MINISTRY OF EDUCATION AND TRAINING
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RESEARCH SOLUTIONS TO DESIGN AND PROCESS GEODETIC NETWORK DATA APPLYING GNSS TECHNOLOGY TO ESTABLISH MILITARY COORDINATE REFERENCE SYSTEM IN VIETNAM

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INTRODUCTION

1. The significance of the research

The reference systems and coordinate systems play a crucial role in ensuring national security and defense, as well as in the economic development and scientific research activities of each country. After more than 20 years of use, the national coordinate system of Vietnam has encountered certain limitations in handling real-time data and managing 3D space on digital platforms for maritime and nearby areas, particularly in military (security-defense) applications.

Therefore, it is essential to research and assess solutions for establishing a military reference system and coordinate system based on modern scientific and technological foundations, as well as the advanced infrastructure that the Department of Cartography and the Ministry of Natural Resources and Environment have equipped or will equip. Alternatively, adjustments can be calculated based on traditional theoretical frameworks while incorporating modern measurement technologies, with the aim of connecting to globally updated reference frameworks.

To meet the current stage's conditions, solutions need to be considered and evaluated from the following key perspectives:

- Historical continuity.
- Present context.
- Future outlook.

2. Research objectives

- Propose a solution for designing a geodetic network using GNSS technology to facilitate the connection between the VN-2000 national coordinate system and the international ITRF coordinate system.
- Provide a solution for least-squares adjustment in processing GNSS data to support the development of a military reference and coordinate system in Vietnam, focusing on solving the problem of determining transformation parameters between the Vietnam coordinate system and the international ITRF coordinate system.

3. Research subjects and scope

- Main research objective: The primary focus is the development of a "Military Reference System and Coordinate System in Vietnam" based on the GNSS CORS (Continuously Operating Reference Stations) network. This involves evaluating solutions for building the system by developing from the national reference system VN-2000 and connecting it to the international ITRF reference system using the GNSS CORS network.
- Scope of research:

+ Theoretical scope: Establish the theoretical foundation for criteria to design solutions for positioning CORS stations within the reference system to meet optimal principles, ensuring reliability, accuracy, and feasibility under Vietnam's conditions. Study the scientific basis for the least-squares adjustment of the GNSS CORS and terrestrial networks, as well as other fundamental problems related to building the reference and coordinate systems.

+ Experimental scope: Develop software for experimental calculation of transformation parameters for the CORS station network covering Vietnam's territory and surrounding maritime areas. Focus on processing and analyzing the coordinate transformation problem and propose solutions to enhance the accuracy of the Geoid model, improving the applicability of modern equipment currently being invested in Vietnam.

4. Research Content

- Study an overview of global reference and coordinate systems.
- Research the equipment systems used in the development of the global reference system (ITRF) and reference systems in several countries within the region. This will serve as the basis for proposing a geodetic network design solution using GNSS technology for building a military reference and coordinate system in Vietnam.
- Propose solutions for processing and least-squares adjustment of GNSS CORS data, thereby developing a theoretical foundation for upgrading and expanding the application of high-precision GNSS coordinate calculations in Vietnam and neighboring areas.
- Focus on experimental calculations using data from GNSS CORS stations managed by the Department of Cartography. Calculate the transformation parameters between the international ITRF coordinate system and the VN-2000 national coordinate system.

5. Research Methods

- Retrospective research method: Collect materials from relevant tasks and studies related to the research direction of the dissertation, as well as search for information in both domestic and international digital libraries.
- Analytical and synthesis method: Analyze information from reference sources, theoretical foundations, and experimental results.
- Mathematical method: Gather theorems and mathematical expressions to prove formulas, build theories, and develop optimal mathematical processing methods for least-squares adjustment and coordinate transformation.
- Expert method: Receive feedback and corrections from the scientific advisor, and consult with scientists and colleagues for input on various issues related to the dissertation content.
- Charting and comparison method: Create charts and compare results and solutions to analyze, evaluate, and identify the optimal approach.
- Experimental method: Use real-world data to carry out calculations, evaluations, and validations of formulas and research hypotheses.

6. Scientific significance and practical significance of the dissertation

- Scientific significance:

+ The research results on the design and processing of GNSS data contribute to enhancing and clarifying the theoretical points of previous studies. The comparative evaluation of results helps elucidate the causes and impacts of error sources on each dataset calculated across Vietnam. This lays the groundwork for proposing the use of

Machine Learning technology to calculate and determine "dynamic" transformation parameters based on duplicate point data.

+ It aids in refining methods for processing to improve the accuracy of data from the national geodetic network.

- Practical significance:

+ It provides a scientific foundation for the application of advanced scientific achievements and fundamental knowledge of modern equipment systems in establishing the military reference and coordinate systems in Vietnam.

+ The results of experimental calculations validate the theoretical foundations, serving as a basis for selecting and constructing the GNSS CORS geodetic control network in a manner that enhances coordinate accuracy in Vietnam.

7. Research Points of the Dissertation

- Research Point 1: Optimal design of the GNSS CORS network to ensure a strong linkage between the military reference and coordinate system in Vietnam and the ITRF system, based on updates to the VN-2000 national reference and coordinate system.

- Research Point 2: Research and development of an algorithm for least-squares adjustment of the GNSS network with CORS stations to support the establishment of the military reference and coordinate system in Vietnam.

- Research Point 3: Solutions for constructing a reliable set of dynamic transformation parameters between the VN-2000 coordinate system and the ITRF coordinate system, serving as a foundation for establishing the military reference and coordinate system in Vietnam.

8. Novel Contributions of the Dissertation

- A scientific foundation has been established for the construction of a military coordinate reference system based on updates to the VN-2000 national coordinate reference system, combined with the addition of GNSS/CORS points in tectonic areas and island regions. An optimal design proposal for the GNSS/CORS network has been suggested, suitable for the territory of Vietnam and linked to the international ITRF coordinate system.

- Research has led to the development of a least-squares adjustment algorithm that integrates GNSS network data with CORS station measurements. A solution has been proposed for determining tidal heights using GNSS technology extended to maritime and island areas, and a combined approach for processing GNSS tidal network data using a constrained adjustment method has been suggested.

- A solution has been identified for constructing software to calculate coordinate transformations from a dynamic perspective between the VN-2000 coordinate system and the GNSS/ITRF systems, laying the groundwork for establishing a military coordinate system based on the VN-2000 system and additional measurements from the GNSS/CORS network.

- The Principal Component Analysis (PCA) method has been employed to assess the relationships and connections between the components of transformation parameters, such as translation, rotation, and distortion ratios. This innovative approach differs significantly from previous studies and helps identify and control the coordinates involved in calculations (coordinates in the VN-2000 system and other coordinate systems).

9. The structure of the dissertation

Aside from the introduction, conclusion, recommendations, references, and appendices, the dissertation is structured into four chapters as follows:

Chapter 1: Overview of research on the design and processing of data using GNSS technology to establish the reference and coordinate system.

Chapter 2: Solutions for designing a geodetic network using GNSS technology to support the establishment of the reference and coordinate system.

Chapter 3: Solutions for least-squares adjustment and processing of GNSS data to support the establishment of the military reference and coordinate system in Vietnam.

Chapter 4: Experimental analysis.

CHAPTER 1: OVERVIEW OF RESEARCH ON DESIGN AND DATA PROCESSING USING GNSS TECHNOLOGY TO ESTABLISH THE REFERENCE AND COORDINATE SYSTEM

1.1. Research on the Construction and Development of Reference and Coordinate Systems

1.1.1. Overview Global Research

The modern national geodetic reference systems of developed countries around the world currently include a network of high-precision permanent GPS stations established within the framework of the International Terrestrial Reference Frame (ITRF).

1.1.2. Overview Domestic Research

In 2005, Bùi Yên Tĩnh defended a doctoral dissertation titled "Establishing and Researching Methods to Improve the Accuracy of Geodetic Reference Points in the Socialist Republic of Vietnam" at the Moscow Institute of Geodesy, Aerial Surveying and Cartography.

In 2011, Nguyễn Văn Đông presented a dissertation on "Establishing and Researching Methods to Enhance the Accuracy of Coordinate Determination in the Socialist Republic of Vietnam" at the Moscow Institute of Geodesy, Aerial Surveying and Cartography.

In 2014, Bùi Thị Hồng Thắm defended her doctoral dissertation at the University of Mining and Geology with the topic "Researching Theoretical Foundations for Modernizing the National Geodetic Control Network in Vietnam Using Global Navigation Satellite System (GNSS) Technology."

In 2018, Lương Thanh Thạch defended his doctoral dissertation at the Vietnam Institute of Geodesy and Cartography, focusing on "Researching Methods for Establishing and Developing the National Spatial Reference and Coordinate System".

1.2. The VN-2000 National Coordinate Reference System and Geodetic Infrastructure in Vietnam

1.2.1. VN-2000 Reference System

On July 12, 2000, the Prime Minister of Vietnam issued Decision No. 83/2000/QĐ-TTg regarding the unified use of the VN-2000 reference and coordinate system nationwide. This decision aimed to standardize geospatial data management and ensure consistency in the application of the VN-2000 system across the country. The implementation of this system is crucial for enhancing the accuracy and reliability of geodetic measurements, thereby supporting various sectors such as land administration, urban planning, and environmental monitoring in Vietnam.

1.2.1.1 Advantages of the VN-2000 Reference System

As a unified reference and coordinate system throughout the country, VN-2000 ensures a high level of mathematical accuracy for applications in surveying, basic map production, geographic data acquisition, and the development of specialized geographic information databases.

1.2.1.2. Disadvantages of the VN-2000 Reference System

- Incomplete Coverage of Land and Maritime Areas: The VN-2000 data has not been computed to encompass the entire territory of Vietnam, particularly due to the lack of data for the offshore and island regions.

- Use of Geoid-96R Model: The VN-2000 national coordinate system utilizes the Geoid-96R model, which may not provide high accuracy, potentially impacting the precision of height measurements and related applications.

1.2.2. Current Status of the Geodetic Network in Vietnam

The evaluation of the geodetic infrastructure in Vietnam and the geodynamic research projects within this framework will focus on the potential for utilizing GPS reference points and establishing physical benchmarks in the field.

1.3. International Reference Systems

1.3.1. International Astronomical Reference System

To study the motion and spatial position of both natural and artificial celestial bodies, including GPS satellites, a standardized inertial reference system is required.

1.3.2. International Terrestrial Reference Frame (ITRF)

The International Terrestrial Reference Frame (ITRF) provides solutions for establishing a reference framework suitable for utilizing measurements taken on or near the Earth's surface.

1.3.3. International Geodetic Reference System 1984 (WGS84)

The World Geodetic System 1984 (WGS84) was established by the U.S. National Geospatial-Intelligence Agency primarily to address problems related to global military mapping.

1.4. Plan for Establishing a Military Reference and Coordinate System

1.4.1. Problem Statement

The issues that need to be substantiated serve as a foundation for evaluating the military reference and coordinate system, which are as follows:

- Legal Basis: Military doctrine, assessment, and forecasts of the situation over the next two decades, approved policies, strategies, and plans for the surveying and mapping sector, the functions and missions of the Mapping Department and the Military Geography Department, and the objectives and tasks that have been approved for the project to establish the military reference and coordinate system.

- Current Status Basis: The application of the VN-2000 reference and coordinate system for the activities of the armed forces: results and existing issues in practice that need to be addressed.

- Practical Basis: Reference models used by other countries and practical experiences from the previous establishment of the reference and coordinate system in Vietnam.

1.4.2. Applications for Military Purposes

1.4.2.1. Ensuring Topographic Data for the Defense Mapping Agency

1.4.2.2. Applications for Tactical Command

1.4.2.3. Applications for Various Military Branches

1.4.3. Plan for Establishing a Military Reference and Coordinate System

1.4.3.1. Basic Criteria

(1) Inheritability: Building upon the achievements and research outcomes of Vietnam and the world, represented by the VN-2000 and ITRF systems. The inheritance of VN-2000 serves as a foundation for developing transformation solutions that meet the military's requirements.

(2) Unity: Establishing a unified coordinate system for command and combat operations. Currently, there are still discrepancies between the data managed by the Navy, Army, and Air Force. It is essential to establish a unified coordinate system for military operations and create conversion relationships between specific activities and the common system.

(3) Operational Scope: The military is tasked with operations across a vast space. Therefore, the military reference frame and coordinate system need to extend its scope. This is why linking with the international coordinate system is necessary.

(4) Security: Meeting the requirements for confidentiality in combat missions, coordination, or mission reporting, as well as in real-time data transmission calculations.

(5) Accuracy: Aligning with the capabilities of technology and equipment while effectively meeting the military's usage needs.

(6) Dynamism: To monitor shifts within the international reference system, thereby facilitating international cooperation and research in Earth sciences.

1.4.3.2. Accuracy Requirements

With today's modern weaponry, the accuracy of modern missiles is typically between 1-2 meters, with a damage radius of several tens of meters. If there are n components of error (such as position, orientation, thrust, etc.), where coordinate and altitude errors are among the main influencing factors, then the accuracy of the control network points serving the construction of the military coordinate reference system will be $\frac{1}{\sqrt{n}}\, metre.$

1.5. Ensure a terrain database for modern weaponry and equipment

1.5.1. Spyder Air Defense Missile System

The Spyder air defense missile system was invested in and put into operation by the Air Defense-Air Force Service around 2014.

1.5.2. Su-30Mk2 flight simulator system

The Su-30Mk2 flight simulator system is equipped for pilots to practice flying before conducting actual flights on the Su-30Mk2 aircraft. This allows pilots to train under conditions related to the aircraft, airfields, terrain, and weather that closely resemble real-life scenarios.

1.5.3. The Bastion-Monolit coastal missile system

The Bastion coastal missile system and Monolit radar have been invested in by the Navy since 2014. The system is supplied by Russia through Rossexpo, and Vietnam receives it through Vaxuco Company.

1.6. Chapter 1 Summary

Chapter 1 provides an overview of the research on the design of networks and data processing using satellite positioning technology to establish the national reference and coordinate system VN-2000, along with other common coordinate systems worldwide. This serves as a scientific basis for researching and developing the military reference and coordinate system of Vietnam, aiming to upgrade the VN-2000 coordinate system from the International Terrestrial Reference Frame (ITRF).

This is an urgent issue that has garnered the attention and direction of the leadership of the Defense Mapping Agency/General Staff in particular, and the Surveying and Mapping sector under the Ministry of Natural Resources and Environment in general. These pressing issues provide the foundation for the researcher to establish their research objectives for the topic report.

The criteria for processing GNSS network data must meet the technical requirements outlined in the circular issued by the Ministry of Natural Resources and Environment. This will serve as a basis for the researcher to handle calculations and evaluate results against references.

Focusing on the critical issues of the topic allows the researcher to identify the core research focus needed to address the problem of establishing a reference and coordinate system in accordance with legal requirements and practical applications for civil, military, and scientific research purposes, as well as international cooperation. This includes a theoretical research direction for designing the positioning of temporary CORS points. Consequently, it is essential to explore the scientific theoretical foundations of GNSS CORS network adjustment problems and other basic issues related to the establishment of the reference and coordinate system.

CHAPTER 2:
SOLUTIONS FOR THE DESIGN OF GEODETIC NETWORKS USING GNSS TECHNOLOGY TO SUPPORT THE ESTABLISHMENT OF THE REFERENCE AND COORDINATE SYSTEM

2.1. Infrastructure for Building Reference and Coordinate Systems Worldwide

2.1.1. GNSS Satellite Positioning Techniques

GNSS (Global Navigation Satellite Systems) positioning is based on measuring the time it takes for signals to travel to determine the distance (or range) between the satellites and the receiver.

2.1.2. Very Long Range Base Interferometry

VLBI (Very Long Baseline Interferometry) is a space geodetic technique based on radio astronomy.

2.1.3. Satellite Laser Ranging

Laser distance measurements are conducted from ground stations to satellites equipped with corner-cube reflectors (SLR - Satellite Laser Ranging) or to retroreflectors on the surface of the Moon (LLR - Lunar Laser Ranging).

2.1.4. Doppler Orbitography and Radiopositioning Integrated by Satellite

DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) uses the Doppler effect to determine the distance between ground stations and satellites orbiting the Earth.

2.1.5. Gravimetry

Gravity (also known as gravitational force) is the force that binds all matter on the Earth's surface, with mass and weight influenced by the centrifugal acceleration caused by the Earth's rotation.

2.2. The infrastructure for establishing the reference coordinate system in some countries around the world

2.2.1. Canada

In Canada, the application of satellite positioning stations in updating and upgrading the national coordinate system has been published and demonstrated, showing accuracy when linked to other coordinate systems worldwide.

2.2.2. China

The China Geodetic Coordinate System 2000 (CGCS2000) and the coordinate reference frame have been in effect since July 1, 2008. CGCS2000 is a reference frame based on ITRF97, with the epoch of the reference frame set to January 1, 2000.

2.2.3. Korea

In 2007, South Korea officially adopted the KGD2002 reference frame, which is connected to the International Terrestrial Reference System (ITRS).

2.3. Assessment of equipment for the development of the coordinate reference system in Vietnam

2.3.1. The GNSS CORS (Continuously Operating Reference Stations) base station system

Among the 65 CORS stations that have been built and put into operation, 24 Geodetic CORS stations are designed with deep-drilled concrete pillars reaching stable layers (which can be as deep as 50m-60m), evenly distributed across the country. The distance between these stations ranges from 150-200km, and they are used as the national reference framework, for research, determining Earth's crust movements, as well as ground uplift and subsidence with millimeter-level accuracy. The remaining 41 NRTK CORS (Real-Time Kinematic stations) work in combination with the 24 Geodetic CORS stations to provide real-time kinematic measurement services, with distances between stations ranging from 50-70km, located in the Red River Delta, Southern Delta, and the coastal areas of Central Vietnam.

2.3.2. Military control network

In 2004, before the completion of the national geodetic network, the military control network had been surveyed in several areas such as Thanh Hoa and Yen Bai. The surveying method began from the points of the control network established by the French in the past. The processing of measurement results (including coordinate transformation) was carried out using classical methods.

2.4. Design Solutions for GNSS Geodetic Network to Support the Construction of a Reference Coordinate System

The design of the fundamental geodetic network is essential and crucial before implementing it in the field. Depending on the purpose of each network, there will be different criteria, but the most basic requirements are: accuracy, the ability to detect and filter out gross errors, and the ability to provide information for monitoring purposes.

2.4.1. Criteria for GNSS Network Design

2.4.1.1. Accuracy Criteria

To design a GNSS network that meets quality and applicability criteria, the accuracy criterion is the most important.

2.4.1.2. Reliability Criteria

A network is considered optimally reliable, in addition to meeting accuracy criteria, when it can detect gross errors and minimize the impact of errors at GNSS points.

2.4.1.3. Implementation Cost Criteria

The third criterion that ensures the optimal design of the network is the implementation cost criterion. Unlike the previous two criteria, the cost criterion always aims to achieve the minimum value. The relationship between accuracy and reliability criteria is often inversely proportional.

2.4.1.4. Sensitivity Criteria

For the criteria for establishing a monitoring network for deformation or tectonic array displacement, such as the GNSS CORS station network, sensitivity criteria are also considered an important aspect of the design.

2.4.2. Solutions for Optimizing GNSS Network Design

In optimizing the GNSS network, the covariance matrix of the measurement points system contains information about accuracy as well as information about the correlation between the measurement points.

2.4.3. Proposed solutions in Vietnam

2.4.3.1. Tectonic blocks in the territory of Vietnam

According to the report from the Institute of Geology and Mineral Resources, the territory of Vietnam can be divided into five tectonic structural blocks, namely the Northeast block; the Muong Te block; the Northwest - North Central block; the South Central - South block; and the East Sea block.

2.4.3.2. Proposal for the design of GNSS CORS network

The design of a GNSS CORS (Continuously Operating Reference Station) system must take into account the displacement of tectonic plates in Vietnam. Therefore, it is essential to establish a CORS network with the following minimum criteria:

- CORS stations should be located in the stable part of each block, and the foundation of the system must prioritize drilling down to the bedrock. In areas where drilling to bedrock is not feasible, choosing suitable locations based on actual conditions is also considered an optimal solution.
- Each block has a large structure, so a minimum of three CORS stations should be arranged to accurately calculate displacements according to the block.
- Data processing and construction of a database for the national GNSS network should be established to calculate and connect control points for managing accumulated errors in the system.
- These CORS stations will be calculated to be linked with Class 0 reference points in Vietnam and will be established as a control station network.
- Additional CORS stations should be densely arranged in the area and can be designed along fault lines, allowing for regular calculations that enable easy adjustments of displacement parameter values for each tectonic structure.

In the future, it is proposed to select points from the national CORS network to participate in the IGS (International GNSS Service) to enhance the accuracy of the national CORS network while leveraging the advantages of the International Terrestrial Reference Frame (ITRF). These CORS points will be connected, calculated, and managed according to the state regulations on international research cooperation, while ensuring security in national defense missions.

2.5. The current situation in the military

Nowadays, civilian infrastructure relies increasingly on GNSS positioning systems. The weapon systems and equipment used by the military also primarily utilize satellite positioning for guidance. Intelligence information and imagery are collected by satellites and transmitted to operational centers around the world.

2.6 Chapter 2 Summary

The doctoral candidate has presented several systems of equipment serving the construction of reference coordinate systems worldwide. By examining each technological solution in detail and comparing it with the equipment available in Vietnam, the researcher will focus on solving the problem of establishing a coordinate reference system in Vietnam that is most compatible with the existing data. This involves building a transformation parameter set to connect the ITRF reference coordinate system to upgrade and develop the national VN-2000 coordinate system based on the coordinates of GNSS CORS points, which will serve as a foundation for developing the military coordinate system in Vietnam based on the upgraded VN-2000 version.

Chapter 2 has outlined the theoretical basis and criteria for designing the locations of temporary CORS points within the reference system, ensuring optimal principles related to reliability, accuracy, and construction values in Vietnam. This provides a practical theoretical foundation for managers to plan and develop investment strategies for the Geodesy and Mapping sector. To achieve this, establishing a CORS control network is based on studying the main tectonic plates in Vietnam, which helps ensure the stability and optimal design of the CORS stations, meeting all technical criteria set out in national security and defense tasks. Understanding the mechanism and security solutions for connecting calculations between the satellite positioning system managed by the Ministry of Natural Resources and Environment and the positioning system managed by the Department of Mapping and Geographic Information also requires attention.

In this section, the researcher has also introduced several systems of modern weaponry and equipment, while discussing their usage and application in the context of Vietnam. Assessing the technologies that support GNSS solutions in combat is essential and is a current trend. The doctoral candidate has briefly presented the ELORAN technology solution and the method for establishing military coordinates in combat. This provides a broader perspective on the problem of building a Reference System - Coordinate System, including application solutions and practical applications to propose directions for developing support systems for the military coordinate reference system. However, the dissertation will delineate the research scope and assign weighting to each specific task

CHAPTER 3.
SOLUTIONS FOR CALCULATING ADJUSTMENTS IN GNSS DATA PROCESSING FOR THE ESTABLISHMENT OF A COORDINATE REFERENCE SYSTEM - MILITARY COORDINATE SYSTEM

Through the research process and the direction of Professor Dr. Hoàng Ngọc Hà, the PhD candidate will propose and focus on presenting solutions for calculating adjustments to upgrade the VN-2000 coordinate system, as well as new interpolation methods compared to the previously used interpolation methods. This will serve as the basis for developing a reference system - military coordinate system suitable for the conditions of Vietnam.

3.1. VN-2000 coordinate reference system

The problem of determining the reference system and coordinate system can be reduced to its basic form as follows:

1. Identify a reference ellipsoid with appropriate dimensions (semi-major axis aaa and semi-minor axis bbb, or semi-major axis aaa and flattening f=((a-b) /a) that is properly positioned in space by determining the coordinates of the ellipsoid's center (X0, Y0, Z0) in the global system. For a global ellipsoid, physical parameters must also be determined: gravitational constant GM, mass of the Earth M, rotational speed of the Earth ω\omegaω, normal gravitational potential U0, normal gravity at the equator γe, and at the poles γp.

2. Determine the appropriate transformation from the ellipsoidal reference system to the planar reference system to establish a national basic map system, including the division of sheets and the nomenclature for each map sheet according to different scales.

3. Rigorously process the coordinate grid of points, including all relevant measurement values, to ensure the highest level of accuracy.

3.2. Solutions for adjustment calculations in data processing

3.2.1. Methods for calculating the planar grid

3.2.1.1. Mixed adjustment of the planar grid and GNSS with CORS station points

Nowadays, with the strong development and convenience of GNSS systems, geodetic networks are being constructed more diversely through the use of traditional technology combined with GNSS data. Theoretically, processing data is more rigorous and simpler when conducted in geocentric and geodetic coordinate systems. However, achieving high accuracy in determining geodetic heights remains challenging due to the computation of height anomalies associated with the completion of the gravity network and Geoid model in Vietnam. In practice, mixed adjustment calculations of terrestrial and GNSS networks are still performed separately for horizontal and vertical components.

In recent years, alongside the development of GNSS technology, CORS stations have been established and widely disseminated throughout the country. Therefore, there is a need to research and supplement algorithms for processing a mix of terrestrial measurements such as angle and distance measurements, satellite measurements like baselines, and data from CORS stations to address practical issues in surveying and mapping engineering tasks.

3.2.1.2. Conditional adjustment with hidden variables in mixed processing of GNSS leveling networks

To achieve the goal of modernizing the elevation system, an important objective is to connect the elevation lines of state-level Class I and Class II networks with GNSS CORS station points and state gravity points. Currently, our country is using the Geoid model 2010, which is built on the basis of the global Geoid model EGM2008, supplemented with data from over 30,000 detailed gravity points and more than 800 GPS-leveling points. The processing of combined GNSS-leveling data and gravity Geoid models to upgrade the local Geoid model to achieve high accuracy (around 4 to 10 cm) may allow for the application of satellite-based height measurement technology to gradually replace traditional leveling technology in determining heights with accuracy classes III and IV, which is an urgent task for surveying and mapping in our country.

Regarding data processing to upgrade the Geoid model, there are many documents, both domestic and international, that address this issue. These documents mainly discuss the application of models for interpolation functions, such as the Collocation method, first and second-degree linear functions, or spline functions.

3.2.2. Methods for calculating leveling heights networks

3.2.2.1. Solutions for determining leveling heights using GNSS technology

Vietnam is a country with a long coastline and a diverse system of islands and coastal islets. Therefore, transmitting leveling heights to the islands is a unique and challenging task when applying geometric leveling solutions. The current VN-2000 coordinate system, according to reports, only fully addresses part of the land area. With the application of GNSS technology, LiDAR data acquisition technology for land and island areas, as well as seabed model data using modern echo sounding methods, the calculation of transmitting leveling heights from land to islands using satellite-based height measurement technology with upgraded global gravity models like EGM2008 is becoming increasingly feasible.

3.2.2.2. Geoid interpolation algorithms

a. Kriging

Kriging is a group of techniques used in geostatistics to interpolate the value of a random field at unmeasured points based on nearby measured points.

b. IWD

The IDW (Inverse Distance Weighting) method determines the values of unknown points by calculating the weighted average of the distances of the values from known points in the neighborhood of each unknown point.

c. Natural Neighbor

Natural Neighbor interpolation is a spatial interpolation method developed by Robin Sibson. This method is based on the Voronoi grid of a set of discrete spatial points.

3.3. Solutions for processing GNSS data

3.3.1. Technology and equipment for measuring coordinate networks

Three-dimensional (3D) coordinate network measurement technology is based on GNSS technology; it receives satellite signals from the International GNSS Service (IGS) and uses specialized software to measure and calculate the coordinates and geodetic heights for various points.

3.3.2. Technical regulations for coordinate measurement using GNSS technology

Provide requirements to ensure that the collected data has the highest reliability.

3.3.3. Solutions for processing GNSS data

The main task is to perform a mixed adjustment calculation in the WGS84 coordinate system with the International Terrestrial Reference Frame (ITRF).

3.4. Solutions for determining the transformation parameter

The transformation of GNSS measurement results in the ITRFyy reference frame to the VN-2000 coordinate system can be performed using different transformation models. According to Bursa-Wolf:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \ (1+s) R_Z\,(\omega_Z) R_Y\,(\omega_Y) R_X\,(\omega_X) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (3.43)$$

Where:

$$R_X\,(\omega_X) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega_X & \sin\omega_X \\ 0 & -\sin\omega_X & \cos\omega_X \end{bmatrix}$$

$$R_Y\,(\omega_Y) = \begin{bmatrix} \cos\omega_Y & 0 & -\sin\omega_Y \\ 0 & 1 & 0 \\ \sin\omega_Y & 0 & \cos\omega_Y \end{bmatrix}$$

$$R_Z\,(\omega_Z) = \begin{bmatrix} \cos\omega_Z & \sin\omega_Z & 0 \\ -\sin\omega_Z & \cos\omega_X & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

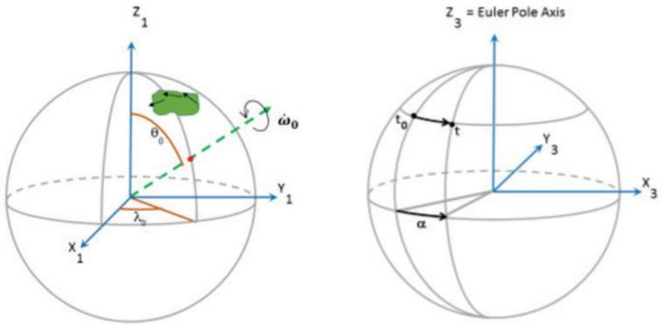

Figure 3. 1: Transformation parameters from a dynamic perspective

However, when determining the transformation parameters between the ITRF GNSS network coordinates and the VN-2000 coordinate system, it is necessary to consider the velocity of tectonic plate movement. Therefore, the transformation formula using 7 parameters according to Bursa-Wolf (3.43) will no longer be suitable and must be converted to a 14-parameter transformation:

$$\begin{bmatrix} x(t) \\ y(t) \\ z(t) \end{bmatrix} = \begin{bmatrix} T_x(t) \\ T_y(t) \\ T_z(t) \end{bmatrix} + \left(1 + s(t)\right) R_Z\left(\omega_Z(t)\right) R_Y\left(\omega_Y(t)\right) R_X\left(\omega_X(t)\right) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (3.44)$$

Where:

$$\begin{bmatrix} T_x(t) \\ T_y(t) \\ T_z(t) \\ s(t) \\ \omega_X(t) \\ \omega_Y(t) \\ \omega_Z(t) \end{bmatrix} = \begin{bmatrix} T_x(t_0) + (t - t_0)\dot{T}_x \\ T_y(t_0) + (t - t_0)\dot{T}_y \\ T_z(t_0) + (t - t_0)\dot{T}_z \\ s(t_0) + (t - t_0)\dot{s} \\ \omega_X(t_0) + (t - t_0)\dot{\omega}_X \\ \omega_Y(t_0) + (t - t_0)\dot{\omega}_Y \\ \omega_z(t_0) + (t - t_0)\dot{\omega}_z \end{bmatrix}$$

and

$$R_{ZYX}(t) = \begin{bmatrix} \cos\omega_Y \cos\omega_Z & \cos\omega_Z \sin\omega_X \sin\omega_Y + \cos\omega_X \sin\omega_Z & -\cos\omega_X \cos\omega_Z \sin\omega_Y + \sin\omega_X \sin\omega_Z \\ -\cos\omega_Y \sin\omega_Z & \cos\omega_X \cos\omega_Z - \sin\omega_X \sin\omega_Y \sin\omega_Z & \cos\omega_Z \sin\omega_X + \cos\omega_X \sin\omega_Y \sin\omega_Z \\ \sin\omega_Y & -\cos\omega_Y \sin\omega_X & \cos\omega_X \cos\omega_Y \end{bmatrix}$$

If we can establish a system for continuous and regular updates, then the angle α (the angle of the corresponding vector of tectonic plate movement) will be very small and can be considered as 0. In this case, the transformation formula will simplify to a more straightforward form:

$$\begin{bmatrix} X(t) \\ Y(t) \\ Z(t) \end{bmatrix}_{VN2000} = \left\{ I + (t - t_0) \begin{bmatrix} 1 & \dot{\omega}_Z & -\dot{\omega}_Y \\ -\dot{\omega}_Z & 0 & \dot{\omega}_X \\ \dot{\omega}_Y & -\dot{\omega}_X & 0 \end{bmatrix}_{VN2000} \right\} \begin{bmatrix} X(t) \\ Y(t) \\ Z(t) \end{bmatrix}_{ITRF} \quad (3.45)$$

Because of:

$$\cos(\omega_X(t)) \approx 1 \qquad \sin(\omega_X(t)) \approx \omega_X(t)$$
$$\cos(\omega_Y(t)) \approx 1 \qquad \sin(\omega_Y(t)) \approx \omega_Y(t)$$
$$\cos(\omega_Z(t)) \approx 1 \qquad \sin(\omega_Z(t)) \approx \omega_Z(t)$$

3.5. Chapter 3 Summary

The doctoral candidate has presented solutions for calculating the adjustment of GNSS geodetic networks and the problems related to establishing reference systems and coordinate systems. With the development of ground surveying and GNSS technology, geodetic networks have become more diverse. This brings about the requirement for calculation methods and data processing to be flexible while still ensuring theoretical rigor.

In this chapter, the doctoral candidate has proposed a mixed adjustment algorithm for traditional horizontal networks, incorporating baseline measurements that are transformed into the plane and include GNSS CORS points based on the adjustment theory with original data errors and retroactive adjustments. The algorithm allows for a rigorous adjustment of mixed networks and can be broken down into steps for analysis and evaluation of the network's measurement quality. The calculation results affirm the reliability of the algorithm. The research has experimentally computed adjustment problems in the geocentric coordinate system, which has the advantage of being based on the center of the Earth, with the coordinate axes defined according to conventional dimensions to facilitate the representation of points on the Earth's surface. Therefore, the X, Y, Z coordinate structure is suitable for complex calculations in the problem of coordinate transformation on a global scale. The problems are introduced through a scientific theoretical basis, thus serving as a foundation for building coordinate systems in the future.

The proposal suggests using GNSS data to calculate the transmission of tide gauge elevations, especially in coastal and island areas. This is an urgent issue, given that Vietnam has a long and narrow land terrain, while the sea and island regions cover an area three times larger than the land, making the transmission of tide gauge elevations through geometric height measurement impractical.

The proposal includes a solution for managing map databases based on the principles of linear and nonlinear shifts between evaluation and processing times. This is an important and urgent issue in developing solutions to apply "dynamic" transformation parameters in the current digital transformation phase in Vietnam.

CHAPTER 4. SCIENTIFIC EXPERIMENTATION

4.1. Calculating Adjustment for Connecting the CORS Station System with the IGS Station System

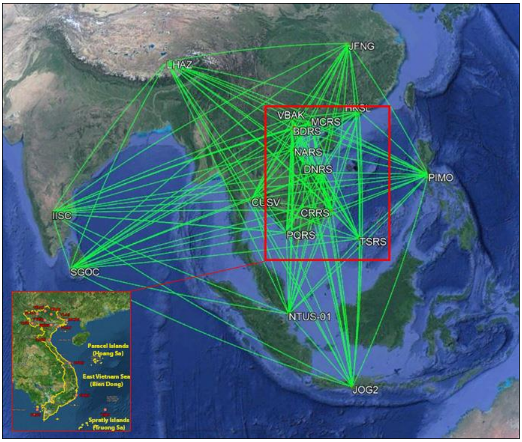

Figure 4.1: Diagram of Measurement Point Position Connected to IGS Station

We have the following observations:

- The mean error of the position of the points in the adjusted network is less than 3 mm.

- The deviations in latitude, longitude, and geodetic height after calculation indicate a coordinate change of approximately 4 cm/year and a height change of about 1 cm/year for points in the International System. Considering the absolute values (magnitude), these values are consistent with studies on tectonic plate movement. The relatively large change in coordinate values highlights the need for frequent updates of coordinates within the International System.

4.2. Determining the Coordinate Transformation Parameter

4.2.1. Determining the 7 Transformation Parameters Between the International GNSS Network Coordinates (ITRS Reference System) and the VN-2000 Reference System

The calculation of transformation parameters is carried out at two levels: one level only uses national GNSS reference frame points (which may include points/stations on islands) and the other at the national GNSS network level.

4.2.1.1. Determining Coordinate Transformation Parameters Based on Random Points

Using Python programming language to generate a dataset of random duplicate points based on the assumption of differences in computational accuracy, in order to assess the relationships between the number of duplicate points and the accuracy of the duplicate points (noise) when constructing the transformation parameters.

4.2.1.2. When using 14 CORS points to calculate transformation parameters

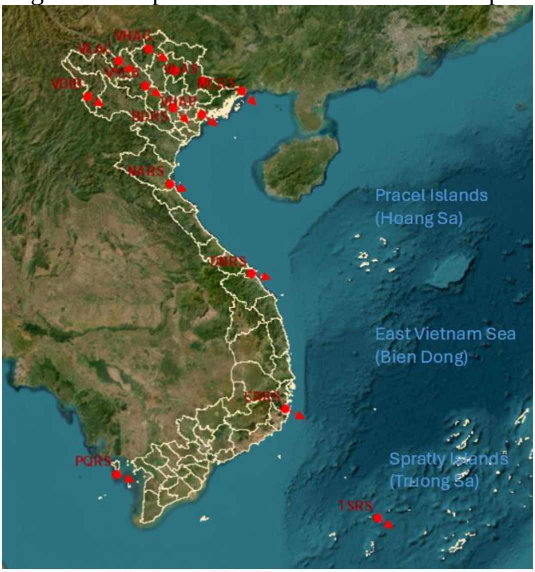

Figure 4.2: Direction of displacement of the 14 measurement points

Table 4.1: Transformation parameters calculated using 14 CORS points

No	Parameter	Value	Units
1	Translation on X	200.430146	m
2	Translation on Y	37.619010	m
3	Translation on Z	118.817630	m
4	Rotation on X	0.248591160175	["]

5	Rotation on Y	0.109019952415	["]
6	Rotation on Z	-0.229255646386	["]
7	Scale	0.143193561250	[ppm]

Standard deviation of the weight unit So = 1.06184752 m

Three solutions for calculating transformation parameters were tested using 14 CORS points, with calculations performed for 12 CORS points on the mainland and 7 CORS points in the northern region to compare and evaluate the results. The transformation parameter calculation results show significant differences in the Earth's center shift values, possibly due to the uneven accuracy of VN-2000 processing data across regions. The comparison with the results from the 2017 study by the Vietnam Institute of Geodesy and Cartography and the 7 parameters published in 2000 is as follows:

Table 4.2: Comparing the Results of Calculating 7 Parameters from WGS84 to VN-2000

No	Parameter	Government of Vietnam published values in 2000 year	Values Calculated by the Vietnam Institute of Geodesy and Cartography in 2017	Units
1	Translation on X	191.90441429	204.511083	m
2	Translation on Y	39.30318279	42.192468	m
3	Translation on Z	111.45032835	111.417880	m
4	Rotation on X	-0.00928836	-0.011168229	["]
5	Rotation on Y	0.01975479	0.085600577	["]
6	Rotation on Z	0.00427372	0.400462723	["]
7	Scale	0.252906278	0.00000	[ppm]

The results of the calculations indicate significant displacement errors in the VN-2000 coordinate system. When using the coordinate system based on the fundamental land registration points or GNSS network points established and calculated according to the seven transformation parameters provided by the Ministry of Natural Resources and Environment, it will no longer be suitable for calculating data connections and conversions with the international coordinate system as of the present time.

4.2.2. Determining 14 Transformation Parameters Between International GNSS Network Coordinates and the National VN-2000 Coordinate System

First, we calculate and determine the transformation parameters between the ITRF versions to serve as a basis for selecting the appropriate time to establish the reference version.

Calculating according on 14 pairs of duplicate points, we obtain the following results:

Table 4. 3: Results of the transfer parameter calculations from VN-2000 to ITRF

Frame ITRFx	Frame ITRFy	ΔX (mm) *$\Delta X1$(mm/n)*	ΔY (mm) *$\Delta Y1$(mm/n)*	ΔZ (mm) *ΔZ 1(mm/n)*	*k* (10 - 9) *k1 (10- 9/n)*	ωX (mas) *$\omega X1$(mm/n)*	ωY (mas) *$\omega Y1$(mm/n)*	ωZ (mas) *$\omega Z1$(mm/n)*	Epoch
VN-2000	ITRF2014	200.3650	37.5659	119.1408	-24.2668	0.3840	0.4421	-0.5777	2017
		0.0790	0.0360	-0.0188	-0.1600	0.8500	-1.3300	3.5200	
VN-2000	ITRF2008	200.3666	37.5678	119.1432	-24.2668	0.3840	0.4421	-0.5777	2017
		0.0790	0.0360	-0.0189	-0.1600	0.8500	-1.3300	3.5200	

Frame ITRFx	Frame ITRFy	ΔX (mm) $\Delta X1$(mm/n)	ΔY (mm) $\Delta Y1$(mm/n)	ΔZ (mm) ΔZ 1(mm/n)	k (10 - 9) $k1$ (10- 9/n)	ωX (mas) $\omega X1$(mm/n)	ωY (mas) $\omega Y1$(mm/n)	ωZ (mas) $\omega Z1$(mm/n)	Epoch
VN-2000	ITRF2005	200.3691	37.5669	119.1385	-23.2968	0.3840	0.4421	-0.5777	2017
		0.0793	0.0360	-0.0189	-0.1600	0.8500	-1.3300	3.5200	
VN-2000	ITRF2000	200.3662	37.5676	119.1057	-21.6968	0.3840	0.4421	-0.5777	2017
		0.0791	0.0361	-0.0207	-0.0800	0.8500	-1.3300	3.5200	
VN-2000	ITRF97	200.3729	37.5629	119.0620	-19.9668	0.3840	0.4421	-0.2177	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF96	200.3729	37.5629	119.0620	-19.9668	0.3840	0.4421	-0.2177	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF94	200.3729	37.5629	119.0620	-19.9668	0.3840	0.4421	-0.2177	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF93	200.3006	37.5687	119.0686	-19.4768	-2.9760	-3.8879	0.1723	2017
		0.0762	0.0359	-0.0213	-0.0700	0.7400	-1.5200	3.5900	
VN-2000	ITRF92	200.3809	37.5649	119.0540	-20.6768	0.3840	0.4421	-0.2177	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF91	200.3929	37.5789	119.0480	-19.2768	0.3840	0.4421	-0.2177	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF90	200.8064	38.1614	117.5620	89.3232	0.3840	0.4421	0.3823	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF89	200.7364	37.6454	117.1640	139.2232	1.8840	0.4421	0.3823	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	
VN-2000	ITRF88	200.3894	37.5704	119.0180	-13.8268	0.4840	0.4421	-0.5177	2017
		0.0791	0.0355	-0.0221	-0.0700	0.8500	-1.3300	3.5400	

Table 4.3 presents the results of calculations based on data from two cycles from 2017 to 2019 (data provided by the Mapping Department), calculating the 7 transfer parameters for coordinates and the corresponding 7 velocity parameters (between ITRF reference frames with updated calculations and shifts at each point in time). The Principal Component Analysis (PCA) method is used to determine the linear relationship of the calculated results in Table 4.3.

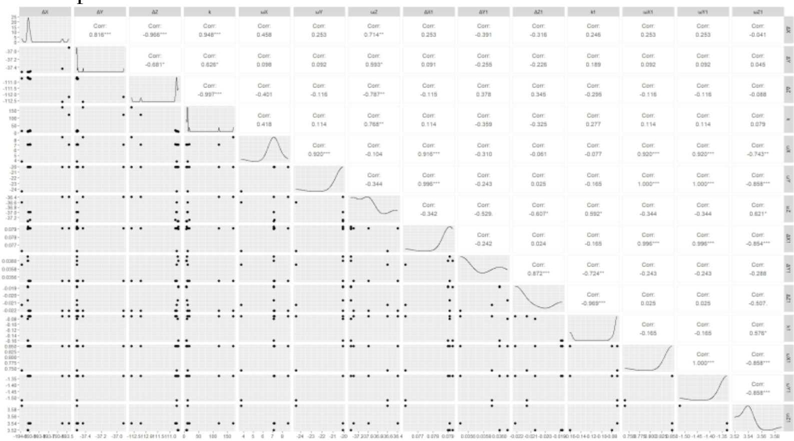

Figure 4.3: Correlation relationships of each component in the transformation parameter

The PCA algorithm, in essence, is a dimensionality reduction problem aimed at finding a new feature space that maximizes the variance of the data in that new space. It then selects nnn dimensions with the highest variance, facilitating the correlation analysis of the data.

4.3. Calculate supplementary height interpolation for the Geoid model based on ground measurement points with precise height data

With the input dataset comprising GNSS precise height measurement points and LiDAR data, the researcher proposes the following solution for interpolation to construct a local Geoid height model:

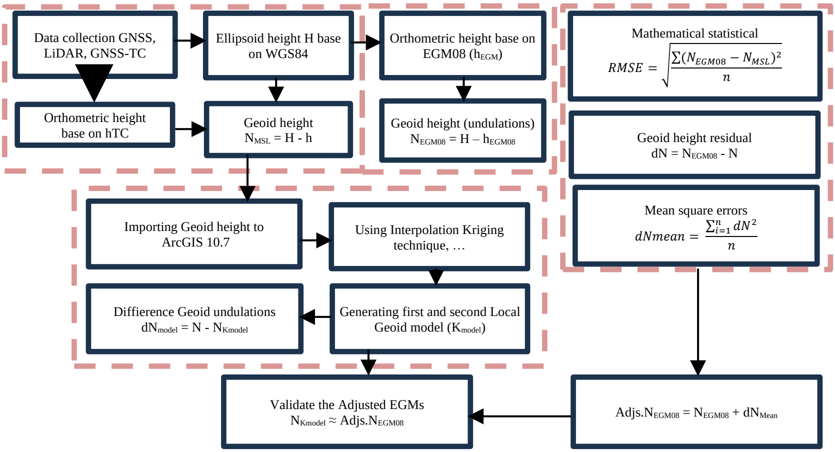

Figure 4.4: Experimental Diagram for Constructing a Local Geoid Model

After analyzing the data as shown in Figure 4.4, the statistical error data between the models after interpolation and the reference results at the reference points is as follows:

Table 4.4: Results of the wave undulation of the 3 models

Model	RMSE (m)	Std. dv (m)
dN_{EGM96}	0.8561	0.8451
$dN_{EGM2008}$	0.0158	0.0157
$dN_{VNGeoid}$	1.0816	1.0470

Table 4.5: Statistical results comparing the model with the Kriging interpolation model

Model	RMSE (m)	Std. dv (m)
dN_{EGM96}	0.425	0.433
$dN_{EGM2008}$	0.312	0.328
$dN_{VNGeoid}$	0.725	0.742

With the results of the local digital elevation model interpolation, when compared with the globally applied models, a consistency and corresponding error rate are observed. However, the advantage of the VNGeoid model lies in its suitability for the topographical characteristics within the area where actual measurement data exists in Vietnam. The base points and interpolation points have high accuracy and are updated in the international coordinate system. The task of constructing a local digital elevation model while ensuring it is appropriately linked to the global elevation model is entirely feasible and suitable.

4.4. Implementation Plan for Military Application

4.4.1. Building a Command and Control System in Joint Operations

Develop a method and tool for automatic conversion between the Navy and Air Force coordinate systems currently in use and the military coordinate system, ensuring consistency in command and control during operations within our territorial land, airspace, and maritime areas.

Develop a method and tool for automatic conversion between the military coordinate system and various international coordinate systems, especially WGS84, as well as the coordinate systems and references of neighboring countries to support military operations in the regional context.

4.4.2. Security of Coordinate Information During Combat Operations

You can use one or more of the following security mechanisms in parallel:

- Cryptography for Data Security: This involves encrypting data to protect it from unauthorized access.

- Establishment of Transformation Parameters: Develop a set of "dynamic" transformation parameters specific to each operational area and tailored to specific missions, with the addition of a time parameter for each calculation instance based on digital map data. This "dynamic" parameter set will be secured under an encryption mechanism and will only be decrypted for individuals with command and operational planning responsibilities.

4.5. Chapter 4 Summary

The researcher has presented methods for processing data to support the establishment of a coordinate reference system, focusing on solving the problem of constructing a set of transformation parameters based on the Bursa-Wolf formula. The research has compared the influence of various transformation parameters, evaluating how the number of points involved in constructing the transformation parameters and the positional error affect the parameters.

Principal Component Analysis (PCA) helps identify which parameters contribute most to the variance in the data. In this case, PCA can determine which parameters among "ΔX," "ΔY," "ΔZ," "k," "ωX," "ωY," "ωZ," and the velocity parameters "ΔX1," "ΔY1," "ΔZ1," "k1," "ωX1," "ωY1," "ωZ1" are most important in the transition between VN-2000 and ITRF. Additionally, PCA can be used to detect anomalies or outliers in the parameter data, enhancing the quality and reliability of the coordinate transformation process. This serves as a foundation for evaluating the application of Machine Learning algorithms to construct transformation parameters based on forecast functions declared by transformation models, such as linear regression methods.

The analysis of the calculation parameters nationwide, on land, and specifically in the northern region helps assess the feasibility of using unified transformation parameters across the country and expanding their applicability for national security and defense tasks.

The coordinates of ITRFyy reference frames are published in different phases and are not identical. Therefore, the 14-parameter transformation formula mentioned above allows for more convenient conversion of coordinates from the VN-2000 system to any specific epoch of the ITRFyy international reference frame.

Furthermore, the researcher has proposed an interpolation solution to construct a local Geoid model based on data collected from modern equipment currently deployed at the Mapping Department. This solution has been evaluated and compared to control the uniformity and linearity concerning other global gravity models. It is also a suitable solution for testing and applying in the context of establishing a military coordinate reference system that ensures security and maintains consistency in accuracy for both horizontal and vertical measurements.

CONCLUSION AND RECOMMENDATIONS

1. Conclusion

On the basis of the theoretical research on adjustments and the analysis of actual computational data from CORS stations presented in the dissertation, the researcher draws several conclusions as follows:

1. Establishment of Theoretical Basis: The dissertation has developed a theoretical basis for establishing solutions for designing the positions of temporary CORS stations within the coordinate reference system, ensuring optimal principles of reliability, accuracy, and construction value under the conditions in Vietnam. Given the current equipment is basic and needs gradual upgrading in the future, exploring and directing the gradual enhancement of technological equipment is essential. This will provide practical theoretical foundations for managers to plan and develop investment strategies for the geodetic mapping sector.

2. Scientific Foundation for GNSS Adjustment: The dissertation presents the scientific foundation for the adjustment of the GNSS CORS network and ground stations, as well as other basic problems serving the construction of the coordinate

reference system. This modern and optimal solution is superior to traditional surveying methods. The connection of the CORS network to the international ITRF stations will help establish a new active GNSS CORS network to replace the "0" level network in Vietnam, which will be a sustainable development direction and enhance the applicability of the foundational grid in practical production.

3. GNSS Data for Hydrostatic Height Transfer: The dissertation proposes a solution using GNSS data to calculate the transfer of hydrostatic heights, particularly in island regions and surrounding areas. This is a pressing issue as Vietnam has a long and narrow land topography, and the sea and archipelagic areas cover three times the land area, making geometric height transfer infeasible.

4. Software Development for Transformation Parameters: The dissertation has developed software to experimentally calculate the transformation parameters for the CORS station network as well as simulated model points. This research solution contributes to building a military coordinate system based on the upgrade of the VN-2000 coordinate system.

5. Use of PCA for Parameter Relationships: The dissertation employs Principal Component Analysis (PCA) to evaluate the relationships and connections among transformation parameters, helping to identify which parameters contribute the most and influence changes in the computational processing data. This assists in forecasting as well as controlling error sources in each computation cycle, integrating various data sources with differing accuracy. The application of PCA is novel and distinct from previously published research both domestically and internationally. This is crucial as the military uses numerous coordinate systems in operational planning (the air force, navy, and army utilize different coordinate systems).

From these resolved issues, a foundation has been established for building a modern, dynamic coordinate system that meets multiple objectives, not only within the land territory but also potentially extending beyond national borders. The close integration of the security and defense coordinate system ensures confidentiality with the national coordinate system.

2. Recommendations

It is proposed that, in the next phase, functional units will select CORS points located in stable positions within each tectonic block to participate in international organizations providing GNSS system services (IGS).

To develop options for the military coordinate system, the next phase should focus on designing CORS stations to cover nearshore islands and key outpost island clusters. At the same time, further research should be conducted to improve the solutions for the height system, particularly in extending geodetic leveling to maritime and adjacent areas.

The application of principal component analysis algorithms and Machine Learning models is a very innovative idea for addressing classic problems in Vietnam. In terms of practical implementation, the calculation results have so far only met basic requirements, stopping at reporting outcomes. Developing forecasting models and proactively analyzing data will enable technicians to gain deeper insights into the data and assess whether the calculation methods are appropriate. This, in turn, helps optimize data control based on database construction methods. Consequently, this provides a favorable foundation for upgrading the Reference System - Coordinate System, as well as flexibly providing “dynamic” parameters for both military operations and mapping applications.

LIST OF AUTHOR'S PUBLISHED SCIENTIFIC WORKS RELATED TO THE DISSERTATION

1. Hoang, N. H., & Leu, H. N. (2021), “Research on algorithm of adjustment of horizontal and GNSS networks with GNSS CORS points”, *The Journal of Geodesy and Cartography*.

2. Nam, L.H.; Hà, H.N. (2024), “Evaluating the adaptability of the VN-2000 national coordinate system with the international reference frame ITRF based on determining transformation parameters”, *Journal of Hydro-Meteorology*.

3. Leu, H. N., Hoang, N. H., & Nguyen, C. S (2024), “Theoretical basis for upgrading the national coordinate reference system VN-2000 to adapt to the International Terrestrial Reference Frame (ITRF)”, *The Journal of Geodesy and Cartography,* (59), 19-26.

4. Nam, L.H.; Ha, H.N. Optimal design the GNSS CORS network to upgrade the VN-2000 coordinate system in Vietnam. *The International Conference Advanced Technologies and Artificial Intelligence in the Earth and Environmental Sciences* **2024**, vol.1, 243-249.

5. Proctor, C.; Leu, N.; Wang, B (2024) "The Physiology of Betula glandusa on Two Sunny Summer Days in the Arctic and Linkages with Optical Imagery", *Remote Sens*. **2024**, *16*, 2160.