Using NTv2 Files for Datum Transformations in Deforming Regions: The Cases of Bhutan and Chile

Rui FERNANDES, Portugal; José Antonio TARRIO, Chile; Chokila CHOKILA, Bhutan; Gonçalo HENRIQUES, Portugal; Pedro ALMEIDA, Portugal; Marcelo CAVERLOTTI, Chile

Key words: Reference Frames, Transformation Parameters, NTv2, GNSS

SUMMARY

Datum transformations are critical for maintaining geospatial coherence when a new datum is established. All existing georeferenced information in the old datum needs to be converted into the new datum with minimal errors. This process has been necessary in many countries due to the implementation of modern datums based on space-geodetic techniques, materialized by GNSS (Global Navigation Satellite Systems) CORS (Continuously Operating Reference Stations).

Most of the old classical datums suffer from large internal deformations caused by the existing methodologies used to compute them in the past. The surveying errors of the angles and sides of the triangulations not compensated by simultaneous adjustments led to significant propagation errors. Moreover, in countries like Bhutan and Chile, located in regions characterized by dynamic geological processes, the static datums defined in the past have undergone degradation over time due to internal temporal deformations.

To address the challenges posed by complex datum transformations over large areas, NTv2 (National Transformation Version 2) files present an advantageous methodology. NTv2 files, containing control points and shift values, offer an alternative to traditional approaches like 7-Helmert parameters or other conformal transformations. Their advantage lies in their ability to account for regional variations in deformation, making them particularly suitable for regions with dynamic geological processes and/or where the classical datums have significant internal errors.

In this work, we present the work being done in Bhutan and Chile to estimate and apply NTv2 files to transform old classical datums into modern geocentric datums. We demonstrate that the use of conformal transformations, in particular 7-Helmert transformations, does not permit converting all existing geo-information with sufficient accuracy, which is a major issue, particularly for the cadastral information which has requirements defined by law.

Although the final NTv2 grids cannot completely remove the existing errors in the definition and materialization of both datums, particularly in the old ones, they permit the minimization of such errors allowing the implementation of modern geodetic datums with a minimal disturbance in the workflow of the responsible agencies for their maintenance.

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1. INTRODUCTION

The backbone of any georeferencing activity is the use of a common datum to which all surveyed entities must be referred to. In the past, the datum of a country was defined locally and materialized using a dense network of triangulation points. With the advent of the GNSS technology, the majority of the countries started to move to geocentric datums based on this technology.

The initial geocentric datums were also based on passive control points observed during dedicated campaigns. However, in the last two decades, many countries have installed networks of CORS (Continuously Operating Reference Stations) GNSS (Global Navigation Satellite Systems) stations that permanently materialize the national datum of the country. Such networks provide geodetic control for land administration, support topographical surveys, assist engineering works, monitor the Earth's crust, support the acquisition of data for Geographical Information Systems (GIS), machine control and precise positioning, as well as for monitoring natural and man-made structures.

Many countries in the recent years are upgrading their national datums to rely on CORS networks to define and materialize them permanently. In some countries, this can be done by estimating the coordinates of the CORS stations using the initial passive control points as references. However, such procedure implies that the final coordinates are not normally internally consistent introducing errors on the datum definition. This is particularly truth when the original datum is very old (normally not geocentric) and/or internal deformations exist due to observational or tectonic processes, such is the case in Bhutan and Chile. In such cases, the best approach is to define the new datum with respect to the latest realization of ITRS (International Terrestrial Reference System), currently ITRF2020, and to estimate the transformation parameters between the old datum and the new datum.

The estimation of the best possible set of transformation parameters is essential and necessary since it is required to transform all existing information from the old datum to new datum. This is particularly important for the cadastral information since the demarcated areas must have minimal (negligible) changes.

2. LIMITATIONS OF 7-PARAMETER TRANSFORMATION – BHUTAN EXAMPLE

However, the application of a single set of transformation parameters based on a single conformal transformation (normally known by 7-parameters or Helmert transformation) for an entire country reveals to be in many cases of too few-quality with errors that are unacceptable. Figure 1 illustrates this problem using the exercise carried out in 2021 to define a new datum for Bhutan (Tashi et al., 2021). The initial datum, DrukRef03, is a geocentric datum defined through the observation of six points of the classical 0-Order network in campaign mode that was linked to ITRF2000 at the epoch 2003.87 (Jivall, 2003). Additionally, the coordinates of 38 points of the 1st order geodetic network of Bhutan were also computed (Lilje, 2004) to materialize DrukRef03 for most of the territory of Bhutan.

To compute the transformation parameters, 10 of the DrukRef03 reference control points (0- and 1-Order) were re-observed with respect to a new datum directly materialized by the existing network of CORS stations (eight stations in 2021). Figure 1 shows the residuals when all points were used to estimate a 7-parameter transformation between the old and the new datum. The results showed that the residuals of the transformation between the two reference frames were already of several centimeters, particularly in the eastern part of the country which reached 10 cm for some stations (partially caused by the 2009 Bhutan earthquake that occurred on 21 September and caused co-seismic displacements for some of the DrukRef03 stations).

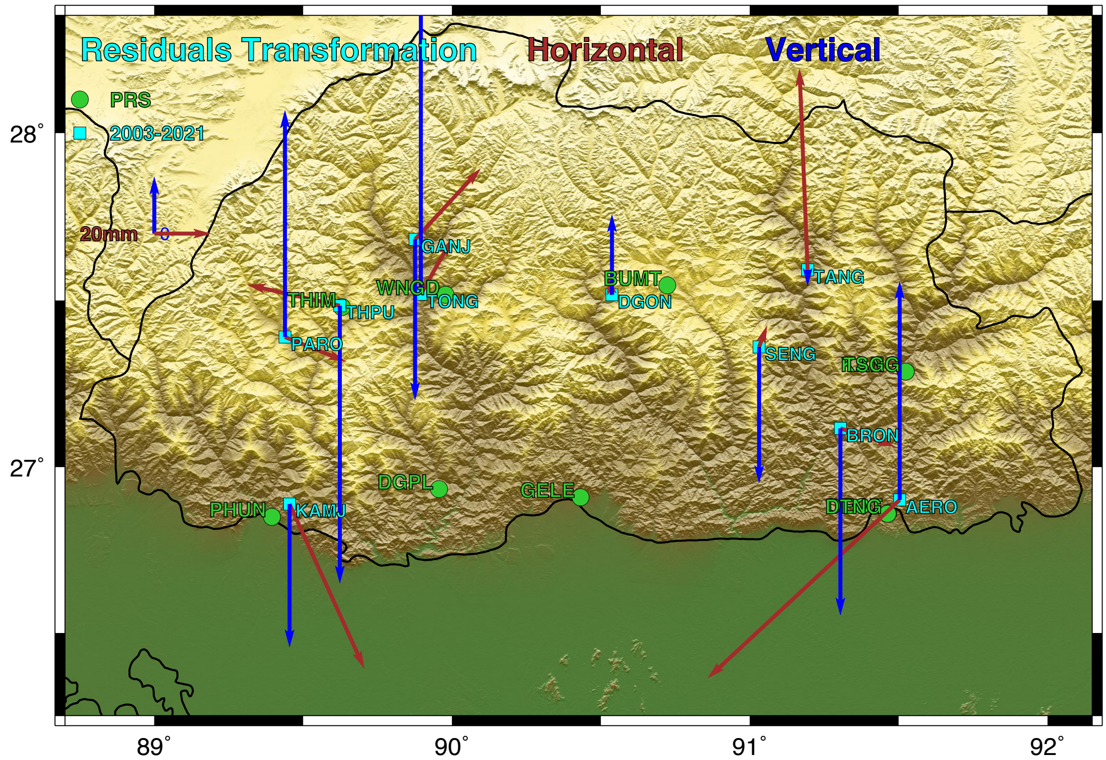

Figure 1 – Horizontal and Vertical residuals of the transformation between DrukRef03 and DrukRef2021 using 10 common stations. PRS indicate the existing CORS stations used to define DrukRef2021.

To further understand the implications of using each transformation, it was computed the residuals between the transformed coordinates for all 0- and 1-Order DrukRef03 control points using the transformation with all common points or the transformation when AERO and TONG are excluded. Figure 2 shows that the implications of selecting one or the other can imply differences in the horizontal component that reach almost 3cm in the eastern part of the country (the vertical component can reach a little bit more than 1cm in the southern part of the country). It is important to note that Figure 2 does not permit the assessment of which set of transformation parameters is better. It only allows us to evaluate the robustness of the computations; if all points were correct (or had similar errors), the exclusion of one to estimate the transformation parameters would not imply large differences between the transformed coordinates using the two sets of parameters.

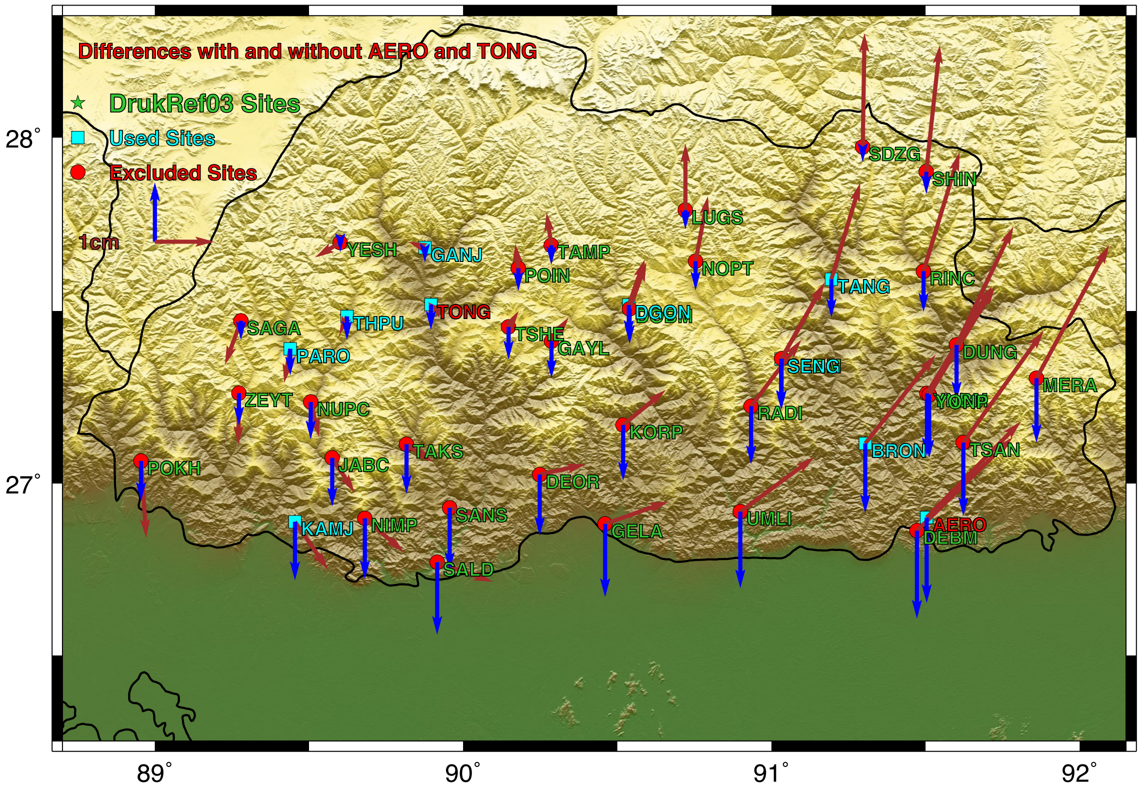

Figure 2 – Horizontal and vertical residuals between the positions of the DrukRef03 points estimated by applying the transformation parameters computed using all 10 common points and using the eight common points

In March 2023, NLCS (National Land Commission Secretariat), the governmental agency responsible for the definition and maintenance of the geodetic datums of Bhutan, has carried out another campaign where 50 points with known coordinates in DrukRef03 were measured and their coordinates computed together with the DrukNet stations (at the time, ZHEM was not yet installed). Figure 3 shows the residuals of the 7-parameters transformation of the estimated coordinates in 2023 into DrukRef03. A threshold value of 12cm of residuals was defined to consider a point as outlier. This led to the exclusion of 15 points (30%), particularly on the eastern part of the country.

It can be observed that the residuals are mostly randomly showing that the adjustment is not biased due to an uneven distribution of the points, but that the large errors are caused by internal deformations derived from tectonics and errors on the computation of the coordinates.

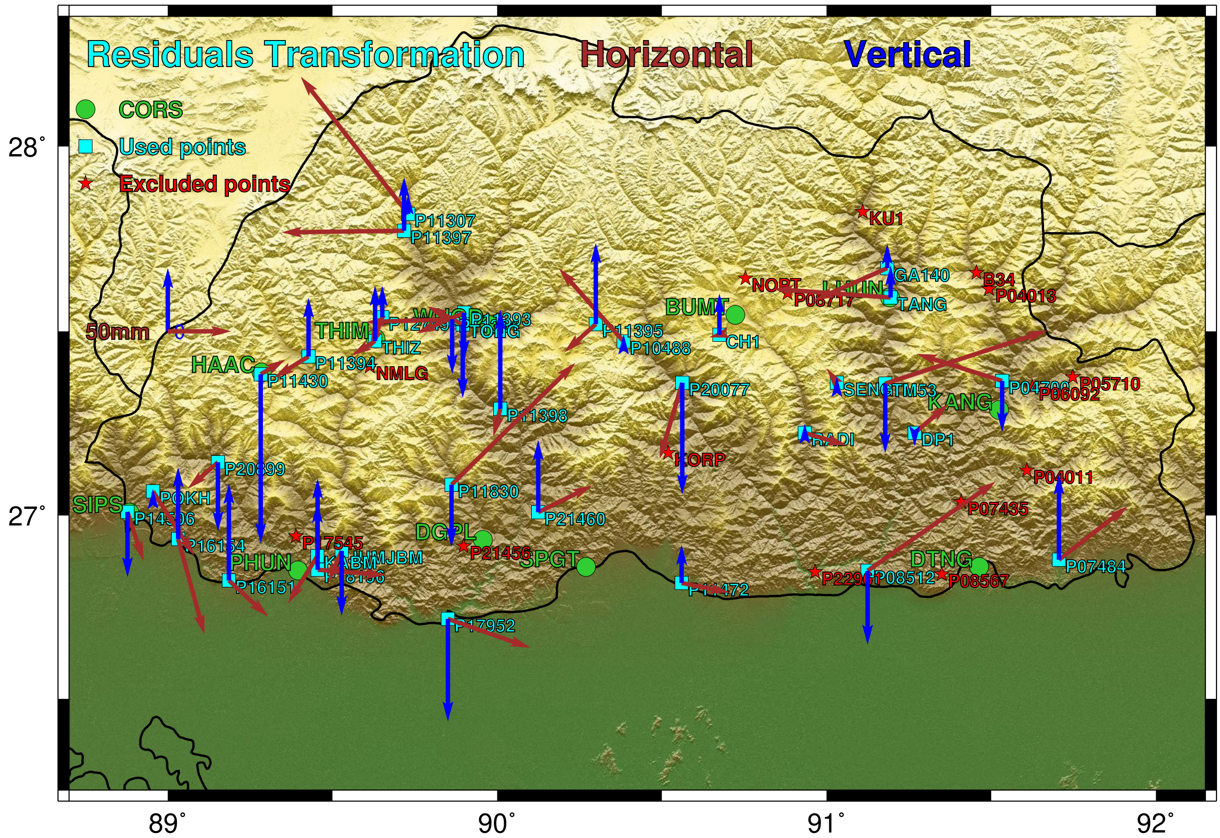

Figure 3 – Residuals of the transformation between DrukRef21 and DrukRef03 using eight common points.

3. NTV2 FILES

NTv2 (National Transformation version 2) is a technique utilized for the conversion of georeferenced data between different datums. Initially developed by the Geodetic Division of Natural Resources of Canada, it has since evolved into a globally recognized standard for grid-based transformations of geospatial data. This format efficiently stores correction values, making it effective for both horizontal and vertical adjustments (Garnero, 2014).

The methodology of NTv2 relies on a structured grid of geographic coordinates, with associated shift values stored in a designated file, representing the variance between two distinct datums. To execute a coordinate transformation between these systems, the grid mesh containing the point in question is first identified. Subsequently, utilizing the shift values of the four grid points surrounding this location, interpolation is employed to determine the shift for the point within the mesh. These interpolated shift values for longitude and latitude are then combined with the coordinates of the source datum to derive an equivalent coordinate within the target datum.

NTv2 files can be easily integrated into various software platforms and geographic information systems, simplifying the implementation of the datum transformations. Moreover, NTv2 files are lightweight and can cover large geographic areas, reducing computational overhead and storage requirements.

The use of NTv2 files is particularly important in regions where the Earth's surface exhibits significant deformation, such as tectonically active areas or regions affected by subsidence or uplift. They allow for the incorporation of localized grid shift values that capture the specific deformations occurring in a given area. By utilizing NTv2 files for datum transformation in such regions, geospatial applications can account for the spatial distortions caused by geological processes.

Furthermore, NTv2 files provide the flexibility to accommodate custom or user-defined datum transformations tailored to specific regional needs. This is particularly valuable in areas where standard transformation models do not adequately capture all local deformation patterns. By allowing users to generate their own NTv2 files based on localized survey data or geodetic models, these files permit to obtain precise and reliable datum transformations adapted to the unique characteristics of the region.

4. APPLICATION OF NTV2 FILES – BHUTAN EXAMPLE

NLCS has decided in 2023 to implement a new datum, DrukRef23, permanently materialized by DrukNet, the network of CORS (Continuously Operating Reference Stations) of Bhutan. DrukNet is currently formed by 12 active stations already providing good coverage of the country as shown in Figure 4 with plans to further densify in the areas still lacking good coverage, particularly in north, middle and eastern parts of the country.

The computation of DrukRef23 was already done using data between June 20th and July 9th, 2023, with the reference epoch selected to be July 1st, 2023.

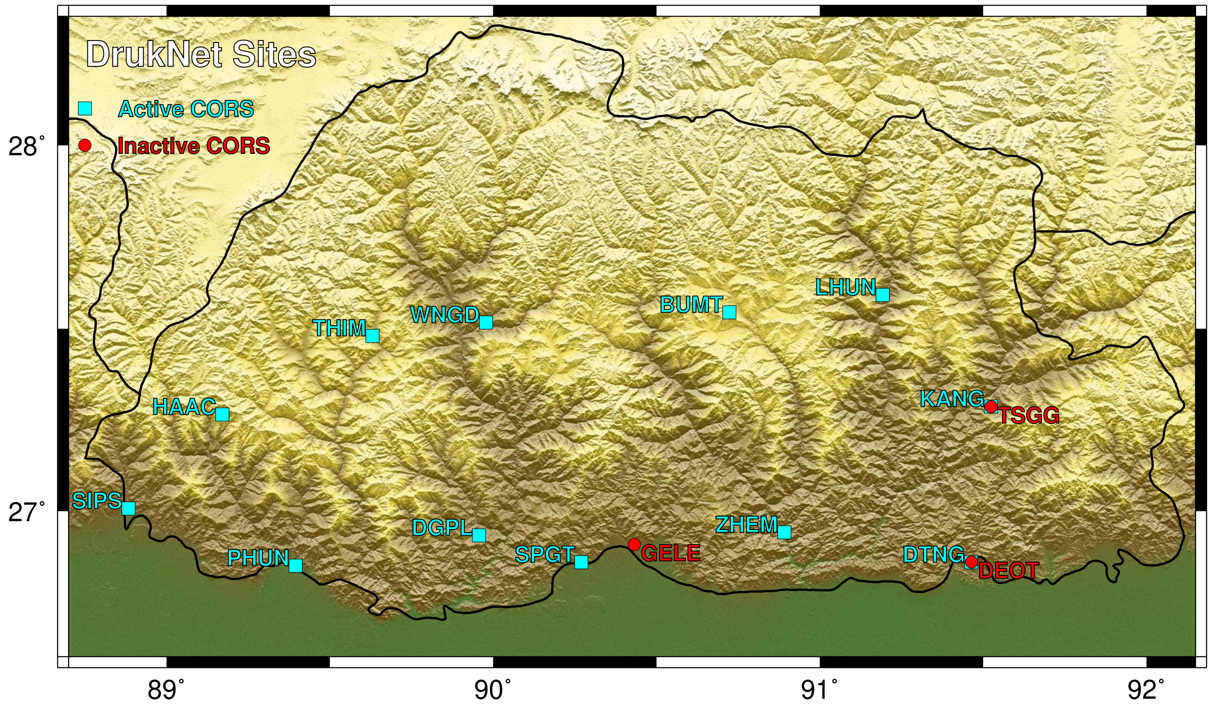

Figure 4 – CORS stations forming DrukNet. THIM, BUMT, KANG, PHUN, GELE and DEOT were installed in 2011/2012; DTNG was installed by a scientific project and formally added to the network in 2020; WNGD and DGPL were installed in 2020; HAAC, LHUN and SPGT were installed in 2022; and SIPS and ZHEM were installed in 2023. DEOT, GELE, and TSGG are being decommissioned.

The implementation of DrukRef23 as the new datum for Bhutan implies that all existing geo-information in DruRef03, in particular all cadastral information needed also to be converted into the datum.

Currently, there are approximately 27200 control points with known coordinates in DrukRef03 (cf. Figure 5). These control points have been estimated mainly to support the acquisition of cadastral information in the entire country.

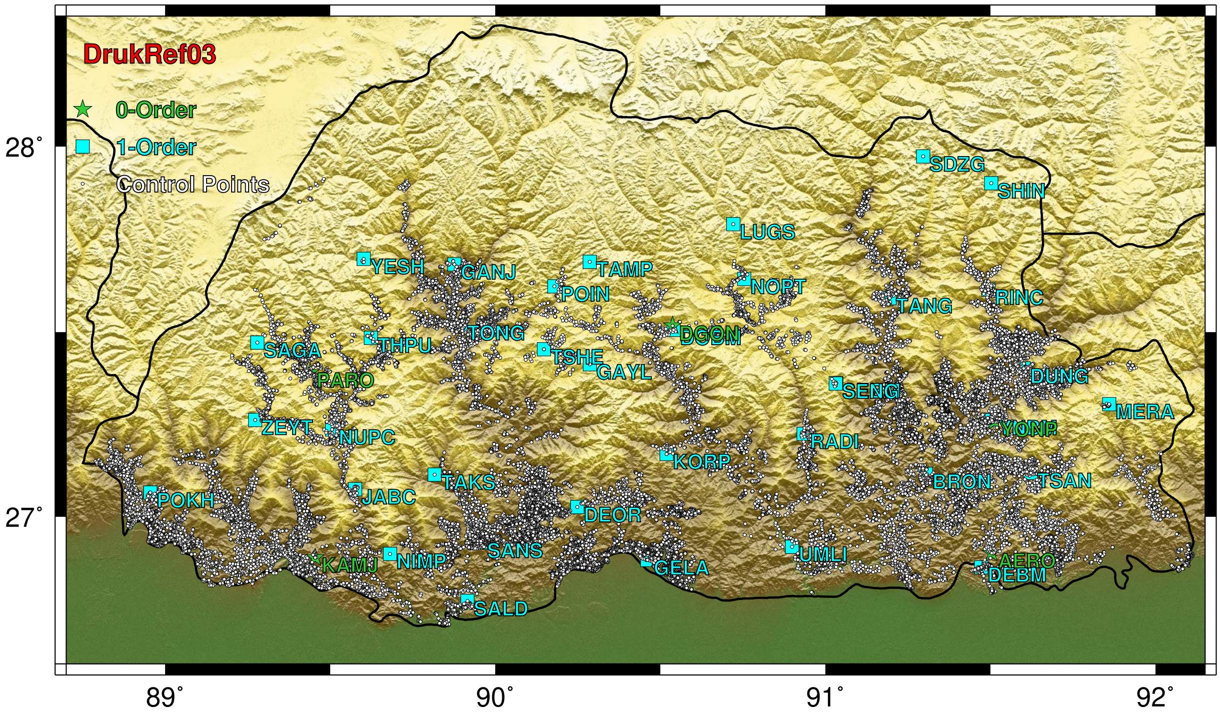

Figure 5 – Control Points with known coordinates in DrukRef03

Due to the reasons detailed in Section 2, it was decided that a 7-parameter transformation could not provide a sufficient accurate relation between DrukRef03 and DrukRef23 and the solution was to implement the transformation between both datums using NTv2 files.

To ensure the accurate development of the NTv2 transformation files for the entire country, it was decided to first refine the procedures on a smaller scale. The Thimphu and Paro areas were selected for this initial case study due to their logistic convenience. Due to some delays, the fieldwork has been carried out in the first weeks of 2024.

The initial plan was to observe one control point by a 2km cell as the best compromise between the necessary accuracy and the required workload in this evaluation of the quality of the NTv2 files that can be produced. It was also decided to use RTK solutions to observe the maximum number of possible points. In fact, attending to the uncertainties in the existing coordinates of the control points in DrukRef03, the accuracy of RTK solutions (1-2 cm when using fixed ambiguities) was sufficient to estimate the coordinates with respect to DrukRef23. Errors were minimized by reobserving the points several times consecutively (and some at different times of the day with different passages by the same or different teams).

With the development of the fieldwork (carried out by eight teams in parallel) where it was observed that a significant number of control points had been destroyed or moved, and the number of observed points per day was large, it was decided to measure more points with a minimum of two points per cell. This would ensure a large redundancy and the possibility to better detect outliers and areas with local deformation patterns.

Figure 6 shows the distribution of control points in the pilot region (Thimphu and Paro districts). From the approximate 1700 control points, a total of 580 control points were observed. It was also found that 223 control points had been destroyed or could not be observed.

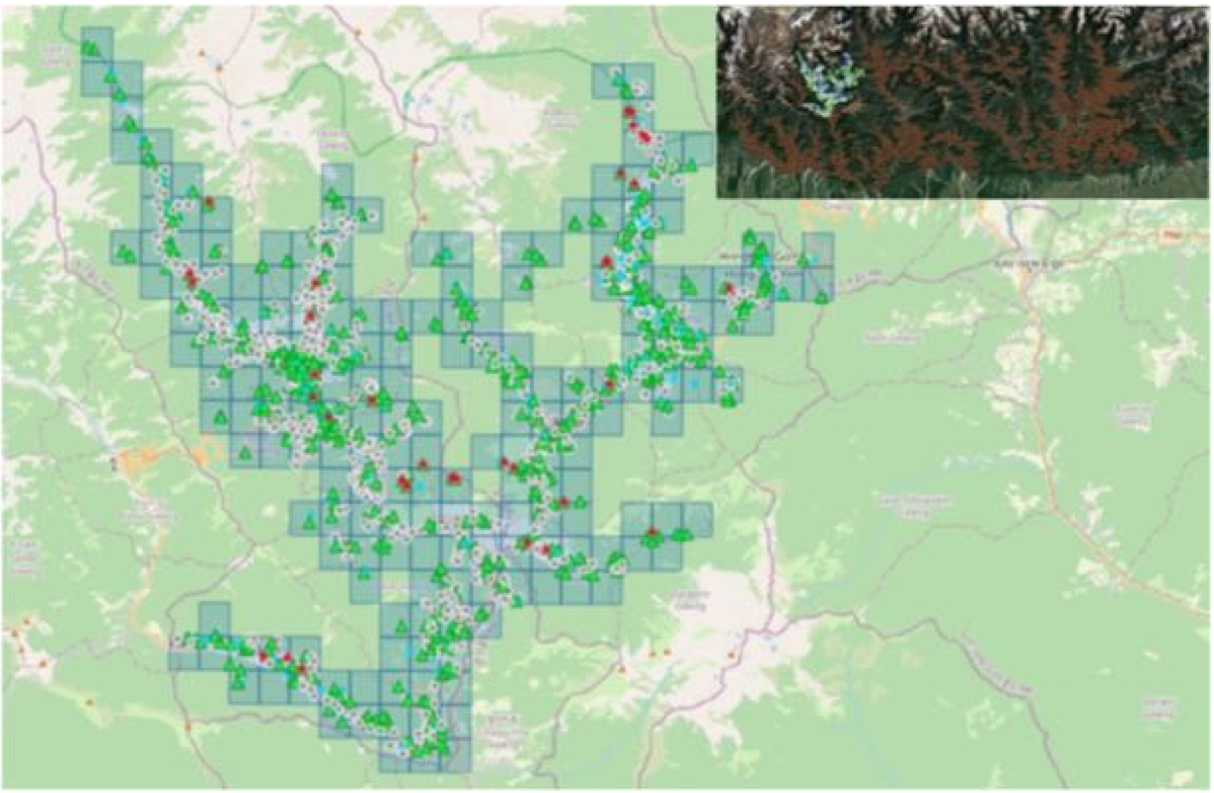

Figure 6 – Control Points in Thimphu and Paro districts (see inset image for location in Bhutan): (green) observed; (blue) destroyed; (red) removed; (white) not observed.

Currently, a local NTv2 file was computed for Thimphu-Paro areas. This NTv2 is still not final since when control points in the other neighbor districts will be observed, slight changes are expected also for the NTv2 file for Thimphu and Paro.

The NTv2 file was computed using NTv2Creator (https://www.killetsoft.de/p_ntta_e.htm). In the estimation of the NTv2 file, an iterative process was carried out to detect and remove outliers, in a total of 34 control points being excluded. Figure 6 shows that the distribution of these outliers is spread over the entire area of interest demonstrating that the produced NTv2 does not suffer from localized biases.

Figure 7 shows the graphical view of the estimated NTv2 file for Thimphu and Paro districts where a total of 676 meshes are used. Due to the inhomogeneous distribution of the existing control points (highly dependent on the topography), 59 grid points have been transformed with a grid-wide Helmert seven-parameter set. This was necessary due to missing identical points in the corner and border areas.

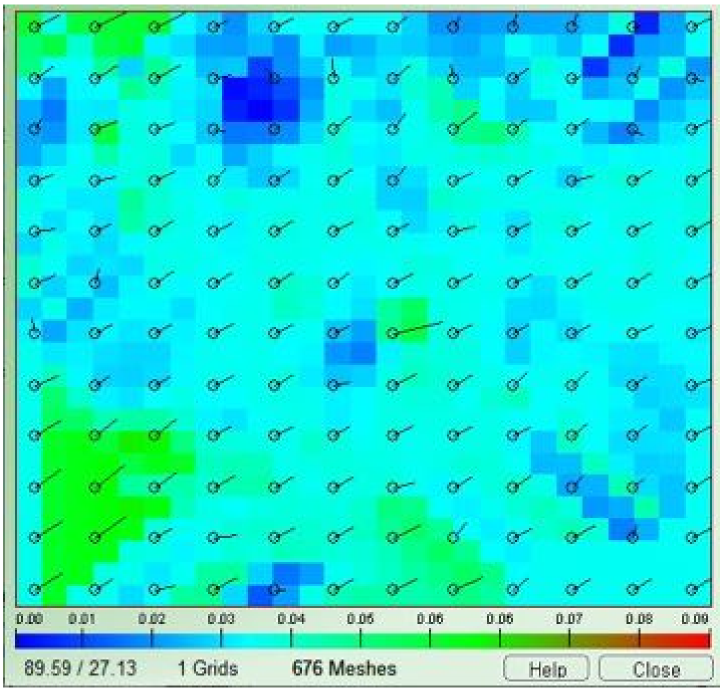

Figure 7 – Derived NTv2 File for Thimphu and Paro districts

5. APPLICATION OF NTV2 FILES – CHILE EXAMPLE

A procedure similar to the one used for Bhutan was used in Chile through a proposal based on transformations using NTv2 grid distortion models. This type of modelling also allows sub-grids to be included in case more data are available, a transformation that has already been used in other countries with its viability proven.

To perform this calculation, an iteration was carried out by removing vertices that exceeded the residue of 1.00 m and then remodeling it. The scope and points used for each grid according to its datum (PSAD56 and SAD69) are found in Figure 8 and Figure 9, and as can be seen, the Atacama Region (north of Chile) could be included for PSAD56, something that does not happen with the other tools. The calculation was made based on a 3D conformal transformation and then modeling the residuals.

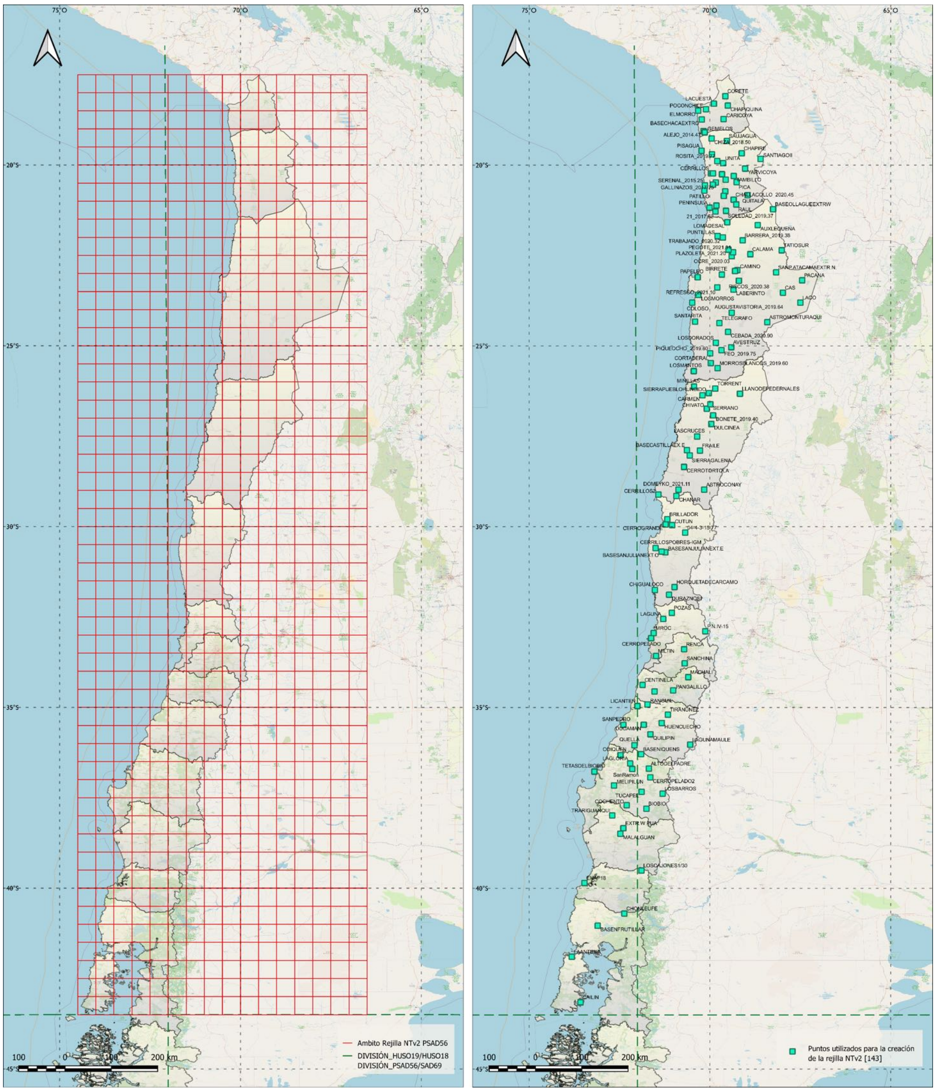

Figure 8 – Scope of the NTv2 file for PSAD56 and points used to model it.

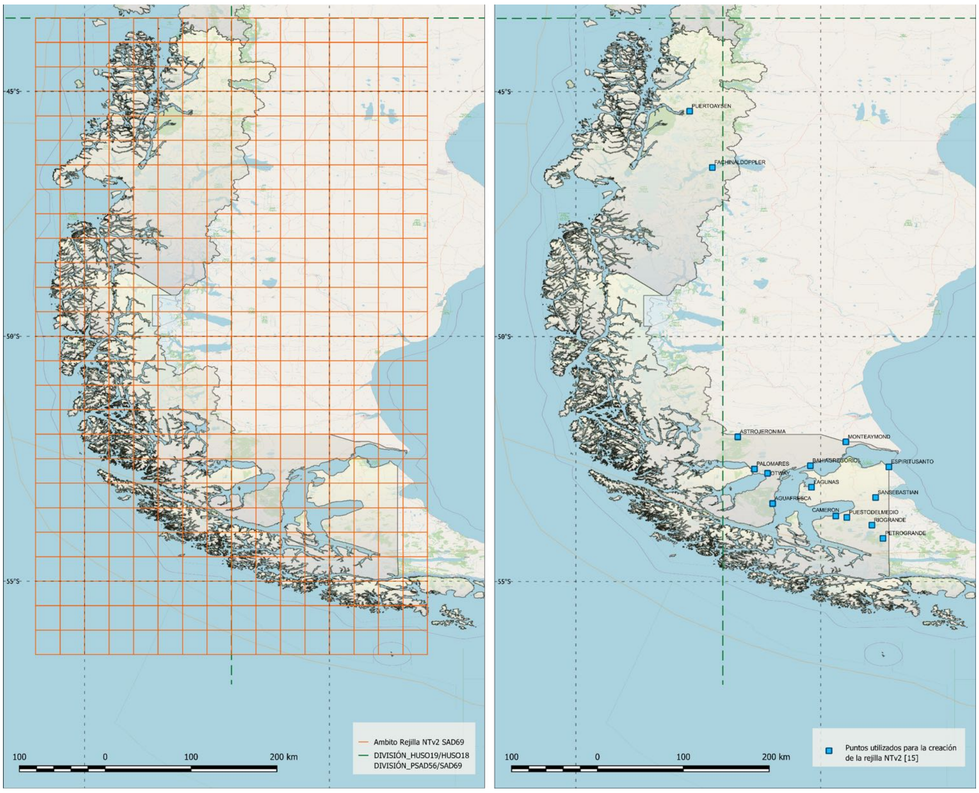

Figure 9 – Scope of the NTv2 file for SAD69 and points used to model it.

The histogram of the residuals in meters are shown in Figure 10, which shows that the majority of the residuals are between ~-0.30 and ~+0.30 m, which can be considered reasonable attending the shape and deformations of the area.

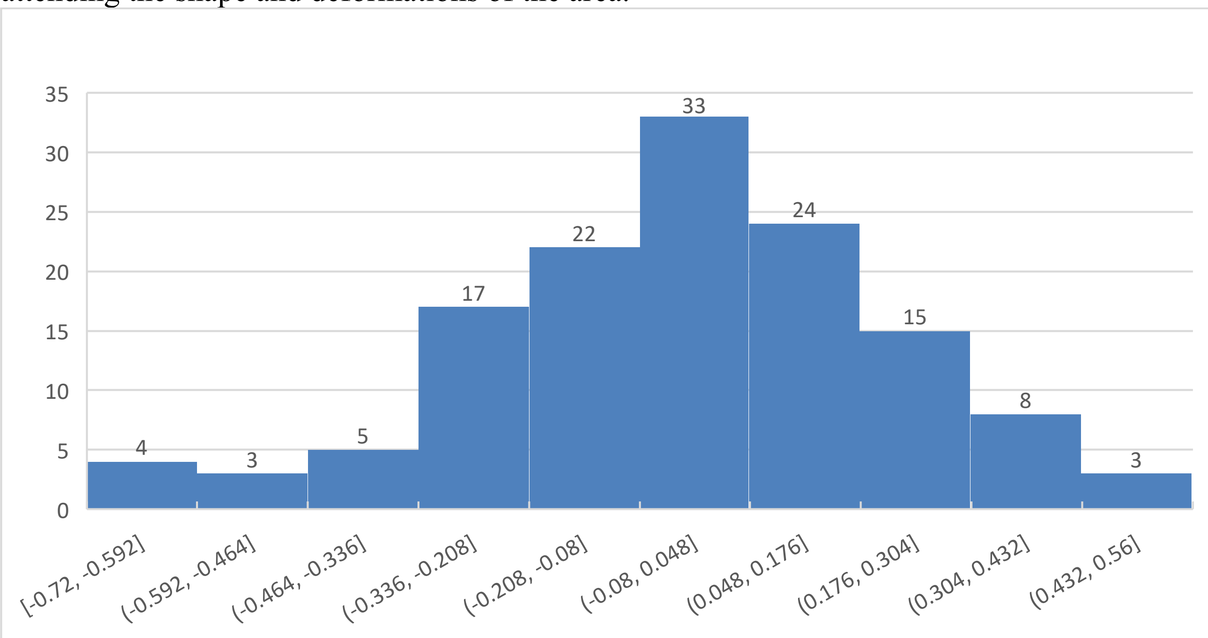

Figure 10 – Histogram of the residuals of the modeling using NTv2 files in Chile.

6. CONCLUSIONS

We demonstrate that NTv2 files are the best option for datum transformations in regions with dynamic geological processes, exemplified by the cases of Bhutan and Chile. Traditional approaches like 7-parameter transformations often make it impossible to adequately capture the internal deformations and errors inherent in old classical datums, leading to unacceptable levels of transformation inaccuracies. The implementation of NTv2 files addresses these challenges by providing a flexible and accurate means of converting coordinates between different datums. The case studies presented for Bhutan and Chile emphasize the efficacy of NTv2 files in overcoming the limitations of traditional transformation methods. In Bhutan, where the adoption of a new datum, DrukRef23, was necessary due to internal deformations and tectonic activity, NTv2 files is proving an efficient tool to achieve a reliable datum transformation. Similarly, ongoing efforts in Chile to implement NTv2-based transformations highlight the versatility and adaptability of this approach in addressing the unique challenges posed by deforming regions.

By offering a comprehensive solution to datum transformations, NTv2 files facilitate the seamless transition to modern geocentric datums while minimizing errors and disruptions in geospatial workflows. As such, NTv2 files are highly recommended for datum transformations in deforming regions or where the quality of the classical datums is low with large internal errors, laying the groundwork for improved geospatial analysis, planning, and decision-making.

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CONTACTS

Rui Fernandes
University of Beira Interior / MIRASpaco, Lda.
R. Marques d'Avila e Bolama
6201-001 Covilhã
PORTUGAL
Email: rui@segal.ubi
Web site: http://segal.ubi.pt/