Low-Cost GNSS Receiver System for Space Weather

Comparison of Results from Low-Cost vs. High-End Receivers

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Background

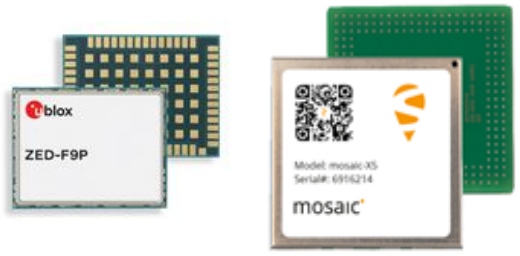
Recommendation of the ICG, Working Group C on Information Dissemination and Capacity Building:

- **Establish a project team within the WG-C to explore the possibilities of using low-cost GNSS receivers for space weather monitoring.**

- Objectives
  - Explore Low-Cost GNSS Receivers that can be used to compute ionosphere-related parameters TEC, S4 and other parameters.
  - Explore software that can be used for processing data from low-cost GNSS receivers to compute TEC, S4 and other parameters.
  - Develop a prototype low-cost GNSS receiver system for space weather applications.
- Project Team Members
  - Sharafat Gadimova, United Nations Office for Outer Space Affairs, ICG Executive Secretariat, Austria
  - Dinesh Manandhar, Center for Spatial Information Science (CSIS), The University of Tokyo, Japan
  - Christine Amory-Mazaudier, Laboratory of Plasma Physics (LPP), France
  - Bruno Nava, International Centre for Theoretical Physics (ICTP), Italy
  - Gabriella Povero, Centre for Earth Observation, Italy
  - Keith Groves, Boston College, United States of America

How to Make a Low-Cost GNSS Receiver System?

GNSS Module or Receiver



Memory

Micro-Controller or Micro-Processor

External Interface

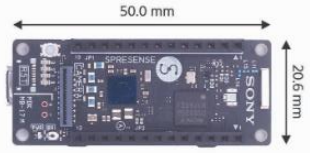
External Memory Device

Hard Disk

Single Board Computer

RaspberryPi

Arduino



Sony, Spresense

WiFi, BT, Ethernet, MQTT, IoT links

ESP32 is a powerful Micro-controller with WiFi/BT

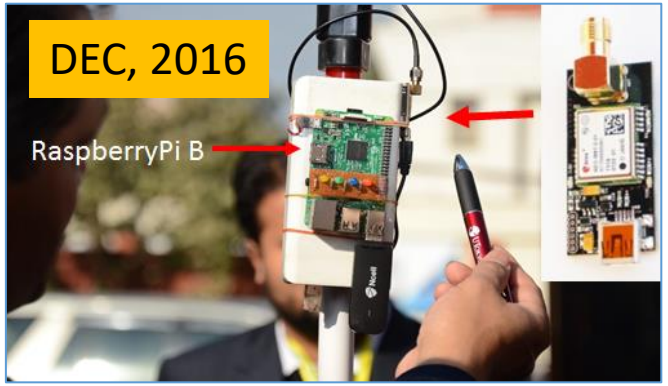
A smart-phone has everything that we need

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

- Note: We use these modules for high accuracy positioning systems 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

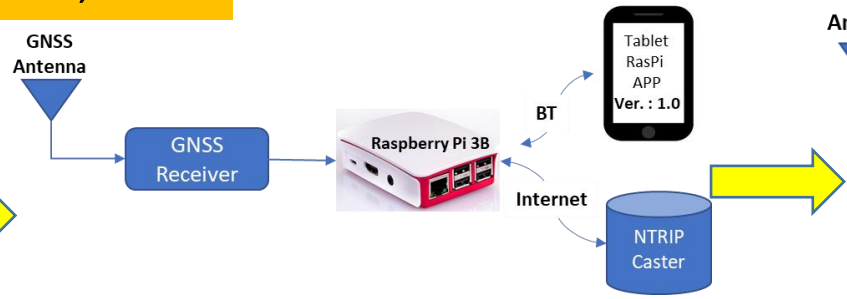
DEC, 2016



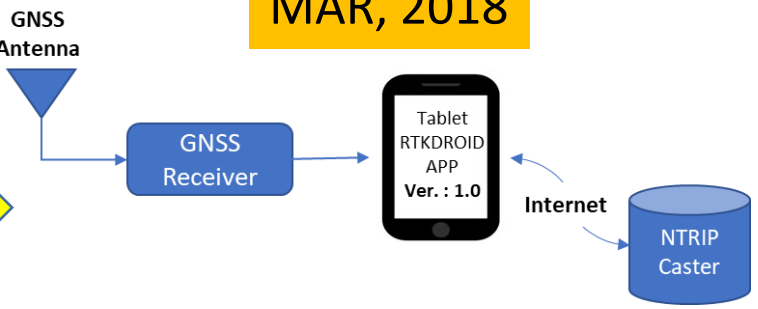
Demo during UN/Nepal GNSS workshop

MAY, 2017

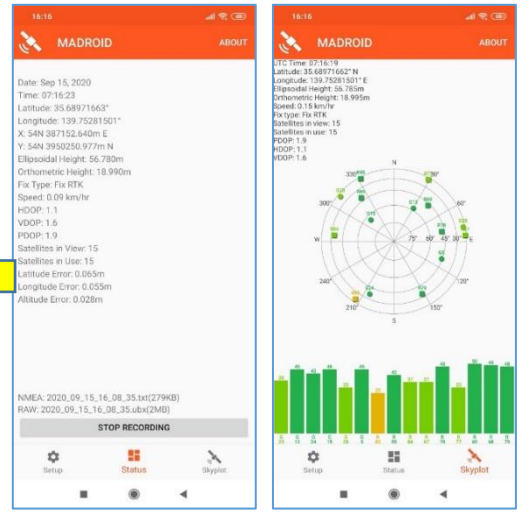
Low-Cost RTK

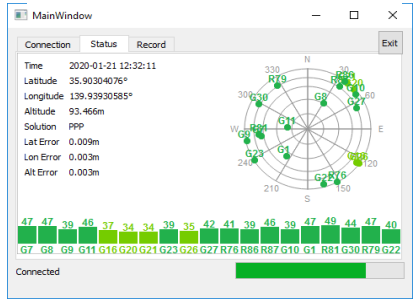


MAR, 2018



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 High-Accuracy GNSS Receiver System: Space Weather Applications

We will explore at least two types of receivers

- u-blox F9P (L1/L2 or L1/L5)
- Septentrio (MOSAIC) (L1/L2/L5)

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 or L1, L5, E5a	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 / ϕ4 Computation	May be (To be explored)/ No	May be (To be explored) / No	
Price (USD)	300	700	

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

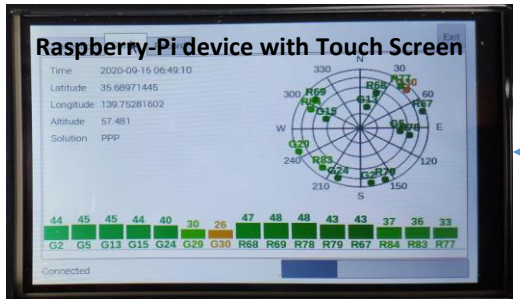
https://content.u-blox.com/sites/default/files/ZED-F9P_ProductSummary_UBX-17005151.pdf

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 for Space Weather Applications

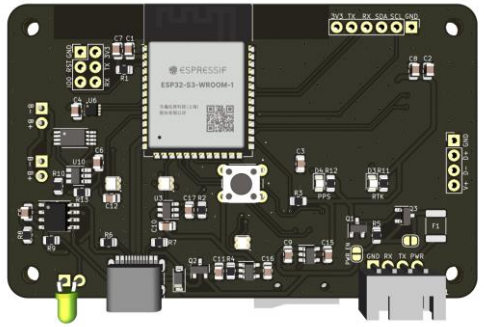
Remote and Unattended Continuous Data Logging

- Design a 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.



U-blox F9P

Type - A



Type - B

Type - C

Low-Cost GNSS Receiver System for Space Weather Applications

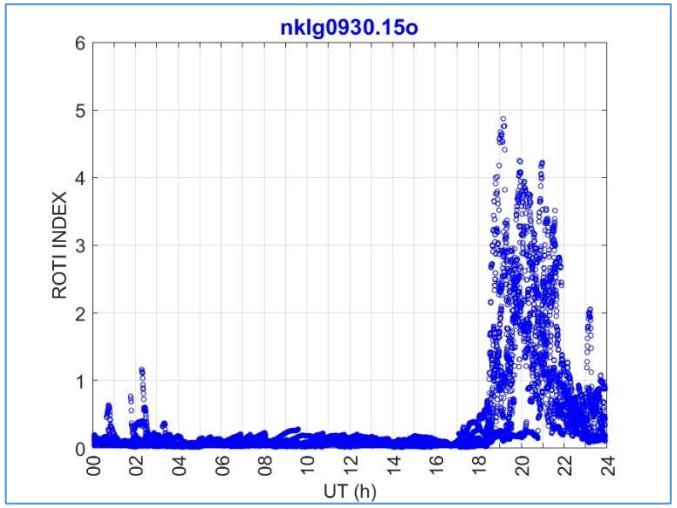
Software for Data Processing: TEC and S4 Parameters

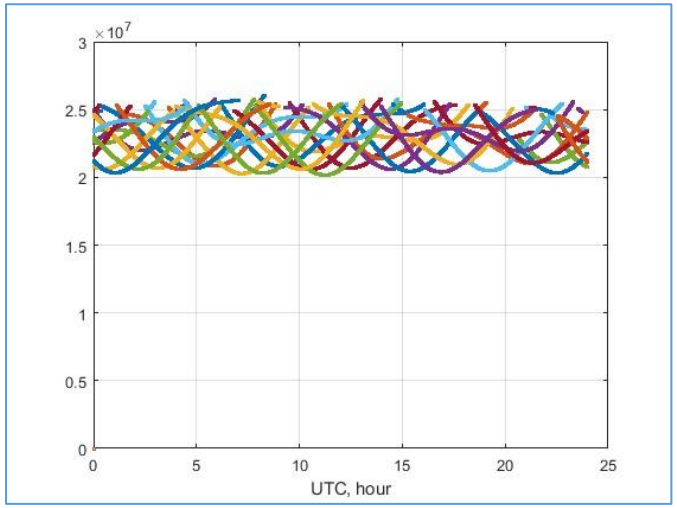
Explore software that can be used for processing data from low-cost GNSS receivers to compute TEC, S4 and other space weather-related parameters.

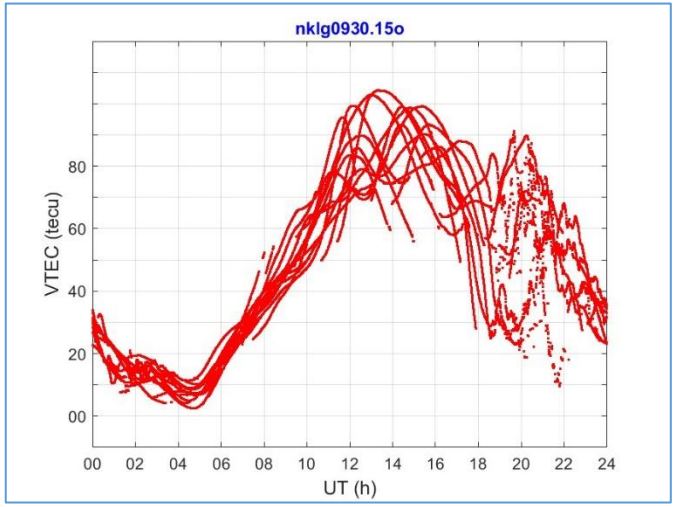
- FLEURY
  - Matlab source code available
- K-TEC
  - Matlab Source code available
- NeQuick
  - Software is available at:
  - https://www.itu.int/rec/R-REC-P.531-14-201908-I/en

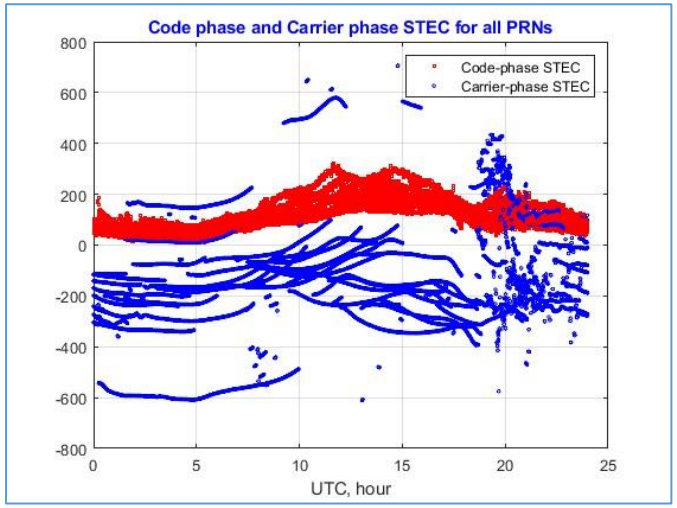
Matlab source files to compute TEC parameters are provided by Rolland Fleury
These outputs are from sample data provided by Fleury
We will modify the software to process data from low-cost GNSS receivers
K-TEC: From KMITL, Thailand

Output of TEC computation from Matlab based software: FLEURY



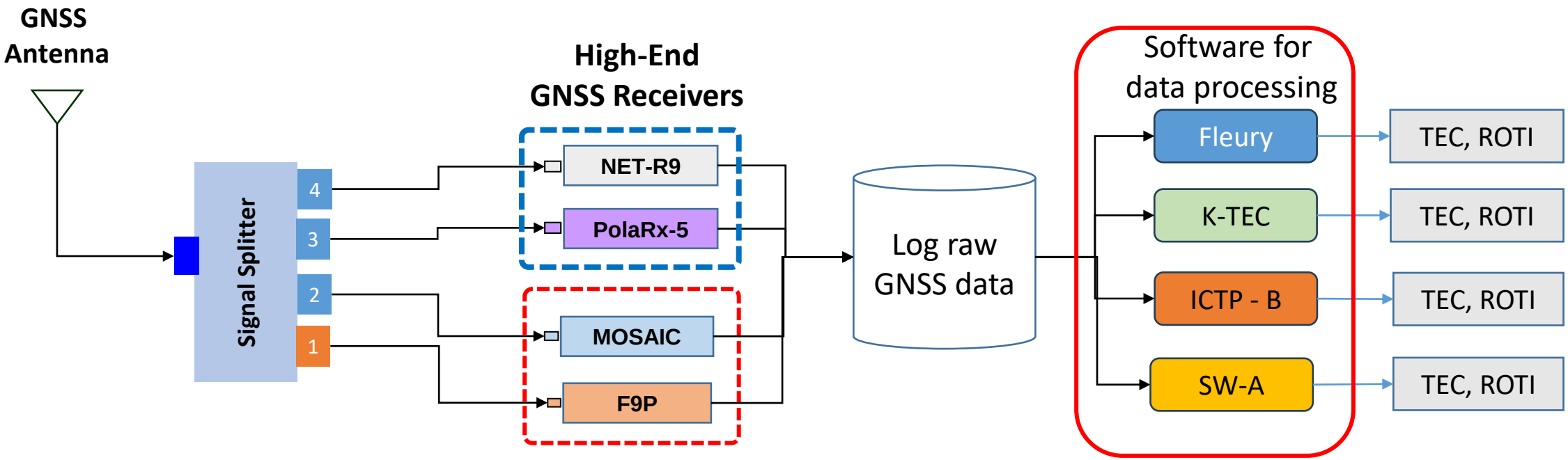






Comparison of
High-End vs. Low-Cost GNSS Receiver for TEC/ROTI

Data Observation Method



Items	Values
Approximate position: PolarRx5	[Lat (°), Lon (°), Height (m)] [35.903, 139.939, 89.159]

Fleury: Software by Robert Fleury
K-TEC: Software by KMITL, Thailand
ICTP-B: Software by B. Nava, ICTP

KMITL: King Mongkut Institute of Technology, Ladkrabang, Thailand
ICTP: International Center for Theoretical Physics, Italy

GNSS Observation Data (K-TEC)

- RTKCONV (demo5, b34g) is used to convert proprietary data into RINEX 3.04 format
- The OBS data files are read by readrinex304 (**mexw64 file**)

Convert proprietary data into RINEX 3.04 data format

Trimble T02 → RINEX 3.04
Septentrio SBF → RINEX 3.04
U-Blox UBX → RINEX 3.04

Items	Values
Observed date	June 18, 2023
Height (Iono-pierce point)	350 km
Elevation mask	30°
ROTI window size	5 min

Items	Observation Data			
GNSS Receivers → Satellites ↓	Net-R9	PolarRx5	MOSAIC	U-box F9P
GPS (**G**)	**C1C** L1C S1C **C2X** L2X S2X C5X L5X S5X	**C1C** L1C D1C S1C **C2W** L2W D2W S2W C5Q L5Q D5Q S5Q	**C1C** L1C D1C S1C **C2W** L2W D2W S2W C5Q L5Q D5Q S5Q	**C1C** L1C D1C S1C **C2X** L2X D2X S2X
GLONAS (**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 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	C1C L1C D1C S1C 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 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 C5I L5I D5I S5I	C1C L1C D1C S1C
BeiDou (**C**)	No SW License to log data	C2I L2I D2I S2I C1P L1P D1P S1P C5P L5P D5P S5P	C2I L2I D2I S2I C7I L7I D7I S7I C5P L5P D5P S5P	C2I L2I D2I S2I C7I L7I D7I S7I

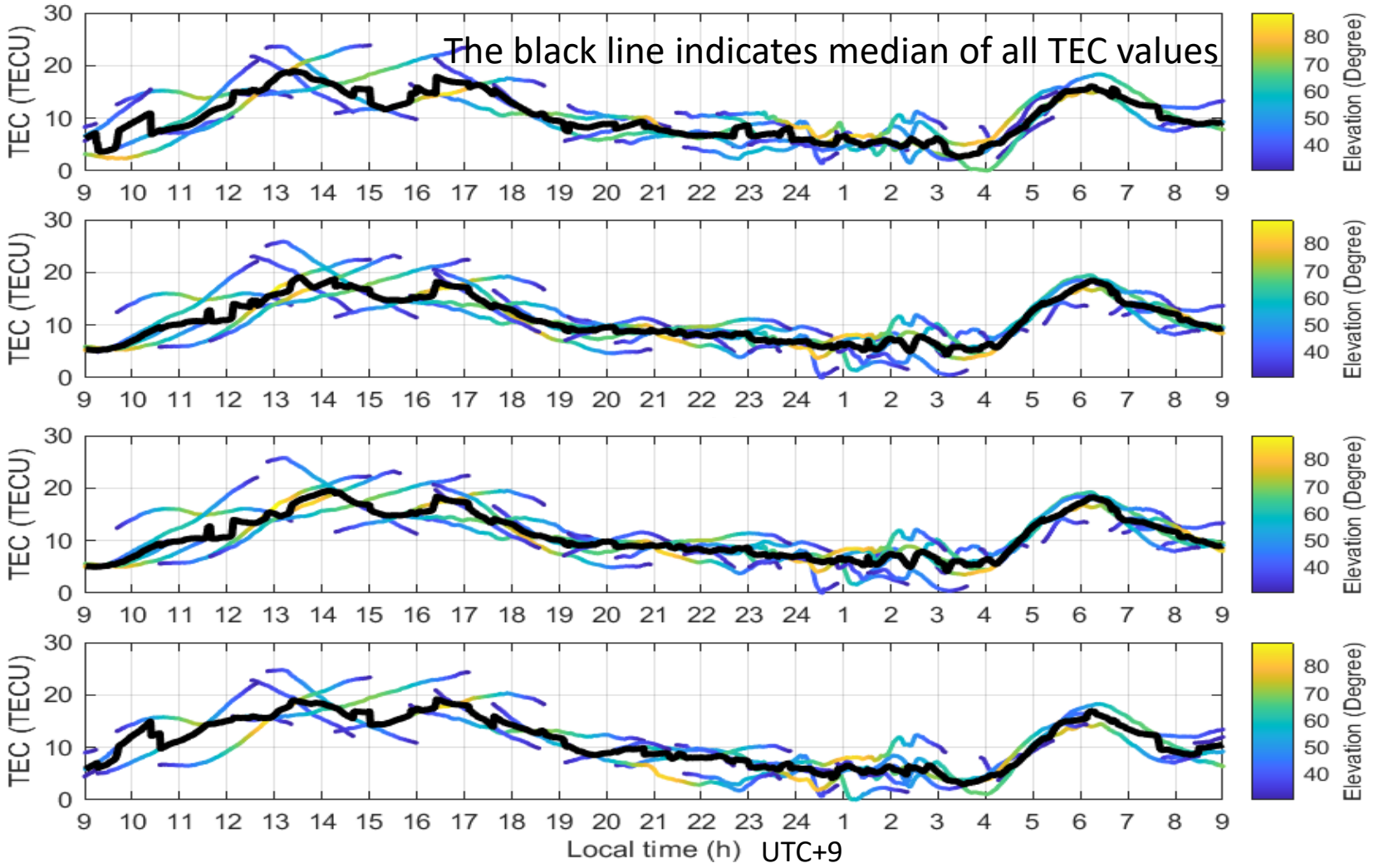
VTEC Results (K-TEC)

Net-R9 (C1C-C2X)

PolarRx5 (C1C-C2W)

MOSAIC (C1C-C2W)

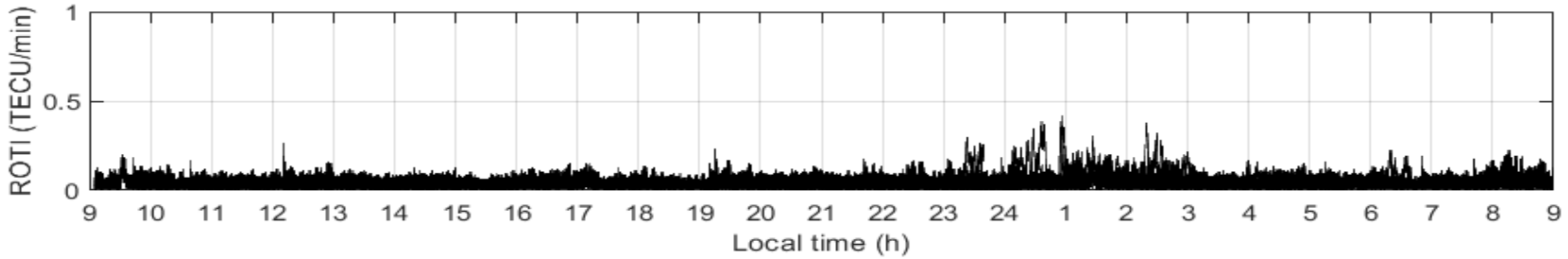
U-box F9P (C1C-C2X)



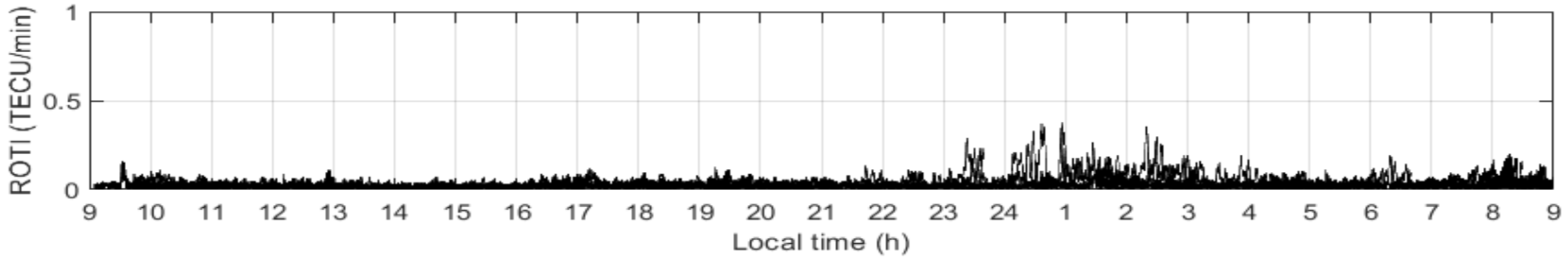
Since the same antenna is used, the VTEC from all receivers has similar trends and levels.

ROTI Results (K-TEC)

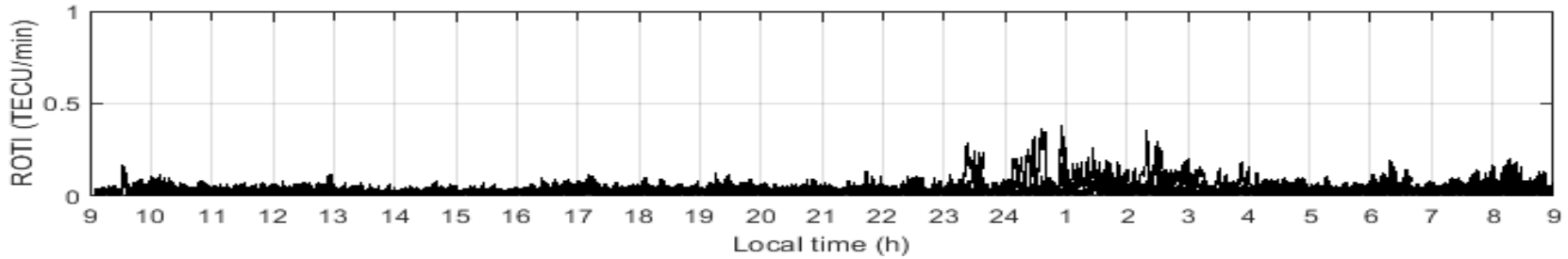
Net-R9
(C1C-C2X)



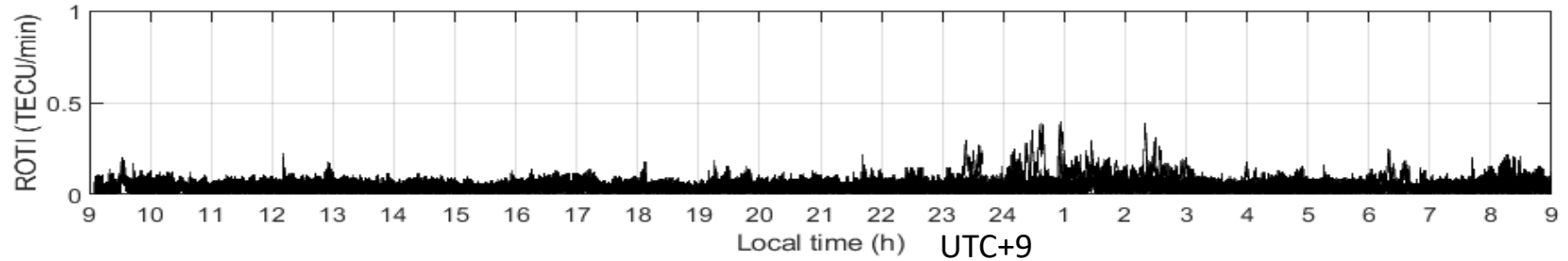
PolarRx5
(C1C-C2W)



MOSAIC
(C1C-C2W)

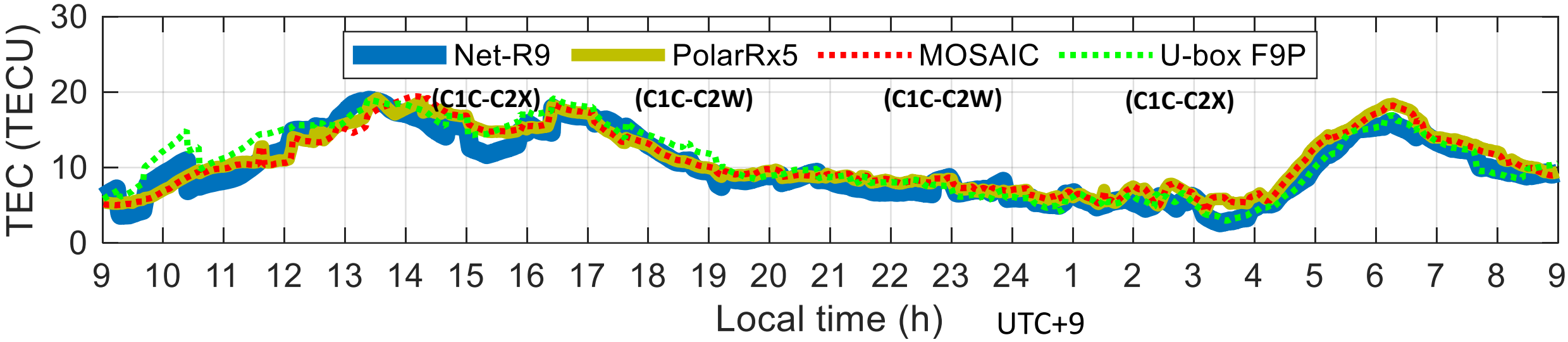


U-box F9P
(C1C-C2X)



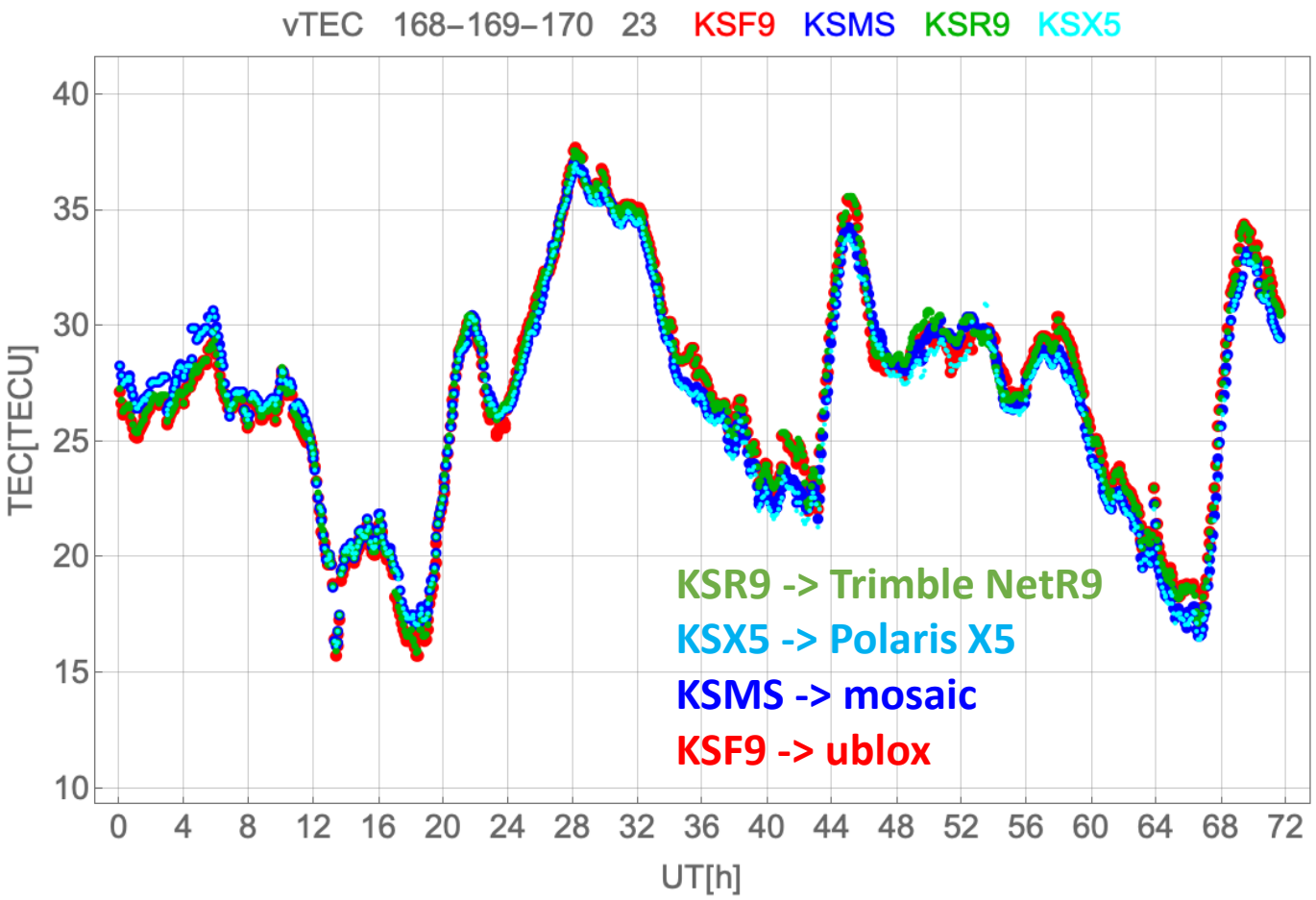
UTC+9

Comparison of VTEC Results (K-TEC)



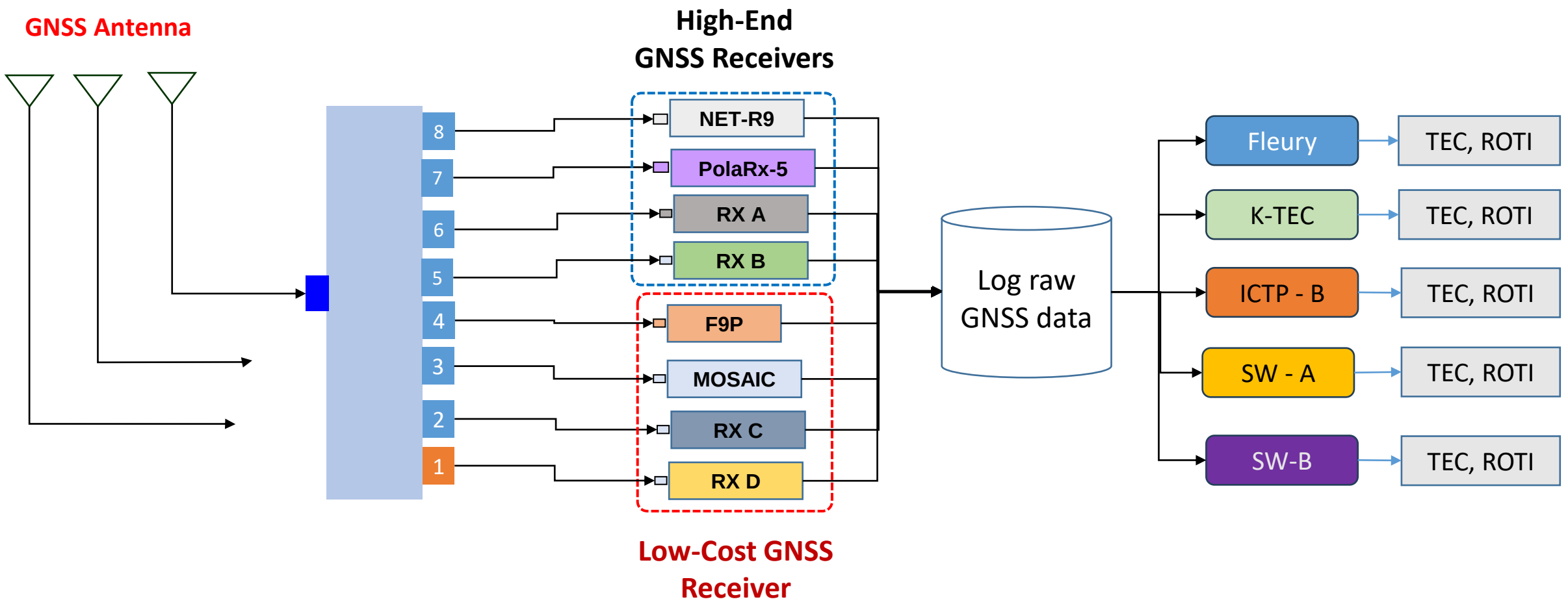
- **The low-cost receiver VTEC values have similar results to the high-end receiver VTEC values.**
- **MOSAIC receiver VTEC values are equivalent to PolaRx5 receiver VTEC values.**

Comparison of VTEC Results: Computed by ICTP-B (Bruno Nava)



Future Works:

- (a) Test more receiver types
- (b) Test more antenna types
- (c) Compute using different software



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 using low-cost receivers
  - TEC preliminary results are satisfactory. Requires further studies on computation
- Data formats and processing algorithms shall be standardized for uniform results
- Need to inform and request receiver manufacturers 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
- Necessary to have close collaboration between the GNSS community and the Space Weather Community
  - We are planning to install multiple low-cost GNSS receivers in Asian countries to explore the possibilities of space weather applications
  - We need your help!