From InSAR Norway to a Global Ground Motion Service: Operational Monitoring for Disaster Risk Reduction

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Abstract

Operational satellite-based ground-motion monitoring has developed from a national service in Norway to a continental service through the European Ground Motion Service (EGMS). This paper examines that progression and uses it to assess the feasibility of extending such services to a global scale. InSAR Norway (InSAR.no), established in 2018, was the first fully operational national ground-motion service based on Sentinel-1. It showed that the value of wide-area deformation monitoring depends not only on processing capability, but also on sustained operations, clear institutional roles, open access, and careful interpretation.

The experience gained in Norway helped inform EGMS, which demonstrated that these principles can be scaled to the continental level through harmonised products and coordinated service delivery. Building on these examples, the paper evaluates the requirements and constraints of a future Global Ground Motion Service (GGMS). The analysis shows that global implementation is technically realistic but cannot rely on a single uniform product model. Outside Europe, satellite coverage is less dense and less consistent, which limits the types of products that can be delivered consistently everywhere.

The main conclusion is that a future GGMS should be designed as a harmonised yet regionally adaptive reference service that supports national authorities and users with consistent data, common standards, and capacity-building.

1. Introduction

1.1 The Evolution of Satellite InSAR for DRR

Ground motion is a fundamental observable associated with a wide range of natural and anthropogenic processes, including landslides, subsidence, tectonic deformation, infrastructure settlement, and climate-driven surface instability. While ground motion itself does not always constitute a hazard, spatially and temporally coherent deformation patterns provide critical indicators of processes that may evolve into hazardous conditions if left undetected. As such, ground-motion information has become an increasingly important input to disaster risk reduction (DRR), supporting early identification, prioritisation, and long-term monitoring of potentially unstable areas.

Over the past two decades, satellite-based interferometric synthetic aperture radar (InSAR) has evolved from an experimental research technique into an operational monitoring tool capable of delivering millimetre-scale deformation measurements over large areas (Biggs and Wright, 2020). This evolution has been driven by improvements in sensor stability, orbit control, processing algorithms, and above all, the availability of long, consistent satellite time series. In a DRR context, the value of InSAR lies less in short-term event detection than in its ability to provide systematic, wide-area observations that complement field investigations and in-situ instrumentation.

Operational experience has demonstrated that large-scale ground-motion products can be misunderstood if their scope and limitations are not clearly specified (Watson et al., 2023; Cuervas-Mons et al., 2024). In certain situations, deformation signals might be interpreted without adequately assessing whether they indicate an emerging hazard, and uncertainties related to line-of-sight geometry, temporal averaging, and surface coherence may not always be fully accounted for. These points underline the importance of explicitly framing InSAR-based ground-motion services as screening and contextual tools within broader risk-management processes, rather than as standalone hazard assessments.

1.2 The Sentinel-1 Revolution

The launch of the Copernicus Sentinel-1 constellation marked a turning point in the operational use of InSAR for ground-motion monitoring (Costantini et al., 2021). Sentinel-1 provides systematic, long-term C-band SAR acquisitions with consistent imaging geometry, global coverage, and short revisit intervals, all under a free and open data policy. These characteristics fundamentally change the conditions under which InSAR-based services can be developed, shifting the focus from ad hoc project-based studies to ongoing, operational monitoring.

For DRR applications, continuity and consistency are often more important than very high spatial resolution. Sentinel-1's acquisition strategy enables the construction of dense time series that support robust deformation estimates over years to decades, allowing slow-moving or progressive instabilities to be detected well before failure. Equally important, the open-data policy lowered barriers to entry for public institutions, enabling national geological surveys and civil protection authorities to develop in-house capabilities and long-term services without reliance on proprietary data streams.

However, access to global satellite data alone is not sufficient to ensure effective use. Converting Sentinel-1 observations into reliable and usable ground-motion information requires robust processing infrastructure, systematic quality control, and long-term institutional engagement. This distinction between simply providing data and delivering an operational service places ground-motion monitoring at the intersection of technical capability, governance, and sustained public investment.

1.3 Norway as a Global Prototype

Norway was the first country to translate Sentinel-1’s technical potential into a fully operational national ground-motion service. Established in 2018, InSAR Norway (InSAR.no) was designed as a long-term public infrastructure to provide systematic, nationwide access to ground-motion information (Dehls et al., 2019). Its primary objective is disaster risk reduction, particularly for landslides, rock-slope instabilities, and subsidence-prone areas, but the service also supports a broader range of applications. These include monitoring of urban environments, transport corridors, and critical infrastructure, where slow ground deformation may affect safety, maintenance planning, and long-term asset management. By addressing both geohazard-related and non-catastrophic deformation processes within a single operational framework, InSAR Norway functions as a multi-purpose service for diverse public-sector needs.

Operational ground-motion services require not only technical capability, but also an institutional framework that supports sustained production, interpretation, and use. In Norway, this has been addressed through a formal inter-agency model with clearly defined roles and responsibilities. At the same time, the service demonstrates that wide-area deformation products cannot be used in isolation: the signals require validation and contextualisation through geological expertise, field investigation, and complementary monitoring methods. InSAR.no has substantially increased the identification of previously unknown unstable slopes, while also illustrating the organisational and interpretative conditions required for operational use. In this sense, Norway provides not only a national implementation of ground-motion monitoring but also a practical prototype for scaling such services to continental and potentially global levels.

2. The InSAR Norway Operational Model

2.1 Institutional Framework and Governance

InSAR.no was established as a national ground-motion service with a clear operational mandate and long-term governance structure. The service is operated by the Geological Survey of Norway (NGU), with co-funding and strategic support from the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Space Agency. This institutional arrangement was designed to ensure continuity, transparency, and a clear division of responsibilities between data production, interpretation, and application in hazard and risk management.

From the outset, the service was conceived as a public infrastructure rather than a research or pilot initiative. This distinction proved critical for adoption, as it enabled public authorities to integrate ground-motion data into established workflows for landslide hazard assessment, monitoring of unstable rock slopes, and evaluation of subsidence-related risks. At the same time, the open and free-access model ensured that municipalities, infrastructure owners, consultants, and researchers could use the same reference dataset, thereby supporting consistency across sectors and jurisdictions.

The governance model also helped clarify the role of InSAR-derived products within decision-making processes. While InSAR.no provides systematic observations of ground deformation, responsibility for hazard classification and risk management remains with the relevant authorities. This separation is important both operationally and institutionally, reinforcing confidence in the service as a stable and credible source of supporting information.

2.2 Technical Architecture and Processing

Operational delivery of nationwide ground-motion products requires substantial processing capacity and a high degree of automation. InSAR.no is built on Norway’s collaborative ground segment and relies on a high-performance computing cluster for routine processing of Sentinel-1 data. Processing is carried out using software developed by NORCE (Dehls et al., 2019).

The transition from earlier, project-based InSAR analyses to an operational service was enabled by the systematic acquisition strategy of Sentinel-1. Prior to Sentinel-1, Radarsat-2 data were used for targeted monitoring of selected high-risk areas, but the workflow remained fundamentally project-based (Dehls et al., 2014). Data acquisition had to be planned and ordered for specific areas of interest, and substantial manual effort was required to organise scenes, define processing areas, and set up and maintain individual stacks. Limited revisit intervals and seasonal snow cover further constrained update frequency and geographic coverage. With Sentinel-1, these constraints changed fundamentally: nationwide systematic acquisitions made it possible to move from manually assembled, area-specific analyses to large, standardised burst-level stacks that could be incrementally updated as new acquisitions became available. InSAR Norway now processes thousands of interferometric wide-swath products within a repeatable operational framework.

Automation is central to this architecture. New Sentinel-1 acquisitions are downloaded nightly, coregistered to existing stacks, and incorporated into updated interferogram and time-series analyses. This approach allows deformation time series to be reanalysed efficiently as needed, while maintaining consistency across successive product releases. Design choices prioritised robustness and reproducibility over methodological complexity, reflecting the requirements of an operational public service.

2.3 Data Products and Public Dissemination

InSAR.no provides nationwide ground-motion time series for billions of measurement points, freely accessible through a web-based interface. The portal supports interactive visualisation of deformation velocities and time series in a fully three-dimensional map environment, which is particularly important in Norway’s steep and topographically complex terrain. Users can explore deformation patterns along valley sides, across urban environments, and within infrastructure corridors, and can download data for further analysis.

The service was deliberately designed to support a wide range of users with differing levels of expertise. While the data are publicly accessible, accompanying documentation and user guidance emphasise appropriate interpretation and limitations. InSAR products are framed as screening and monitoring tools that support, rather than replace, field investigations, in-situ instrumentation, and expert judgement.

Update strategies reflect differing user needs and environmental conditions. For much of Norway, where snow cover limits coherent observations for large parts of the year, annual nationwide updates of persistent scatterer products are considered sufficient. In urban areas and at selected high-risk sites, more frequent updates are produced. Local networks of snow-protected corner reflectors are integrated into the system and processed automatically, providing higher temporal resolution for critical slopes and infrastructure (Dehls et al., 2018).

2.4 Operational experience and lessons learned

Operational deployment of InSAR Norway demonstrated both the benefits and the challenges of national-scale ground-motion services. Shortly after the first nationwide Sentinel-1 dataset was released, numerous previously unknown unstable slopes were identified, illustrating the value of systematic, wall-to-wall coverage. At the same time, experience confirmed that deformation signals must be interpreted in context, with geological understanding and complementary monitoring data playing a central role.

Beyond geohazards, InSAR.no has proven valuable for monitoring urban subsidence and infrastructure stability, particularly in areas built on anthropogenic fill or affected by construction activities. The establishment of a consistent national baseline of ground deformation has also supported planning and assessment for major transport projects, reducing uncertainty and monitoring costs.

Overall, the Norwegian experience shows that the effectiveness of a ground-motion service depends not only on data quality, but also on sustained operations, clear governance, and active user engagement. In this respect, InSAR Norway provided an important operational reference for scaling the concept from the national to the continental level through the European Ground Motion Service.

3. Applications and Impact on Disaster Risk Reduction

3.1 Systematic Landslide Identification

One of the most immediate impacts of the InSAR Norway service has been its contribution to the systematic identification of previously unknown unstable slopes. Prior to the availability of nationwide Sentinel-1–based products, InSAR analyses in Norway were largely limited to targeted areas identified through prior geological mapping or historical events. While effective, this approach inevitably missed unstable slopes outside predefined areas of interest.

The transition to wall-to-wall national coverage fundamentally changed this situation. By providing consistent ground-motion information across the entire country, InSAR.no revealed deformation patterns in many areas that had not previously been identified as potentially unstable. Across Norway, these observations have led to the recognition of numerous new areas affected by slope movement, prompting systematic follow-up using established field investigations, geological mapping, and, where appropriate, dedicated monitoring. This shift from targeted analysis to systematic screening has substantially strengthened national landslide inventories and provided a more robust basis for prioritising fieldwork and monitoring resources.

3.2 Integrated Monitoring: Satellite and In-Situ Networks

InSAR Norway has also demonstrated the value of integrating satellite-based observations with in-situ monitoring networks. For medium- and high-risk unstable rock slopes, InSAR data complement ground-based instrumentation by providing spatial context and continuity between measurement points. This integration is particularly effective when combined with dedicated corner reflector networks, which improve measurement reliability and temporal sampling in snow-prone and steep terrain.

At Norway’s latitude, the large number of overlapping Sentinel-1 tracks enables frequent observations at selected sites. Corner reflector networks installed on critical slopes are automatically processed as part of the operational workflow, providing deformation updates several times per week. These satellite-based observations supplement continuous in-situ measurements, supporting both long-term trend analysis and detection of changes that may warrant closer attention.
This combined approach reduces reliance on any single monitoring technique and allows resources to be allocated more efficiently. Satellite data provide broad spatial coverage and early indications of activity, while in-situ systems deliver high-resolution measurements where risk levels justify more intensive monitoring.

3.3 Beyond Geohazards

While landslides represent the most immediate threat to life in Norway, ground subsidence often has the greatest economic impact due to its effects on buildings, transport infrastructure, and coastal developments. InSAR.no was therefore designed to support applications beyond classical geohazards, particularly in urban and peri-urban environments.

Many Norwegian cities have expanded onto reclaimed land or soft sediments, where gradual settlement can continue long after construction. InSAR-based time series provide an effective means of monitoring such deformation over long periods, allowing differential settlement to be identified and tracked. This information supports maintenance planning, condition assessment, and dialogue between public authorities, infrastructure owners, and developers.

Transport infrastructure presents a similar use case. Norway’s extensive network of tunnels, bridges, and embankments requires careful monitoring during construction and operation. InSAR.no provides a consistent national baseline of ground deformation, enabling the assessment of changes associated with major infrastructure projects in context. In several cases, InSAR data have been used as a cost-effective supplement to traditional monitoring, reducing the need for dense in-situ instrumentation while maintaining situational awareness.

3.4 Climate Sensitivity and Permafrost

Ground-motion monitoring in Arctic environments raises additional challenges that differ from those encountered on the Norwegian mainland (e.g., Rouyet et al., 2021). In Svalbard, seasonal thaw and refreezing, short snow-free periods, and more variable coherence conditions influence both the interpretation of deformation signals and the types of products that can be provided. These environments are of particular interest because ground movement may reflect changes in permafrost, slope instability, and impacts on settlements, infrastructure, and cultural heritage.

The recent development of the InSAR Svalbard service illustrates this need for adaptation to local conditions. The service has been introduced with products tailored to Arctic environments and is initially being provided for selected pilot areas rather than as immediate full regional coverage. This reflects that operational ground-motion services do not necessarily develop through a single, uniform product model; they may require staged implementation and region-specific product concepts where

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environmental conditions differ substantially. In the Norwegian context, Arctic monitoring therefore extends the operational logic of InSAR Norway while also highlighting the need for specialised products in climatically sensitive areas.

4. Scaling to Continental Levels: The European Ground Motion Service

4.1 Transferring Operational Experience from National to Continental Scale

The European Ground Motion Service (EGMS) represents a significant step in extending operational ground-motion monitoring from national to continental scales. Developed under the Copernicus Land Monitoring Service (CLMS), EGMS provides harmonised, regularly updated ground-motion products based on Sentinel-1 time-series InSAR across most of Europe. While its scope and governance differ from those of national initiatives, the conceptual and operational foundations of EGMS are closely aligned with experience gained from long-running national services.

In particular, the design of EGMS reflects lessons learned from the sustained operation of InSAR Norway, which demonstrated the feasibility and value of a routinely updated, open-access national ground-motion service embedded within a public institutional framework. Experience from InSAR Norway highlighted the importance of systematic coverage, repeatable processing, clear product definition, and a separation between data provision and hazard interpretation. These principles informed early discussions on continental ground-motion services and are reflected in EGMS specifications and service architecture.

The development of EGMS involved contributions from a broad European expert community through white papers, technical specifications, and advisory groups. This collaborative process ensured that the service addressed diverse geological, institutional, and user contexts across Europe. At the same time, the resulting EGMS structure closely mirrors an operational model that had already been tested at a national scale, reducing risk and accelerating the transition from concept to service delivery.

By providing a harmonised continental reference dataset while leaving interpretation and application to national and regional authorities, EGMS extends the national-service paradigm rather than replacing it. In this sense, EGMS can be seen as a scaling of an operational concept that had already proven its robustness in practice, adapted to meet the requirements of a pan-European user community.

4.2 Tiered Product Architecture

A key feature of EGMS is its tiered product architecture, designed to accommodate different use cases while managing interpretation risk. The service provides multiple product levels, commonly referred to as the Basic, Calibrated, and Ortho products, each with distinct characteristics and intended applications.

Basic products provide large-area deformation velocities and time series derived directly from Sentinel-1 observations, serving as an entry point for regional screening. Calibrated products incorporate corrections based on external reference data, improving consistency across wide areas and national borders. Ortho products further enhance interpretability by combining ascending and descending geometries to derive additional motion components, where feasible.

This tiered approach reflects experience from national services, where a single, undifferentiated product can lead to misuse or unrealistic expectations. By clearly distinguishing between product levels, EGMS supports a broader user community while encouraging appropriate interpretation and follow-up analysis by expert users.

4.3 Standardization and Harmonization

One of the principal motivations for EGMS is the need for harmonised ground-motion information across national boundaries. Many geohazards, infrastructure networks, and environmental processes extend across borders, making consistent reference datasets essential for regional planning and risk assessment. EGMS addresses this need by applying uniform processing strategies and calibration approaches across participating countries.

Calibration using GNSS reference data plays a central role in ensuring long-wavelength consistency and reducing artefacts at national boundaries (Dehls et al., 2022) This harmonisation improves confidence in continental-scale deformation patterns and allows national services to align their own products with a common European reference. Importantly, harmonisation does not imply uniform interpretation; instead, it provides a stable foundation upon which national expertise and local knowledge can be applied.

The EGMS experience reinforces the distinction between harmonised data provision and decentralised interpretation. By separating these functions, the service supports both consistency at the continental scale and flexibility at national and regional levels.

5. The Case for a Global Ground Motion Service (GGMS)

5.1 Addressing the Global Processing and Access Gap

Despite major advances in satellite-based Earth observation, access to systematic ground-motion information remains highly uneven globally. Many of the regions most exposed to landslides, subsidence, and other deformation-related hazards, particularly in mountainous, tropical, and rapidly urbanising areas, lack the institutional capacity, infrastructure, or resources required to process and maintain large InSAR time series. As a result, the availability of open satellite data has not translated into equitable access to operational ground-motion information.

Experience from national and continental services demonstrates that the principal barrier is no longer data availability, but the ability to transform data into stable, interpretable, and regularly updated products. Requirements for processing, quality control, and sustained operations place ground-motion services beyond the reach of many institutions, particularly in low- and middle-income countries. This gap has direct implications for disaster risk reduction, as it limits early identification of unstable areas and constrains the ability to prioritise mitigation and monitoring efforts.

A Global Ground Motion Service (GGMS) would address this imbalance by providing a harmonised baseline of ground-motion information for regions where national or regional services are not currently feasible. Rather than replacing local expertise or detailed studies, such a service would serve as a screening and contextual layer, supporting national authorities, humanitarian organisations, and development agencies in identifying areas where further investigation and risk-reduction measures may be warranted.

5.2 Multi-Sensor Synergy and Global Coverage

At the global scale, reliance on a single satellite mission is neither realistic nor desirable. While Sentinel-1 has demonstrated the value of systematic C-band observations, global ground-motion monitoring would benefit from integrating data from multiple current and future missions. In particular, the combination of C-band and L-band sensors offers complementary strengths in terms of coherence, vegetation penetration, and sensitivity to different deformation processes.

NISAR has now been launched and has begun delivering data, but it will take additional time before sufficiently long time series are available for routine ground-motion analysis at service scale. Planned L-band contributions from missions such as ROSE-L nevertheless point toward a future in which global services can be made more resilient to decorrelation and better suited to challenging environments, including densely vegetated and mountainous regions. A GGMS framework could accommodate multiple sensors through harmonised processing strategies and product definitions, while maintaining consistent output formats and interpretation guidance.

Importantly, multi-sensor integration should be driven by service needs rather than technical optimisation. The objective is not to maximise spatial resolution or algorithmic sophistication, but to ensure continuity, robustness, and interpretability at the global scale. As demonstrated by EGMS and InSAR Norway, service stability and clarity are prerequisites for operational uptake.

5.3 Alignment with International DRR and Development Frameworks

The rationale for a GGMS aligns closely with international frameworks for disaster risk reduction and sustainable development. The Sendai Framework emphasises the importance of understanding disaster risk through improved access to hazard-related information, particularly in regions with limited capacity. Similarly, several United Nations Sustainable Development Goals, including those related to resilient infrastructure, sustainable cities, and climate adaptation, depend on the availability of consistent geospatial information.

A GGMS would provide a practical mechanism for translating these high-level objectives into actionable information. By offering a globally consistent reference dataset, such a service could support early-stage risk screening, infrastructure planning, and climate adaptation efforts, while enabling international organisations to target resources more effectively. Coordination through existing structures, such as the Group on Earth Observations (GEO), would help ensure that a GGMS complements rather than duplicates existing initiatives.

Crucially, alignment with international frameworks also implies a responsibility to avoid one-size-fits-all solutions. Global services must be designed with flexibility, transparency, and respect for national sovereignty, ensuring that data provision supports, rather than overrides, local decision-making processes.

6. Challenges and Pathways to Implementation

6.1 Scalability and Observational Constraints

Scaling ground-motion services from continental to global extent requires careful consideration of the underlying satellite observation strategy. Although Sentinel-1 provides global coverage, acquisition density and geometry are not uniform worldwide. Over Europe, the systematic Copernicus observation plan delivers coverage every six days in both ascending and descending geometries, enabling dense time series and robust separation of deformation components. Outside Europe, revisit frequency is typically lower, and in many regions, data are acquired in only a single geometry.

Sentinel-1 acquisition priorities are driven in part by tectonic activity and associated geohazard exposure. As a result, many tectonically active regions, including areas prone to landslides and subsidence, receive more frequent coverage than surrounding regions, while other parts of the world are observed less frequently. This spatially variable acquisition strategy has direct implications for the design of large-scale ground-motion services, particularly regarding achievable temporal resolution and product consistency.

These observational constraints mean that a global ground-motion service cannot deliver a uniform product portfolio everywhere. While some regions may support product levels comparable to the full EGMS hierarchy, others will only support more basic outputs suitable for large-area screening. More advanced products should therefore be treated as conditional rather than universal, depending on whether the underlying observations are sufficient to support them reliably. Product levels in a global framework should be matched to regional feasibility and practical user needs, not defined by a single standard applied everywhere. The objective should be global service coherence, not global uniformity of every product type.

6.1.1 Implications for global processing volume: These global acquisition patterns have an important consequence for scalability. Although a global service might be expected to require orders of magnitude more data than a continental system, the actual increase in Sentinel-1 input volume is more moderate. Because much of the world is observed at 12-day intervals and often in only one geometry, the total number of scenes available for global processing is substantially lower than would be implied by a simple extrapolation from European acquisition density.

Based on current acquisition patterns, processing all available global Sentinel-1 ground-motion data would require handling a data volume on the order of several times that of EGMS, rather than a full order-of-magnitude increase. Preliminary estimates suggest a total scene volume of roughly six times that currently processed for EGMS. This scaling reflects reduced revisit frequency and reduced geometric redundancy outside Europe, rather than any simplification of the processing problem.

In practice, fewer acquisitions do not make large-scale ground-motion processing easier. Sparser time series provide less temporal redundancy, reduce robustness in quality control and noise separation, and often limit the generation of higher-level products. Lower acquisition density can also make deformation signals more difficult to interpret consistently, particularly in regions affected by seasonal snow cover, monsoon-driven decorrelation, vegetation dynamics, or episodic motion. The challenge is therefore not only one of total data volume, but also of uneven observability and reduced analytical strength across many regions.

This distinction is important for feasibility assessment. Global processing remains a substantial undertaking, but one that appears to lie within the reach of incremental expansion of existing high-performance computing infrastructures. At the same time, the main constraints are not purely computational. They also concern the ability to generate reliable and appropriately differentiated products from data sets that, in many regions, are less dense, less redundant, and less uniformly interpretable than those available in Europe.

6.1.2 Product Implications and Communication of Limitations: Non-uniform acquisition density has direct implications for product definition, service design, and user expectations. A global ground-motion service cannot assume that the same products can be generated everywhere, nor that all regions should be expected to support the same level of interpretation. In areas with only a single acquisition geometry, longer revisit intervals, or less stable coherence conditions, the feasible outputs will necessarily be more limited than those available in Europe. In such cases, the emphasis is likely to be on broad-area screening products, line-of-sight deformation information, and longer-term trends, rather than on more advanced or higher-frequency outputs.

This variability should not be treated as an exception, but as a normal characteristic of a global service. Product definitions, therefore, need to be aligned with regional observational conditions and operational user needs, while remaining embedded within a common overall framework. The objective is not to reproduce an identical product portfolio everywhere, but to provide the most robust and useful level of information that can be supported in each region.

Clear communication of these differences is essential. Experience from both national and continental services shows that confidence in the products depends not only on technical quality, but also on a transparent explanation of what the data can and cannot support. A global service must therefore communicate spatial differences in observation density, product level, and interpretative confidence in a clear and consistent way, particularly in regions where coverage is sparse or product capability is more limited.

6.1.3 Practical Pathways for Scaling: The practical challenge of scaling is therefore not defined by raw data volume alone, but by the need to operate across highly variable observation conditions within a coherent service framework. Global implementation will require a system that can accommodate differences in acquisition frequency, viewing geometry, coherence conditions, and expected product levels, while still maintaining common standards for processing logic, metadata, quality description, and user guidance.

In this respect, the most relevant foundation is not simply large-scale processing capacity, but operational experience in managing a tiered and harmonised service. The experience gained through EGMS, together with the earlier national experience from InSAR.no, demonstrates how automated ingestion, incremental stack updating, structured product levels, and consistent delivery principles can support this kind of scaling. The pathway to a global service is therefore not a direct replication of the European model across regions, but an extension of its operational logic to a more heterogeneous observational environment.

6.2 Capacity Building and Regional Engagement

Technical scalability alone is not sufficient to ensure the effective use of global ground-motion products. Experience from national and continental services shows that the value of InSAR-based information depends critically on the presence of institutions capable of interpreting, contextualising, and acting on the data. In most countries, this role is naturally assumed by national geological surveys, geotechnical authorities, or equivalent public institutions with mandates in hazard assessment, land-use planning, or infrastructure oversight.

In a global context, a GGMS would therefore need to function not as a replacement for national capabilities, but as a supporting layer that enables and strengthens them. Global ground-motion products can provide consistent baseline information and early screening, but meaningful application requires regional expertise to integrate deformation signals with geological knowledge, local inventories, field investigations, and socio-economic context. Without such engagement, there is a risk that global products remain underutilised or misinterpreted.

Capacity building should thus be considered an integral component of any global ground-motion service. This includes training, documentation, and sustained dialogue with regional users, as well as mechanisms for feedback and product refinement. By actively involving national institutions in the use and interpretation of global data, a GGMS can promote local ownership, improve relevance, and support long-term sustainability. In this way, global services can enhance—not dilute—the role of national geological surveys and related authorities in disaster risk reduction and environmental monitoring.

7. Discussion

7.1 Ground-motion Services as Enabling Infrastructure

The progression from InSAR Norway to the European Ground Motion Service shows that the principal challenge in large-scale ground-motion monitoring is no longer whether wide-area InSAR processing is technically possible. That question has already been answered at both the national and continental scales. The more important issue is how such capability is translated into an operational service that can be maintained over time, interpreted responsibly, and integrated into real decision-making contexts.

A central point emerging from both the Norwegian and European experience is that ground-motion services derive their value from continuity, clarity, and usability as much as from technical sophistication. Systematic processing alone is not sufficient. The data must be delivered through a stable service framework, accompanied by clear product definitions, transparent limitations, and an institutional structure that distinguishes between data provision, expert interpretation, and formal hazard or risk assessment. This separation is not a weakness of the service model, but one of its essential strengths. It allows deformation information to be used widely without implying that the service itself provides definitive hazard classifications or prescriptive decisions.

The comparison between national, continental, and prospective global scales also shows that scaling is not simply a matter of processing more scenes. The European case already demonstrates that harmonisation across large and diverse

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territories requires common standards, consistent product logic, and coordinated governance. At a global scale, this challenge becomes more pronounced because observational conditions are far less uniform. Outside Europe, acquisition density, viewing geometry, coherence conditions, and environmental constraints vary substantially from region to region. A future global service cannot therefore be based on the assumption that the same products can be generated everywhere with the same reliability or interpretability.

This has important implications for service design. The most realistic pathway is not a globally uniform replication of the full European model, but a harmonised framework with regionally differentiated outputs. In some regions, the service may support only basic line-of-sight screening products and long-term trends. In others, denser and more redundant observations may justify more advanced products. Such variation should not be regarded as an inconsistency, but as an operationally honest response to differences in observability. The objective of a global service should be coherence in standards, metadata, and communication, rather than identical product content in every region.

The Norwegian and European experiences also underline the importance of user engagement and institutional embedding. Services of this kind are most effective when linked to organisations that already have responsibility for hazard assessment, infrastructure management, or environmental monitoring. In practice, this means that the success of a future Global Ground Motion Service would depend not only on processing capacity but also on mechanisms for regional uptake, interpretation support, and capacity building. In many parts of the world, the limiting factor is unlikely to be satellite availability alone but the absence of operational frameworks and expert institutions capable of incorporating deformation information into practice.

From this perspective, the argument for a Global Ground Motion Service is not based solely on technological ambition. It is based on the recognition that access to systematic ground-motion information remains highly uneven worldwide, despite the global availability of satellite observations. A globally coordinated service could help reduce this imbalance by providing a common reference layer, shared methods, and a framework for strengthening national and regional capabilities over time. Its role would not be to replace local expertise or national responsibility, but to support them.

The broader implication is that operational ground-motion monitoring should be understood as a form of public geospatial infrastructure. Like other reference services, its significance lies in providing a consistent evidence base that can be reused across multiple sectors and applications. The lessons from InSAR.no and EGMS suggest that this model is transferable, but only if scaling is approached as a combined technical, institutional, and communicative task. In that sense, the future of global ground-motion monitoring depends as much on service architecture and governance as on sensor performance and processing efficiency.

8. Conclusions

Operational ground-motion monitoring has now evolved from national implementation to continental-scale service provision, with Norway and the European Ground Motion Service providing two successive demonstrations of what is technically and institutionally achievable. Across these scales, the central point is that the societal value of InSAR-based ground-motion monitoring lies not in methodological novelty, but in the sustained provision of consistent, interpretable, and openly accessible reference data.

The experience of InSAR Norway shows that routinely updated national ground-motion services can significantly strengthen disaster risk reduction, infrastructure management, and environmental monitoring when they are embedded within clear institutional frameworks. The subsequent scaling of these principles to EGMS shows that harmonised continental services are both technically and organisationally achievable, provided that data provision remains clearly separated from interpretation and decision-making.

The case for a Global Ground Motion Service is therefore grounded not in abstraction, but in demonstrated need and operational precedent. Sentinel-1 acquisition characteristics, together with existing processing architectures, indicate that global scaling is within reach without requiring a fundamental change in observation strategy. At the same time, global-scale implementation will require careful attention to spatial heterogeneity in coverage, environmental conditions, product feasibility, and institutional capacity.

A future GGMS should therefore be conceived as an enabling service that supports national authorities and regional institutions, rather than as a prescriptive hazard-assessment system. Built incrementally on proven national and continental models and combined with capacity building and user engagement as core components, such a service could make a meaningful contribution to more equitable access to ground-motion information and to long-term disaster risk reduction worldwide.

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