Low-cost instruments for SW applications

A. Kashcheyev

Physics Department, University of New Brunswick, Canada

Outline

- Motivation
- GNSS receivers
  - Piksi
  - Tersus
  - U-BLOX F9P
- Ionosonde
  - Ionograms
  - Polarization measurements
  - Oblique sounding
- Conclusions

Market evolution

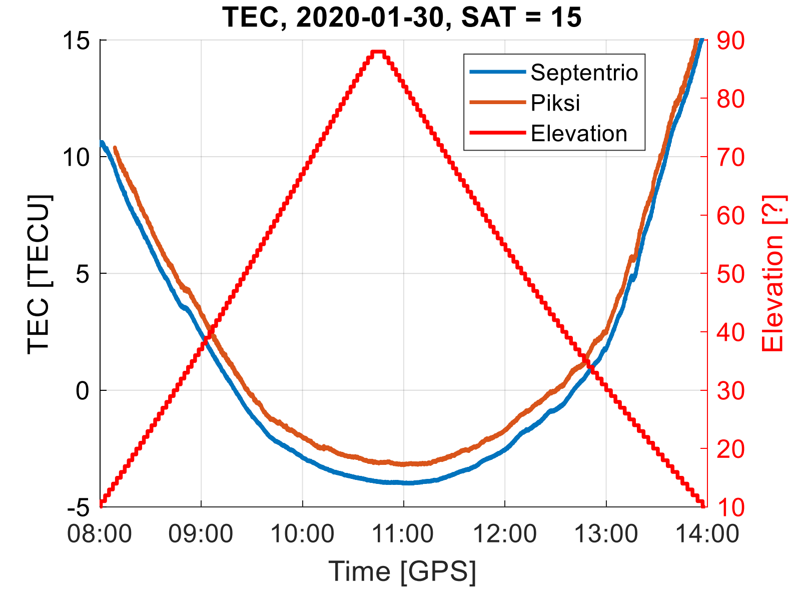
>10k $

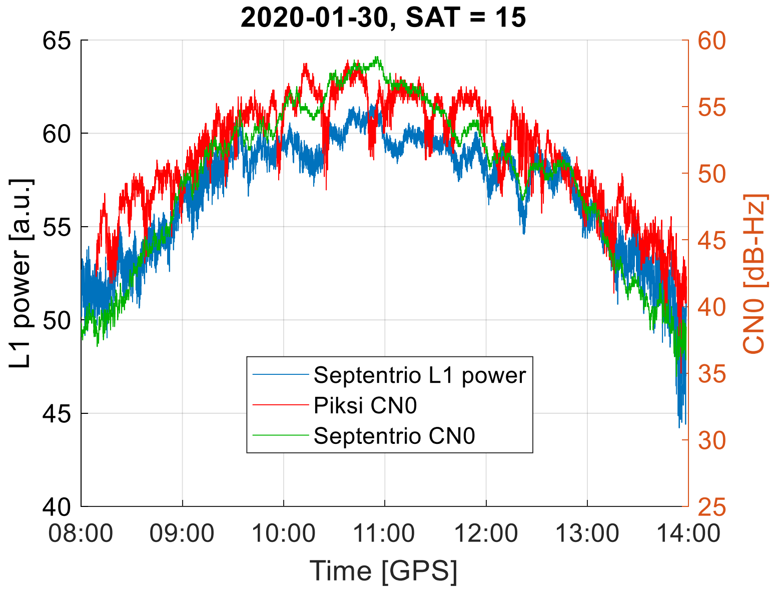
<= 1k $

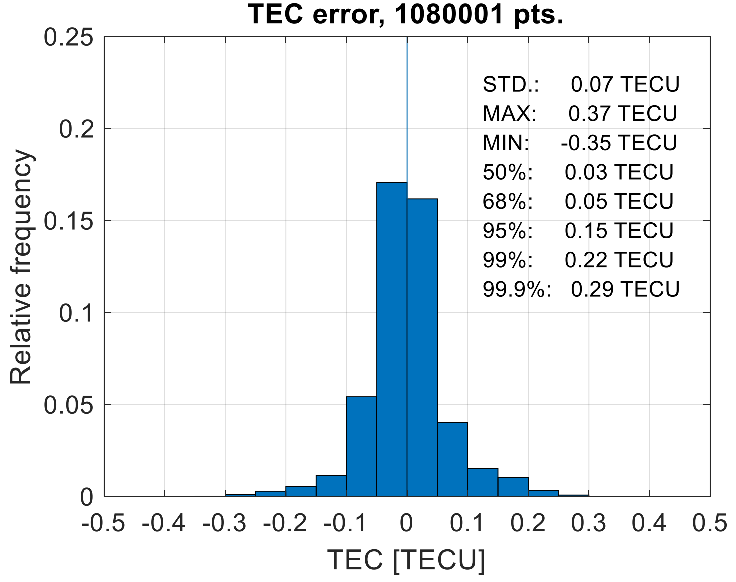
GNSS receivers under test

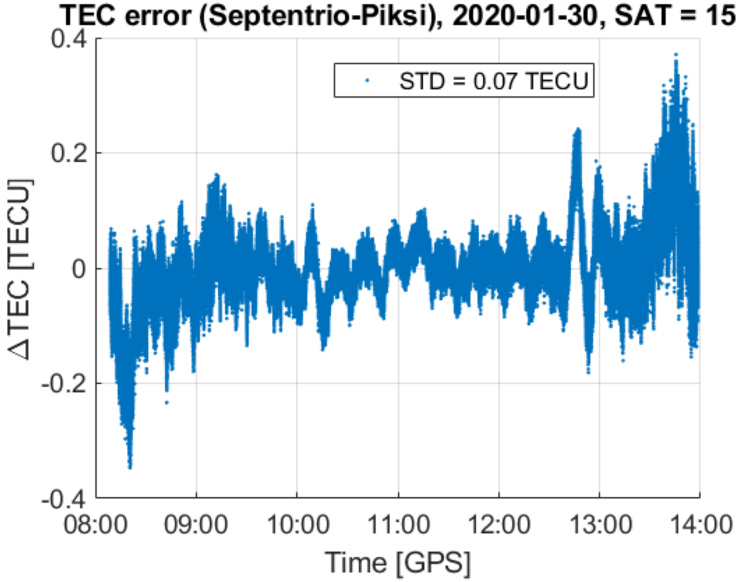
- Septentrio PolaRxS PRO, 50 Hz, >10k $
- Swift Piksi Multi, 20 Hz, 1k $
- Tersus BX-316D, 20 Hz, 1k $
- U-BLOX ZED-F9P, 20 Hz , 350$

Piksi (GPS-702-GG) vs **Septentrio** (PolaNt*_GG), on **UNB roof**

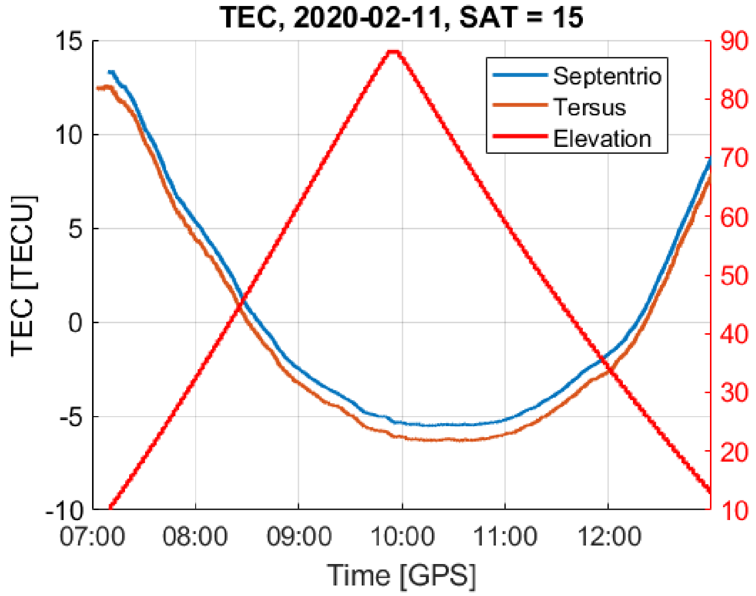


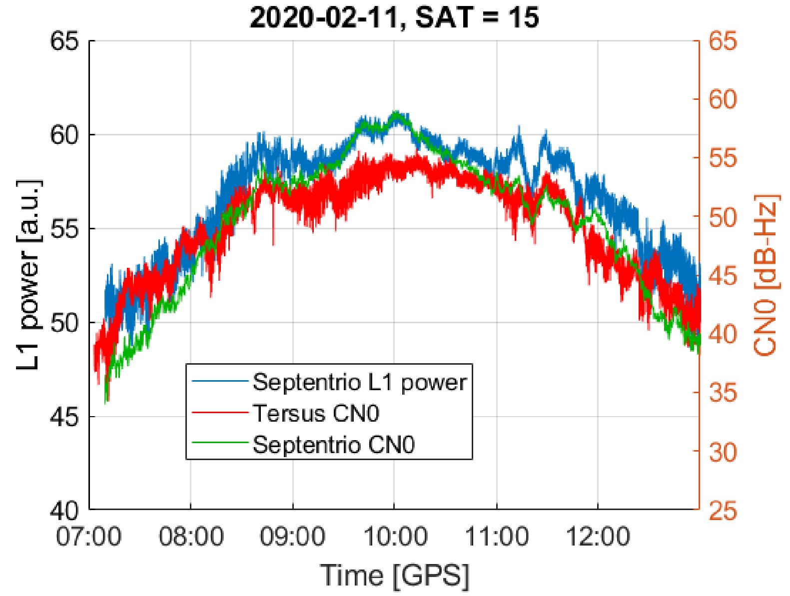


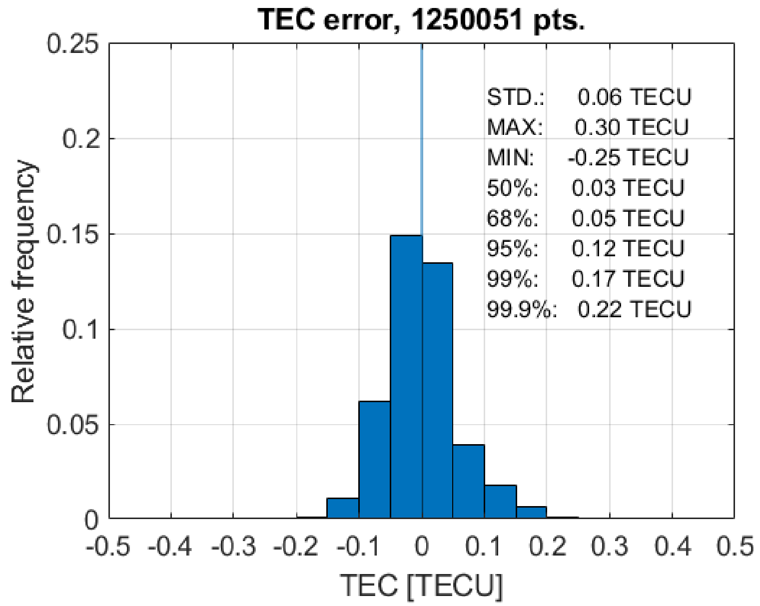


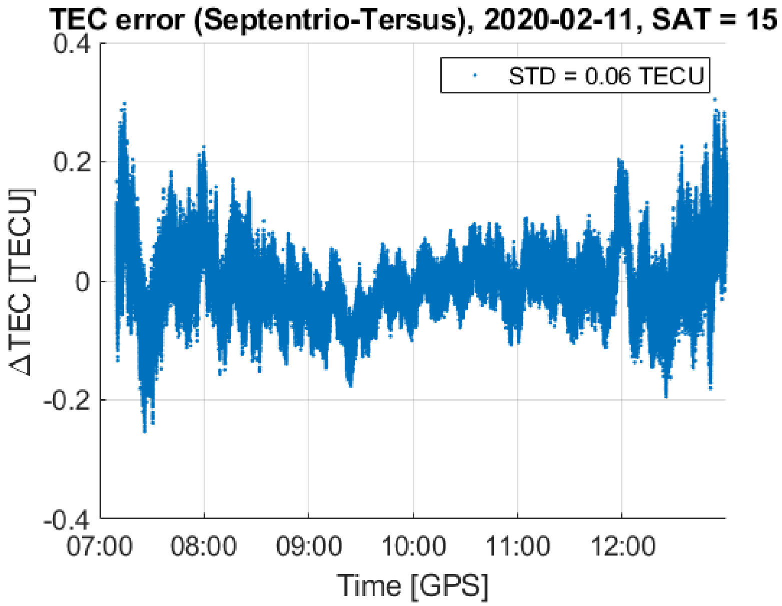


Tersus (GPS-702-GG) vs **Septentrio** (PolaNt*_GG), on **UNB roof**

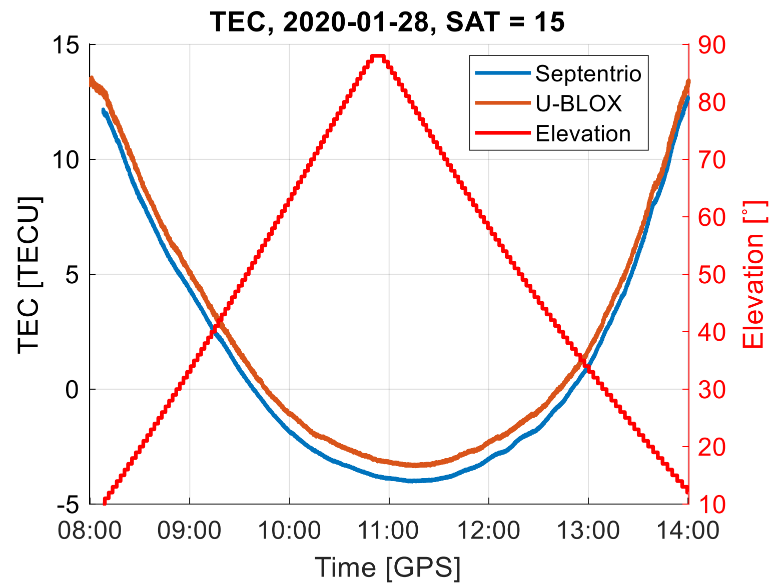


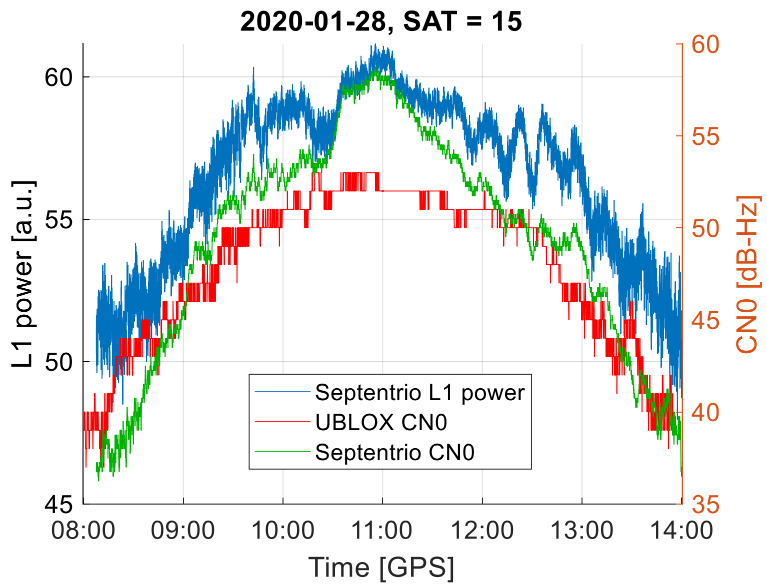


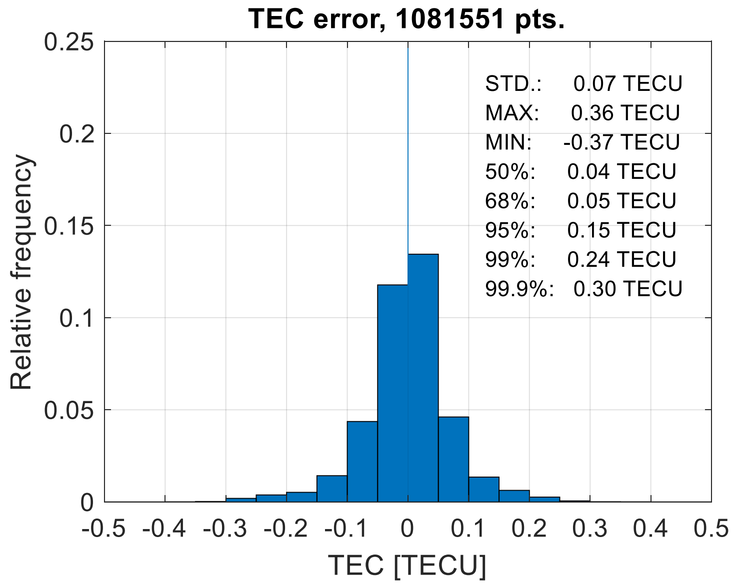


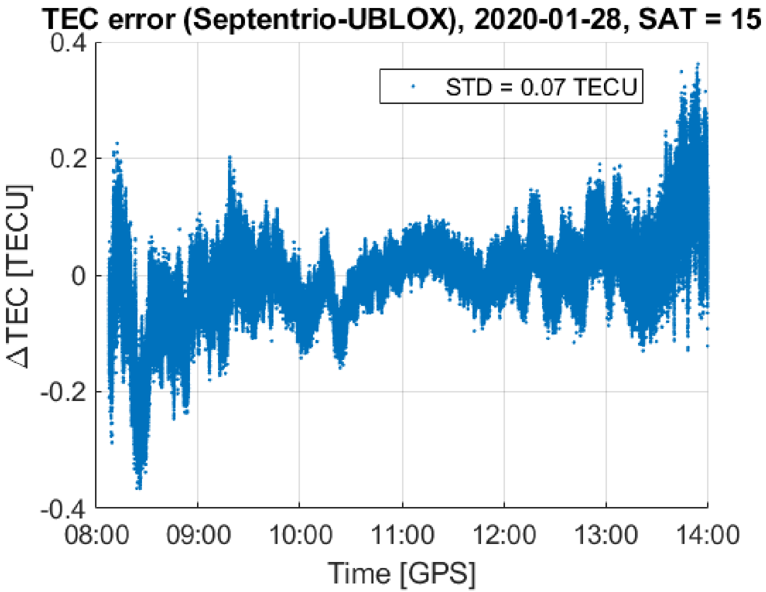


U-BLOX (GPS-702-GG) vs Septentrio (PolaNt*_GG), on UNB roof

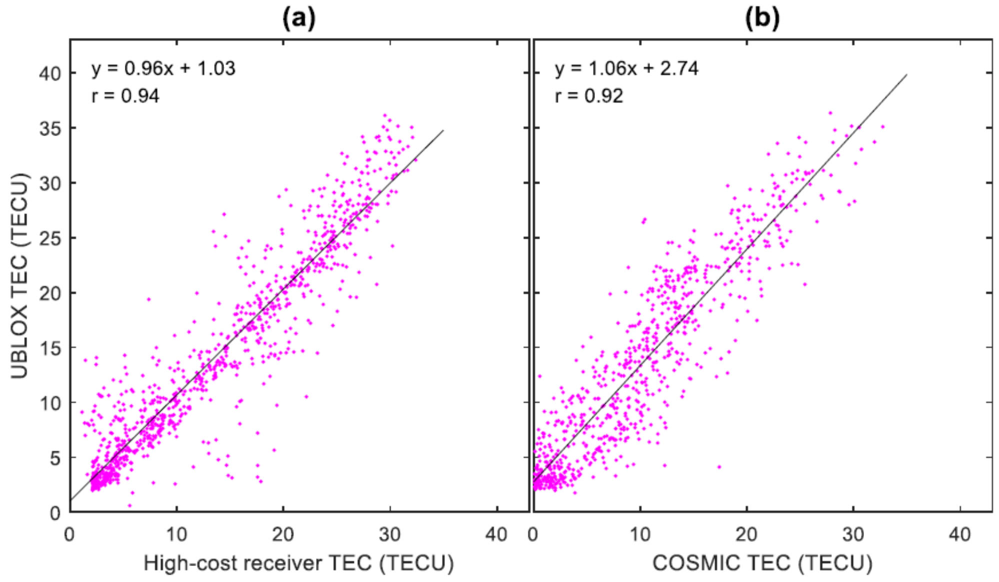


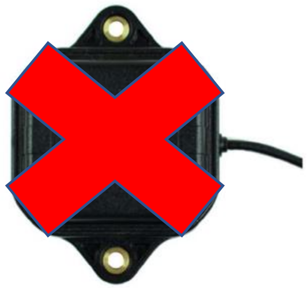


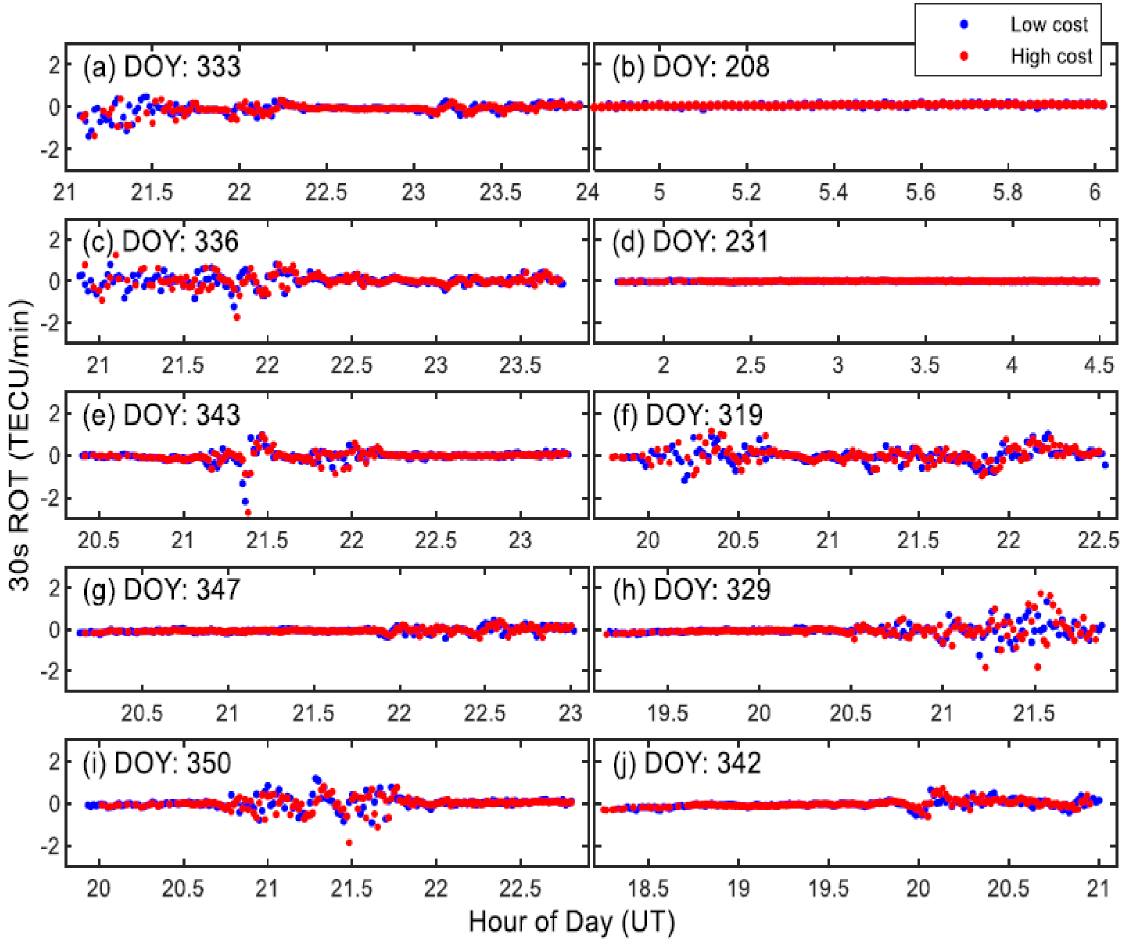




U-BLOX: TEC in low latitudes

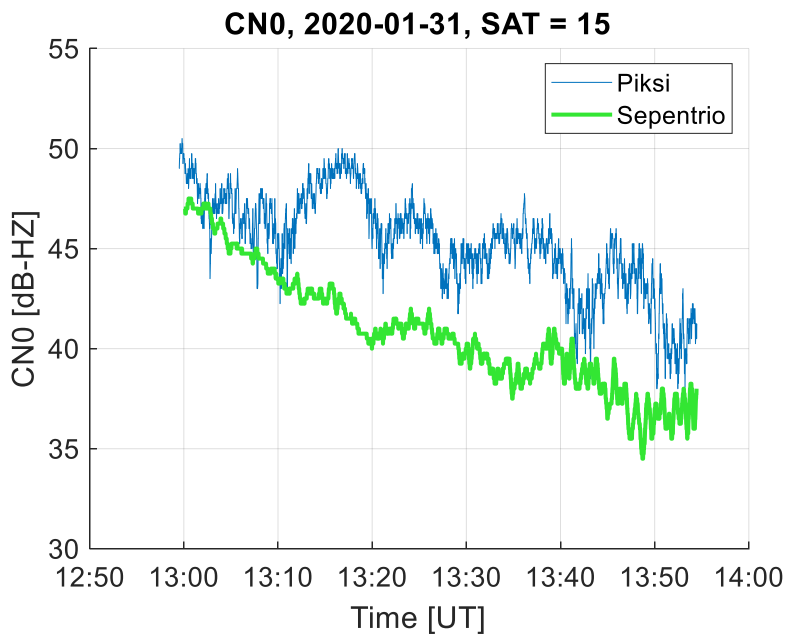


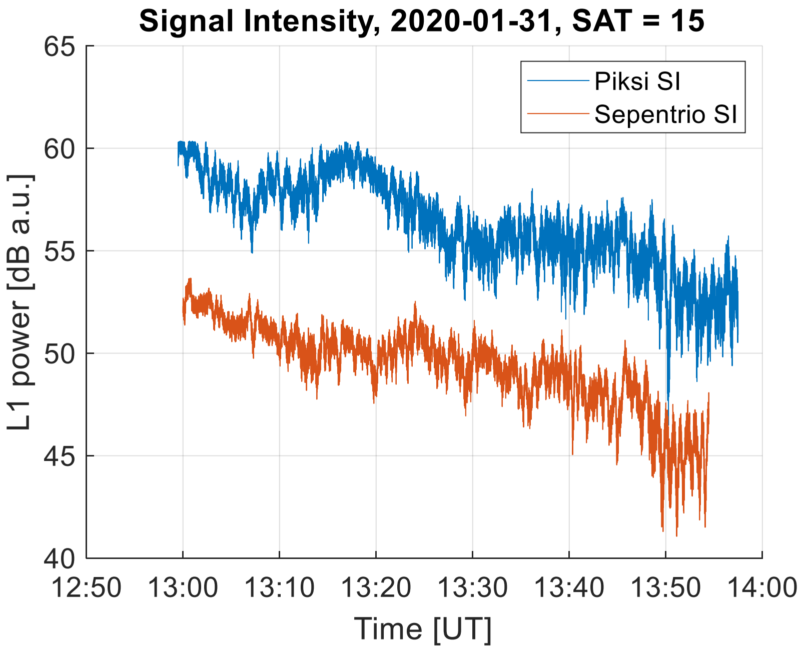


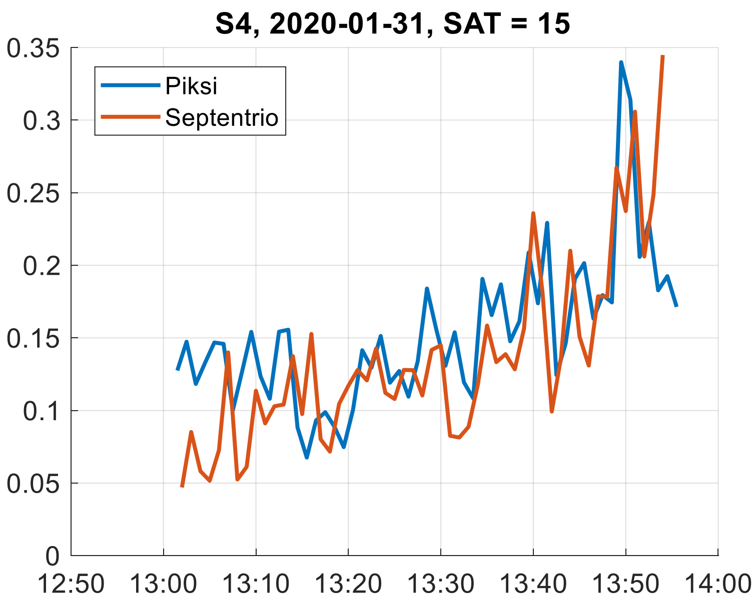


Okoh, D.; Obafaye, A.; Rabiu, B.; Seemala, G.; Kashcheyev, A.; Nava, B. New results of ionospheric total electron content measurements from a low-cost global navigation satellite system receiver and comparisons with other data sources. *Adv. Sp. Res.* **2021**, *68*, 3835–3845

Piksi (GPS-702-GG) vs **Septentrio** (PolaNt*_GG), on **UNB roof**





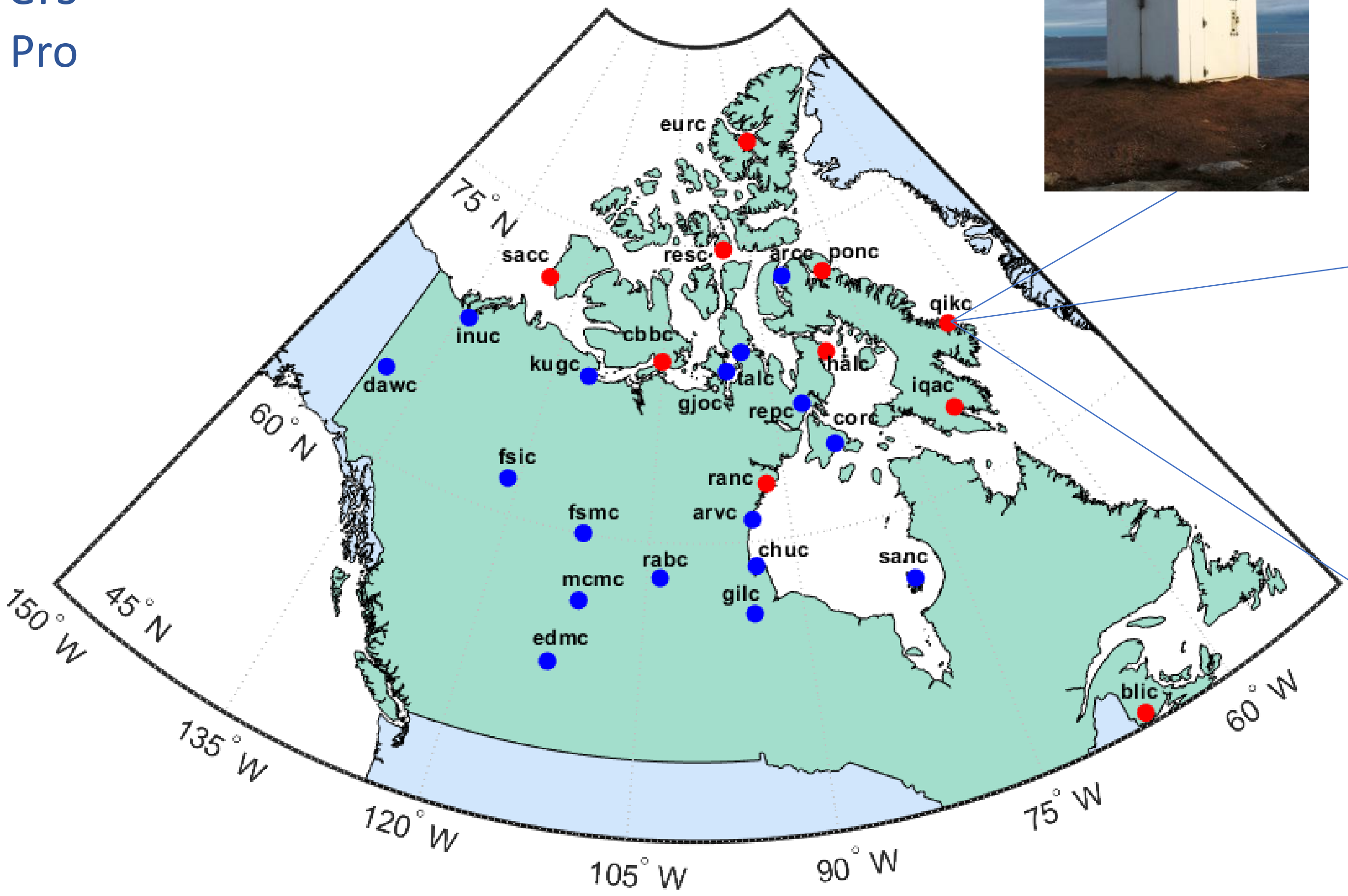


CHAIN (Canadian High Arctic Ionosphere Network)

http://chain.physics.unb.ca/chain/

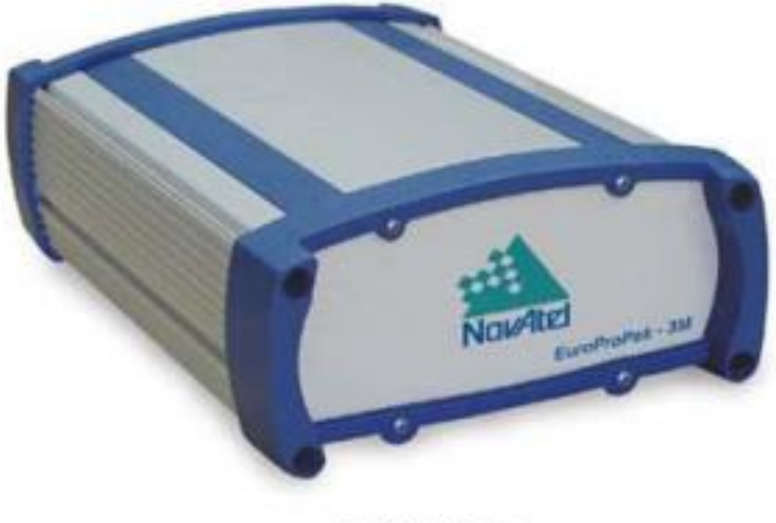
- 28 GNSS Ionospheric Scintillation and TEC Monitor (GISTM) receivers
  - 19 Septentrio PolaRxS Pro
  - 9 Novatel GSV4004B
- 10 ionosondes (CADI)

GSV4004B

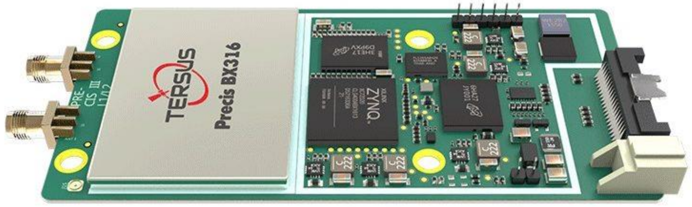


GNSS receivers in test

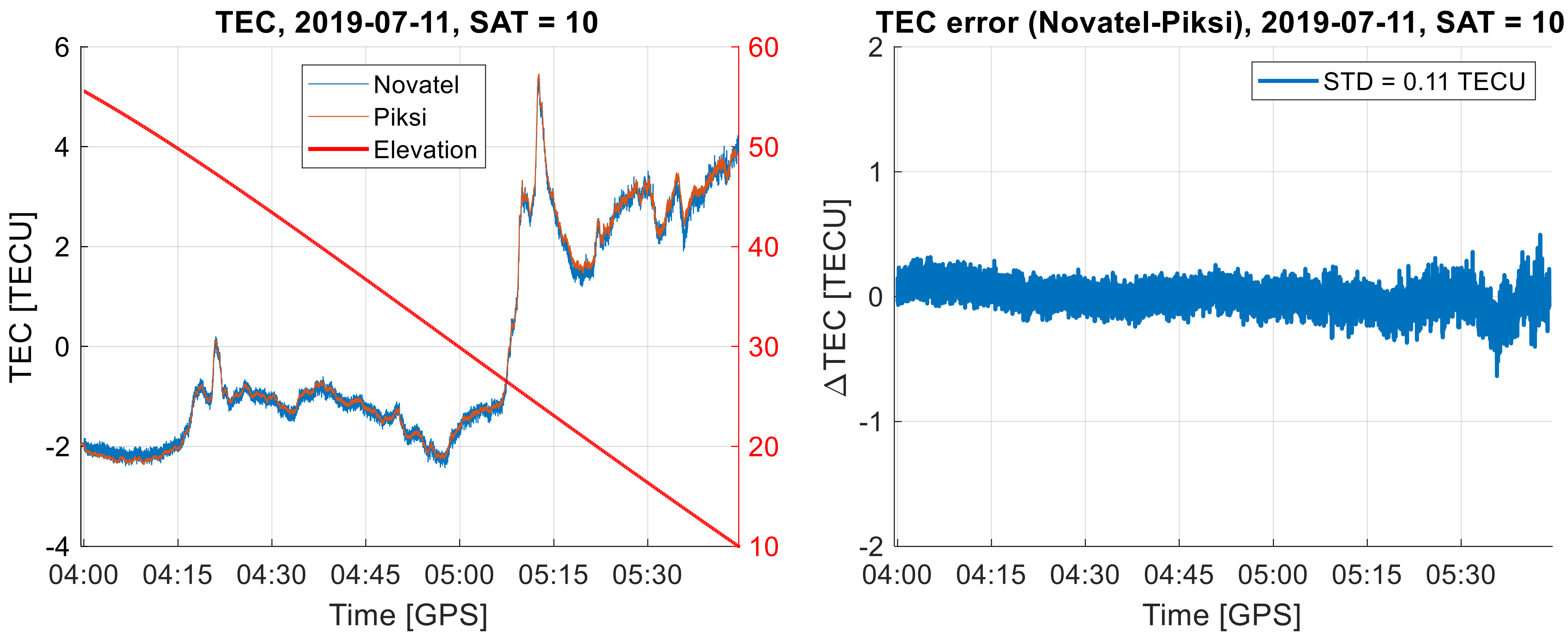
- Novatel GSV4004B (Ashtech choke ring antenna), L1 50Hz, L2(L2Y) 1Hz
- Tersus BX316D (Septentrio PolaNt antenna) L1 & L2(L2C/L2Y) 20Hz
- Piksi-Multi (Septentrio PolaNt antenna) L1 & L2(L2C) 20Hz



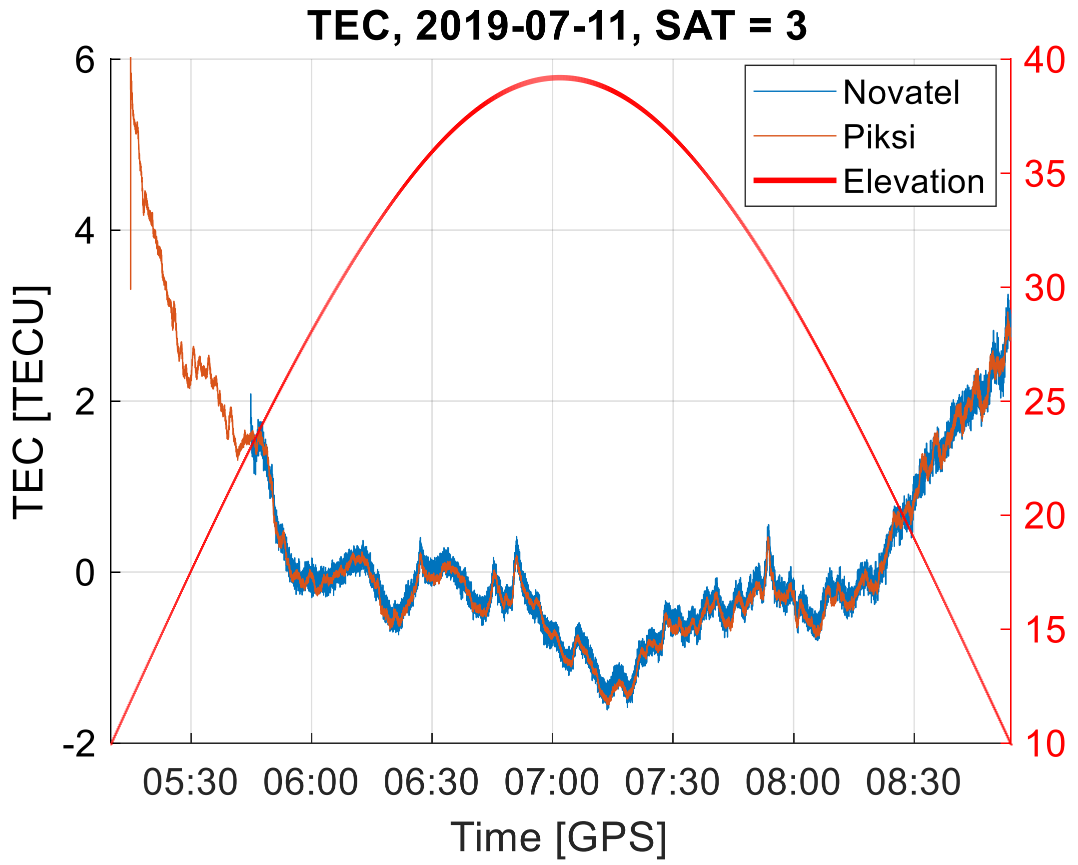
GSV4004B

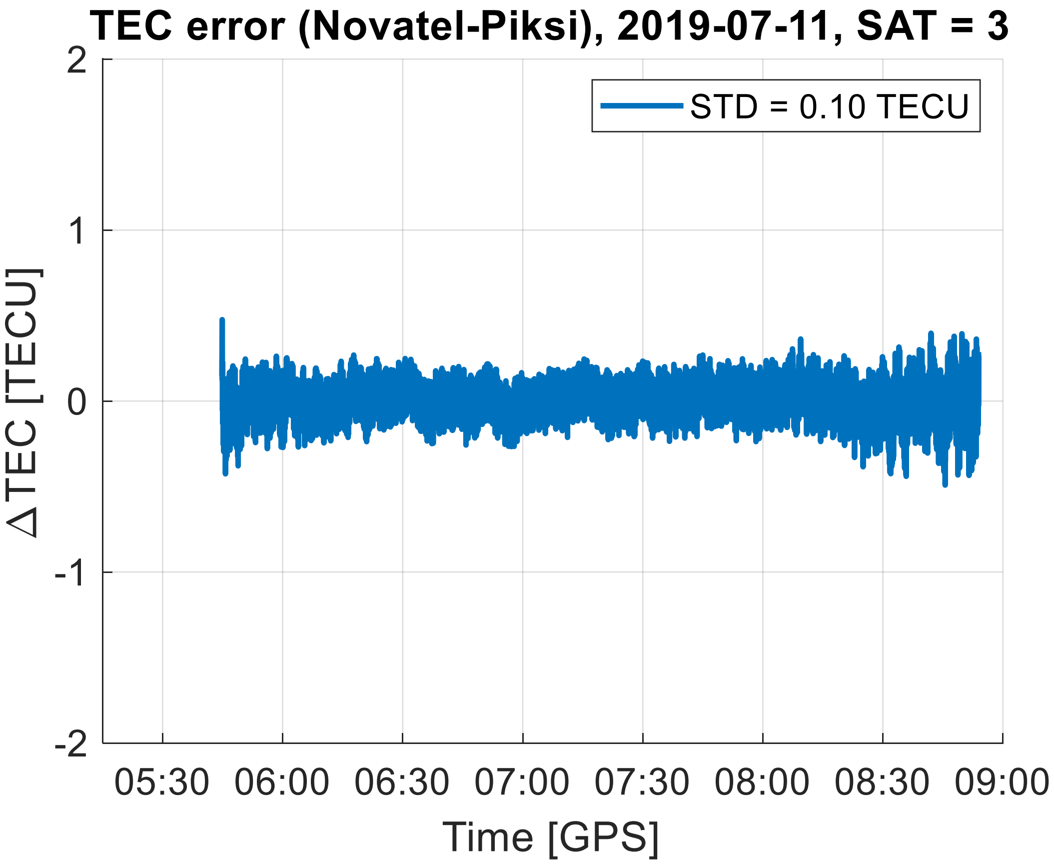


TEC, Piksi vs Novatel

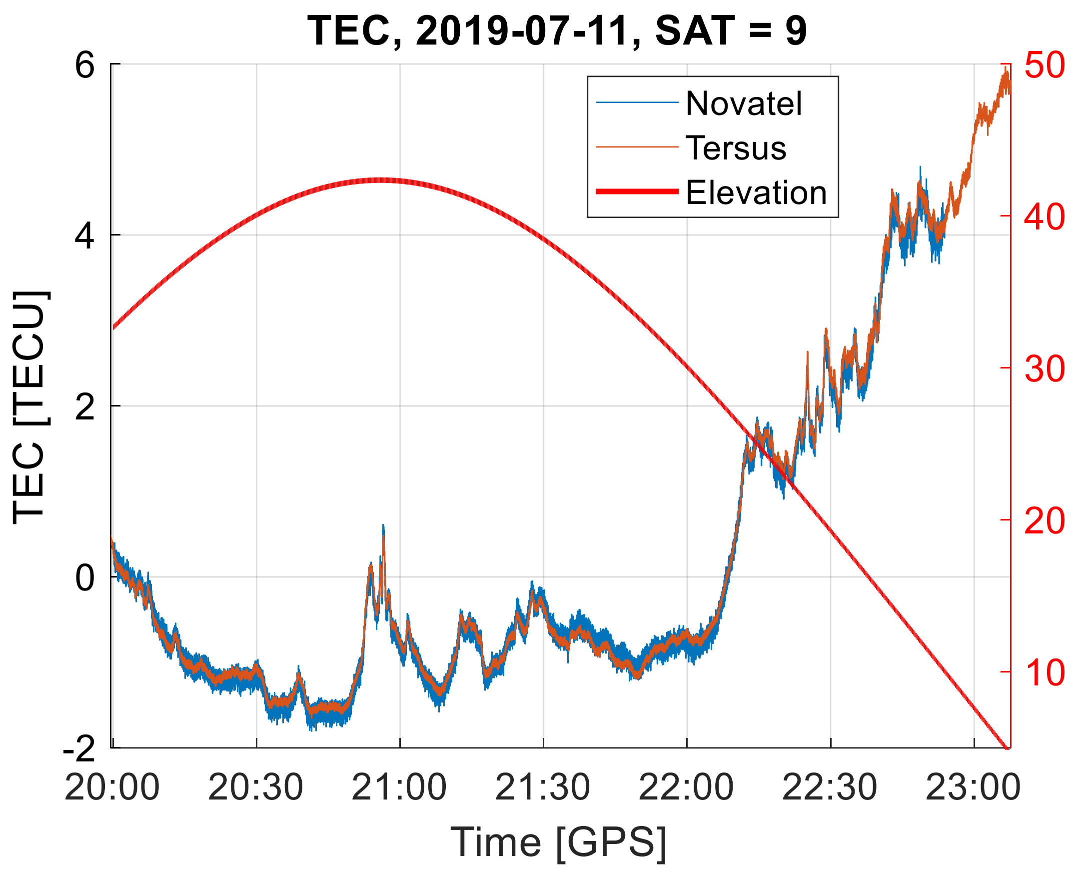


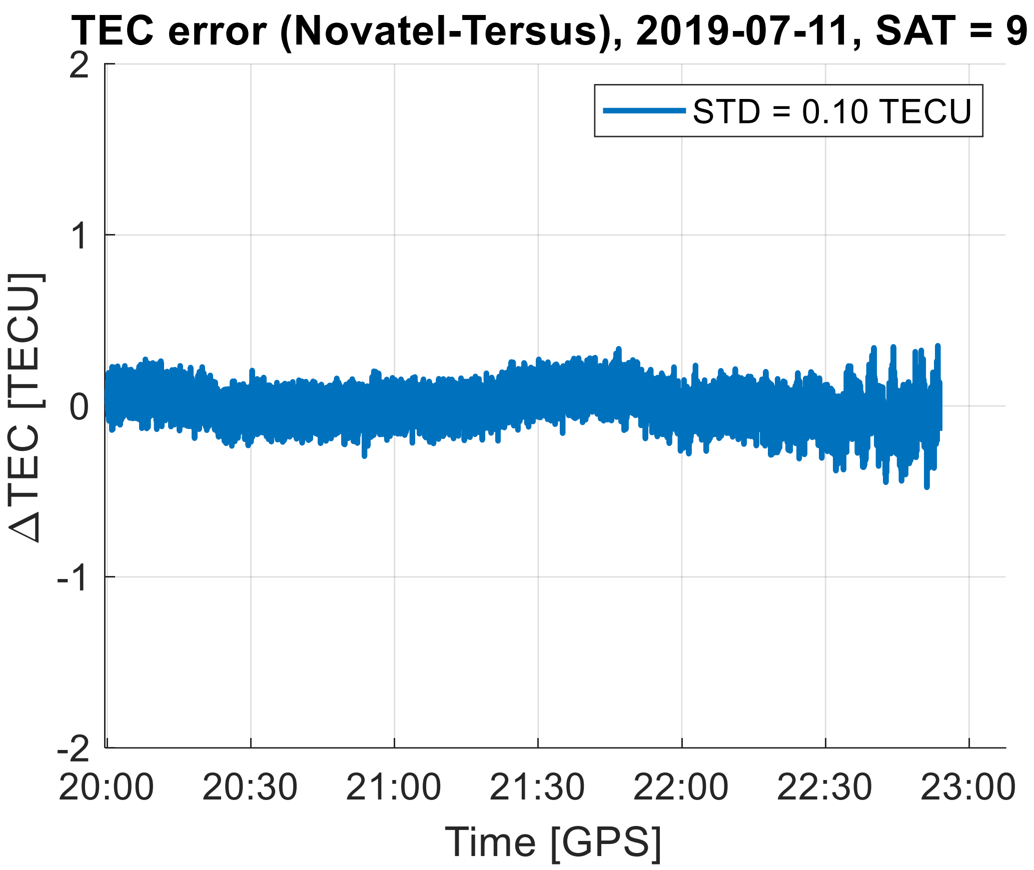
TEC, Piksi vs Novatel



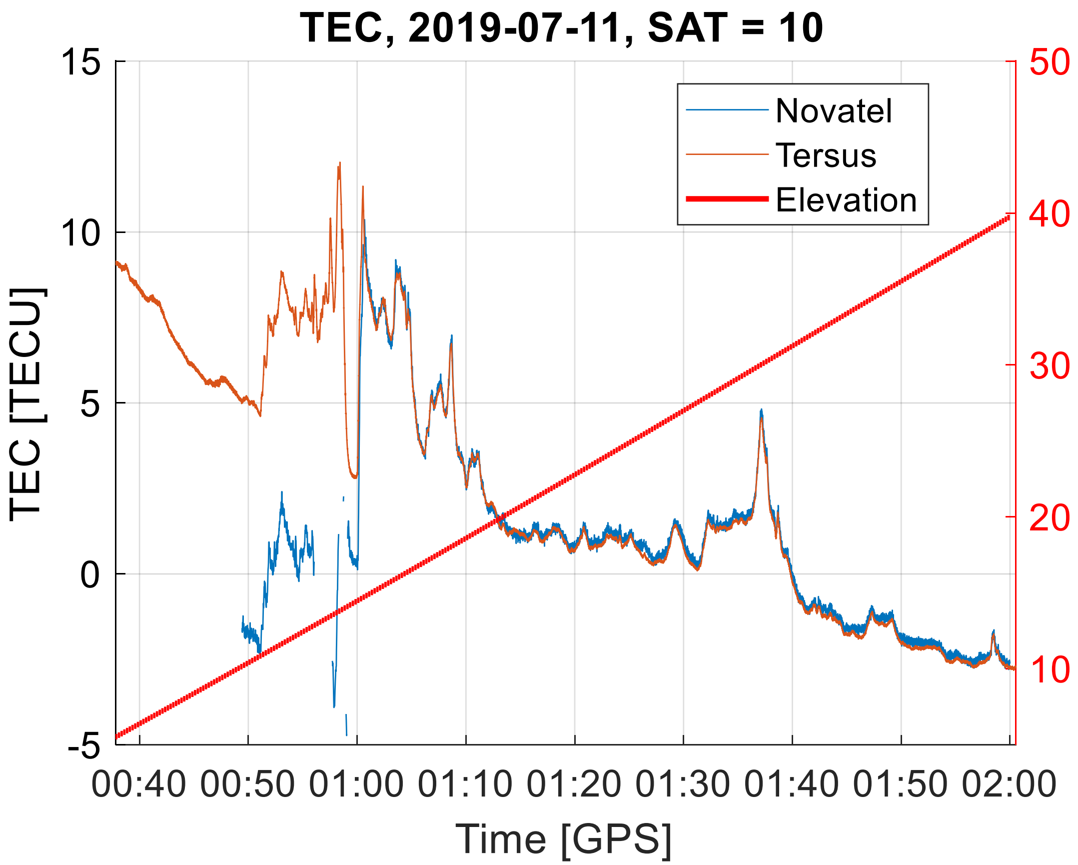


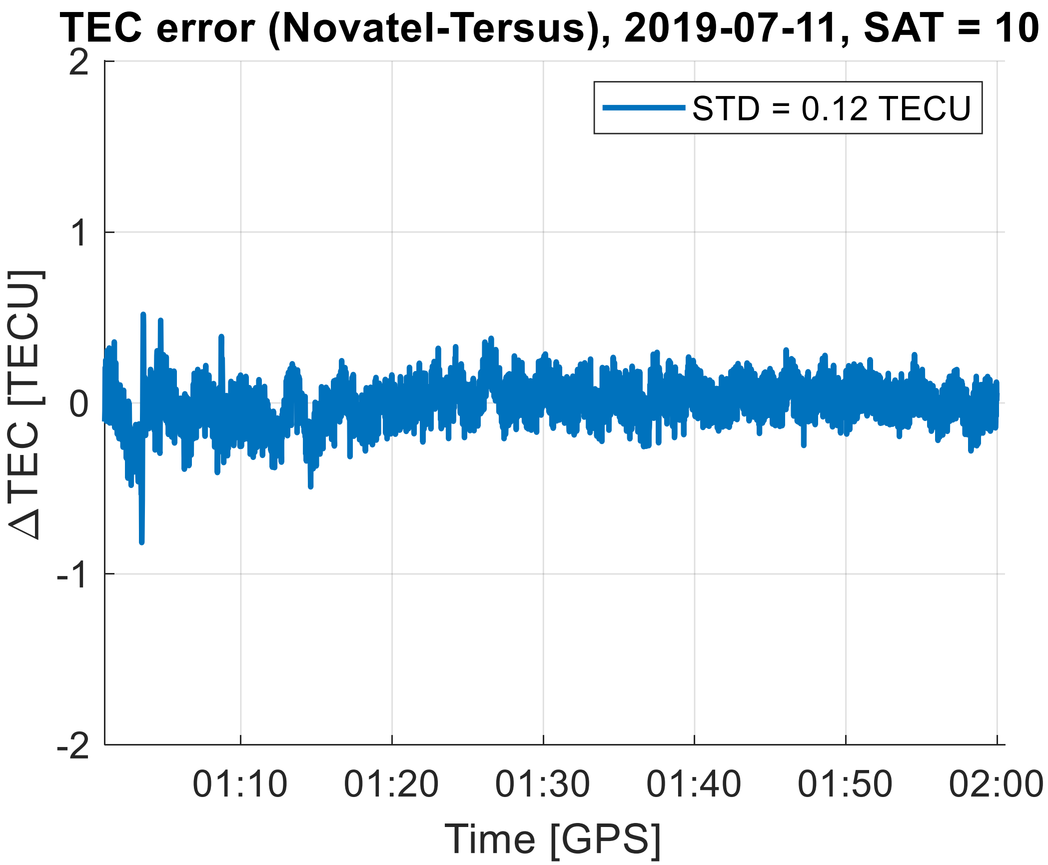
TEC, Tersus vs Novatel



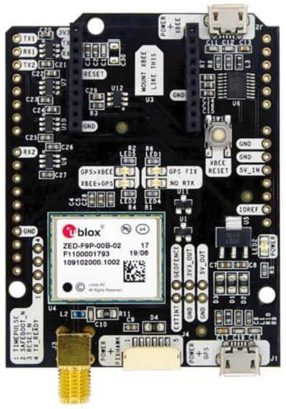


TEC, Tersus vs Novatel





Proposed setup



- ArduSimple U-BLOX F9P evaluation board - $235 USD

https://www.digikey.com/en/products/detail/ardusimple/AS-RTK2B-F9P-L1L2-NH-02/14309736

TOPGNSS®
Professional GNSS Wireless Solution Provider

- TOPGNSS AN-105L antenna - $65 USD

https://www.aliexpress.us/item/3256802908957760.html

- LMR-240 cable 15m - $80 USD

https://www.digikey.com/en/products/detail/amphenol-times-microwave-systems/LMR-240/9644146

- Raspberry Pi 4B, 4GB, 32 GB - ~$100 USD (pre-covid times)

any other single board computer with one USB port, Ethernet/WiFi and Linux/Windows OS will work

Existing installations

- High latitudes: Qikitarjuak, 67.6N

ftp://ftp.chain-project.net/gps/data/daily/yyyy/doy/qikr...gz

- Mid latitudes: Fredericton, 45.9N

ftp://ftp.chain-project.net/gps/data/daily/yyyy/doy/chic...gz

- Low latitudes: Lagos, 6.5N

Ionospheric sounders (ionosondes)

Digisonde

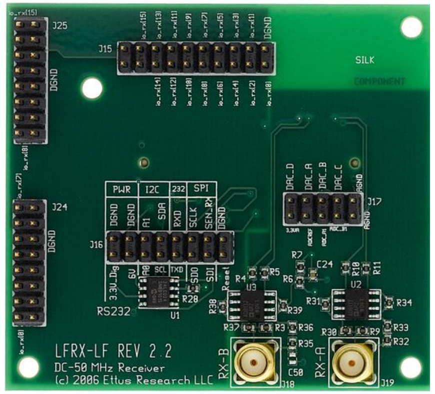
CADI

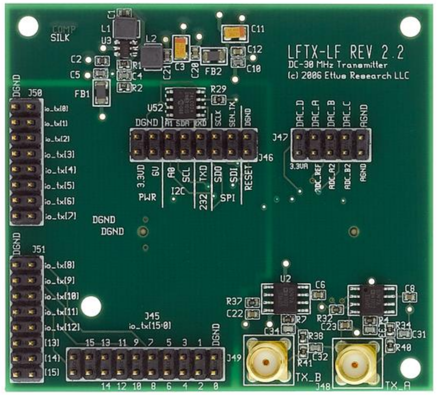
VIPIR

>50k $

Low-cost software defined radio: USRP N-200/210

- Fully software-defined radio (Spartan FPGA-based)
- Direct conversion receiver/transmitter (no hardware intermediate frequencies)
- Dual 100 MS/s, 14-bit ADC
- Dual 400 MS/s, 16-bit DAC
- Up to 50 MS/s Gigabit Ethernet Streaming
- UHD drivers (open source available via Github)
- Supports different daughterboards (in our case they are LFRX and LFTX, 0-30 MHz)
- Supports external reference oscillator and PPS signal input

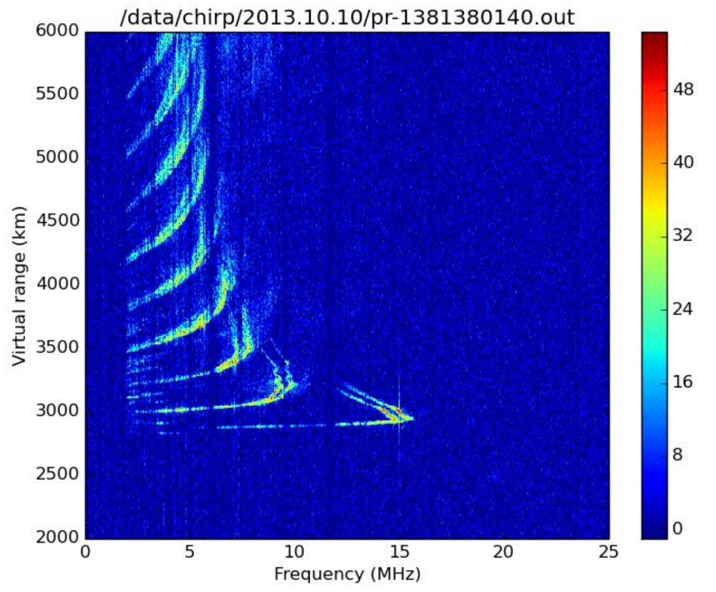


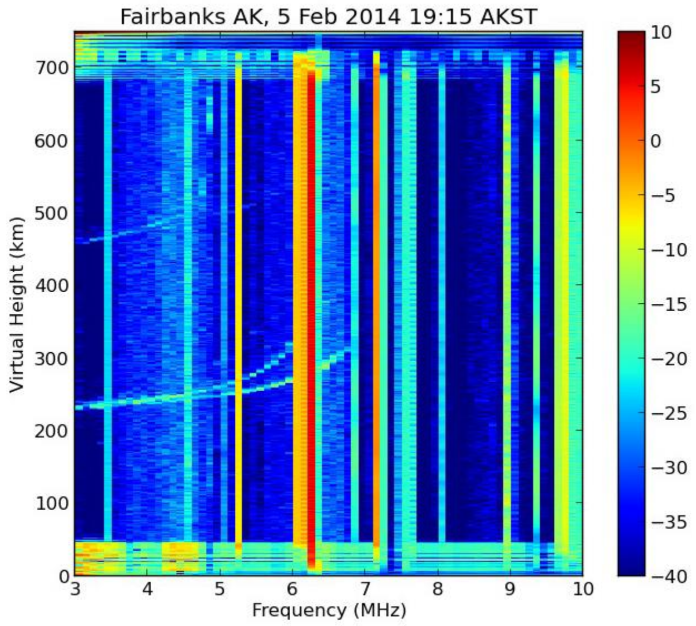


USRP-based experiments

- GNU Chirp sounder, Yuha Vierinen (https://www.sgo.fi/~j/gnu_chirp_sounder)
  - Software defined radio-based receiver for monitoring ionospheric sounders (ionosondes) and over-the-horizon radars that use linear frequency sweep FM-CW transmissions
  - Based on gnuradio and relies on Ettus research USRP2 and USRP N210 based digital receivers
  - The receiver can be used to receive the whole HF band (typically at 25 MHz bandwidth) simultaneously, and to receive multiple sounders simultaneously

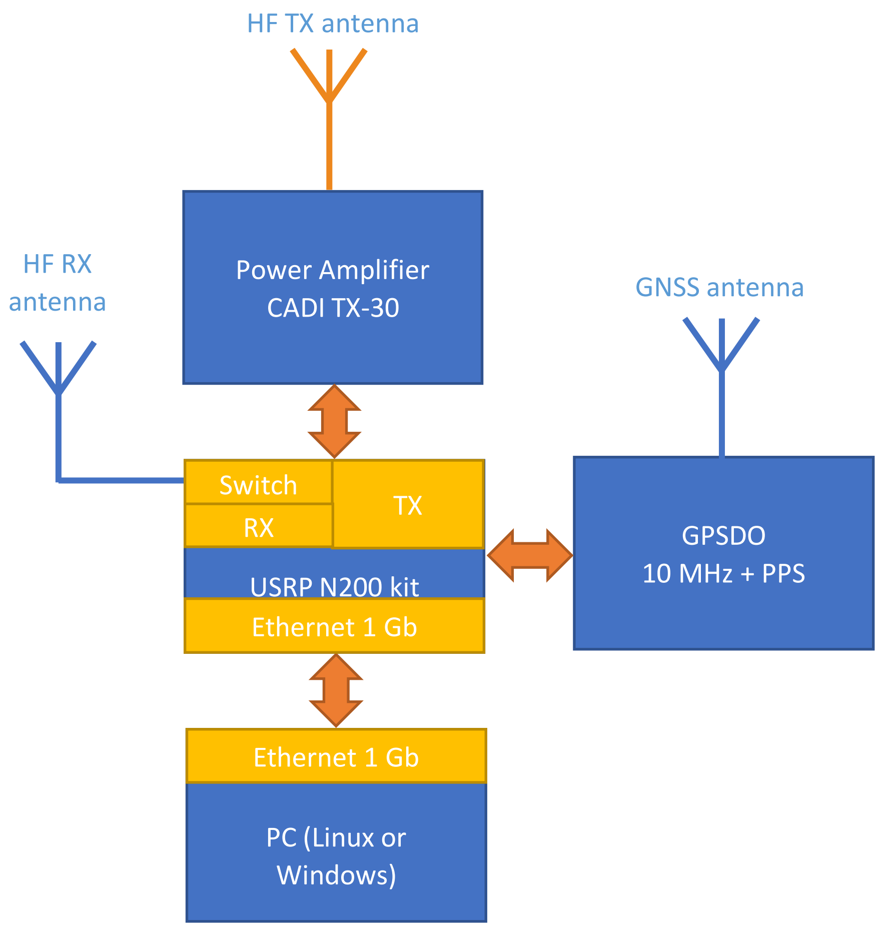
- Design of a flexible and low-power ionospheric sounder, Alex Morris, M.S. Thesis (https://scholarworks.alaska.edu/handle/11122/4535)
  - USRP-N200 based ionospheric sounder
  - Active magnetic loop antenna
  - Peak transmit power 10W
  - Barker code





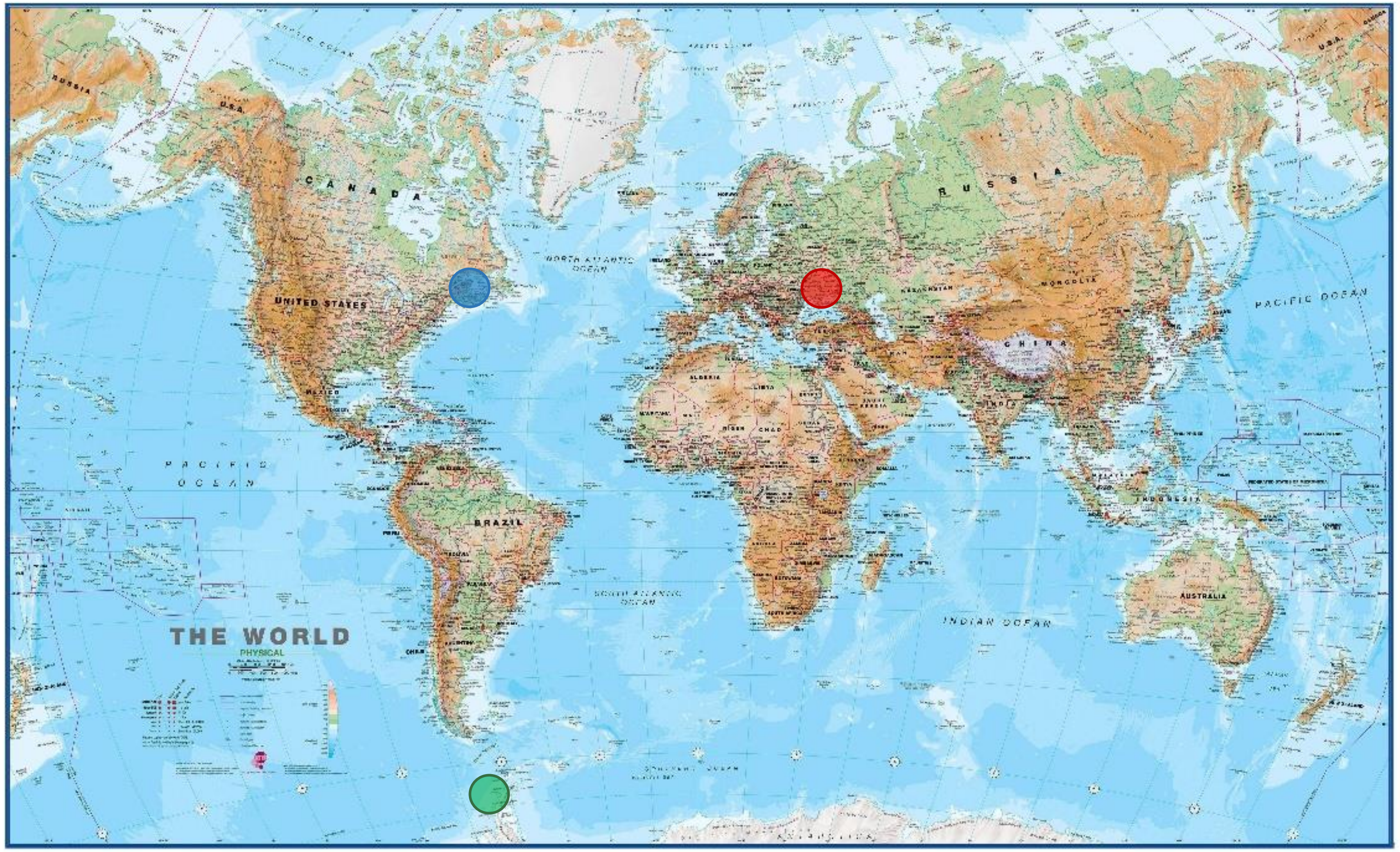
Low-cost sounder: block diagram

Vertical sounder



Credits: A. Koloskov

USRP-based ionospheric sounder, field tests

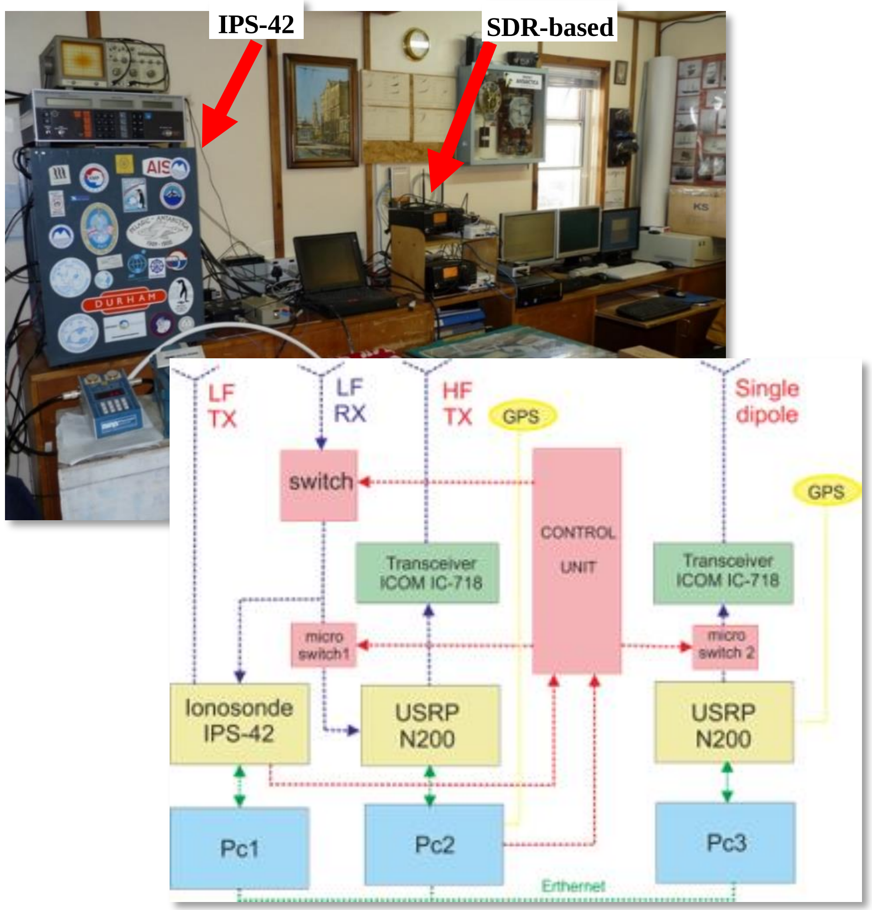


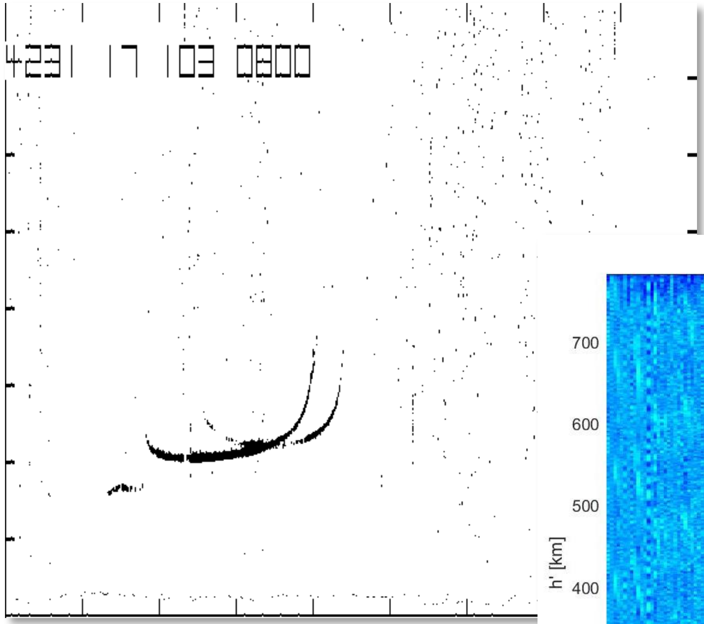
- Research Base “Ak Vernadksy”, Antarctica (Apr 2017)
- Kharkiv, Ukraine (Dec 2017)
- Blissville, Canada (Dec 2019)

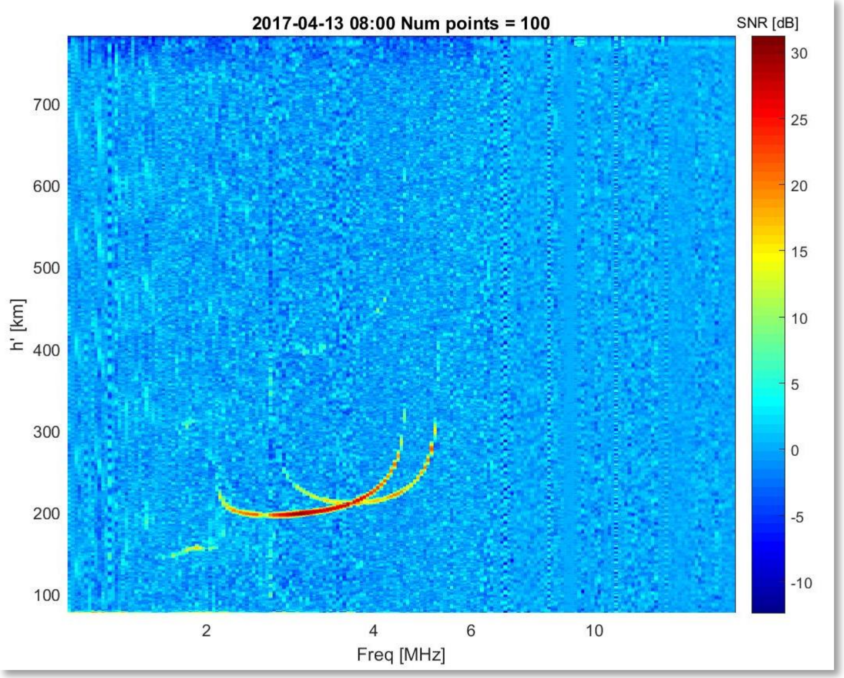
USRP-based ionospheric sounder, data comparison

Research base “Ak Vernadsky” IPS-42 vs SDR-based

3.5 kW vs 0.1 kW

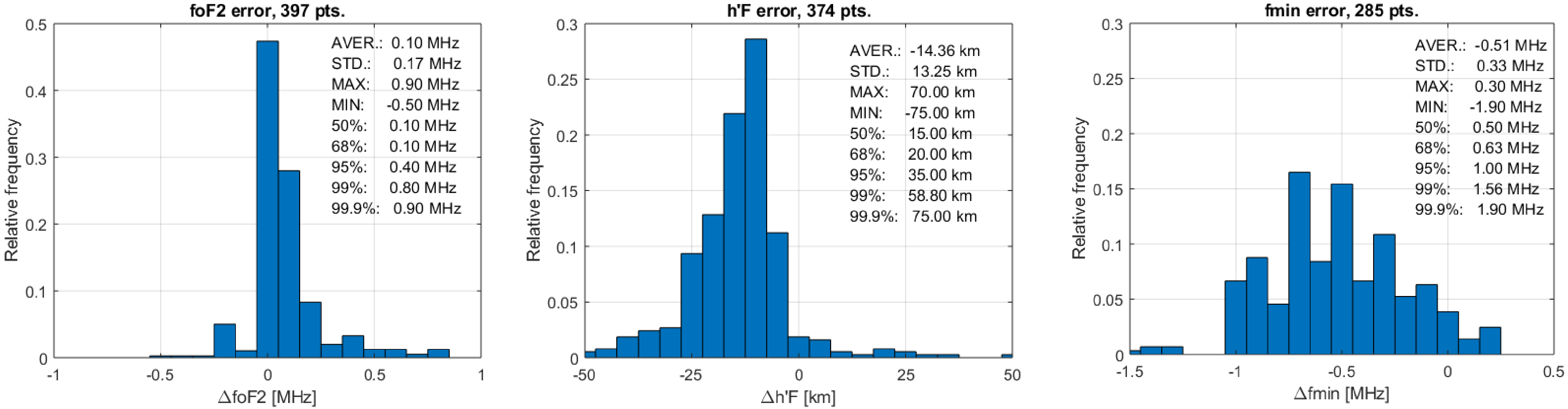






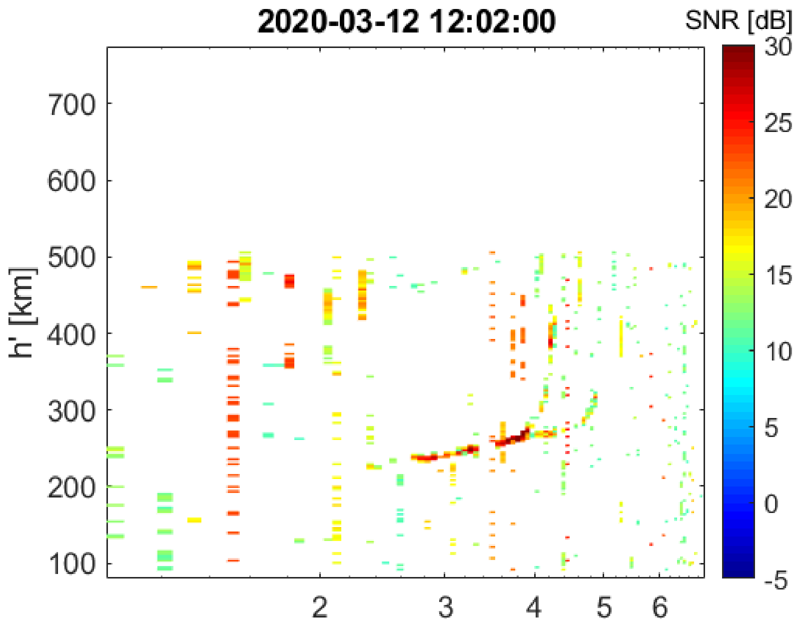
USRP-based ionospheric sounder, comparison statistics

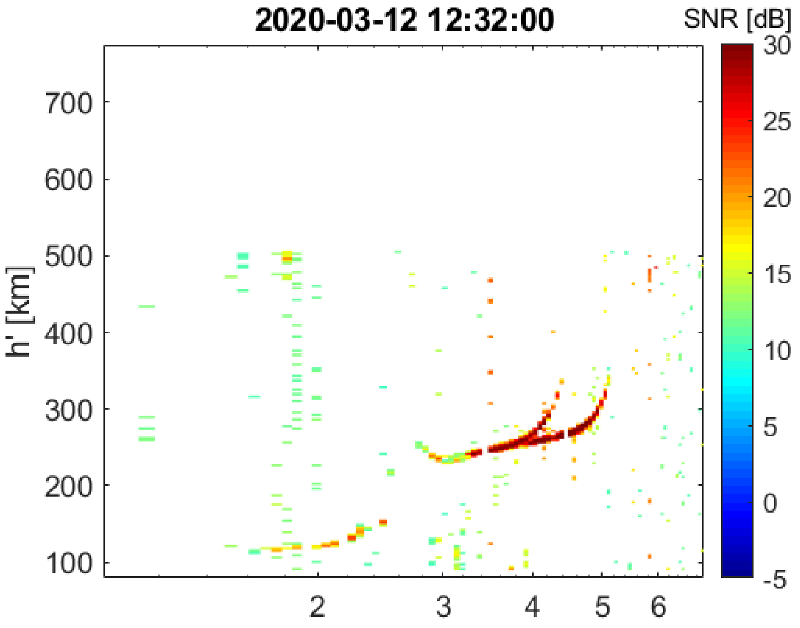
July 2017, manually scaled ionograms



Low-cost ionosonde: CADI vs SDR

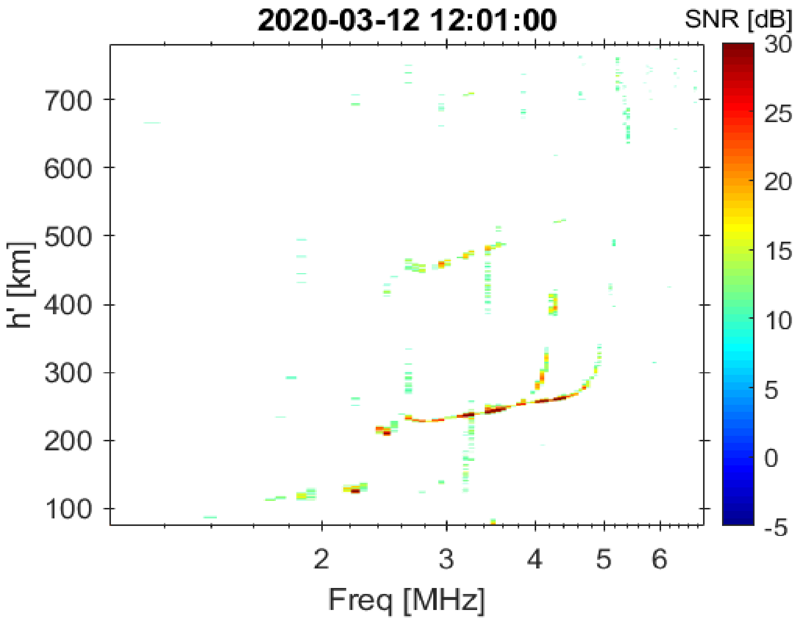
CADI

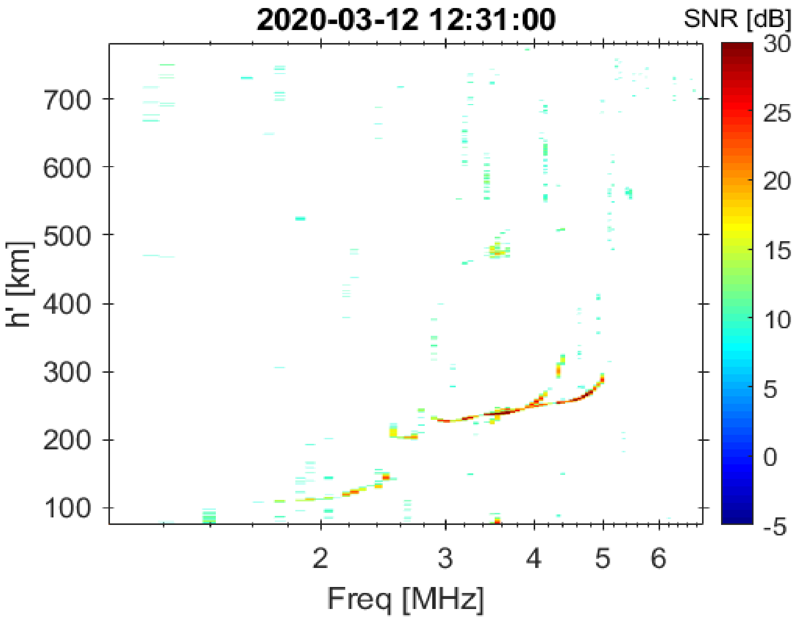




CADI

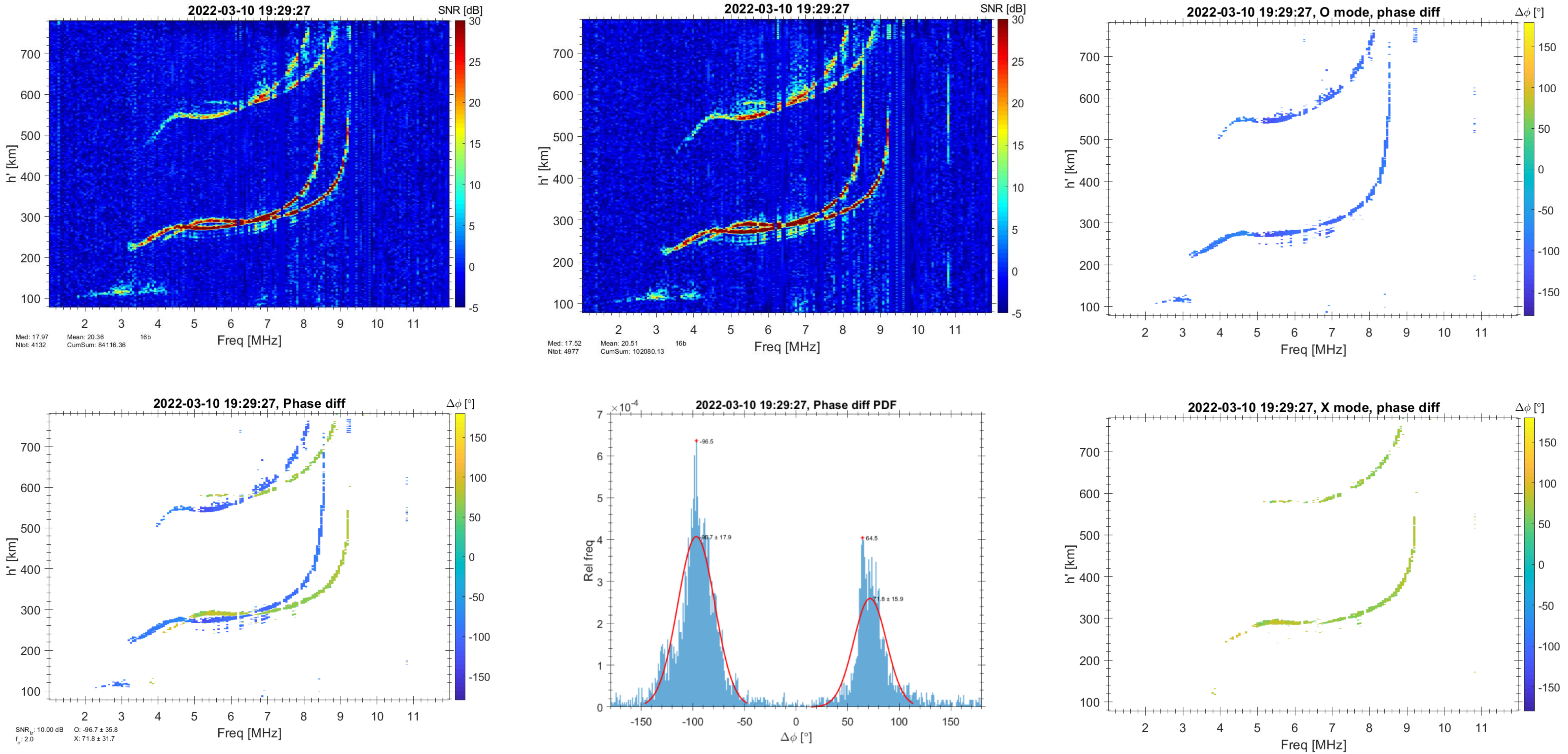
USRP



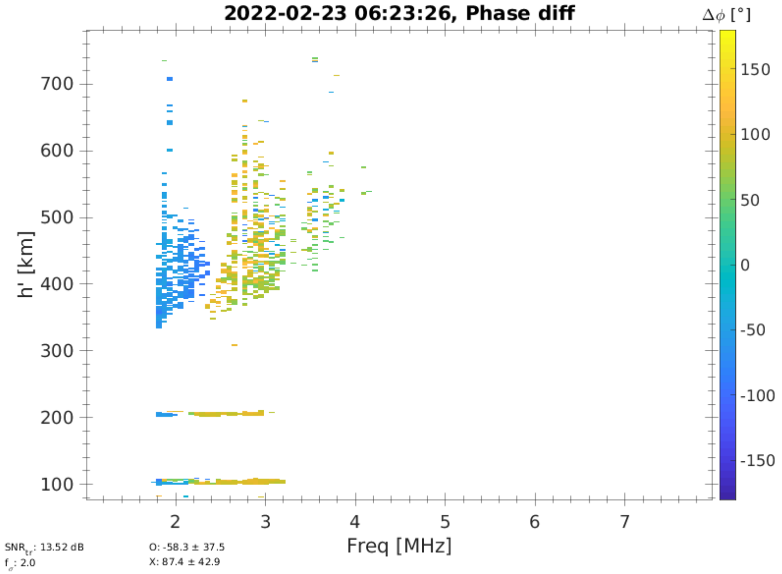


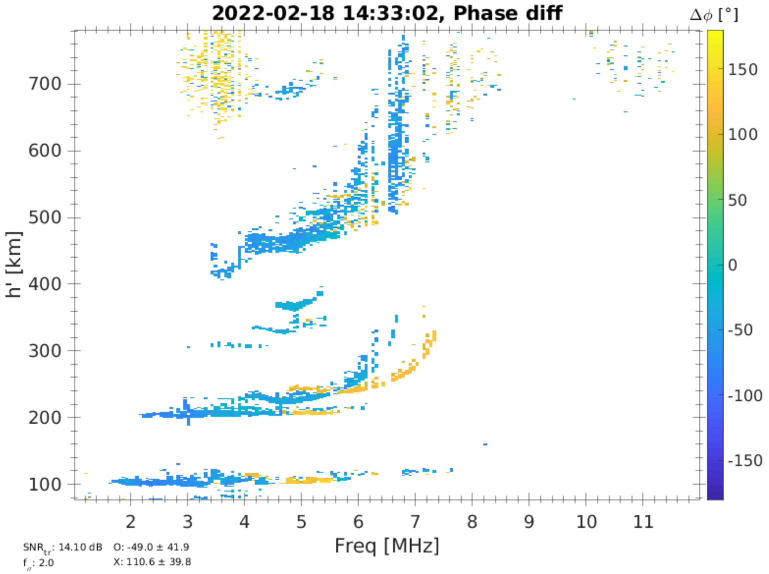
USRP

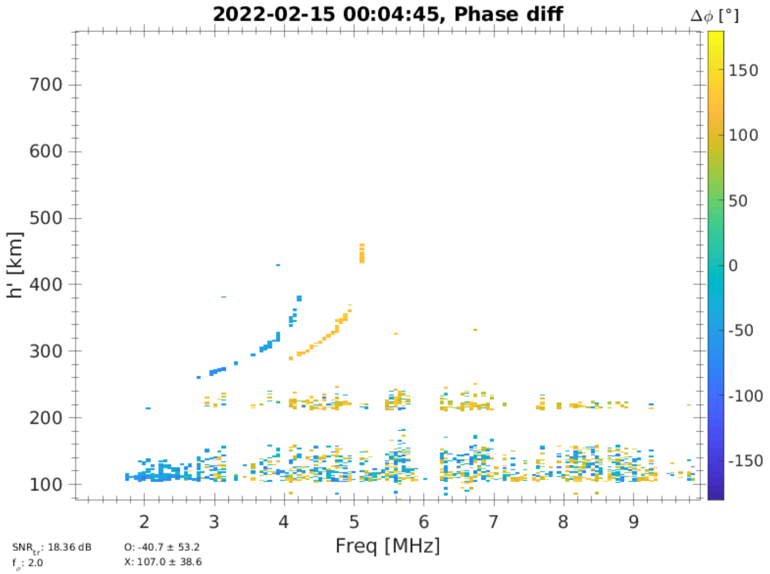
Polarization measurements

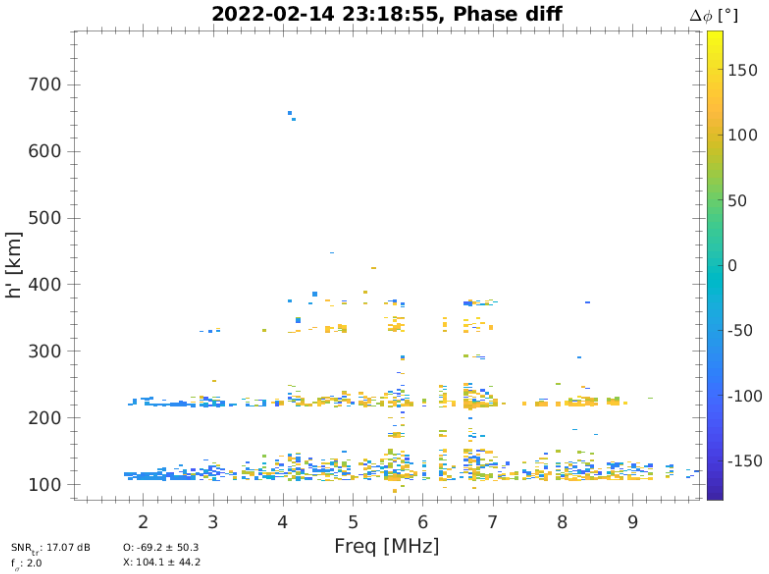


Polarization measurements: disturbed conditions



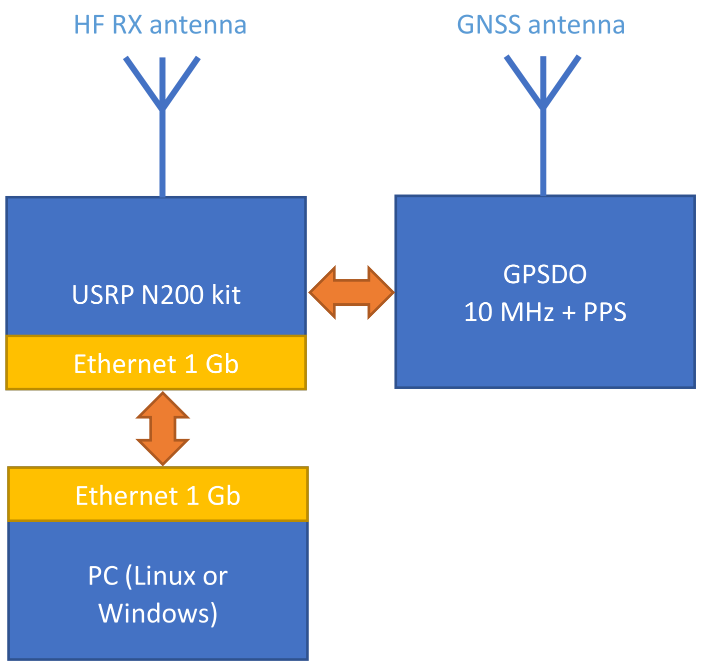


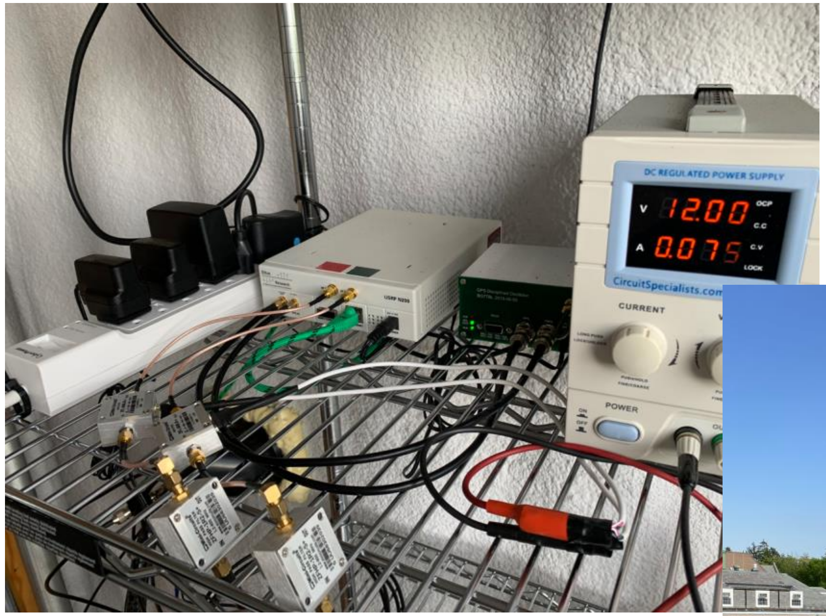




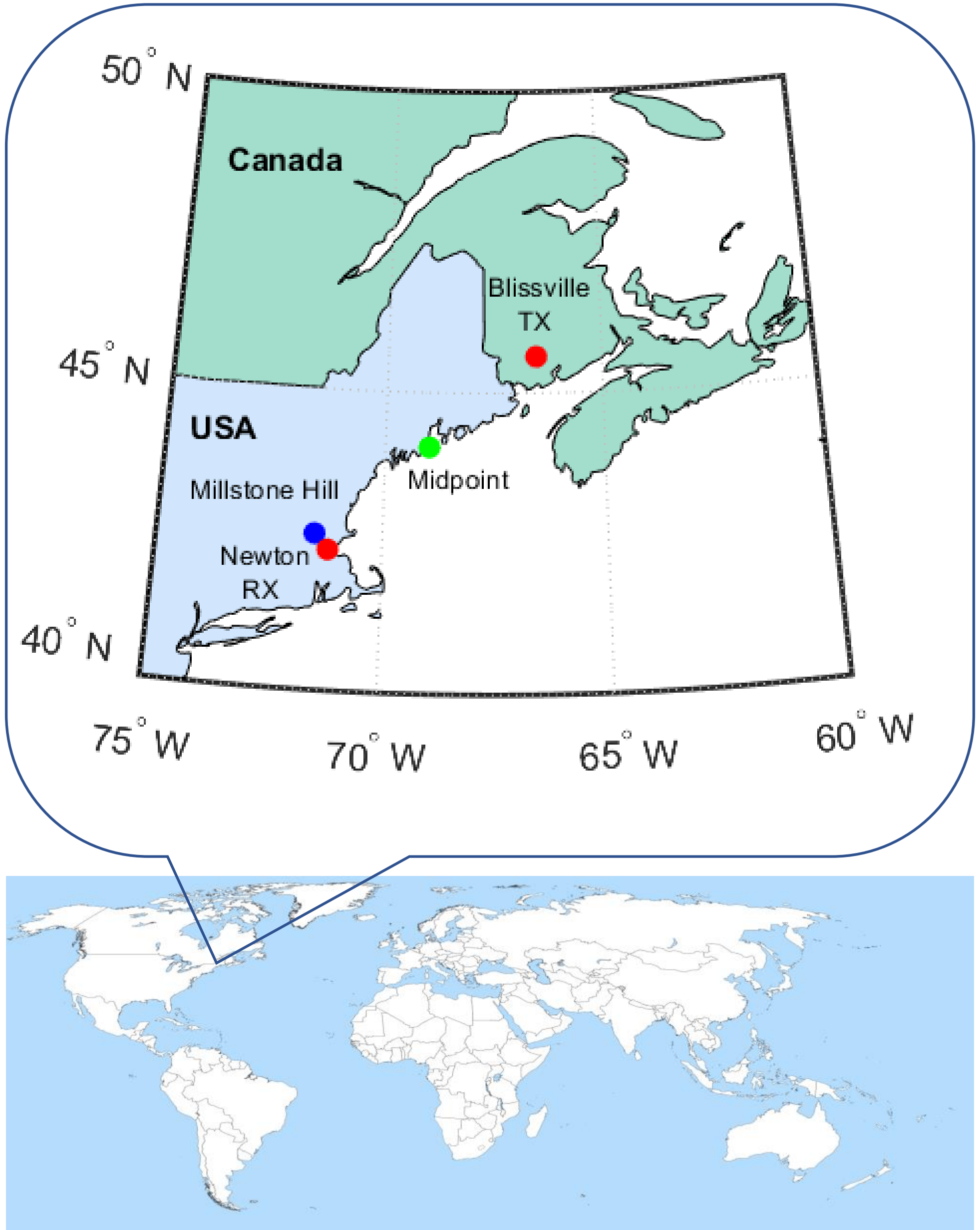
Low-cost sounder: block diagram

Oblique sounder

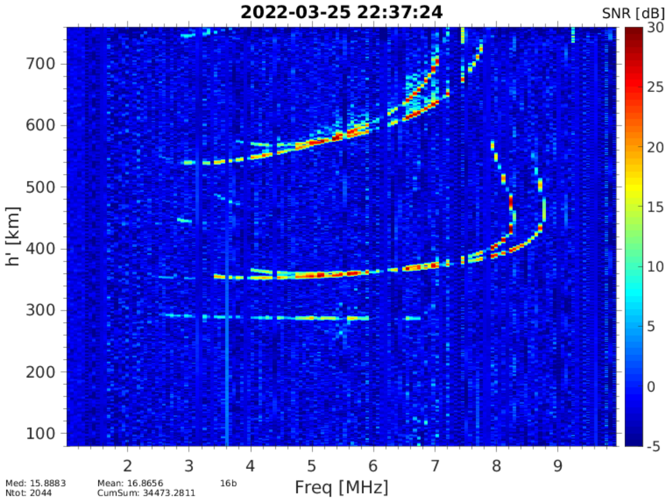


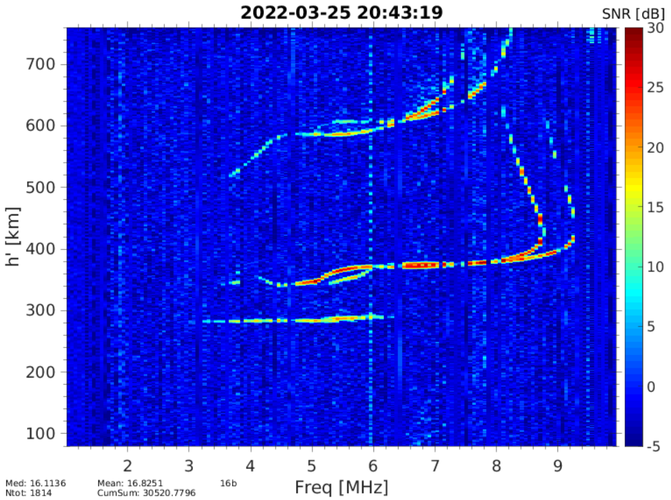


Experiment layout



	Site	Location
🔴	Blissville, NB, Canada (TX & RX)	45.6 N, 66.6 W
🔴	Newton, MA, USA (RX)	42.3 N, 71.2 W
🔵	Millstone Hill, MA, USA (Digisonde)	42.6 N, 71.5 W
🟢	Midpoint	44.0 N, 69.0 W





Conclusions

- Low-cost GNSS receivers can be a good alternative to estimate TEC
- At this moment low-cost receivers can not be used for scintillation monitoring. Neither for amplitude nor for phase

- Low-cost ionospheric sounders can be used as a replacement for conventional ionosondes
- They have a great potential to be used for building ionosphere sounder networks
- Further work to demonstrate the capabilities of the low-cost sounders to reconstruct plasma drift velocities is ongoing

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Thank you!