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The Evolution of Remote Sensing for Regional Characterization and Response to Geohazards and Extreme Events

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Abstract: Regional remote sensing provides large-area observation capabilities that support geo-asset management, geohazard monitoring, and post-event recovery, particularly under changing climate conditions. Recent advances have expanded what is possible, driven by both technological innovation and the increasing democratization of data. Freely accessible datasets such as satellite-derived Interferometric Synthetic Aperture Radar (InSAR), soil moisture products, vegetation health indices, and high-resolution terrain models derived from aerial lidar are becoming widely available. These resources, when interpreted together, enable improved understanding of ground movement, environmental change, and hazard vulnerability across broad regions. However, the value lies not only in access to data, but in converting it into actionable knowledge. Cloud-based geospatial platforms now allow efficient integration, visualization, and interpretation of large, diverse datasets on a scale. This evolution supports communities and infrastructure networks in identifying risks, prioritizing interventions, and accelerating recovery, thereby providing a pathway to building resilience to extreme events.

Keywords: ***Lidar, InSAR, Lidar change detection, Earth observation, Remote sensing, Resilience, GIS, rdNDVI.***

Introduction

Regional remote sensing, wherein sensors observe 10s, 100s or 1000s of square kilometers, offers value to communities, governments, and owners of distributed private infrastructure. Especially in recognition of a changing climate, characterizations for geo-asset and geohazard management and extreme event recovery are some of the values offered. As demonstrated in this keynote lecture, regional remote sensing can be used to build or maintain resilience to extreme events in a community, for an infrastructure network or for an inventory of assets.

Over the past few years, independent innovations and advances have led to a change in what is possible. Though there are differences in local availability, there is an evolution that reaches many parts of the world. The evolution is built from innovations to specific technologies but there is a trend that transcends all of them.

The trend is that there is a democratization of raw data, meaning that access is becoming more widely available, and free. In some cases, initial processing is also being undertaken by government bodies and being made available, such as Interferometric Synthetic Aperture Radar (InSAR) from SAR data and terrain models from aerial lidar data. This development not only improves affordability, but it encourages innovation in uses of data. Democratization has another effect, which is part of the trend, and that is to place focus on what it takes to build knowledge from the freely available data. The data themselves do not imply understanding, nor do they build the conviction to take action to manage geohazards or prioritize resources. With freely available data and a focus on understanding, evolution includes tools for building knowledge, improving communication and taking the actions to build resilience at scale. Progress in this evolution is illustrated by examples with specific technologies, and it is followed by a discussion on how these developments can improve resilience to extreme events.

Example technologies and applications

InSAR is SAR data processed primarily to track ground movement, and it is in an exciting period of innovation and democratization. Recent examples of regional InSAR applications are provided from Europe, North America (Froese et al., 2022) and Myanmar (Gunay et al., 2025), where the objectives are quite different. The 2025 NASA-ISRO Synthetic Aperture Radar (NISAR) mission promises to bring better global SAR data and InSAR to Asia and globally.

Spatial and temporal trends in ground movement, as provided through InSAR interpretation, can be correlated to other changes observed by satellite, such as soil moisture and vegetation health. Soil moisture derived from missions like NASA's Soil Moisture Active Pressure (SMAP) and ESA's Soil Moisture and Ocean Salinity (SMOS) or climate reanalysis data such as ERA5 can be interpreted with InSAR to improve understanding. Further correlations can be made to the Relative Difference in Normalized Difference Vegetation Index (rdNDVI), which refers to a change in the index representing healthy vegetation, e.g. Scheip and Wegmann (2021). Movement, moisture and vegetation health can be interpreted together in many ways to improve understanding of vulnerability, forecast possible outcomes of a potential extreme event, and to understand the impacts of a past event.

In parts of the world, fixed-wing, aerial lidar has now been collected for decades and processed to provide increasingly accurate point cloud representations of the ground surface. An important recent innovation is the ability to compute topographic change between two successive acquisitions at a regional scale (Weidner et al., 2023). Using this method, it is possible to observe changes as small as a few square meters in plan area, and as small as a few hundred millimeters in topographic change, and to do this tor 1000s of square kilometers (Scheip et al., 2025). An example of this use for building resilience through rapid recovery is described by Anderson (2025).

The data collected in the examples here need to be interpreted regionally and in the context of one another because without doing this, the value of each is greatly diminished. So, the evolution of regional remote sensing is dependent on a spatial platform that can manage large data, of different types, efficiently and in ways that the user can view things differently and query the data for better understanding. Fortunately, there has also been evolution in GIS platforms that make these data interpretable at scale. Cambio Earth is a web-based, cloud-hosted platform that has been used for this purpose (Baumgard and Burkell, 2024), and examples are provided in how these different types of data, when combined, provide a more complete understanding of vulnerabilities prior to extreme events, and to recovery needs after extreme events.

Building resilience at scale

Another evolution that has been occurring in the United States, and perhaps elsewhere, is the explicit consideration of the attribute of resilience. In terms of extreme events, something resilient is less severely impacted and/or the impact is shorter, so that the consequence is less. Resilience can be achieved in many ways, often categorized as through robustness, redundancy, rapidity and resources, and it can be considered at many scales, as in for a particular bridge or structure, or for a network of roads, or the essential services of a community.

Regional remote sensing, when combined with a dynamic platform to get knowledge from the data and build the conviction to act, is a powerful and cost-effective way to build resilience at the larger scale of communities and infrastructure networks.

Examples are provided in how this can work prior to extreme events, where knowledge gained from remote sensing indicates vulnerabilities and how these technologies help after extreme events, when there is a need to recover and rebuild.

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