Enhancing Land Governance and Disaster Resilience in Bhutan through DrukNet

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SUMMARY

Bhutan, a nation situated at the tectonic boundary between the Indian and Eurasian plates, has undertaken significant steps to modernize its geospatial reference systems, aiming to improve land governance. DrukNet, the national network of CORS (Continuously Operating Reference Stations) managed by NLCS (National Land Commission Secretariat) is vital to these efforts by materializing permanently the national datum of Bhutan, namely their latest realization, DrukRef23, which is being currently under implementation. DrukNet is also an essential tool to monitor the dynamic geological processes taking place in Bhutan greatly contributing for disaster resilience in the country. DrukNet initially comprised six CORS installed in 2010-2012. In the last three years this network was greatly expanded and currently is formed by 14 stations providing a continuous and accurate geospatial reference across Bhutan. This network addresses the limitations of the previous reference frame, DrukRef03, which was established in 2003 by measuring some 0- and 1-order control points and has since experienced significant internal deformations due to tectonic activities. These deformations have been measured at up to 0.6 cm/year between the southern and central regions of Bhutan, leading to substantial cumulative distortions over time.

To ensure long-term stability and accuracy, Bhutan is implementing DrukRef23, a modern and static datum aligned with ITRF2020 at the epoch 2023.5. The continuous data provided by the DrukNet network is essential to maintaining the accuracy of DrukRef23, enabling precise monitoring and adjustment of the reference frame as needed. The implementation of DrukRef23 and the expansion of DrukNet significantly enhance Bhutan's capability to monitor and respond to environmental changes, natural disasters, and land-use planning needs. The accurate and real-time geospatial information from DrukNet supports effective urban planning, infrastructure development, environmental conservation, and disaster management.

In this work, we present the current status of DrukNet, highlighting its expansion and the implementation of DrukRef23. We detail the methodologies employed for maintaining and updating the network, including the creation and application of NTv2 files for transforming the existing geo-referencing information from DrukRef03 into DrukRef23 and its importance for the disaster resilience in Bhutan.

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1. INTRODUCTION

Bhutan, located in a geologically active zone, faces unique challenges in land governance and disaster management due to its tectonic setting. Positioned at the convergence of the Indian and Eurasian tectonic plates, Bhutan is subjected to frequent geodynamic activity, which not only poses risks to life and infrastructure but also impacts the accuracy of geospatial reference systems. In response to these challenges, Bhutan has embarked on a journey to modernize its geospatial infrastructure, focusing on enhancing land governance and disaster resilience.

The modernization efforts are driven by the need for a stable and accurate geodetic reference framework that can withstand the dynamic geological processes inherent to the region. This paper discusses the evolution of Bhutan's geospatial reference systems, from the establishment of the DrukRef03 to the recent ongoing implementation of DrukRef23, and the expansion of the national CORS network, DrukNet. These developments play a critical role in ensuring accurate land management, disaster preparedness, and overall national resilience.

2. DRUKNET: THE BACKBONE OF BHUTAN'S GEOSPATIAL INFRASTRUCTURE

2.1 Establishment of DrukNet

DrukNet, Bhutan's national network of Continuously Operating Reference Stations (CORS), was established as a strategic initiative to provide a robust and reliable geodetic infrastructure across the country. Initially consisting of six stations installed between 2011 and 2012 (cf. Figure 1), DrukNet was designed to serve as the foundation for precise positioning and geospatial data collection across Bhutan.

These initial CORS provided a significant improvement over traditional survey methods, enabling continuous monitoring of geospatial reference points and supporting a wide range of applications, from cadastral surveys to infrastructure development. However, as the need for more accurate and real-time data grew, it became clear that the network needed to be expanded to cover a larger portion of the country and to improve the overall accuracy and reliability of the data.

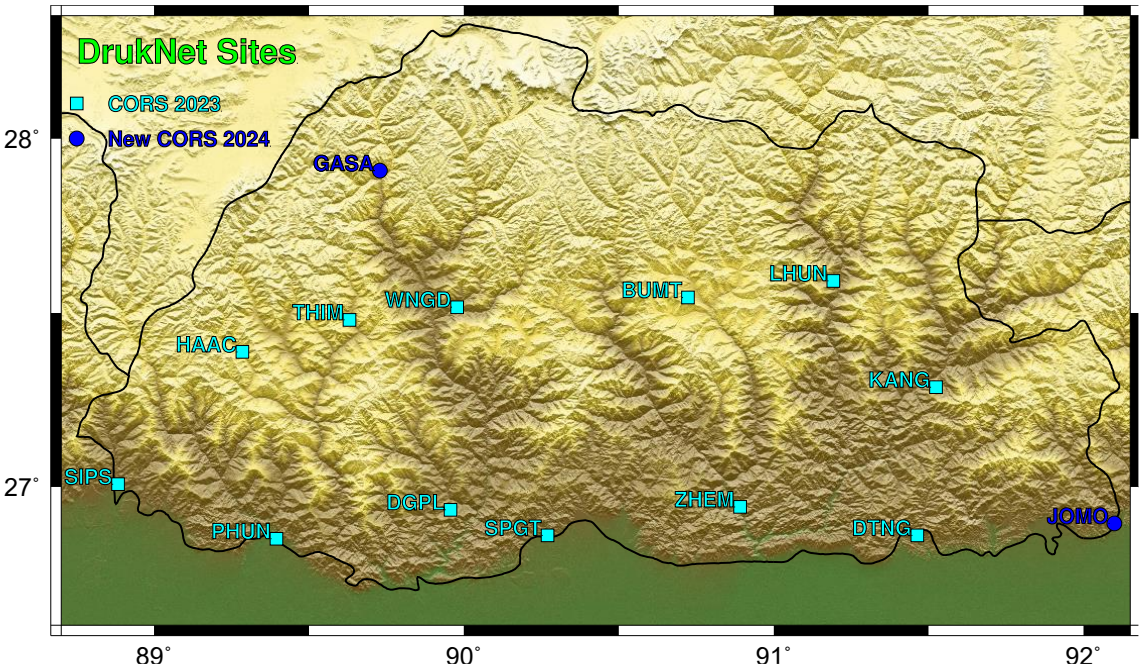

Figure 1 – CORS stations forming DrukNet. THIM, BUMT, KANG, PHUN, GELE and DEOT were installed in 2011/2012; DTNG was installed by a scientific project and formally added to the network in 2020; WNGD and DGPL were installed in 2020; HAAC, LHUN and SPGT were installed in 2022; and SIPS and ZHEM were installed in 2023. Finally, GASA and JOMO were installed in 2024.

2.2 Expansion and Technological Enhancements

In the past four years, significant efforts have been made to expand DrukNet, increasing the number of CORS from six to fourteen. This expansion was driven by the need to enhance spatial coverage and improve the precision of geospatial measurements across the country (cf. Figure 1). The new stations are strategically located to provide comprehensive coverage, particularly aiming to serve both to permanently materialize the national reference frame and to provide RTK corrections for geo-referencing activities.

Each CORS is equipped with state-of-the-art GNSS receivers that provide continuous data, which is essential for maintaining an accurate and up-to-date geodetic reference frame. The data collected by these stations is transmitted to a central processing center at the NLCS, where it is used to provide RTK corrections, monitor tectonic movements, update the national reference frame, and support various land management and disaster resilience initiatives.

3. TRANSITION FROM DRUKREF03 TO DRUKREF23

3.1 Limitations of DrukRef03

DrukRef03, established in 2003, served as Bhutan's first national geodetic reference frame. It was based on a network of 0- and 1-order control points (Jivall, 2003; Lilje, 2004), which provided a relatively accurate reference system at the time of its establishment. However, over the years, Bhutan's dynamic tectonic environment led to significant internal deformations within the DrukRef03 framework. These deformations, primarily caused by the ongoing convergence of the Indian and Eurasian plates, resulted in cumulative distortions that compromised the accuracy of the reference frame (cf. Figure 2 for an illustration of the deformation patterns observed in DrukRef03).

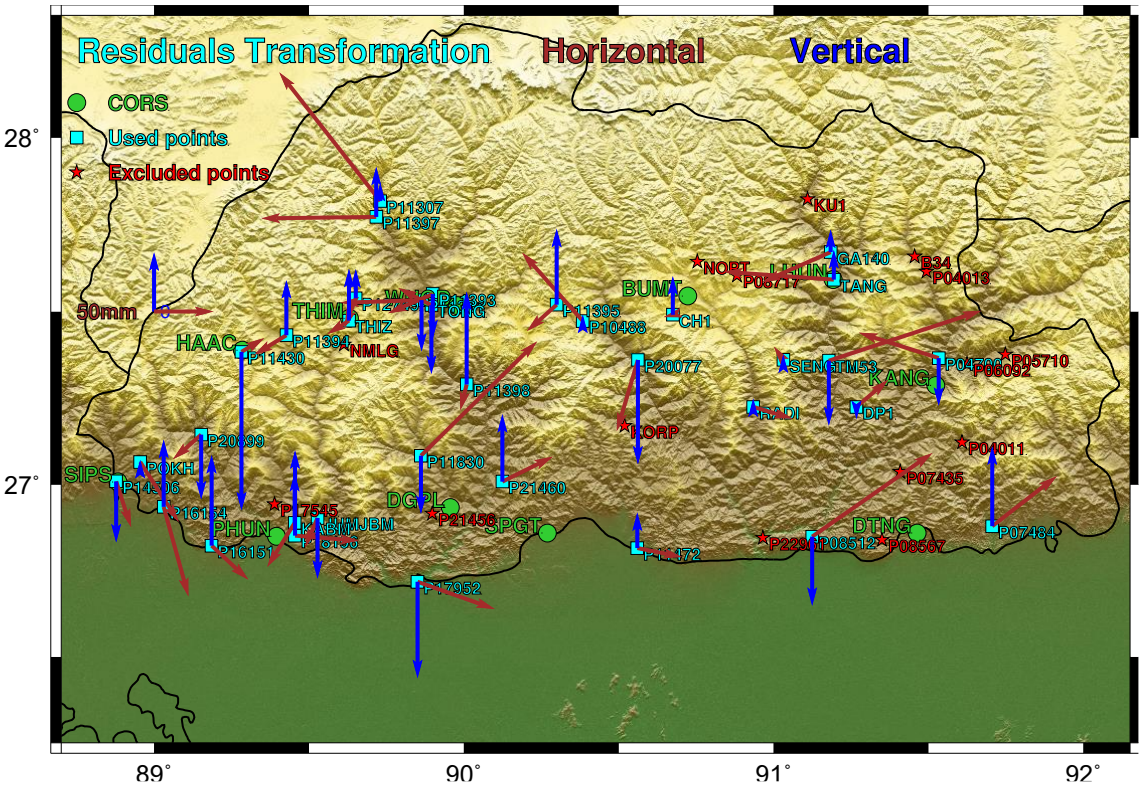

Figure 2 – Residuals of a 7-parameter (Helmert) transformation between DrukRef21 (a first attempt to create a new datum based on CORS) and DrukRef03 using eight common points.

The tectonic movements were particularly detected between the southern and central regions of Bhutan, with deformation rates measured at up to 0.6 cm per year. These distortions accumulated over time, leading to discrepancies in the positioning and geospatial data used for land management and other applications.

3.2 Implementation of DrukRef23

To address the limitations of DrukRef03, Bhutan is implementing a new geodetic reference frame, DrukRef23. This modern, static datum is aligned with the International Terrestrial Reference Frame (ITRF) 2020, ensuring consistency with global standards. DrukRef23 is anchored to the epoch 2023.5, providing a stable and accurate reference system that can accommodate the ongoing tectonic movements in Bhutan in the next years.

The implementation of DrukRef23 involved the re-measurement of the national geodetic network using the expanded DrukNet CORS. This process ensures that the existing control points (cf. Figure 3) can be tied to the new datum, minimizing the impact of any distortions caused by tectonic activity and observational errors.

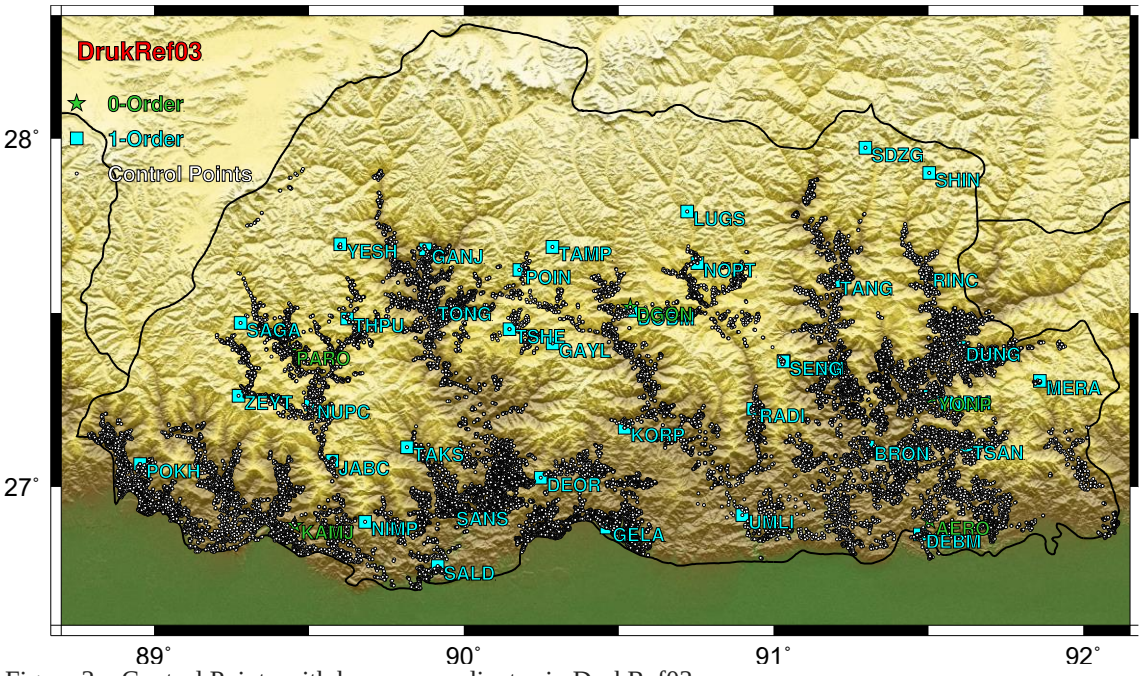

Figure 3 – Control Points with known coordinates in DrukRef03

Advanced computational techniques are being employed to create the transformation grids, known as NTv2 files (Garnero, 2014), which facilitate the conversion of geospatial data from DrukRef03 to DrukRef23 (cf. Figure 4 for an example of the NTv2 transformation grid applied during this process).

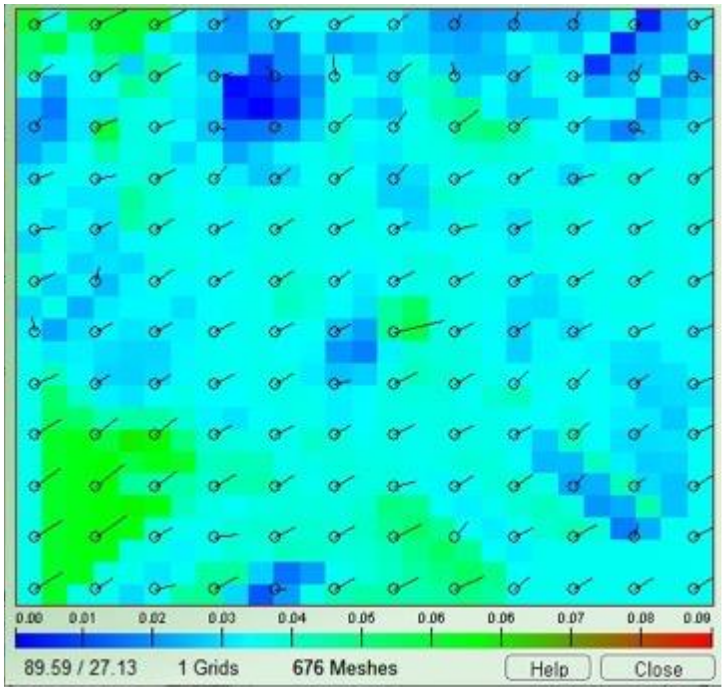

Figure 4 – Derived NTv2 File for Thimphu and Paro districts

4. DRUKNET ROLE IN ENHANCING DISASTER RESILIENCE

4.1 Monitoring Dynamic Geological Processes

One of the primary benefits of DrukNet is its ability to provide continuous, real-time data on the dynamic geological processes affecting Bhutan. The CORS network plays a crucial role in monitoring tectonic movements, which is essential for understanding and

mitigating the risks associated with earthquakes and other geological hazards. By providing precise geospatial data, DrukNet enables the NLCS and other government agencies to monitor ground deformations, assess the stability of infrastructure, and plan for potential disaster scenarios.

The continuous data collected by DrukNet is also used to update the national reference frame, ensuring that it remains accurate and reliable even as the tectonic environment evolves. This capability is particularly important for maintaining the integrity of land management systems, as any distortions in the reference frame could lead to errors in cadastral surveys, property boundaries, and infrastructure planning.

4.2 Supporting Disaster Management Efforts

In addition to monitoring geodynamic processes, DrukNet supports disaster management efforts by providing accurate and timely geospatial information during and after natural disasters. For example, in the event of an earthquake, DrukNet can provide real-time data on ground deformations, helping authorities to assess the extent of the damage and prioritize response efforts. This information is critical for coordinating emergency response operations, assessing the stability of critical infrastructure, and planning for recovery and reconstruction.

The expanded DrukNet network also contributes to disaster resilience by supporting early warning systems. For example, the data from CORS can be integrated with seismic sensors and other monitoring tools to provide early warnings for earthquakes or landslides, allowing for timely evacuation and other preventive measures. This integration of real-time GNSS data with other geospatial technologies enhances Bhutan's ability to respond proactively to potential natural disasters, thereby reducing the risk to lives and property.

Furthermore, DrukNet data are instrumental in post-disaster recovery efforts. Accurate and up-to-date geospatial information is critical for assessing the damage to land and infrastructure, re-establishing property boundaries, and guiding reconstruction activities. The ability to quickly and accurately map affected areas enables authorities to plan and implement recovery projects more effectively, ensuring that resources are allocated efficiently and that rebuilding efforts are aligned with the country's long-term land-use plans.

DrukNet not only strengthens Bhutan's disaster resilience by providing the necessary tools for monitoring and responding to natural hazards but also plays a vital role in the country's overall land governance and development strategies. The network's contribution to both immediate disaster response and long-term recovery underscores its importance as a key component of Bhutan's national infrastructure.

5. METHODOLOGIES FOR MAINTAINING AND UPDATING DRUKNET

5.1 Data Processing and Analysis

The effectiveness of DrukNet in supporting land governance and disaster resilience depends on the continuous processing and analysis of the data collected by the CORS. The GNSS data are processed using advanced software tools that ensure high accuracy in positioning and monitoring. This involves several steps, including the preprocessing of raw data, quality control checks, and the application of precise satellite ephemerides and clock corrections.

The processed data is then used to update the national geodetic reference frame and monitor tectonic activities. Regular maintenance of the CORS is crucial to ensure the

reliability of the data. This includes periodic calibration of the equipment, updating the software, and conducting routine checks to identify and resolve any issues that may affect data quality.

5.2 Creation and Application of NTv2 Files

To facilitate the transition from DrukRef03 to DrukRef23, NTv2 (National Transformation Version 2) files are being created. These files are essential for transforming existing geospatial data into the new reference frame, ensuring that all cadastral, topographic, and infrastructure data is consistent with DrukRef23. The creation of NTv2 files involves the generation of a grid-based transformation model that accounts for the differences between the old and new reference frames.

The application of NTv2 files is particularly important for organizations and professionals involved in land surveying, urban planning, and infrastructure development. By using these files, they can convert legacy data into the new reference system with minimal loss of accuracy, thereby maintaining the integrity of Bhutan's geospatial datasets.

he transformation process also includes rigorous validation to ensure that the converted data meets the required standards of accuracy. This validation is carried out by comparing the transformed coordinates with those obtained from direct measurements in DrukRef23, ensuring that the transformation process does not introduce significant errors.

6. CONCLUSION

The modernization of Bhutan's geospatial infrastructure through the expansion of DrukNet and the implementation of DrukRef23 represents a significant achievement in enhancing the country's land governance and disaster resilience. DrukNet provides a critical foundation for accurate and reliable geospatial data, which is essential for a wide range of applications, from cadastral surveys to disaster management.

By transitioning to DrukRef23, Bhutan is addressing the limitations of the previous reference frame and establishing a stable and accurate geodetic datum that is aligned with global standards. This transition ensures that Bhutan's geospatial infrastructure can support the country's development goals and withstand the dynamic geological processes inherent to its tectonic environment.

The expanded DrukNet network, combined with the application of NTv2 files, ensures that Bhutan's geospatial data remains accurate and consistent across all sectors. This infrastructure not only supports effective land management and urban planning but also plays a critical role in enhancing Bhutan's resilience to natural disasters.

As Bhutan continues to develop, the ongoing maintenance and enhancement of DrukNet will be essential to ensuring the long-term accuracy and reliability of the country's geospatial infrastructure. The lessons learned from Bhutan's experience in modernizing its geodetic reference systems can serve as a valuable model for other countries facing similar challenges.

In conclusion, the strategic investments in DrukNet and DrukRef23 have positioned Bhutan at the forefront of geospatial innovation in the region, enabling the country to achieve its goals of sustainable development and disaster resilience.

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