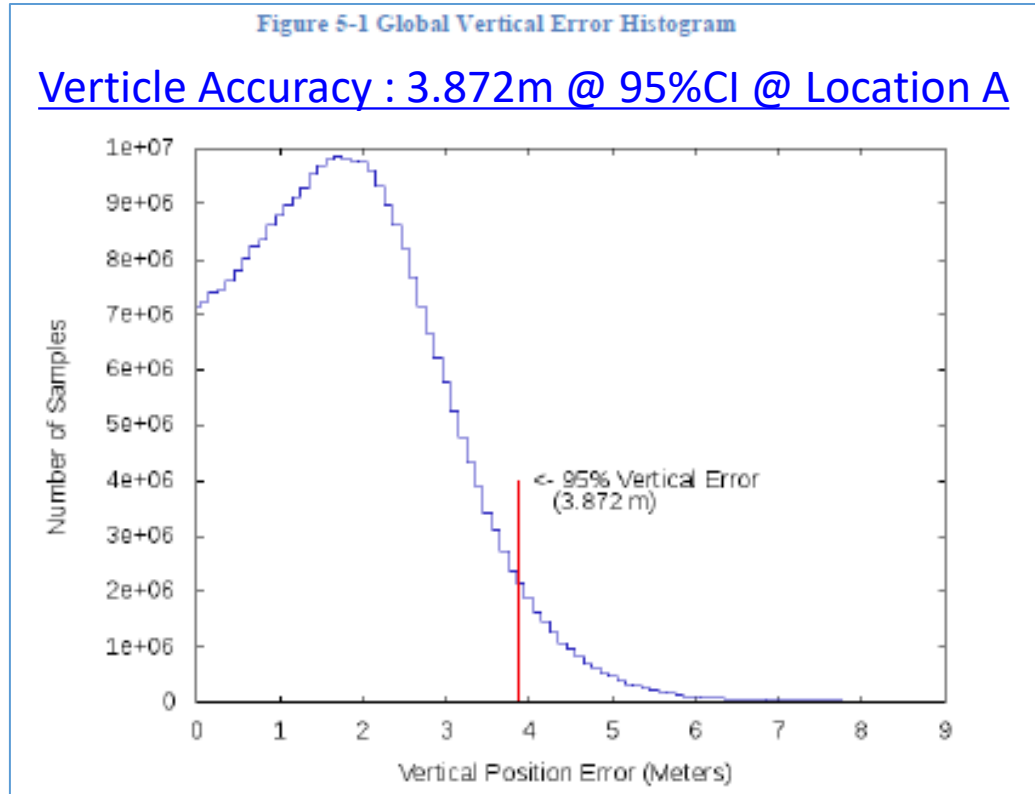
- ITS
  - ITS-Station (infra on the road side)
  - ADAS
  - V2X, V2I
- Public Transport Monitoring
  - Traffic Congestion
  - Public Safety and Security
  - Driver's Behavior Monitoring
- Toll Charge
  - ERP (Electronic Road Pricing)
- Precise Agriculture
- Drone Mapping
  - Direct Geo-referencing
- Timing Application
  - Internet
  - Financial Institutes
  - Power Grids
- Logistics Services
- Emergency Services
  - eCall / ERA GLONASS
  - SAR (Search And Rescue)
- Construction Management and Monitoring
- Aviation
  - SBAS
- Marine
  - VMS, AIS

# Many Applications require Low-Cost, Small-Size & Low-Power Receiver System

But, is it possible to get  
High-Accuracy with Low-Cost  
Receivers?



# How Accurate is GPS?



Global Accuracy Standard:

Better than 12.8m at 95% CI Global Average URE

Better than 30m at 99.94% CI Global Average URE

URE: User Range Error → Pseudorange Accuracy

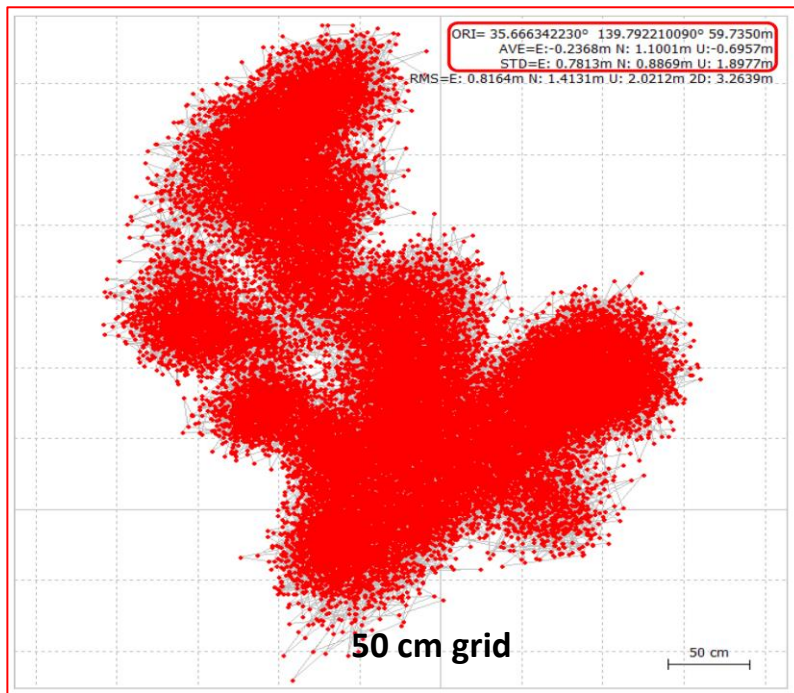
Ref: <https://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf>

# Question?

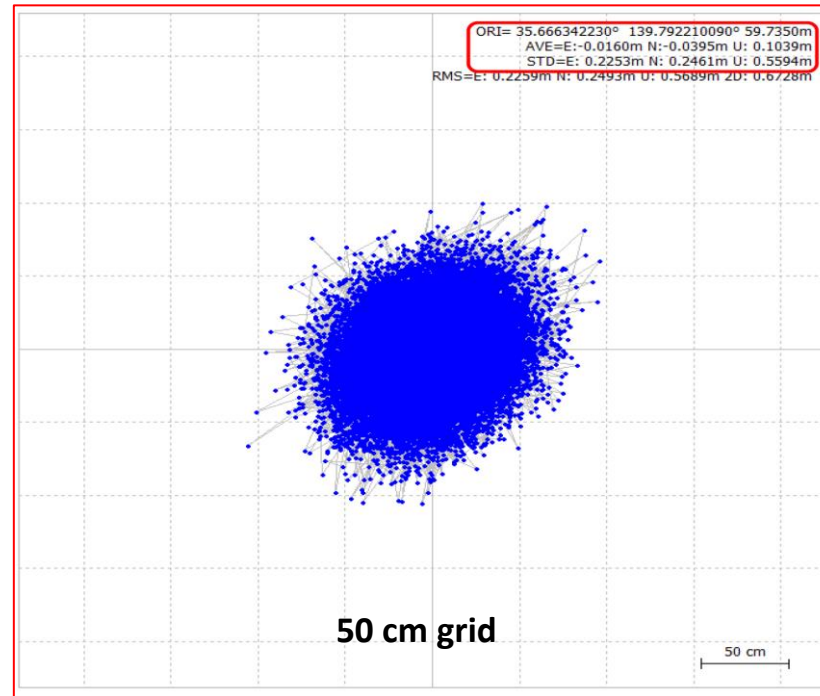
Though the Normal Accuracy of GPS is about 10m,  
why can we get Centimeter Level Accuracy?

# GPS Position Accuracy: From few meters to centimeter

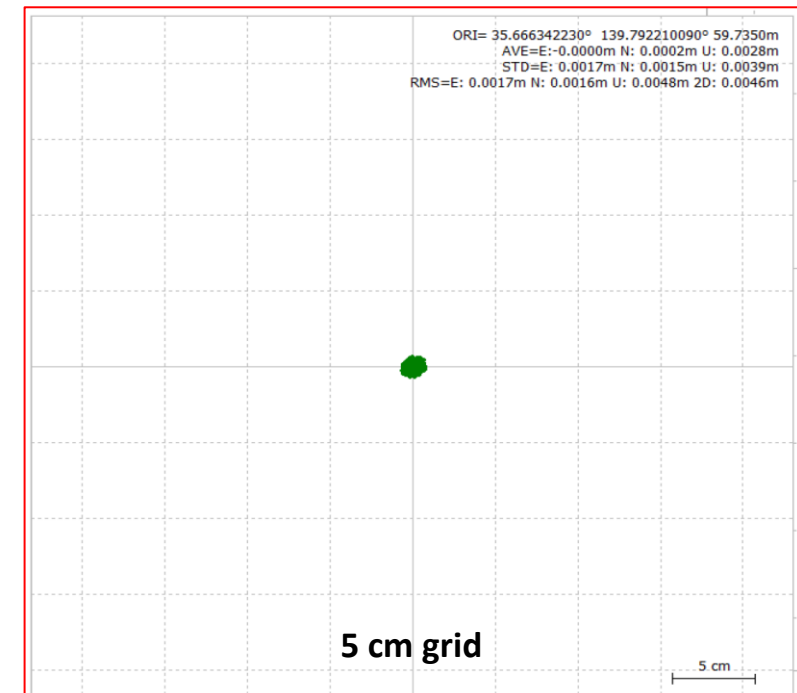
meter  centimeter



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	2.0	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	

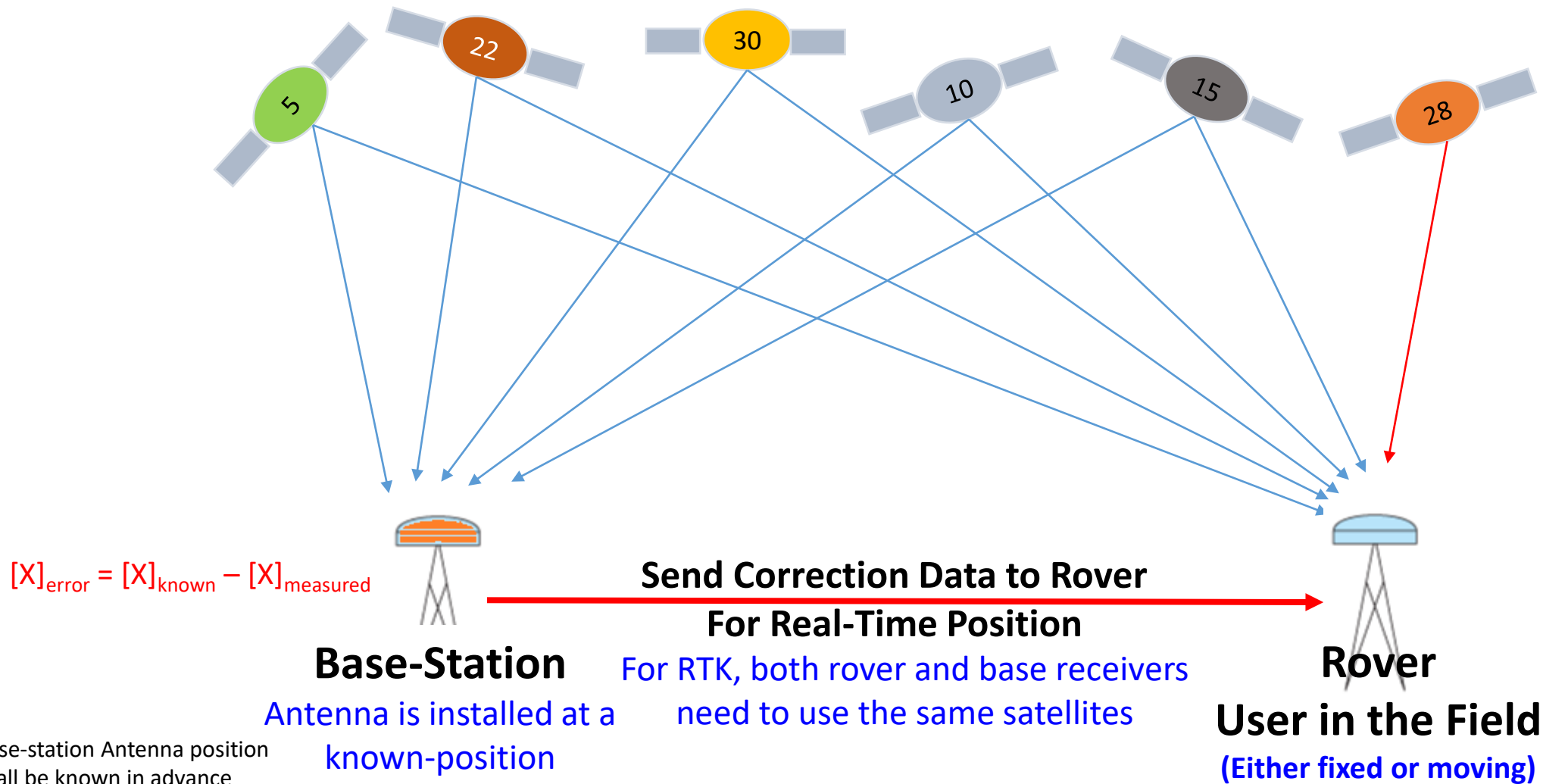
**If we can remove common errors, position accuracy can be increased.**

**Common errors are: Satellite Orbit Errors, 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](http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath)

# How to Remove or Minimize Common Errors?

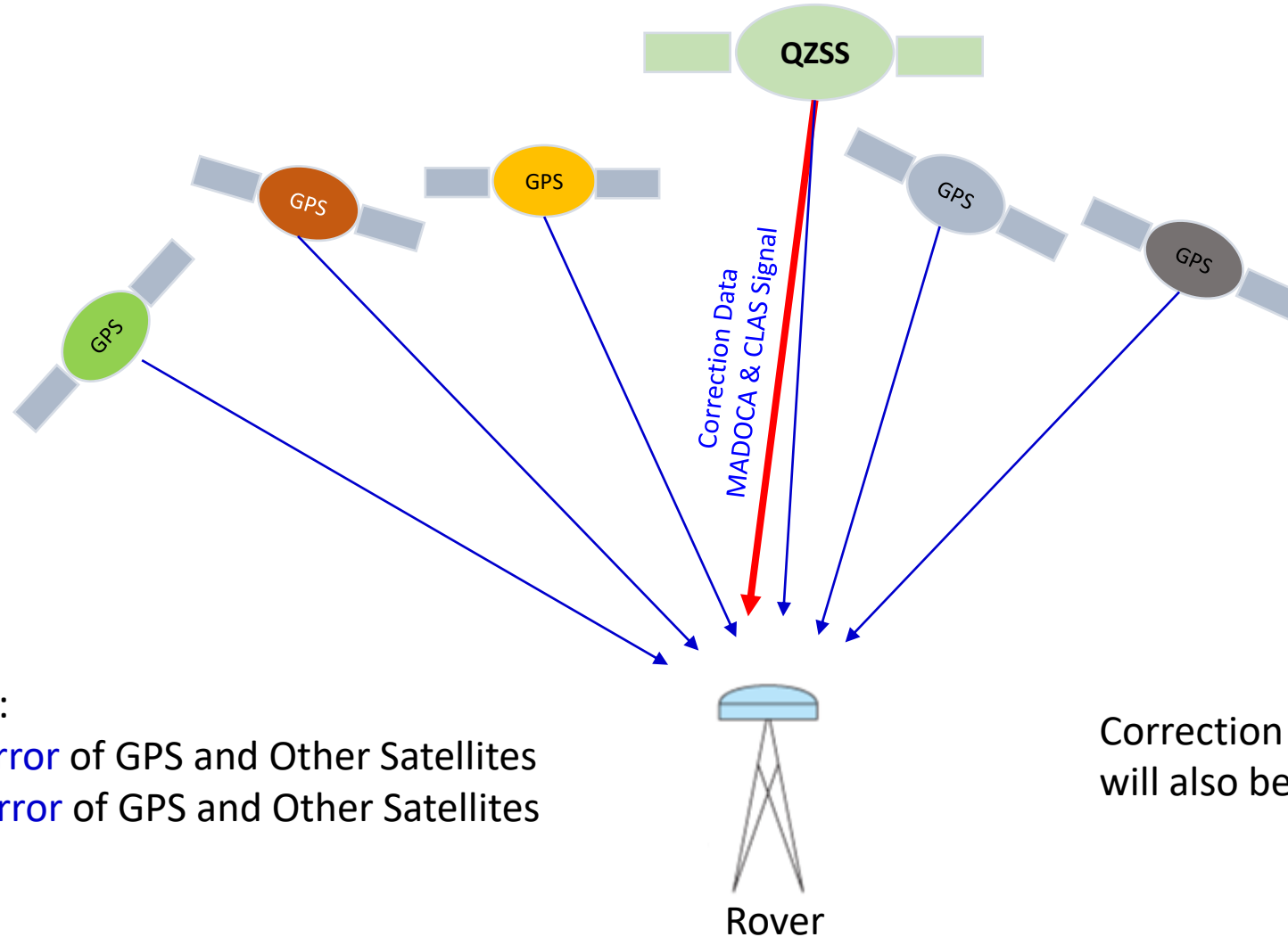
## Use Differential Correction



Base-station Antenna position shall be known in advance

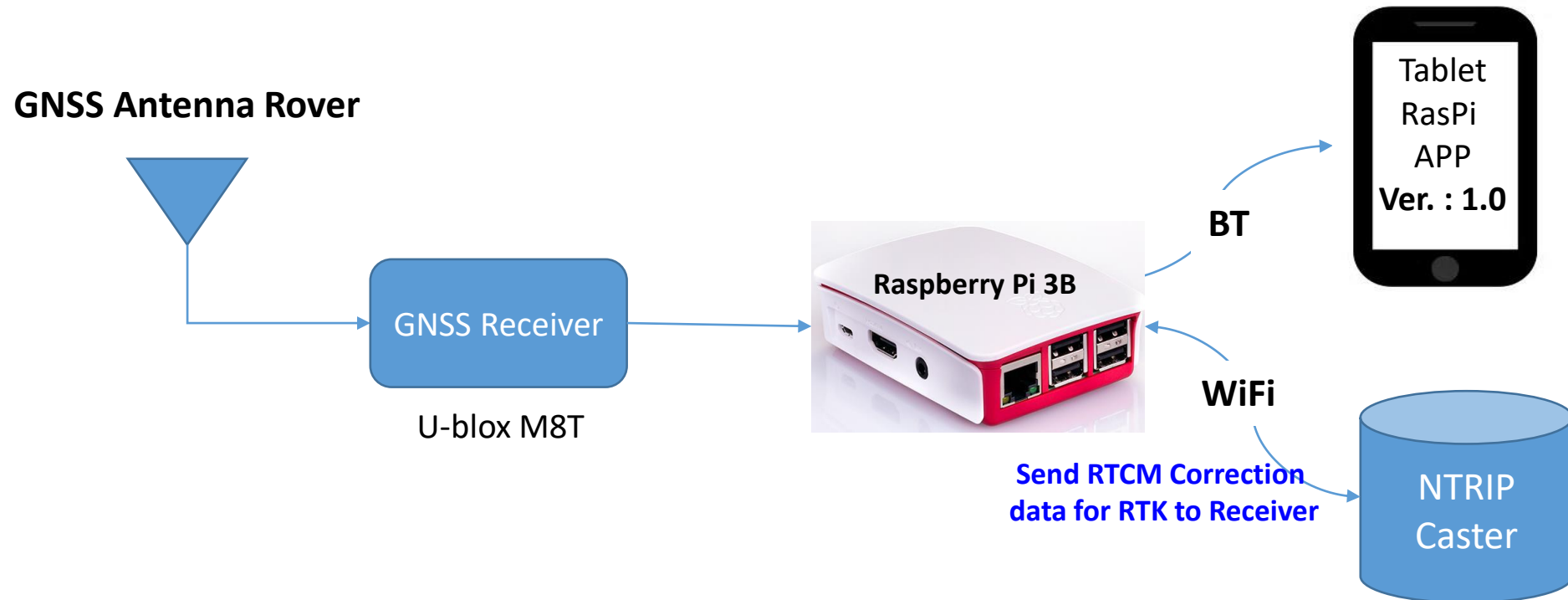
# How to Remove or Minimize Common Errors?

## Principle of QZSS MADOCA and CLAS Services



# Low-Cost Receiver System : Type A

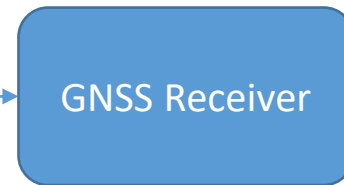
## Real-Time or Post-Processing RTK, Base and Rover Mode



# Low-Cost Receiver System: Type B

## Post-Processing RTK, Rover Mode Only

GNSS Antenna Rover



U-blox M8T



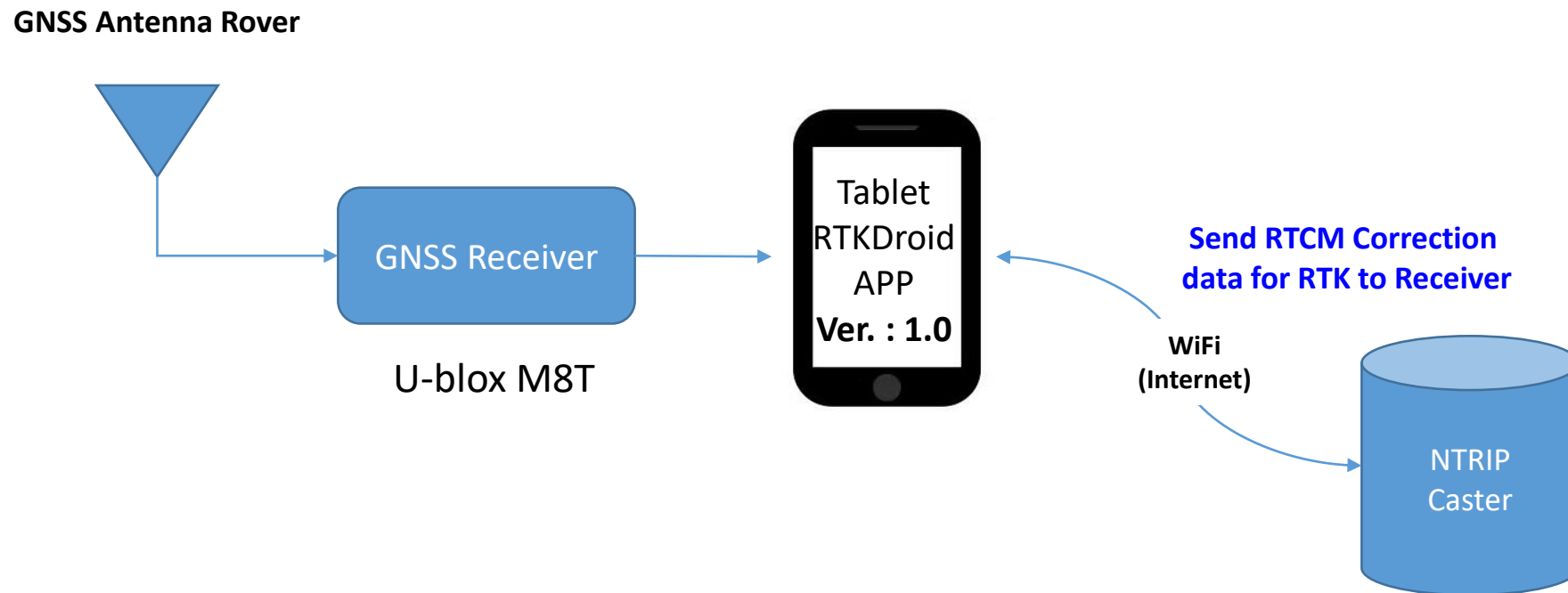
Raspberry Pi Zero w/WiFi&BT





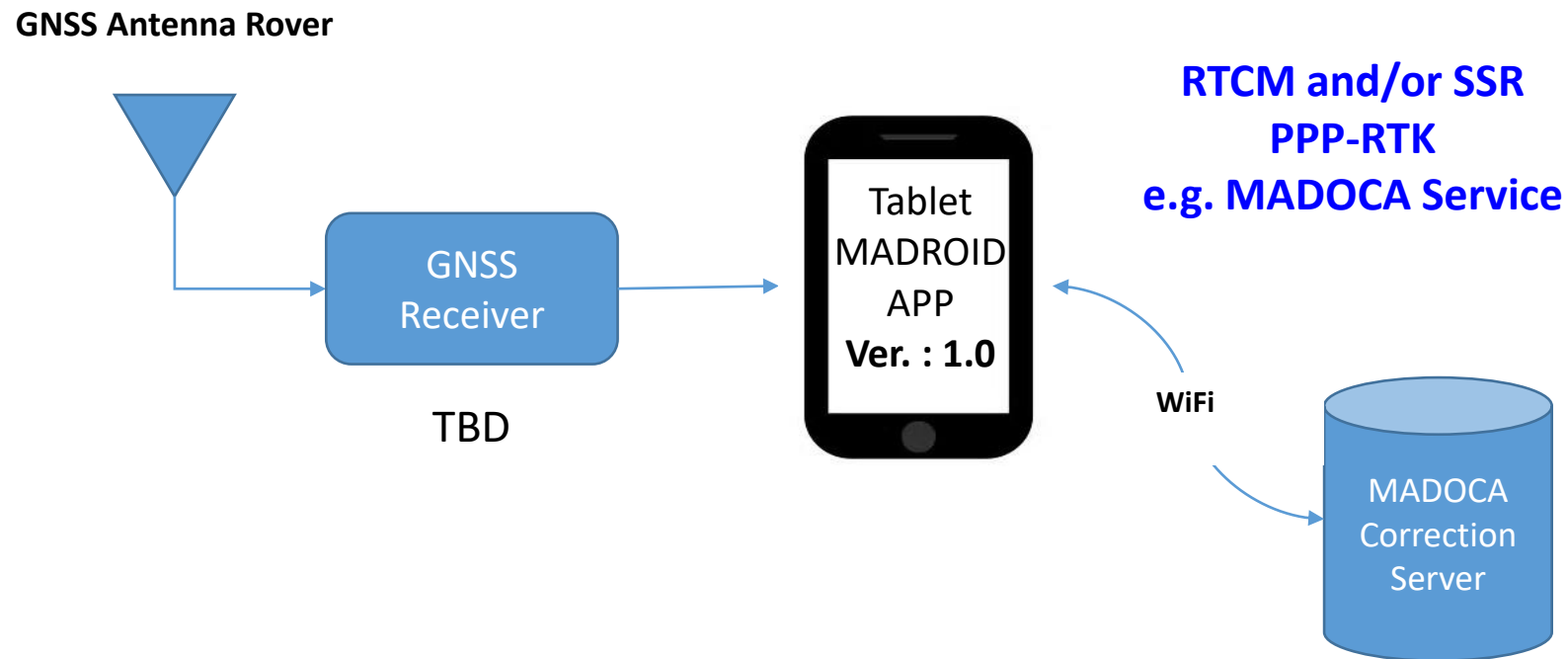
# Low- Cost Receiver System : Type C

## Real-Time or Post-Processing RTK, Rover Mode Only



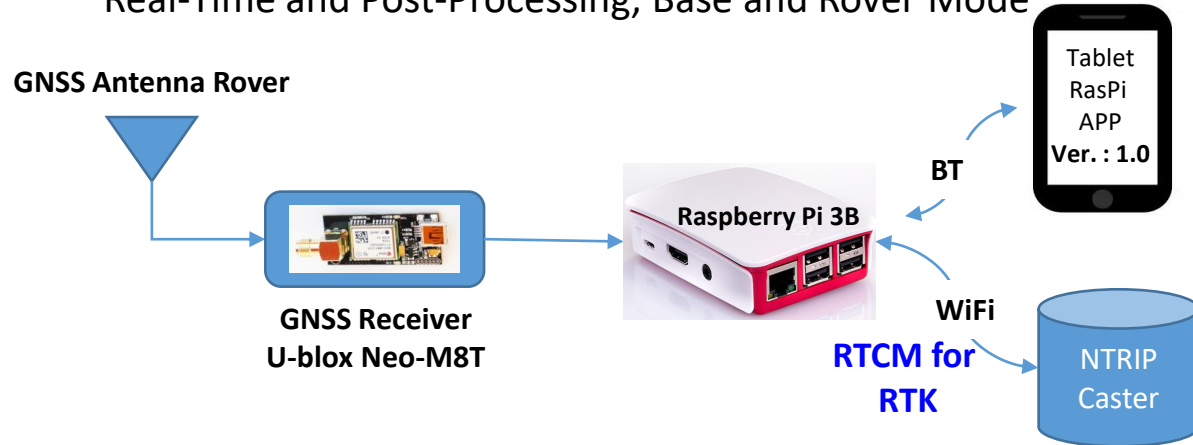
# Low-Cost Receiver System : Type D

## Real-Time or Post Processing PPP, Rover Mode Only

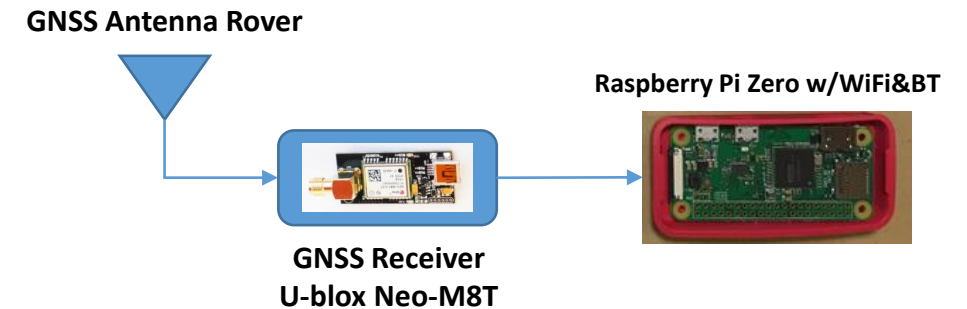


# Low-Cost High-Accuracy Receiver System

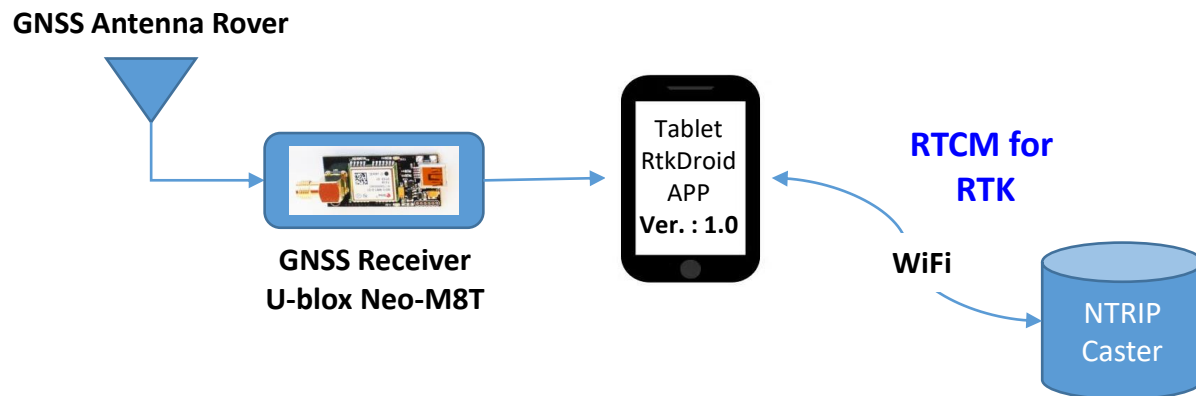
**TYPE A** Type A: Low-Cost, High-Accuracy Receiver System  
Real-Time and Post-Processing, Base and Rover Mode



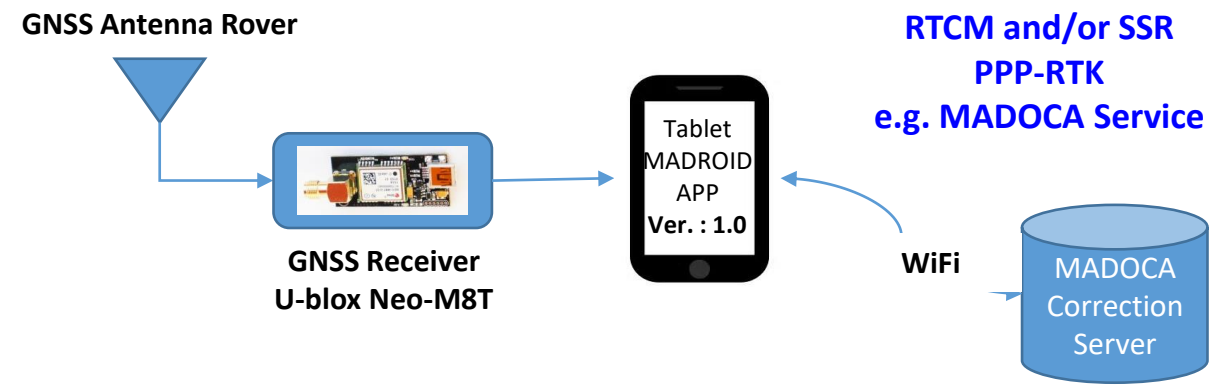
**TYPE B** Type B: Low-Cost, High-Accuracy Receiver System  
For Post-Processing & Rover Mode Only



**TYPE C** Type C: Low-Cost, High-Accuracy Receiver System  
Real-Time and Post-Processing, Rover Mode Only



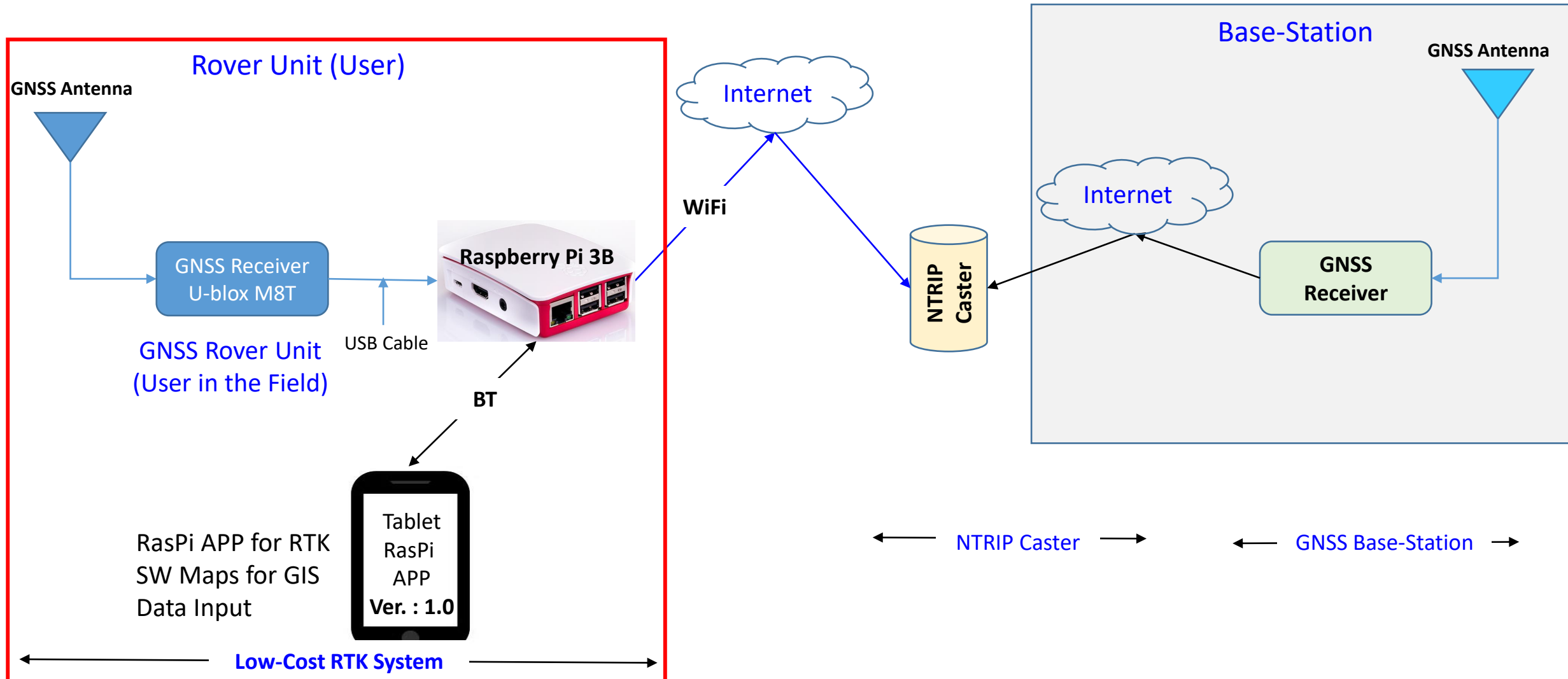
**TYPE D** Type D: Low-Cost, High-Accuracy Receiver System  
Real-Time and Post-Processing, Rover Mode Only



# Low-Cost Receiver Systems

Type	Receiver System	Usage	RTK Processing Engine	Mode	User Interface	Base-Station Data	Correction Data Format
<b>Type A</b> 2018 Q3 Beta Ver. Available		Real-time RTK Base and Rover Setting	Raspberry Pi 3B	Base or Rover	Android Device APP: RTKPI	NTRIP Server or VRS (future)	RTCM 3
<b>Type B</b> 2018 Q3 Beta Ver. Available		Log Raw Data for Post-processing RTK	Raspberry Pi Zero/WiFi&BT Option: RaspberryPi Camera	Rover Only	None	Post-processing	RINEX User Defined
<b>Type C</b> 2018 Q3 Beta Ver. Available		Real-time RTK Simultaneous Log of Raw Data	Android Device	Rover Only	Android Device APP: RTKDROID	NTRIP Server or VRS (future)	RTCM 3
<b>Type D</b> 2018 Q4 Development in Pipeline		Real-time PPP Based on MADOCA Correction Data from Internet	Android Device	Rover Only	APP: MADROID	MADOCA Correction Data Server	MADOCA Format Future: CLAS

# Low-Cost High Accuracy System : Type A



# RTK-Pi APP for Low-Cost RTK System

The screenshot displays the RtkPi application interface, which is divided into several sections for configuration and monitoring:

- Satellites:** Options include GPS + QZSS, GPS + GLONASS + QZSS (selected), and GPS + BEIDOU + QZSS.
- NTRIP Settings:** Fields for Address (202.xxx.xx.xx), Port (5000), Mount Point (t1), and Password (1234).
- Base Station Position:** Fields for Latitude, Longitude, and Elevation.
- Rover Mode:** Options include Autonomous (selected), RTK, and RTK.
- Satellites (Rover):** Options include GPS + QZSS, GPS + GLONASS + QZSS (selected), and GPS + BEIDOU + QZSS.
- NTRIP Settings (Rover):** Fields for Address (153.121.59.53), Port (2101), Mount Point, Username, and Password.
- Status/Information:** Latitude: 48.873416°, Longitude: 2.294480°, Elevation: 133.622m, Fix type: Autonomous, Satellites: 8, PDOP: 2.0, HDOP: 1.0, VDOP: 1.7.
- Signal Strength Diagram:** A circular diagram showing signal strength for various satellites, with labels 3, 11, 14, 17, 19, 22, 23, 31, 11, 23, 14, 17, 19, 22, 23, 31.
- Data Logs:** NMEA: 2017\_07\_27\_22\_58\_48.nmea, Size: 24KB; UBX: 2017\_07\_27\_22\_58\_48.ubx, Size: 95KB.
- Buttons:** START BASE, START ROVER, and STOP RECORDING.

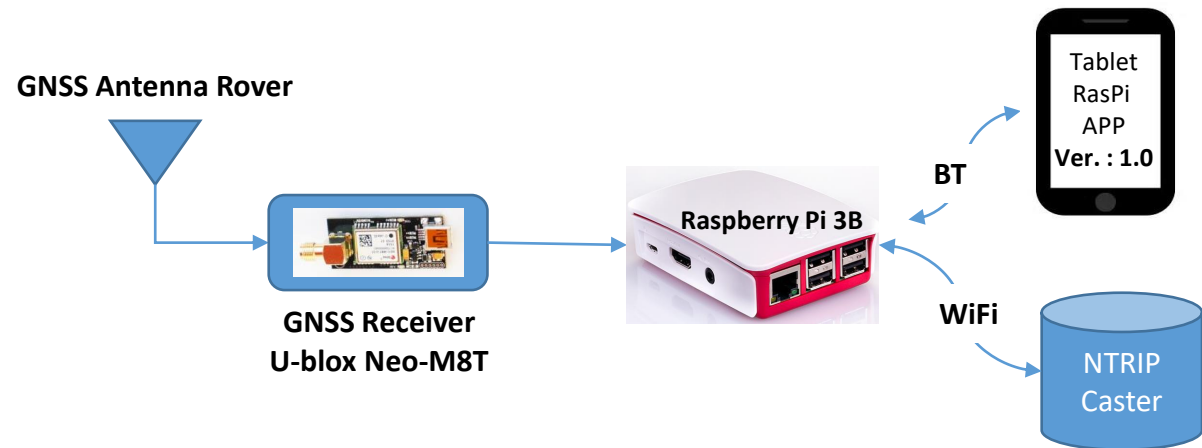
# Board Computer for Low-Cost RTK System

Raspberry Pi 3B for  
Real-time and Post-processing RTK

Raspberry Pi Zero w/WiFi & BT  
for Post-processing RTK

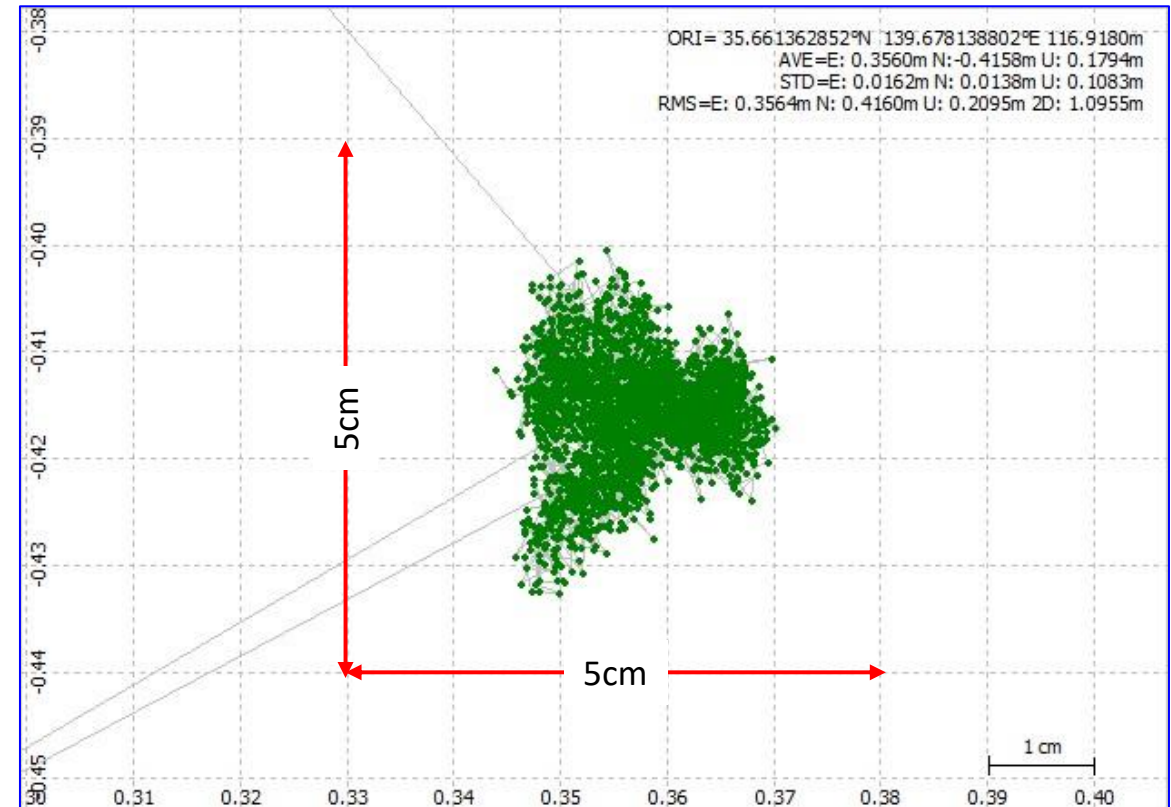


# Accuracy from Low-Cost RTK System



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





# Data from Low-Cost RTK System

2017\_09\_15\_17\_27\_13.ubx - u-center 8.24 - [Messages - UBX - RXM (Receiver Manager) - RAWX (Multi-GNSS Raw Measurement Data)]

File Edit View Player Receiver Tools Window Help

UBX - RXM (Receiver Manager) - RAWX (Multi-GNSS Raw Measurement Data) 1 s

Local Time 1966.462474.993000000 [s]  
Leap seconds 18 (VALID) [s] Clock reset

SV	Sign...	G	Pseudo Ra...	Carrier Phas...	Doppl...	Loc...	S...	PR ...	CP ...	DO ...	P...	C...	H...
G05	L1C/A	-	18440103.75	96903400.86	14.7	59000	49	0.32	0.004	0.512	Y	Y	Y...
G13	L1C/A	-	18601850.88	97753379.60	1014.6	59000	48	0.32	0.004	0.512	Y	Y	Y...
G02	L1C/A	-	18573259.87	97603139.07	-2055.6	59000	46	0.32	0.004	0.512	Y	Y	Y...
G30	L1C/A	-	19859876.78	104364373.57	-597.6	59000	44	0.32	0.004	0.512	Y	Y	Y...
G20	L1C/A	-	20430479.14	107362880.69	2133.0	59000	42	0.32	0.004	0.512	Y	Y	Y...
G15	L1C/A	-	20771576.02	109155349.83	2408.4	59000	45	0.32	0.004	0.512	Y	Y	Y...
G29	L1C/A	-	20903778.52	109850085.47	-1155.1	59000	44	0.32	0.004	0.512	Y	Y	Y...
G06	L1C/A	-	21631909.01	113676445.45	-3990.4	59000	38	0.64	0.004	0.512	Y	Y	Y...
S129	L1C/A	-	35066490.95	184275647.07	-425.5	49000	39	0.32	0.004	0.512	Y	Y	Y...
E05	E1C	-	21344085.07	112163928.52	-662.5	59000	45	0.32	0.004	0.512	Y	Y	Y...
E22	E1C	-	20082053.72	105531895.04	-1088.8	59000	44	0.32	0.004	0.512	Y	Y	Y...
E03	E1C	-	23506058.91	123525178.26	1096.2	59000	40	0.32	0.004	0.512	Y	Y	Y...
E09	E1C	-	21582857.80	113418678.85	-2222.5	59000	40	0.32	0.004	0.512	Y	Y	Y...
Q01	L1C/A	-	36867772.19	193741450.32	-242.0	860	46	0.32	0.004	0.512	Y	Y	N...
R01	L1OF	1	17998950.52	962133123.30	1593.5	57660	49	0.32	0.004	0.512	Y	Y	Y...
R24	L1OF	2	18108736.12	968336123.30	1554.3	57660	43	0.32	0.004	0.512	Y	Y	Y...
R08	L1OF	6	19569203.37	104792162.67	-2523.8	57660	43	0.32	0.004	0.512	Y	Y	Y...
R28	L1OF	3	20502600.83	109405739.36	1759.8	57660	45	0.32	0.004	0.512	Y	Y	Y...
R10	L1OF	-7	19767836.25	96320328.70	-2.7	57680	43	0.32	0.004	0.512	Y	Y	Y...
R11	L1OF	0	20133149.94	107585397.10	2936.8	57680	45	0.32	0.004	0.512	Y	Y	Y...
R17	L1OF	4	20054419.86	107315221.51	2260.3	57680	45	0.32	0.004	0.512	Y	Y	Y...
R02	L1OF	-4	20502600.83	109405739.36	1759.8	57660	45	0.32	0.004	0.512	Y	Y	Y...
R09	L1OF	-2	22370432.66	119456772.21	-3119.6	57660	36	0.64	0.004	0.512	Y	Y	Y...
S137	L1C/A	-	35066503.25	184275722.38	-425.9	35000	39	0.32	0.004	0.512	Y	Y	Y...
Q02	L1C/A	-	35066132.73	184273770.71	34.0	860	42	0.32	0.004	0.512	Y	Y	N...
E24	E1C	-	22721209.02	119400766.85	1920.7	59000	37	0.32	0.004	0.512	Y	Y	Y...
S128	L1C/A	-	37609584.24	197639700.85	-419.8	54000	38	0.64	0.004	0.512	Y	Y	Y...
G07	L1C/A	-	21587585.86	113443514.44	-2356.2	59000	41	0.32	0.004	0.512	Y	Y	Y...

Raw Data from Receiver  
Pseudorange, Carrier Phase, Doppler etc

Speedometer: 0.00 m/s = 0.0 km/h  
Altitude: 118.400 m x100  
Time: 08:27:36 UTC  
Date: Friday 09/15/2017

# Data from Low-Cost RTK System

2017\_09\_15\_17\_27\_13.ubx - u-center 8.24 - [Messages - UBX - RXM (Receiver Manager) - SFRBX (Subframe Data NG)]

File Edit View Player Receiver Tools Window Help

UBX - RXM (Receiver Manager) - SFRBX (Subframe Data NG) 1 s

## denotes data received on subChn  Strip Parity Bits

SV	MSG	DATA (* denotes invalid words)
GAL 3	E1B 0 E0	00955555 55555555 55555555 4EB9C000 83A74000 0000002A AAAA632E 87BF4000
GAL 5	E1B 0 E0	00955555 55555555 55555555 4EB9C000 83A74000 0000002A AAAA632E 87BF4000
GAL 9	E1B 0 E0	00955555 55555555 55555555 4EB9C000 83A74000 0000002A AAAA632E 87BF4000
GAL 22	E1B 0 E0	00955555 55555555 55555555 4EB9C000 83A74000 0000002A AAAA632E 87BF4000
GAL 24	E1B 0 E0	00955555 55555555 55555555 4EB9C000 83A74000 0000002A AAAA632E 87BF4000
GLO 1	L1OF 1 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 2	L1OF -4 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 8	L1OF 6 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 9	L1OF -2 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 10	L1OF -7 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 11	L1OF 0 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 17	L1OF 4 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 23	L1OF 3 14 1/3156	752856E0 5D706C48 0A4B0000
GLO 24	L1OF 2 14 1/3156	752856E0 5D706C48 0A4B0000
GPS 2	L1C/A 0 2	22C3AE0B 25A34ABB 0E3D5BD5 8D7EF996 B00ED3CB 3DB44210 2EDCDC5A 8402E875 832C83CB 1C909F7C
GPS 5	L1C/A 0 2	22C3AE0B 25A34ABB 033FF65A 8CE7D348 36E920B1 BFF58087 2A4E4660 05792861 831E5F97 1C9093EC
GPS 6	L1C/A 0 2	22C3AE0B 25A34ABB 22338888 22338888 22338888 22338888 22338888 22338888 22338888 22338888
GPS 7	L1C/A 0 2	22C3AE0B 25A34ABB 03404DB3 0C196F50 02CFE2D9 802A4174 2A8FDAF4 0523E852 83729150 1C909478
GPS 13	L1C/A 0 2	22C3AE0B 25A34ABB 06002439 8CA2FB8A AD89F7F6 8014C070 328B1F03 03482848 034D7BCA 9C909FF0
GPS 14	L1C/A 0 2	22C3AE0B 25A34ABB 0E3D5BD5 8D7EF996 B00ED3CB 3DB44210 2EDCDC5A 8402E875 832C83CB 1C909F7C
GPS 20	L1C/A 0 2	22C3AE0B 25A34ABB 0A800B59 0E01C210 22702E31 00100050 149C0D28 0376A03D 0376DEDF 1C909F7C
GPS 29	L1C/A 0 2	22C3AE0B 25A34ABB 01BF15E0 0BDAD92A ADA76857 3F1E8029 90F5C377 01A96847 03220618 1C909478
GPS 30	L1C/A 0 2	22C3AE0B 25A34ABB 0A805139 8D0B6F0B 01C4A960 00238048 246C1FD9 85416853 0343752B 1C909F2F
QZSS 1	L1C/A 0 2	22C0AA24 25A34254 10494F43 067A62DE 8A7BAAB5 84AB49A3 1D0554C4 0AF1F2AF 3BC08DFD 9C585FC7
QZSS 1	L1SAIF 0 50	53CA767 E0000070 31027FDD FD8FD8FE 502F0000 00000000 00000000 3294C0A6
QZSS 2	L1C/A 0 2	22C0AA81 A5A3524F 107D9E77 037ECC21 BCA9FE77 3F294966 B57BC11D 879B728F 3B22D081 9C585F94
QZSS 2	L1SAIF 0 50	53CA767 E0000070 31027FDD FD8FD8FE 502F0000 00000000 00000000 3294C0A6
SBAS 128	L1C/A 0 3	530D9FFF FF9FFDFD C011FFC0 00001FFD FFC007FF 7FF797B9 B95BBA16 B71493A6
SBAS 129	L1C/A 0 25	536611C7 EBFDC05F EC7FFE81 7F9DBA80 00000000 00000000 00000000 0D6D0226
SBAS 137	L1C/A 0 25	536611C7 EBFDC05F EC7FFE81 7F9DBA80 00000000 00000000 00000000 0D6D0226

Navigation Data from Receiver  
Includes Satellite Ephemeris Data, Satellite Clock Data etc

0.00 m/s = 0.0 km/h

118.500 m

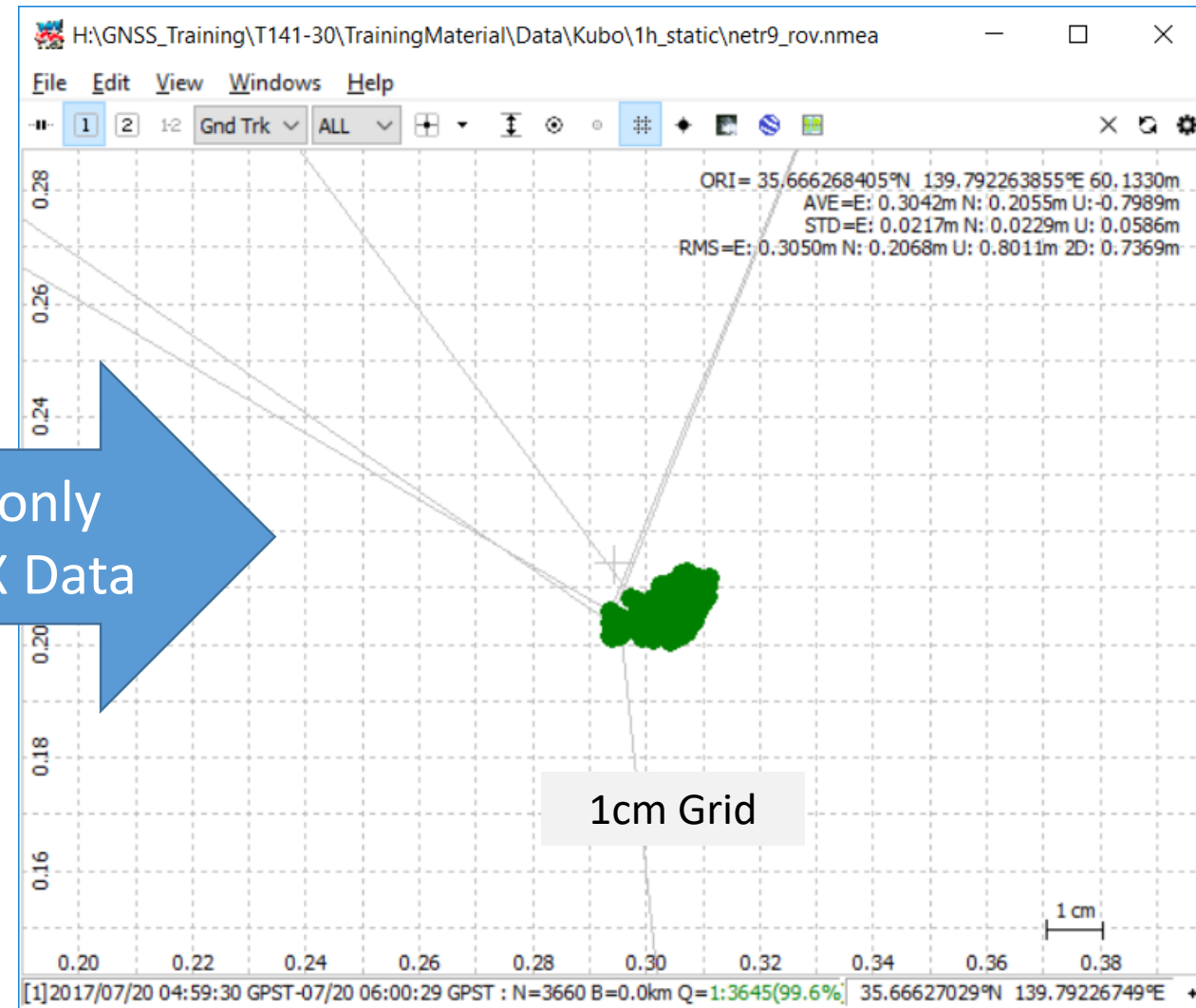
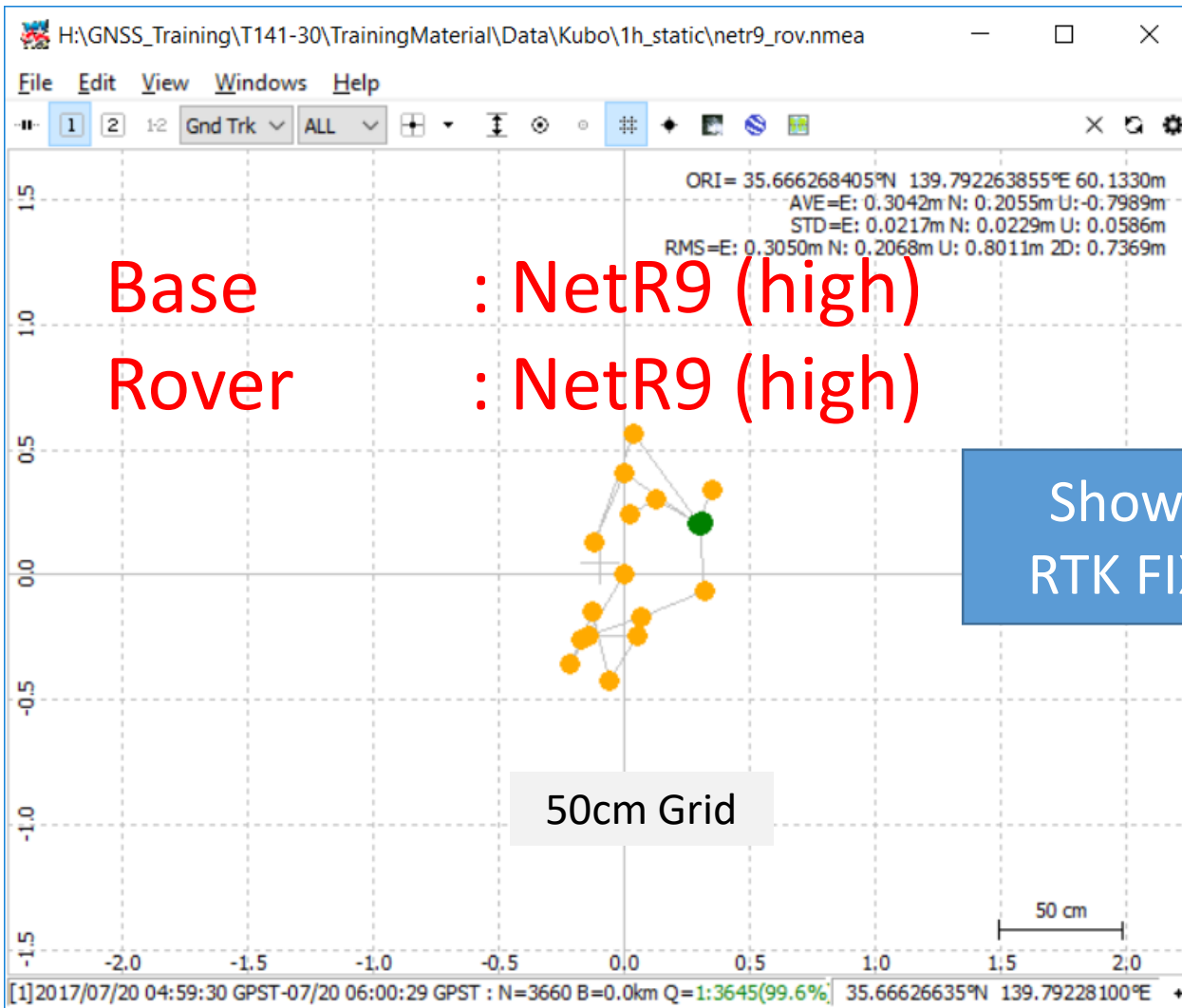
08:27:58 UTC

Friday 09/15/2017

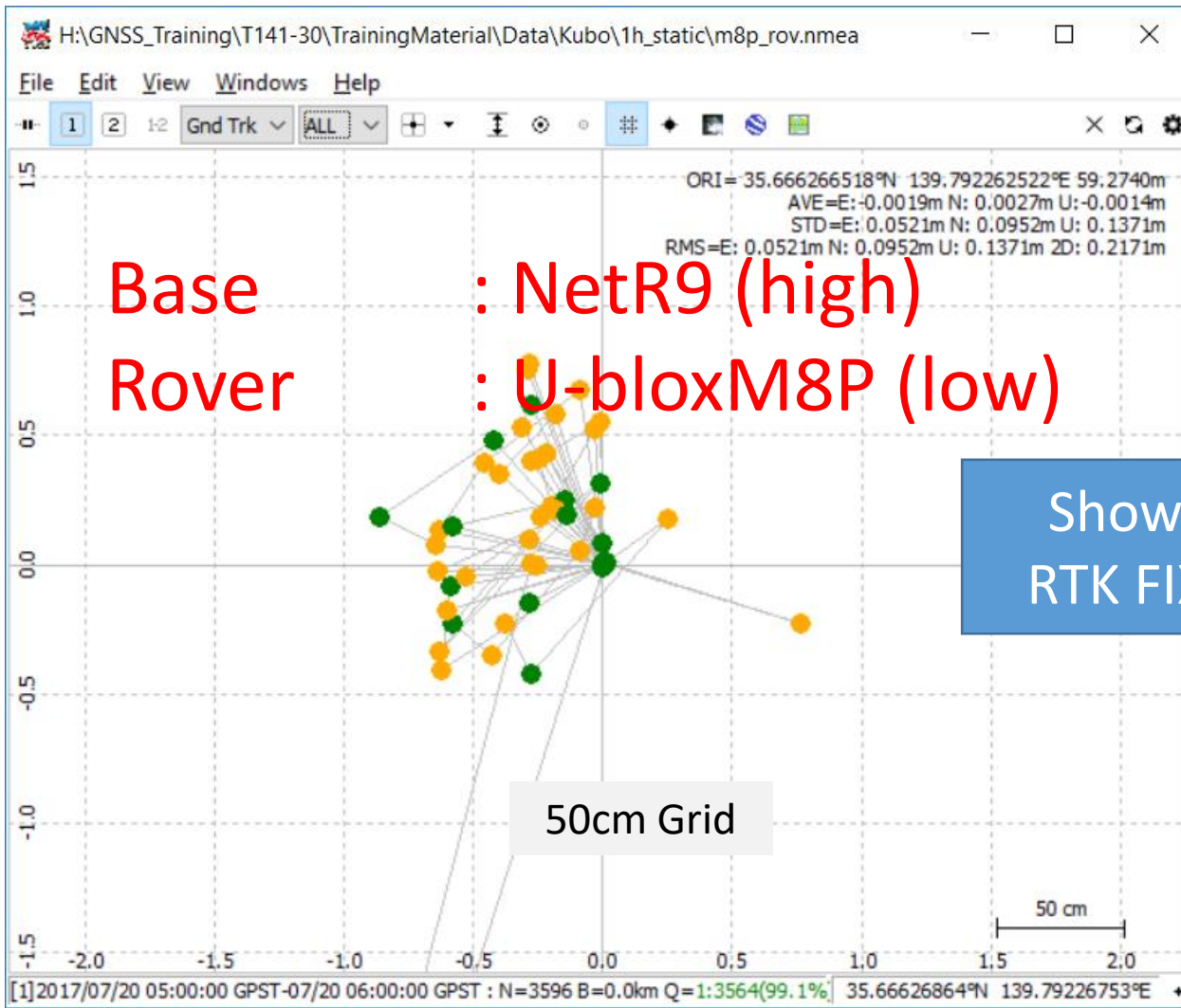
u-blox M No port o 2017.09.15 NMEA/00:00:08:27

# Low-Cost RTK Field Survey Data Static, Tokyo

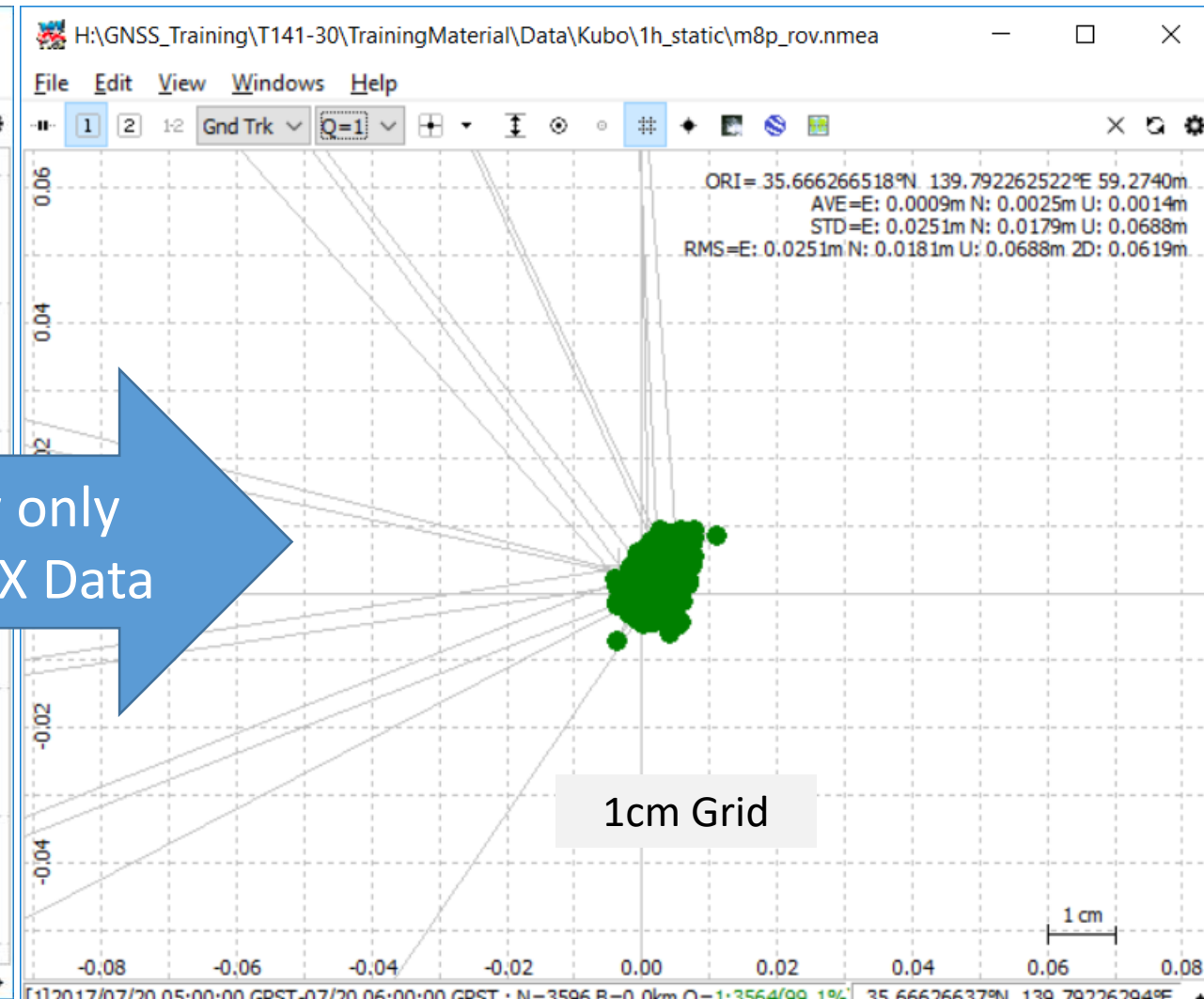
# One Hour RTK Post-processing, Static, Tokyo



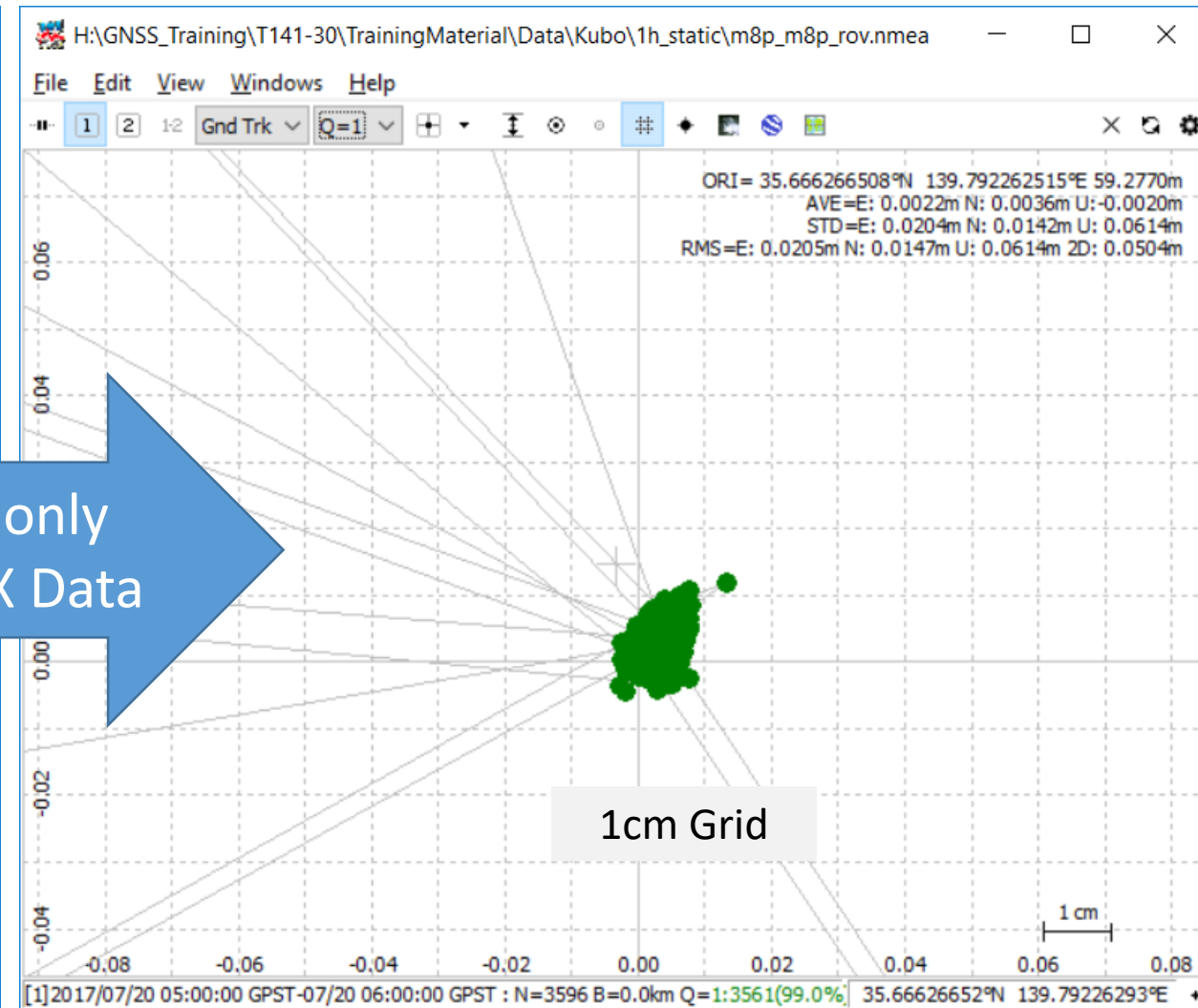
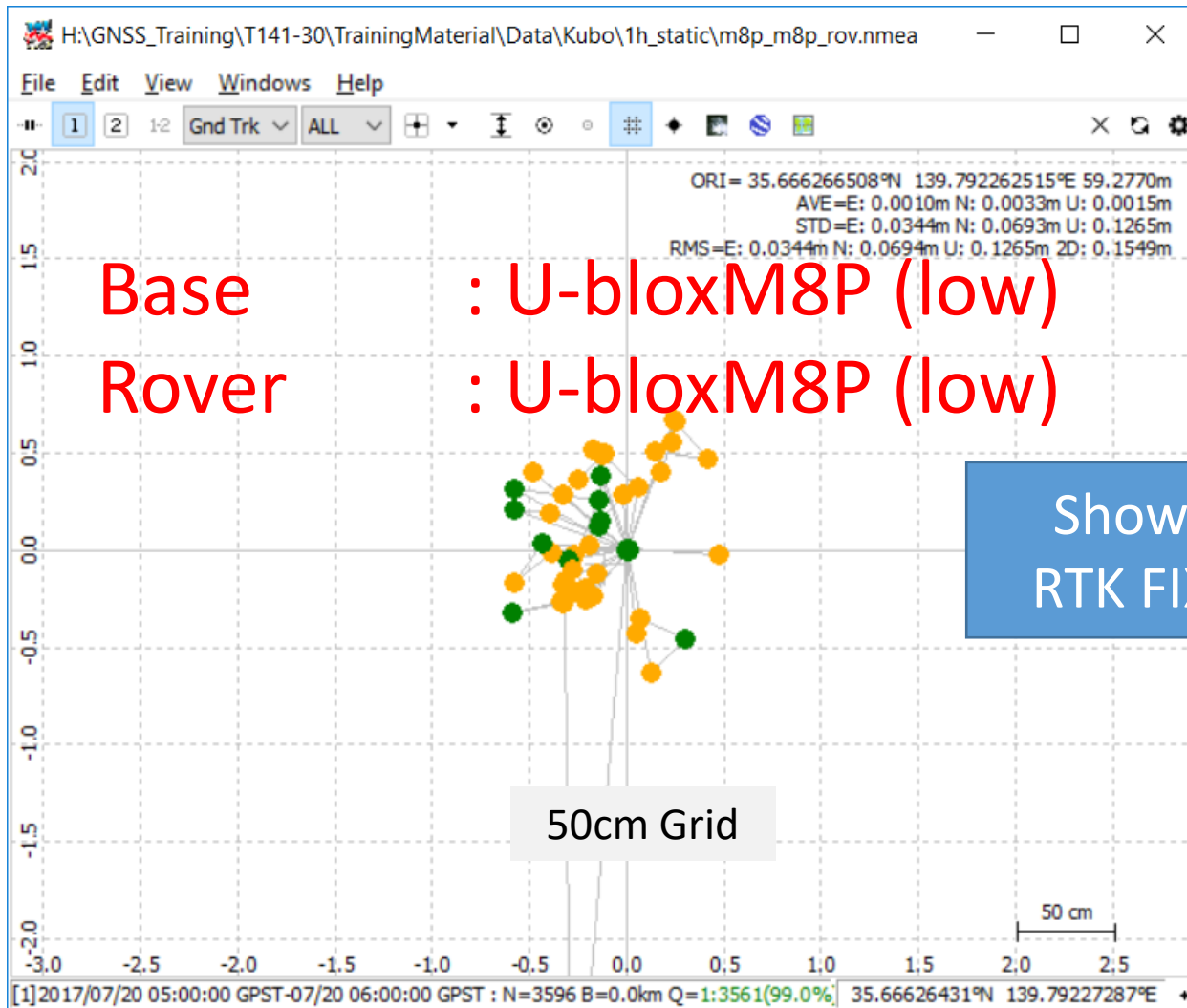
# One Hour RTK Post-processing



Show only RTK FIX Data



# One Hour RTK Processing



Show only  
RTK FIX Data

# Future of Low-Cost GNSS Receiver Systems

# Future of Low Cost GNSS Receiver System

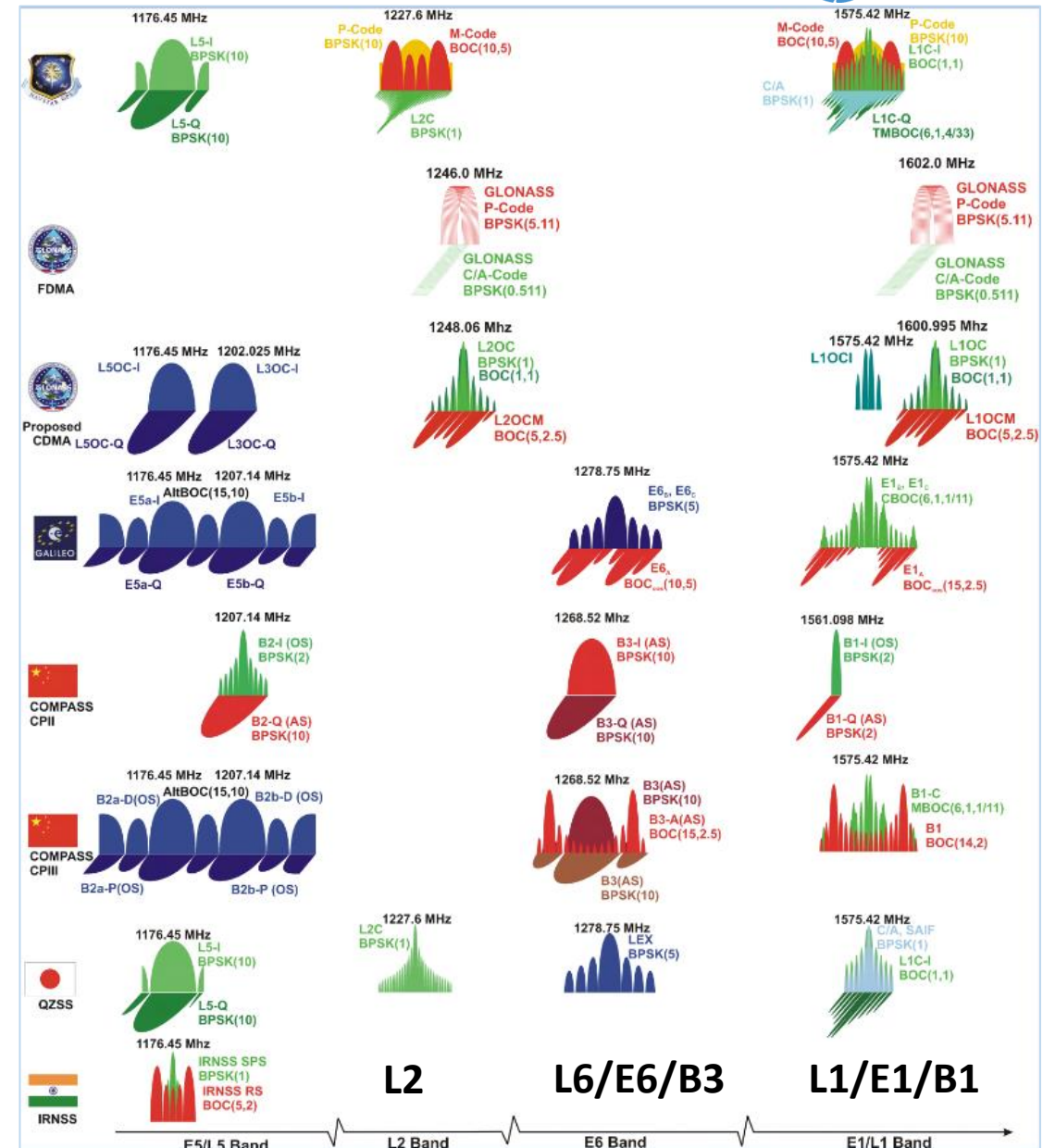
- IoT, ITS, UAV and many other location data related markets are driving the receiver manufacturers to produce low-cost, high-accuracy and better performance receiver systems even in difficult environments.
- Manufacturers are also moving towards low-cost, high-accuracy and better performance receivers systems to meet the demand from location business.



# Why Manufacturers are going for Low-Cost, Dual-Frequency Systems?

- The figure shows that many GNSS signals are crowded either in L1 or L5 bands.
- All GNSS have at least one signal either in L1 or L5 band
- L5 signals are stronger than L1 signals by few dBs
- L5 signals performs better than L1 signals in difficult environment like urban area, forest or semi-indoor
- L5 frequency spectrum is reserved and protected for RNSS
- All these may lead receiver designers to focus on L1/L5 Dual Frequency Receiver rather than L1/L2 receiver

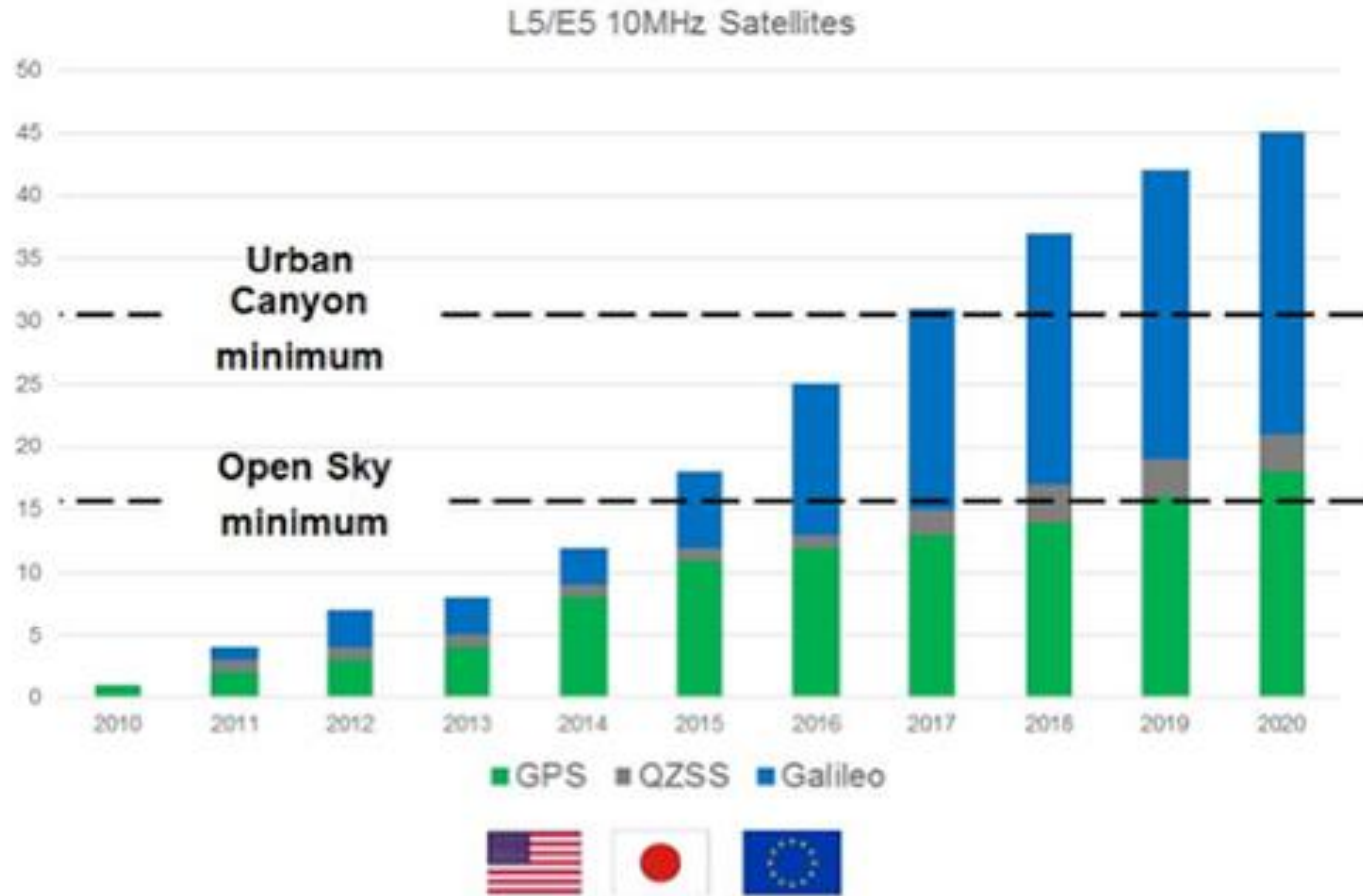
Source: [http://www.navipedia.net/index.php/File:GNSS\\_All\\_Signals.png](http://www.navipedia.net/index.php/File:GNSS_All_Signals.png)



# Why Dual Frequency now?

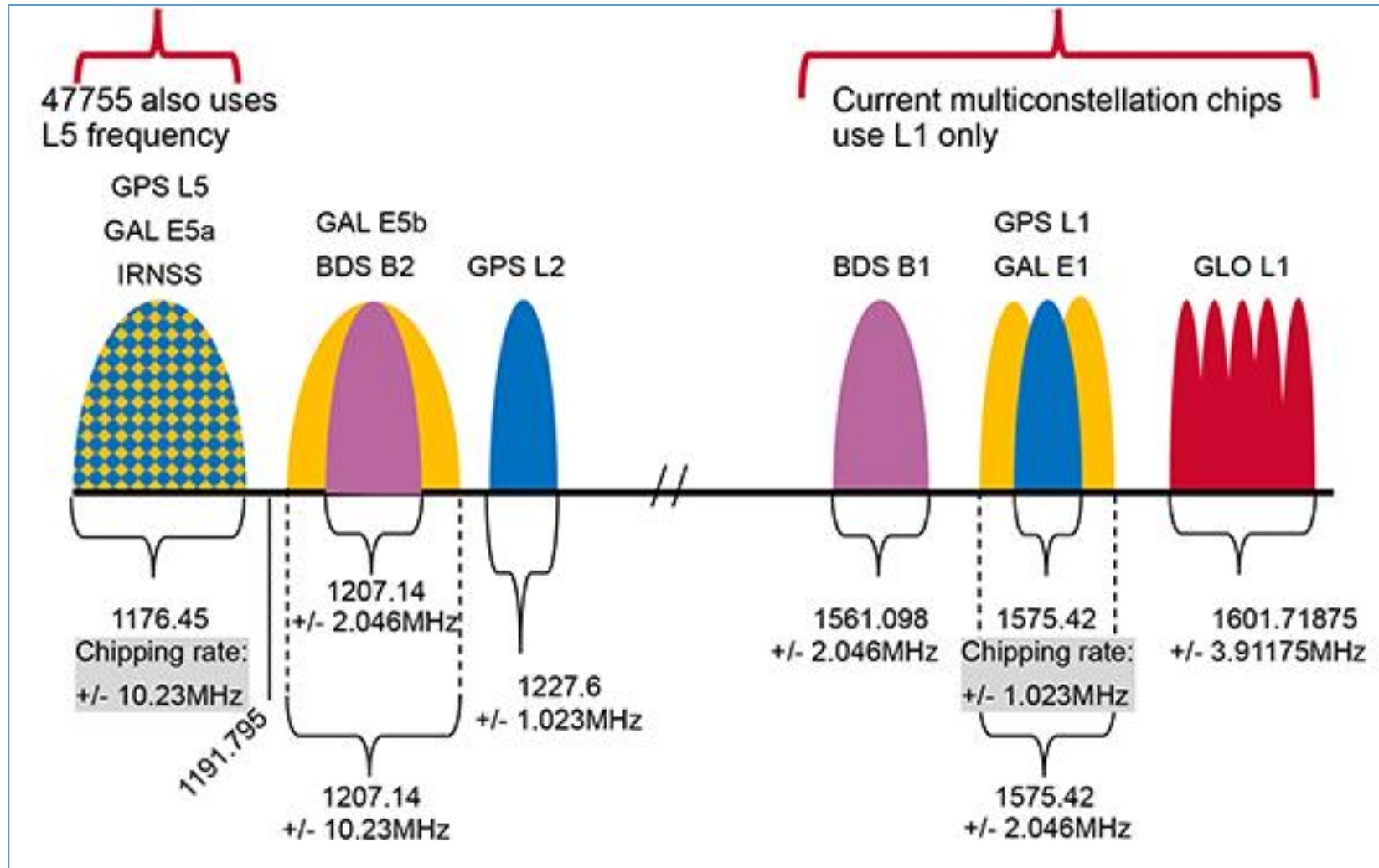
L5/E5 satellite launches have sped up in 2015 and 2016

Now, there are enough L5/E5 satellites that it is worth using a dual frequency receiver



Source : Broadcom

# Broadcom already announced Dual-Frequency GNSS chip



Source : Broadcom

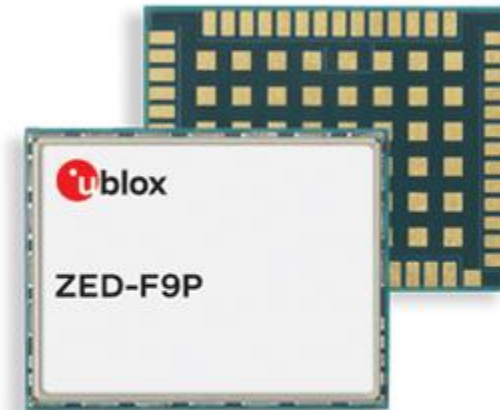
# Multi-Band GNSS Receiver from u-Blox

## ZED-F9P module

u-blox F9 high precision GNSS module

**Multi-band GNSS receiver delivers centimeter level accuracy in seconds**

- Concurrent reception of GPS, GLONASS, Galileo and BeiDou
- Multi-band RTK with fast convergence times and reliable performance
- High update rate for highly dynamic applications
- Centimeter accuracy in a small and energy efficient module
- Easy integration of RTK for fast time-to-market



ZED-F9P module / 17 x 22 x 2.4 mm

# Smart-Phone GNSS for High-Accuracy Position

- Android Smart-Phone devices provide GNSS Raw Data
  - Android OS Nougat (7.0) and higher output GNSS Raw Data
- GNSS Raw Data are necessary for RTK Processing
  - Pseudorange, Carrier Phase, Doppler etc.
  - It's possible to do RTK with Smart-Phone device
    - The only problem is Antenna
- An accuracy within One Meter from Smart-Phone device will revolutionize Location Business

# GNSS raw data on Android devices opens up a range of possibilities and opportunities

Dive deep to understand your users

## Where you are



### Places API

Give your users contextual information about where they are, when they're there. Access detailed information about 100 million places across a wide range of categories.



### Geofencing

Geofencing combines awareness of the user's current location with awareness of the user's proximity to locations that may be of interest.



### Fused Location Provider API

Get location data for your app based on combined signals from the device sensors using a battery-efficient API.

## What you're doing



### Google Fit Platform

Enable your users to record their fitness activity and track their fitness and health goals. Fit is a universal platform that lets users access their fitness data across multiple apps.



### Activity Recognition API

The Activity Recognition API processes low power signals from multiple sensors in the device to accurately detect your users' current activity.



### Sensors API

Access raw data from all device sensors, as well as fused information from multiple sensors.

## What's nearby



### Nearby Messages

Allow your users to find nearby devices and share messages in a way that's as frictionless as a conversation. Enable rich, collaborative group interactions.



### Nearby Connections

Discover other devices nearby and create connections that enable real-time cross-device experiences.



### Nearby Notifications

Nearby Notifications is an upcoming feature for contextual discovery. Associate your website or app with beacons, to provide low-priority notifications when scanned by devices that are nearby.