Low-Cost GNSS Receiver Systems for High Accuracy, Space Weather and Technology Promotion

United Nations International Meeting on the Applications of Global Navigation Satellite Systems
VIENNA, AUSTRIA, 5 - 9 DECEMBER 2022

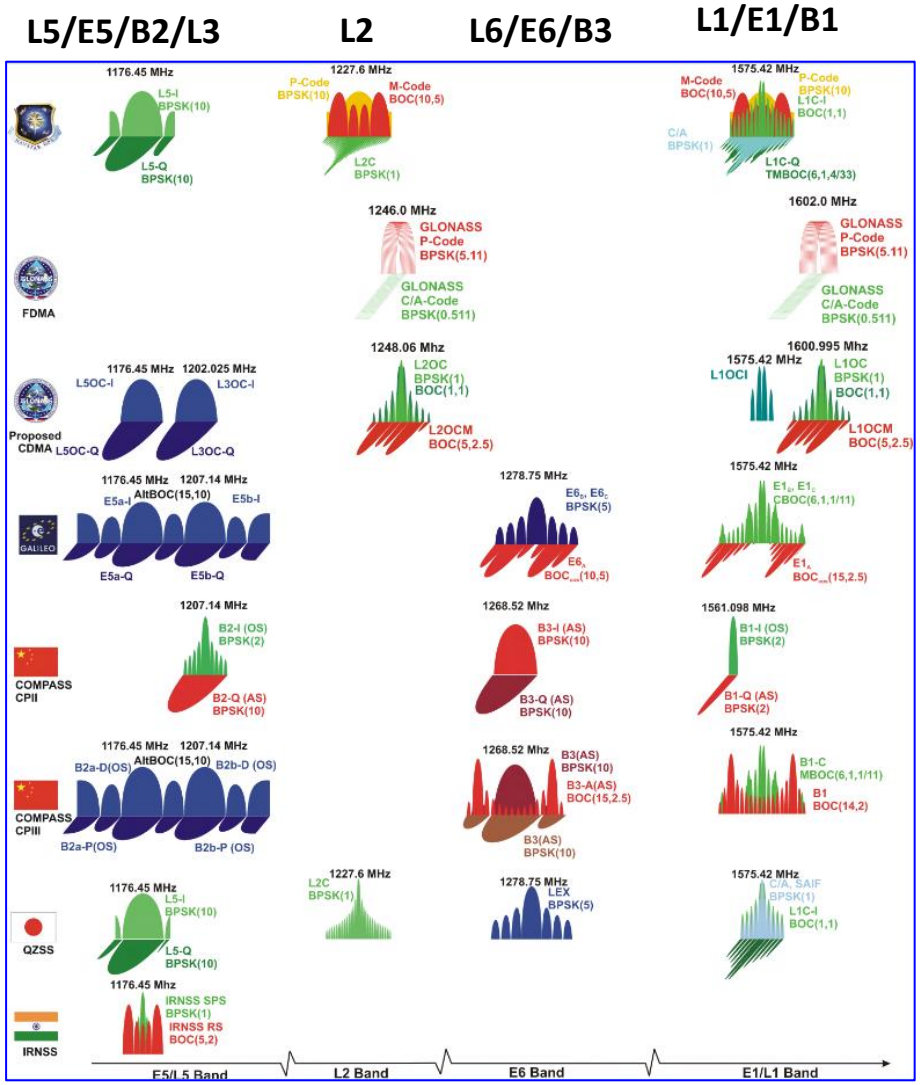
Dinesh MANANDHAR, Associate Professor (Project)

Center for Spatial Information Science, The University of Tokyo

dinesh@csis.u-tokyo.ac.jp

GNSS Signals

Satellite	Country	Coverage
GPS	USA	Global
GLONASS	Russia	Global
Galileo	Europe	Global
BeiDou (BDS)	China	Global
QZSS (Michibiki)	Japan	Regional
NavIC	India	Regional

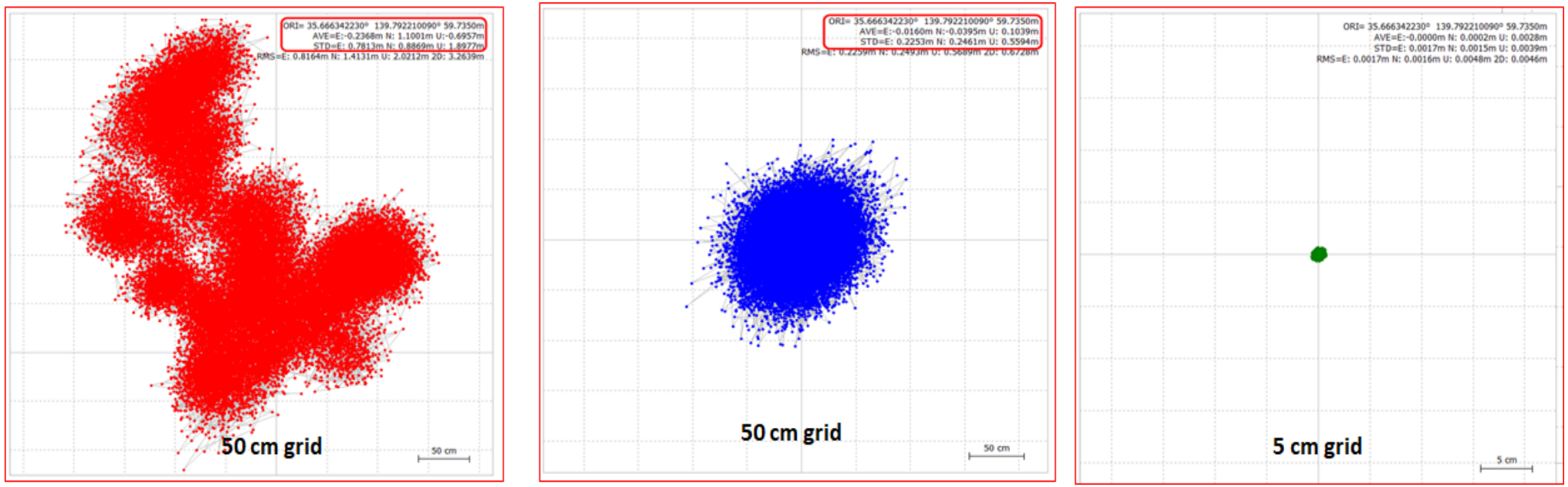


https://gssc.esa.int/navipedia/images/c/cf/GNSS_All_Signals.png

Can Low-Cost GNSS Receiver provide High-Accuracy?

- Even a Low-Cost GNSS Receiver can provide centimeter level accuracy
  - Provided proper data processing methodologies are used

From Standard Accuracy to Centimeter Accuracy



Position accuracy varies depending upon data processing methods

GNSS Data Processing
Even a Low-Cost GNSS Receiver can provide High-Accuracy

It may be UBX, SBF, BINEX, RTCM or other proprietary formats

Get Base and Rove Data Files

Check Data File Formats

Convert All files to RINEX Format
Use RTKCONV

Post Process ROVER Data using SINGLE Option
Use RTKPOST

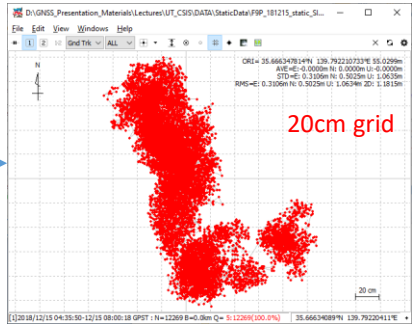
Post Process ROVER Data using DGPS Option
Use RTKPOST

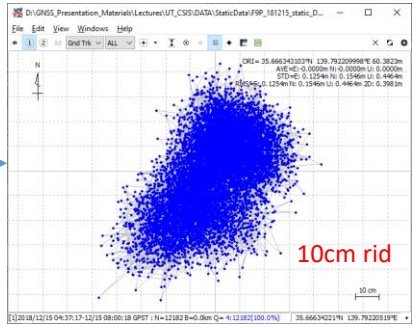
Post Process ROVER Data using KINEMATIC Option
Use RTKPOST

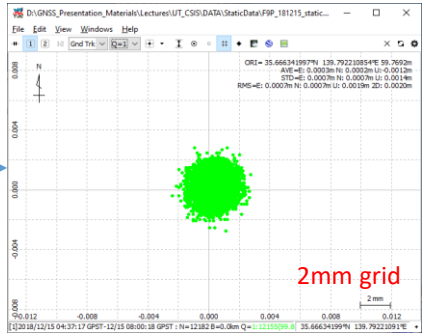
OUTPUT

OUTPUT

OUTPUT







Our Definition of Low-Cost GNSS Receiver System

	Price	Accuracy	Weight	Remarks
Sub-meter Level	< $100	< 100 cm	< 100 g	100 x 100 x 100
Decimeter	< $ 300	10 – 30 cm	< 300 g	Antenna size and price are critical
Centimeter	< $ 300	5 – 10 cm	< 300 g	

Notes:

- The receiver and antenna requirements are the same when we go for decimeter level of accuracy
- The differences are in data processing methods and hence the necessary software tools
- We need low-cost and light-weight antenna

How to Make a Low-Cost GNSS Receiver System?

GNSS Module or Receiver

Low-Cost SDR Device
$30

+

- Memory
- Micro-Controller or Micro-Processor
- External Interface

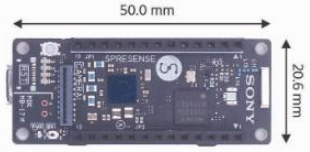
External Memory Device

Hard Disk

Single Board Computer

RaspberryPi

Arduino



Sony, Spresense

WiFi, BT, Ethernet, MQTT, IoT links

ESP32 is a powerful Micro-controller with WiFi/BT

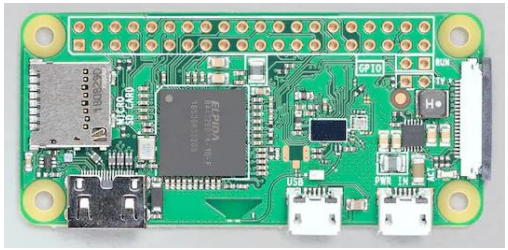
A smart-phone has everything that we need

- CPU
- Memory
- External Interface
- GNSS Receiver
- Sensors

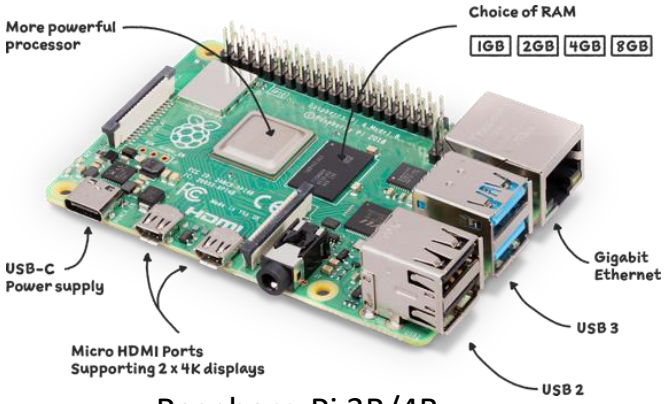
- Note: We use these modules for high accuracy positioning system based on RTK and MADOCA PPP or other GNSS/QZSS special applications.
- There are many other GNSS modules as well. We have no intention of any purpose to name some of the makers here.

Low-Cost Computing Devices

RaspberryPi Pico

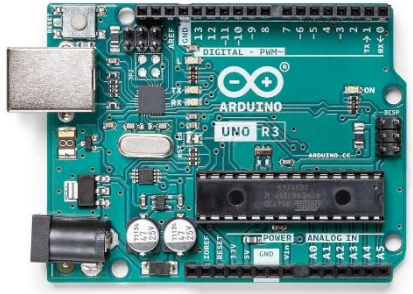


RaspberryPi Zero/W



RaspberryPi 3B/4B

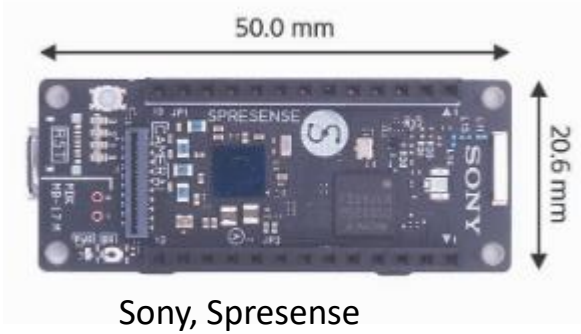
https://www.raspberrypi.com/products/



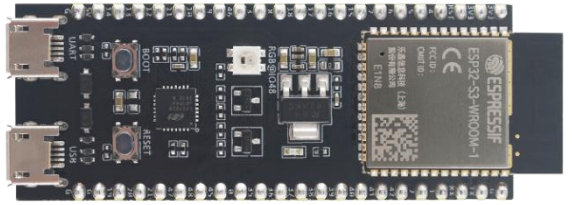
Arduino Uno

Arduino Due

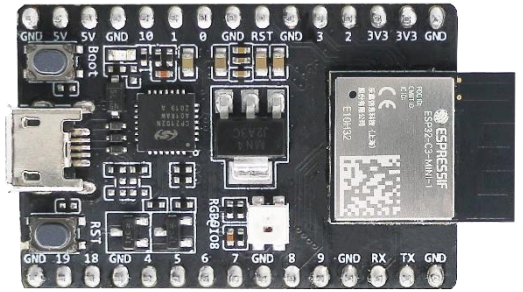
https://www.arduino.cc/en/hardware#boards-1



Sony, Spresense
https://developer.sony.com/develop/spresense/



Espressif, ESP32-S series

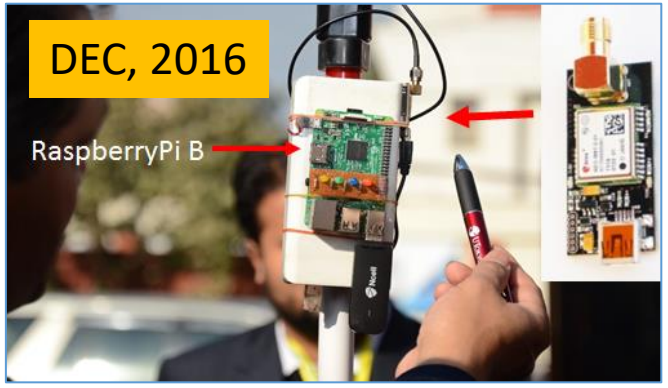


Espressif, ESP32-C series

https://www.espressif.com/en/products/devkits/esp32-devkitc

Low-Cost High-Accuracy Receiver system Development Cycle

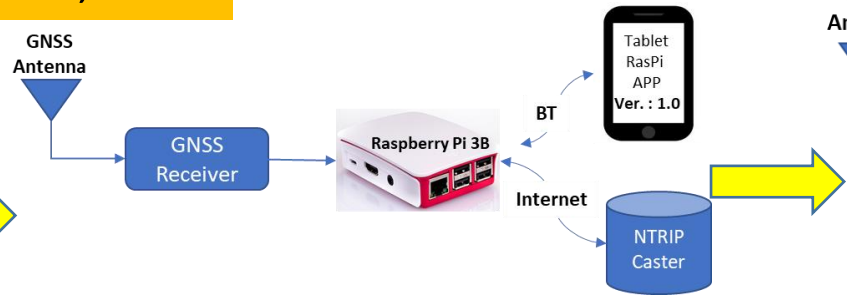
DEC, 2016



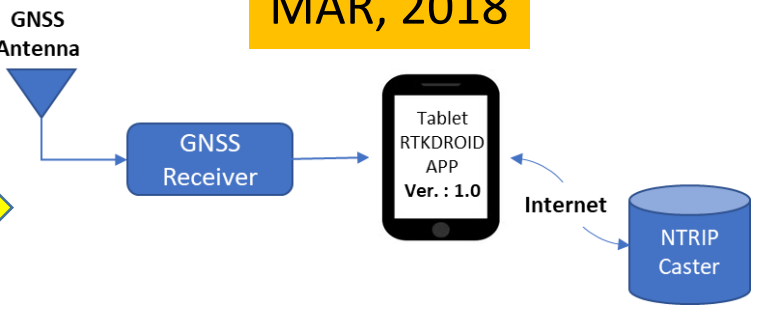
Demo during UN/Nepal GNSS workshop

MAY, 2017

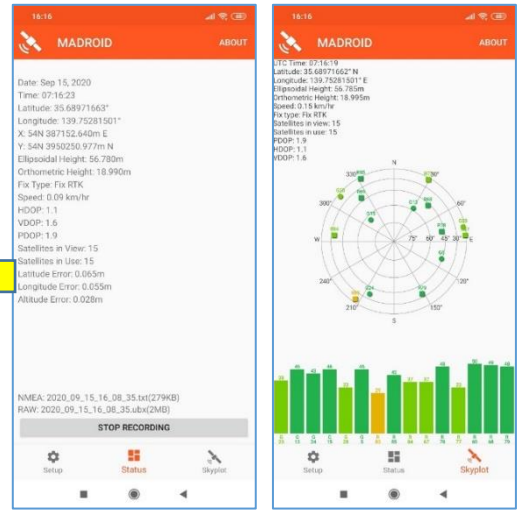
Low-Cost RTK

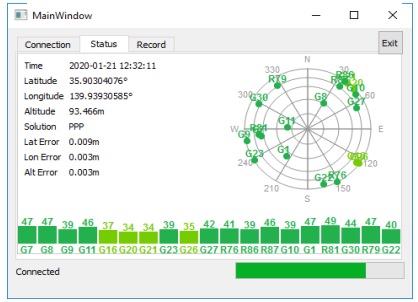


MAR, 2018



Low-Cost MADOCA





DEC, 2019

What Application or System Do you Want?

- Enhancement of MADOCA System 2022 / 2023
- Android Device based Applications RTK / MADOCA / EWS / SAR
- Space Weather Applications
- Dynamic Air Quality Monitoring System

2022 - 2023

Low-Cost GNSS Receiver Systems for High-Accuracy and Space-Weather Applications

Low-Cost High-Accuracy GNSS Receiver System
RTK and MADOCA-PPP: RaspberryPi version

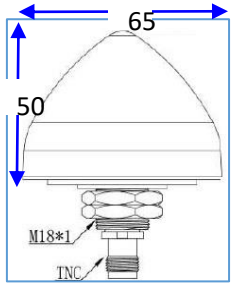
Antenna Cable

GNSS Receiver Multi-Frequency MADOCA Compatible

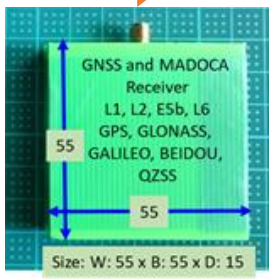
Micro-USB to USB Cable

RTK-PI
MAD-PI

- Connect Antenna to the GNSS/MADOCA receiver using the provided antenna cable.
- Connect the receiver to a RaspberryPi 4 device using a "micro-USB to USB" cable.
- Connect a USB Memory Drive to RasPi device.
- Either use a Power Bank or an AC Adapter for power supply.



GNSS Antenna



UT RECEIVER

Micro-USB to USB Cable

Micro-USB to USB Cable

OR

Power Adapter for Raspl4

USB Memory

Low-Cost High-Accuracy GNSS Receiver System RTK and MADOCA-PPP: Android Version

Antenna Cable

GNSS Receiver Multi-Frequency MADOCA Compatible

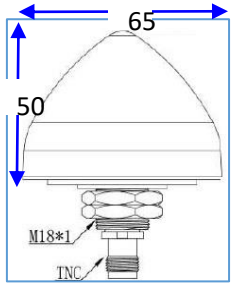
Micro-USB to USB Cable

RTKDROID
MADROID

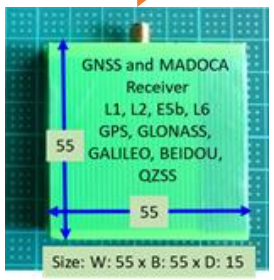
OTG Cable

Select OTG Cable based on Android Device Connector Type

- Connect Antenna to the GNSS/MADOCA receiver using the provided antenna cable.
- Connect the receiver to an Android device using a "micro-USB to USB" cable and an OTG cable.
- OTG (On-The-Go) cable may be either Type-C or Micro-USB Type depending upon android device's connection port.



GNSS Antenna



UT RECEIVER

Micro-USB to USB Cable

OTG Cable Type: C

OTG Cable Type: Micro USB

Low-Cost High-Accuracy GNSS Receiver System: Space Weather Applications

We will explore at least two types of receivers

- u-blox F9P
- Septentrio (MOSAIC)

Criteria for Receiver Selection

- Any receiver that is capable to output raw data
- Dual frequency receiver
- Price less than $1,000

	U-Blox F9P	Septentrio MOSAIC	Other Brand (To be Explored)
GNSS	GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS	GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS	
Frequency Bands	L1, L2, E5b	L1, L2, L5 or L1, L2, L6*	
Raw Data	Code Phase, Carrier Phase, Doppler, Signal quality related data	Code Phase, Carrier Phase, Doppler, Signal quality related data	
Navigation Frame Data	Yes including data bits	Yes including data bits	
Output Rate	Max 20Hz	Upto 100 Hz for Measurement 50Hz for RTK	
RTK / PPP Capable	Yes	Yes	
TEC Computation	Yes (To be checked)	Yes (To be checked)	
S4 Computation	To be explored	To be explored	
Price (USD)	300	700	

https://shop.septentrio.com/en/shop/mosaic-go-gnss-module-receiver-evaluation-kit

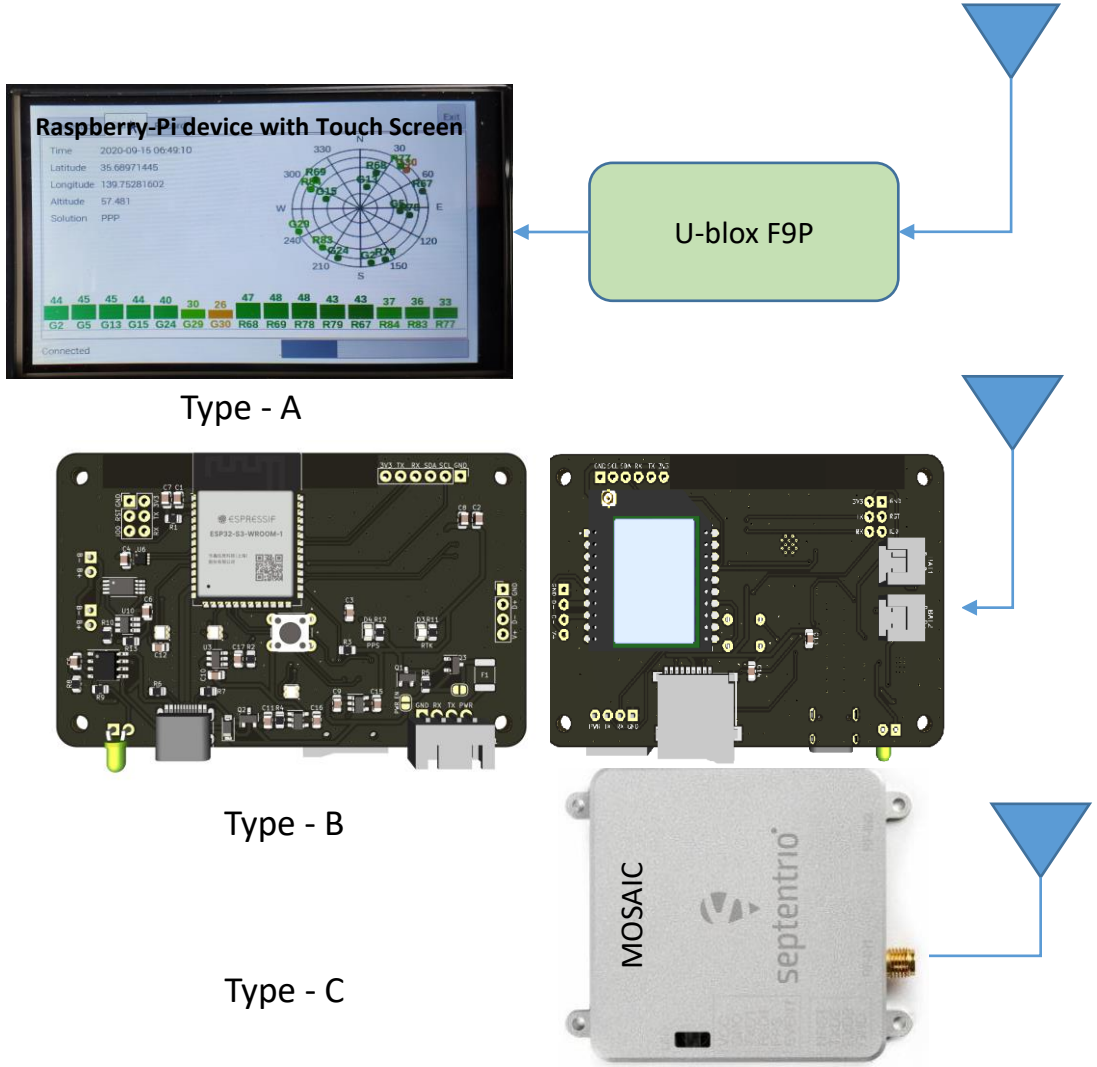
https://content.u-blox.com/sites/default/files/ZED-F9P_ProductSummary_UBX-17005151.pdf

Note: We have no preferences of whatsoever on any brand or name.
The receivers are selected based on our selection criteria.
Any suggestions on receiver types are highly appreciated.

Low-Cost High-Accuracy GNSS Receiver System: Space Weather Applications

Remote and Unattended Continuous Data Logging

- Design low-cost GNSS receiver system for unattended data logging
  - Integrate receiver module with RaspberryPi device or ESP32 module or single board computer
  - Log GNSS data automatically to a local memory device
  - Connect the device to a remote server via internet
- Explore different types of configurations
  - Type – A : based on RaspberryPi device
  - Type – B : based on ESP32 device
  - Type – C : based on MOSAIC, Septentrio
- Requirements
  - The system shall be able to Log raw data when power is connected.
  - Recover all setups including network information when the receiver is rest or power supply is turned off and on.
  - Connect remote server or NTRIP caster automatically.
  - Log raw data locally in a SD Card.



Note: Type-B Pictures from AVIYAAN, Nepal

Low-Cost High-Accuracy GNSS Receiver System: Space Weather Applications

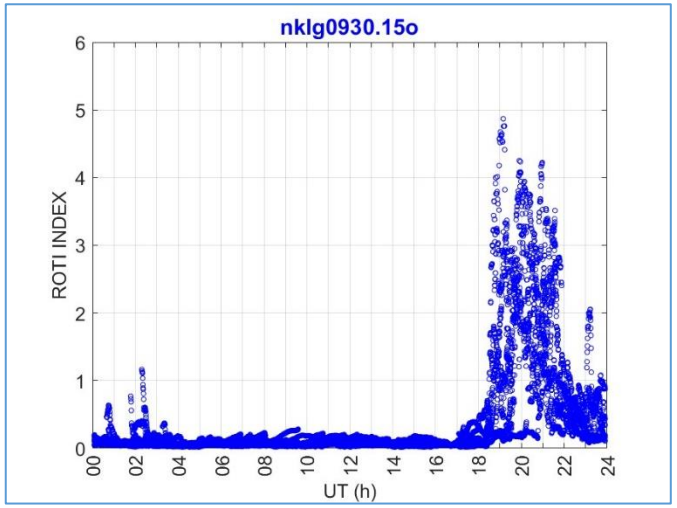
Software for Data Processing: TEC Parameters, S4 Index etc.

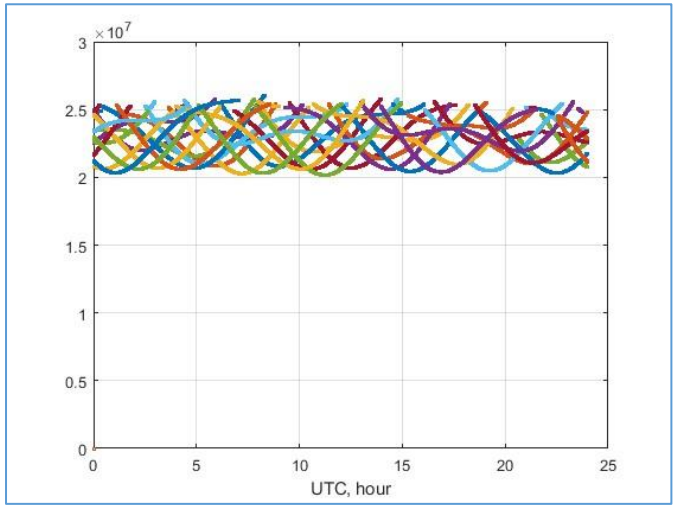
Explore software that can be used for processing data from low-cost GNSS receivers to compute TEC, S4 and other space weather related parameters.

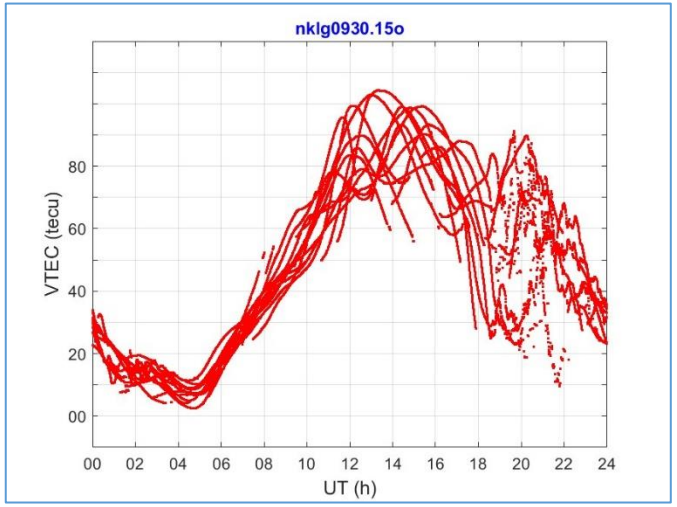
- FLEURY
  - Available with source code
- GOPI
  - Only Binary executable program
- NeQuick
  - Software is available at:
  - https://www.itu.int/rec/R-REC-P.531-14-201908-I/en

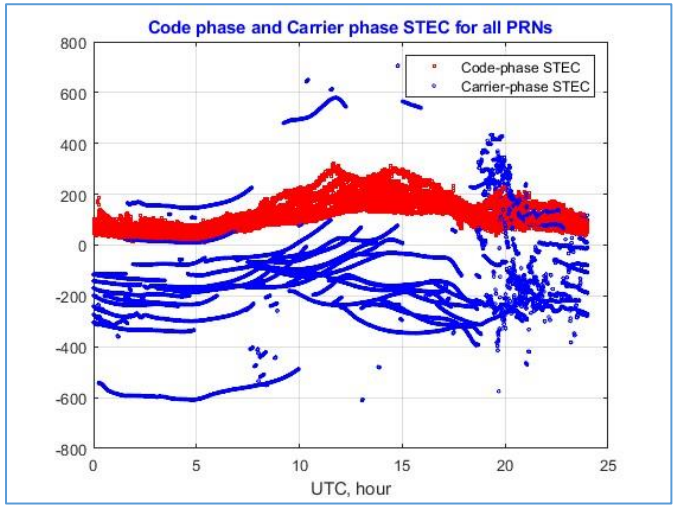
Matlab source files to compute TEC parameters are provided by Rolland Fleury
These outputs are from sample data provided by Fleury
We will modify the software to process data from low-cost GNSS receivers

Output of TEC computation from Matlab based software: FLEURY







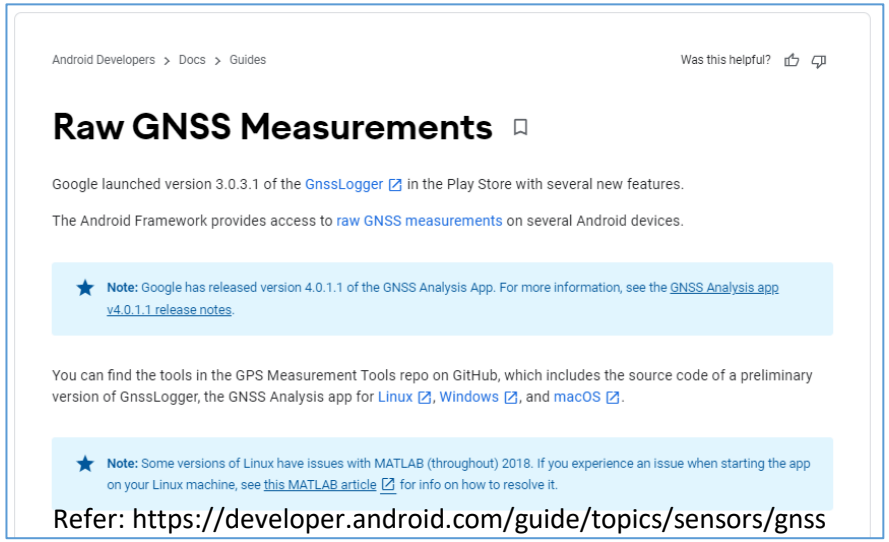


Is it possible to use a Mobile Phone for Space Weather Data?

- Most of the mobile phones have a GNSS receiver
- Some mobile phones also have Dual-Frequency GNSS Receiver (L1/ L5)
- Android devices can output GNSS Raw data
  - Code-Phase, Carrier-Phase, Doppler, Signal Strength, Ephemeris Data, Navigation Data, Antenna Gain Values and several others
- These data can be used for high accuracy GNSS data processing
  - Ionospheric and Tropospheric values can be computed
  - But not enough for Scintillation such as S4 index

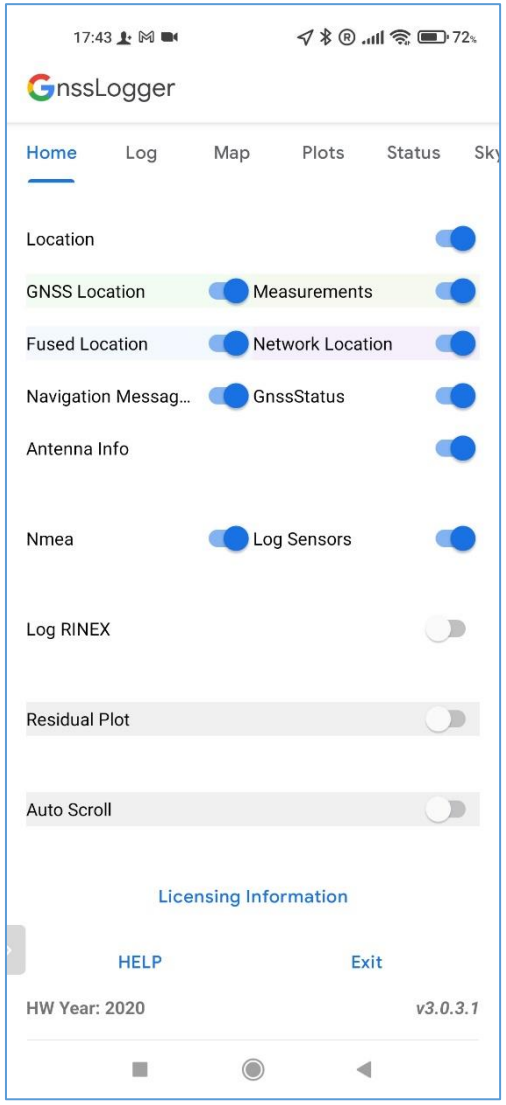
Mobile Phones that provide GNSS Raw Data

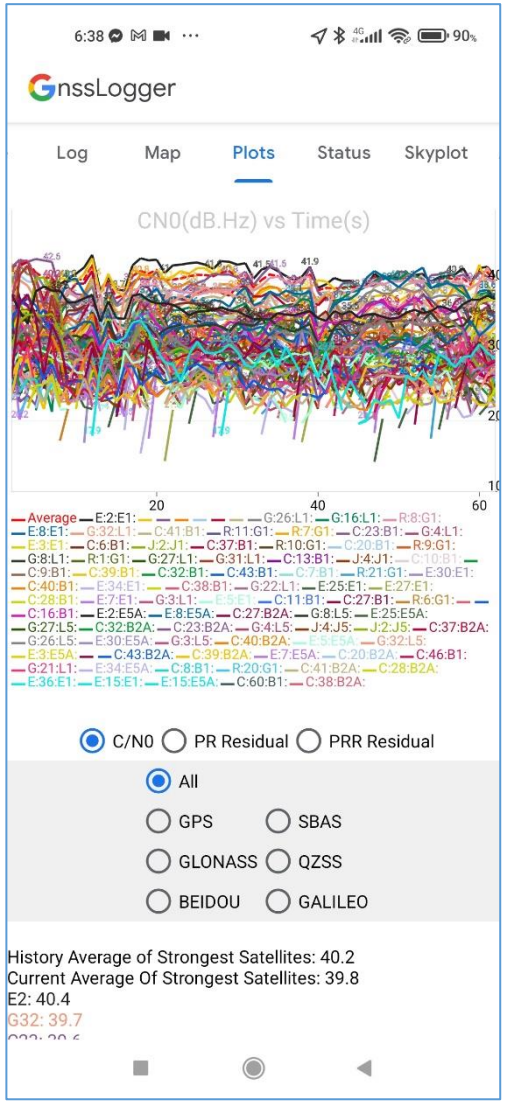
- Google Pixel 4/5/6
- Xiaomi Mi11 Lite5G
- Xiaomi Mi9
- Xiaomi Mi8
- Huawei P30 Pro
- One Plus 7 Pro
- Samsung Galaxy S20/S21 Ultra

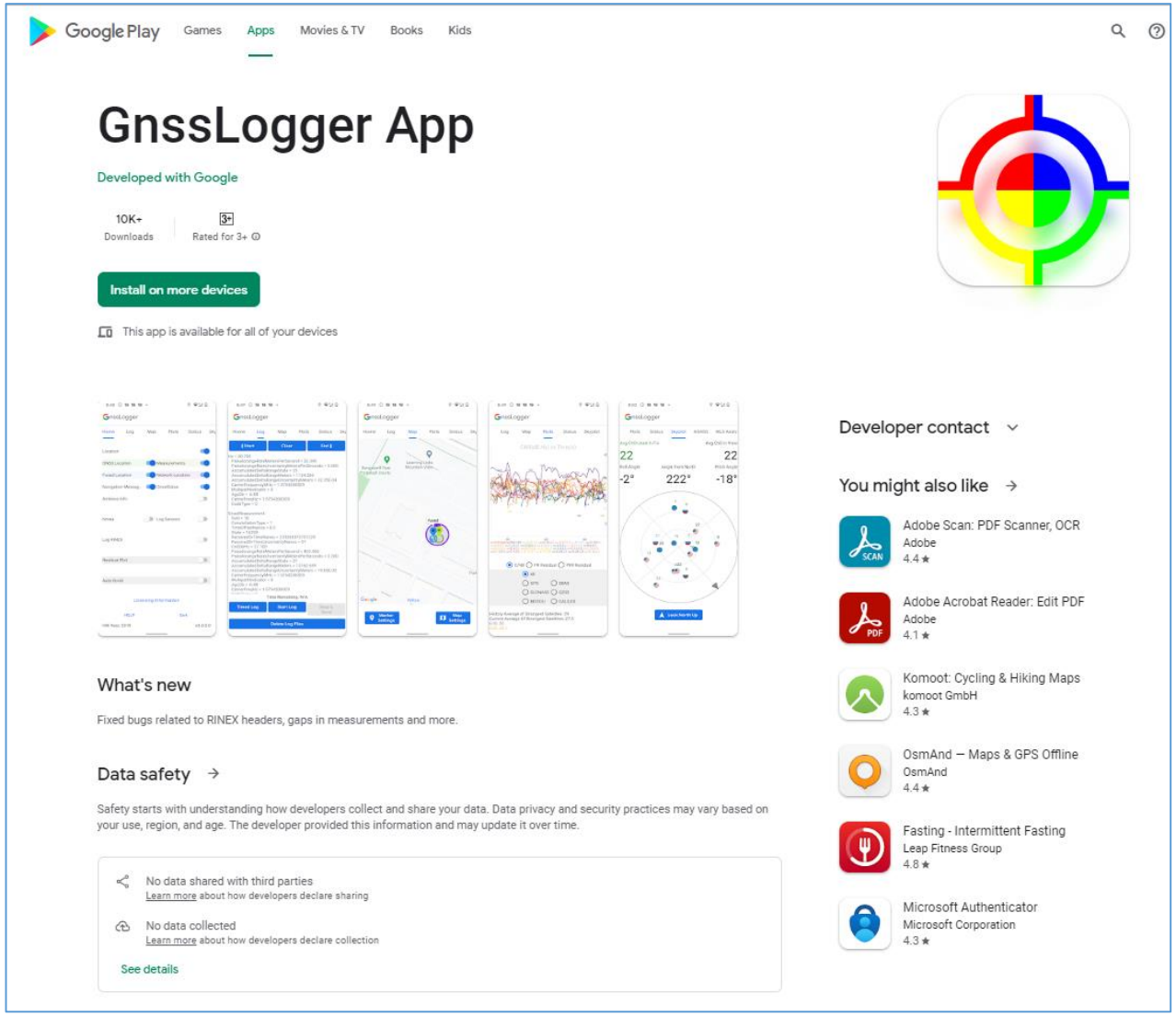


Refer: https://developer.android.com/guide/topics/sensors/gnss

GnssLogger App: To Log GNSS Raw Data from Android Smart-Phone







Technology Promotions through Trainings, Seminars and Workshops

GNSS Technology Promotion through University Collaborations

- Promote GNSS Technology by
  - conducting lectures, trainings, workshops and seminars
  - establishing CORS for data observation and analysis
  - conducting pilot projects in various applications based on GNSS
- Countries
  - Thailand
  - Philippines
  - Indonesia
  - Malaysia
  - Vietnam
  - Singapore
  - Australia
  - Nepal
  - Laos
  - Myanmar
  - India
  - Bangladesh
  - Sri Lanka
  - Mozambique
  - Rwanda

UTOKO/ICG GNSS Training

Hybrid ← → ONLINE

Participants Information	11 – 14 JAN 2022	19 – 21 JAN 2021	28 JAN 2021	JAN 2020	JAN 2019	JAN 2018
	GNSS Training	Course A	Course B	T-151	T-151/T-131	T-141
Number of Participants	**72**	150+	100+	71	94	67
Applicants	**120 (About)**	360 (270 Selected)	190 (160 Selected)	160+	180+	80+
Number of Countries	**16**	70+	60+ tbc	15	15	15

Activities to Promote GNSS Technology Abroad: Establish Asian Base-Station Network (ABN)

Country	Place	University	Receiver Type		
			GNSS	GNSS/MADOCA	MADOCA Low Cost
Indonesia	Jakarta	University of Indonesia	NetR9	MSJ	Yes
Japan	Tokyo-A	The University of Tokyo	NetR9	NA	Yes
Japan	Tokyo-B	Tokyo University of Marine Science & Tech.	NetR9	MSJ	Yes
Japan	Tokyo-C	KEIO University	NetR9	NA	Yes
Laos	Vientiane	National University of Laos	NetR9	NA	SW only
Malaysia	Kuala Lumpur	Malaysia Japan International Institute of Tech.	NetR9	MSJ	Yes
Myanmar	Yangon	Yangon Technological University	NetR9	NA	SW only
Thailand	Bangkok	Chulalongkorn University	NetR9	MSJ	Yes
Thailand	Pathumthani	Asian Institute of Technology	NetR9*	NA	Yes
Philippines	Manila	University of the Philippines	NetR9	MSJ	Yes
Vietnam	Ho Chi Minh City	International University	NetR9	MSJ*	Yes
Mozambique	Maputo	Universidade Eduardo Mondlane	NetR9	NA	NA
Singapore	Singapore	Nanyang Technological University	NA	MSJ	Yes
Australia	Perth	Curtin University	NA	MSJ	Yes

Yes: MADOCA Low-Cost Receiver and Software will be provided

Lecture on how GPS can help to fishermen

About 50 local fishermen attended the program

May 2018

CSIS

ICG International Committee on Global Navigation Satellite Systems

AIT GIC Geoinformatics Center

GNSS Training, Course T-151 and GNSS for Policy and Decision Makers, Course T-131

14 – 18 January 2019

AIT Conference Center, AIT, Thailand

GNSS Training organized at AIT, Thailand every year in JAN from 2018 – 2020, jointly organized with ICG/UNOOSA and AIT

University of Indonesia, Aug 2017

Yangon Technological University, Myanmar

International University, HCM City, Vietnam

GNSS Training in Laos, Feb 2018,

GNSS Seminar in 2016, 2017 and 2018
National Institute of Metrology, Thailand (NIMT)

International University, HCM City, Vietnam

UN-Nepal Workshop on GNSS

12 – 16 DEC 2016

- Organized by Survey Dept. of Nepal and UNOOSA/ICG
- **Total 154 participants from 32 different countries**
- **66 International participants from 31 countries**
- 25 International participants were fully funded by ICG
- Full Five days workshop including ICG's IDM WG Meetings

6th ICG / UTOKYO GNSS Training 2023 (Hybrid Format)

- Program – 1 : GNSS Training
- Program – 2 : Workshop on GNSS for Policy and Decision Makers
- Dates
  - Program 1: 3 – 6 January 2023
  - Program 2: 9 January 2023
- Venue
  - Onsite : Tribhuvan University, Pokhara, Nepal
  - Hybrid Format
- Notice will be announced soon. Please check ICG's homepage.


On-Site participants during opening ceremony of ICG/UTOKYO GNSS Training in January 2022

Multi-GNSS Asia (MGA) Events

- 13th MGA Annuanl Conference
  - Date : 31st JAN – 2nd FEB 2023
  - Venue : Science and Technology Park, Chiang Mai University, Thailand
  - Website: https://www.mga-conference.com/

- RPD (Rapid Prototype Development) Challenge
  - Date : December 2022 – March 2023
  - Venue : Online
  - Website: https://www.rpdchallenge.com/

URSI GASS 2023, Sapporo, Japan

- XXXVth URSI General Assembly and Scientific Symposium
  - Date : August 19 – 26, 2023
  - Venue : Sapporo Convention Center, Japan
  - Website : https://www.ursi-gass2023.jp/
    - **Commission A**: Electromagnetic Metrology
    - **Commission B**: Fields and Waves
    - **Commission C**: Radiocommunication and Signal Processing Systems
    - **Commission D**: Electronics and Photonics
    - **Commission E**: Electromagnetic Environment and Interference
    - **Commission F**: Wave Propagation and Remote Sensing
    - **Commission G**: Ionospheric Radio and Propagation
    - **Commission H**: Waves in Plasmas
    - **Commission J**: Radio Astronomy
    - **Commission K**: Electromagnetics in Biology and Medicine
  - Download Link for Sessions: https://cloud.ilabt.imec.be/index.php/s/6jp5tnASX5DbY2n
    - Commission C, Session C01 for “Low-Cost GNSS Receivers”
    - Commission C, Session C05 for “Satellite Systems and Positioning”
  - Paper Submission Deadline: 25th January 2023

Summary

- Low-Cost GNSS Receivers are getting powerful for High-Accuracy positioning application
  - It helped to reduce cost from thousands of dollars to few hundred dollars
- Need to develop software so that low-cost receiver systems can be used
  - Easy integration with other systems
  - Signal analysis for various applications such as TEC, Scintillation computation
- Need to inform and request receiver manufactures to provide necessary outputs
  - Output required for space weather is too heavy in terms of memory and CPU that consumes power, so manufacturers are not happy to output raw data
  - But, it might be possible to output by using a special firmware for scientific applications
- We are planning to setup multiple low-cost GNSS receivers in Asian countries to explore the possibilities of space weather applications
  - But we don't know much about space-weather. Need your help!
- Need to have close collaboration between GNSS community and Space Weather Community

Link for Reference Materials

- Lab Home Page
  - https://www.csis.u-tokyo.ac.jp/en/
  - https://home.csis.u-tokyo.ac.jp/~dinesh/
- GNSS Training Materials, Data etc.
  - https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
- Low-Cost High-Accuracy Receiver Systems
  - https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
- GNSS Webinar
  - https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm
  - https://gnss.peatix.com
- Link to Documents, Software, Android APP etc.
  - https://home.csis.u-tokyo.ac.jp/~dinesh/Download.htm
- Facebook : https://www.facebook.com/gnss.lab (GNSS Related)
- Contact : dinesh@csis.u-tokyo.ac.jp