1 IonoScope: Measuring the Ionosphere with GNSS Signals

1.1 Learning Objectives

By the end of this activity you should be able to:

- Interpret real GNSS satellite measurement data.
- Explain how signal travel time depends on the ionosphere.
- Compute and interpret Total Electron Content (TEC).
- Perform basic statistical analysis and visualization in Excel.

1.2 Background (from the IonoScope App)

Smartphones can measure the travel time of radio signals transmitted by navigation satellites. Signals at different frequencies (L1 and L5) travel at slightly different speeds through the ionosphere due to dispersion. This delay can be used to estimate the number of free electrons along the path between the satellite and the receiver.

Key idea:

Different frequencies $\Rightarrow$ different delays $\Rightarrow$ estimate electron density (TEC).

1.3 Part I – Understanding the Dataset

You are given a CSV file exported from IonoScope containing measurements from multiple satellites.

a. How many unique satellites appear in the dataset?

Solution: 12 unique satellites (using unique pairs of svId + constellation)

b. Select one satellite with at least 30 measurements. Record the Satellite ID (svId) and GNSS constellation (GPS, Galileo, etc.).

Solution: Satellite ID: 36

Constellation: GALILEO

c. Go online and determine which country or organization operates this constellation.

Solution: **European Union / European Space Agency (ESA)**

1.4 Part II – Signal Delay Verification

For your selected satellite, choose one measurement (one row).

a. Compute the transit time difference:

$$\Delta t = t_{L5} - t_{L1}$$

If the transit difference is positive that is a physically meaningful and expected result. If negative it indicates the satellite may have a bias adjustment and shows some of the limitations and challenges of using real-world smartphone data.

Solution: For Galileo-36 (example row):

$$t_{L1} = 77{,}998{,}233 \text{ ns}$$
$$t_{L5} = 77{,}998{,}247 \text{ ns}$$
$$\Delta t = t_{L5} - t_{L1} = 77{,}998{,}247 - 77{,}998{,}233 = \boxed{+14 \text{ ns}}$$

This positive value is physically meaningful: the L5 signal (lower frequency) travels slower through the ionosphere than L1 (higher frequency), as expected from dispersion.

b. Compare your result with the provided `signalDelayNanos` column. Do they match?

Solution: Dataset value: `signalDelayNanos` $= 14$ ns

✓ Match confirmed.

c. Report the carrier frequencies for L1 and L5 (in MHz).

Solution:

Signal	Frequency (MHz)
L1	1575.42
L5	1176.45

1.5 Part III – TEC Calculation

The dataset includes a column called `tecApproximate`.

a. Using the frequency values for L1 and L5 and your computed Δt, show how TEC is calculated.

Solution: The dispersive delay relation is:

$$\Delta t = \frac{40.3}{c} \cdot 5\text{TEC} \cdot \left(\frac{1}{f_{L1}^2} - \frac{1}{f_{L1}^2}\right)$$

Solving for TEC:

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

Where:

- $c = 3.00 \times 10^8$ m/s
- Frequencies in Hz (e.g., $f_{L1} = 1.57542 \times 10^9$ Hz)

b. The reported quantity is called “STEC”. What does this acronym stand for?

Solution: STEC = Slant Total Electron Content

This represents the total number of electrons integrated along the *slanted* path from satellite to receiver. (Vertical TEC would be VTEC.)

1.6 Part IV – Statistical Analysis in Excel

Using only your chosen satellite:

a. Compute the mean and standard deviation of TEC. Report your results in TECU.

Note: 1 TECU $= 10^{16}$ *electrons/m*^{2}

Solution: For Galileo-36:

Quantity	**Raw Value**	**In TECU**
Mean TEC	3.26×10^{17} electrons/m^2	**32.6 TECU**
Std Dev	$\sim 3 \times 10^{17}$ electrons/m^2	$\sim$**30 TECU**

Excel formulas:

- Mean: `=AVERAGE(range)`
- Std Dev: `=STDEV.S(range)`

1.7 Part V – Time Series Visualization

a. Create a plot in Excel with `id` on the x-axis and `TEC` on the y-axis. Paste or sketch your plot below.

Solution: *[Student pastes Excel plot here]*

b. Briefly comment on the trend or variability you observe in your plot.

Solution: TEC fluctuates around a roughly constant mean with rapid variations, indicating short-term ionospheric structure and measurement uncertainty. No strong monotonic trend is observed.

1.8 Part VI – Signal Quality (Carrier-to-Noise)

a. Compute the average values of `L1Cn0DbHz` and `L5Cn0DbHz` for your satellite.

Solution:

Signal	Average C/N_0 (dB-Hz)
L1	40.43
L5	36.16

b. Qualitatively describe the signal quality (Excellent / Good / Fair / Poor).
Rule of thumb: > 40 *dB-Hz = Excellent;* 30–40 *dB-Hz = Good;* < 30 *dB-Hz = Poor*

Solution:

- L1: **Good–Excellent** (40.43 dB-Hz)
- L5: **Good** (36.16 dB-Hz)

1.9 Reflection

a. In 2–3 sentences: How does this dataset demonstrate that smartphones can be used as scientific instruments?

Solution: This dataset shows that smartphones can measure precise signal timing from multiple GNSS satellites, detecting nanosecond-scale delays caused by ionospheric electrons. By analyzing dual-frequency signals, we can extract quantitative physical information (TEC) about Earth's upper atmosphere—turning a consumer device into a portable ionospheric sensor.