UNITED STATES MILITARY ACADEMY
WEST POINT

Distributed Sensor Array for Space Weather Characterization

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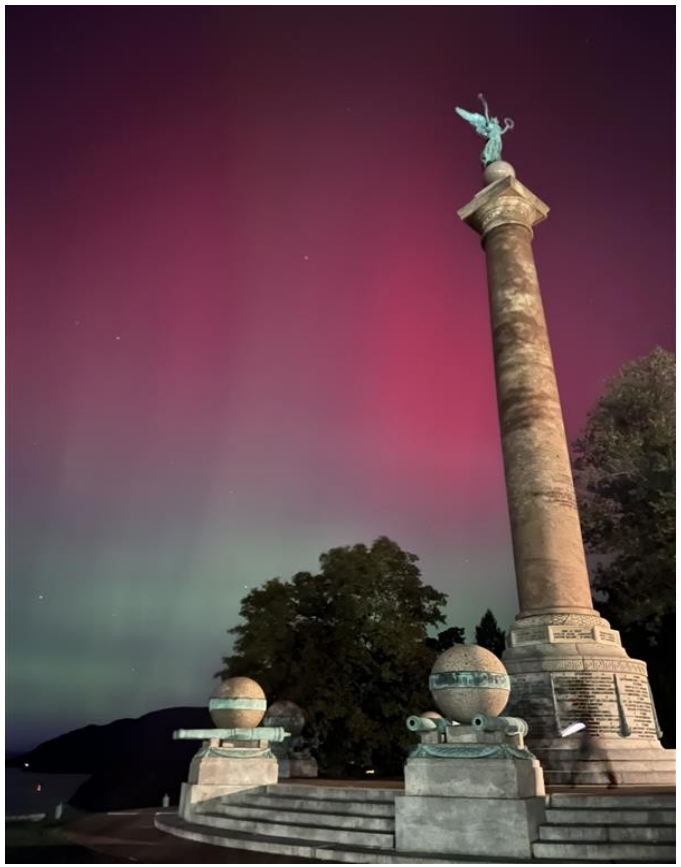


Agenda

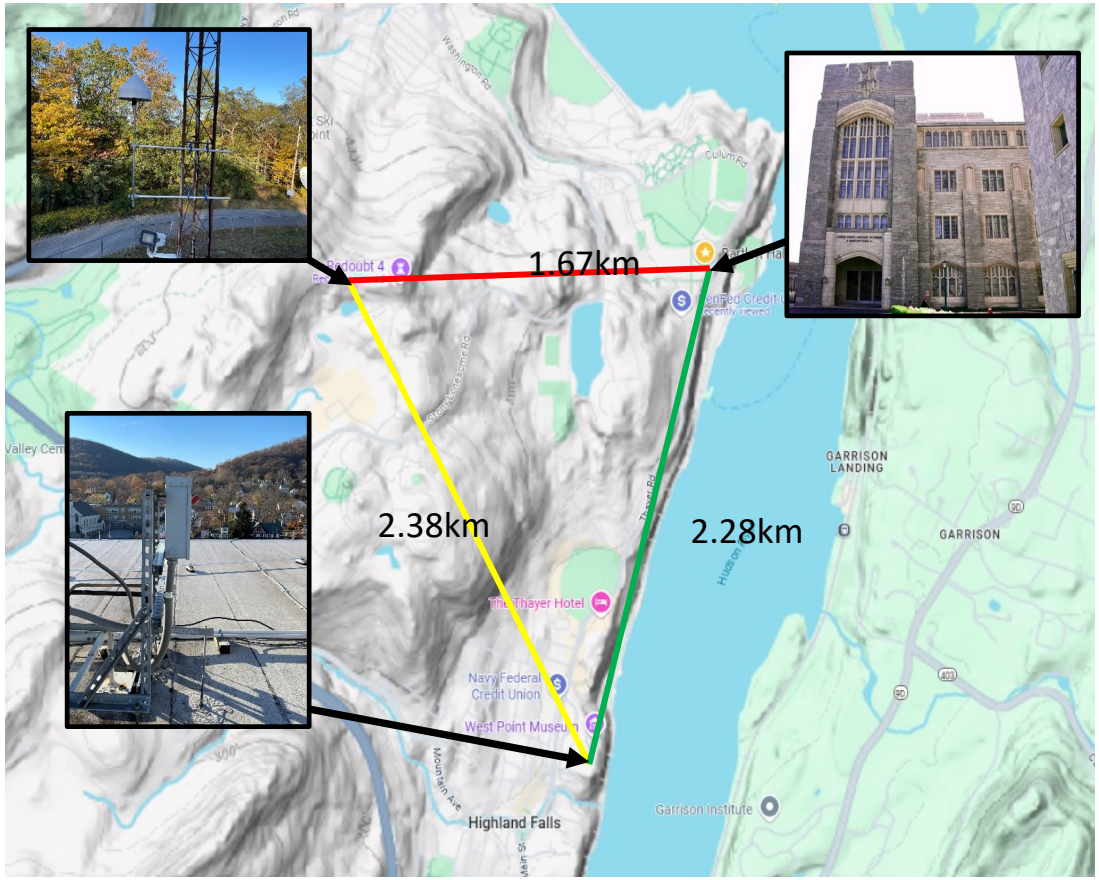
Background

Problem Statement

Current Status

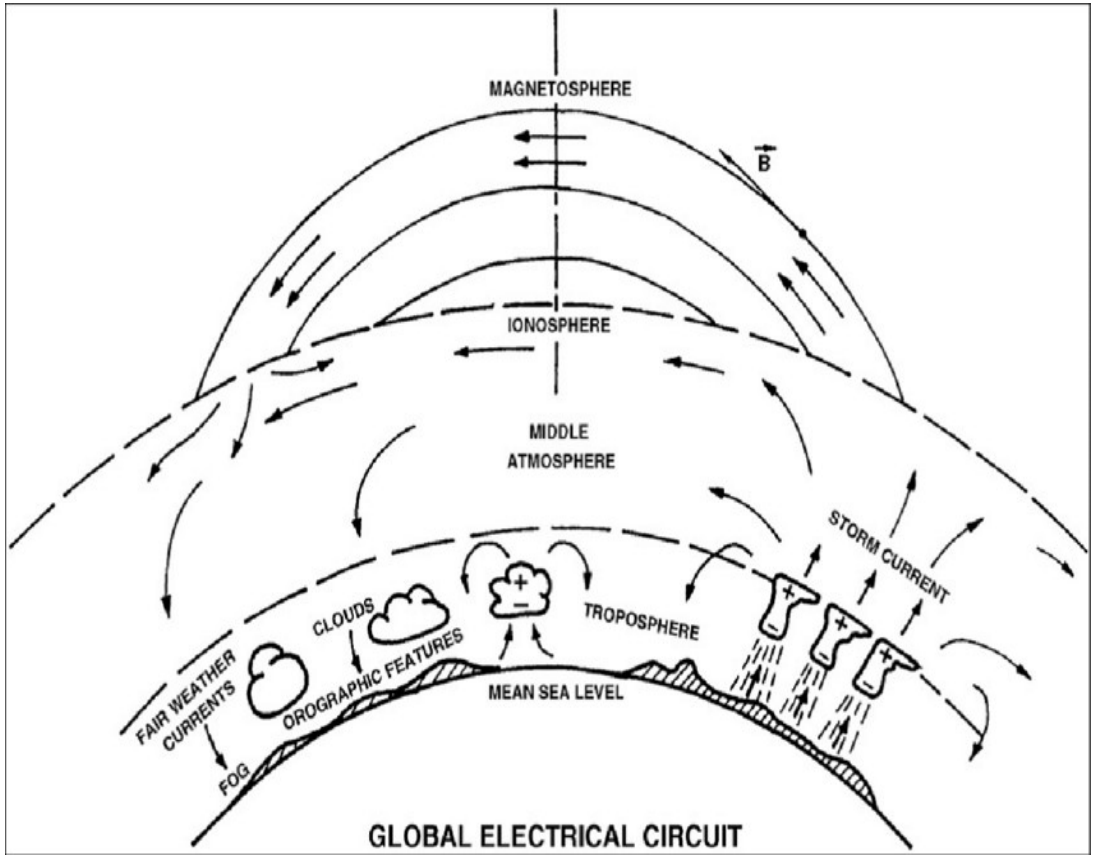
Project Schedule

End State



BLUF: The goal of this project is to construct a distributed sensor array on West Point property to measure and characterize the ionosphere. This data will be recorded, analyzed, and used to contribute to the body of mid-latitude ionospheric research (a relatively smaller body compared to what has been done in the polar regions).

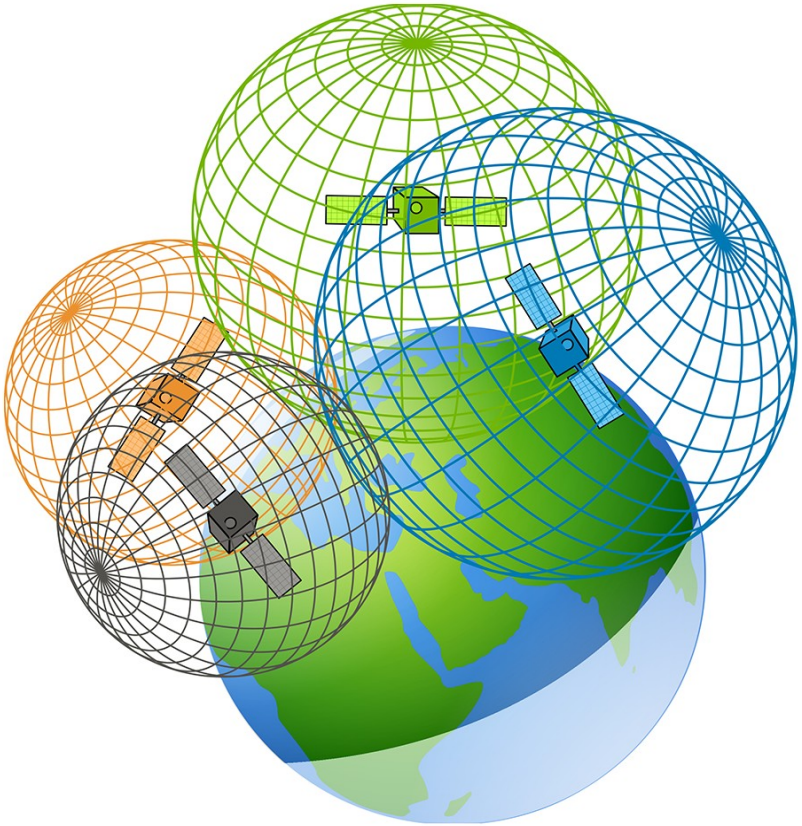
GEC

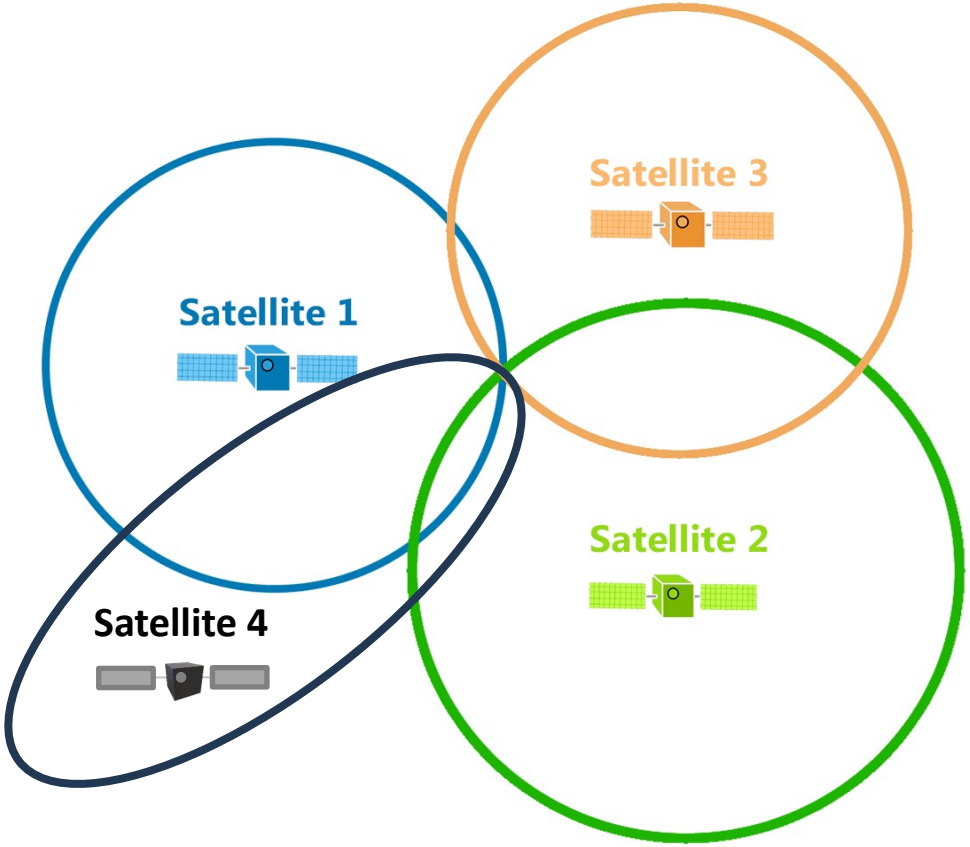


Global Electric Current

- Charge moves from Ionosphere to Earth's surface along magnetic currents
- Fair weather potential difference ~100V/m at ~7.4 Hz
- Terrestrial weather increases potential difference
- TIDs in the Ionosphere affect the conductivity

Global Navigation Satellite System



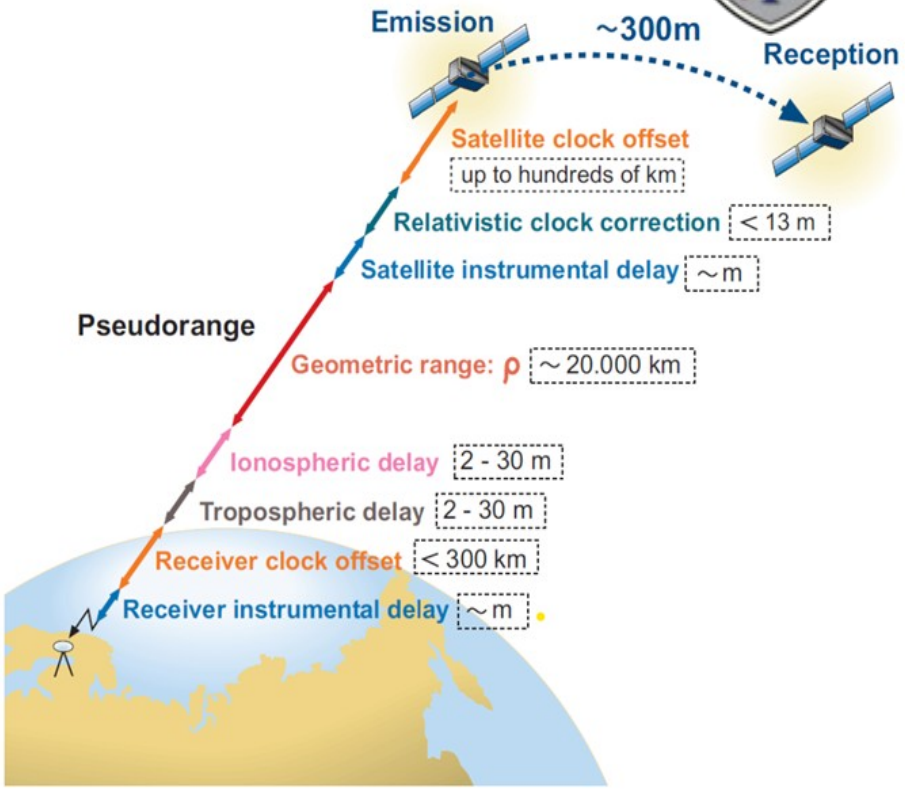


Pseudorange

Pseudorange Offset

When passing through the atmosphere, GNSS signals are affected by various phenomena called offsets.

- These alter the data received, and can introduce error in the position solution calculated

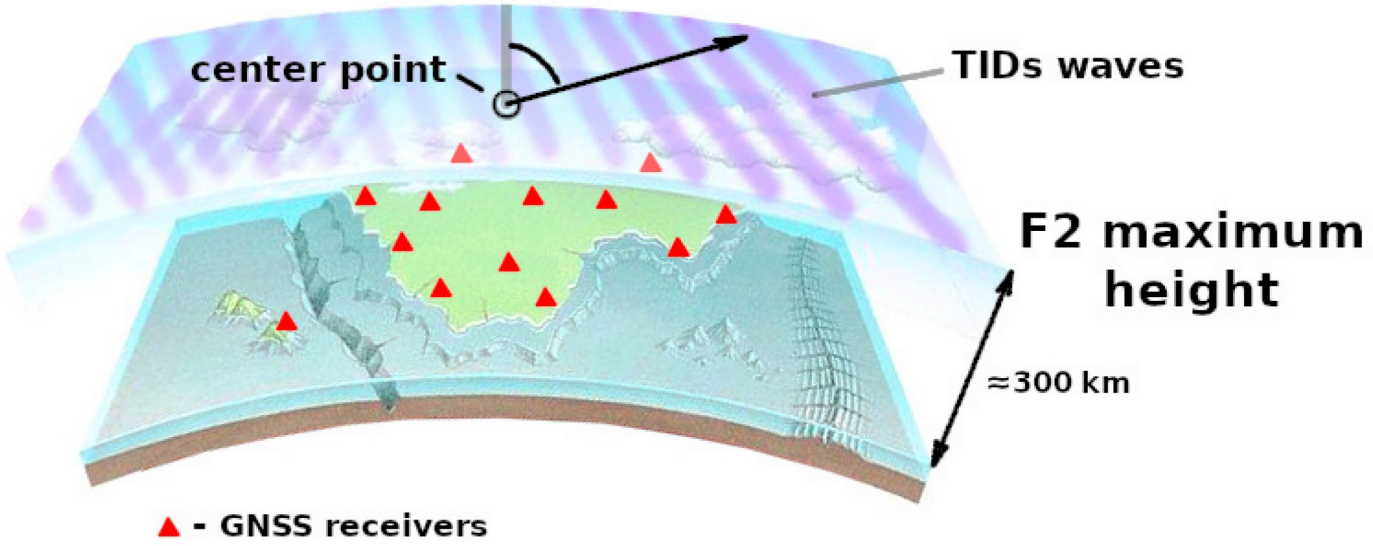


Pseudorange

$$p = \rho + d_p + c(dt - dT) + d_{ion} + d_{trop} + \epsilon_{mp} + \epsilon_p$$

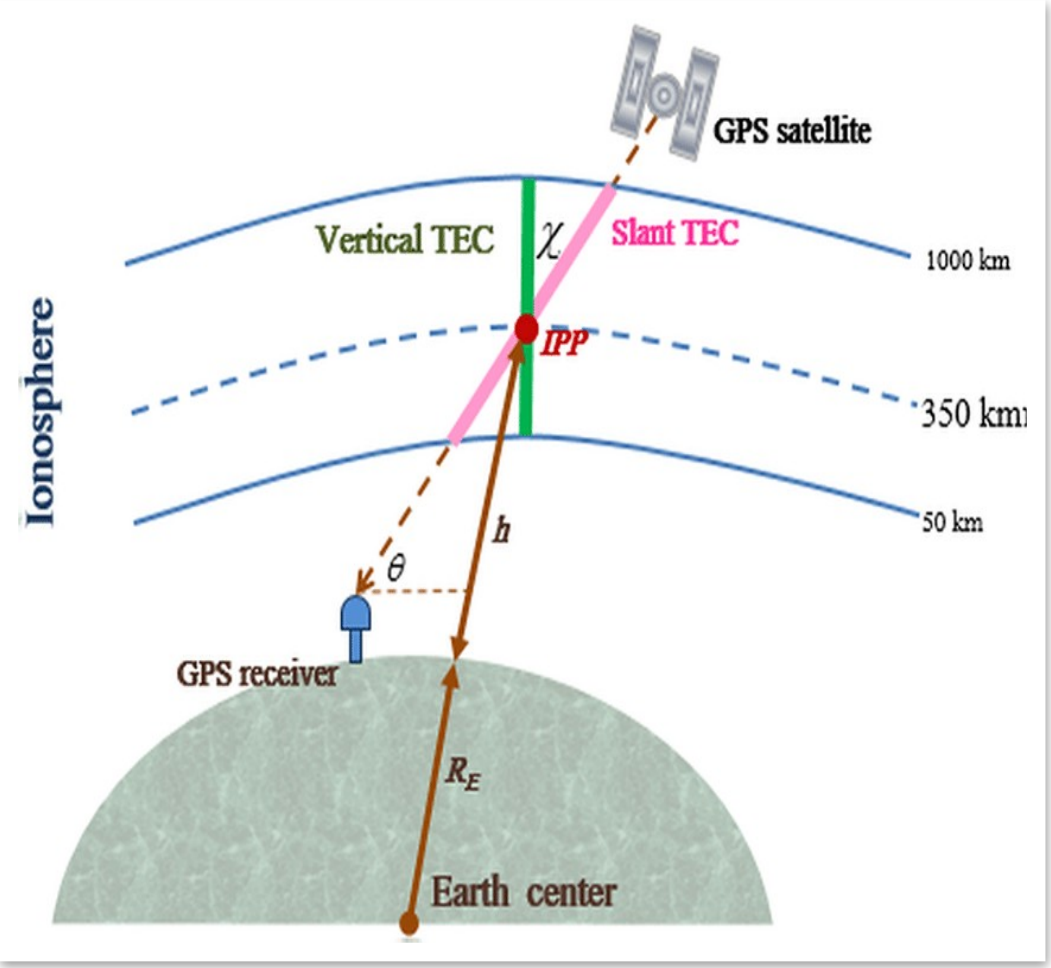
- p: Pseudorange
- ρ: True Range
- d_p: Orbital Error
- $c(dt - dT)$: Clock Errors
- d_{ion}: Ionospheric delay
- d_{trop}: Tropospheric delay
- ϵ_{mp}: Multipathing
- ϵ_p: Receiver Noise

TIDS



TID Scale	Medium Scale	Large Scale
Wave Size	100-1000 km	>1000 km
Propagation Speed	100-300 m/s	300-1000 m/s

Total Electron Content (TEC)



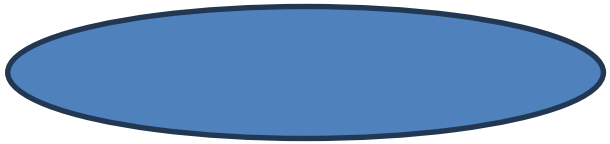
The number of free electrons along a path between a signal transmitter and receiver.

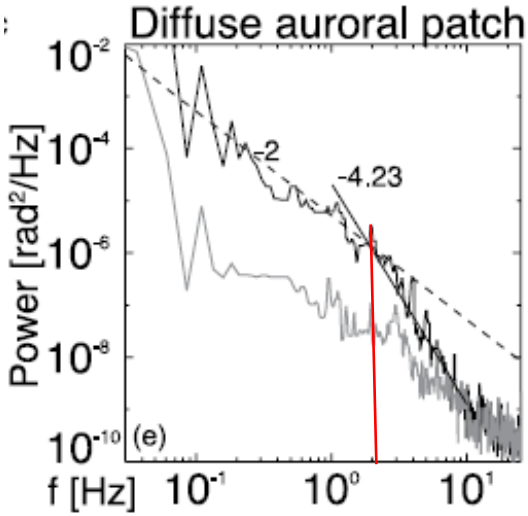
The electrons cause the signal to refract as it travels through the ionosphere.

- This refraction interferes with the signal's path, causing a delay in the time from the transmitter to the receiver.
- This delay makes GPS systems less accurate.

[3A, 3B]

Fresnel Frequency





Fresnel frequency: The frequency at which signals interacting with an obstruction will diffract, causing increased signal noise and loss.

$$f_F = \frac{v_{TID}}{r_F}$$

$$r_F = \sqrt{n\lambda d_{rec}}$$

$r_F \equiv Fresnel\ radius$

$f_F \equiv \boldsymbol{Fresnel}$ **frequency**

$v_{TID} \equiv Propagation\ speed$

$\lambda \equiv Signal\ wavelength$

$\mathrm{d_{rec}} \equiv TID\ to\ receiver\ distance$

CASES

CASES Capabilities and Data Logging

CASES On-Board Data Products

	Per Channel High Rate	Per Channel Low Rate	Scintillation Params	Navigation Solution
Default Rate	**100 Hz**	**1 Second**	**100 Second**	**1 Second**
Configurable Rate?	Yes 50 or 100 Hz	Yes >= 1 Second	Yes	Yes >= 1 Second
Parameters	I's, Q's, Integrated Carrier Phase	Pseudorange-based TEC	$S4$, σ_Φ, T_0	Position Velocity
		Phase-based Delta-TEC	Scint. Power Ratio	
		Integrated Carrier Phase		
		Pseudorange		
		Doppler Frequency		

[4]

Problem Statement

Statement

The goal of this project is to install a distributed sensor array on West Point to provided meaningful ionospheric TEC, phase scintillation, and amplitude scintillation data and analysis in a mid-latitude region. The reason this this is important is because minimal study of the mid-latitude ionosphere has been conducted, and it is the atmospheric region under which the majority of military and U.S. civilian operations are done. Additionally, using this research and network, atmospheric and remote sensing courses will be created for cadets.

Purpose

Can a distributed system of ionospheric sensors be installed, at a relatively low cost, to measure the TEC, amplitude scintillations, and phase scintillations in the ionosphere over a mid-latitude site to characterize the ionosphere.

The Application of Spherical Elementary Current Systems (SECS)

$$\nabla \times \vec{B} = \mu_O \vec{J} + \mu_O \varepsilon_O \frac{\partial \vec{E}}{\partial t}$$: Ampere-Maxwell Law

$$B(r) = \int G(r, r') J(r') dV'$$: Green's Function

Horizontal Currents

$$G_B(\theta, \varphi) = \frac{I}{4\pi} \frac{1}{R sin\theta}$$

Field Aligned Currents

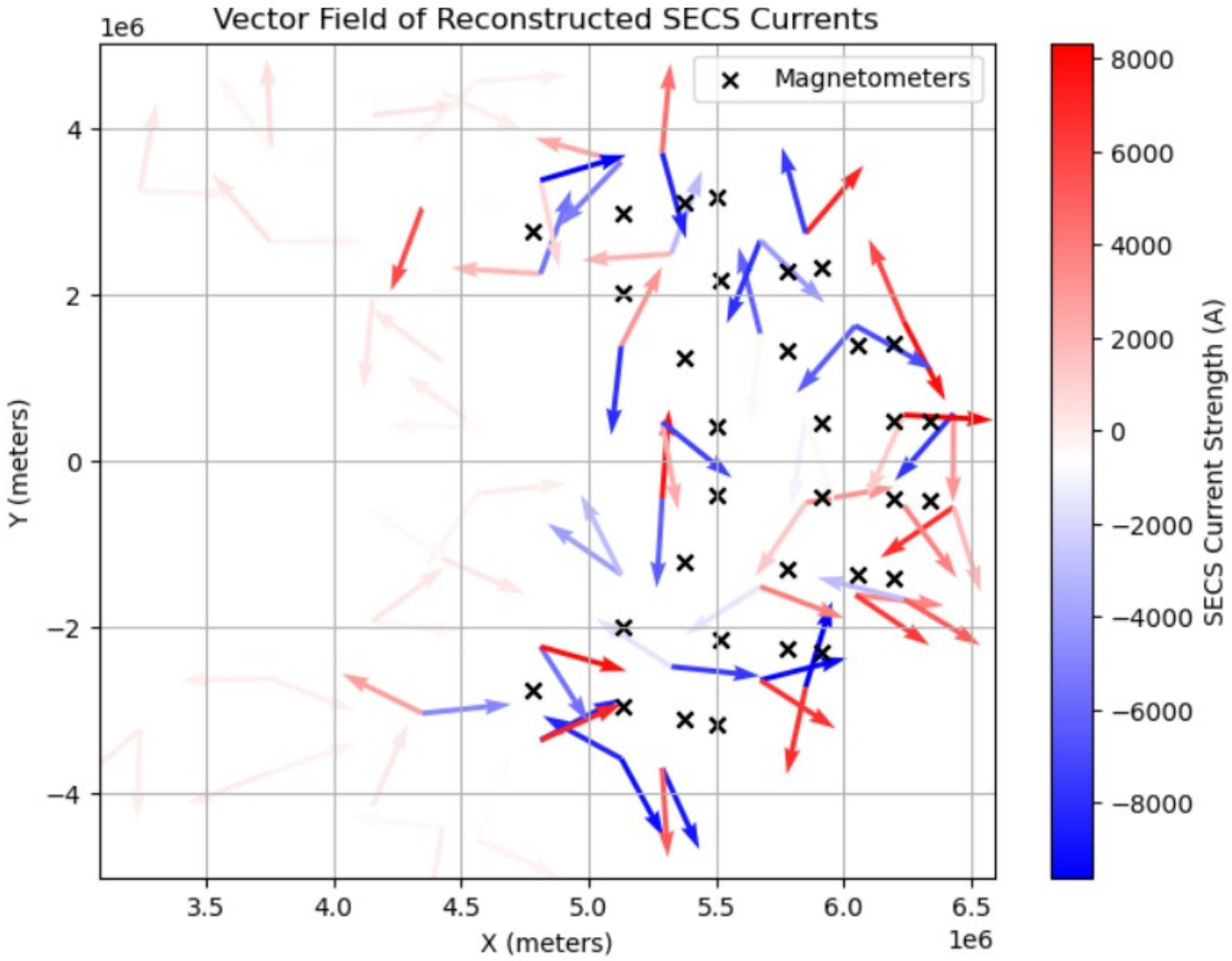
$$G_h(\theta, \varphi) = \frac{I}{4\pi R} \frac{1}{sin\theta} \hat{e}_\varphi$$

$J = G^{-1}B$ – Solving for the Currents Strength

Assumptions, Pros, and Cons of SECS

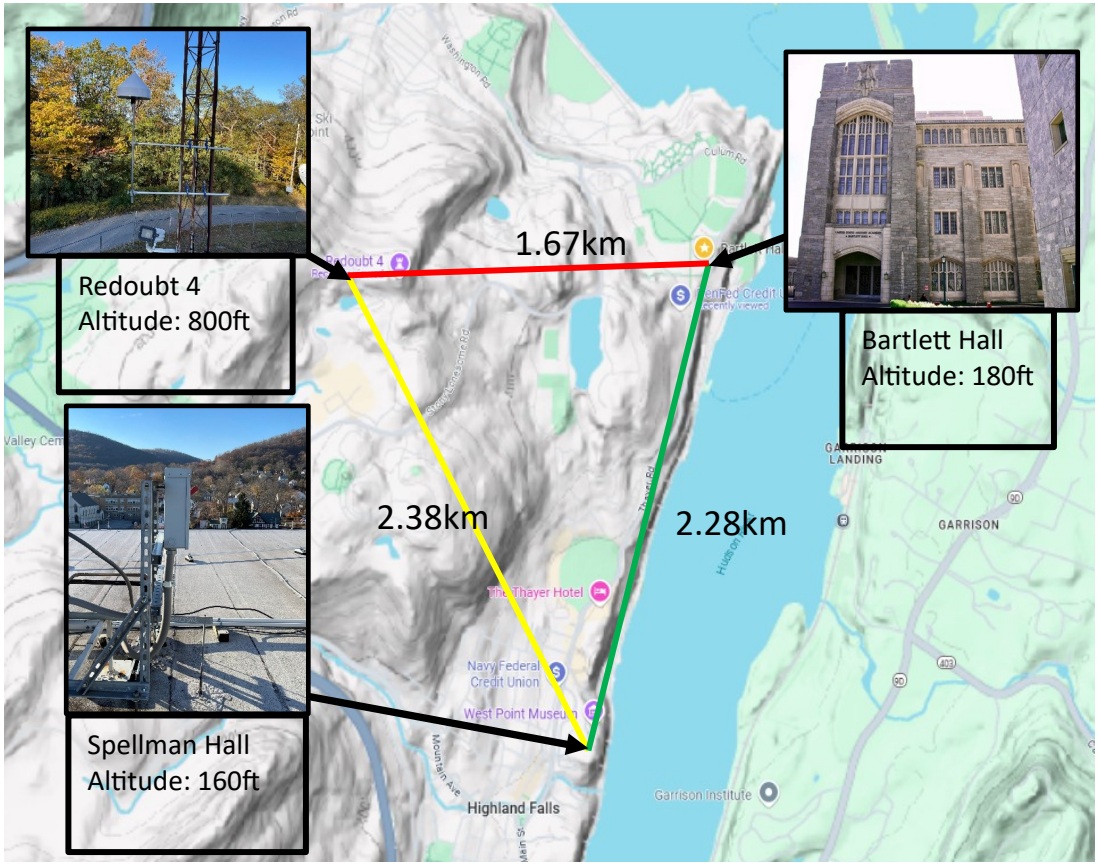
- The ionosphere is assumed to be a uniform sheet at 110km
- An array of nodes gives reference points over the sensor array of for current reconstruction – these are mathematical points
- Can't differentiate from non-ionospheric sources
  - GIC analysis will need to be conducted
- Requires multiple sensors free of electromagnetic disturbances
- Pros
  - The sensor location can be irregular
  - Scalable Spatial Resolutions
  - Characterizes regional currents
- Cons
  - Only a 2D rendition of or currents, can't determine vertical structure
  - Can't account for fast fluctuations from geomagnetic storms

Simulation Of Code



Current Status

Installation Process

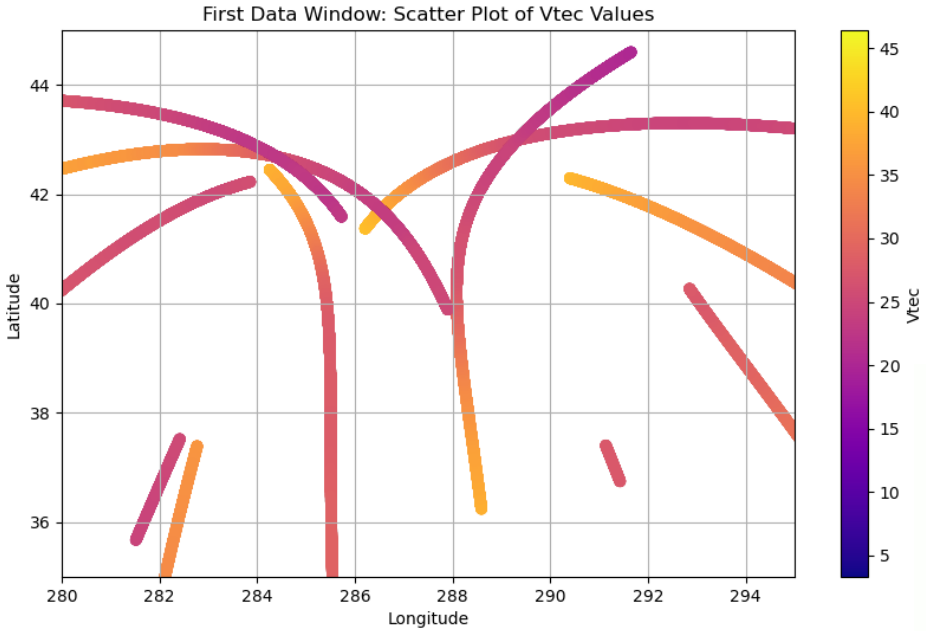


What's the difference between environmental sensors and sies/electro-meters?

1. Installed: 3 x GPS receivers
2. Pending requisition and installation:
    1. Magnetometers and Environmental Sensors
    2. Seismometer
    3. Electrometer

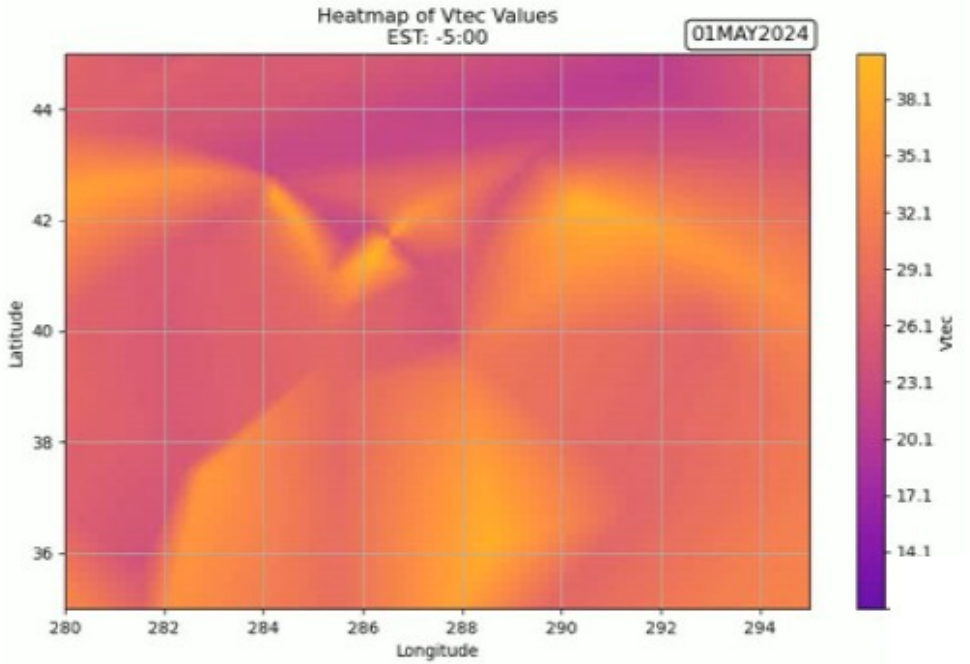
Current Status

Propagation Speed Derivation Methodology



- VTEC Data unbiased by CDT Halfhill
- 4-Hour binning with 15-minute step
- ~500km radius of view
  - > 1 million kilometers of area

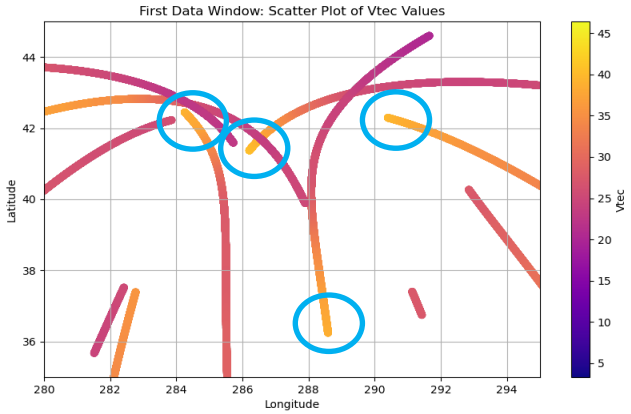
Linear Interpolation between data points



Current Status

Propagation Speed Derivation Methodology (Cont'd)

Step 1: Identify maxima in time bin-1



Step 2: Log time bin-1 maxima information

Maximum	vTEC	Location
#1	1st Highest	Lat-Long 1
#2	2nd Highest	Lat-Long 2
#3	3rd Highest	Lat-Long 3
#4	4th Highest	Lat-Long 4

Step 3: Repeat steps 1-2 for time bin-2

Step 4: Calculate straight line distance between maxima from bin-1 to bin-2 in rank order

Step 5: Repeat step 4 for all maxima in bins and average results.

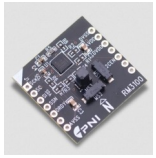
Step 6: Repeat step 1-5 for Bin-2 and Bin-3, Bin-3 and Bin-4, etc. Average the results over desired time period to get TID propagation speed

Maximum #1:
(Bin-1) Lat-Long 1
(Bin-2) Lat-Long 1

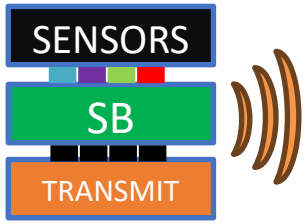
→ Distance Formula → Bin Timestamps w/ Speed Formula → Maxima movement Speed

Future Procurement

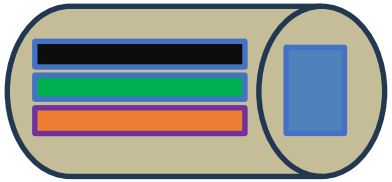
STEP 1:
Run RM3100 and other sensors on standard microcontroller, start programming. (SPI/I2C)



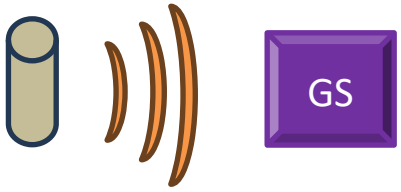
STEP 2:
Start work with LoRaWAN Gateways. Set up remote indoor operation with sensor board and transmitter.



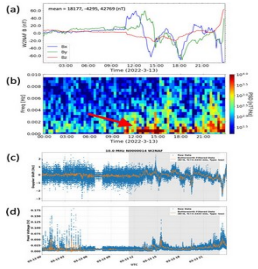
STEP 3:
Design a weatherproof enclosure for the components. Integrate solar panel and battery.



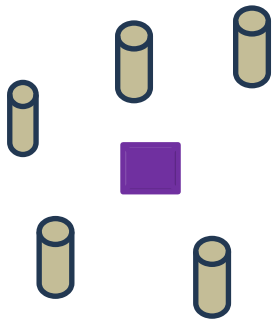
STEP 3:
Install node in tested outdoor location, set up link with rooftop ground station.



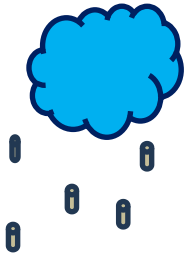
STEP 4:
Test the system and hardware, monitor results remotely.



STEP 5: Repeat, Build a Network of Nodes.



STEP 6: Crowdsource data with HAMSCI Network/Web Server/Machine Learning Algorithm



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