FINAL SCIENTIFIC REPORT

SERVE

Strengthening the Provision of Core Services and Data to the European Plate Observing System

Carine Bruyninx – Royal Observatory of Belgium
Juliette Legrand – Royal Observatory of Belgium
Fikri Bamahry – Royal Observatory of Belgium
Andras Fabian – Royal Observatory of Belgium
Anna Miglio -Royal Observatory of Belgium

IN SUPPORT OF THE VALORISATION OF BELGIAN FEDERAL COMPONENTS IN ESFRI DISTRIBUTED AND VIRTUAL

SERVE

Strengthening the Provision of Core Services and Data to the European Plate Observing System

Contract N° EF/211/SERVE

PROMOTORS: Carine Bruyninx (Royal Observatory of Belgium)

AUTHORS: Juliette Legrand (Royal Observatory of Belgium)
Fikri Bamahry (Royal Observatory of Belgium)
Andras Fabian (Royal Observatory of Belgium)
Anna Miglio (Royal Observatory of Belgium)

Published in 2025 by the Belgian Science Policy Office
WTCIII
Simon Bolivarlaan 30 bus 7
Boulevard Simon Bolivar 30 bte 7
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11
http://www.belspo.be
https://www.belspo.be/belspo/ESFRI-FED/index_en.stm

Contact person: Aline van der Werf
Tel: +32 (0)2 238 36 71

Bruyninx C., Legrand J, Bamahry F., Fabian A., Miglio A., ***Strengthening the Provision of Core Services and Data to the European Plate Observing System***. Final Report. Brussels: Belgian Science Policy Office 20025 – 31 p. (ESFRI-FED - (In support of the valorisation of belgian federal components in esfri distributed and virtuaL))

TABLE OF CONTENTS

ABSTRACT

The European Plate Observing System (EPOS) is a unique pan-European e-infrastructure that provides open access to multidisciplinary scientific data and services, enabling better understanding of the dynamic processes shaping the Earth system.

The SERVE project, funded under Phase 1 of BELSPO's ESFRI-FED programme, was implemented from 15 December 2021 to 14 June 2025, with a total budget of €498,000. Coordinated by the GNSS[1] team of the Royal Observatory of Belgium (ROB) and supported in-kind by the Universidade da Beira Interior (UBI) in Portugal, SERVE aimed to strengthen the sustainability of Belgium's federal contribution to EPOS.

Importantly, during the SERVE project, EPOS evolved from its Pilot Operational Phase to its full Operational Phase. In this context, SERVE contributed significantly to consolidating and embedding Belgian services within the now fully operational EPOS ecosystem.

To achieve its goals, SERVE focused on three key areas:

- It modernized and expanded ROB's European GNSS data node, ultimately providing access to the data from 446 GNSS stations, and established a new national GNSS data node with data from 82 stations across Belgium. Both nodes were integrated into the EPOS infrastructure, making their data discoverable via the central EPOS data portal.
- It upgraded ROB's prototype GNSS data quality monitoring service into a fully operational EPOS service running on daily data gathered by thousands of GNSS stations.
- It formalized a collaboration agreement with EPOS ERIC, securing the legal and operational embedding in EPOS of all GNSS-related services provided by ROB.

In addition, SERVE conducted a mapping of Belgian data contributions to EPOS and identified opportunities for further data integration. This effort significantly increased the number of Belgian agencies participating to EPOS.

The project's results were disseminated through more than 20 presentations or posters at (inter)national conferences, a general outreach article in Science Connection, and two peer-reviewed papers. SERVE also launched a dedicated website: https://www.epos-be.eu.

Keywords EPOS, GNSS, services, data node, data quality

[1] GNSS – Global Navigation Satellite Systems, such as GPS, GLONASS, Galileo

1. INTRODUCTION

The European Plate Observing System (EPOS) is a unique research infrastructure supporting solid Earth science across Europe. It aims to improve our understanding of the complex and dynamic Earth system by providing integrated access to a wide range of scientific data and services.

Through a single, unified platform, EPOS connects data and services from distributed National Research Infrastructures (NRIs) covering disciplines such as geodesy (GNSS), geology, seismology, volcanology, and geomagnetism. To manage this multidisciplinary landscape effectively, EPOS is structured around Thematic Core Services (TCS). Within each TCS, selected Service Providers (SPs) ensure that data from NRIs are standardized, quality-controlled, and made discoverable through the EPOS central data portal (https://www.epos-eu.org/dataportal) running the Integrated Core Services (ICS) – see Figure 1.

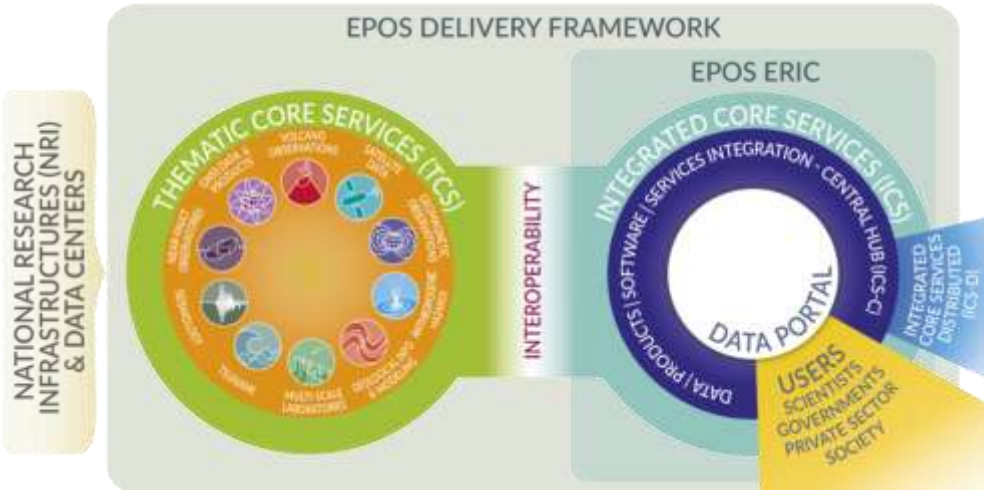

Figure 1 - Schematic overview of the EPOS delivery framework. Source : https://www.epos-eu.org/about-epos/what-we-do

The idea for EPOS emerged in the early 2000s, driven by a growing recognition among European geoscientists that solid Earth science data were fragmented across national infrastructures, making integrated research on a continental scale difficult. This fragmentation limited the ability of scientists to study pan-European geohazards, tectonic processes, and Earth system dynamics.

Around 2005–2007, discussions began among leading European Earth science institutions and research infrastructures about the need for a coordinated, long-term data infrastructure for the solid Earth sciences. These conversations were shaped by broader European developments such as (i) the European Strategy Forum on Research Infrastructures (ESFRI), which was identifying priority research infrastructures for the EU and (ii) the increasing importance of open science and data sharing across scientific domains.

In 2008, EPOS was officially included in the ESFRI Roadmap, marking a key milestone in its development and recognizing it as a strategic research infrastructure for Europe. This inclusion provided EPOS with the formal mandate and support to develop a pan-European distributed infrastructure, leading to the launch of the EPOS Preparatory Phase project (EPOS PP), funded under the EU's 7th Framework Programme (FP7). During the Preparatory Phase, the foundational architecture of EPOS was defined, such as the distinction between TCS and ICS. Although ROB was not

an official project partner, it was invited to contribute to two of the key EPOS PP working groups: Seismology and Geodesy. Within the Geodesy Working Group, ROB's GNSS team played a pivotal role in shaping the structure of the future Geodesy TCS, including identifying the key partners needed to build and operate it. During EPOS PP, the Geodesy TCS vision evolved into the TCS "GNSS Data and Products".

Building on its early involvement, ROB became a partner in the EPOS Implementation Phase (EPOS IP), which began in 2015 under the Horizon 2020 programme. This phase focused on developing initial services, establishing the legal framework, and designing the central IT architecture of EPOS. During this period, ROB's GNSS team helped to design and develop the GNSS TCS, hereafter called EPOS-GNSS.

In 2018, EPOS ERIC (European Research Infrastructure Consortium) was officially established, with Italy as the host country and Belgium among the founding members. To support Belgium's role in delivering services to EPOS, BELSPO funded the EPOS-BE project (2018-2022). Through this initiative, ROB upgraded its infrastructure to enable the provision of both national (GNSS and seismic) data services and pan-European GNSS services to EPOS.

2. MOTIVATION AND OBJECTIVES OF THE PROJECT

In 2019, strengthened by the approval of the EPOS-BE project, ROB reaffirmed its long-term commitment to EPOS by signing the EPOS-GNSS Consortium Agreement (CA). Through this agreement, ROB engaged to delivering six key EPOS services that form a cornerstone of EPOS' GNSS infrastructure and are essential to the successful operation of the GNSS segment within EPOS. These services comprise four Virtual Access (VA) services and two coordination services supporting the broader GNSS component of EPOS as outlined in Table 1. In parallel, ROB proposed the establishment of a service contract with EPOS ERIC to support the delivery and sustainability of these services.

Thanks to the combined efforts under the EPOS IP and EPOS-BE projects, several of ROB's GNSS services reached full operational maturity by 2021. However, two VA services still required further development. In addition, to secure the long-term sustainability of ROB's contributions and strengthen Belgium's role within EPOS, further action was necessary.

To respond to these needs, the SERVE project was launched on Dec. 15, 2021 as part of Phase 1 of BELSPO's ESFRI-FED program. SERVE also aligned with EPOS's Pilot Operational Phase (POP), which spanned from 2020 to 2022. The POP was a transitional phase crucial for testing and validating the operational readiness of the initial EPOS services. Key activities included the launch of an early version of the EPOS Data Portal, the collection of user feedback to refine service delivery pipelines, strategic planning for long-term sustainability, and the reinforcement of connections between national research infrastructures and EPOS ERIC.

SERVE was closely aligned with this final objective, as its primary goal was to secure the delivery, long-term maintenance, and formal integration of Belgium's federal services within the EPOS infrastructure.

To address these needs, the SERVE project targeted the following objectives:

- Technical objective: Ensure that ROB is both technically and organisationally prepared to deliver and maintain all six services, declared in the EPOS-GNSS CA, over the long term.
- Legal objective: Facilitate the signing of a Collaboration Agreement with EPOS ERIC, formally anchoring ROB's GNSS services within the EPOS infrastructure.
- Strategic objective: Expand the involvement of Belgian Federal Scientific Institutions (FSIs) in EPOS, reinforcing Belgium's long-term engagement in the research infrastructure.

3. METHODOLOGY

3.1 Technical

In this section we describe the methodology used to ensure that ROB could deliver and maintain all the services it included in the EPOS-GNSS Consortium Agreement. For that purpose, SERVE focussed on these two VA services that were not yet fully operational (indicated by the purple rectangle in Table 1) with the goal to turn them into fully operational EPOS services: the pre-operational EUREF GNSS data node and the prototype GNSS data quality monitoring service.

Table 1 GNSS services included by ROB with the Consortium Agreement of the EPOS TCS GNSS data and products. The services surrounded by a purple box required further development in SERVE.

DECLARED PAN-EUROPEAN EPOS-GNSS SERVICES	MATURITY	LINK WITH EPOS
VIRTUAL ACCESS (VA) SERVICES		
EUREF GNSS data node	Pre-operational	Included in EPOS Pilot Operational Phase (POP)
GNSS data quality monitoring service	Prototype available	Declared in Consortium Agreement
GNSS metadata management system (M^3G)	Operational	Included in EPOS POP
EUREF reference frame product	Operational	Included in EPOS POP
COORDINATION SERVICES		
Interface EPOS and EUREF	N/A	Running
Harmonization with federated GNSS data providers	N/A	Running

To further elaborate on the methodology, it is essential to first describe how GNSS data dissemination is organized within EPOS. To make GNSS data discoverable through EPOS, station operators sign the EPOS-GNSS Data Supplier Letter, submit station metadata (including equipment details, data license, and ownership) to M^3G (https://gnss-metadata.eu), and upload GNSS data to a designated repository. This repository runs the open-source Geodetic Linkage Advanced Software System (GLASS), which establishes a virtualization layer over the data repository. GLASS performs multiple key functions: it indexes the GNSS data files, validates them against the station metadata, conducts quality checks, and stores all related information into the local node database. It then synchronizes the metadata of the GNSS data files from the local database to the database of the EPOS-GNSS Data Gateway (DGW) database, where these metadata, including the location (URL) of the GNSS data become accessible via both an Application Programming Interface (API) and a web portal. Once a repository has installed GLASS, populated its database with newly available GNSS data, and synchronized it with the DGW, it becomes an EPOS-GNSS data node.

In addition, the EPOS architecture includes a GNSS Data Quality Monitoring Service (DQMS), designed to retrieve information on GNSS data availability and quality (called Data Quality Metrics -DQM- hereafter) from both the data nodes and the DGW, derive from them Data Quality Indicators (DQI), continuously monitor these indicators, and inform nodes and GNSS station operators when abnormal conditions are detected.

GNSS data nodes

At the start of the SERVE project, ROB's EUREF data node provided EPOS with pre-operational access to the GNSS data from the EUREF network. However, this original node installation was not suited for

long-term operational use. It was deployed on a virtual machine based on a pre-configured image that included all GLASS components and its database. This setup lacked scalability, was inflexible to changing requirements, and offered limited database security. Additionally, it was not designed to accommodate the expected growth in GNSS data volume.

To overcome these limitations, transition the EUREF data node into a fully operational service, and establish in addition a new robust national GNSS data node aligned with SERVE's strategic goal, the SERVE project launched a focused software development effort. The aim was not only to enhance the GLASS node software's robustness, security, and scalability, but also to improve the software to facilitate the maintenance and the operation of the data node. The development proceeded in iterative cycles that combined implementation and testing, supported by a short feedback loop involving both internal and external users working.

The following key steps were undertaken:

- Analysis of the GLASS workflow and components, with particular attention to system security, the use of the API, and the identification of deprecated technologies.
- Revision of software requirements, use cases, and system design, based on the insights gained from the initial analysis.
- Enhancement of the GLASS node software, including bug fixes, improvements to database security, integration of the latest version of the GNSS data quality check software, and performance upgrades to the GLASS API to improve operational efficiency.
- Deployment of the improved GLASS software on two distributed server infrastructures: one to replace the pre-operational EUREF node and another one for the new Belgian national GNSS node. The nodes were split in three separate systems: a dedicated database server, a high-performance computing (HPC) server for GNSS data file indexing and quality checks, and an application server running the GLASS synchronization system, API, and web portal.
- Publication of the improved GLASS software package on the public GLASS Gitlab repository.
- Update of the swagger documentation to include the new functionalities of the GLASS API.

After the deployment and testing cycle, the two new GNSS data nodes had to be put into operation by

- Preparing the complete historical Belgian and EUREF GNSS datasets for integration in the two nodes, e.g. adapt GNSS data file formats to new international standards, correct metadata errors…
- Use the upgraded GLASS software and whole GNSS datasets to run the new quality check software on all GNSS data and populate all GLASS databases

In addition to the deployment of the GLASS software, several supporting actions were necessary to facilitate the maintenance and the operation of the nodes:

- Upgrade of local management tools: The tools used to manage the GLASS nodes locally were enhanced to support key operational tasks. These include the automated daily ingestion of new GNSS data, the integration of additional GNSS stations, the reprocessing of updated datasets, and the monitoring of node performance in a production environment.

- Development of internal documentation: Comprehensive documentation was created and published for ROB staff to ensure long-term maintainability and support future development and operations. This documentation covers the full-service workflow, operational procedures, and the use of the monitoring and management tools.

Data Quality Monitoring Service (DQMS)

SERVE also converted the prototype GNSS data quality monitoring service into a scalable and maintainable operational service. To achieve this goal, the following steps were taken:

- Evaluate the existing DQMS prototype by identifying shortcomings, bug, and missing functionalities.
- Revise the original DQMS service design: This involved
    - redesigning the method for retrieving and updating the DQM from EPOS-GNSS data nodes in order to improve response times and ensure more robust handling of erroneous DQM values.
    - Identify the Quality Indicators that must be visualized and monitored.
    - Optimize the structure of the local database to support fast and efficient access, and suitable plotting tools were selected for DQI visualization, with execution speed considered a critical factor.
- Initial software was then implemented to support the core functionalities of the DQMS service. On the backend, this included the retrieval of historical, new, and updated DQM from all EPOS-GNSS data nodes, computation of the DQI as well as the population of a local DQI database. Additionally, APIs were developed to enable querying of the database, and software was created to support DQI visualizations. On the frontend, an initial version of the DQMS web portal was developed, providing users with access to the DQI visualizations.
- In addition, to enable generating alarms, it was necessary to implement initial tools to create static and dynamic (on-request) visualisations as well an initial version of the DQMS alarm software.

The initial software was then used to provide an initial service used as a basis for an iterative testing and development cycle involving data nodes and GNSS station managers (see section 5.2 for more details on stakeholder engagement). During this process, we also performed internal testing (full system test) and validation to evaluate service execution speed using real data from 1200+ EPOS-GNSS stations.

After all this, and taking user feedback into account, the DQMS software (backend, frontend, and alarms) was finalized and documented by describing workflows as well as procedures and responsibilities for the future operation and maintenance of the services.

3.2 Strategic

This section outlines the methodology adopted to enhance the participation of Belgian Federal Scientific Institutions (FSIs) in the European Plate Observing System (EPOS).

The first step was to assess the current level of Belgian engagement in EPOS. Therefore SERVE conducted in the period 2022-2023 an initial mapping of Belgian data and service contributions To

EPOS. This was done by consulting the EPOS ICS portal (https://www.ics-c.epos-eu.org/) and the individual portals of the Thematic Core Services. This mapping focused primarily on FSIs, but given the complexity and breadth of EPOS, the mapping was quickly expanded to include contributions from all Belgian institutions, such as universities, governmental authorities, and regional research agencies—acknowledging that EPOS extends beyond the scope of FSIs alone.

Following the mapping, a national outreach initiative was launched. This involved visiting agencies active in relevant scientific and technical domains but potentially unaware of EPOS or unclear on how to contribute. These meetings aimed to:

- Raise awareness about EPOS and its structure.
- Explain the process of becoming a data provider.
- Identify opportunities for these agencies to engage with EPOS.

In parallel, to support and sustain broader national participation in EPOS, the following complementary actions were planned:

- Update the EPOS-BE website (https://www.epos-be.eu, originally created during the previous EPOS-BE project) to serve as a central information hub, offering guidance on EPOS developments and how Belgian institutions can contribute.
- Organise a national EPOS workshop targeting FSIs and other interested Belgian institutions to foster direct dialogue and explore potential collaboration opportunities.
- Act as an intermediary between Belgian stakeholders and relevant EPOS contact persons, helping to clarify procedures, resolve uncertainties, and facilitate communication.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

The SERVE project delivered substantial progress across its three main objectives, significantly reinforcing the role of ROB within the EPOS infrastructure and enhancing Belgium's overall contribution to EPOS-GNSS services.

Importantly, these achievements were realized during a period of major transition for EPOS itself which moved from its Pilot Operational Phase into full Operational Phase during the SERVE project. The official launch of the EPOS Data Portal in spring 2023 marked a milestone in the infrastructure's maturity, accompanied by rapid technical developments and procedural shifts. The SERVE project had to adapt its work to maintain alignment with EPOS's emerging standards, workflows, and expectations.

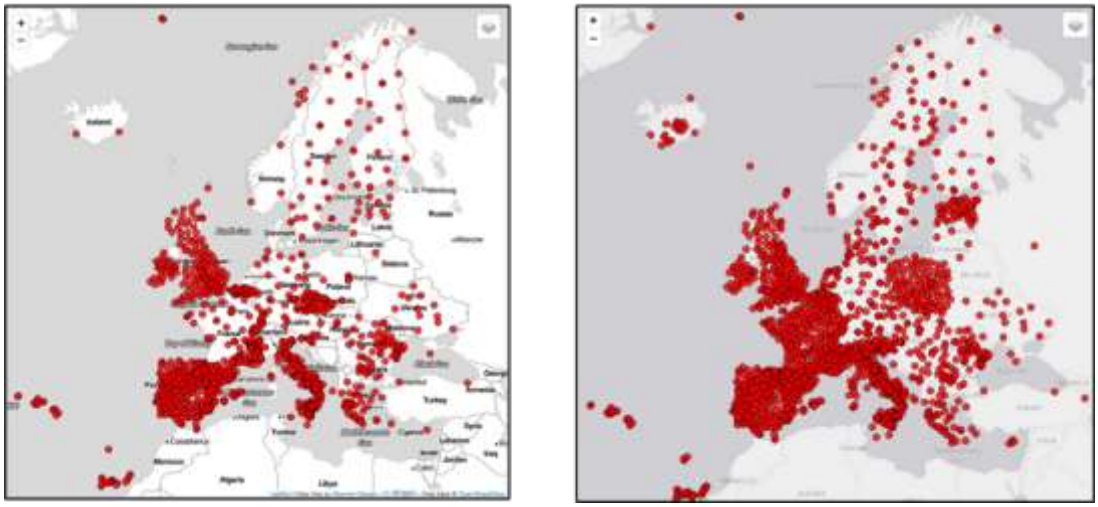

Figure 2 – Map of the EPOS-GNSS stations at the start (left) and end (right) of SERVE.

In parallel, EPOS-GNSS experienced significant growth at the European level: the number of stations in the network expanded from approximately 1200 to 2143 stations during the project period (see Figure 2). Also, the volume of GNSS data available through the EPOS nodes increased substantially - not only through the addition of new stations, but by populating the nodes with historical data (up to 1996), thereby enriching the temporal depth of the datasets available via EPOS. This increase further underscored the need for scalable, reliable, and well-coordinated services—needs which SERVE addressed directly through the results described below.

4.1 Objective A – Ensure long-term maintainability of ROB's EPOS-GNSS services

To secure the sustainability of ROB's data services, several key technical developments were achieved.

The node software underwent major improvements

During the SERVE project, several issues and limitations were identified in the existing GLASS software used by the data nodes to distribute GNSS data within EPOS. 14 issues were identified and, in addition, the initial Data Quality Monitoring Service revealed further GLASS software bugs and inconsistencies.

To address all these challenges and enhance the robustness of the GLASS software, ROB intensified its direct involvement in the software's development, working in close collaboration with established partners UBI (Portugal), OCA (France), and INGV (Italy). ROB also assumed a co-leadership role in the development process, taking responsibility for organizing weekly coordination meetings to ensure

effective communication, monitor progress, and facilitate rapid issue resolution. During this process, the identified issues were addressed either through standard software updates, or, in the case of more fundamental limitations, they were documented for resolution in a future iteration of the GLASS software.

Several improvements were also implemented across the GLASS software suite aiming at facilitating the node management by the local node operators. One of the key outcomes was the introduction of a central management table for GNSS station inclusion, which streamlined the process of tracking and controlling the integration of new GNSS station data into the system.

Furthermore, the node metadata workflow became more reliable, allowing node operators to better assess the status and integrity of their GNSS data submissions and take appropriate actions. The API used to insert metadata of GNSS data files into the local GLASS database was enhanced to provide improved error handling, clearer status codes, and updated documentation. The GLASS tool that generates the metadata of the GNSS data files was enhanced to take into account the new status codes from the metadata insertion. These improvements enable not only more accurate detection and resolution of issues during the ingestion of the metadata, but they also improve the decision-making process, enabling clearer alerts and better diagnostics.

In addition to these workflow enhancements, the software was adapted to support new GNSS data formats, by implementing a new version of the GNSS quality check software.

Finally, documentation across all components of the GLASS ecosystem was revised and improved, providing better guidance for system administrators, developers, and data nodes. The improved GLASS software package was published on the public GLASS Gitlab repository (https://gitlab.com/gpseurope/) and the updated the documentation including the new functionalities of the GLASS API is available from (https://gnss-epos.eu/glass-api/) and the swagger documentation is available from (https://gnssdata-epos.oca.eu/GlassFramework/swagger.html).

As already mentioned, requirements for the next-generation GLASS software were also collected (https://gitlab.com/gpseurope/issuetracker/-/issues/). This next version is expected to tackle deeper architectural challenges, including synchronization mechanisms, database design, and full alignment with FAIR data principles. However, such a redesign will be part of a broader software modernization effort, which lies beyond the scope of the SERVE project.

In parallel, SERVE enhanced node monitoring and issue tracking across the EPOS-GNSS infrastructure. The efforts included:

- A general increase in the monitoring of node performance, with the ability to detect emerging issues more proactively (see the section on the DQMS).
- An annual tour of the nodes, coordinated by ROB, to assess individually with each node their operational status and help node operators to understand and properly use the GLASS software, an activity that ensured that the stakeholders were engaged (see section 5.2) from the start in all software developments.
- Continuous follow-up of software deployments, ensuring that each node was running the latest stable and tested version.

Significant efforts were also made to re-design and improve ROB's node management software surrounding the GLASS components. This redesign aimed to improve overall operational efficiency and reliability through improved error handling and diagnostics, as well as system performance

tracking. Finally, the node documentation was elaborated in order to facilitate future maintenance of the ROB nodes as well as their day-to-day operation.

Operational GNSS data nodes

ROB implemented a new infrastructure for its EUREF node through the installation of new servers using a distributed system architecture, designed to support a more flexible deployment and maintenance. In addition, ROB used a similar set up for its new Belgian data node, ensuring that the services delivered through the Belgian and EUREF nodes both meet EPOS requirements.

The improved node software was installed on the distributed systems and then used to populate the Belgian national node and the EUREF node with GNSS data:

- The Belgian node became operational in April 2023. It currently hosts data from 82 GNSS stations, comprising approximately 500 000 GNSS data files that are now available through the EPOS data portal.
- The ROB-EUREF node was also fully populated and now serves data from 446 GNSS stations, amounting to roughly 2.5 million GNSS data files available through the EPOS data portal.

In addition, thanks to the improved API and database security, the two ROB nodes are now open without restrictions and accessible via https://rob-euref-epos.gnss.be/ and https://belgium-epos.gnss.be/ (see Figure 4).

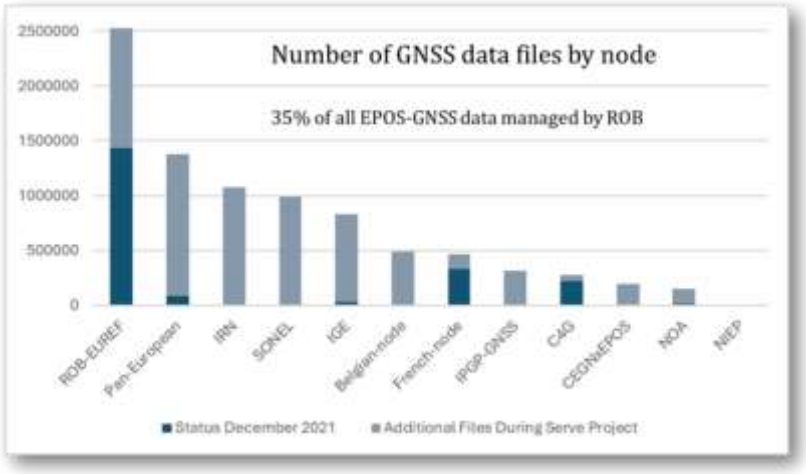

Figure 3 – Number of GNSS data files made available by each EPOS-GNSS data node.

Figure 4 – Web portal of the Belgian national EPOS-GNSS data node

As a result, the EUREF GNSS node and the newly established Belgian national node were brought to full operational status, representing 35% of all GNSS data distributed through EPOS-GNSS. Together, these two nodes form a critical component of Belgium's contribution to EPOS-GNSS, providing a stable, scalable, and well-documented infrastructure that supports GNSS data delivery at the national and European level.

Operational Data Quality Monitoring Service

Through SERVE, ROB's prototype DQMS became a fully operational EPOS service, and the system is now fully documented. The operational DQMS consists of three main components: a local internal database storing all information from external sources, a backend and a frontend (see Figure 5).

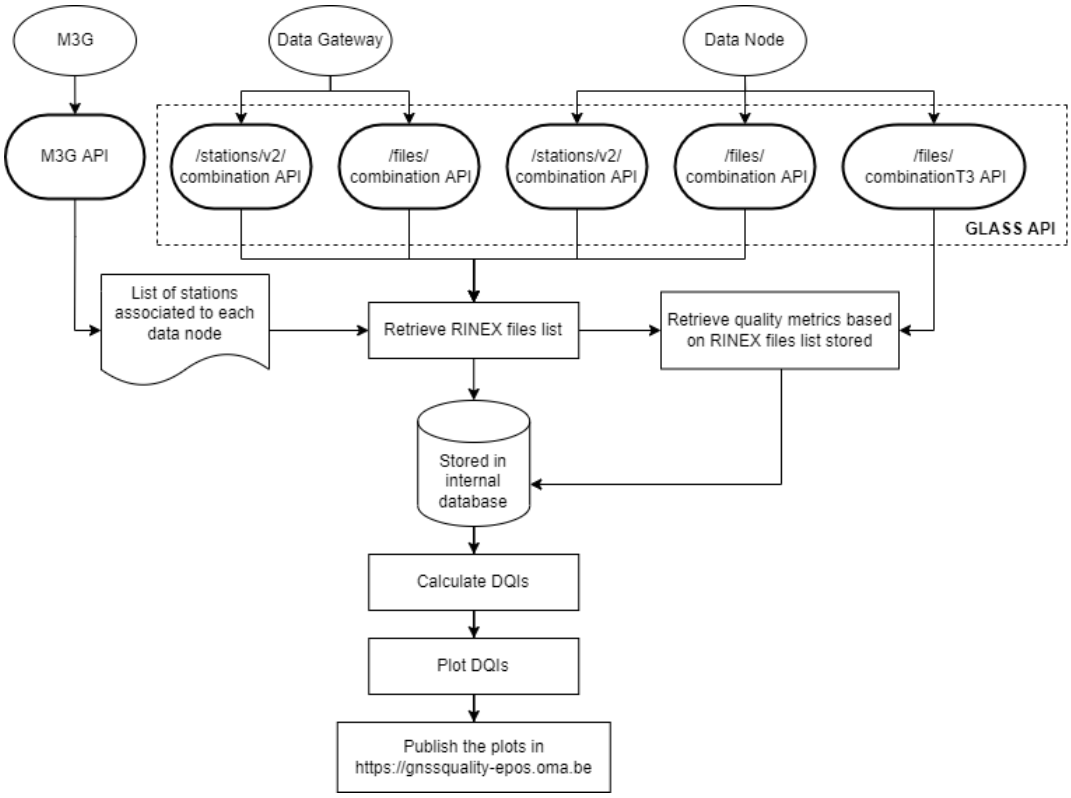

Figure 5 - Overview of the DQMS system architecture describing the main GLASS API retrievals, the storing of information in the DQMS database, and the plotting of data quality indicators plots.

The backend performs the following tasks

- Data and information retrieval: In this step, the DQMS retrieves information from external sources such as the EPOS-GNSS Data Gateway (DGW), and M^{3}G (GNSS metadata management system) and the EPOS-GNSS data nodes. From each of the EPOS-GNSS data nodes every day the list and metadata of available daily GNSS data as well as their associated DQM computed by the nodes are retrieved.
- Store information in the DQMS database: All metadata and associated DQMs that have been retrieved from the nodes are then stored in the DQMS internal database.
- Data quality engine: In this step, the system applies validation rules (checking duplicates, wrong filenames, wrong day of year) and computes for each GNSS data file (1 file/station/day) the selected GNSS DQIs based on the retrieved DQM. These DQIs are
    i. the percentage of observed vs. expected observations computed as the ratio of the number of actual observations with respect to the number of expected observations for each constellation,
    ii. the percentage of epochs without any observations,
    iii. the number of observed satellites for each constellation tracked by the station,
    iv. the maximum number of observations counted for each frequency and each constellation tracked by the station,
    v. the ratio of the number of identified phase cycle slips × 1000 with respect to the number of phase observations for each constellation tracked by the station,

vi. the deviation of the estimated Standard Point Positioning coordinates with respect to their median value over the station history,

vii. the daily mean of code multipath per frequency band and satellite constellation,

viii. the satellite signals tracked

- The GNSS DQIs are then plotted and copied to the DQMS frontend to be published via a web portal https://gnssquality-epos.oma.be/ (see Figure 6).

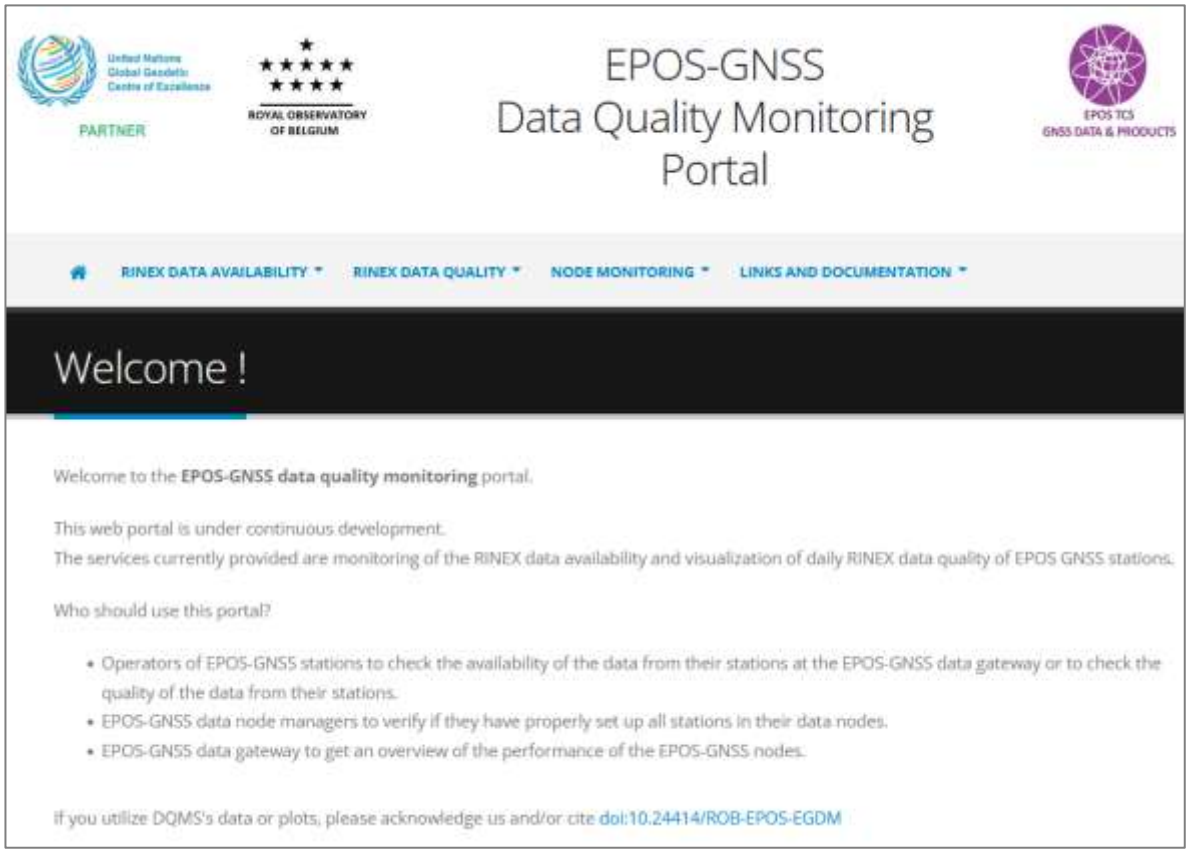

Figure 6 – Portal of ROB's new operational GNSS Data Quality Monitoring System

The DQMS portal is structured into three main sections:

The first section focuses on GNSS data availability. It allows to check the distribution and the availability of the GNSS data that are discoverable through EPOS and filter them by EPOS-GNSS data node, GNSS network, or M^{3}G metadata maintainer. For each station, the resulting number of available daily GNSS data files are then graphically represented on a map (see Figure 7). Compared to the prototype, this new DQMS map is faster and not impacted by a potential overload of an EPOS-GNSS data node.

The second section focusses on GNSS data quality (see Figure 8) and provides plots of the GNSS DQIs computed within the Data Quality Engine.

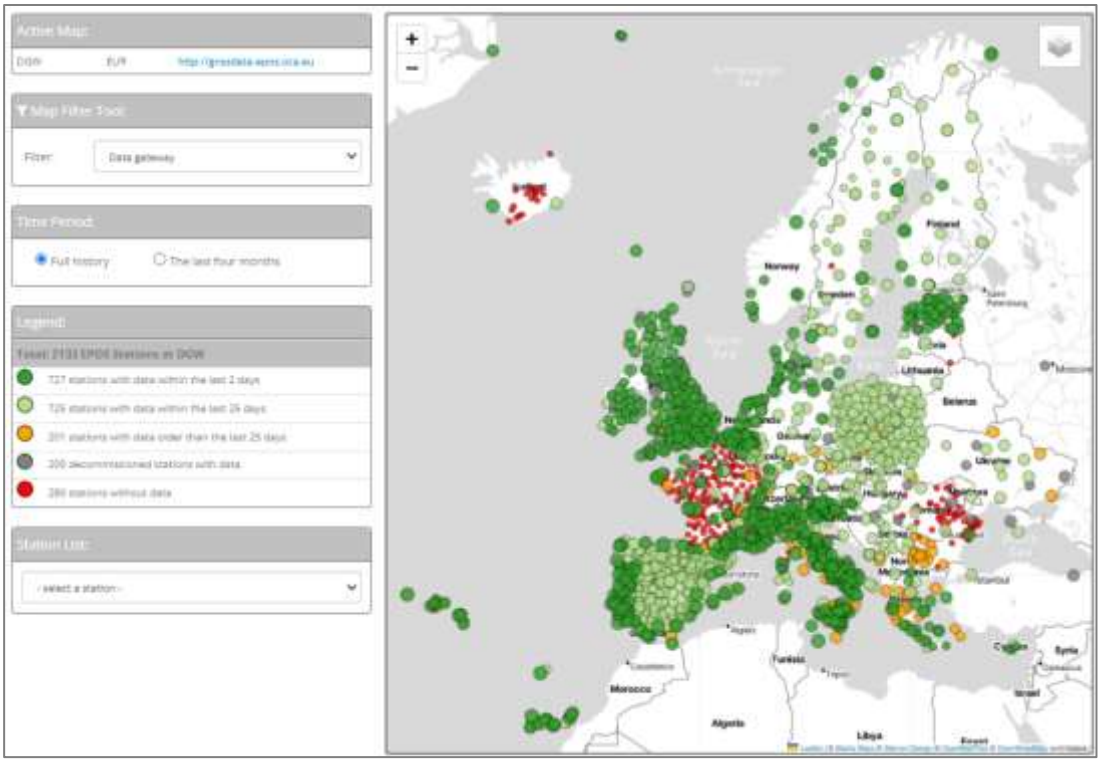

Figure 7 – GNSS data availability map provided on DQMS web portal

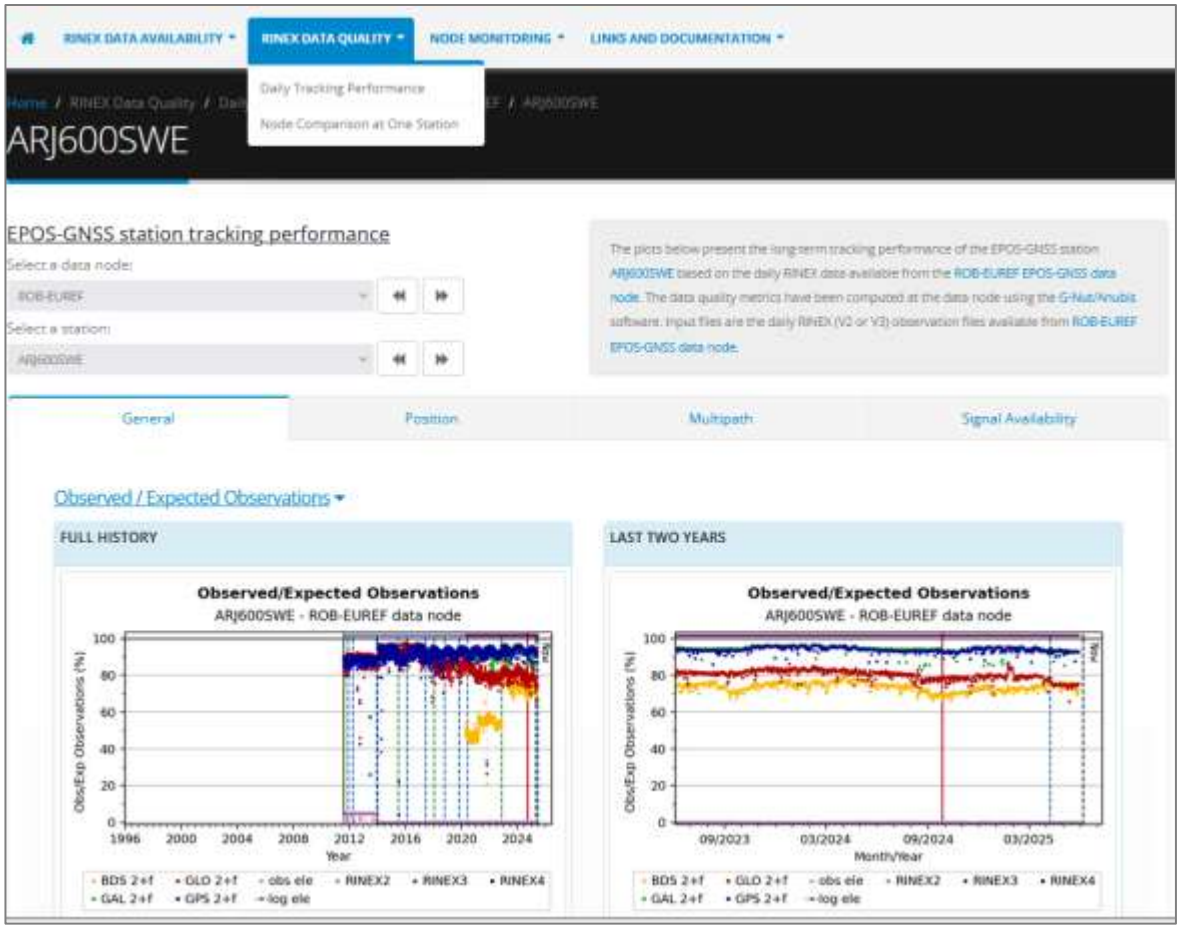

Figure 8 – Screenshot of GNSS data quality monitoring as provided by the DQMS web portal

The final section of the DQMS web portal—though not originally included in the SERVE proposal—was developed to monitor EPOS-GNSS nodes and support node managers in resolving issues efficiently. These monitoring pages were specifically designed in response to the data nodes' needs. They feature APIs that generate dynamic lists of problems detected in GNSS data files and track the progress made by node managers in addressing them. By integrating these tools into the DQMS web portal and encouraging close collaboration with node managers and GLASS software developers, the identification and resolution of issues at the data nodes have been significantly improved. This collaborative approach has led to measurable progress, reflected in the increased number of validated GNSS datasets now accessible through the EPOS data portal.

Finally, SERVE developed four types of email alarms/reports which are now operationally sent out to station or node managers:

- Weekly/Monthly GNSS data availability: Provides a report on the presence of GNSS data available from each node on a weekly and monthly basis.
- Duplicate GNSS files: Reports for each node instances where duplicate GNSS data files exist for the same station and date.
- GNSS data quality issues: Reports on problems such as data gaps, inconsistencies, or anomalies in the quality of GNSS observations.
- Recent discrepancies between the observed minimum elevation and the minimum elevation documented in the station metadata extracted from M^3G.

In September 2023, the Consortium Board of EPOS-GNSS declared the DQMS as officially operational and its portal was accepted by EPOS as one of the EPOS-GNSS community portals, see https://www.epos-eu.org/tcs/gnss-data-and-products/services.

Since 2024, over 180 email discussions with GNSS station operators or node managers have been initiated through the DQMS. These communications include data quality alarms, detailed explanations of DQMS features, and guidance for resolving detected data quality issues.

In summary, ROB's operational DQMS now supports the EPOS-GNSS component in monitoring the quality of GNSS data available on the EPOS platform, contributing to improved data reliability for subsequent analyses and research. It also helps to maintain compliance with EPOS standards, ensuring GNSS data adheres to the requirements needed for integration into the EPOS platform.
The DQMS provides a centralized platform where users can monitor and analyse different data quality metrics in one place. Using historical data quality metrics, users can track data quality over time, identify recurring issues, and improve the interpretation of their GNSS position time series.
Finally, the data quality alarms enable quick responses to issues affecting the availability or quality of GNSS data.

4.2 Objective B – Anchor ROB's GNSS services within the EPOS delivery framework

To formalize its role within EPOS, ROB initially planned to sign direct collaboration agreements with EPOS ERIC for the operation of its GNSS services. However, as noted earlier, EPOS was undergoing a period of rapid evolution during the SERVE project. In response to this dynamic context —and to reduce the administrative burden— EPOS ERIC revised its approach. Rather than establishing

agreements with individual service providers, EPOS ERIC opted to sign collaboration agreements exclusively with the institutions formally coordinating each TCS, listing the relevant service providers as funded third parties within those agreements.

For the GNSS TCS, coordination was handled by the University of Beira Interior (UBI). As a result, ROB was formally included as a third party in the following agreements:

- TCS GNSS Data and Services Provision – Collaboration Agreement (DSP_GNSS03/22) covering the years 2022–2023, in which ROB was awarded 81k€/yr for its data services to EPOS.
- TCS Governance and Services under the EPOS Delivery Framework – Multi-Year Collaboration Agreement (TCS MYCA 2024–2028 – 03 GNSS), covering the years 2024-2028, in which ROB was awarded 95k€ in 2024 and 67k€ 2025 for its services to the EPOS. The reduction of budget in 2025 is a result of the fact that the overall budgetary envelope attributed by EPOS ERIC to the GNSS TCS was significantly reduced in 2025.

These agreements ensure the official recognition and integration of ROB's GNSS services within the EPOS delivery framework, providing a stable basis for their long-term contribution to EPOS.

4.3 Objective C – Facilitate broader Belgian data contribution to EPOS

The survey of Belgian data and service provision to EPOS done in 2022-2023 by querying the EPOS data portal revealed that several federal and regional institutions—including the ROB, the Royal Meteorological Institute, the Flanders Marine Institute (VLIZ) already contributed to various TCS, such as GNSS, Seismology, Geomagnetism, and Multi-scale Laboratories.
In a second step, the SERVE team focused on mapping the solid Earth research landscape in Belgium and which national NRI's could be interesting as potential new data providers to EPOS. The following TCSs and NRIs were deemed as promising in the Belgian context:

1. Geological Information & Modelling:
    a. Vlaams Planbureau voor Ondergrond (VPO) – Databank Ondergrond Vlaanderen: large range of datasets on deep subsurface of Flanders presented online in portal (https://www.dov.vlaanderen.be/)
    b. Service Geologique de Wallonie: geological maps of Walloon area
    c. Geological Survey – Royal Belgian institute for Natural Sciences (RBINS)
2. Satellite Observations
    a. ULiège – Centre Spatial de Liège – Signal Processing Lab: expertise in utilizing InSAR to measure ground deformation, subsidence + development InSAR suite
3. Anthropogenic Hazards
    a. VITO : Balmatt geothermal plant
    b. Fluxys : Loenhout underground gas storage
    c. Johnson & Johnson – Janssen Pharmaceutica : geothermal plant

4) Multi-scale Laboratories
    a. KU Leuven : laboratories from Geology Division and Material Science department integrated in Materials Research Centre (MRC - https://set.kuleuven.be/mrc/index)

b. UGent : laboratories from Geology Division (e.g. Renard Centre of Marine Geology, Centre for X-ray Tomography)
c. ULiège : laboraties from Geology and Engineering (e.g. CSL, GeMMe)

Subsequently, most of these NRI's were contacted and when the initial communication was positive, a follow-up meeting was arranged to introduce EPOS in depth and discuss possible pathways of data integration. As a result, VITO showed strong interest in contributing data from its Balmatt geothermal site to the Anthropogenic Hazards (AH) TCS. This led to fruitful discussions with both ROB and the EPOS AH-TCS team about setting up a data node and sharing seismic, industrial, and geological data - ultimately working toward the creation of a digital twin for the Balmatt site.
Other institutions, such as Fluxys and Johnson & Johnson, were also approached regarding their geothermal and underground storage projects. While Fluxys expressed conceptual interest, the absence of documented induced seismicity limited immediate collaboration.
The major results were however achieved within the GNSS TCs, which is also the natural habitat of the SERVE team. Indeed, supported by the establishment of the new Belgian GNSS data node, several new GNSS data providers started to make their GNSS data discoverable through EPOS:

- Digitaal Vlaanderen
- Service Publique de Wallonie
- Agentschap Maritieme Dienstverlening & Kust
- Centre Spatial de Liège
- National Geographic Institute
- Royal Belgian Institute of Natural Sciences - Geological Survey of Belgium
- European Space Operations Centre (ESA)

SERVE also promoted EPOS to the Belgian research community by revisiting the EPOS-BE website in order to centralize information about Belgium's contributions to EPOS and the broader EPOS infrastructure. Social media channels on LinkedIn and X (formerly Twitter) were created to increase visibility. Additionally, a popular science article was published in Science Connection.

Finally, in collaboration with the EPOS communication office and representatives of several EPOS TCS, SERVE organised the "Meet EPOS-BE webinar". The webinar took place on November 24, 2023, and focused on introducing the EPOS and its Belgian national node to researchers, students, and data professionals. The webinar aimed to provide practical information on using EPOS for research, highlighting its Pan-European infrastructure for sharing solid earth science data. It also included a tutorial on how to use the EPOS data portal.

To summarize, through a series of dissemination activities and stakeholder engagement efforts, the SERVE project successfully broadened Belgian participation in EPOS. Through these activities, the groundwork was laid to both consolidate Belgium's existing role in EPOS and strategically grow its future participation across various scientific domains.

EPOS-BE PROGRAMME

Time	Title	Duration	Speaker
09:30 - 09:40	Opening and housekeeping information	(2')	FEDERICA TANLONGO Chief of Communications, EPOS ERIC (moderator)
	Welcome and short introduction to EPOS-BE	(8')	LAURENT GHYS Adviser, BELSPO
09:40 - 10:00	An introduction to EPOS, the pan-European Research Infrastructure to openly share solid Earth science data and services	(20')	LILLI FREDA Executive Director, EPOS ERIC
10:00 - 10:10	EPOS TCS Anthropogenic Hazards Consortium introduces the EPISODES Platform, a digital space for research into anthropogenic seismicity	(10')	ANNA LEŚNODORSKA Head TCS Anthropogenic Hazards, Institute of Geophysics of the Polish Academy of Sciences
10:10 - 10:20	EPOS TCS Satellite Data: observations and products for geohazards analyses	(10')	MICHELE MANUNTA Head TCS Satellite Data, CNR-IREA
10:20 - 10:30	EPOS TCS GNSS Data and Products	(10')	CARINE BRUYNINX Chair Executive Board TCS GNSS Data and Products, Royal Observatory of Belgium
10:30 - 10:40	EPOS TCS Seismology: Open seismic data Everybody seismologist!	(10')	KOEN VAN NOTEN Earthquake Geologist, TCS Seismology, Royal Observatory of Belgium
10:40 - 11:00	INTERACTIVE SESSION: QUESTIONS, ANSWERS AND INPUT FROM THE AUDIENCE	(20')	
11:00 - 11:15		Coffee Break	
11:15 - 11:45	Live demonstration of the EPOS Data Portal	(30')	JAN MICHALEK EPOS ICS-TCS Interaction Coordinator, University of Bergen
11:45 - 11:55	The use of the EPOS Data Portal in seismotectonic studies: applications to Southern Italy	(10')	FABIO FERIOZZI PhD student, INGV and Roma Tre University
11:55 - 12:25	INTERACTIVE SESSION: QUESTIONS, ANSWERS AND INPUT FROM THE AUDIENCE	(30')	
12:25	End of Sessions		

www.epos-be.eu/

Figure 9 – Program of the "Meet EPOS-BE webinar" organised by SERVE

4.3 Evaluation of the impact of the SERVE project

The SERVE project successfully contributed to achieving its primary goals, particularly Objectives A and B, by strengthening the operational, strategic, and international positioning ROB within EPOS and the broader GNSS community.

Achieving Objectives A and B

Thanks to the advancements made under SERVE:

- ROB could engage with full confidence in the MYCAs with EPOS ERIC, confirming its operational commitment to the declared EPOS services.
- The project facilitated a symbiosis between EPOS and EUREF services, allowing ROB to leverage its existing developments and longstanding expertise in both networks.
- ROB's services demonstrated high credibility among users, as reflected in impressive usage statistics, further validating their quality and relevance.
- The visibility of ROB within the GNSS and EPOS communities was significantly enhanced, leading to new collaborations and reinforcing its international role. This is evidenced by ROB taking on the role of Chair of the EPOS Service Coordination Committee and establishing new strategic contacts.
- The strengthened position also increased ROB's potential for participation in EU-funded EPOS-related projects, such as: Geo-INQUIRE (2022–2026), EPOS ON (2024–2027), EQUIP-G (2025–2029).

Achieving Objective C

In terms of national coordination:

- ROB now plays a central role in coordinating EPOS-GNSS activities at the national level, including the development and operation of a national GNSS data node.
- The project also helped foster collaboration with other FSIs by informing them about EPOS and encouraging participation in GNSS-related activities under the EPOS umbrella.

4.4 Recommendations

The following recommendations offer a strategic roadmap for maintaining the momentum of the SERVE project. However, they cover a broad range of domains and not all fall within ROB's expertise or responsibilities. As such, they are not intended for implementation by ROB alone. Their successful realization will require not only coordinated effort, but also sustained investment —both in time and funding— which is currently not secured. Continued support —at the institutional, national, and European levels, including from EPOS itself— will be essential to ensure the long-term impact of this work.

A. Ensure long-term sustainability of the developed services

- Secure institutional and financial support to maintain and further develop the ROB's GNSS services to EPOS.
- Plan for regular software and infrastructure updates to ensure robustness, scalability, and security of the ROB's operational services (e.g. GLASS nodes).

B. Strengthen national coordination and communication

- Establish or formalize a national EPOS coordination body or forum involving key Belgian stakeholders (ROB, NGI, FSIs, universities).
- Organize annual or semi-annual EPOS-BE meetings to share updates, foster synergies, and align national contributions with EPOS priorities.

C. Continue and expand stakeholder engagement

- Maintain contact with institutions and companies that showed interest (e.g. VITO, Fluxys, universities) to support data integration.

- Re-approach entities that did not respond or required more time (e.g. Johnson & Johnson, CSL–ULiège) with updated offers of collaboration.

D. Support data integration and technical onboarding

- Provide guidance and training for new partners on EPOS data standards, metadata requirements, and platform integration (e.g. EPISODES, CBIS).
- Facilitate joint technical sessions between potential data providers and EPOS TCS teams.

E. Enhance visibility and outreach

- Maintain and regularly update the EPOS-BE website and social media channels.
- Promote EPOS use cases from Belgian institutions to demonstrate the added value of participation.
- Publish lessons learned from the SERVE project in relevant journals or platforms.

F. Monitor and evaluate Belgian contributions to EPOS

- Develop metrics to track usage, visibility, and scientific impact of Belgian services and datasets within EPOS.
- Use these metrics to inform national research and infrastructure policy.

G. Leverage participation in EU projects

- Actively coordinate Belgian participation in ongoing and future EPOS-related EU projects (e.g. Geo-INQUIRE, EPOS ON, EQUIP-G).
- Use these projects to further develop services, enhance integration, and promote Belgian expertise at the European level.

5. DISSEMINATION AND VALORISATION

5.1 Anchor services in EPOS

As outlined in Section 4.2, the objective of integrating ROB's GNSS services into EPOS (objective C) was successfully achieved through the establishment of Multi-Year Collaboration Agreements. This was achieved thanks to ROB's strong and sustained provision of its EPOS services and its engagement within the EPOS governance framework. Indeed, ROB took on several key leadership and coordination roles, including serving as chair of the EPOS Service Coordination Committee (SCC) and member of the EPOS Executive Committee and the EPOS Data Policy Working Group. In addition, within the GNSS TCS, ROB chaired the EPOS-GNSS Executive Board, co-chaired the EPOS-GNSS software group and contributed as a member to the EPOS-GNSS Consortium Board. All these roles allowed ROB to play a central part in shaping strategic and operational decisions within EPOS, while also ensuring alignment of its own services with EPOS requirements. ROB's active participation in EPOS meetings further enabled the promotion of its GNSS services as key EPOS services. The following provides a non-exhaustive list of the EPOS meetings attended by SERVE team members:

- EPOS SCC meetings: 3 online meetings and one face-to-face meeting in 2022, 4 online meetings in 2023, 5 online meetings and 1 face-to-face meeting in 2024, 1 online and one face-to-face meeting in 2025
- EPOS executive committee meetings: 2 online meetings in 2022, 3 online meetings and one face-to-face meeting in 2023, 2 online and 1 face-to-face meeting in 2024
- EPOS working group on data policy meetings: 4 online meetings in 2024, 3 online meetings in 2025
- EPOS days:
    - EPOS days 2024: Presentation of Belgian contribution to EPOS
    - EPOS days 2025: chairing session on international collaboration and co-author of poster about EPOS-GNSS progress

SERVE team members also actively participated in meetings focused on the interaction between the Integrated Core Services and Thematic Core Services, particularly regarding the integration of TCS services into the EPOS Data Portal. This engagement included 5 online meetings in 2022, 10 online and 1 face-to-face meeting in 2023, and 11 online meetings and 1 face-to-face meeting in 2024.

Finally, SERVE participated to the following meetings within the TCS GNSS data and products:

- Consortium Board meetings: 1 online and 1 face-to-face meeting in 2022, 1 online and 1 face-to-face meetings in 2023, 2 online meetings and organization of one face-to-face meeting in Brussels;
- Executive Board meetings (chaired by ROB): 5 online meetings in 2022, 5 online meetings in 2023, 3 online meetings in 2024, and 1 online meeting in 2025.

5.2 Engagement of service stakeholders

GNSS data nodes

The development of the GNSS data node software was closely coordinated with its user community (node managers and data users) to ensure that the resulting tools met operational needs.

To enable continuous feedback and collaborative problem-solving, a dedicated GitLab repository (https://gitlab.com/gpseurope/issuetracker) was maintained, allowing users to report issues and suggest improvements directly.

In parallel, the SERVE team held individual consultations with each node operator to collect targeted input on node software performance and usability. Over the course of the project, 13 online meetings were held in 2022, 8 in 2023, and 11 in 2024. These sessions also served as opportunities to demonstrate the functionality of the node-specific monitoring pages provided by DQMS, emphasizing how these tools could support node operators in enhancing the quality and reliability of their services.

To ensure a rapid and coordinated response to reported issues, the GLASS software development team convened weekly meetings to review, discuss, and prioritize user feedback. A structured procedure was put in place to address issues efficiently - either resolving them promptly through updates or deferring more complex matters to the next generation of the GLASS software when they involved significant architectural changes. Since 2023, ROB has chaired these software coordination meetings, reflecting its leadership role in the development process. The meeting timeline is as follows: 2022: 7 online meetings, 2023: 27 online meetings and 1 face-to-face meeting, 2024: 69 online meetings, along with the organization of a face-to-face meeting in Brussels.

In addition, to enable following up closely the usage of ROB's data nodes, SERVE developed a new system to monitor the data downloads from its nodes. The system revealed 15 million GNSS data downloads in 2024 from the EUREF data node.

DQMS

The DQMS was developed in close collaboration with the data nodes (as explained above) but also with the station managers and data analysists who used the data for computing station velocities. During product meetings, analysis centers offered valuable suggestions for improvements based on their operational requirements and experience with data usage. 5 online product meetings were held in 2023, followed by 9 in early 2024 and 13 later in the same year, reflecting a growing engagement with the analysis community and a commitment to iterative, user-informed development.

In addition, as mentioned in section 4.1, since 2024, over 180 email discussions with GNSS station operators or node managers have been initiated through the DQMS. These communications include data quality alarms, detailed explanations of DQMS features, and guidance for resolving detected data quality issues.

Finally, interactions with GNSS data providers were initiated and coordinated through a dedicated EPOS-GNSS data providers mailing list, maintained by ROB. This mailing list includes at least one representative from each agency operating GNSS stations that are integrated into EPOS. Through this communication channel, the SERVE team introduced the initial version of the DQMS and invited feedback from users. The input received was carefully reviewed and incorporated into the final version of the DQMS, ensuring that the service better met the needs and expectations of its user community.

5.3 Outreach

The SERVE project also actively contributed to promoting both ROB's EPOS services and the EPOS infrastructure more broadly through participation in a wide range of national and international conferences. These included major scientific events such as the EGU General Assemblies (2022, 2023, 2024, 2025), the EUREF Symposia (2022, 2023, 2024), the IUGG General Assembly 2023, the Southern African Geophysical Association's 18th Biennial Conference, the EPOS Days (2024, 2025), the IGS Symposium and Workshop 2024, and the E-GVAP Joint Expert Team Meeting 2024. These

engagements played a key role in increasing the visibility of EPOS and highlighting Belgium's contributions to the GNSS component of the infrastructure.

6. PUBLICATIONS

Fernandes, R., Bruyninx, C., Crocker, P., Menut, J.L., et al. (2022) *A new European service to share GNSS Data and Products*. Annals of Geophysics, 65 issue 3, https://doi.org/10.4401/ag-8776

Jacques, D., Bruyninx, C., Van Noten, K., Zeckra, M., et al. (2023). *EPOS - L'infrastructure de recherche paneuropéenne pour les sciences de la Terre*. Science Connection, 69 issue sept-oct-nov, pp. 24-28

Jacques, D., Bruyninx, C., Van Noten, K., Zeckra, M., et al. (2023). *EPOS - De pan-Europese onderzoeksinfrastructuur voor Aardwetenschappen*. Science Connection, 69 issue sept-okt-nov, pp. 24-28

Bamahry, F., Legrand, J., Bruyninx, C., Fabian, A. (2024). *EPOS-GNSS Data Quality Monitoring Web Portal*. In: Freymueller, J.T., Sánchez, L. (eds) Together Again for Geodesy. IUGG 2023. International Association of Geodesy Symposia, vol 157. Springer, Cham, https://doi.org/10.1007/1345_2024_264

Pizzulo, P., Randazzo, D., Legrand, J., Menut, J.L., Bruni, S., Avallone, A. (2024) The GNSS data and metadata management system through the EPOS-GNSS framework and the IRN Node (INGV), Istituto Nazionale di Geofisica e Vulcanologia (INGV), 2024-12-17 | Journal article, https://doi.org/10.13127/rpt/488

7. ACKNOWLEDGEMENTS

The SERVE team thanks the members of the Follow-up Committee (Véronique Dehant, Rui Fernandes, Lilli Freda, Laurent Ghys, and Eric Pottiaux) for their support throughout the SERVE project.

ANNEXE 1: LIST OF PRESENTATION/POSTERS

1. Bamahry, F., Legrand, J., Bruyninx, C., Fabian, A. (2022, May 5–6). *GNSS data quality monitoring service* [Conference presentation]. EPOS-GNSS Technical Workshop 2022, Online.
2. Bamahry, F., Legrand, J., Bruyninx, C., Fabian, A. (2022, May 24). *First experience with GNSS data quality monitoring in the distributed EPOS e-infrastructure* [Conference presentation]. EGU General Assembly 2023, Vienna, Austria.
3. Fernandes, R., Bruyninx, C., Crocker, P., Socquet, A., et al. (2022, May 27). *EPOS-GNSS – Current status of service implementation for European GNSS data and products* [Conference presentation]. EGU General Assembly 2023, Vienna, Austria.
4. Bruyninx, C., Bamahry, F., Legrand, J., Fabian, A. (2022, June 3). *Update on the GNSS component of the European Plate Observing System* [Conference presentation]. EUREF Symposium 2022, Zagreb, Croatia.
5. Bamahry, F., Bruyninx, C., Bodranghien, F., Legrand, J. (2022, November 4). *Development of EPOS-GNSS data monitoring: Webportal and alarms* [Poster presentation]. BNCGG Study Day, Brussels, Belgium.
6. Fabian, A., Bruyninx, C., Miglio, A., Legrand, J. (2022, November 4). *Belgian metadata catalogue for permanently tracking GNSS stations in Europe* [Poster presentation]. BNCGG Study Day, Brussels, Belgium.
7. Bamahry, F., Legrand, J., Bruyninx, C., Pottiaux, E., et al. (2023, April 27). *Correlation analysis of GNSS data quality indicators and position time series using machine-learning algorithms* [Conference presentation]. EGU General Assembly 2023, Vienna, Austria.
8. Bamahry, F., Legrand, J., Bruyninx, C., Pottiaux, E., et al. (2023, May 23). *Why considering machine learning for quality evaluation of GNSS observations? (Challenges we faced and are still facing)* [Invited talk]. EUREF Symposium 2023, Gothenburg, Sweden.
9. Bamahry, F., Legrand, J., Pottiaux, E., Bruyninx, C., et al. (2023, May 26). *Using machine learning algorithms for automated data cleaning of GNSS position time series based on data quality indicators* [Conference presentation]. EUREF Symposium 2023, Gothenburg, Sweden.
10. Fernandes, R., Bruyninx, C., Crocker, P., Socquet, A., et al. (2023, July 17). *EPOS-GNSS data and products for Solid Earth applications* [Conference presentation]. XXVIII General Assembly of the International Union of Geodesy and Geophysics (IUGG), Berlin, Germany.
11. Legrand, J., Bamahry, F., Bruyninx, C., Bodranghien, F., et al. (2023, July 18). *EPOS-GNSS data quality monitoring web portal* [Poster presentation]. XXVIII General Assembly of the International Union of Geodesy and Geophysics (IUGG), Berlin, Germany.
12. Bamahry, F., Legrand, J., Pottiaux, E., Bruyninx, C., et al. (2023, July 19). *Using supervised machine learning for flagging GNSS observations based on data quality indicators* [Conference presentation]. XXVIII General Assembly of the International Union of Geodesy and Geophysics (IUGG), Berlin, Germany.
13. Bruyninx, C., Bamahry, F., Fabian, A., Legrand, J., et al. (2023, November 30). *EPOS' progress towards making quality-controlled (meta)data discoverable from thousands of GNSS stations* [Seminar presentation]. The fourth Geo-INQUIRE seminar, Online.

14. Bruyninx, C. (2023, December 6). *TCS GNSS data and products* [Invited talk]. EPOS ERIC General Assembly.
15. Bruyninx, C., Legrand, J., Bamahry, F., Fabian, A., et al. (2024, April 16). *Open science in solid Earth science – The contribution of EPOS* [Poster presentation]. Belgian EOSC National Tripartite Event, Belgium.
16. Fernandes, R., Bruyninx, C., Carvalho, L., Crocker, P., et al. (2024, April 17). *EPOS-GNSS – Operational advancements in EPOS GNSS data and product services* [Conference presentation]. EGU General Assembly 2024, Vienna, Austria.
17. Bailo, D., Paciello, R., Glaves, H., Roquencourt, J.B., et al. (2024, April 17). *The EPOS open-source platform for multidisciplinary data integration and data analysis in solid Earth science* [Conference presentation]. EGU General Assembly 2024, Vienna, Austria.
18. Bamahry, F., Legrand, J., Bruyninx, C., Pottiaux, E. (2024, May 9). *Application of machine learning to identify outliers in GNSS position time series based on observation's data quality indicators* [Poster presentation]. 4th ESA-ECMWF Workshop on Machine Learning for Earth Observation and Prediction, ESA/ESRIN, Frascati, Italy.
19. Miglio, A., Bruyninx, C., Fabian, A., Legrand, J. (2024, June 6). *Application of FAIR data principles on the EPN Historical Data Center* [Conference presentation]. EUREF 2024 Symposium, Barcelona, Spain.
20. Bamahry, F., Legrand, J., Bruyninx, C. (2024, June 7). *Towards long-term data quality monitoring of EPOS-GNSS stations* [Poster presentation]. EUREF Symposium 2024, Barcelona, Spain.
21. Bruyninx, C., Legrand, J., Bamahry, F., Fabian, A., et al. (2024, June 7). *Assessment of EPOS' GNSS data* [Conference presentation]. EUREF 2024 Symposium, Barcelona, Spain.
22. Bamahry, F., Legrand, J., Bruyninx, C. (2024, July 1). *Long-term GNSS data quality monitoring in the distributed EPOS e-infrastructure.* [Poster presentation]. IGS Symposium & Workshop 2024, Bern, Switzerland.
23. Fonseca, J., Lovholt, F., Tanlongo, F., Bruyninx, C., et al. (2024, October 1). *EPOS – European Plate Observing System: opportunities for reinforced EU-Africa cooperation in Earth sciences* [Conference presentation]. Southern African Geophysical Association's 18th Biennial Conference, Windhoek, Namibia.
24. Pottiaux, E., Bamahry, F., Bruyninx, C., Fabian A., et al. (2024, November 27). *European Plate Observing System (EPOS): GNSS data and products thematic core service (TCS)* [Invited talk]. E-GVAP Joint Expert Team Meeting 2024.