Comparative analysis of Sentinel-1 InSAR ground motion data dissemination strategies: towards an optimal model for Serbia

Miloš Basarić [1]

[1] Military Geographical Institute - "General Stevan Bosković", Belgrade, Serbia - m-basaric@protonmail.com

Keywords: InSAR, Ground Motion Services, EGSM, Spatial Data Infrastructure, Data Dissemination.

Abstract

Ground Motion Services (GMS), based on Interferometric Synthetic Aperture Radar (InSAR) technology, are key components in monitoring terrain deformation and managing geohazards. European countries have developed various national GMS platforms that differ significantly in their data dissemination approaches, including access models, update frequency, visualization tools, and integration with national geospatial infrastructures. This paper presents a comparative analysis of online accessible open GMS platforms of Norway, Sweden, Germany, the Netherlands, Romania, and Hungary alongside the European Ground Motion Service (EGMS). The focus is placed on identifying strengths and limitations in current dissemination practices, with the aim of determining optimal strategies for user accessibility, data transparency, and interoperability. Based on the findings, the paper proposes a conceptual model for a future Serbian GMS (SrbGMS), grounded in principles of open access, standardized visualization, and harmonization with European frameworks. The results contribute to a better understanding of best practices in InSAR-based data dissemination, supporting the development of more effective and inclusive ground motion monitoring services. Special emphasis is placed on alignment with the INSPIRE Directive, as the foundational premise of this research is that the future SrbGMS should be fully compatible with the INSPIRE framework. The study establishes the optimal criteria for the evaluation of dissemination platforms and presents a comparative assessment of existing services.

1. Introduction

1.1 Scientific context and importance of research

In the last decade, the increasing availability of EO data and improved processing techniques have led to a significant transformation in the way ground deformations are monitored. One of the most representative methodologies in this area is interferometric analysis of synthetic aperture radar (InSAR) data, especially in Persistent Scatterer Interferometry (PSI) analysis, which enables extremely precise measurement of vertical and horizontal displacements of the Earth's surface, with an accuracy reaching millimeters per year (Crosetto et al., 2016). In this context, progress in Advanced Differential InSAR (A-DInSAR) techniques, especially with the availability of data from missions such as ERS, Envisat, Radarsat, TerraSAR-X, COSMO-SkyMed and Sentinel-1, has contributed to the increasing application of these technologies at the national and regional level (Crosetto et al., 2020) . In addition, developed PSI algorithms, wide availability of powerful computer resources and increasingly better visualization platforms contribute to the implementation of reliable ground motion services that enable deformation monitoring of high precision and spatial coverage (Crosetto et al., 2025).

In parallel with technological progress, the intensive use Sentinel-1 mission data, realized within the Copernicus program, encouraged the development of an increasing number of national and regional Ground Motion Services (GMS). These services enable a synoptic display of ground motion, decision support, timely warning and a deeper understanding of geodynamic processes, making them key resources for the scientific community, civil protection and management institutions (Constantini et al., 2022) . A special role in the standardization and democratization of these data is fulfilled by the European Ground Motion Service (EGMS), which represents the largest open access European PSI service, covering the territory of 30 Copernicus participant states and offering users spatial components of deformations (vertical and east-west) and time series of movements (Crosetto et al., 2022; Crosetto and Solari, 2023) . However, despite the comprehensiveness of EGMS, a significant number of countries, including Serbia, are currently not covered by this service, which opens up space, but also imposes the need for the development of a national service that could fill this gap. The Ground Motion Service of Serbia (SrbGMS) should not only be a replica of the European model, but should respond to specific local and national needs, with carefully defined aspects of interoperability, data openness, update frequency and user accessibility. In this way, its usability would be maximized, and the data could be seamlessly integrated into wider geoinformation infrastructures and other applications. The development of GMS systems enables their scientifically based comparison, with a focus on utility value, technical realization, advantages and limitations from the point of view of users and scientific validity. When it comes to publicly available GMS web geoportals, additional space is opened for the analysis of data dissemination models, as well as for the comparison of methodological approaches used in different GMS implementations. On the basis of such comparisons, the best examples of practice can be identified, redundant elements can be eliminated, and the key functionalities that modern WebGIS platforms for the dissemination of such data should have. Such an analytical framework enables the formation of an effective dissemination model for GMS systems that are in the development phase, which contributes to increasing their functionality and social usefulness.

1.2 Research goal and question

In an era of increasing dependence on geospatial information in decision-making, the way in which the results of ground displacement measurements are presented to end users becomes a key factor in the effective use of these data. Although an increasing number of European countries are developing their own GMS based on InSAR technology, there are evident differences in the approach to the dissemination of these data - both in technical and organizational terms. The aim of this paper is to analyze the way in which different countries present the results of these open access analyzes and to identify their key

https://doi.org/10.5194/isprs-archives-XLVIII-4-W13-2025-57-2025 |

features through a comparative analysis of dissemination models in several selected GMS platforms.

Based on the conducted analysis, the optimal structure of the potential SrbGMS based on Sentinel 1 images is proposed. This service could function as a complement to the European Ground Motion Service (EGMS) in areas that it does not currently cover, but also ensure a high degree of interoperability through compliance with the relevant OGC and INSPIRE standards. Additionally, SrbGMS would provide national institutions, experts and decision-makers with direct access to time series and spatial components of ground movement, which would significantly improve the ability to respond to geodynamic processes and risk management. Based on that, the research question that this paper asks is: What are the advantages and limitations of existing GMS solutions in Europe from the point of view of data dissemination, and what features should the future national service have in order to maximize its usability and interoperability?

2. Data and materials

2.1 Overview of Existing Ground Motion Services

Although the European Ground Motion Service (EGMS, 2025) currently represents the most significant and comprehensive GMS service in Europe, an increasing number of countries – including those already covered by EGMS – are developing their own national or regional GMS platforms based on Sentinel-1 data. These services enable greater spatial and thematic specificity, as well as better adaptation to the needs of local institutions, sectoral policies and end users. It is important to note that some countries developed and published their national or regional GMS services before the publication of the EGMS, and the trend of developing such services continued even after its establishment. This indicates the need for more specific and flexible solutions, which complement the EGMS and allow national institutions greater control over the dissemination of data, as well as a deeper analysis of local deformation processes. Back in 2007, one of the first regional GMS services was developed in Italy, based on data from the ERS-1/2, Envisat and COSMO-SkyMed satellites (Constantini et al., 2017). However, the focus of this work is exclusively on services based on the Sentinel-1 mission, which is in line with the research objective, which are publicly available and function as open platforms for visualization and download of results.

Publicly available national GMS based on Sentinel-1 data are: Norwegian (InSAR Norway), Swedish (GMS Sweden), German (Bodenbewegungsdienst Deutschland - BBD), Dutch (Bodemdalingskaart - BDK), Romanian (GMS Romania) and Hungarian (InSAR.Hungary). The Norwegian service (InSAR Norway, 2025), launched in 2018, is the first national GMS service based on Sentinel-1 data, which includes measurements from 2015, but also contains older data from Radarsat-2 imaging. (Dehls et al., 2019). The Swedish platform (InSAR Sweden, 2025) is based on the infrastructure of the Norwegian Panda dissemination platform (Nilfouroushan et al., 2022). The German BBD (BGR, 2025) provides national coverage of Germany and a clear interface for downloading data (Kalia et al., 2017; Even et al., 2023). The Dutch BDK (Bodemdalingskaart.nl, 2025) is a service developed by the SkyGeo company and covers the territories of the Netherlands, Belgium and Luxembourg. The Terrasigna company developed the PSTool platform (PSTool, 2025) was published in 2021 and represents the first national deformation service of Romania (Toma et al., 2021), while the Hungarian service (InSAR Hungary, 2025) was launched in March 2025 and includes data from 2015 to 2023, with the integration of PS-InSAR and GNSS measurements (Magyar, 2024).

In addition to the above examples, some countries have operational GMS systems or services under development based on Sentinel 1 data that are not publicly available such as Denmark and Greece (Bischoff et al., 2020; Papoutsis et al., 2020). The Canadian GMS (C-GMS, 2025) is reported as active and available, but due to technical problems registering users during the study, it could not be included in the comparative analysis. In addition to national services, there are also a number of regional services, among which those in Italy and Spain stand out. The regional GMS service for Tuscany (Toscana GMS, 2025) uses Sentinel-1 data and is updated every two weeks since 2018. Similar systems have been developed in Veneto (Veneto GMS, 2025) around 2019 and Catalonia (Catalonia GMS, 2025) since 2017. In Australia there are regional systems focused on landslides and mining activities, but without public access. These services offer frequent updates and are focused on urban and infrastructure risks. Although there are other local and city GMS services developed through academic and pilot projects around the world, they were not the subject of this analysis, because the work aims to focus on national services with a functional system of data dissemination to a wide range of users, in accordance with the principles of open data and interoperability standards.

2.2 Data Dissemination Strategies in GMS

In one sense, InSAR data are published within the GMS system through web platforms that communicate with end users, so dissemination can be seen as the language of that dialogue. The value of InSAR analysis results remains limited if these data are not effectively available, understandable and technically usable for different user groups. As stated by Watson et al. (2023), despite the increasing availability of open InSAR datasets, their interpretation and practical application are often limited due to the complexity of the format, the low intuitiveness of the interface and the presence of uncertainty in the results. Therefore, dissemination strategies must include not only technical access to data, but also clear communication of metadata and demonstration of reliability of results. Watson et al. (2022) identify three key pillars of successful dissemination: technical availability through open portals, communication adapted to expert and non-expert users, and relevance of data for specific applications. By combining technical reliability, clear interpretation and orientation towards the end user, a wider use of data and its integration into operational systems for risk management and decision-making is enabled. Unlike traditional geodetic measurements, GMS systems generate spatially extensive and temporally continuous datasets. Their value depends on the way these data are presented, organized and distributed. Therefore, dissemination must not be seen as a secondary aspect, but as a key bridge between the technical result and its actual application. Effective dissemination involves:

- wide availability of data without technical and administrative barriers;
- multipurpose application - from scientific research and technical analysis to institutional planning and risk management;
- visually and functionally adapted interfaces, which enable searching, filtering, displaying and exporting data;
- interoperability, i.e. connecting GMS platforms with other national and international systems, e.g. through standardized OGC and INSPIRE protocols.

According to Crosetto et al. (2025), it is particularly important that the dissemination platforms are aligned with the specific needs of the users – in terms of local context, expected applications and added value in the decision-making process. In modern geospatial infrastructures, where special emphasis is placed on data openness and technical interoperability, the way GMS results are disseminated has a direct impact on their relevance, usability and social significance. It is necessary to ensure that these data are available and understandable both to experts (geoinformaticians, engineers, analysts), as well as to the general public and decision makers. The need for value-added services and tools for the optimal dissemination of radar data from the Copernicus Sentinel-1 satellite mission encourages the scientific community to find effective solutions (Festa and Del Soldato, 2023).

3. Methodology

In order to comprehensively compare modern open services for the vizualization and analysis of ground movement data, a systematic approach to evaluating key criteria has been developed. The methodology is focused on the functional aspects of the service, its visualization capabilities, deformation analysis tools, as well as technical capacities for downloading and using data in different user scenarios. Below are presented the key steps and approaches within the conducted analysis.

3.1 Selection of services and data sources

Based on the review of existing ground motion monitoring services outlined in section 2, this research focuses primarily on national services. The selection of the seven platforms was guided by their public availability, operational status, and representativeness of national ground motion monitoring efforts. The European Ground Motion Monitoring Service (EGMS) is also included in the analysis, as it represents the continental framework for ground motion monitoring in Europe. Regional or other supranational platforms were excluded from the methodological analysis, as the aim was to evaluate services that are directly connected to the national geospatial infrastructure of individual countries. Included in the analysis are seven services that represent relevant premieres in the field of ground motion monitoring, and which are based on Sentinel-1 data, and they are:

1. EGMS (European Ground Motion Service);
2. InSAR Norway (Norway);
3. GMS of Sweden;
4. GMS of Romania;
5. Bodemdalingskaart – BDK (Netherlands);
6. Bodenbewegungsdienst Deutschland – BBD (Germany);
7. InSAR.Hungary (Hungary).

After the selection of the service, the structuring of the comparative analysis framework was started in order to enable an objective and comprehensive comparison of the various functionalities and visual features that these systems offer to end users.

3.2 Defining comparison criteria

In order to objectively evaluate GMS services and their geoportals, it was previously necessary to precisely define the criteria on the basis of which the comparison will be made. The criteria are designed to include all relevant aspects of functionality, availability and user experience, and are divided into six thematic blocks:

1. Visualization and interactivity - includes the possibilities of adaptive symbology for displaying deformations, including changing colors, ranges and display styles; control of the display of minimum and maximum deformation values; legend display, layer transparency; support for three-dimensional display.
2. Analytical functions and working with data - advanced data search functions; support for time series that allow monitoring of changes over time, analysis of trends and filtering of data according to defined criteria; downloading data in different formats.
3. Basemaps and cartographic layers - access to basemaps, including global sources like OpenStreetMap, as well as national topographic maps; integration of vertical layers; the option of adding your own GIS layers.
4. Data quality and reliability - transparency of used processing methodologies and validation of data sources; reliability and up-to-dateness of data; the indicator has reliability.
5. Interoperability - import of user-defined layers, as well as API access; compatibility with INSPIRE and other standards.
6. Availability and Support – optimization for mobile devices; multilingual interface; available documentation; technical support is organized.

Each of these criteria represents one row in the evaluation matrix, while the columns represent individual services that are the subject of analysis. Such organization enables visibility and easy comparison of different aspects of each service. Criteria are classified according to their importance (value) at three levels: critical - C (impact on basic functionality, weight = 1), desirable - D (contribute to improving the experience, weight = 0.5), additional - A (additional options, weight = 0.25).

3.3 Approach to analysis and evaluation

For the purposes of evaluating the analyzed geoportals, a simple quantitative framework based on pre-defined criteria was used. Each service was evaluated according to criteria, which, depending on their nature, were evaluated Binary - B (0 or 1) or Qualitative - Q (0, 1, 2 or 3). Criteria that did not allow a more nuanced evaluation were treated binary, while those that required a more detailed difference in the degree of fulfillment were evaluated qualitatively. The influence of binary ratings on the overall result is limited, since only a minimal part belongs to the criteria with the highest weights. The normalization of qualitative grades and the balanced distribution of binary and qualitative grades avoided the distortion of the weighted score, thus ensuring the representativeness and stability of the overall grade. In order to equalize the impact of different rating scales, all qualitative ratings were normalized to a range of 0 to 1 by dividing by 3, bringing them on par with binary ratings. After that, a predefined weighting was applied to each criterion, according to its importance for the overall analysis. The weighted score for each service per thematic block was calculated as the sum of the products of normalized ratings and associated weights, and then the final result was obtained by dividing by the sum of all weights. The result is additionally expressed in percentages (0–100%) for easier comparison and interpretation. It is important to note that the evaluation was not conducted in order to compare the thematic blocks, nor was the relative importance of individual blocks within the entire matrix additionally evaluated. Instead, the emphasis is on showing the performance of each individual service within the thematic context to which it belongs. The applied approach represents a basic statistical method of evaluation that enables an objective and transparent analysis of a large number of services according to several criteria of different types. The goal of this approach is to systematically assess the level of development and functionality of the service, while maintaining practical applicability in conditions of limited input data. The table that shows all the used evaluation criteria together, along with related questions, descriptive descriptions, scoring methods and specific grades, is given in the form of an overview in the appendix of the work, where it represents the central element of the evaluation.

4. Results

Although the final values within the applied evaluation system could theoretically range from 0 to 100%, most of the obtained results obtained from the analysis showed a practical interval of 40% to 90%. This range indicates that all observed services have a certain level of functionality and development, but at the same time it enables the identification of clear differences in terms of their technical maturity, comprehensiveness of data and level of up-to-dateness. Table 1 shows the obtained results expressed in percentages.

Thematic block\service	NO	SWE	EGMS	GE	NO	HU	RO
Visualization and Symbology	68.18	68.18	68.18	42.42	57.58	28.79	43.94
Analytical Functions	75.00	69.44	75.00	63.89	33.33	16.67	80.56
Basemaps and Cartographic Layers	48.48	48.48	36.36	30.30	42.42	33.33	24.24
Data Quality and Reliability	76.67	76.67	90.00	83.33	56.67	70.00	53.33
Interoperability	77.78	77.78	77.78	72.22	11.11	0.00	38.89
Availability and Support	72.73	72.73	72.73	84.85	42.42	69.70	30.30

Table 1. Comparative analysis results of various GMS platforms.

Norwegian, Swedish and European services are highly developed, especially in visualization, symbology and analytics. They allow customization of colors, ranges and 3D display, with an intuitive interface and detailed legends. They have advanced time series and trend analysis tools. Norwegian stands out for its address search, and European for its ability to download data for defined areas. All support spatial search and logical queries. Norwegian and Swedish have national maps and elevation layers, while European relies on standard basemaps and land cover data. It is possible to add external layers (WMS/WMTS). The data are of high quality, with validation and available documentation. The Norwegian one includes Radarsat-2 data and the European one offers more deformation components. All support CSV export (only EGMS download according to Area of Interest (AOI), others according to individual points) and API, they are compliant with the INSPIRE directive. The platforms are mobile-friendly, but not multilingual. The documentation and tutorials are extensive and helpful. The German GMS shows good performance, with some limitations. The interface is clear and functional, but the symbology cannot be changed. The deformation range is adjustable symmetrically, without 3D display. Analytics include charts, logical queries, and point comparisons, but no trend analysis. Data can be downloaded for AOI in CSV and GDB format. API is available and the service is INSPIRE compatible. It uses imagery basemap and different national layers. The quality is high, with scientific studies and validation. E-W and vertical deformation components are available. It is mobile optimized, but the portal is only in English. The documentation is of high quality and makes it easy to use. The Dutch Ground Motion service exists in two versions - one through the manufacturer's website (SkyGeo) and the other as a publicly available platform (version 2.0). The analysis took into account a compromise approach, focused on the functionalities available to the average user. It has a pleasant interface and good symbology, including a unique time window setting option. The range of deformations can be basically adjusted. Analytics are limited - there is no search, point comparison or detailed trend analysis. Data are available only for individual points. It does not support logical queries or advanced views. Cartographically, it uses basic basemaps without elevation layers, but includes additional data on water authorities, stations and administrative units. The quality and transparency of validation are weaker; scientific documentation is lacking, although there are indicators such as confidence and coherence. There are no API or INSPIRE support. Export is only possible for points, without the ability to add layers. The platform is only in Dutch and is not mobile friendly. The documentation is basic, but the interface is intuitive. It is visually innovative, but technically lagging behind. The Hungarian national service is simple and functionally limited, but easy to use. The interface is very intuitive, with clear legends. The visualization is static - without the possibility of changing the symbology and scales. Analytics are limited - no graphs, trends or tables. However, "advanced search" makes it easier to use. "Tilt view" improves perception, but without 3D display. It uses basic basemaps without national layers and elevation data. It enables work in multiple projections, including national. It supports Hungarian and English, with solid documentation. Deformation data are horizontal and vertical, but without indicators like coherence. Interoperability is low - no user layers, exports or APIs. Overall, the service is reliable, but limited in analytical features. The Romanian GMS achieves excellent results in analytics. The visualization is limited, but it allows changing the deformation range with a detailed legend. The interface has been reviewed. Analytics include coordinate search, detailed point analysis, trends, time filters, and multiple logical queries. Data can be downloaded by AOI and along lines - a unique option. It uses basic basemaps, with no national layers or add-ons. Supports export to CSV and KMZ and user layers. The quality of the data are solid, with publications and reliability indicators, but it is not clear at what level of processing they are. There is no INSPIRE compatibility, nor a Romanian language version. It is not mobile optimized, but it is user friendly and efficient to use.

5. Discussion

Based on these services, a general discussion can be made that illuminates the dominant tendencies, advantages and limitations of modern systems for monitoring deformations on the ground by means of satellite interferometry. Visualization and user interface represent one of the key components of the quality of any service. Norwegian, Swedish and EGMS services show a high level of development in this segment, with advanced options for customizing symbology, changing deformation scales and even 3D display. These elements not only improve the visual interpretation of the data, but also contribute to a better spatial perception of deformation patterns by the user. Compared to them, the German and Dutch services offer functional but less flexible displays, while the Hungarian and Romanian services, although functional, remain limited in the possibilities of personalizing the display. The Hungarian service stands out with an interesting but unique "tilt view" option that improves the spatial context, while the Dutch service is the only one that offers the possibility of a time window for data display, although without deeper analytical support. When it comes to analytical functionalities, the Romanian service leads the way, offering advanced options such as multiple logical queries, trend analysis with linear models, temporal filtering and various download options. The Norwegian and EGMS services also demonstrate a high degree of analytical sophistication, with the ability to export time series (where the EGMS leads because it allows more data to be downloaded by AOI), model definition and advanced search. In contrast, the Hungarian and Dutch services remain functionally limited – without the ability to display trends, advanced filtering or multi-point analysis. The German service offers a solid foundation and provides very good functionality in various areas. In the domain of cartographic resources, a diversity of approaches is observed. The Norwegian and Swedish services use national map layers and elevation data such as DTM, DSM and hillshade, which gives them an advantage in localizing and relating deformation patterns to topographic and geological contexts. EGMS offers a wider, pan-European base with solid support for different basemap layers and also has a landcover base. The German service uses high-quality national geological layers, but is visually supported only by the imagery base map. On the other hand, the Dutch, Hungarian and Romanian services use basic topographic and satellite basemaps, without additional national cartographic bases, with the Dutch having some additional spatial data with its own legend that can be displayed. In terms of data quality and reliability, all services generally show a high level of methodological validation. The Norwegian service also uses data from the Radarsat-2 mission. All platforms are particularly transparent in displaying reliability indicators such as coherence and confidence values, except for the Hungarian. EGMS is additionally distinguished by the availability of scientific publications documenting the validation procedures. In contrast, the Dutch services do not have sufficiently transparent validation documents, although they nominally use GNSS measurements to check accuracy. The German service has high quality data, but no display indicators. In terms of interoperability and data access, the Norwegian, Swedish, EGMS and German services lead the way thanks to support for export in various formats, API access and INSPIRE compliance. The Romanian service also offers a high degree of accessibility – it allows exporting by points, AOIs and cross-section lines, as well as in multiple formats (CSV, KMZ), but it lacks full INSPIRE support. The Dutch, Hungarian, Romanian services are the least interoperable - no APIs, no support for user layers, no flexible export formats. Finally, aspects of availability and accessibility, such as multilingualism and optimization for mobile devices, remain neglected in most services. Most platforms are available exclusively in English, while only the Hungarian service offers bilingualism. A varying degree of optimization for mobile device access is observed across the services. Extensive documentation and quality of support also vary, but in general it can be said that Norwegian, Swedish, EGMS, German services are above average in this respect.

5.1 INSPIRE compliance

Compliance with the INSPIRE directive is a key dimension in evaluating the functionality and interoperability of Ground Motion services, especially considering their role in the common European infrastructure for spatial data. As the analyzed services include data that cross national borders, compliance with the INSPIRE directive is not only a technical, but also a strategic issue - it enables standardization, comparability and integration of data into broader analytical systems for risk management, infrastructure and environmental protection. The directive obliges member states to make spatial data available through interoperable services with harmonized metadata and standardized access mechanisms. The Norwegian, Swedish, EGMS and German services are aligned with the INSPIRE directive, enabling direct integration and use of data in sectoral systems. This compliance involves automated data exchange and efficient connectivity with other geospatial layers. EGMS is particularly distinguished by the possibility of downloading data for wider areas of interest, API support and compliance with European standards, which greatly facilitates integration both at the national and cross-border level. On the other hand, other services are still not fully aligned with INSPIRE standards. When it comes to the Hungarian service, it should be noted that it is the most recently developed system, and it is to be expected that it will be further adapted in the following stages and there is a clear potential for further development. In the context of digital transformation and open data, INSPIRE compliance is increasingly becoming a prerequisite for the functional use of geoportals. It ensures that soil deformation data, crucial for natural hazard monitoring, urban planning and infrastructure protection, is available, reusable and easily comparable. Inconsistency, on the other hand, can hinder cooperation, slow down data exchange, and create obstacles in decision-making in critical situations.

5.2 Towards an Optimal Model for Serbia

Considering the current instability of the national service for ground deformations in Serbia, it is necessary to consider what functionalities the future service should have in order to be in line with EGMS practices and maximally functional for users from the academic, professional and crisis community. The future service for display and analysis of ground deformations must be based on clearly defined criteria of functionality, availability and interoperability. Data visualization should be customizable, with the ability to set the symbology, including different scales of deformation, as well as the display of vertical and horizontal (E-W) components of ground displacement. As part of the analytical functions, the service must enable the display of time series and trend analysis, data export in formats such as CSV and KMZ, as well as advanced search by coordinates, addresses and administrative zones. It is necessary to include indicators of measurement reliability, such as probability and coherence. The system must be fully compliant with the INSPIRE directive and support interoperability through standardized services (WMS/WFS), as well as an open API, which enables integration into wider information-analytical systems. Cartographic bases must also include national geospatial layers, with mandatory support for working in multiple projections, especially within the national WGS 84 / UTM zone 34T (EPSG:32634), which is the standard in spatial analysis in Serbia, and EGMS, WGS 84 (EPSG:4326) projections. The quality of the data must be ensured through validation through GNSS measurements and their referencing in the relevant scientific literature, which guarantees the reliability and scientific foundation of the presented results. The service interface should be intuitive, localized in Serbian and English, and access to the system must also be enabled via mobile devices, in order to ensure maximum availability to users in different contexts of use. In addition to the above, the national service could also have an operational role as a supplementary tool to EGMS, given that EGMS does not cover the territory of the Republic of Serbia. This would enable national institutions, crisis headquarters and expert teams to have timely access to highly relevant spatial data in case of natural disasters, infrastructure damage and urban planning. Such a service would not only serve the purpose of science and research, but would directly contribute to the resilience of society and the safety of the population, making Serbia functionally connected to European geoinformation systems, while at the same time preserving national needs and priorities.

6. Conclusions

This paper provides a comprehensive analysis of ground motion data dissemination strategies through national and pan-European Ground Motion Services (GMS), with a focus on the development of an optimal model for Serbia (SrbGMS). A comparative evaluation of seven services (EGMS, Norway, Sweden, Germany, the Netherlands, Romania and Hungary) identified the key components of successful platforms: intuitive interface, flexible visualization (including symbology and 3D display), advanced analytical functions (time series, trend analysis, export to CSV and GDB formats), as well as a high degree of interoperability and compliance with open standards. The highest performing services (Norway, Sweden, EGMS) also stand out with a transparent approach to validation, including GNSS data and a clearly documented methodology. In contrast, the limitations of less developed solutions (eg Hungary, the Netherlands) include rigid visualizations and a lack of analytical capabilities, which limits application in operational scenarios.

For the development of the SrbGMS service, a model based on four pillars is proposed: interoperability and standardization (INSPIRE compliance, WMS/WFS, open API), user-centered design (customizable visualizations, localization, trend analysis), reliability and transparency (indicators such as coherence and confidence, GNSS validation, published methodology), and accessibility and availability (mobile optimization and multilingualism). The technical framework must include support for work in the national cartographic projection of the UTM zone 34T, as well as the use of national geospatial layers. SrbGMS, as a complement to EGMS, would provide locally adapted data for risk management, urban planning and infrastructure monitoring, improving Serbia's capacities in the field of geohazards. By relying on the open data of the Sentinel-1 mission and cooperation with scientific and European partners, SrbGMS would have the potential for regional applications of modern geoinformatics technologies, contributing to sustainability and social resilience.

References

BGR, 2025. Bodenbewegungsdienst Deutschland – German Ground Motion Service. [Online] Available at: https://bodenbewegungsdienst.bgr.de (15 April 2025)

Bodemdalingskaart.nl, 2025. National Dutch Ground Motion Portal. [Online] Available at: https://bodemdalingskaart.nl/en-us/ (12 April 2025)

Bischoff, CA, Ferretti, A., Novali, F., Uttini, A., Giannico, C., & Meloni, F. (2020). Nationwide deformation monitoring with SqueeSAR® using Sentinel-1 data. *Proceedings of the International Association of Hydrological Sciences* , 382, 31–37. https://doi.org/10.5194/piahs-382-31-2020

Catalonia GMS, 2025. Ground Motion Viewer - Institut Cartogràfic i Geològic de Catalunya. [Online] Available at: https://visors.icgc.cat/moviment-del-terreny/#/0419 (11 April 2025)

C-GMS, 2025. Canadian Ground Motion Service. [Online] Available at: http://c-gms.com/ (11 April 2025)

Costantini, M., Ferretti, A., Minati, F., Falco, S., Trillo, F., Colombo, D., Novali, F., Malvarosa, F., Mammone, C., Vecchioli, F., et al., 2017. Analysis of surface deformations over the whole Italian territory by interferometric processing of ERS, Envisat and COSMO-SkyMed radar data. *Remote Sensing of Environment*,202, 250-275. https://doi.org/10/1016/j.rse.2017.07.017

Costantini, M., Ferretti, A., Minati, F., Colombo, D., Trillo, F., Novali, F., Vecchioli, F., Falco, S., Rucci, A., Fumagalli, A., et al., 2022. EGMS: Europe-Wide Ground Motion Monitoring based on Full Resolution InSAR Processing of All Sentinel-1 Acquisitions. *IGARSS 2022 – IEEE Int. Geoscientists. Remote Sens. Symp.* , Kuala Lumpur, Malaysia, 5093–5096. https://doi.org/10.1109/IGARSS46834.2022.9884966

Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., Crippa, B., 2016. Persistent Scatterer Interferometry: A review. *ISPRS J. Photogramm. Remote Sens.* , 115, 78–89. https://doi.org/10.1016/j.isprsjprs.2015.10.011

Crosetto, M., Solari, L., Mróz, M., Balasis-Levinsen, J., Casagli, N., Frei, M., Oyen, A., Moldestad, DA, Bateson, L., Guerrieri, L., et al., 2020. The Evolution of Wide-Area DInSAR: From Regional and National Services to the European Ground Motion Service. *Remote Sens.* , 12, 2043. https://doi.org/10.3390/rs12122043

Crosetto, M., Solari, L., Mróz, M., 2022. Pan-European deformation monitoring: The European Ground Motion Service. *JISDM 2022*, doi:10.4995/JISDM2022.2022.13876.

Crosetto, M. & Solari, L., 2023. *Satellite Interferometry Data Interpretation and Exploitation: Case Studies from the European Ground Motion Service (EGMS)* . 1st ed. San Diego: Elsevier. ISBN: 978-0-443-13397-8.

Crosetto, M., Crippa, B., Mróz, M., Cuevas-González, M., Shahbazi, S., 2025. Applications based on EGMS products: A review. *Remote Sensing Applications: Society and Environment* , 37, 101452. https://doi.org/10.1016/j.rsase.2025.101452

Dehls, JF, Larsen, Y., Marinkovic, P., Lauknes, TR, Stødle, D., Moldestad, DA, 2019. INSAR.No: A National InSAR Deformation Mapping/Monitoring Service in Norway – From Concept to Operations. *IGARSS 2019 – IEEE Int. Geoscientists. Remote Sens. Symp.* , Yokohama, Japan, 5461–5464. https://doi.org/10.1109/IGARSS.2019.8898614

EGMS, 2025. European Ground Motion Service – Copernicus Land Monitoring. [Online] Available at: https://egms.land.copernicus.eu/ (12 April 2025)

Even, M., Westerhaus, M., Kutterer, H., 2023. A Comparison of the German and the European Ground Motion Services. *IGARSS 2023 – IEEE Int. Geoscientists. Remote Sens. Symp.* , Pasadena, CA, USA, 7898–7901. https://doi.org/10.1109/IGARSS52108.2023.10281585

Festa, D., Del Soldato, M., 2023. EGMStream, a Desktop App for EGMS Data Downstream. *Remote Sens.* , 15, 2581. https://doi.org/10.3390/rs15102581

InSAR Hungary, 2025. National InSAR Ground Motion Monitoring Platform of Hungary. [Online] Available at: https://insar-hungary.hu/en (15 April 2025)

InSAR Norway, 2025. InSAR-based Deformation Monitoring – Geological Survey of Norway. [Online] Available at: https://insar.ngu.no/ (12 April 2025)

InSAR Sweden, 2025. Swedish Ground Motion Portal – Swedish Space Agency. [Online] Available at: https://insar.rymdstyrelsen.se/ (12 April 2025)

Kalia, AC, Frei, M., Lege, T., 2017. A Copernicus downstream-service for the nationwide monitoring of surface displacements in Germany. *Remote Sensing of Environment* , 202, 234–249. https://doi.org/10.1016/j.rse.2017.05.015

Magyar, B., 2024. Review of SAR based deformation monitoring case studies related to the development of Hungarian Ground Motion Service (HGMS). *Scientia et Securitas* , 5. https://doi.org/10.1556/112.2024.00188

Nilfouroushan, F., Gido, NAA, & Darvishi, M. (2022). Cross-checking of the nationwide Ground Motion Service (GMS) of Sweden with the previous InSAR-based results: Case studies of Uppsala and Gävle Cities. *EGU General Assembly 2022* , Vienna, Austria, 23–27 May 2022. https://doi.org/10.5194/egusphere-egu22-5293

Papoutsis, I., Kontoes, C., Alatza, S., Apostolakis, A., Loupasakis, C., 2020. InSAR Greece with Parallelized Persistent Scatterer Interferometry: A National Ground Motion Service for Big Copernicus Sentinel-1 Data. *Remote Sens.* , 12, 3207. https://doi.org/10.3390/rs12193207

PSTool, 2025. Persistent Scatterers Online Software Tool - Terrasigna. [Online] Available at: https://pstool.terrasigna.com/ (15 April 2025)

Toma, S.-A., Teleagă, D., Poncoş, V., Grozea, C., 2021. Ground Motion Patterns Analysis from the National Persistent Scatterer Deformation Map of Romania. *IEEE Int. Geoscientists. Remote Sens. Symp. (IGARSS)* , Brussels, Belgium, 2021, 6237–6239. https://doi.org/10.1109/IGARSS47720.2021.9553835

Toscana GMS, 2025. WebGIS Portal for Ground Motion – Regione Toscana. [Online] Available at: https://geoportale.lamma.rete.toscana.it/difesa_suolo/#/viewer/326 (11 April 2025)

Veneto GMS, 2025. Ground Motion WebGIS – Regione Veneto. [Online] Available at: https://idt2.regione.veneto.it/idt/webgis/viewer?webgisId=185 (11 April 2025)

Watson, CS, Elliott, JR, Ebmeier, SK, Biggs, J., Albino, F., Brown, SK, Burns, H., Hooper, A., Lazecký, M., Maghsoudi, Y., Rigby, R., Wright, TJ, 2022. Strategies for improving the communication of satellite-derived InSAR ground displacements. *Geoscience Communication* , 6, 75–89. https://doi.org/10.5194/gc-2022-15

Watson, CS, Elliott, JR, Ebmeier, SK, Biggs, J., Albino, F., Brown, SK, Burns, H., Hooper, A., Lazecký, M., Maghsoudi, Y., Rigby, R., Wright, TJ, 2023. Strategies for improving the communication of satellite-derived InSAR data for geohazards through the analysis of Twitter and online data portals. *Geoscience Communication* , 6, 75–96. https://doi.org/10.5194/gc-6-75-2023

Appendix

Table 2. Overview of Ground Motion Services Data Dissemination Evaluation: Criteria, Descriptions, and Rating Information.

Thematic Block	Criteria	Value	Description/Question	Rating Type	Rating Scale	NO	SWE	EGMS	GE	NE	HU	RO
Visualization and Symbology												
	Customizable deformation data symbols	C	Is it possible to flexibly change colors, value ranges, display styles?	Q	0: No setting; 1: Minimal control (color change only); 2: There is a choice of scale, colors and symbols; 3: Complete freedom of choice (creating scales and symbols).	2	2	2	0	0	0	0
	Deformation range display	C	How precisely can the user adjust the display of min/max deformations?	Q	0: No setting; 1: Selection of fixed ranges; 2: Symmetric input min and max; 3: Free entry of values.	3	3	3	2	1	0	3
	Time window adjustment	C	Can the time frame be freely chosen for the analysis?	B	0: Fixed time range; 1: There is a time slider, the ability to choose a time range.	0	0	0	0	1	0	0
	Layer transparency	D	Can layers be made partially transparent?	B	0: No opacity setting; 1: There is a layer transparency control.	1	1	1	1	1	0	1
	3D view and tilt	D	Does the service allow 3D visualization or view rotation?	B	0: 2D view only; 1: There is a 3D or tilt view option.	1	1	1	0	0	1	0
	Additional cartographic elements	A	Are scale, scale, north arrow, coordinates, elevation, projection displayed?	Q	0: None of the elements; 1: One to two of the element; 2: It has three to four elements; 3: Has five or more elements).	3	3	3	3	2	2	1
	Legend quality and explanations	C	Are the legends clear, intuitive and explain all displayed values?	Q	0: No legend; 1: Basic legend; 2: Basic legend with written extreme values; 3: Legend showing the value for each shade in the scale	2	2	2	2	3	2	2
	Interface appearance	A	How user-friendly is the interface design?	Q	0: The interface is disorganized, confusing, without clear logic and hierarchy; 1: The basic functionality is there, but the design and organization confuses the user; 2: The interface is intuitive, with basic consistencies in colors, icons, and layout; 3: The interface is very refined, with clearly defined themes and a good user experience.	2	2	2	3	2	3	2
Analytical Functions												
	Advanced location search	C	Is it possible to search by coordinates, address or administrative unit?	Q	0: None of the functionality; 1: One of the functionalities; 2: Two of the functionalities; 3: Three of the functionalities.	3	2	2	2	0	2	3
	Deformation data display for points	C	Is there a time series with graph, table and export?	Q	0: No functionality; 1: Basic deformation data available, no time series data; 2: Available basic deformation data and graphical representation of	3	3	3	2	3	1	2

					the time series; 3: Available deformation data, tabular and graphical display of time series.							
	Trend analysis	C	How is the line of best fit function or trend line implemented?	Q	0: No analysis; 1: Baseline trend without the option to turn off the display; 2: Baseline trend with option to turn off display; 3: More functions, model selection, statistics.	3	3	3	0	2	0	1
	Time filtering for point time series	D	Is it possible to define a time frame for a point in the time series view?	B	0: Unable to perform a time query for a point; 1: Possible to perform a time query for a point.	0	0	0	1	0	0	1
	Multiple point comparison	C	Can multiple points be analyzed simultaneously?	B	0: Single analysis only; 1: Possible comparison of multiple points on one graph or table.	1	1	1	1	0	0	1
	Filters and logical expressions	D	Is it possible to filter data by values, time, probability?	Q	0: No filter; 1: Basic filter according to deformation value; 2: Multiple filters with basic logical operations; 3: Fully custom filters	1	1	1	2	0	0	2
	Data download	C	Is it possible to download point, AOI, time series data?	Q	0: Unable to download; 1: Single point export available 2: AOI export available; 3: Available export by direction and by AOI	1	1	2	2	1	0	3
Basemaps and Cartographic Layers												
	Availability of common basemaps	C	Are users enabled to use globally recognized basemaps such as Google Maps, OpenStreetMap, Bing Maps, Esri World Imagery and similar?	Q	0: Does not support commonly known basemaps; 1: Supports Imagery basemap; 2: It also supports cartographic basemaps; 3: It also supports landocover basemaps	1	1	3	1	2	2	2
	National basemap availability	D	Are national (or local) cartographic bases available in the system that reflect the official topography, infrastructure and toponyms of the country in which the analysis is performed?	Q	0: No local basemaps available; 1: Available aerial national basemaps; 2: Available topographical national basemaps; 3: Available geological national basemaps	3	3	0	3	0	0	0
	Elevation layers availability	D	Does the system use or enable the display of height bases (eg DTM, DSM, hillshade) for better interpretation of deformation data?	B	0: No height pads available; 1: Height pads are available.	1	1	0	0	0	0	0
	Additional GIS layers	D	Are there additional layers available?	B	0: Basic platform basemaps only; 1: Possible to include additional layers.	0	0	0	0	1	0	0
	Map projections	A	Does the service also support local map projections?	B	0: Only supports WGS84 projection; 1: Support multiple projections?	0	0	0	0	0	1	0
Data Quality and Reliability												
	Processing transparency	D	Is it clearly presented to the user how the deformation data are generated?	Q	0: No information; 1: Method name only; 2: Basic parameters and software; 3: Detailed explanation with validation.	2	3	3	3	1	3	2
	Data sources and validation	C	Is there validation at the service level?	Q	0: Unknown data origin; 1: Insufficient validation documentation; 2: Limited validation documentation; 3: Detailed validation documentation	2	3	3	3	1	3	2
	Data reliability	C	Is there a confidence rating for the point?	B	0: No accuracy rating at all; 1: Displayed confidence, coherence or other indicators of reliability.	1	1	1	1	1	0	1
	Additional SAR/InSAR Data Sources	D	Are there any other deformation InSAR data besides Sentinel 1 based?	B	0: There is nothing but Sentinel 1 based data; 1: There is data from an additional source	1	0	0	0	0	0	0
	Update Frequency	C	How up-to-date is the currently available InSAR data on the geoportal compared to the time of the last available recording?	Q	0: Obsolete; 1: Data 5-6 years old; 2: Data 3-4 years old 3: Data 1-2 years old	3	2	3	2	2	3	1
	Deformation data processing level	C	What level of detail and deformation data processing is available on the portal?	Q	0: No clear information; 1: ASC/DESC (LOS) given; 2: Calibrated ASC/DESC (LOS) data with GNSS validation; 3: East/West and Vertical deformation data	1	2	3	3	2	3	1
Interoperability												
	Custom layer import	D	Is it possible to import custom layers?	B	0: Not possible; 1: It is possible to load.	1	1	1	0	0	0	1
	Data export formats	C	What formats are supported for data export (csv, gdb, kmz)?	Q	0: No possibility to export data; 1: Export of one of the offered formats; 2: Export of two of the offered formats; 3: Export three of the offered formats.	1	1	1	2	1	0	2
	API access	C	Is programmatic access enabled?	B	0: None; 1: There is API access (REST, OGC WFS/WMS etc.).	1	1	1	1	0	0	0
	INSPIRE compliance	D	Is the platform compliant with the INSPIRE directive regarding metadata, interoperability and standardized services (eg WMS/WFS)?	B	0: No information on metadata and standardization; 1: INSPIRE compliance (ISO, OGC, metadata).	1	1	1	1	0	0	0
Availability and Support												
	Mobile accessibility	D	Does the platform have an optimized version for use on mobile devices?	Q	0: Unable to use on mobile; 1: Version not customized; 2: Adapted version; 3: Mobile application.	2	2	2	2	1	2	1
	Multilingualism	A	Is the interface available bilingually?	B	0: Only one language; 1: Available in both English and native.	0	0	0	0	0	1	0
	Documentation and Help	C	Is there quality documentation and support?	Q	0: No documentation; 1: Basic aid; 2: Detailed help/documentation; 3: There are tutorials, forums, contact support.	3	3	3	3	1	1	0
	Learning rate	C	How easy is it to use the service without prior knowledge?	Q	0: Very difficult to use; 1: Required professional training; 2: Possible independently with effort; 3: Intuitive and simple.	2	2	2	3	2	3	2

https://doi.org/10.5194/isprs-archives-XLVIII-4-W13-2025-57-2025