Scintillation Observations with a Low-Cost GNSS Receiver

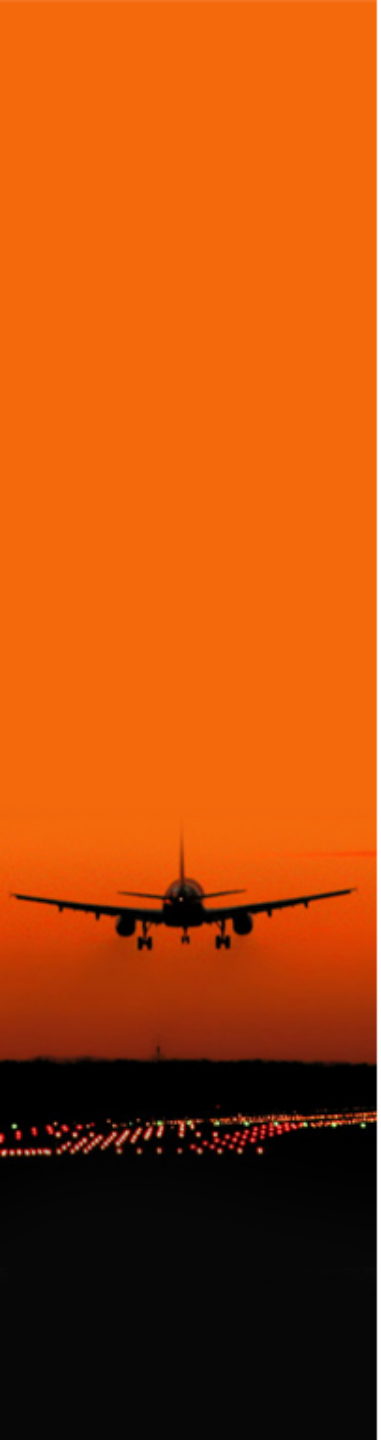
Dr. Keith Groves

Institute for Scientific Research, Boston College

Keith.Groves@bc.edu

United Nations Workshop on the International Space Weather Initiative

Vienna, Austria 26-30 June, 2023

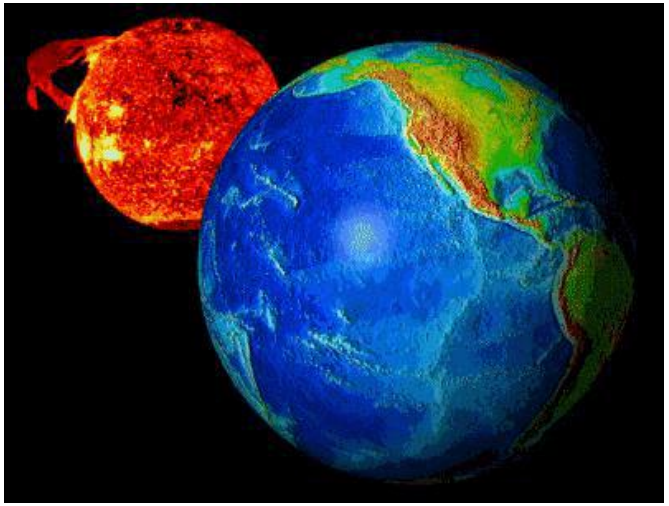


Acknowledgments

- **Dima Paznukhov, Ted Beach, Chris Bridgwood** Boston College; system procurement, integration and data collection
- **Anton Kascheev**, Univ of New Brunswick; system options and data acquisition software kernel
- **Dinesh Manandhar**, CSIS; pioneering analysis and development of systems' capabilities
- **Bruno Nava**, ICTP; early exploitation and TEC demonstration and comparisons
- **Sharafat Gadimova**, UNOOSA; promotion and formation of formal ICG working group to coordinate and motivate activities

Low-Cost GNSS Receivers for Space Weather Monitoring

- What does low cost mean and why is it important?
- The low-cost BC system
- Preliminary scintillation observations from Ascension Island
- Summary



The Promise of Low-Cost Receivers

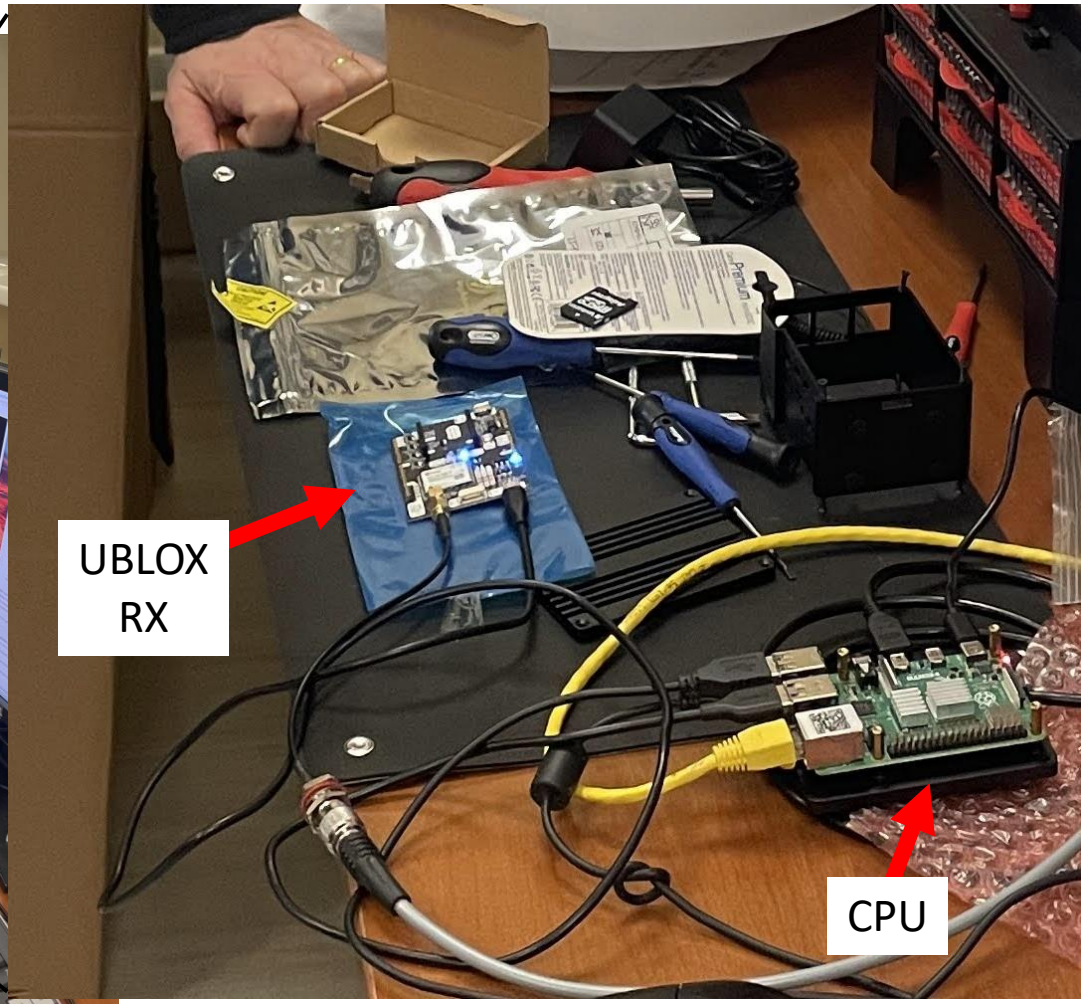
- Similar to computer technology, the real cost of GPS/GNSS receivers has been decreasing for the last three decades, but a capable truly low cost GNSS system has only become possible in the last 1-2 years
- When system reproduction costs fall below $1,000 ($500) dollars, the ability to proliferate installations becomes much more feasible
- Initial system cost is just one, albeit critical, barrier to the challenges of launching a successful remote sensing project
  - Coordination, commitment and care are necessary to achieve a worthwhile scientific return on the investment

BC Ublox System Components (as fielded)

Item Description	Part/Model Number	Qty	UOM	Value (US)	Mfg
TOPGNSS L1/L2 Antenna	TOP106	1	ea	$133.95	TOPGNSS
RAK RASPBERRY PI 4 BASIC KIT /4G	RASPBERRY PI 4 MODEL B -4GB-US STANDARD	1	ea	$161.17	RAKwireless Technology Ltd
ARDUSIMPLE RTK2B GPS/GNSS RTK ZED-F9P EVAL KIT	AS-RTK2B-F9P-L1L2-NH-02	1	ea	$233.78	Ardusimple
microSDXC Memory Card w/ SD Adapter, 64GB	VER44084RZ1	1	ea	$11.95	Verbatim
		Total Cost		$540.85	

- Supply chain issues have resulted in a systemic shortage of low-cost Raspberry Pi computers
- We had to purchase a kit with enclosure ($161), but the base price for the Raspberry Pi 4 with 4GB ram is $54, 2GB version is $35 (not tested, but probably adequate)
- A capable system can be produced for < $500 USD
- This unit provided 20 Hz C/No measurements with 1-dB-Hz resolution
- Concern: rapid pace of hardware technology development means that today's chipset may not be available tomorrow: need to ensure that manufacturers retain capabilities in future offerings

The Ardusimple FTK28 ZED-F9P (UBLOX) Rx



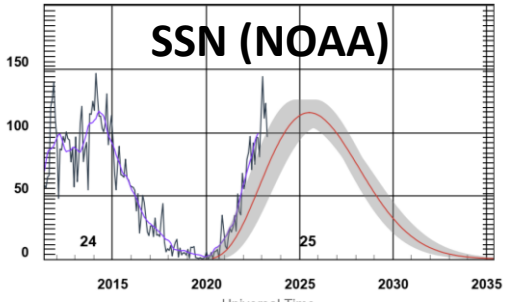
Inexpensive, compact and low power consumption

Ascension Island Measurements 2023

- BC recently operated a variety of receivers under strong scintillation conditions at Ascension Island in the S. Atlantic (7.9 S lat, 14,4 W lon, magnetic anomaly site)
- Solar flux was nearly representative of solar maximum conditions
- Prelminary Ublox results from 22 March will be presented here

Scintillation Activity Log

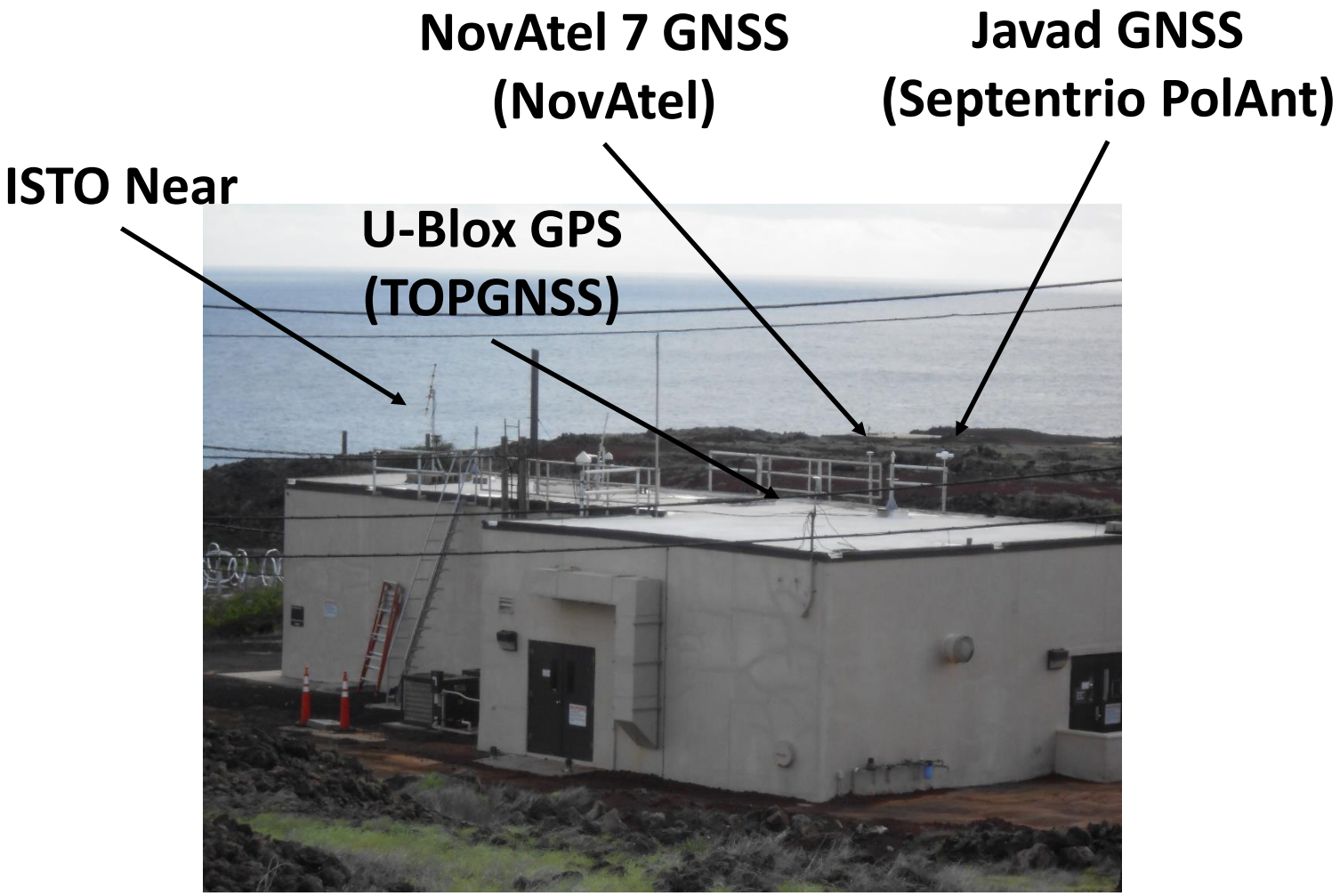
19-Mar-23	78	Strong scintillation (incl. some GPS)	
20-Mar-23	79	Strong scintillation (incl. GPS)	
21-Mar-23	80	Strong scintillation (incl. GPS)	(GNSS S4 ~ 1.0 at EL = 75 deg)
22-Mar-23	81	Strong scintillation (incl. GPS)	Some analysis complete
23-Mar-23	82	Late night VHF scintillation (Kp = 8-)	
~~24-Mar-23~~	~~83~~	~~No scintillation~~	
~~25-Mar-23~~	~~84~~	~~No scintillation~~	
26-Mar-23	85	Strong scintillation (incl. GPS)	
27-Mar-23	86	Strong scintillation (incl. GPS)	(GNSS S4 ~ 1.0 at EL = 85 deg)
~~28-Mar-23~~	~~87~~	~~No VHF scintillation, probable GPS to north~~	
~~29-Mar-23~~	~~88~~	~~No VHF scintillation, probable GPS to north~~	
~~30-Mar-23~~	~~89~~	~~No scintillation~~	
31-Mar-23	90	Strong scintillation (incl. GPS)	
~~01-Apr-23~~	~~91~~	~~No scintillation~~	
02-Apr-23	92	Strong scintillation (incl. GPS)	
03-Apr-23	93	Weak VHF (some GPS to North) (ma	
04-Apr-23	94	Strong scintillation (incl. GPS)	
05-Apr-23	95	Brief burst of strong scintillation (in	
06-Apr-23	96	Brief burst of strong scintillation (in	



Receivers Tested

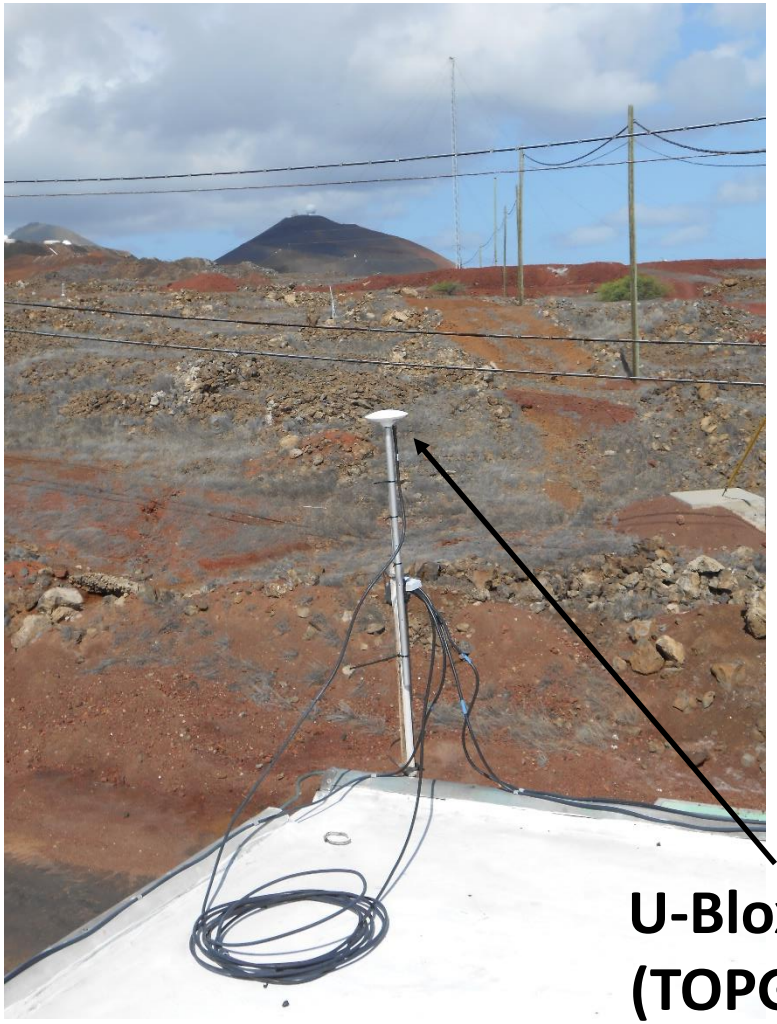
Receiver Manufacturer	Receiver Model	Antenna Manufacturer	Antenna Model
Septentrio (2)	PolaRx5S	Septentrio	Veraphase 6000
NovAtel	GPStation-6	Antcom	123GM1215A
Javad	Delta-3Sa	Septentrio	PolaNt
NovAtel	PwrPak7	NovAtel	GNSS-850
CU Boulder	EDAS	Trimble	Zephyr 3 Base
Ardusimple (u-blox ZED-F9P core)	RTK2B	TOPGNSS	TOP106
Northrop Grumman	ISTO	Northrop Grumman	ISTO

Ascension Island GNSS Antennas



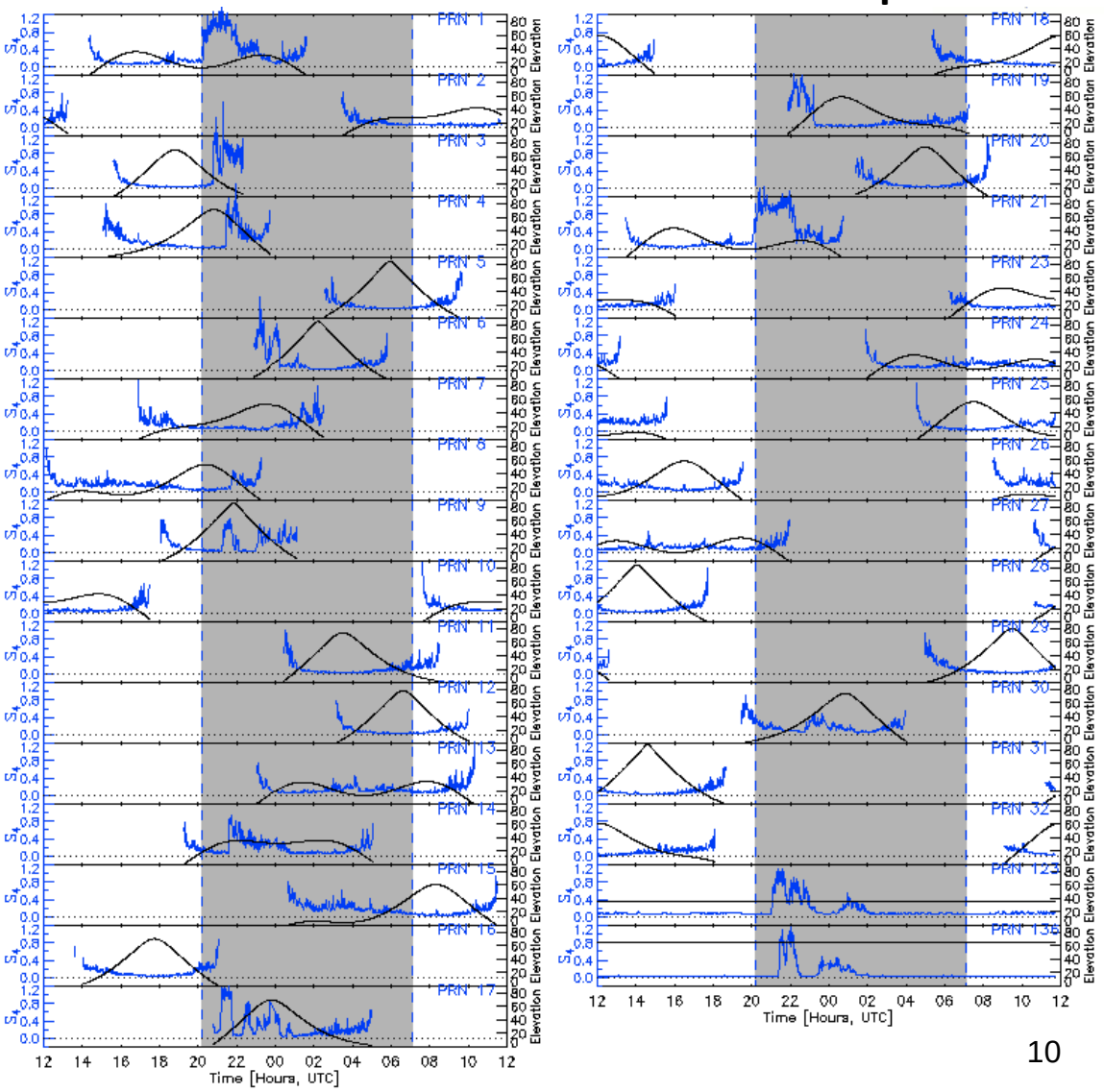
Ascension Island Campaign Set-Up

- U-Blox antenna is an inexpensive, GPS-only unit for these observations, with virtually no multi-path inhibiting technology
- Elevated terrain, ocean reflections and local metallic structure all contribute to relatively high multi-path environment at low elevation angles



Evening of 22 March 2023

- Extended (brief) periods of strong scintillation on low (high) elevation links
- Representative of near solar maximum conditions for solar cycles 24 & 25
- Note that strongest activity occurs soon after sunset; higher flux will extend duration and severity

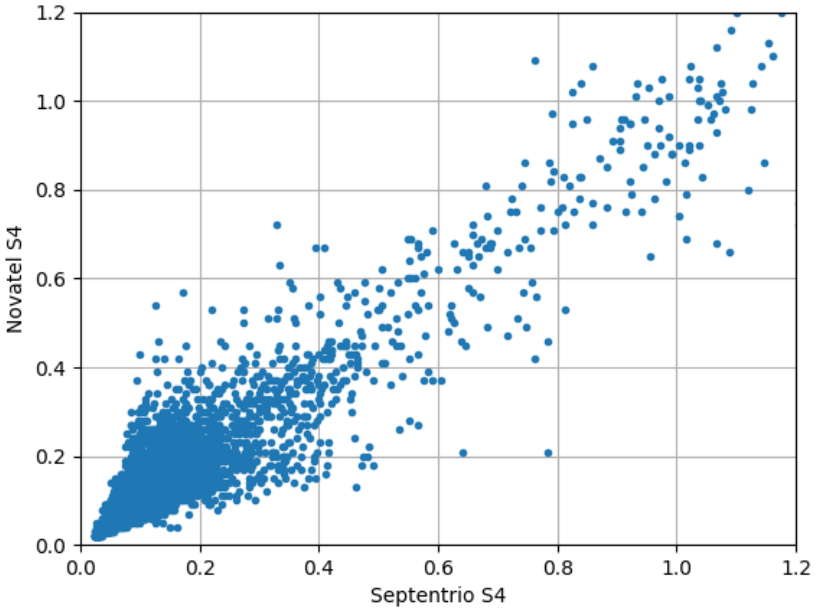


Preliminary Results: Comparison of Two Research Grade Receivers

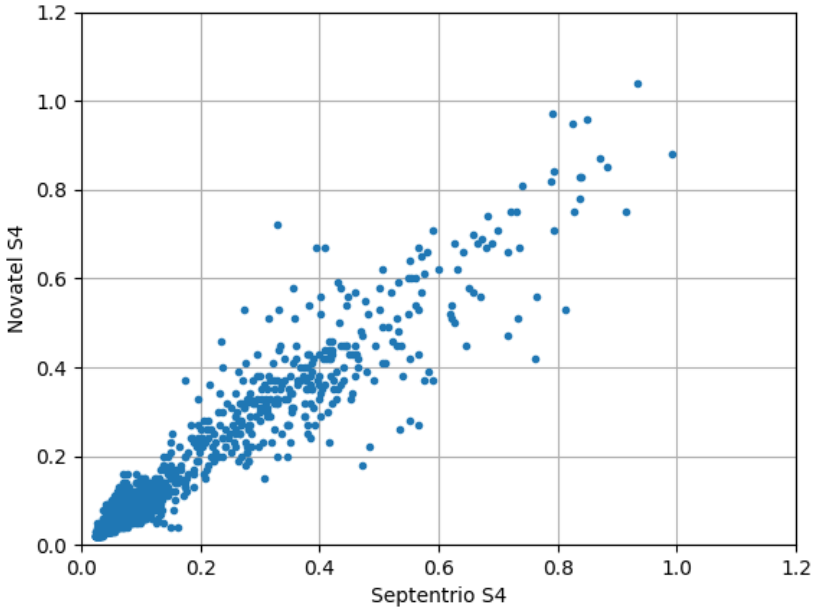
Novatel 6 vs Septentrio PolaRx5s

2023/03/22 12UT - 2023/03/23 12UT

All elevations



Elevation > 30 deg



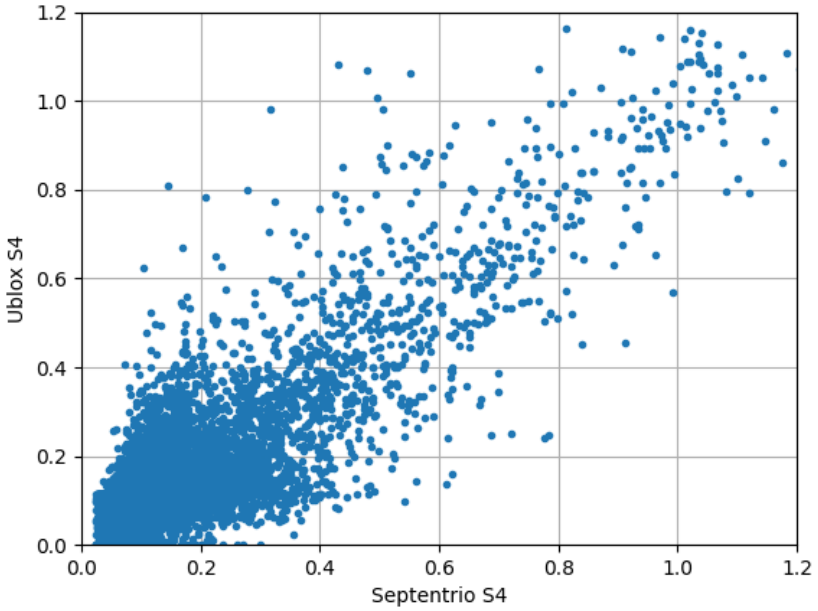
- Low elevation measurements include enhancements due to multi-path associated with specific antenna characteristics and siting factors

Preliminary Results: Comparison of Ublox with Septentrio PolaRx5s baseline system

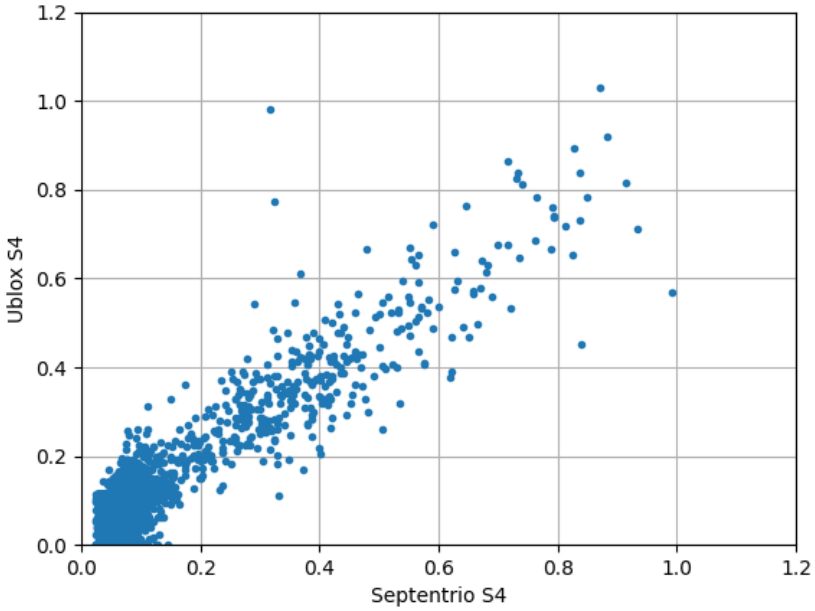
UBLOX vs Septentrio PolaRx5s

2023/03/22 12UT - 2023/03/23 12UT

All elevations



Elevation > 30 deg

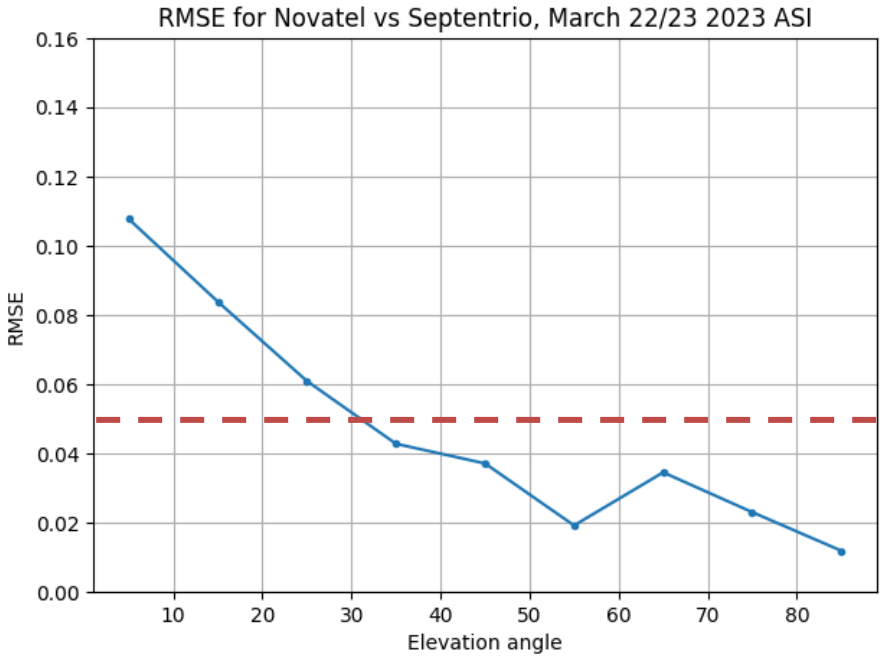


- There is a bit more scatter than with the Novatel 6 data, but with 1 dB C/No resolution this is not surprising; overall it is an excellent result
- The low-cost antenna shows significant multi-path noise below 30 deg elev

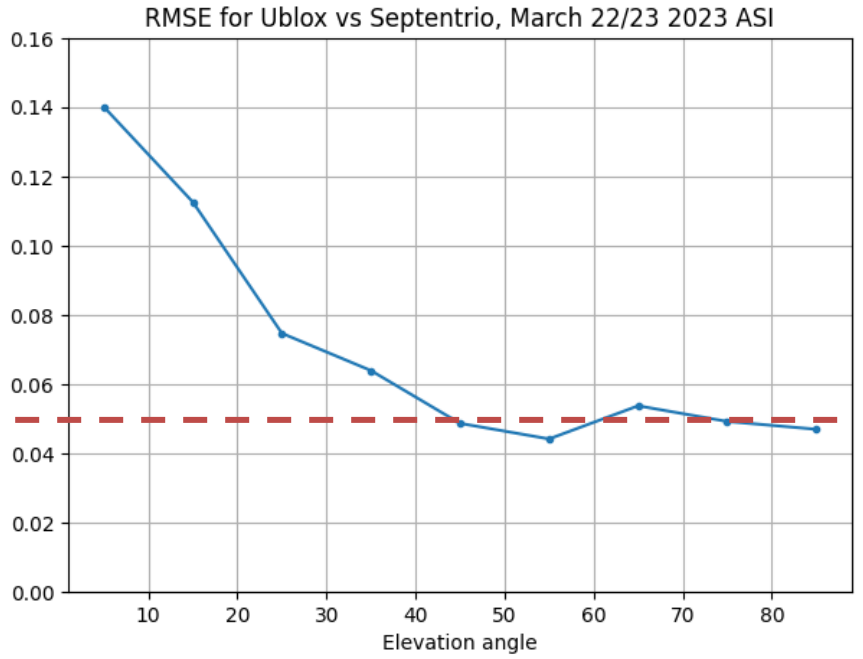
Preliminary Results: RMSE Errors as a Function of Elevation Angle

RMSE errors for each receiver relative to Septentrio PolaRx5s

Novatel 6



Ublox



- At about 40 deg elevation the Ublox seems to hit a floor around the target RMS error of ~0.05 S4 units; possibly due to the 1 dB C/No resolution
- BC has signed a NDA with the manufacturer and may be able to influence improvements in the future

Summary

- A low-cost dual or tri-band GNSS system for monitoring space weather is feasible and may already exist
  - Space weather monitoring implies TEC and scintillation (both phase and intensity)
- Results presented here are preliminary but promising!
  - Full analysis of performance including tracking and other characteristics are in progress
- Scientific programs to exploit these inexpensive systems should be developed, recognizing that initial hardware cost is just one component to be considered for a successful project
- Boston College plans to continue inexpensive sensor analysis and development and pursue opportunities to expand GNSS monitoring in the near future