GNSS Low-Cost Receiver Systems

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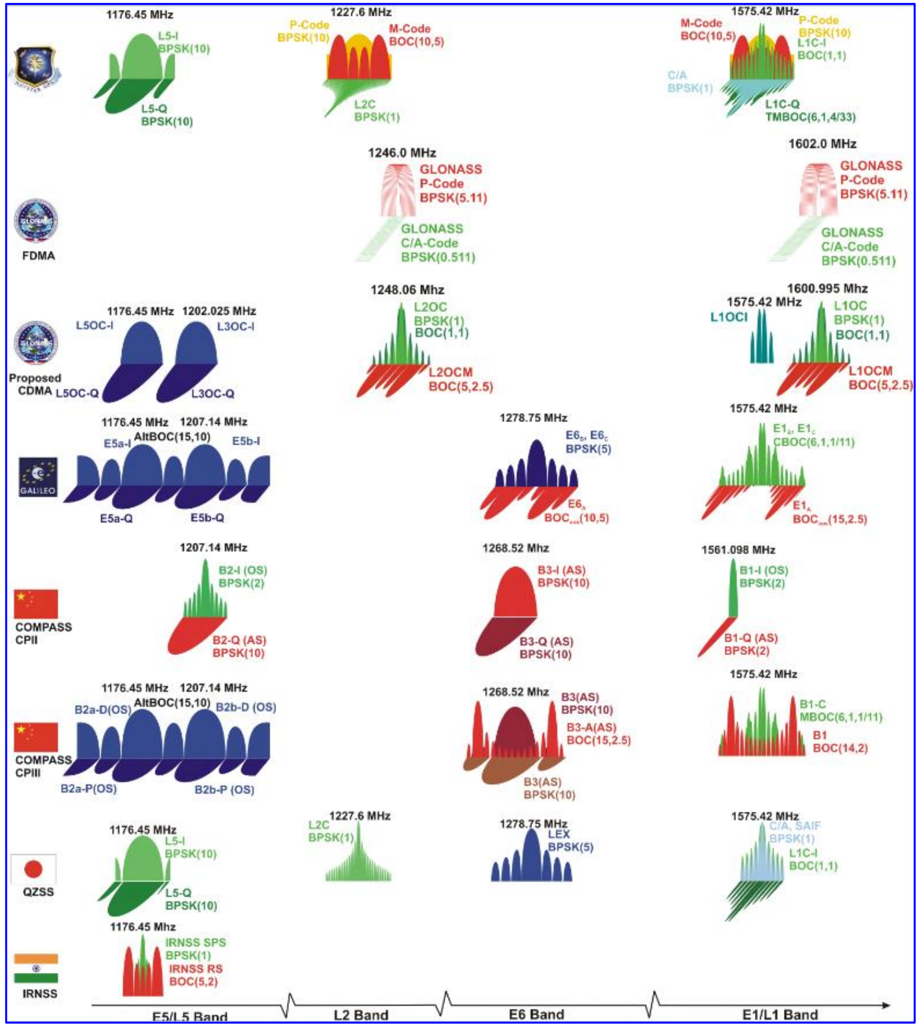
Quiz

- 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

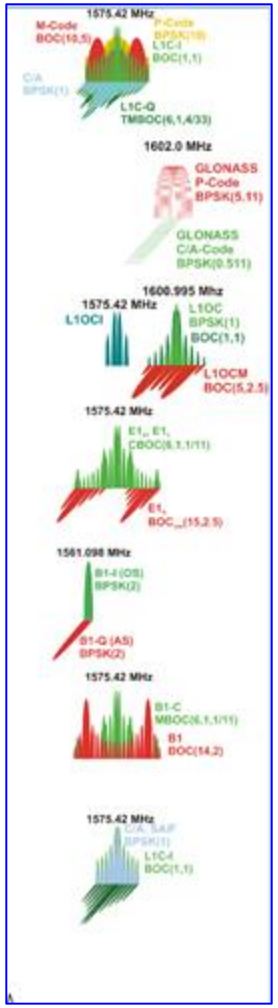
L5/E5/B2/L3 L2 L6/E6/B3 L1/E1/B1



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

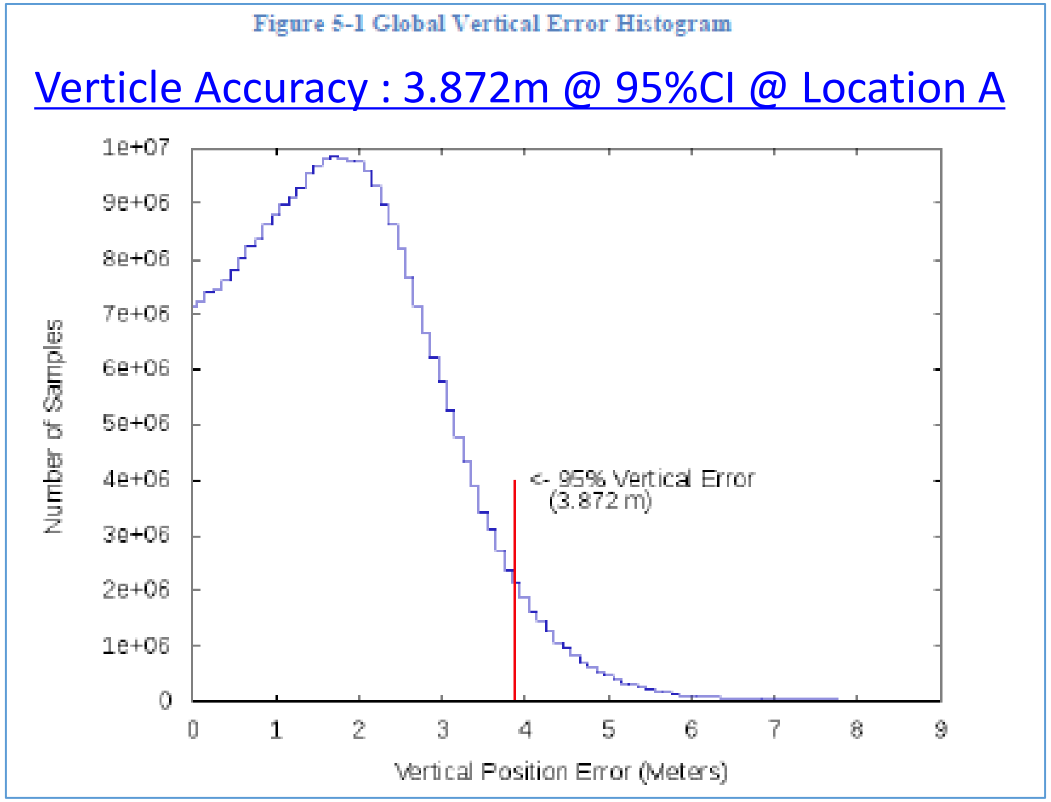
New Emerging Applications

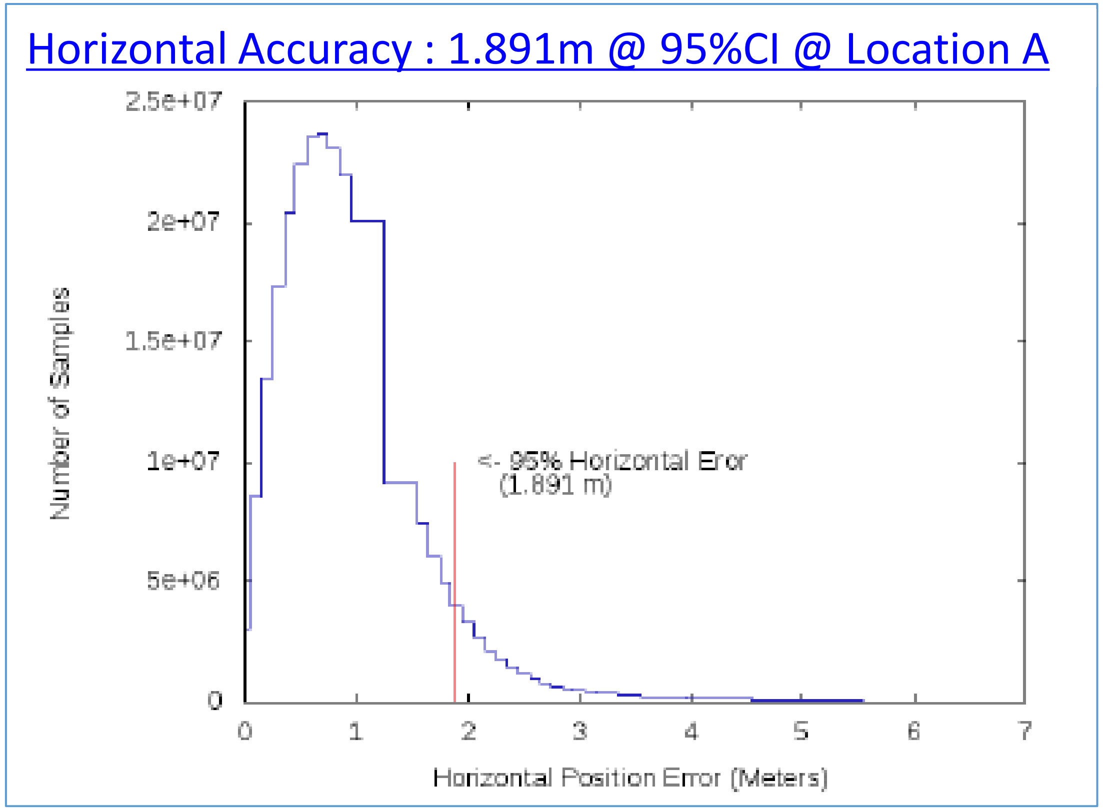
- ITS
  - ITS-Station (infra on the road side)
  - ADAS
  - V2X, V2I
- Public Transport Monitoring
  - Traffic Congestion
  - Public Safety and Security
  - Driver's Behavior Monitoring
- Toll Charge
  - ERP (Electronic Road Pricing)
- Precise Agriculture
- Drone Mapping
  - Direct Geo-referencing
- 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?





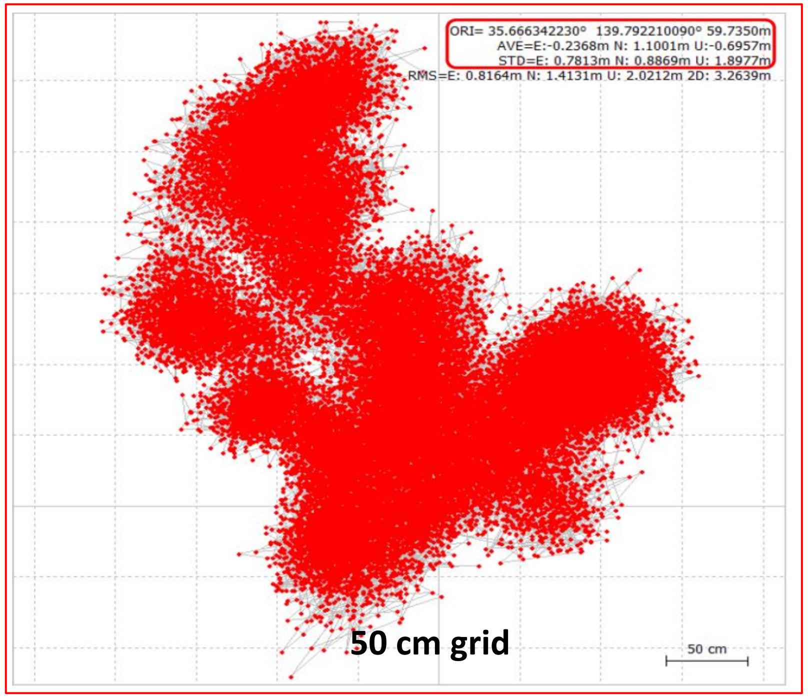
Global Accuracy Standard:
Better than 12.8m at 95% CI Global Average URE
Better than 30m at 99.94% CI Global Average URE
URE: User Range Error ➔ Pseudorange Accuracy
Ref: https://www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf

Question?

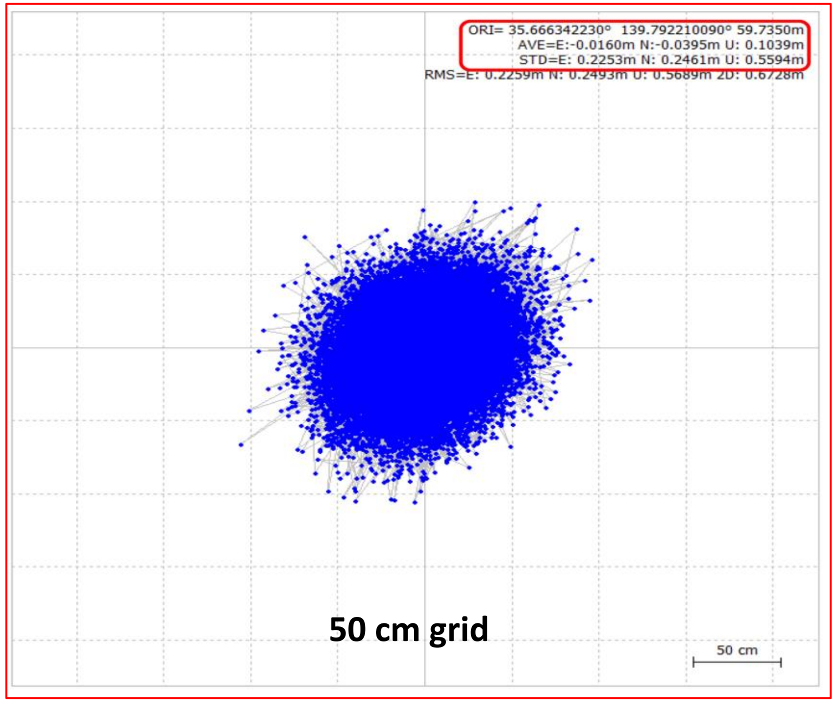
Though the Normal Accuracy of GPS is about 10m, why can we get Centimeter Level Accuracy?

GPS Position Accuracy: From few meters to centimeter

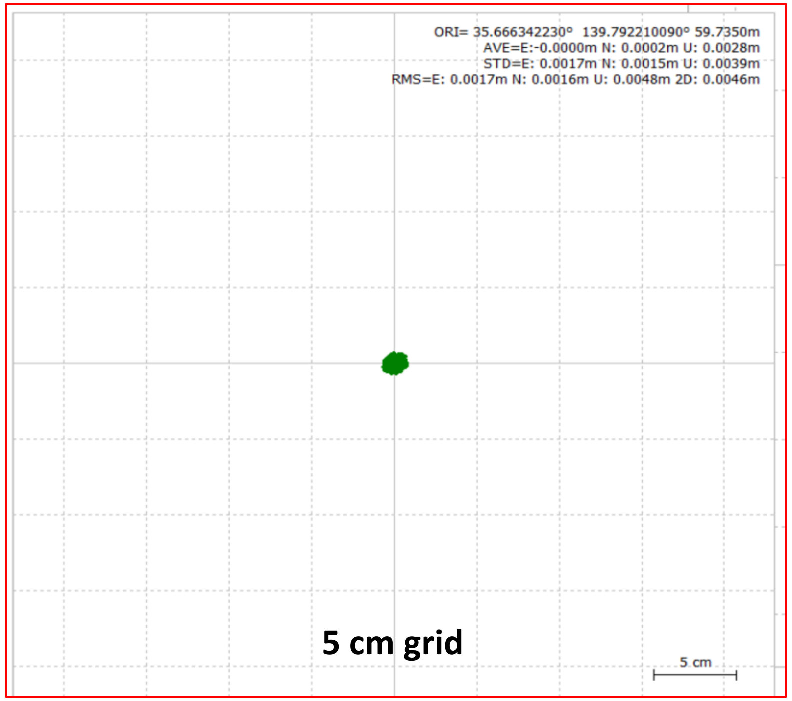
meter → centimeter



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	

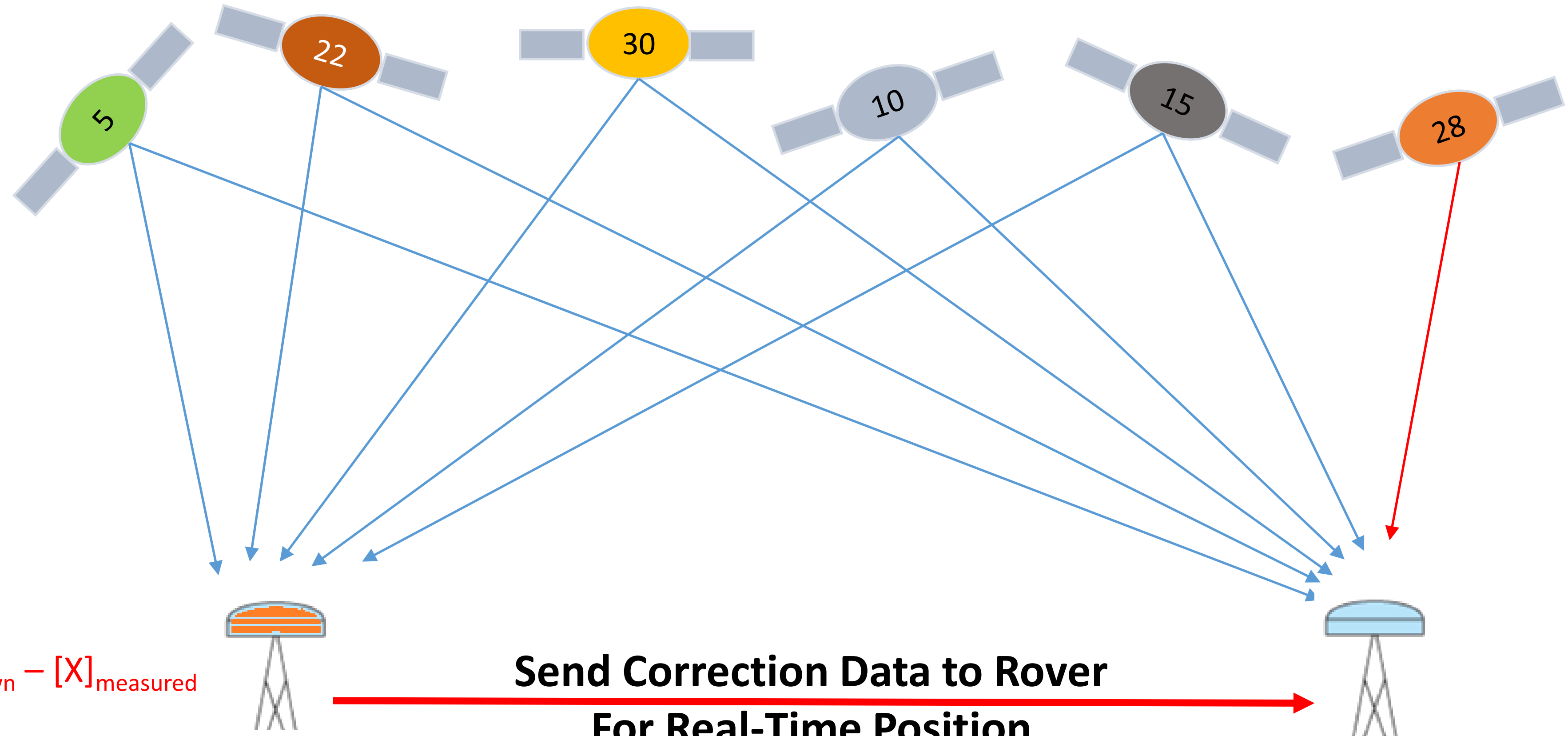
If we can remove common errors, position accuracy can be increased.

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

How to Remove or Minimize Common Errors?

Use Differential Correction



$[X]_{error} = [X]_{known} - [X]_{measured}$

Send Correction Data to Rover

For Real-Time Position

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

Base-Station

Antenna is installed at a known-position

Base-station Antenna position shall be known in advance

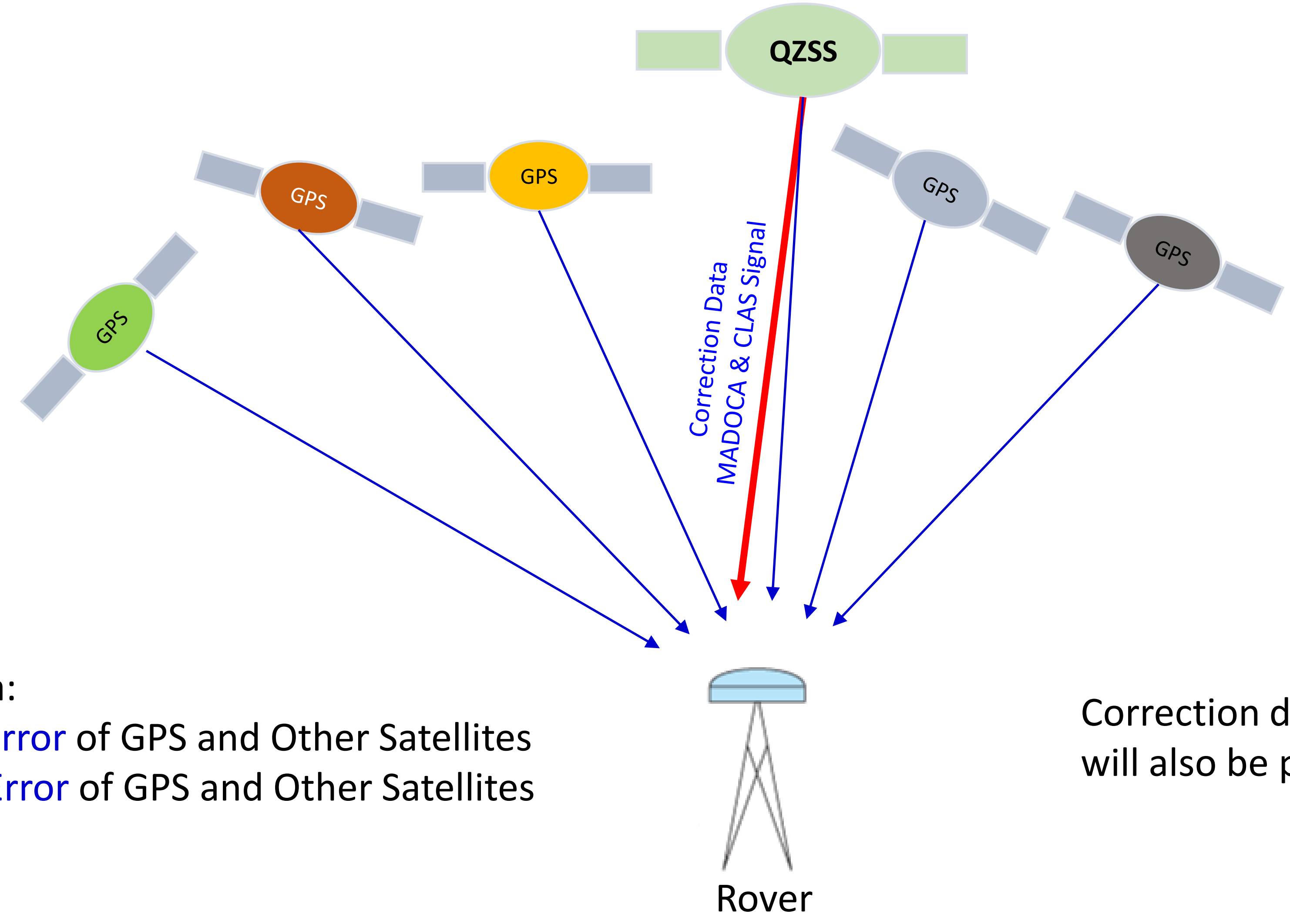
Rover

User in the Field

(Either fixed or moving)

How to Remove or Minimize Common Errors?

Principle of QZSS MADOCA and CLAS Services

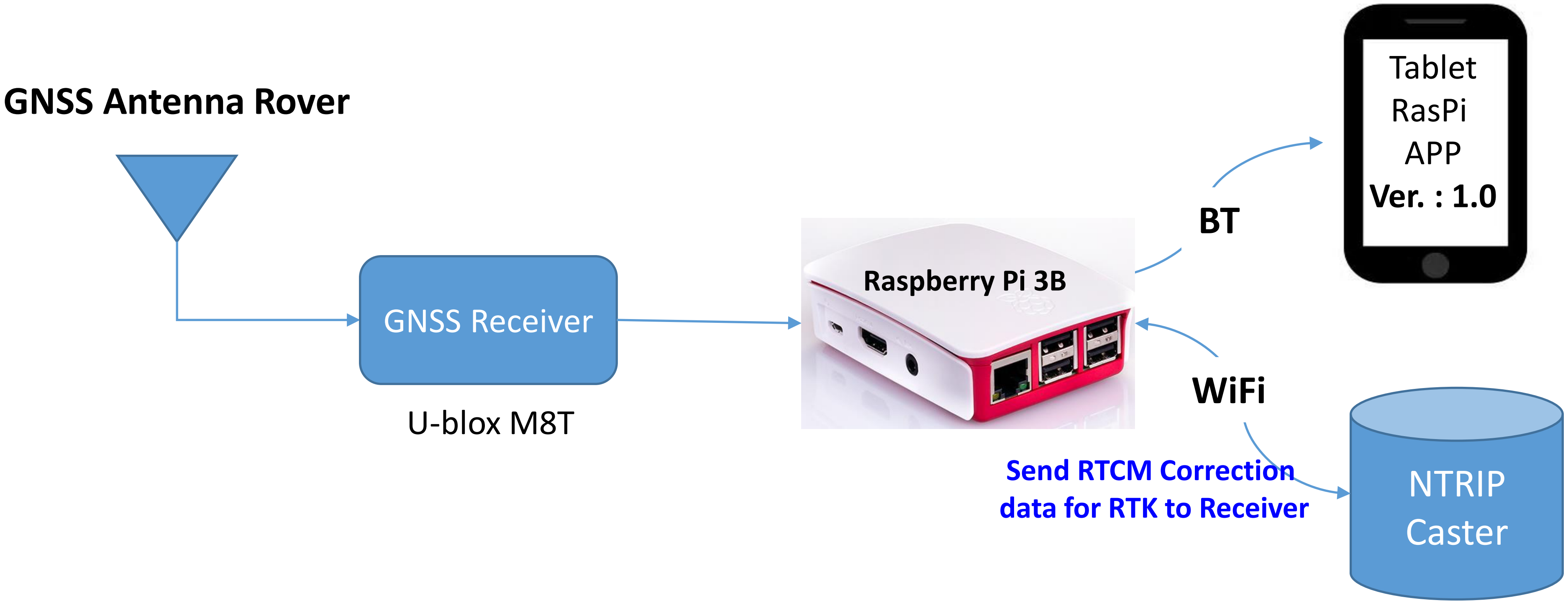


Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

Correction data for other satellites will also be provided

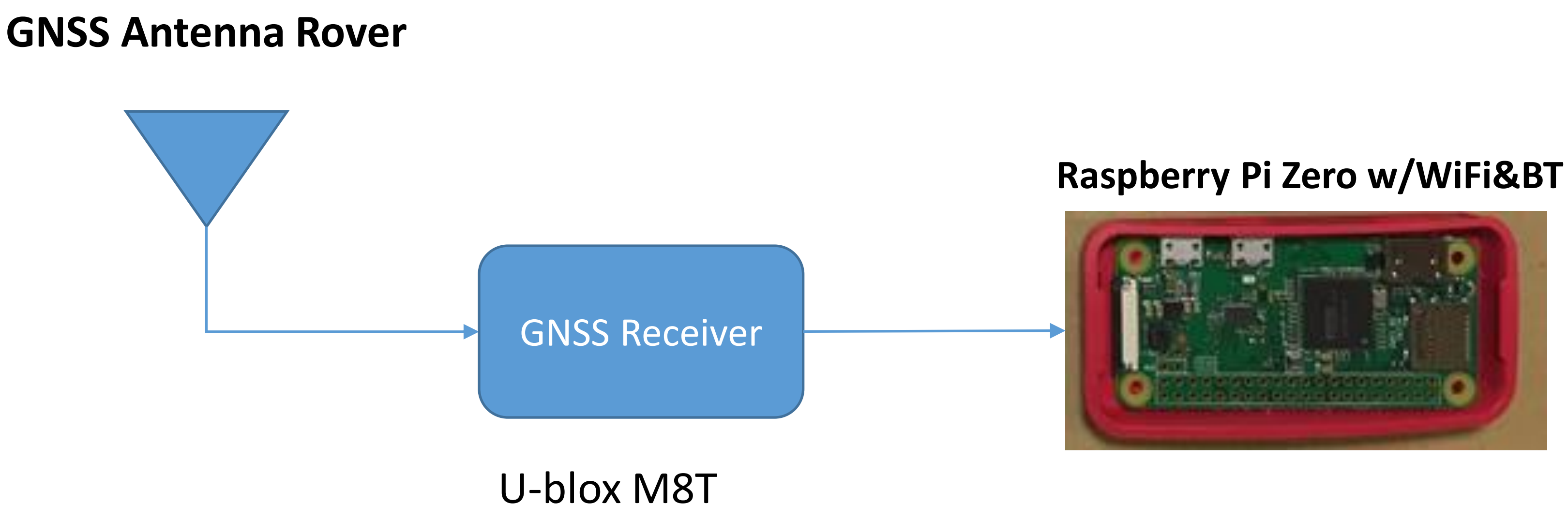
Low-Cost Receiver System : Type A

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



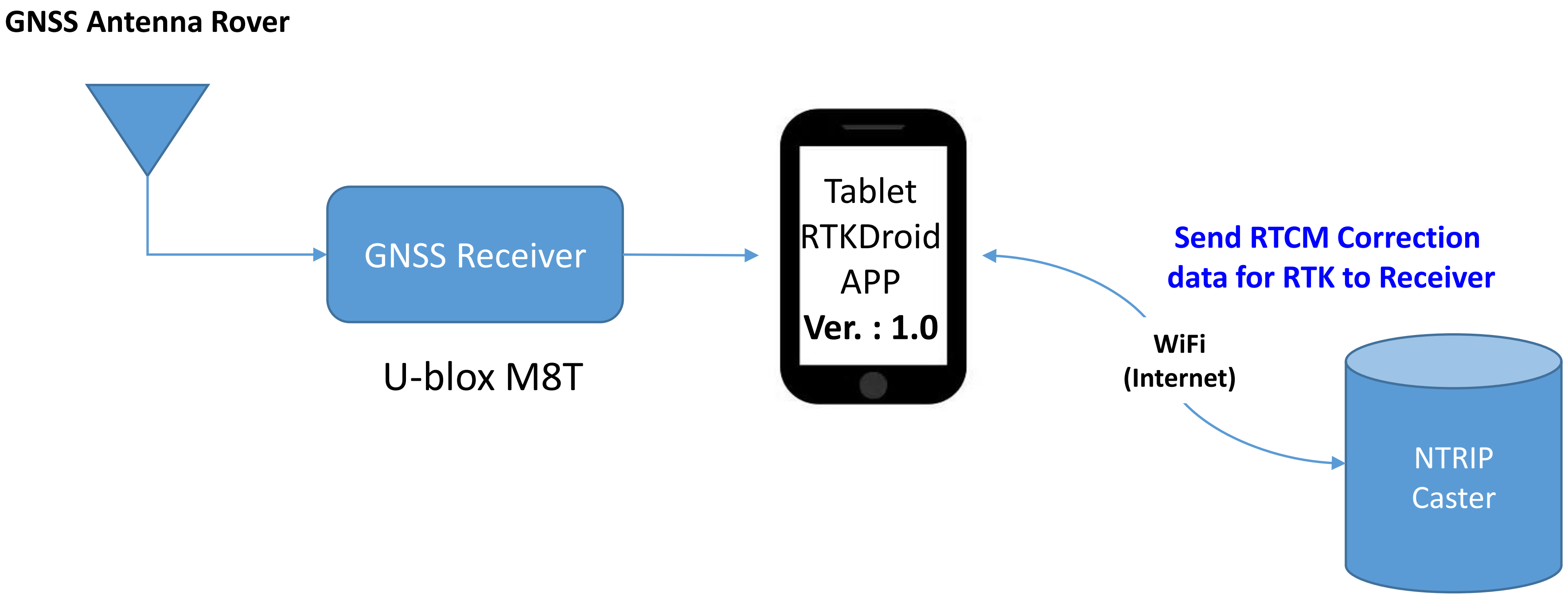
Low-Cost Receiver System: Type B

Post-Processing RTK, Rover Mode Only



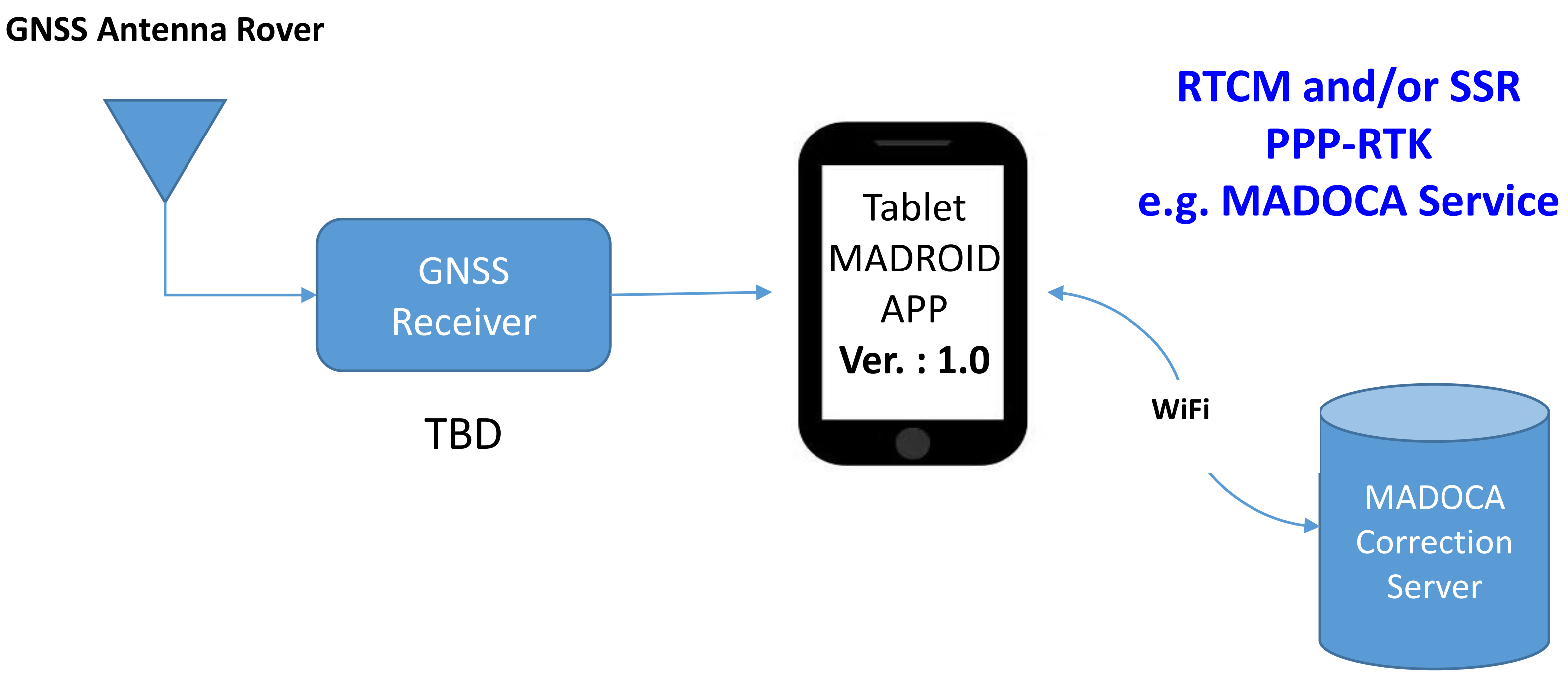
Low- Cost Receiver System : Type C

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



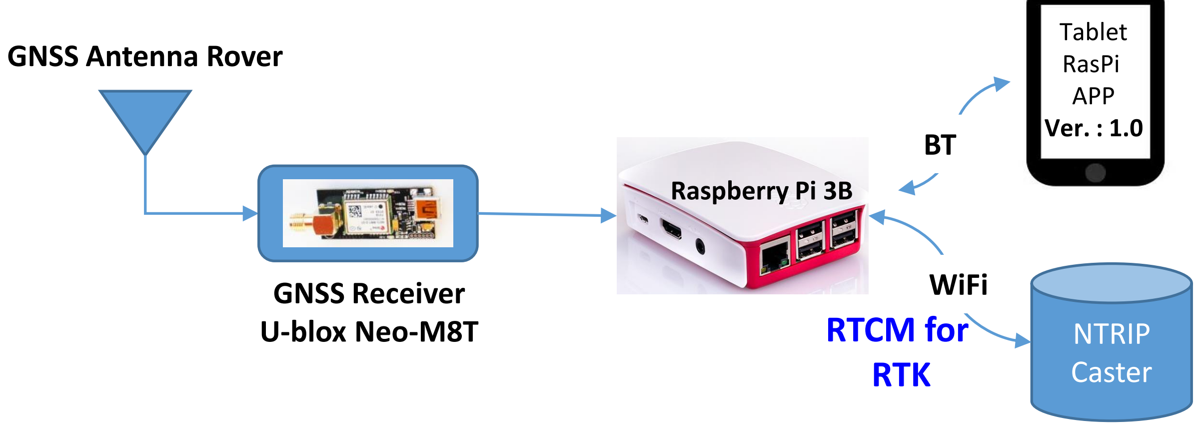
Low-Cost Receiver System : Type D

Real-Time or Post Processing PPP, Rover Mode Only

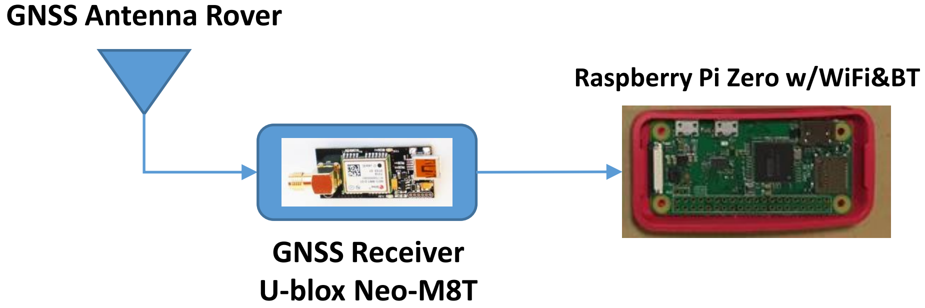


Low-Cost High-Accuracy Receiver System

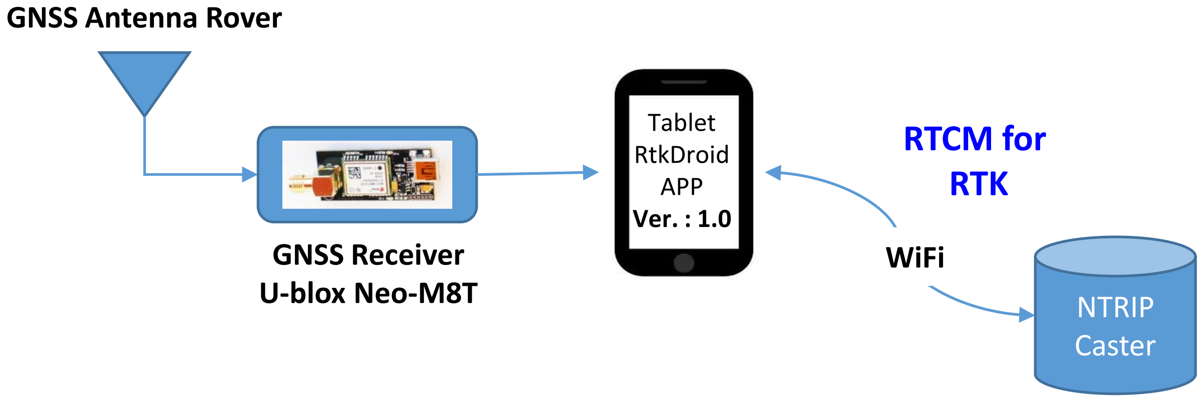
TYPE A Type A: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Base and Rover Mode



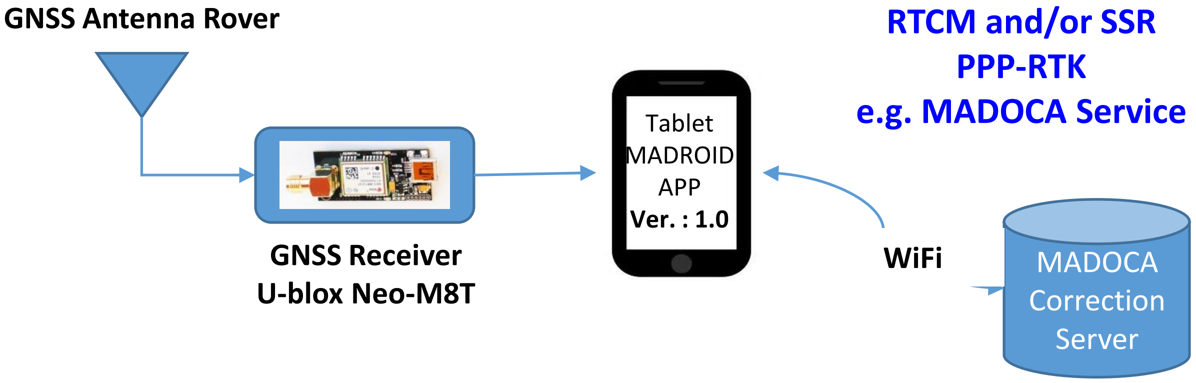
TYPE B Type B: Low-Cost, High-Accuracy Receiver System
For Post-Processing & Rover Mode Only



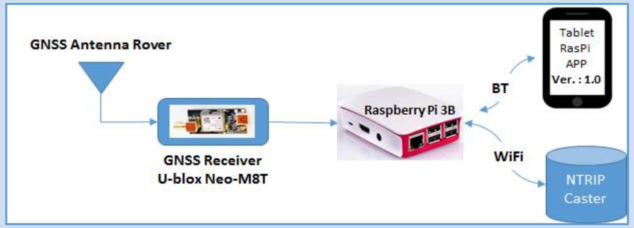
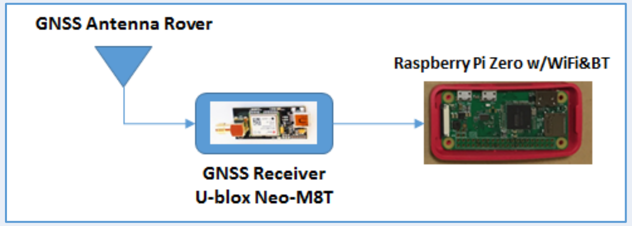
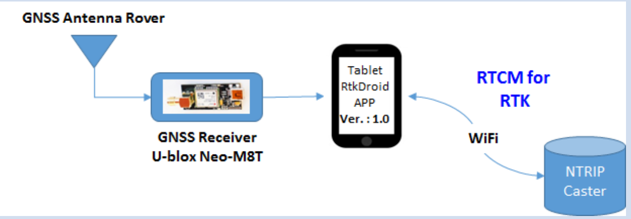
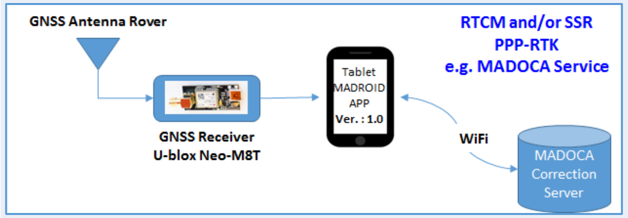
TYPE C Type C: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



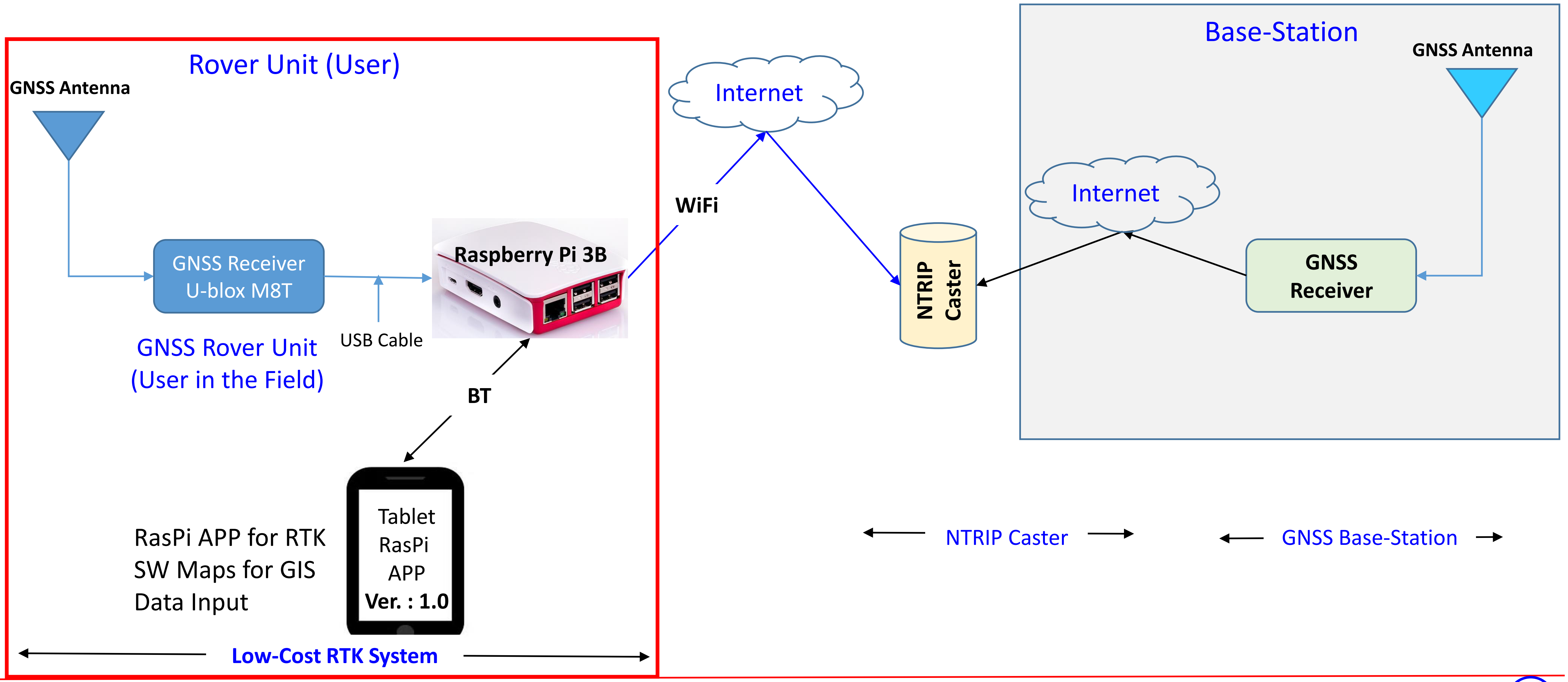
TYPE D Type D: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



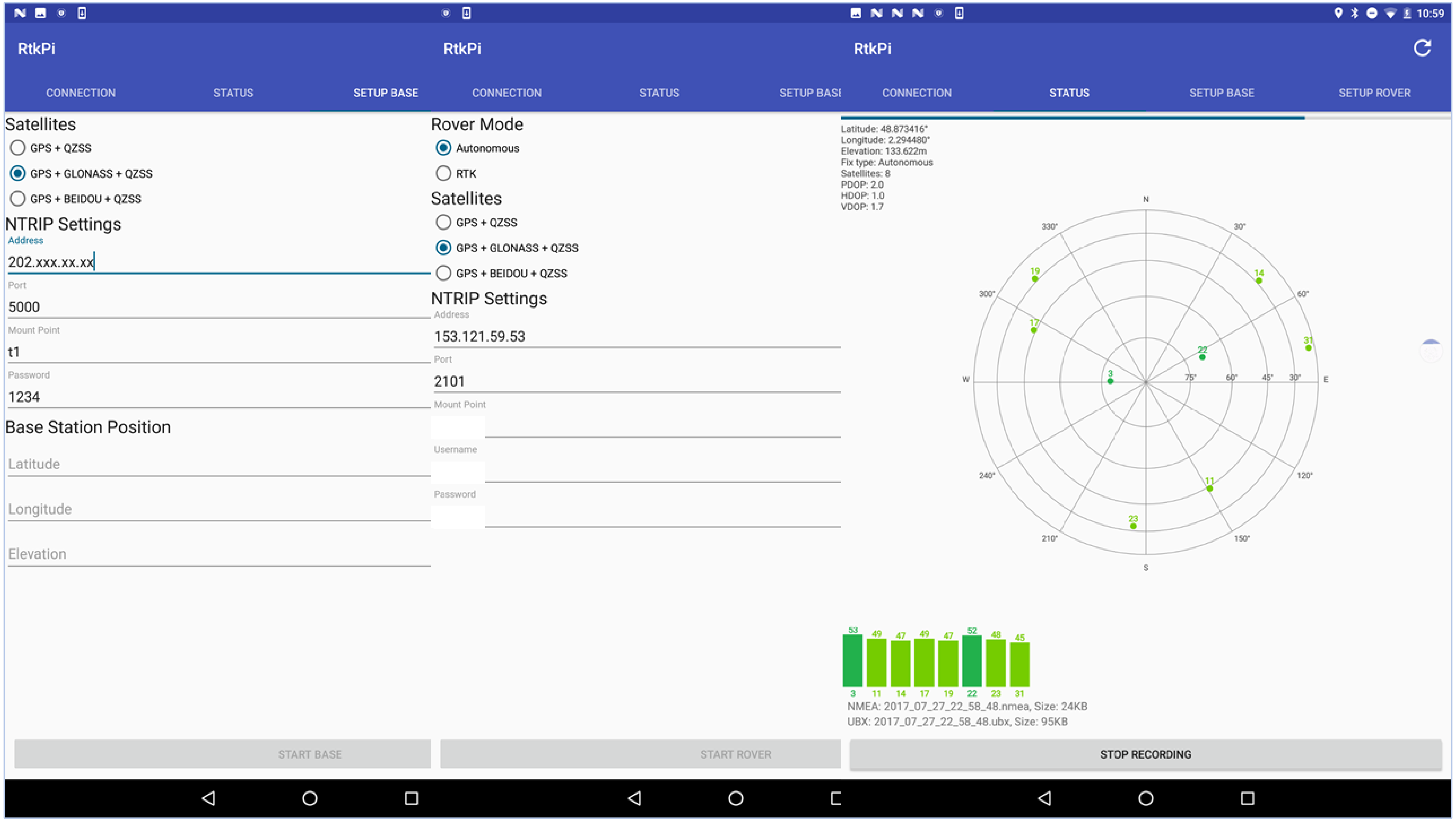
Low-Cost Receiver Systems

Type	Receiver System	Usage	RTK Processing Engine	Mode	User Interface	Base-Station Data	Correction Data Format
Type A 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
Type 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
Type C 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
Type D 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

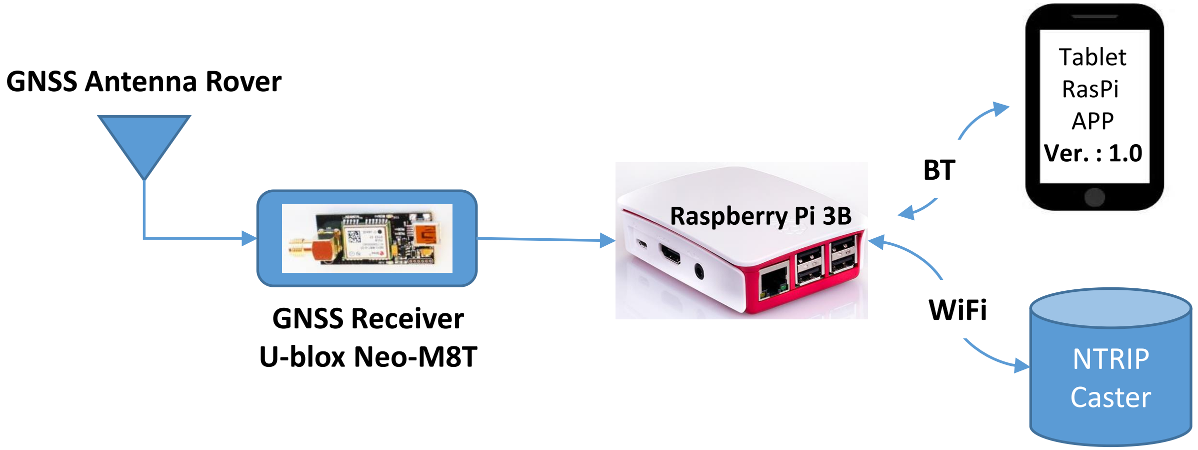


Board Computer for Low-Cost RTK System

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

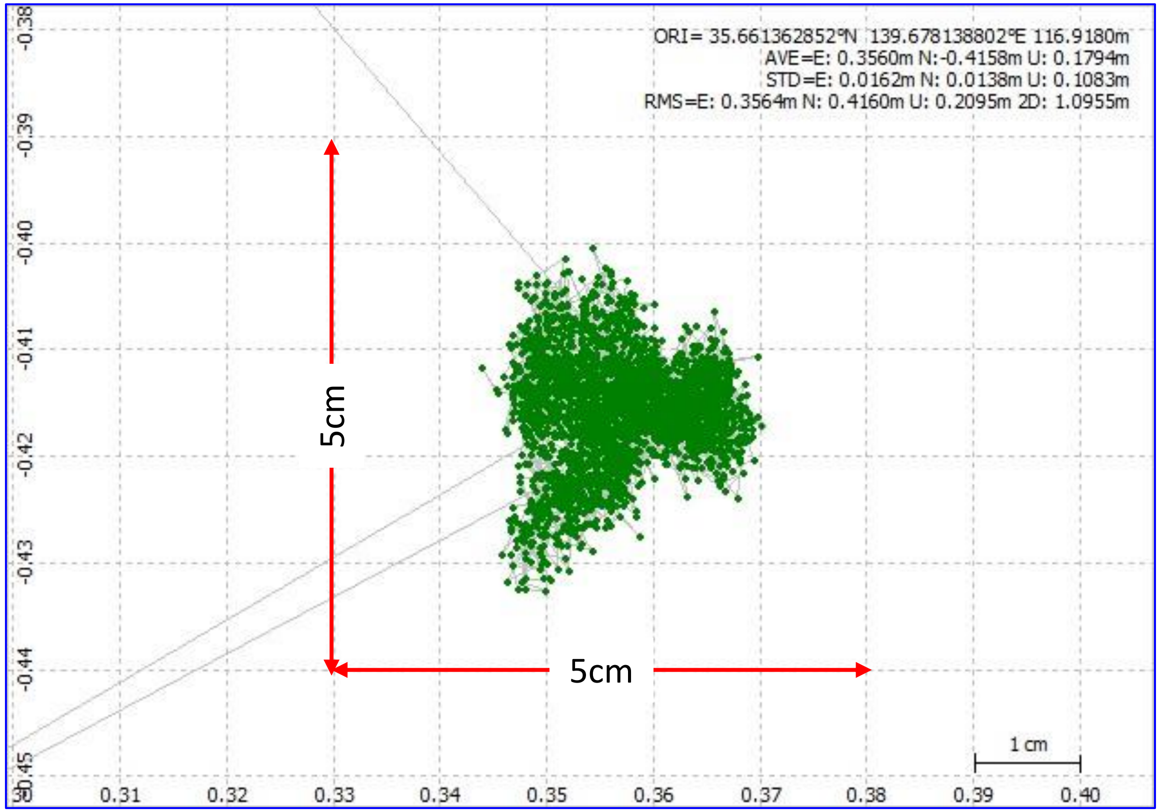
Raspberry Pi Zero w/WiFi & BT for Post-processing RTK

Accuracy from Low-Cost RTK System

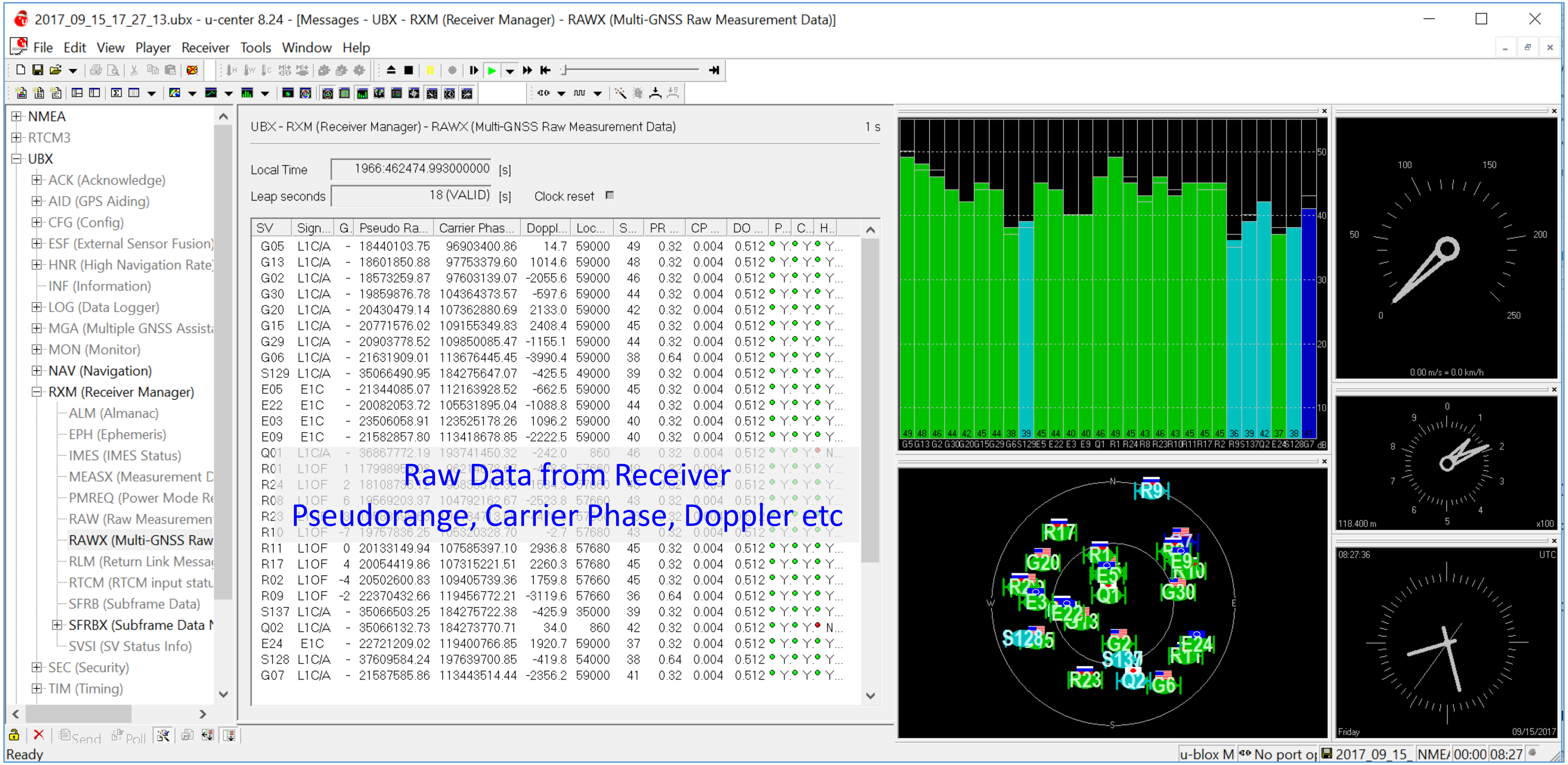


Rover-Station:
Receiver: u-blox M8T
Antenna: Zephyr 2
Computer: RaspberryPi 3B+
Distance between Base and Rover : about 12Km

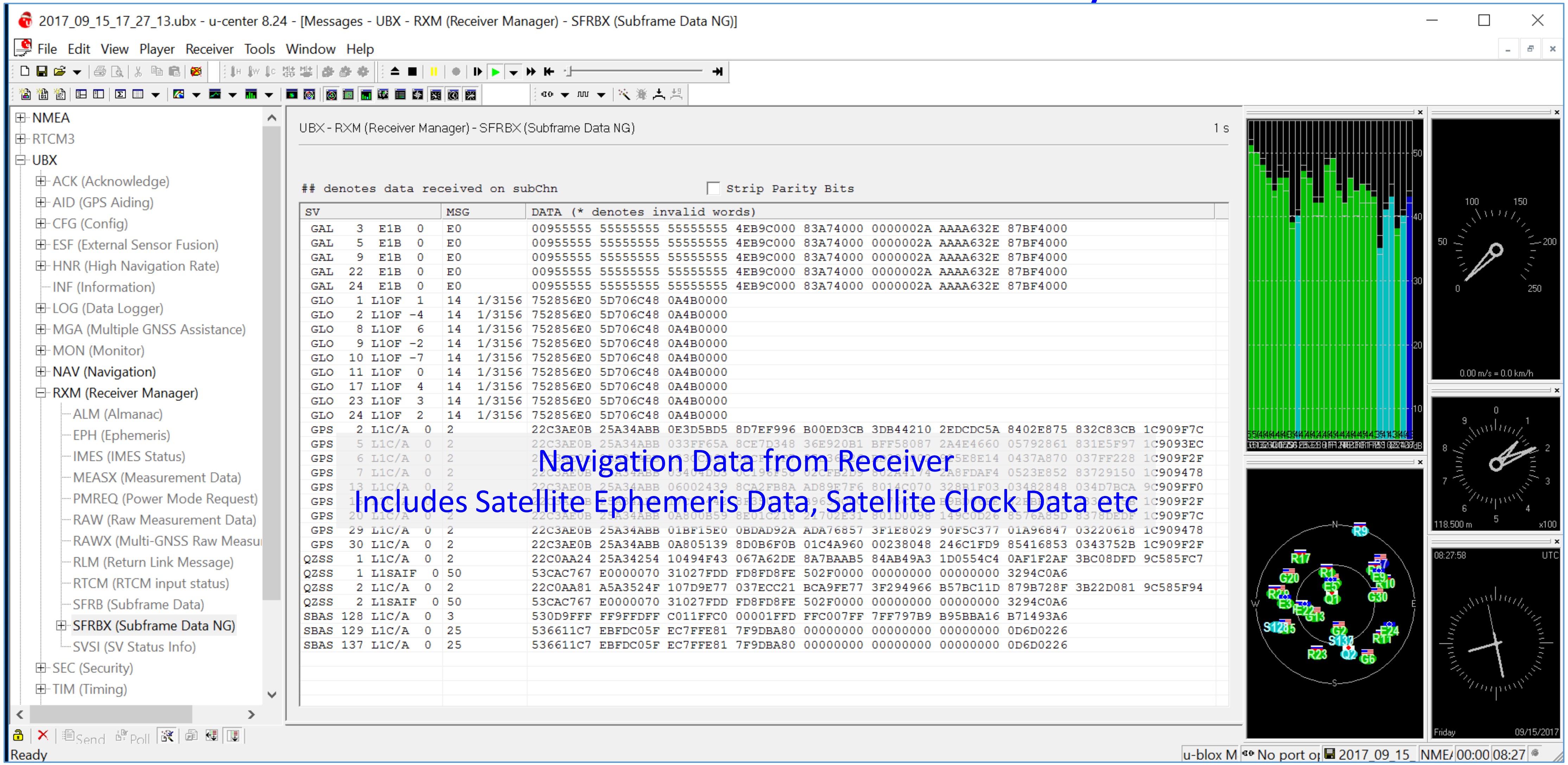
Base-Station:
Receiver: Trimble NetR9
Antenna: Zephyr 2



Data from Low-Cost RTK System



Data from Low-Cost RTK System

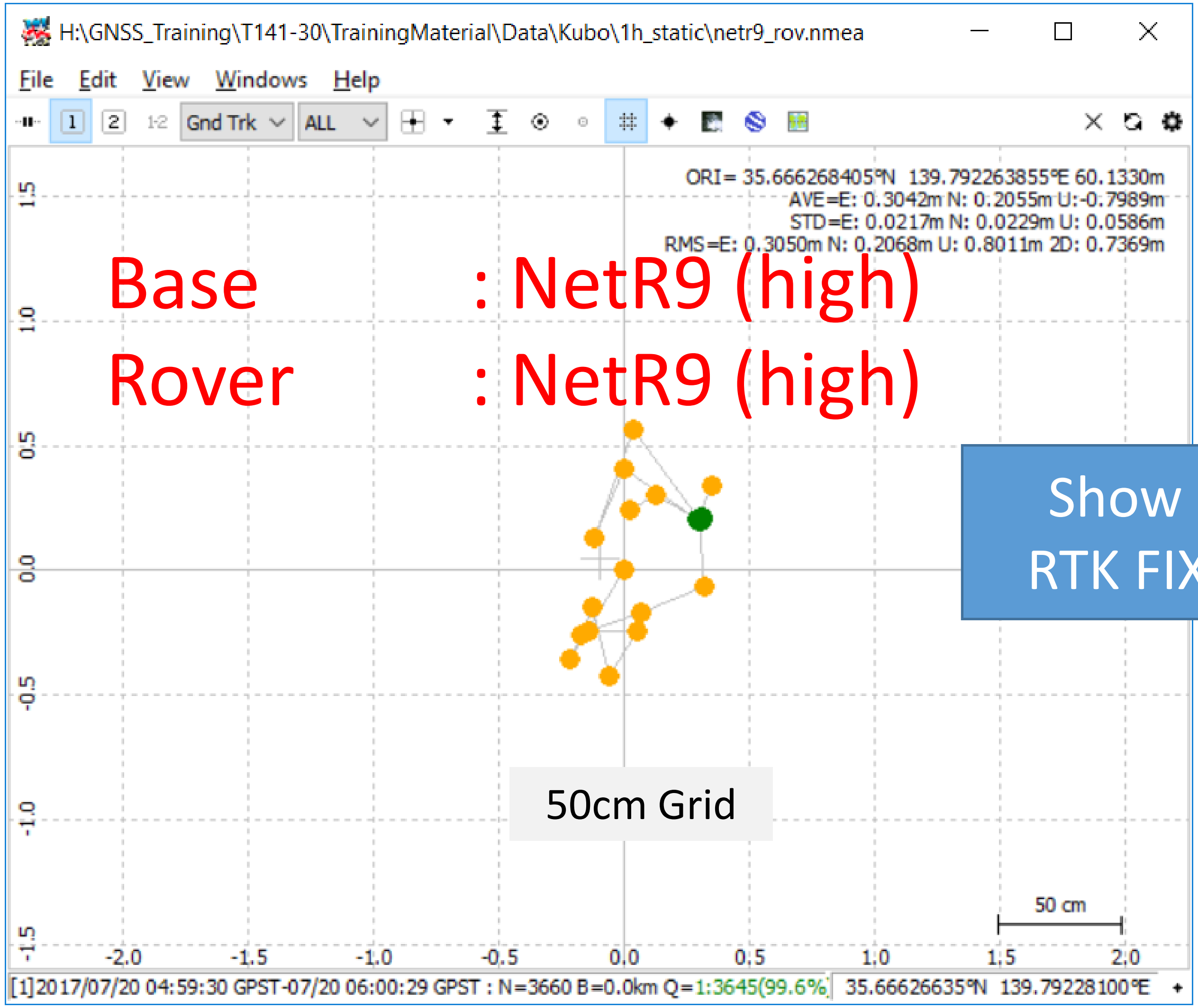


Navigation Data from Receiver

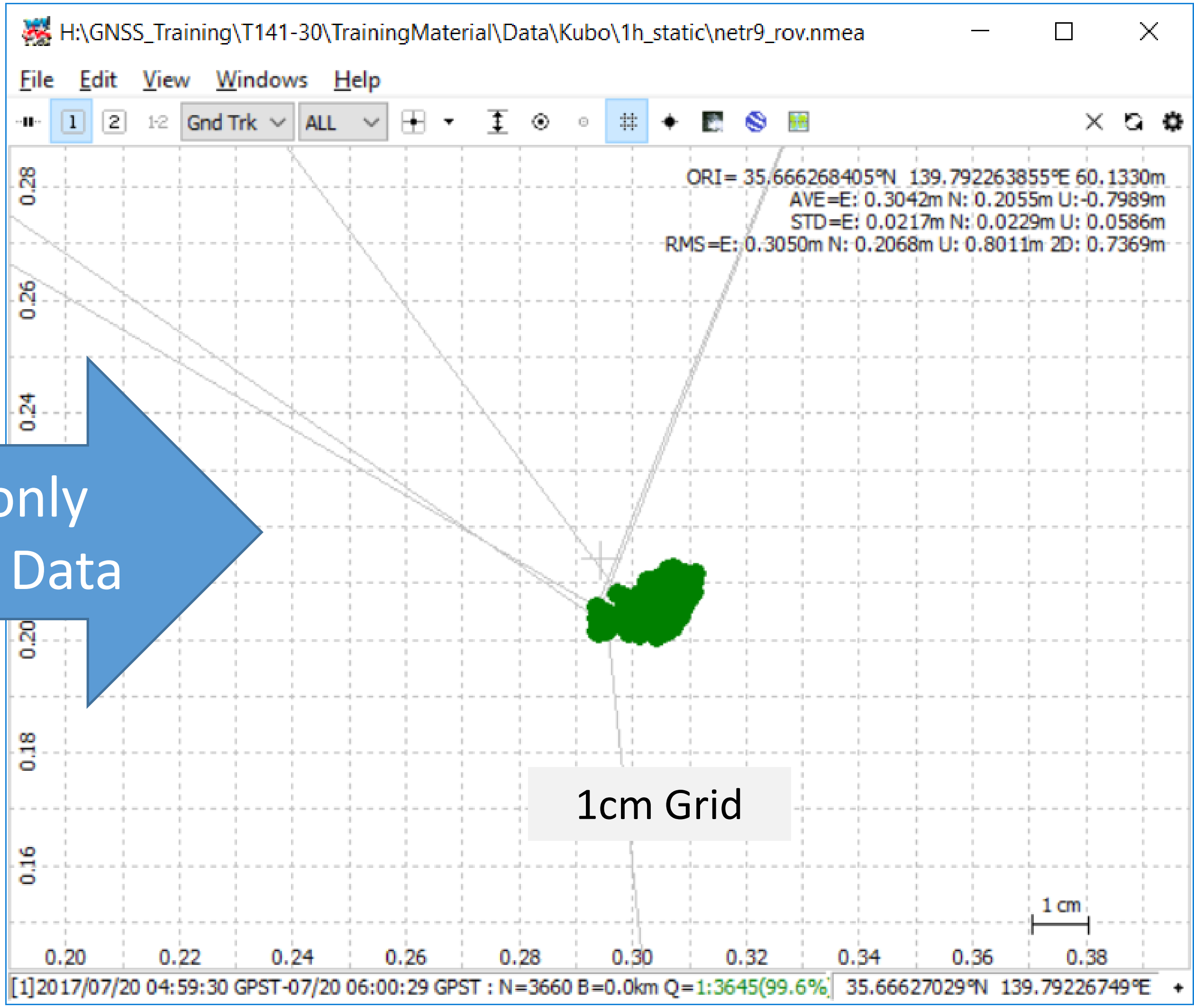
Includes Satellite Ephemeris Data, Satellite Clock Data etc

Low-Cost RTK Field Survey Data
Static, Tokyo

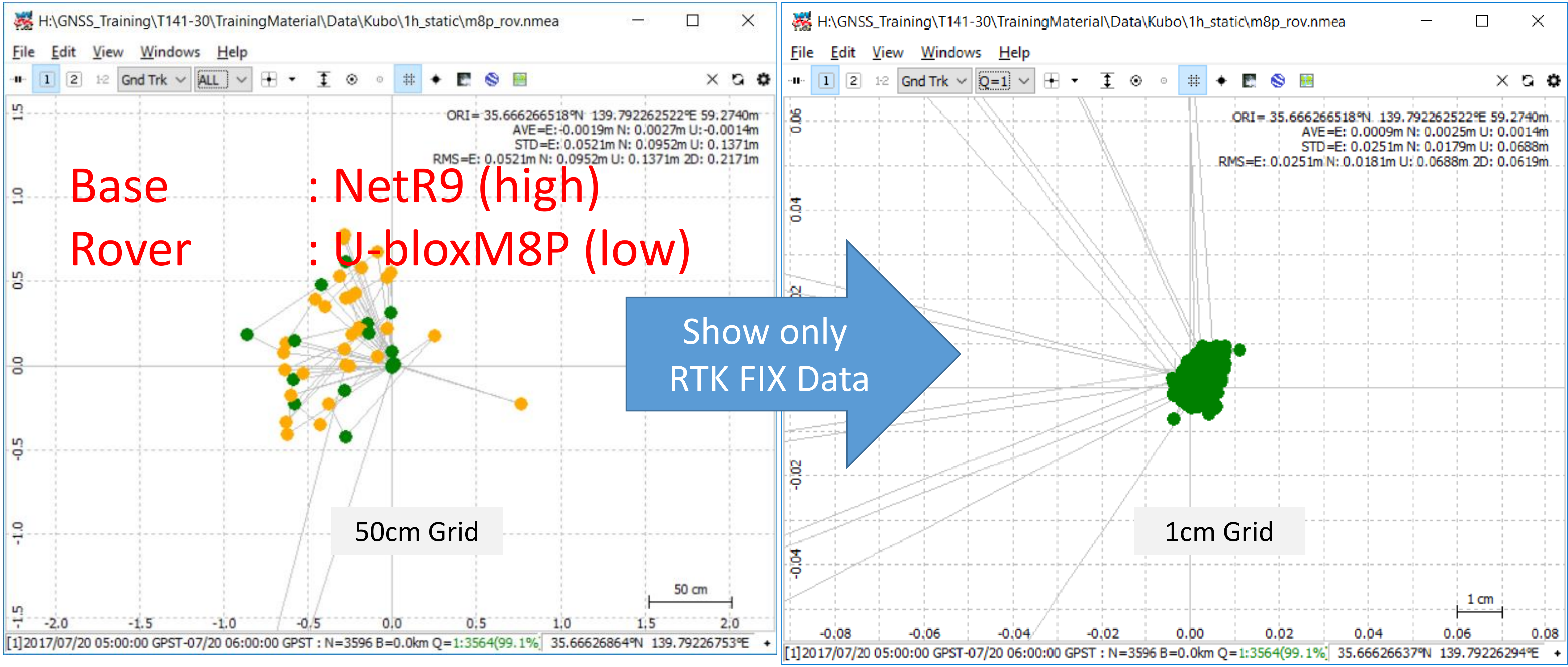
One Hour RTK Post-processing, Static, Tokyo



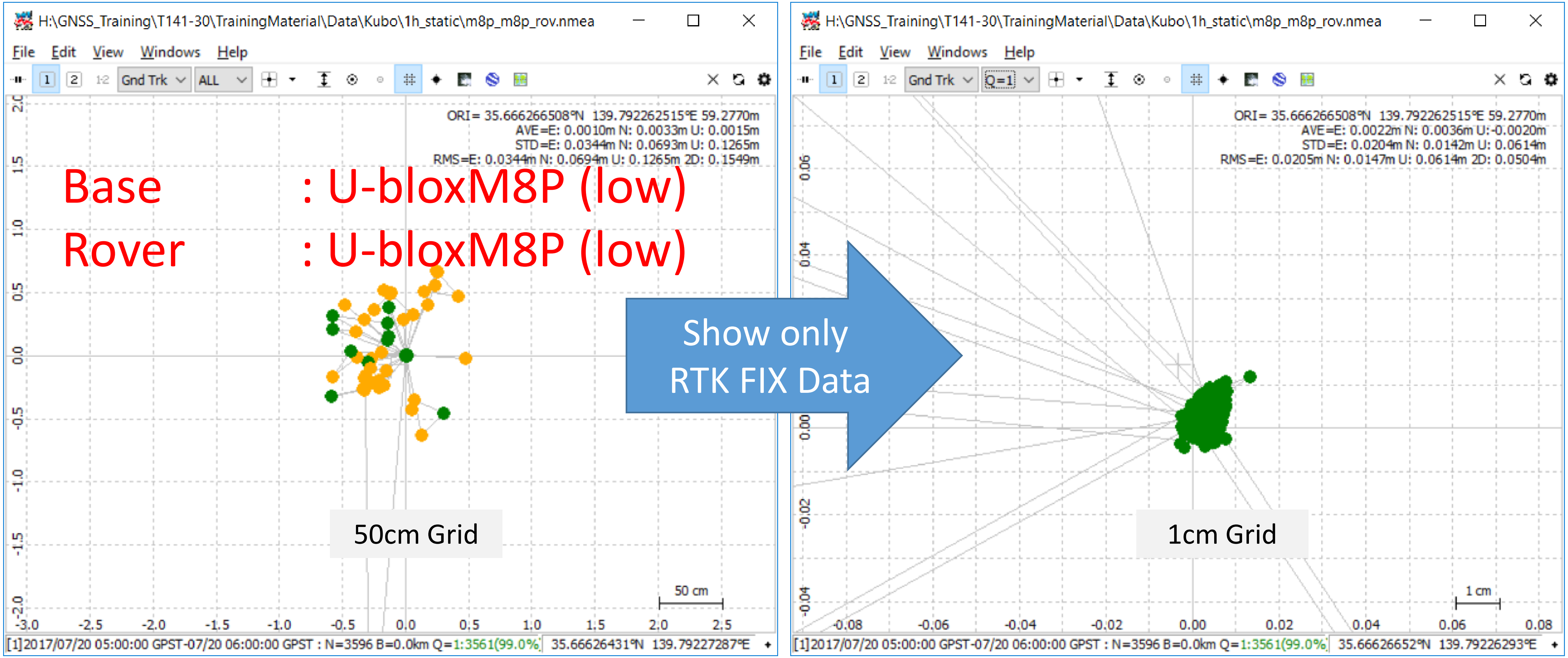
Show only RTK FIX Data



One Hour RTK Post-processing



One Hour RTK Processing



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.

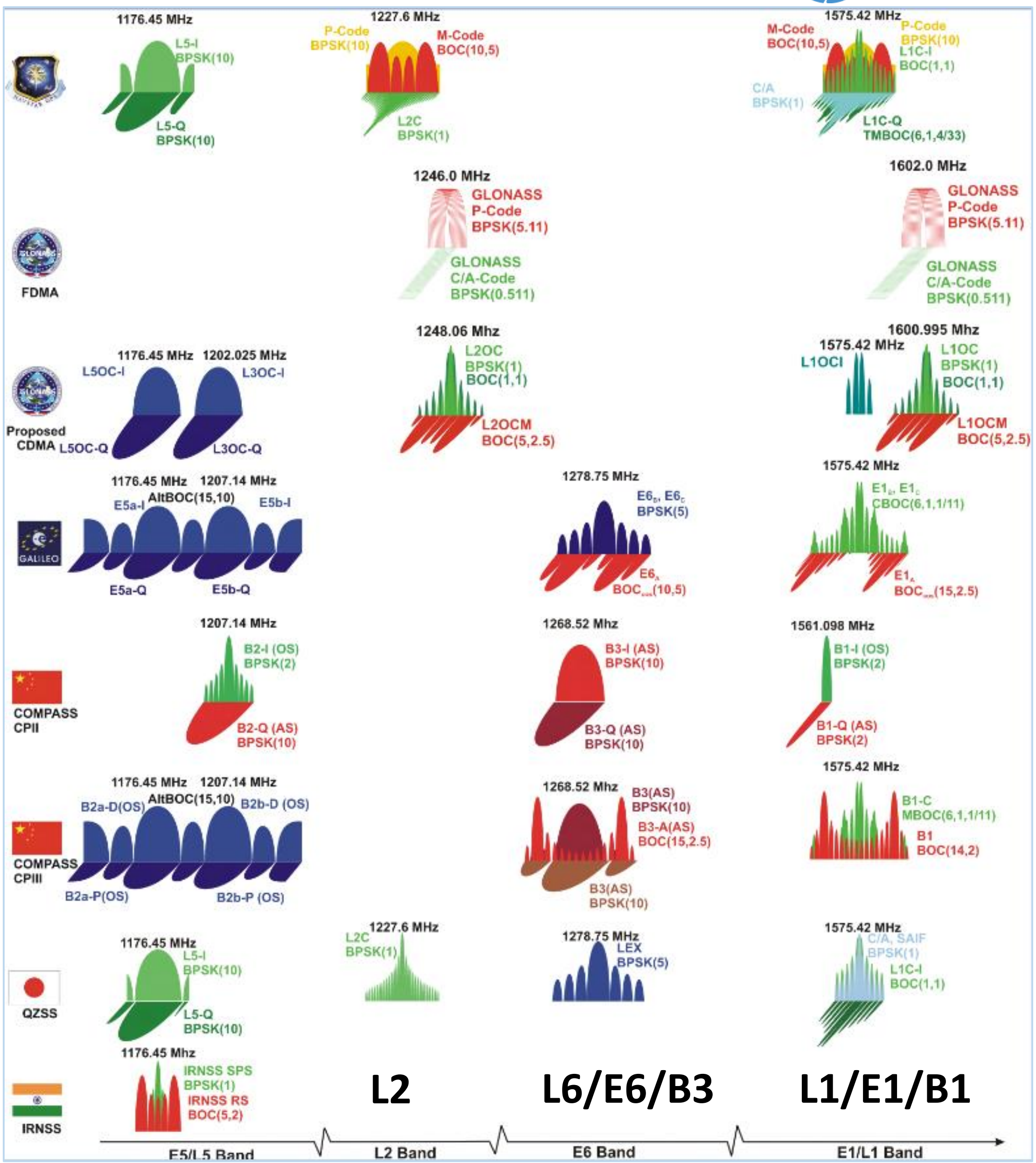
Center for Spatial Information Science
The University of Tokyo

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

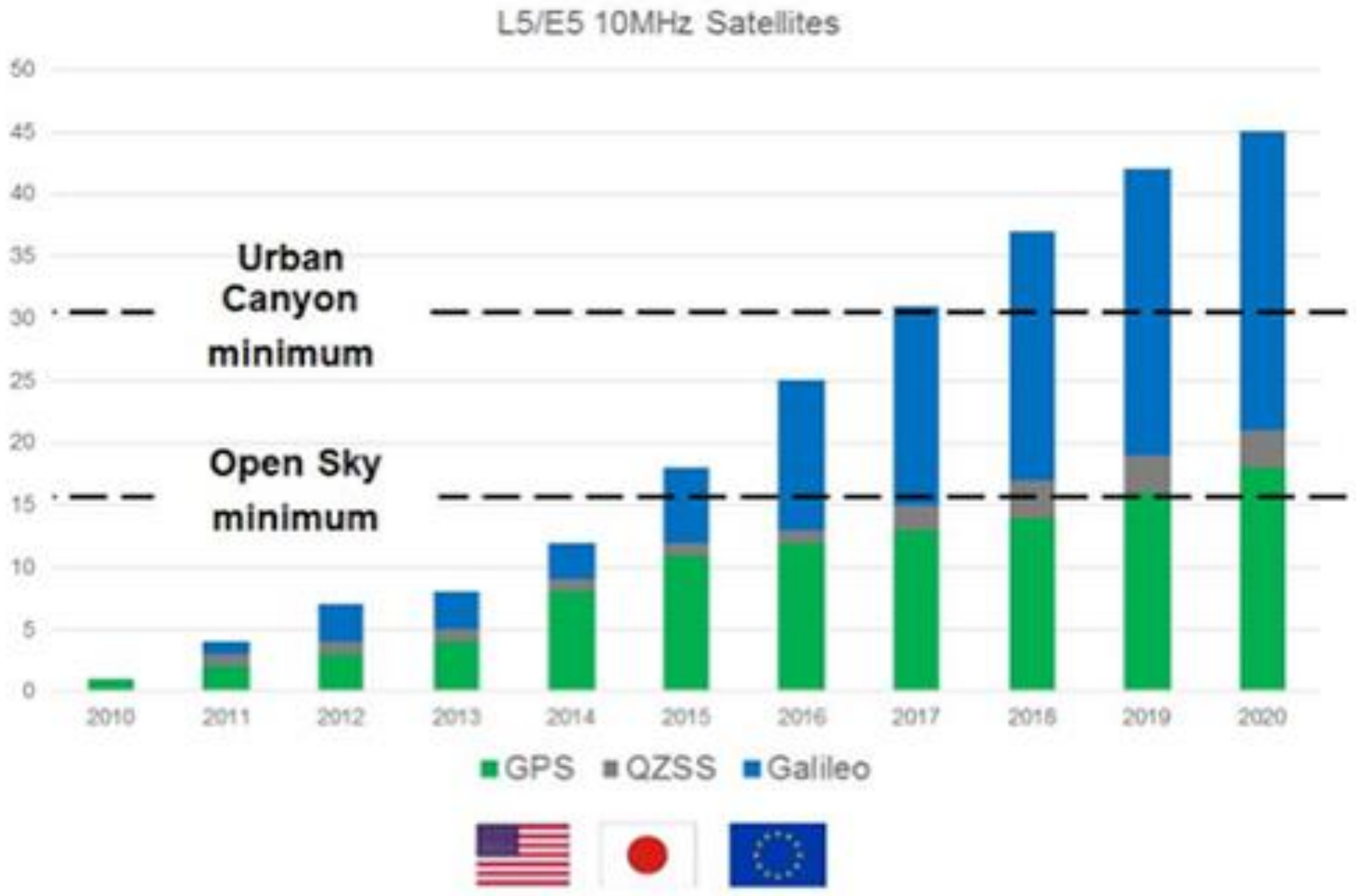
L5/E5/B2/L3 L2 L6/E6/B3 L1/E1/B1



Why Dual Frequency now?

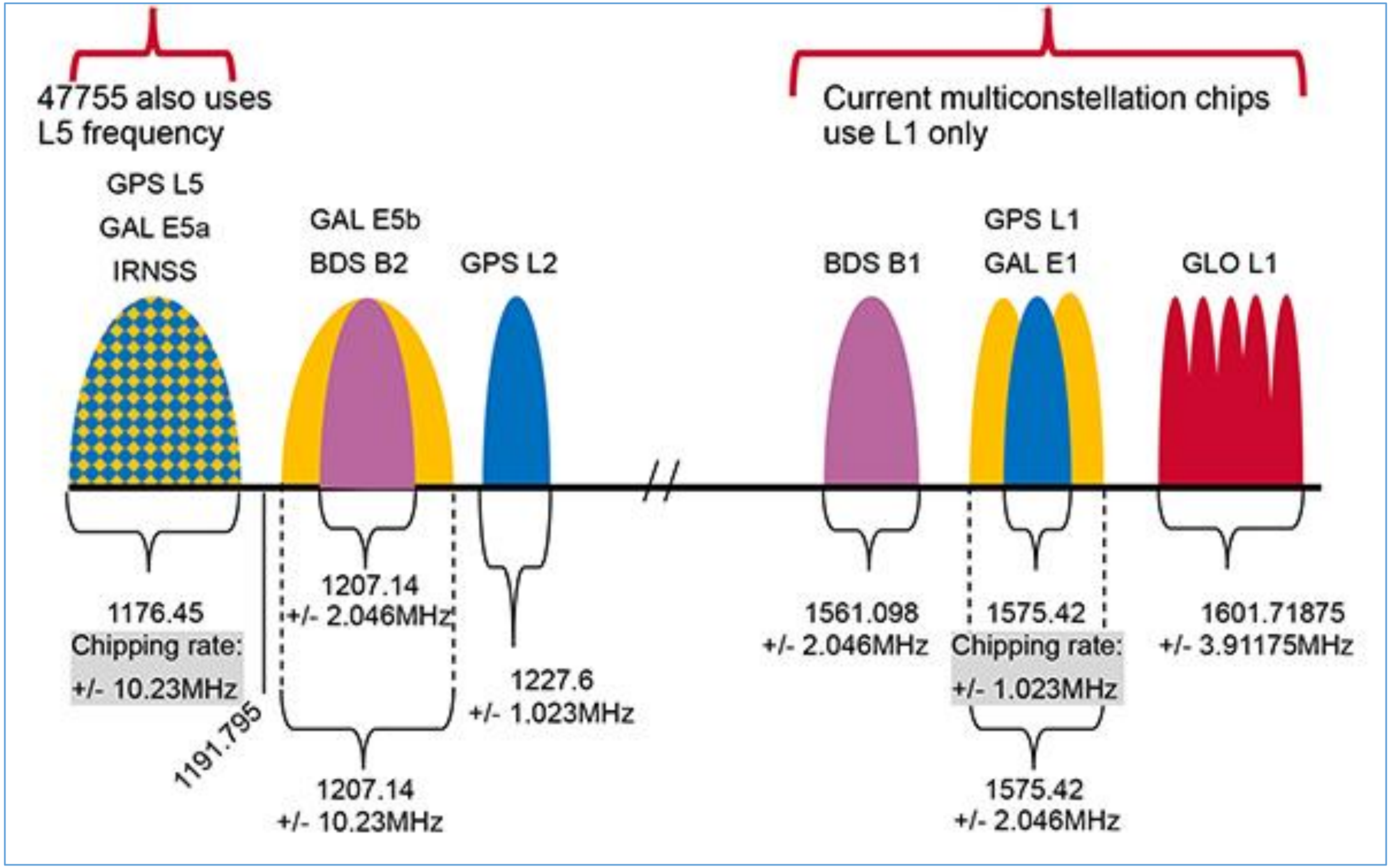
L5/E5 satellite launches have sped up in 2015 and 2016

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

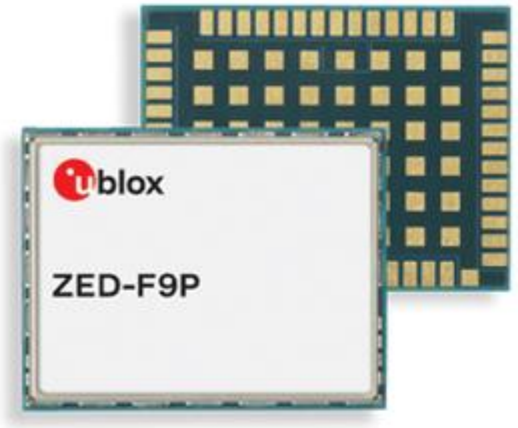
Multi-Band GNSS Receiver from u-Blox

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.

Source: https://developers.google.com/location-context/