Low-Cost GNSS Receiver System for Space Weather

United Nations Workshop on the
International Space Weather Initiative (ISWI): The Way Forward
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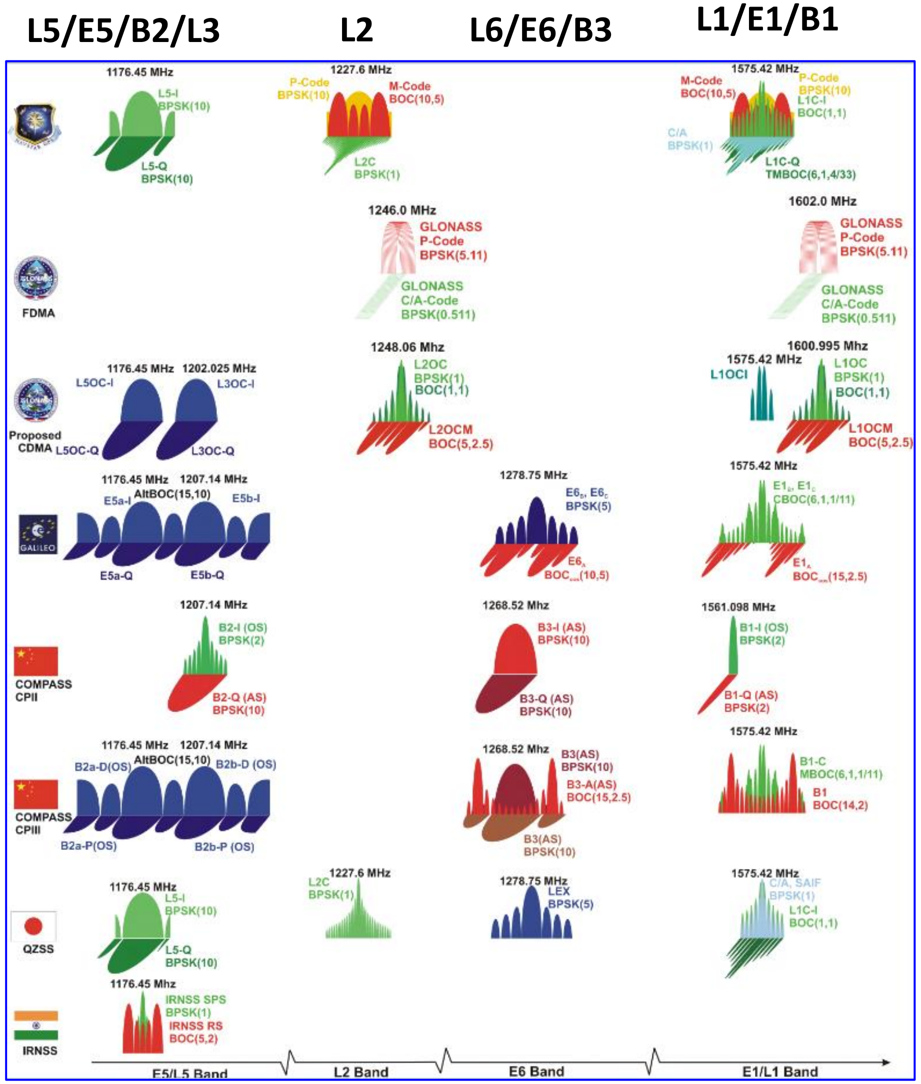
Background Information: GNSS Signals

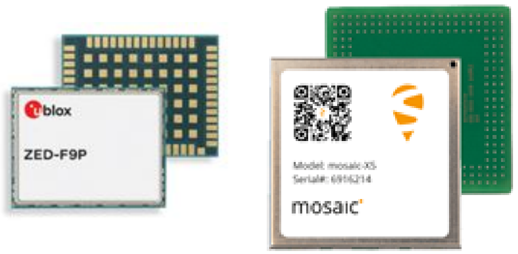
Satellite	Country	Coverage
GPS	USA	Global
GLONASS	Russia	Global
Galileo	Europe	Global
BeiDou (BDS)	China	Global
QZSS (Michibiki)	Japan	Regional
NavIC	India	Regional



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

How to Make a Low-Cost GNSS Receiver System?

GNSS Module or Receiver



Low-Cost SDR Device
$30

+

Memory

Micro-Controller or Micro-Processor

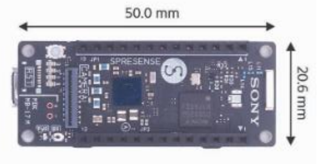
External Interface

External Memory Device

Single Board Computer

RaspberryPi

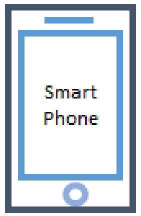
Arduino



Sony, Spresense

WiFi, BT, Ethernet, MQTT, IoT links

ESP32 is a powerful Micro-controller with WiFi/BT

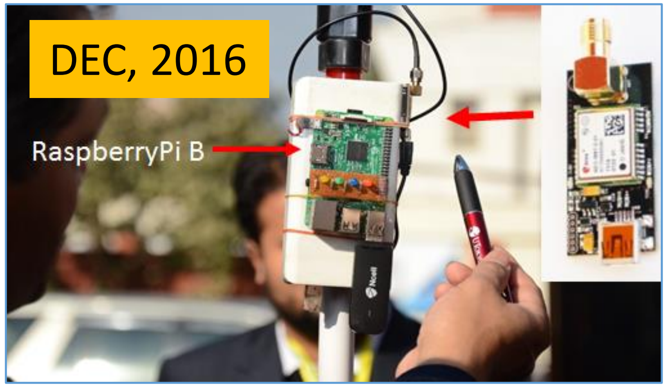


A smart-phone has everything that we need

- 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.

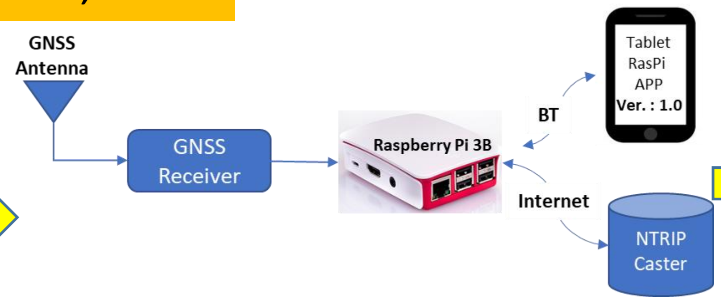
Low-Cost High-Accuracy Receiver system Development Cycle



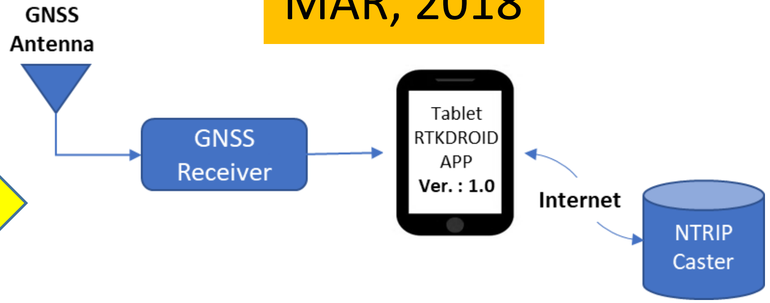
Demo during UN/Nepal GNSS workshop

MAY, 2017

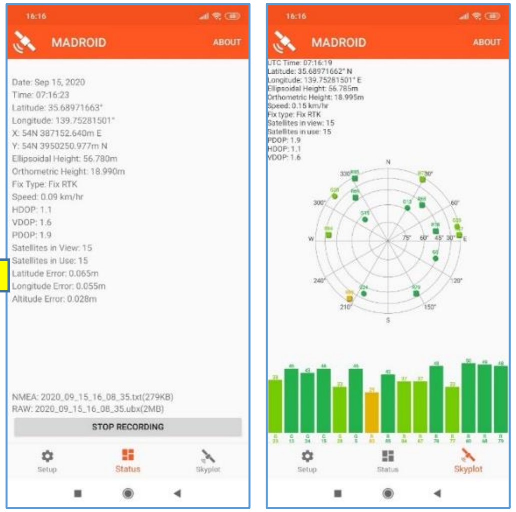
Low-Cost RTK

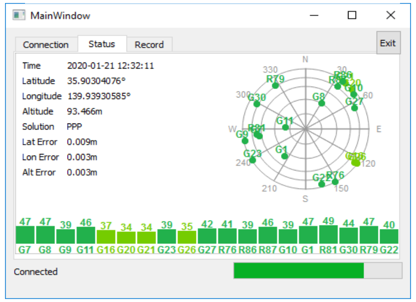


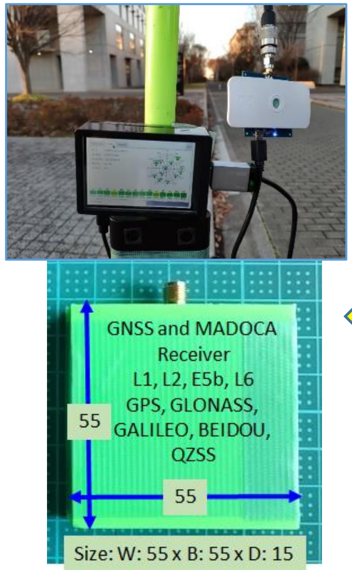
MAR, 2018



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 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
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	Yes	
S4 Computation	No	To be explored	
Price (USD)	300	700	

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

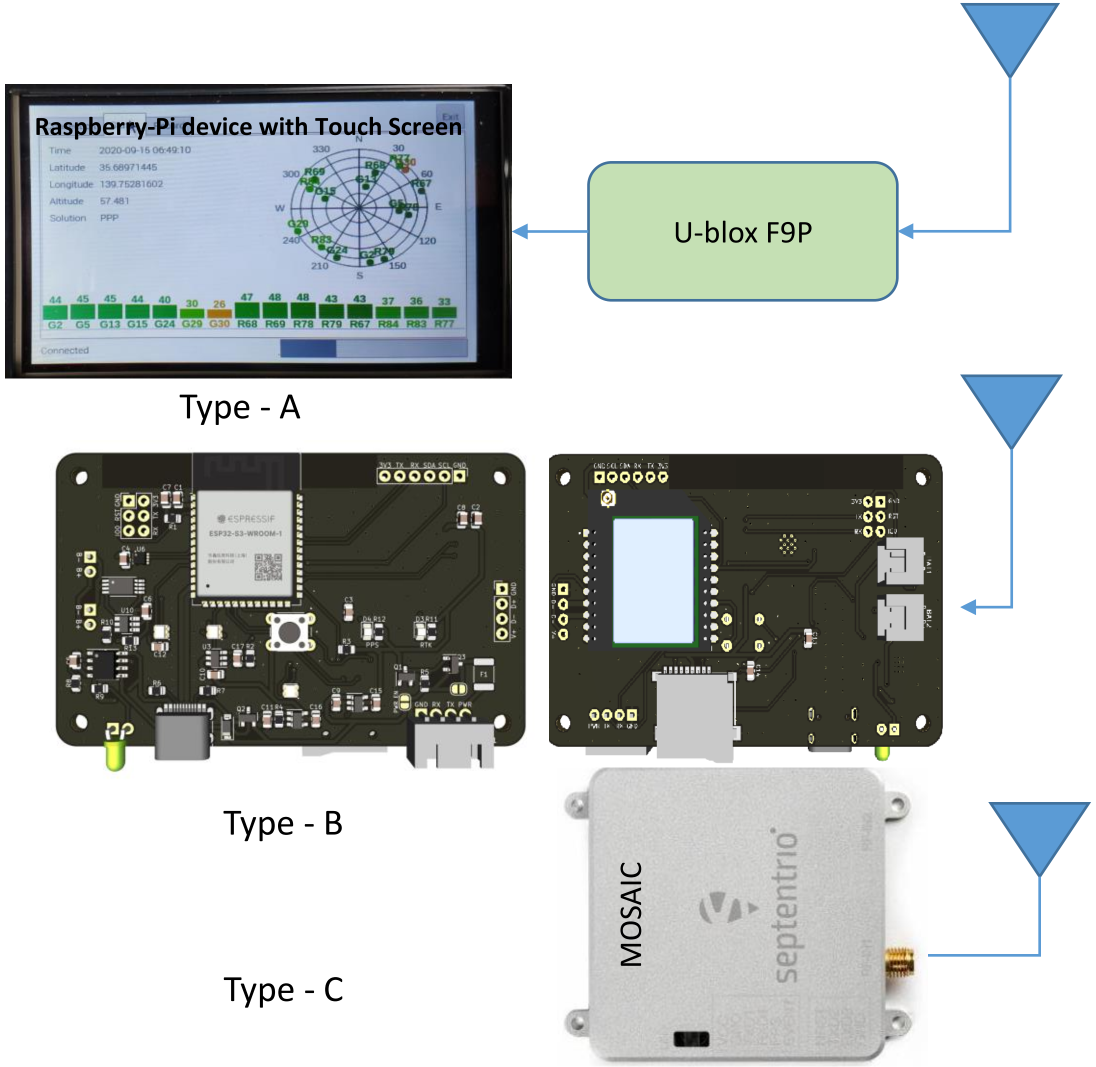
https://content.u-blox.com/sites/default/files/ZED-F9P_ProductSummary_UBX-17005151.pdf

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 GNSS Receiver System: Space Weather Applications

Remote and Unattended Continuous Data Logging

- Design low-cost GNSS receiver system for unattended data logging
  - Integrate receiver with micro-computer
    - RaspberryPi / ESP32 / Android Device
- Explore different types of configurations
  - Type – A : based on RaspberryPi device
  - Type – B : based on ESP32 device
  - Type – C : based on MOSAIC (Septentrio)
- Requirements
  - Automatically log raw data when power is connected.
  - Automatically connect remote server
  - Recover all setups when the receiver is reset
  - Log raw data locally in a SD Card.



Note: Type-B Pictures from AVIYAAN, Nepal

Low-Cost GNSS Receiver System: Space Weather Applications

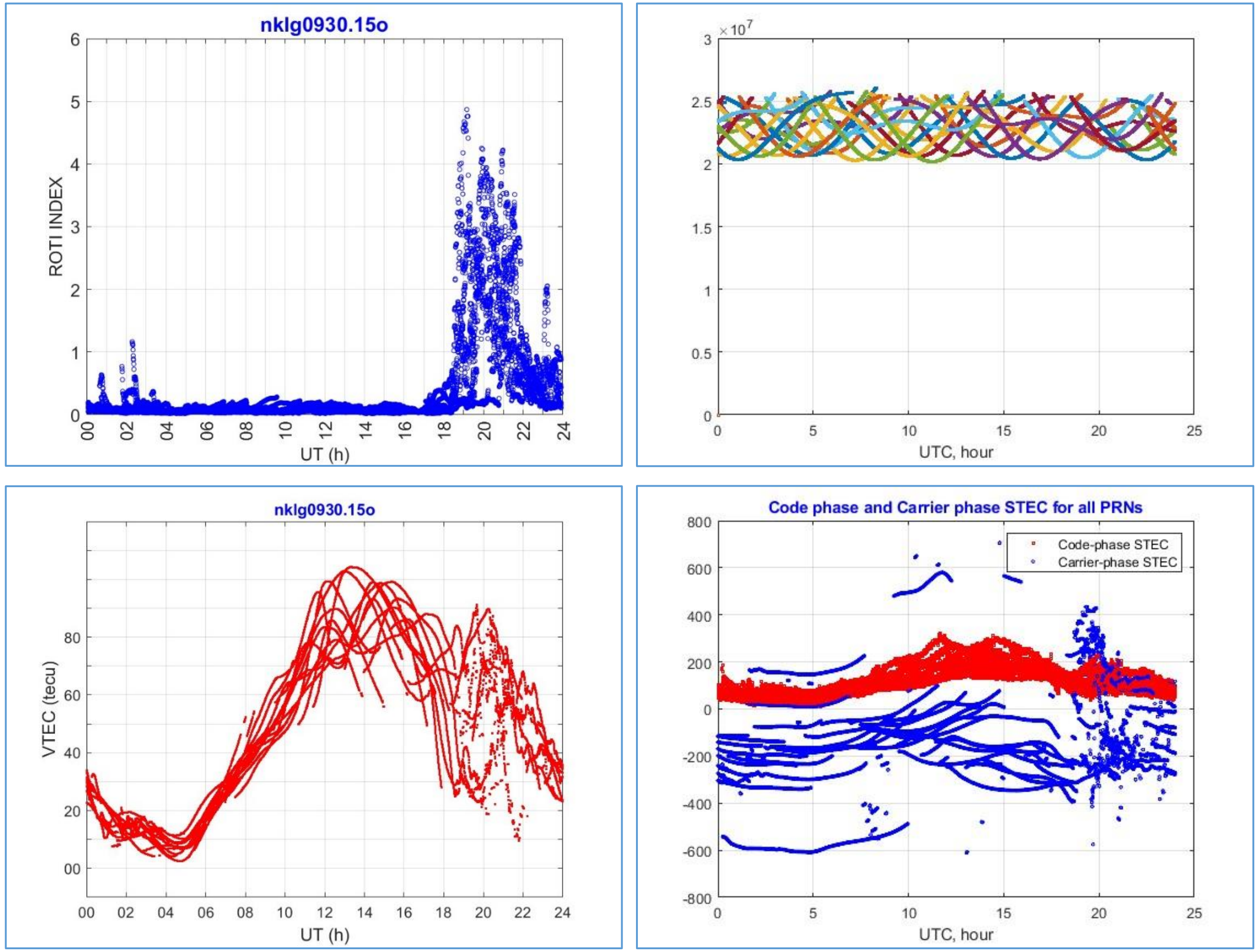
Software for Data Processing: TEC Parameters

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
- NeQuick
  - Software is available at:
  - https://www.itu.int/rec/R-REC-P.531-14-201908-I/en
- KMITL, TEC
  - Matlab Source code available

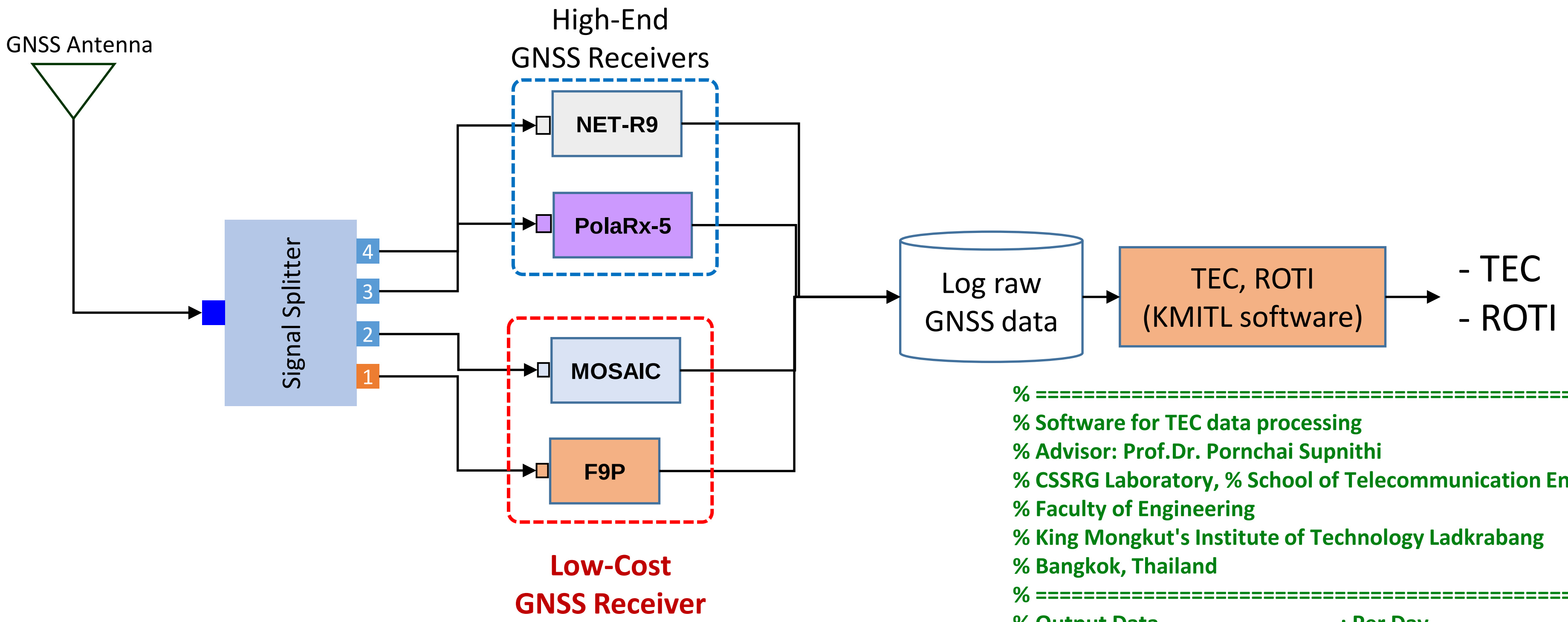
Matlab source files to compute TEC parameters are provided by Rolland Fleury
These outputs are from sample data provided by Fleury
We will modify the software to process data from low-cost GNSS receivers

Output of TEC computation from Matlab based software: FLEURY



Comparison of High-End vs. Low-Cost GNSS Receiver for TEC/ROTI

Data Logging Method



% ==
% Software for TEC data processing
% Advisor: Prof.Dr. Pornchai Supnithi
% CSSRG Laboratory, % School of Telecommunication Engineering
% Faculty of Engineering
% King Mongkut's Institute of Technology Ladkrabang
% Bangkok, Thailand
% ==

% Output Data	: Per Day
% TEC.vertical	= Vertical Total Electron Content(VTEC)
% TEC.slant	= Slant Total Electron Content(STEC)
% TEC.withrcvbias	= STEC with receiver DCB
% TEC.withbias	= STEC with satellite and receiver DCB
% TEC.STECp	= STEC calculated from code range
% TEC.STECl	= STEC calculated from carrier phase
% DCB.sat	= Satellite DCB
% DCB.rcv	= Receiver DCB
% prm.elevation	= elevation angle
% ROTI	= Rate Of Change TEC Index

KMITL : King Mongkut Institute of Technology, Ladkrabang, Thailand
Work conducted by Doctoral student Mr. Somkit@KMITL, currently at CSIS as an Intern Student

GNSS Observation Data

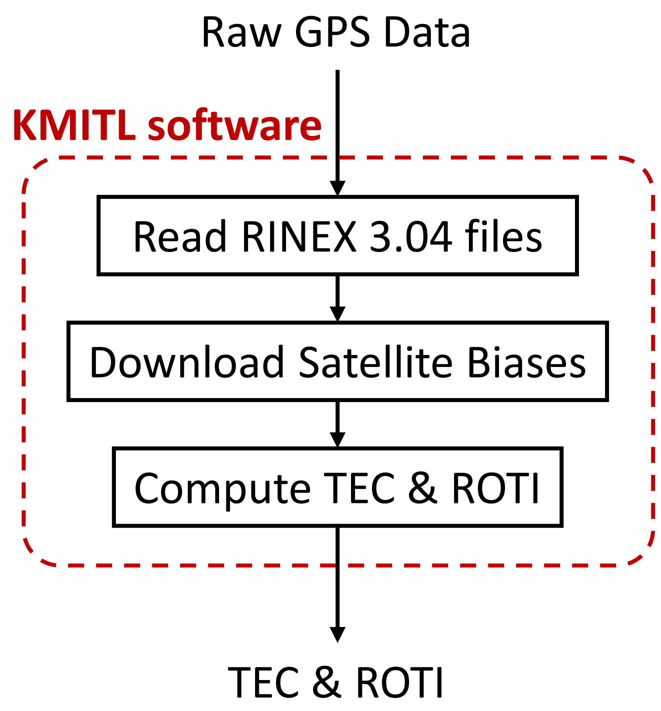
Items	Observation Data			
GNSS Receiver → Satellites ↓	**Net-R9**	**PolarRx5**	**MOSAIC**	**U-blox F9P**
GPS (**G**)	C1C L1C S1C C2X L2X S2X C5X L5X S5X	C1W L1W D1W S1W C2W L2W D2W S2W C5Q L5Q D5Q S5Q	-	C1C L1C D1C S1C C2X L2X D2X S2X
GLONASS (**R**)	C1C L1C S1C C2C L2C S2C	C1C L1C D1C S1C C2C L2C D2C S2C C3Q L3Q D3Q S3Q	-	C1C L1C D1C S1C C2C L2C D2C S2C
Galileo (**E**)	C1X L1X S1X C5X L5X S5X	C1C L1C D1C S1C C7Q L7Q D7Q S7Q C5Q L5Q D5Q S5Q	-	C1X L1X D1X S1X C7X L7X D7X S7X
QZSS (**J**)	C1Z L1Z S1Z C2X L2X S2X C5X L5X S5X	C1C L1C D1C S1C C2L L2L D2L S2L C5Q L5Q D5Q S5Q	-	C1C L1C D1C S1C C2X L2X D2X S2X
SBAS (**S**)	C1C L1C S1C	C1C L1C D1C S1C C5I L5I D5I S5I	-	C1C L1C D1C S1C
BeiDou (**C**)	-	C2I L2I D2I S2I C1P L1P D1P S1P C5P L5P D5P S5P	-	C2I L2I D2I S2I C7I L7I D7I S7I

- RINEX 3.04 converted by RTKCONV demo5 b34g (**last update**).
- The OBS types can be read by the readrinex304 (**.mexw64 file**).

Work conducted by Doctoral student Mr. Somkit@KMITL, currently at CSIS as an Intern Student

Methodology

TEC & ROTI computations



➢ **KMITL software with RINEX 3.04 is developed.**

Experimental setup

Items	Values
Approx position:	[Lat (°), Lon (°), Height (m)]
Net-R9	[35.903, 139.939, 93.463]
PolaRx5	[35.903, 139.939, 89.159]
F9P	[35.903, 139.939, 89.795]
Observed date	June 16 to 19, 2023
Elevation mask	30°
ROTI window size	5 min

➢ **Each approximate position with the same antenna is slightly differences.**
   ➢ **Possibly, there are the different receiver biases.**

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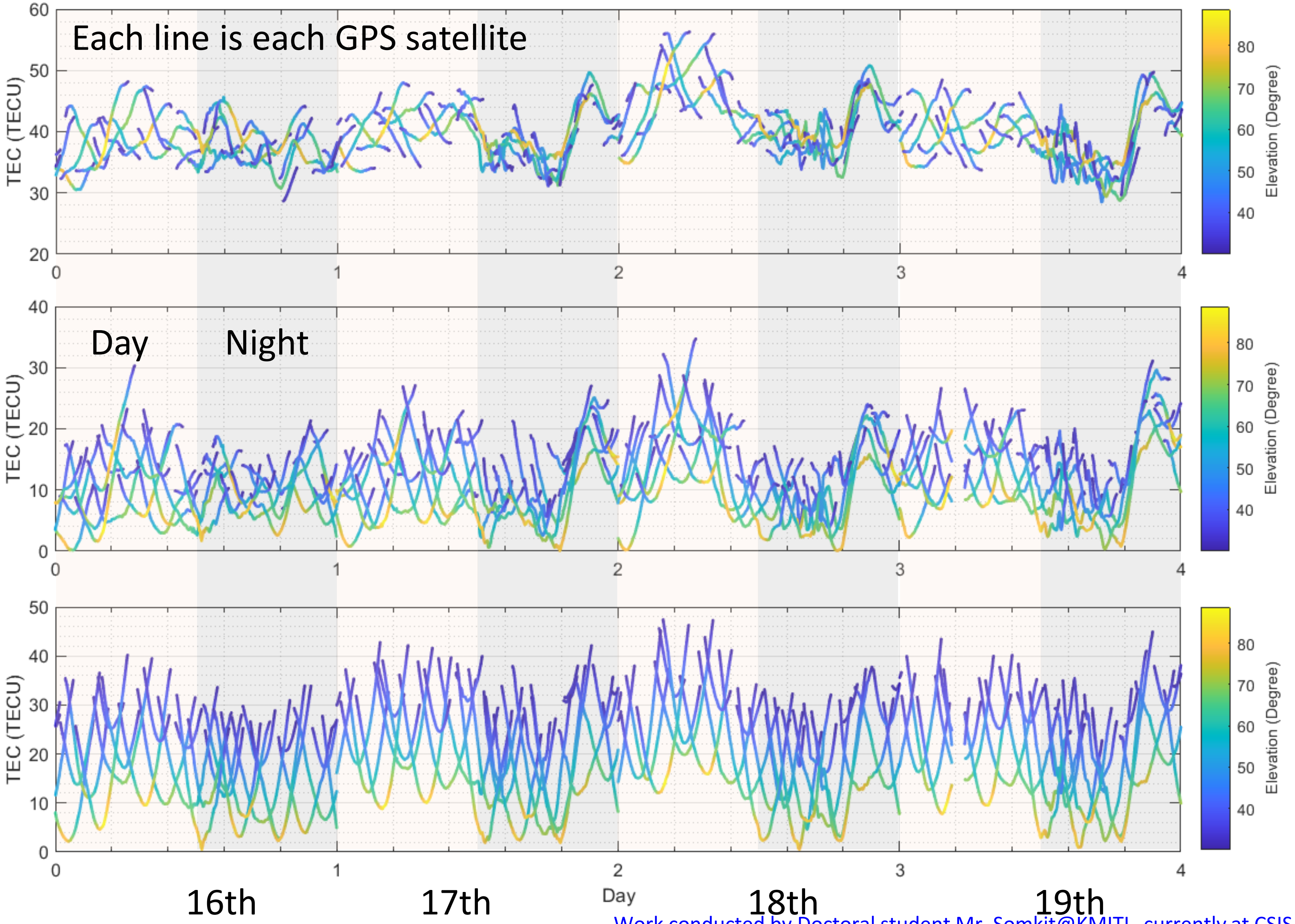
VTEC Results

Net-R9

PolaRx5

F9P



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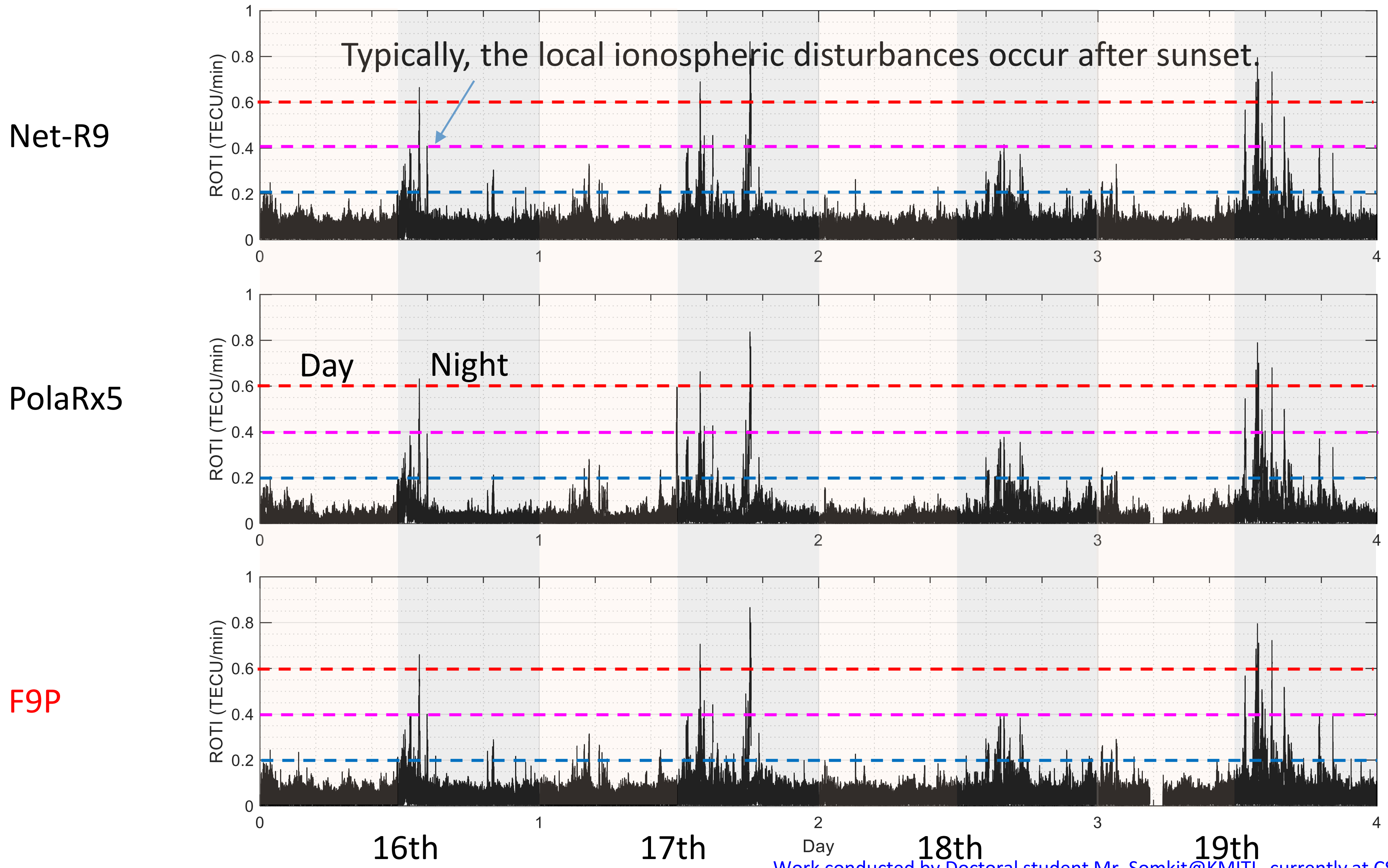
ROTI Results



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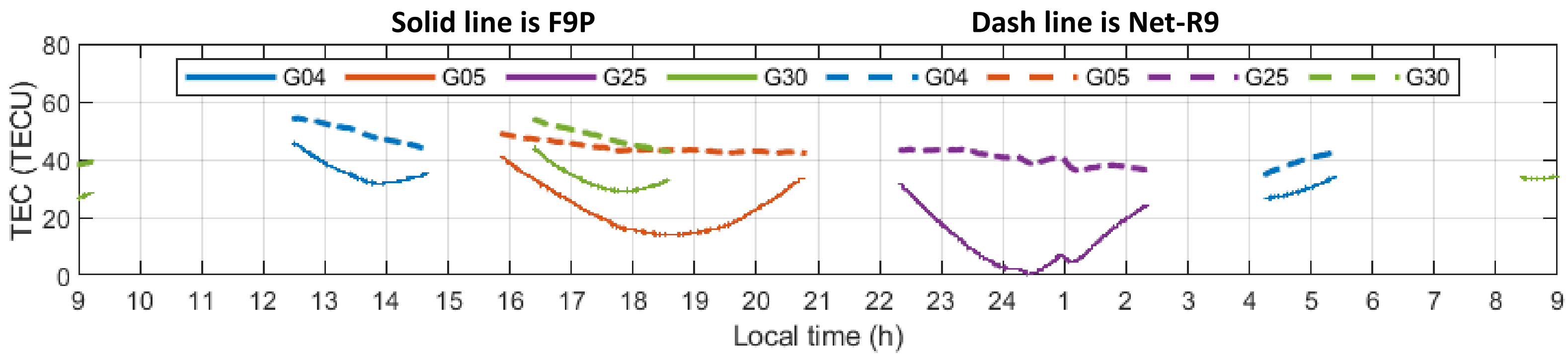
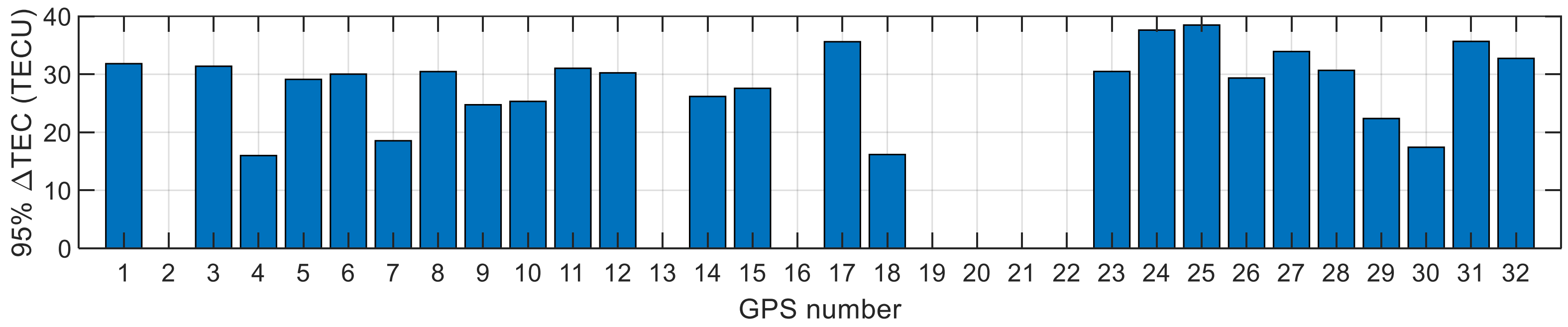
VTEC comparison (F9P vs. Net-R9)

Example



Summary



- Mostly, 95% ΔTEC values with the long period (e.g., G05 and G25) are ranges from 28 to 38 TECU.
- The short period (G04 and G30) are ranges from 15 to 18 TECU.

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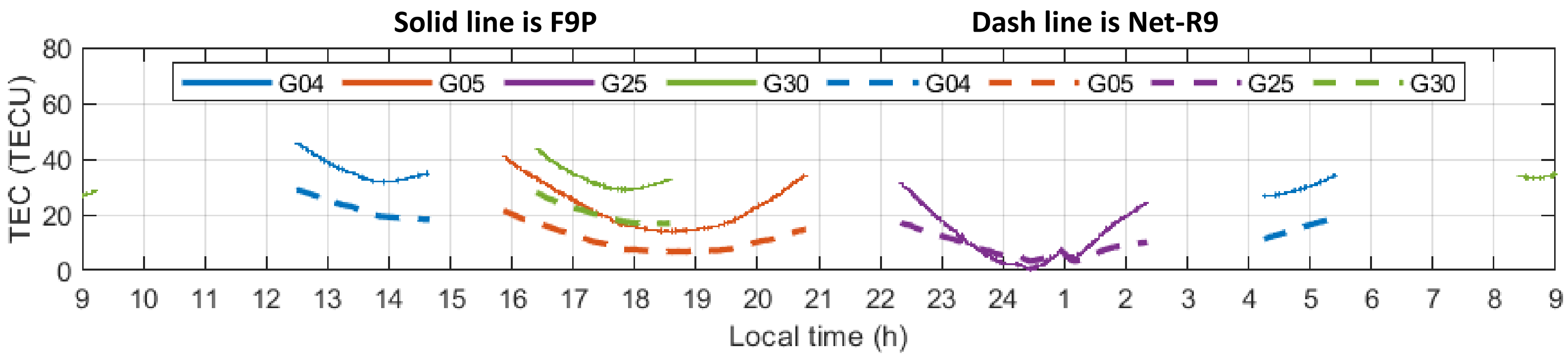
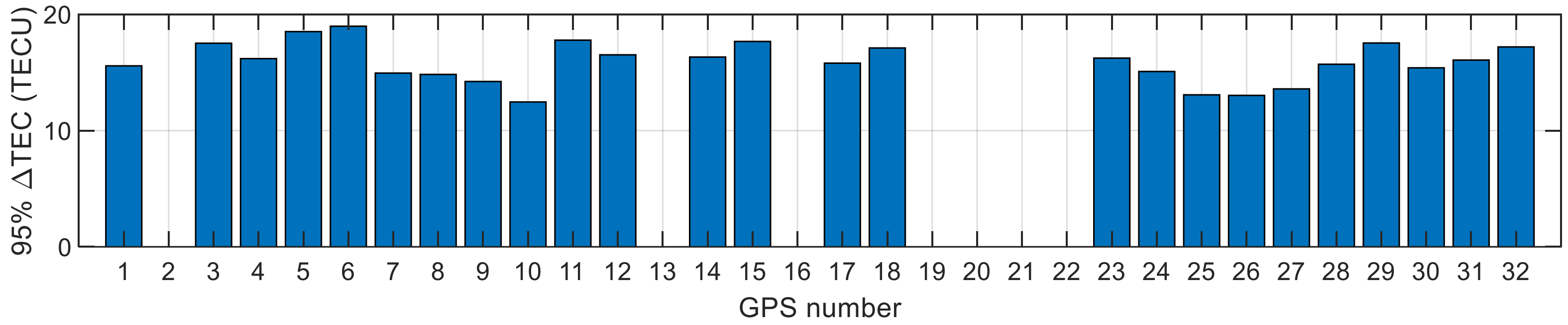
VTEC comparison (F9P vs. PolarRx5)

Example



Summary



➢ **Mostly, 95% ΔTEC values are ranges from 13 to 19 TECU.**

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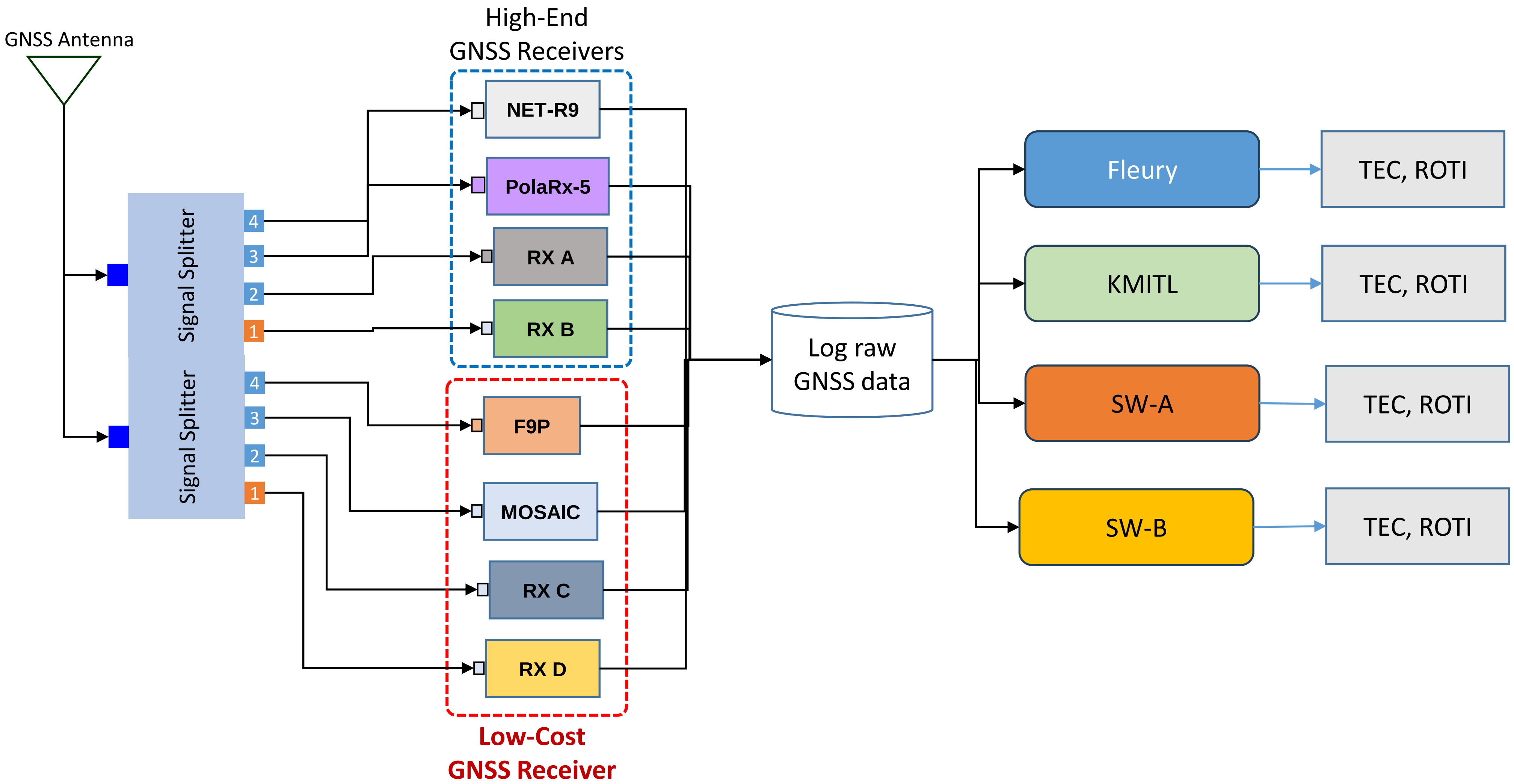
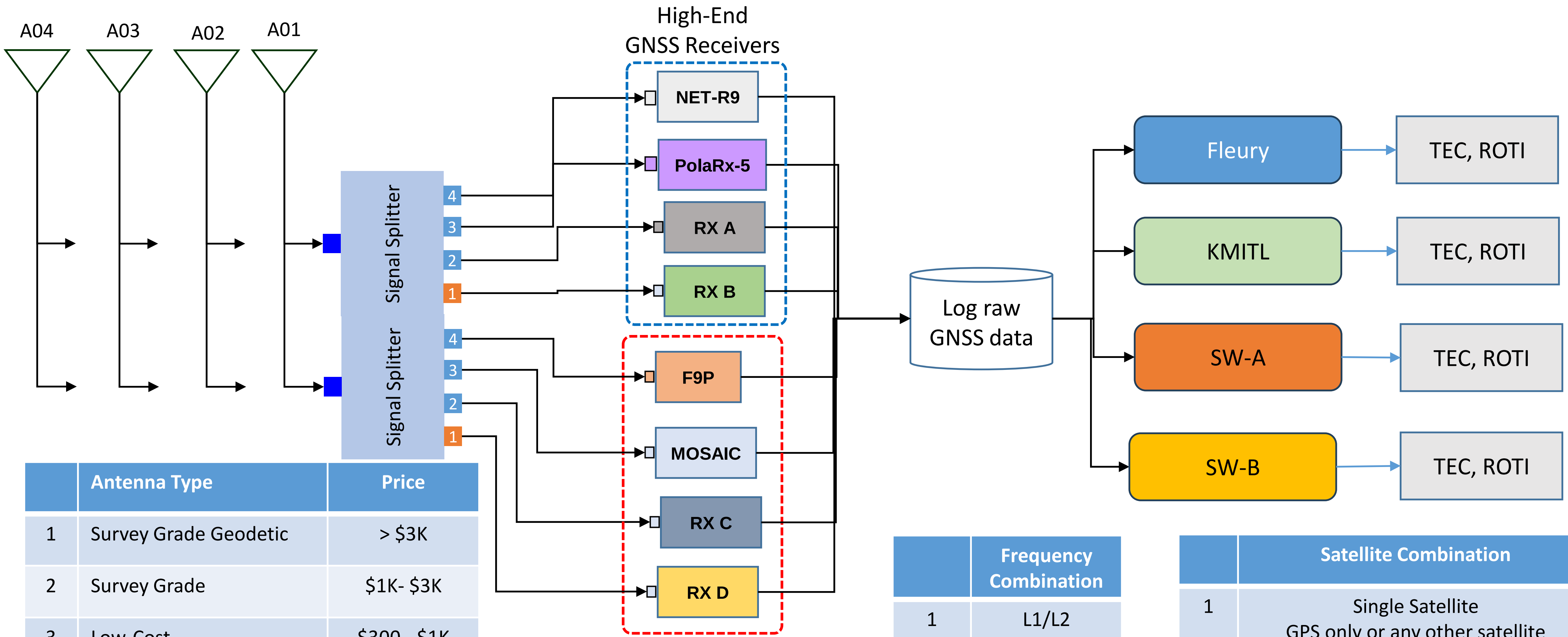
Future Work

Test with more receiver types / Compare results with different software



Future Work

Test with more receiver types / more antenna types / Compare results with different software



	Antenna Type	Price
1	Survey Grade Geodetic	> $3K
2	Survey Grade	$1K- $3K
3	Low-Cost	$300 - $1K
4	Very Low Cost	$100 or lower

	Frequency Combination
1	L1/L2
2	L1/L5

	Satellite Combination
1	Single Satellite GPS only or any other satellite
2	Multiple Satellites GPS + Other Satellites

Summary

- Low-Cost GNSS Receivers are getting powerful for Space Weather applications
  - TEC and ROTI Parameters can be computed
- 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, ROTI, Scintillation computation
- Current results show that TEC/ROTI can be computed
  - TEC computation is not at satisfactory level. Requires improvement.
- Data formats and processing algorithms shall be standardized for uniform results
- Need to inform and request receiver manufactures to provide necessary outputs
  - It helps to reduce the cost
  - 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
- Need to have close collaboration between GNSS community and Space Weather Community
  - We are planning to setup multiple low-cost GNSS receivers in Asian countries to explore the possibilities of space weather applications
  - We need your help!