# CHAPTER 1

# INTRODUCTION

## 1.1 Background

GPS (Global Positioning System), part of the Global Navigation Satellite Systems (GNSS), is a satellite-based navigation system extensively utilized in various applications, including transportation, military operations, and scientific research. The accuracy of GPS signals can be influenced by Total Electron Content (TEC) values and irregularities in the ionosphere, a region of the Earth's upper atmosphere crucial for the propagation of radio signals [4, 10, 12]. The study of ionospheric Total Electron Content (TEC) and irregularities, especially at conjugate points between Indonesia and China, holds significant importance for the telecommunication field. Here is why:

- **Signal Propagation and Quality:** The ionosphere plays a crucial role in the propagation of radio signals, especially those in the High Frequency (HF) and Very High Frequency (VHF) bands. Variations in TEC can cause signal delays, leading to errors in communication systems. When TEC fluctuates, it can cause a phenomenon called a "group delay," where the signal experiences a delay, leading to phase and timing errors. For voice or data communication, this can result in decreased signal quality, dropped calls, or data corruption.
- **Global Navigation Satellite Systems (GNSS) accuracy:** GNSS, which includes systems such as GPS, GLONASS, and GALILEO, relies on signals transmitted from satellites to receivers on the ground or in aircraft. These signals pass through the ionosphere. The speed of the GNSS signal changes as it travels through the ionosphere as a result of the varying electron content. This change in speed causes a delay in the signal arrival time at the receiver. Even small inaccuracies in the signal's travel time can lead to significant positioning errors. For example, a 1-microsecond error in GNSS signal timing can result in a 300-meter positioning error. The ionosphere can introduce additional delays to the GNSS

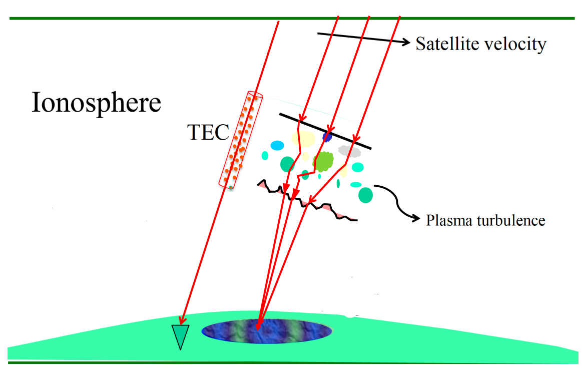


Fig. 1.1: TEC Ionosphere Illustration

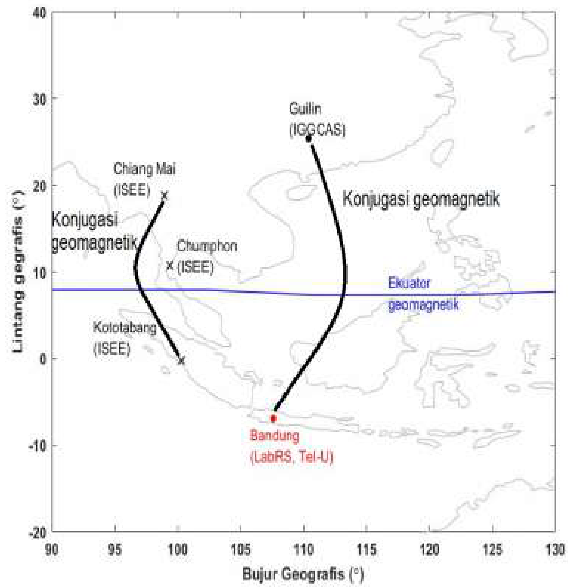


Fig. 1.2: Ionospheric Observation Network between Remote Sensing Lab (Telkom University) in Bandung and IGGCAS in Guilin, China

signal, leading to inaccuracies in the time measurement and consequently the calculated position. By understanding and correcting for TEC variations, GNSS systems can provide more accurate positioning data.

This study focuses on the statistical analysis of the TEC variations between Bandung City, Indonesia, and Guilin City, China, during the period 2021-2022. These two low-latitude cities are hypothesized to have a magnetic conjugate relationship, representing both the Northern and Southern hemispheres. Previous studies have shown that ionospheric phenomena can manifest differently at geomagnetically conjugate points, thereby necessitating a dual-point monitoring system for a more accurate and holistic understanding [7]. Recent advancements in GNSS technology, such as the GNSS Ionospheric Monitor developed by IGGCAS, have enabled more precise monitoring of the ionosphere. The data collected from the device positioned at the INTU station (Telkom University) precisely located at coordinates -6.98N and 107.63E, and the GXGN station (IGGCAS) located at coordinates 25.35N and 110.35E, will be instrumental in this research.

The analysis includes a detailed examination of TEC variations across different satellite systems and the phenomenon of GPS ionospheric irregularities during the 2022 equinox season measured using the Rate of TEC Index (ROTI). Moreover, our research employs data collected from state-of-the-art GNSS Ionospheric Monitors positioned at INTU Station in Bandung and GXGN Station in Guilin. This focus on localized data collection allows for a more precise understanding of TEC variations in these specific regions, marking a methodological advance over prior studies that often rely on more broadly focused or high-latitude data sets.

The findings of this study are designed to contribute to understanding ionospheric behavior in the region and have potential applications in navigation, communication, and space weather monitoring. The research explores the magnetic conjugate relationship between the two cities and includes a comprehensive statistical analysis, enhancing the understanding of ionospheric characteristics and their impact on GNSS signals.

## 1.2 Problem Identification

Signal delays caused by fluctuations in Total Electron Content (TEC) and ionospheric irregularities cascade into communication errors, and amplify positioning inaccuracies—for example, a 1-microsecond error in GNSS signal timing can result in a 300-meter positioning error [11]—and even endanger lives in critical navigation scenarios such as:

- **Aviation Safety:** In aviation, critical navigation scenarios encompass takeoffs, landings, and flight paths in congested airspace. Precision is paramount to avoid collisions, ensure safe landings, and prevent mid-air incidents [1].
- **Maritime Navigation:** Navigating ships through narrow waterways, busy ports, and adverse weather conditions demands precise positioning. Critical navigation is vital to prevent collisions, groundings, and accidents in maritime transportation [16].
- **Emergency Response:** During search and rescue operations, responders rely on accurate navigation to reach distressed individuals swiftly. Inaccurate positioning can delay response times, endangering lives [20].
- **Military Operations:** Military missions often require stealth, precision, and coordination. Accurate navigation ensures troops, vehicles, and aircraft reach their destinations without exposing themselves to unnecessary risks [12].

Previous research has looked into these effects, but there is a requirement to examine these phenomena in particular geographic areas, particularly between cities that are thought to have a magnetic connection.[7].

## 1.3 Research Purpose

To answer the formulation of the problem, the following research objectives will be discussed:

1. Collect ionospheric monitoring data from Bandung station (INTU) & Guilin station (GXGN) for the period 2021 - 2022 using GNSS Ionospheric Monitor device with type of satellite collected data, GPS and Glonass, both in Low Earth Orbit (LEO); Galileo, SBAS, COMPASS, and QZSS, with Galileo in Medium Earth Orbit (MEO) and SBAS, COMPASS, and QZSS in Geostationary Orbit (GEO)
2. Performing statistical analysis of ionosphere data, for the period 2021-2022 to understand the underlying patterns and variations

3. Investigating how GPS ionospheric TEC varies between Bandung and Guilin during the specified period, and exploring the differences in TEC characteristics across different satellite systems.
4. Analyzing the phenomenon of GPS ionospheric irregularities, including the use of the Rate of TEC Index (ROTI) as a measure, during the 2022 equinox season period between the two cities.

In general, this study will provide valuable information on GPS ionosphere studies between Bandung City, Indonesia, and Guilin City, China, which will have important implications for GPS accuracy and understanding of the ionosphere.

## 1.4 Scope of the Problem

The scope of this research is confined to the following aspects:

1. Data Collection: The study is limited to data collected from Bandung (INTU) and Guilin (GXGN) stations using the GNSS Ionospheric Monitor, focusing on the period 2021–2022 and specific satellite systems (GPS, Glonass, Gallileo, SBAS, COMPASS, QZSS).
2. Statistical analysis: The research will perform a detailed statistical analysis of the collected ionosphere data, without venturing into other atmospheric layers or unrelated ionospheric phenomena.
3. TEC Variations: The investigation of TEC variations is confined to the comparison between Bandung and Guilin, focusing on the specified period and satellite systems.
4. Ionospheric Irregularities: The analysis of ionospheric irregularities is limited to the period of the equinox season 2022 between the two cities in the equinox season.

## 1.5 Research Method

1. Data Collection
   (a) Study Locations: Bandung City, Indonesia, and Guilin City, China, were selected as the study locations due to their unique magnetic conjugate relationship and low latitude positioning.
   (b) Instrumentation: The GNSS Ionospheric Monitor developed by IGGCAS was used to collect ionospheric monitoring data from the Bandung station (INTU) & Guilin station (GXGN) for the period 2021–2022. Satellite: The data collection included six satellites, GPS and Glonass, both in Low Earth Orbit (LEO); Galileo, SBAS, COMPASS, and QZSS, with Galileo in Medium Earth Orbit (MEO) and SBAS, COMPASS, and QZSS in Geostationary Orbit (GEO).

(c) Variables: The dataset included variables such as Azimuth angle (AZI), Elevation angle (ELE), Pseudo Random Noise code (PRN), latitude and longitude of the station (Stnlat, Stnlon), Slant Total Electron Content (TECS12), Vertical Total Electron Content (TECV12), and Universal Time (UT).

2. Statistical Analysis

   (a) Data Preprocessing: Raw data were cleaned and pre-processed to remove any noise or inconsistencies.

   (b) Descriptive Analysis: Basic statistical measures were calculated to understand the general trends and characteristics of the TEC variations.

   (c) Comparative analysis: TEC values between Bandung and Guilin were compared to analyze the variations and differences.

   (d) Ionospheric Irregularities Analysis: Using the Rate of Change of TEC Index (ROTI) to measure ionospheric irregularities during the 2022 equinox season period between Bandung and Guilin.

## 1.6 Significance and Novelty of the Study

This research marks a significant step forward in comprehending ionospheric behavior in the specified area, particularly by concentrating on the distinctive magnetic relationship between Bandung and Guilin. An innovative aspect of this investigation is its thorough examination across various satellite systems (GPS, GLONASS, Galileo, SBAS, COMPASS, QZSS), providing a more all-encompassing perspective on irregularities in the ionosphere and fluctuations in TEC. Moreover, incorporating the Rate of TEC Index (ROTI) for both stations during the equinox period in 2022 introduces a time-sensitive dimension to ionospheric research, an area that has received less attention in existing literature.

The methodologies utilized in this study, including the advanced GNSS Ionospheric Monitor at the INTU Station in Bandung—a distinctive feature being its location as the sole ground station below the equator, not only enhance the accuracy and dependability of GNSS-based systems but also represent an innovative addition to the realm of Remote Sensing. This achievement marks a significant advancement in ionospheric research and introduces a new model for gathering and examining data.

Furthermore, the study's findings will be instrumental in fortifying the academic and research capabilities of the School of Electrical Engineering, particularly in the domain of Remote Sensing. The establishment of the new Ground Station (INTU) and the utilization of Devices in Telkom University Bandung symbolize strategic collaboration and technological advancement.

Overall, the study serves as a multifaceted contribution to both academic research and practical applications in navigation, communication, and space weather monitoring, making it a cornerstone for future endeavors within the faculty and the broader scientific community.

## 1.7 Organization of the Thesis

The rest of this thesis is organized as follows:

- **CHAPTER II: LITERATURE REVIEW**
  This chapter describes the literature on Remote Sensing, Ionosphere Monitoring, GNSS Signal, and Ionospheric Irregularities.

- **CHAPTER III: DATA COLLECTION AND METHOD**
  This chapter outlines the data collection process, the input variables, and the methods employed for analysis.

- **CHAPTER IV: ANALYSIS AND DISCUSSION**
  This chapter delves into the analysis process, key findings, and discussions.

- **CHAPTER V: CONCLUSION AND RECOMMENDATION**
  This chapter presents the conclusions drawn from the research and offers recommendations for future research.