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IonoScope

An Educational Android App to Demonstrate Real-time Ionosphere Measurements

GET IT ON Google Play

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MAJ Kevin T. Filip, Dr. Steven Vitale
United States Military Academy

What is IonoScope?

- An educational Android app available free on the Play Store which uses **dual-frequency GNSS** (L1/L5) raw measurements on commercial smartphones.
- Measures transit delay of two common GNSS frequencies to estimate Total Electron Content (TEC) in the ionosphere.

1. **Educational tool**
2. **Low-cost persistent sensing**

Ionospheric Signal Delay

- The ionosphere behaves as a dispersive plasma where electrons can impact GNSS carrier wave speed [1]

- GNSS signals broadcast on two useful frequencies which have different transit times to a receiver.
  - L1 Band ~ 1575 MHz (less delay)
  - L5 Band ~ 1176 MHz (more delay)
  - **On order of sub 50 ns delays**

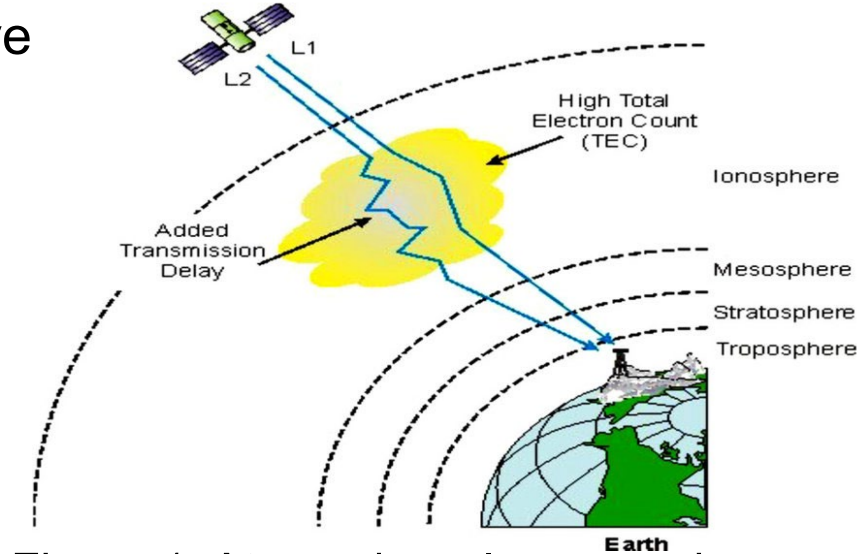


Figure 1. Atmosphere layers and signal delay from TEC (yellow). [2]

- Estimate Slant range Total Electron Content (STEC) [1]
  - Δt_{L5-L1} transit time difference
  - speed of light c
  - a derived quantity
    - $40.3\ m^3 s^{-2} electron^{-1}$

$$STEC = \frac{c\ \Delta t_{L5-L1}}{40.3\ \left(\frac{1}{f_{L5}^2} - \frac{1}{f_{L1}^2}\right)}$$

Smartphone Capabilities

- Newer smartphone hardware and Android APIs support **dual-frequency (L1,L5) GNSS** measurements.
  - **277/742 (~37%) models from 2019-2022 support L1/L5 [3]**
- If we can measure the L1 and L5 GNSS transit times…
- Then we can estimate the Slant TEC of the Ionosphere!
- So, let’s make an app…

App Architecture

- **Capacitor runtime**
  - Bundles the app components
- **Java GNSS Plugin for Android API**
  - Accesses the raw GNSS data
- **Sveltekit**
  - Implements the UI for Learning pages, settings, measurements
  - Also contains the backend for data analysis
- **SQLite**
  - Stores data locally
  - Exports as CSV file, email/shareable.

App uses

Educational tool

1. Learn about the ionosphere and GNSS
2. Use to support Labs investigating ionospheric density

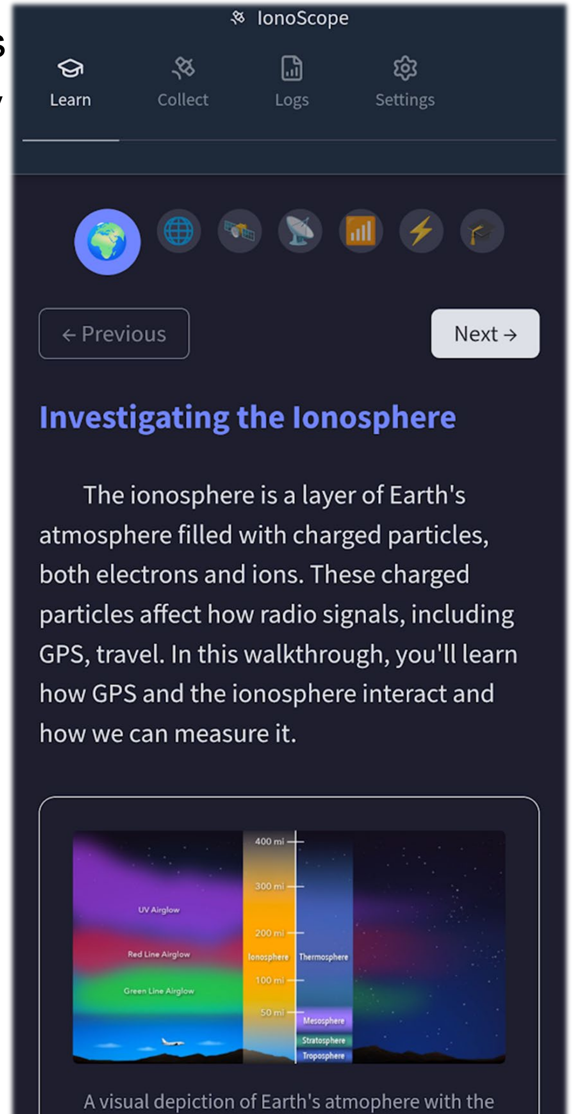
Low-cost persistent sensing

3. Static phones setup for ionosphere measurements

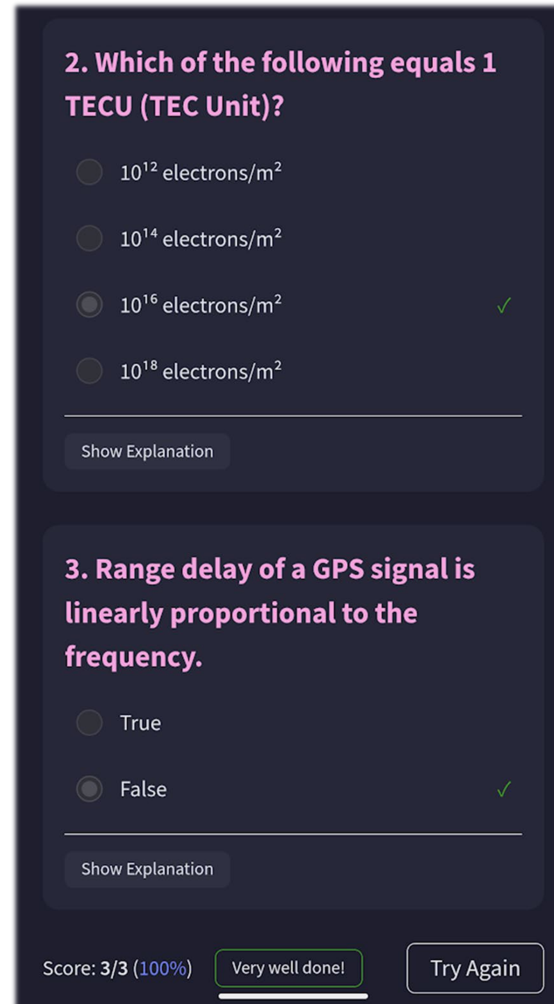
Use 1 - Learning

- **Learn**
  - Ionosphere and GNSS Basics
  - Signal Propagation and Delay
  - Calculating TEC
  - SPACE in mind [4]
    - S: Studying the problem
    - P: Planning investigations
    - A: Analyzing data
    - C: Critical thinking
    - E: Evaluating, and Summarizing
- **Engage**
  - Real-time data output from GNSS signals
  - Figures built in to modules
  - Quiz elements to help connect topics

Lesson Pages



Check on Learning



Use 2 - Labs and Data Analysis

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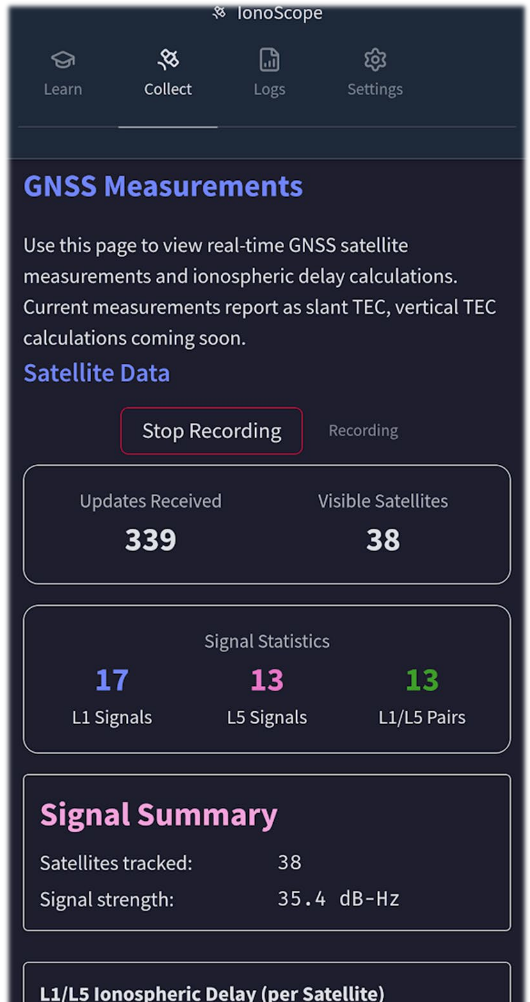
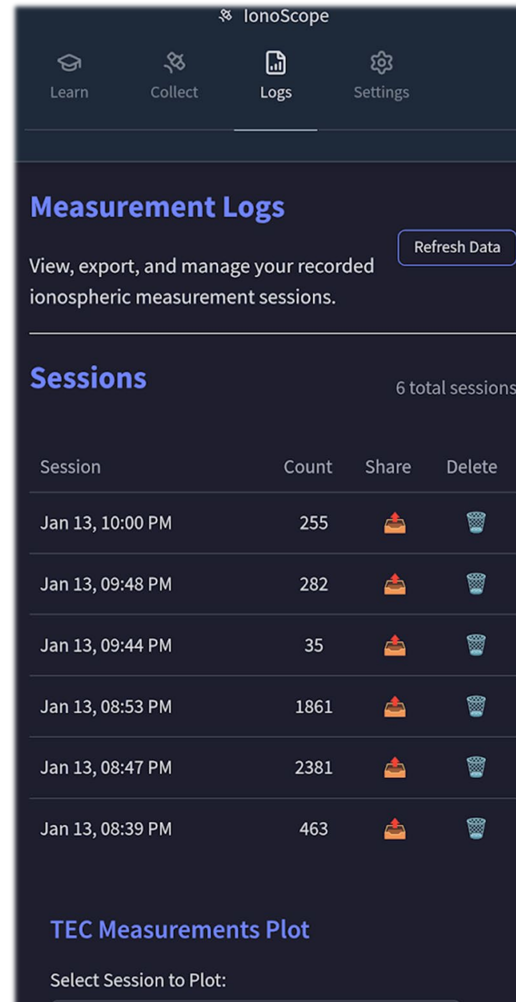
- **Collect data**
  - Real time signal stats
  - Shows user filter impacts
- **View data**
  - Summary data tables
  - Simple graphs
- **Export data**
  - csv format
  - Via normal phone sharing (email, drive saving etc.)
- **Sample Lab Worksheet**
  - Linked in the app and at end of talk
  - Built based on considerations in Freeman [5]

Data Collection



Logs and Export



Use 3 - Low-cost Persistent Sensing

- Purchase a relatively inexpensive android phone
- Setup in a weather shielded area with sky views
- Calculate satellite biases
- Then run for extended time and visualize ionosphere density in ARC-GIS

Eventual goal:

- Data pipeline to collect and export data automatically
- Automatically plot and view ARC-GIS density heatmaps
- Compare with research-grade receivers

Limitations

- Only available on Android
  - Apple doesn’t expose raw GNSS data
- No device specific satellite bias corrections
  - Can result in some satellites with ‘negative’ TEC values
  - Only useful for education right now
- Restricted to newer android phones
  - Must have dual band GNSS capability to fully use the app
- Small research team
  - Updates are slow-going as time and energy are available
  - “Overworked and underpaid”… like most teachers

What's Next?

- **Short-term:**
  - Routine app quality of life improvements
  - Improving data visualization
  - Integrating VTEC calculations into the App
- **Long-term:**
  - Extend to all GNSS constellations (currently GPS and GALILEO)
  - Build in persistent background logging for low-cost sensing
  - Test and incorporate satellite biases for low-cost sensing effort.
  - Compare results to research-grade sensors

References

[1] "Ionospheric Delay - Navipedia." Accessed January 17, 2026. https://gssc.esa.int/navipedia/index.php/Ionospheric_Delay.

[2] Abba, Ibrahim, Wan Azlan Wan Zainal Abidin, Thelaha Masri, Kismet Hong Ping, MS Muhammad, and Bong Voon Pai. "Ionospheric Effects on GPS Signal in Low-Latitude Region: A Case Study Review of South East Asia and Africa." *Nigerian Journal of Technology* 34 (June 2015): 523. https://doi.org/10.4314/njt.v34i3.14.

[3] "Crowd-Sourced List of Android Phones That Support Dual-Frequency GPS: Https://Do... | Hacker News." Accessed January 17, 2026. https://news.ycombinator.com/item?id=32791569. List available at: https://docs.google.com/spreadsheets/d/1jXtRCoEnnFNWj6_oFIVWflsf-b0jkfZpyhN-BXsv7uo/edit#gid=0

[4] Pansong, Chollada, Thanapon Keokhumcheng, Patiphan Sumniang, Wishapol Sittichai, Canjie Huang, and Prasert Kenpankho. "Space STEM Education Guide for Global Positioning System Total Electron Content (GPS TEC)." *2024 9th International STEM Education Conference (iSTEM-Ed)*, July 2024, 1–6. https://doi.org/10.1109/iSTEM-Ed62750.2024.10663134.

[5] Freeman, Ronald H. *Teaching K-12 Particle Physics as an Advocate: A STEM Personal Journey into Radio Wave Science and Technology Research*. n.d.

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Questions?

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Contact:
kevin.filip@westpoint.edu

IonoScope Download

Resources

https://github.com/kfilip10/IonoScope

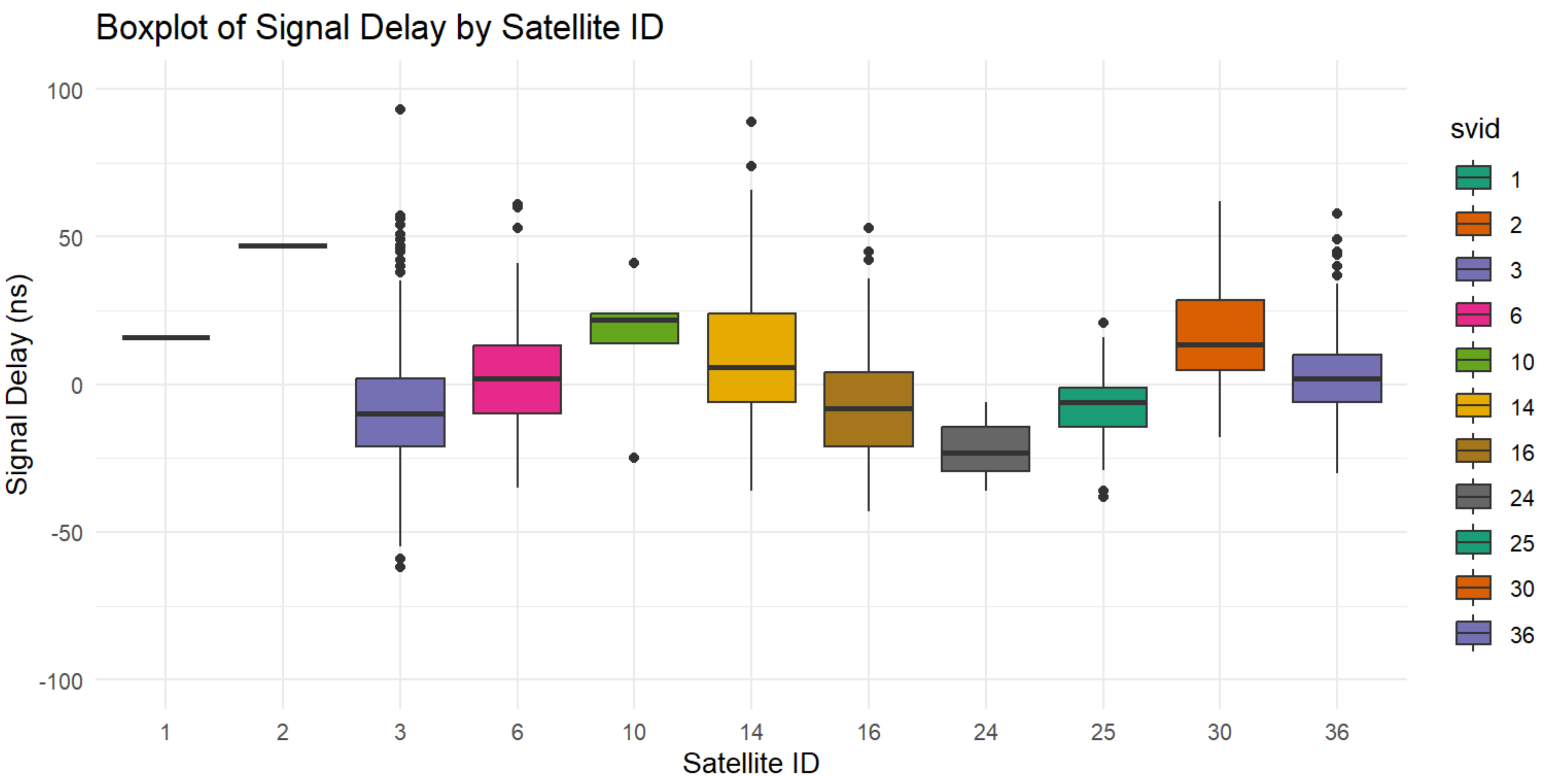
Resources Contains:

- Slides
- Sample lab worksheet
- Sample data from the app

https://play.google.com/store/apps/details?id=com.ktf.ionoscope&hl=en_US

Backup

Sample aggregated data by Satellite for short term sampling window



Data variance shows need for device specific correction factors to achieve low-cost sensing goal.

STEC Calc

$$P_i = \frac{c}{\Delta t}$$ **Pseudorange (1)**

$$I_i = \frac{40.3\ STEC}{f_i^2}$$ **Ionospheric Delay (2)**

$$\Delta P = P_{\mathrm{L5}} - P_{\mathrm{L1}} = I_{\mathrm{L5}} - I_{\mathrm{L1}}$$ **Single Satellite (3)**

$$STEC = \frac{P_1 - P_2}{40.3\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right)}$$ **STEC Calc (4)**
Sub (3) into (2)

Pseudorange vs geometric range errors

$$P_i = \rho + c(dT_b + dT_s) + I_i + T + M_i + \varepsilon_i$$

ρ = geometric range

dT_b = receiver clock error

dT_s = satellite clock error

$\boxed{I_i = \text{Ionospheric delay at frequency } f_i}$

T = Tropospheric delay

M_i = Multipath error

ε_i = Measurement noise

$$STEC = \frac{c\ \Delta t_{L5-L1}}{40.3\left(\frac{1}{f_{L5}^2} - \frac{1}{f_{L1}^2}\right)}$$

STEC Calc based on delay (5)

Sub (1) into (4)

STEC to VTEC

$$VTEC = STEC \cdot \cos \chi \quad (18)$$

- Using Figure 2 we can calculate

The latitude (φ), longitude (θ), and zenith (χ) of the IPP are then given by:

$$\varphi = \sin^{-1}(\sin \varphi_{RX} \cos \beta + \cos \varphi_{RX} \sin \beta \cos \gamma) \quad (19)$$

$$\theta = \theta_{RX} + \sin^{-1}\left(\frac{\sin \beta \sin \gamma}{\cos \varphi}\right) \quad (20)$$

$$\beta = \frac{\pi}{2} - \alpha - \chi \quad (21)$$

$$\chi = \sin^{-1}\left(\frac{R_e \cos \alpha}{R_e + h}\right) \quad (22)$$

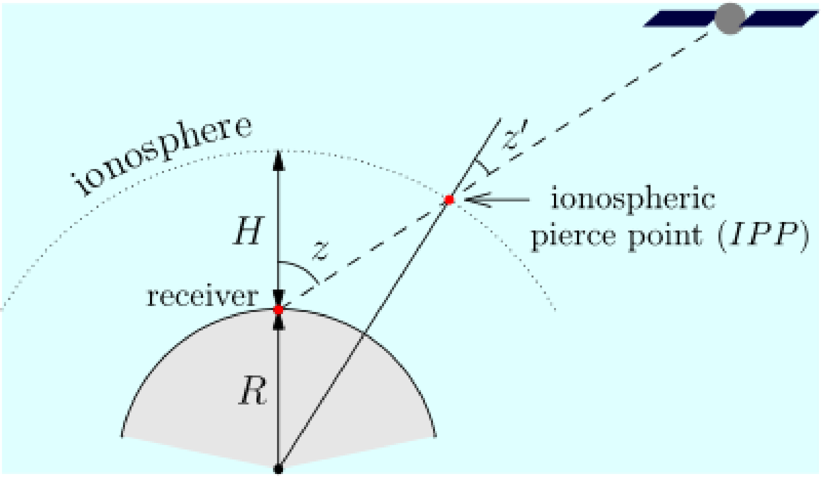


Figure 1: *Ionospheric Pierce Point. The angle z' in the figure corresponds to angle χ in Equation 18.*
https://en.wikipedia.org/wiki/Ionospheric_pierce_point

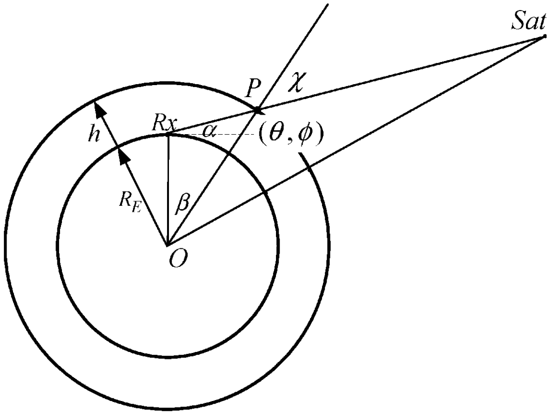


Figure 2: *Diagram for calculating the IPP.*
https://www.mdpi.com/2073-4433/13/2/237