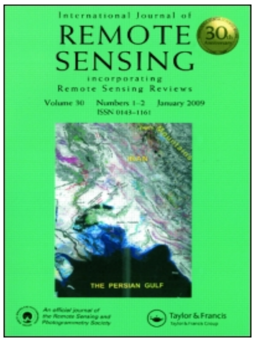

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Earthquakes from space: Earth observation for quantifying earthquake risks

Monday, September 25, 2017
Old Library, Lloyd's of London

1. Earthquakes from space: introduction

The event co-chairs – Chris Ewing (AGI/Aon Benfield Impact Forecasting), Tina Thomson (RSPSoc/MS Amlin), William Forde (RMS), Matthew Foote (ArgoGlobal) and Richard Teeuw (RSPSoc/University of Portsmouth)

The earthquakes (EQs) from space: Earth observation (EO) for quantifying EQ risks event was jointly hosted by the Remote Sensing and Photogrammetry Society (RSPSoc) Disaster Management Special Interest Group (SIG) and the Association for Geographic Information (AGI) Insurance and Risk SIG at the Old Library, Lloyds of London on 25 September 2017. The aim of the workshops was to help insurance industry modellers and analysts investigate how EO, satellite, and geospatial technologies help to better quantify EQ risk through an independent view from academics and industry professionals working in this area.

EQ events, although low in frequency, are high in severity. In recent memory, a number of events have caused havoc in many different places in the world including in Pijijiapan, Mexico, in 2017, Nepal in 2015, L'Acquila, Italy, in 2009, and Northridge, California, in 1994. These events had a massive impact on lives and livelihoods and impacted insurance markets and governments alike.

To help with estimating the frequency and quantifying the loss from EQ events, insurance companies and risk financing professionals use catastrophe models which typically seek to look at the risk to a portfolio of buildings insured by the company. The catastrophe models go through a constant cycle of updates and this year the model software vendors released North America EQ updates, based on the latest findings from the USGS. For example, the latest Uniform California Earthquake Rupture Forecast model (UCERF3) now includes the types of multi-fault ruptures seen in nature, e.g. the 1992 magnitude 7.3 Landers, the 1999 magnitude 7.2 Hector Mine, and the 2010 magnitude 7.2 El Mayor-Cucapah, events which ruptured past fault boundaries and demonstrated that models are not dealing with a few well-separated faults, but with a vast interconnected fault system.

Behind these model updates are advances in EO techniques that have improved our understanding of seismicity. High-resolution daily EO imagery and even real-time video-streaming by satellites are new technologies that will benefit the insurance industry, enabling faster damage assessment and loss quantification following EQ events, as well as facilitating disaster response and recovery.

The event showcased a wide range of quick-fire talks on seismic hazard mapping, insured exposure quantification, damage assessment, and rapid loss assessment, all using recent and innovative EO techniques. This report includes extended abstracts from the event. In publishing this report, we hope to spur the consideration of potential avenues for future partnership between EO, geospatial technology communities, academia, and insurance industry professionals.

2. Monitoring earth's dynamic crust from space

Tim J. Wright, COMET, School of Earth and Environment, University of Leeds

Satellite observations are transforming the way we monitor our dynamic planet. Scientists in the Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) are using new satellite observations of Earth's topography and deformation to transform our understanding of EQ hazard.

Since 1900, 35 EQs have each killed at least 10,000 people. Of these, 26 were in the Alpine-Himalayan seismic belt – a broad zone where the African, Arabian, and Indian tectonic plates collide with Europe and Asia (Figure 1). Most of these deadly EQs were caused by the rupture of faults that had not previously been identified or whose hazard had been underestimated.

Using satellite observations of ground deformation, we can now measure ground movements from most continental EQs within a few days. Examples from recent EQs, including two very different M7.8 EQs, include the 2015 Nepal EQ, where satellite observations show that significant seismic hazard remains for Kathmandu, and the 2016 New Zealand EQ, which broke many 'rules' of EQ behaviour, such as multi-fault rupturing, that are hard-wired into some existing seismic hazard models.

Of course, we would like to be able to forecast EQ activity before it happens. Giving short-term predictions for EQs is likely impossible, but during the long periods between events, the ground surface around faults steadily warps in response to tectonic forces.

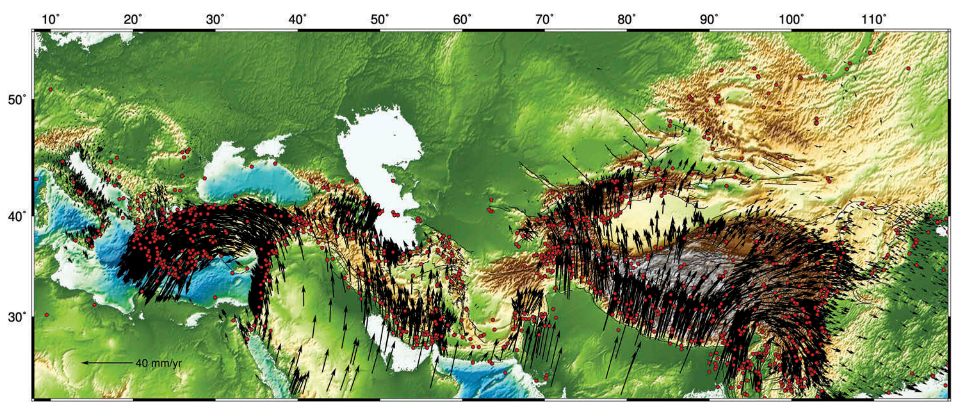

Figure 1. Distribution of earthquakes and GPS velocities in the continents. Background colours show topography. Each circle is a large earthquake (data from the Global Earthquake Model). Arrows show the motion of points relative to the Eurasian plate measured with GPS and were compiled by Kreemer et al. (2014) for version 2 of the Global Strain Rate Model. The collision of Africa, Arabia, and India with Eurasia has created a wide deforming zone of thickened crust, high seismicity, and high strain rates that stretches for up to 2000 km from the foothills of the Himalayas to the distant steppes of Mongolia.

Measuring the slow build-up of this deformation is potentially a powerful new method for assessing and predicting the likelihood of EQs and can complement traditional methods that rely on historical and instrumental seismicity catalogues. The twin Sentinel-1 radar satellites, part of Europe's Copernicus programme, are now providing systematic observations that are enabling us to measure deformation at fault zones globally with sufficient accuracy and spatial resolution to make an impact on seismic hazard assessment. We are using these data, along with observations from Global Navigation System Satellite System (GNSS), to build maps of tectonic strain (e.g. Walters et al. 2014) and discuss how we can use these to inform models of seismic hazard.

On a longer timescale, continued fault movement results in changes in the landscape. Reading these landforms, which are often extremely subtle, it becomes possible to identify active faults even if their long-term rates are too slow to be detected by geodesy. A new generation of high-resolution optical satellites, along with data now readily available from aircraft and drones, are allowing the development of topographic models with sufficient resolution to identify active faults; combined with new dating methods, these techniques can estimate rates of activity.

Collectively, satellite observations provide a more complete view of how the Earth can behave. Yet EO is still only scratching the surface – there have been satellite observations for ~20 years, which is a small fraction of the inter-event period for most faults. The complexity in EQ sources is only beginning to be understood and mapping the distribution of strain across entire mountain belts for the first time. These data, facilitated by GIS tools to develop the models, are changing the way that scientists think about fault zones. This new understanding has clear implications for seismic hazard assessment.

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3. Mapping fault-related displacements using Satellite InSAR: an example across the Los Angeles Basin, USA

Rachel Holley, Adam Thomas, Harry McCormack, Hayley Larkin, NPA Satellite Mapping, CGG, Crockham Park, Edenbridge, Kent TN8 6SR, UK

3.1. *The Los Angeles basin*

Los Angeles (LA) is a city of nearly 4 million people, with more than 18 million across the wider metropolitan area, all of whom live with constant earthquake risk. The LA Basin is located in a geologically complex region, bounded and dissected by major faults. The wider area is undergoing a combination of compressional and strike-slip tectonics in the vicinity of the Pacific-North American plate boundary and San Andreas Fault system, with the Newport–Inglewood, Whittier, Santa Monica, Hollywood, Puente Hills, and various other fault systems providing a complicated context for analysis of the resulting risks.

Although understanding of the faults affecting the LA basin has undoubtedly improved over the past decades, this is still acknowledged to be incomplete; and this has become increasingly pertinent to discussions regarding current and future land use and development across the city.

A number of controversies have surrounded this issue in recent years, for example discussions surrounding possible routes for the Westside Subway extension through Beverly Hills (Gath et al. 2016); planning approval for developments, such as the Millennium Hollywood project (Nagourney 2013); and recent updates to the state's 'Alquist-Priolo' Earthquake Fault Zone maps governing development across active fault traces (Anon 2016).

In the context of ground deformation, the tectonic picture is further complicated by the overlain effects of non-tectonic phenomena such as oil and gas production, aquifer compaction, landslides, and tunnelling activities.

3.2. *Satellite InSAR*

Satellite interferometric synthetic aperture radar (InSAR) is a remote-sensing technique to map and monitor surface deformation. InSAR involves the advanced processing of satellite radar images acquired across the same location of the Earth's surface at different times, to map surface deformation.

The key advantage of InSAR for tectonic applications is the wide spatial scale and dense sampling. It is capable of remotely detecting millimetres to metres of deformation spanning days, months, years, and decades, across specific sites or wide areas (hundreds of square kilometres) all over the world.

Southern California has one of the highest network densities of geodetic GPS in the world, yet these provide a sparse grid of point measurements, in comparison to the near-contiguous measurement coverage obtained across the area using InSAR. This allows spatial variations in the displacement to be mapped at scales of a few metres to hundreds of kilometres, identifying the locations and magnitudes of both sharp discontinuities and more subtle gradients in the displacement field.

The availability of historical archives of ERS satellite radar data acquired from 1992 to the present day allows InSAR to 'look back in time' to provide retrospective assessments of surface deformation. This provides a longer temporal perspective on tectonic deformation, identifying intermittent effects and variations in the location or rate of displacement through time. Ongoing acquisitions and planned future missions also provide continuity for long-term monitoring into the future.

3.3. *InSAR across LA*

InSAR results across LA demonstrate what a complex and dynamic area this is for ground deformation, with superimposed signals from multiple different causes.

Notable signals in various locations across the LA basin can be attributed to oil and gas activities, both subsidence associated with production and areas of uplift where enhanced oil recovery is in progress. Seasonal and longer term variations in water storage within the Santa Ana aquifer system cause substantial displacements across the eastern side of the basin, with ground displacements in other areas also potentially attributable to local water abstraction or

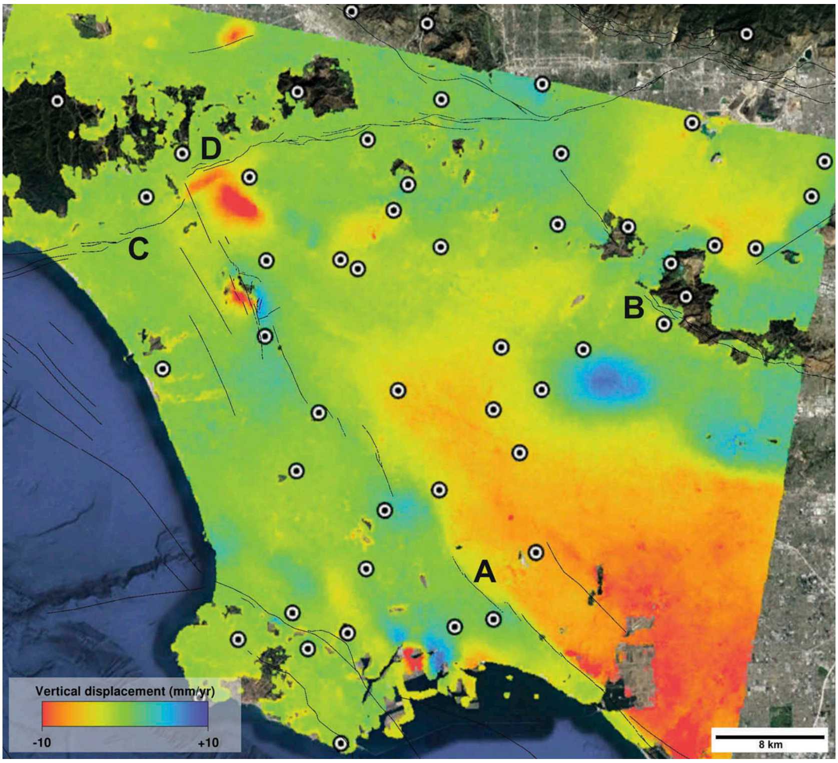

Figure 2. InSAR ground displacement map across the LA Basin, 2005–2010, showing locations of the UNAVCO Plate Boundary Observatory continuous GPS stations and faults locations: A – Newport–Inglewood; B – Whittier; C – Santa Monica; D – Hollywood, and various other fault systems providing a complicated context for analysis of the resulting risks. Image © NPA Satellite Mapping, CGG; SAR data © ESA 2005–2010; Fault locations © USGS (source: https://earthquake.usgs.gov/learn/kml.php). Background image © LDEO-Columbia, NSF, NOAA, USGS, SIO, U.S. Navy, NGA, GEBCO, © Google Earth 2017.

de-watering associated with construction. In some areas of steeper topography, landslide displacements are also visible (Figure 2).

Such displacements can complicate interpretation of tectonic ground deformation signals, but interactions between these factors and the underlying tectonic structures can also highlight the presence of these. Faults which may have low magnitudes of ongoing tectonic displacement may nonetheless accommodate or delimit strain caused by these other factors, indicating the location of these structures.

Comparison of InSAR results derived over more than two decades shows that ground deformation signals associated with both known fault locations and non-tectonic factors change over time, adding temporal context to the observed signals.

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4. Reducing modelling uncertainty with Earth observation data

Charles K. Huyck, ImageCat

As the insurance industry seeks emerging markets in the developing world, it has become evident that a lack of location, occupancy, structural attributes, and pricing information such as used by catastrophe ('cat') models has resulted in a significant amount of uncertainty. Proper pricing requires that uncertain risks must pay a higher premium, which exacerbates insurance uptake in these emerging markets. It is widely recognized that underinsurance can lead to cascading economics that dwarf direct losses. Space-based platforms are ideal for minimizing subjective decisions – such as what to survey or include in an inventory – that skew risks towards known assets. It is the only way to reasonably update exposure annually for multiple countries and when applied correctly allows for a 'best-of-breed', or tiered, approach in which more accurate data from surveys, OpenStreetMap, and GIS can inform a robust exposure data set. ImageCat has launched three products that help this uncertainty, all derived from earth observation (EO) products.

4.1. *Country-level exposure*

These databases provide organizations with the exposure required to mitigate risk at the national level. These products have been developed for the Global Facility for Disaster Reduction and Recovery and others with the goal of bolstering national resilience to disasters. When combined with estimates of insurance uptake, however, these open products can be integrated into commercial loss models. Country-level exposure database are developed through a process that combines EO and image processing to identify development patterns (Figure 3) with a wide array of site-specific data, including virtual reconnaissance, onsite reconnaissance, interviews, and reports. A significant effort is required to integrate point-level observations in a manner that does not skew observations of risk. In many cases, point-level data represent known assets, or perhaps city-level data available for one region but not another. Aggregating point level data directly can result in a skewed assessment of risk, balancing with EO extracted data is key.

4.2. *Disaggregation engine*

Once an exposure database is developed, it can be used as a series of lenses to provide estimated exposures that lack spatial resolution or structural characteristics. These lenses or filters can return a series of possible locations with weights and probable structure type for insurers and reinsurers to run through their model. Depending on the spatial variability, results can change significantly. It is important to understand that this is a modelled result, and in fact the results do not provide actual locations.

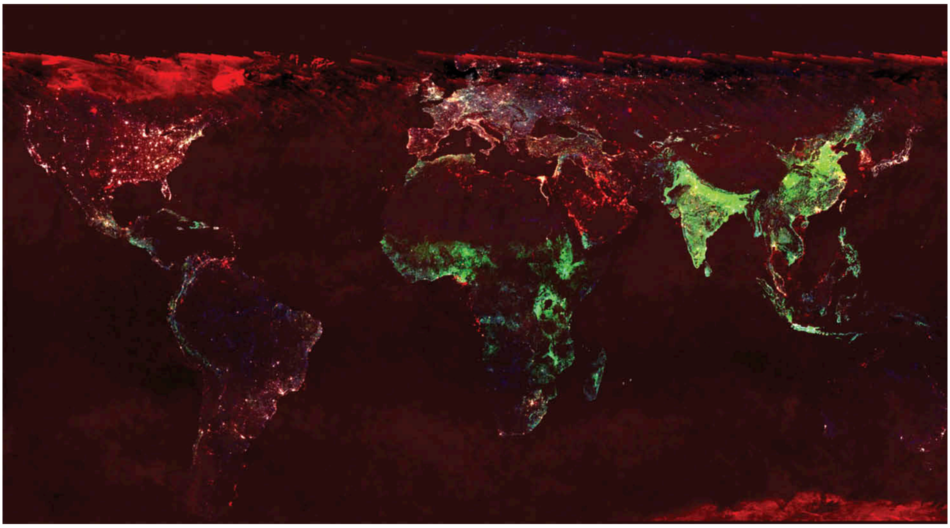

Figure 3. False colour image of night lights in red, population in green, and urban development in blue. The relative intensity of these parameters provides an indication of land development patterns that can be used to distribute insured assets (source: ImageCat).

4.3. *Insurance to value*

The relationship between how much a property is insured and the actual replacement cost of a property, insurance to value (ITV), is a key indicator for (re)insurers during property underwriting. Major deviation between insured value and replacement cost is a matter of concern for (re)insurers. ITV provides an important benchmark for estimating over or under insurance when underwriting a book of business. The ITV API provides an EO-based estimate of replacement cost for US residential, commercial, and industrial structures and is the first of its kind being made available to the insurance industry. An alternate estimate of the replacement cost improves the ability of a (re)insurer to make a quick assessment of the ITV and determine if appropriate covers are being provided for the potential for losses. A wide variety of data sources are used to develop the ITV product including EO data, census data, ImageCat proprietary information, and independent valuation data.

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5. The Global RApid-post-disaster Damage Estimation approach and the incorporation of Earth Observation satellite information

Rashmin Gunasekera, James Daniell, Antonios Pomonis, Rodrigo Andres Donoso Arias, Oscar Ishizawa (World Bank Group), and Harriette Stone (UCL)

This article is two pronged: it will explain the mobilization of the Global RApid post-disaster Damage Estimation (GRADE) approach, while highlighting the innovative use of Earth observation (EO) satellite information to further enhance the accuracy of GRADE.

In the immediate aftermath of a disaster, national and regional governments and authorities face the challenge of estimating damage and economic losses, whilst simultaneously carrying out relief operations, urgent infrastructure repairs, search and rescue, sheltering for the displaced, etc. The economic damage and loss assessment, which although necessarily can only be completed in detail after the initial response phase, is nevertheless also needed much earlier – albeit in a less detail – to initiate discussions such as fund mobilization, response strategies, budget approvals, etc. This information is also critical for the re/insurance industry which provides financial protection across a wide-ranging spectrum of exposures and risks, including housing, services, and production. Although several approaches and tools are already being used for post-disaster damage and economic loss assessment, their response time can be lengthy, and their levels of detail and accuracy can vary significantly.

Increasingly, what is becoming ever more important are approaches and tools which can quantify the physical damage and consequent economic losses within a short period of time, i.e. within days or at most a couple of weeks after the event. GRADE, an approach developed by the World Bank, is able to provide an initial rapid (within 2 weeks) estimation of the physical post-disaster damage in terms of economic loss incurred, informing rehabilitation requirements. The approach combines hazard, exposure and vulnerability modelling to derive damage estimations (Figure 4). GRADE prioritizes assessment in the housing and infrastructure sectors, followed by other sectors, such as agricultural production. Some of the outputs of GRADE include (a) aggregated direct and indirect damage estimations by economic sector, (b) potential

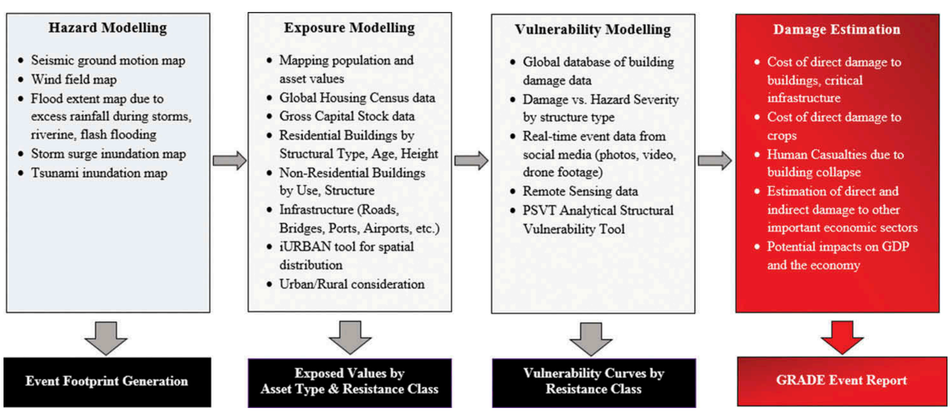

Figure 4. The GRADE Rapid Post-Event Damage Estimation method – Key Components (top boxes) and Outputs (bottom boxes).

impacts on gross domestic product (GDP) and the economy, and (c) estimations of human casualties for earthquakes.

The GRADE approach relies significantly on EO data sets, for assessing spatial distribution of building stock, assessing levels of damage, determining appropriate structural vulnerability classes, and for model validation (including cross-validation of results). The approach uses the ever-increasing drone footage, optical and radar satellite imagery, and derived products available (e.g. from UNOSAT) post-disaster, as well as with video evidence and images from social media. To develop an estimation of the building stock, the GRADE approach uses the Global Urban Footprint data set developed by the German Space Agency. This EO-derived data set assists in the delineation of built up areas. The data set is aggregated from the 75-m binary (built up/non-built up) mask to an output resolution of 1 km^2 preserving the inherent area information to illustrate the continuous degree of built-up. We also use satellite information derived, gridded population data sets to determine population density distribution. The GRADE approach complements these EO-based data sets and integrated information from the housing census (e.g. in Ecuador 2010 census with appropriate projections) and preliminary damage assessment reports from the affected region. Using satellite (EU-Copernicus and UNOSAT) and ground-based observations, and expert judgement, a cross-referencing against initial damage estimates is also conducted. Given the availability of drone and auxiliary imagery, this has proved to be a rich source of information for damage estimation. The cross-validation of satellite imagery supports the GRADE method (e.g. Gunasekera et al. 2015; Aubrecht and Leon Torres (2016); Daniell et al. (2012) and its outputs as they are intended to create an independent, credible sectoral quantification of the spatial extent and severity of a disaster's economic impact. The GRADE approach could also complement other post-disaster damage assessment methods and activities.

The GRADE approach has already been used successfully in four disasters between April 2015 and April 2017, with more than 90% of 'like for like' field estimations accuracy to the residential sector (when compared with subsequent and more-detailed post-disaster analyses, such as the EU-UN-World Bank initiated Post-disaster Damage and Needs Assessment [PDNA]).

Just as an example, one of the disasters on which the GRADE approach was tested was the 16 April 2016 Ecuador earthquake. This magnitude 7.8 shallow earthquake occurred offshore of the west coast of Ecuador, seriously affecting the coastal zone between Esmeraldas in the north and Guayaquil in the south (with a distance of 400 km between these two cities). This was Ecuador's largest magnitude earthquake since 1942, and the most lethal since 1949. In terms of exposure to ground shaking, approximately 12.3% of the GDP was exposed to Modified Mercalli macro-seismic Intensity scale VI (equivalent to slightly damaging ground motion) and 3.7% in intensity zone VII (equivalent to moderately damaging ground motion) or higher. Thirteen days after the event, the GRADE approach released loss estimates of USD 480 million for the residential sector. This loss estimate was over 96% accurate to the detailed official report released value, 45 days after the event. Some limitations of the GRADE approach extend to non-residential sector as estimates did not take into account potential indirect losses due to business interruption, loss of employment, or value added and did not include estimates on the impact on Ecuador's potential output (due to the earthquake's impact on the country's stock of human assets and private and public capital). However, the approach is increasingly and consistently being highlighted as an integral tool in rapid post-disaster response.

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6. Transforming liquefaction modelling with geostatistics

Timothy Ancheta, Risk Management Solutions

Liquefaction or loss of soil shear strength in saturated cohesionless soils during and after an earthquake causes ground displacement that quickly decays in time after an event. Similarly, the attention and surprise it attracts also quickly decays with time. Perhaps that is why the research community has not yet offered a method of reliably predicting its occurrence and severity that would enable building and property owners to fully understand the associated risk. Reliable prediction of liquefaction severity at a single location involves answering three questions: (1) are the soil layers below a site susceptible to liquefaction? (2) at what level of earthquake shaking will liquefaction occur in the layers? (3) if it occurs what will be the resulting surface deformation? These questions can be reasonably answered using a site-specific analysis of *in-situ* data. Therefore, reliably mapping liquefaction severity over a large domain would involve the same analysis for a large set of locations distributed throughout the domain. This larger scale mapping has many unsolved problems including the prohibitive costs of sampling and running the large set of calculations, how to predict severity at un-sampled locations, how to predict severity for a large set of earthquakes.

RMS propose reliable prediction of liquefaction severity over a large domain which involves mapping a set of new fixed parameters that can then be used in a liquefaction ground deformation prediction equation. This approach has been used for predicting lateral displacement which occurs less frequently but has not been implemented for vertical settlement which is more common. If implemented for both types of ground displacement, there are still unsolved issues of prohibitive costs and predicting severity at un-sampled locations. We also propose that these limitations can be solved by mapping the required parameters using *in-situ* and satellite data within a geostatistics framework. Geostatistics is statistical theory for spatial processes. With the recent development of new large public databases of liquefaction site measurements, it is now possible to evolve liquefaction hazard mapping to predict the liquefaction occurrence and severity for all potential earthquakes identified within a probabilistic seismic hazard analysis (PSHA).

Existing liquefaction hazard mapping techniques were developed over the decades that followed two strong 1964 quakes on 27 March in Alaska and 16 June near Niigata, Japan. Most notably, Youd and Perkins (1978) proposed mapping potential liquefaction occurrence from the intersection of probabilistic ground motion intensity maps with liquefaction susceptibility maps and Iwasaki et al. (1978) which proposed the liquefaction potential index (LPI) which is now used in many liquefaction severity maps. While mapping probabilistic seismic hazard advanced, mapping liquefaction occurrence has not significantly changed. Alternatively, researchers have preferred to develop liquefaction severity mapping techniques to predict the amplitude of the liquefaction-induced ground deformation. Currently, severity mapping techniques do not offer a feasible solution to predict liquefaction severity maps for all events within a PSHA. The current index approaches have not created a simplified equation as a function of ground motion amplitude and groundwater depth. The liquefaction displacement maps are too computationally intensive which require iterating displacement predictions over a large set of liquefaction borings for each earthquake.

The evolution of liquefaction hazard mapping requires the development of new equations to estimate the ground displacement and new methods of mapping the required input parameters. Selection of a new set of parameters to map is the first step to predicting liquefaction-induced ground displacements for a set of possible earthquakes and over a large space (i.e. an entire country). Here, we focus on two such parameters: (1) an event and groundwater independent liquefaction thickness (2) the near surface time-independent groundwater depth. To further improve the reliability of the liquefaction hazard assessment, we introduce a new parameter mapping method that utilizes geotechnical boring databases, groundwater time series, and satellite data, in a geostatistics framework. Figure 5 shows an example of the new, boring-derived, liquefiable thickness parameter. Figure 6 shows an example of the, time-series derived, liquefaction-specific groundwater depth.

The results of the new mapping methodology answer unexpected questions, such as How has the built environment changed the liquefaction risk? In what areas should we discourage future development, to improve resiliency of our communities to earthquake risks? Figure 5 illustrates that if groundwater is shallow for all areas within the subject area, the middle of the valleys tends to have the higher liquefaction hazard than near the base of hills. Figure 6 compares groundwater depth prediction in the San Francisco Bay area excluding the interaction of the built environment with the same groundwater prediction including this interaction but only in the San Jose area. While this example may represent how the built environment may reduce the liquefaction hazard, there are many other positive and negative anthropologic affects.

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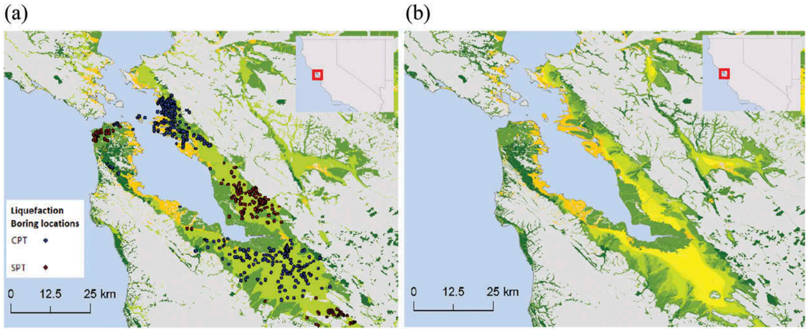

Figure 5. (*a*) Map illustrating the new parameter for predicting liquefiable thickness using cone penetration tests (CPT) and standard penetration tests (SPT) measurements in a geostatistical model. Locations of measurements shown in coloured circles. Zones with thick and loose, liquefiable soils are shown in yellow and orange, while thin and denser liquefiable soils are shown in darker green. (*b*) Updated geostatistical model including use of satellite data. The maps cover the region 37.19° N to 38.08° N and 122.85° W to 121.53° W.

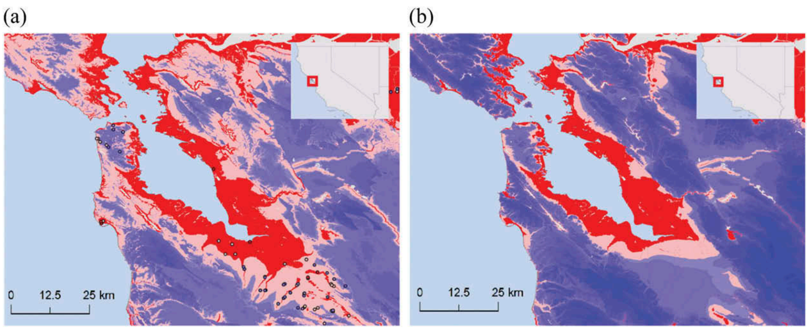

Figure 6. (*a*) Map showing predicted liquefaction-specific depth of groundwater. The map was derived using groundwater time series, from locations shown in coloured circles, within a geostatistical model. Shallow areas are shown in red and pink colours while deeper blue show deep groundwater depths. (*b*) Updated geostatistical model including interaction of groundwater prediction with built environment.

7. Geo's support for the Sendai framework for disaster risk reduction

Stuart Marsh, Nottingham Geospatial Institute, University of Nottingham

The Group on Earth Observations (GEO) is the intergovernmental organization charged with the organization and development of the Global Earth Observing System of Systems (GEOSS). It has 105 member countries and 115 participating organisations. GEOSS aims to bring together all of the separate observing systems in an interoperable network that addresses the needs of end users across eight societal benefit areas (SBA), such as Food Security and Sustainable Agriculture. One of these is on disaster resilience.

GEO supports disaster resilience by increasing coordination of Earth observations (EOs) to forecast and prepare for disasters, to mitigate damage, and to better manage and recover from disasters. This is done by working within the 2015 Sendai Framework on Disaster Risk Reduction, which recognizes that a substantial reduction in the loss of life and property can be achieved by strengthening cooperation and data sharing for satellite and surface data, for managing risks posed by fires, floods, earthquakes, and other hazards. Better information, made widely accessible, leads to improved understanding of disaster risk. The Sendai Framework on Disaster Risk Reduction also recognizes that EOs have a clear role in Disaster Risk Reduction. GEO and other partners proposed to establish a Synergy Framework for the Integration of Earth Observation Technologies into Disaster Risk Reduction.

The Sendai Framework sets seven global targets to be achieved by 2030:

(1) Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005–2015.
(2) Substantially reduce the number of affected people globally by 2030, aiming to lower average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015.
(3) Reduce direct disaster economic loss in relation to global GDP by 2030.
(4) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030.
(5) Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020.
(6) Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this Framework by 2030.
(7) Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030.

The Sendai Framework also identifies four priority actions designed to help achieve these targets. These are

(1) Understanding disaster risk: Disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics, and the environment. Such knowledge can be used for risk assessment, prevention, mitigation, preparedness, and response.
(2) Strengthening disaster risk governance to manage disaster risk: Disaster risk governance at the national, regional, and global levels is very important for prevention, mitigation, preparedness, response, recovery, and rehabilitation. It fosters collaboration and partnership.
(3) Investing in disaster risk reduction for resilience: Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health, and cultural resilience of persons, communities, countries, and their assets, as well as the environment.

(4) Enhancing disaster preparedness for effective response and to 'Build Back Better' in recovery, rehabilitation, and reconstruction: The growth of disaster risk means there is a need to strengthen disaster preparedness for response, take action in anticipation of events, and ensure capacities are in place for effective response and recovery at all levels. The recovery, rehabilitation, and reconstruction phase is a critical opportunity to build back better, including through integrating disaster risk reduction into development measures.

Currently, responding to the Sendai Framework is GEO's third highest priority, after (1) using EO to implement the UN Sustainable Development Goals and (2) to support the Paris Climate Agreement. Substantial new effort can be expected to be put into this in the coming years, once the first two priorities have begun to be addressed. But in the meantime, within the Disaster Resilience SBA, there are two key initiatives and a group of other, related projects that are doing the actual work.

The first is the GEO initiative on Data Access for Risk Management – GEO-DARMA – which supports the implementation of the Sendai framework 2016–2030, the first of the post-2015 global agreements to be adopted. GEO-DARMA aims to support operational risk reduction activities through the implementation of end user priorities in line with the Sendai Framework, on a trial basis, in several regions of the developing world (such as Latin America, South Asia, and Southern Africa). One of the main objectives of GEO-DARMA is to address critical issues related to disaster risk reduction affecting most of the countries in a region through a series of end-to-end projects (initially demonstrators) that rely on the use of multiple sources of observation data (space, *in-situ*, socio-economic, models outputs) in response to needs of the end user communities. The methodology followed for defining and implementing has already been experimented and consolidated by the Committee on Earth Observing Satellites (CEOS) and its partners during the last 4 years, with the CEOS disasters pilots. Main outcomes (information products) from each project will be defined and generated with the objective of improving the quality and accuracy of information made available to national and local decision-makers in political and socio-economic sectors, to implement disaster risk reduction and resilience measures, during all disaster risk management phases, whenever those products and services require satellite EO combined with other sources of data (*in-situ* ground observations, socio-economic, model outputs).

The second is the Geohazard Supersites and Natural Laboratories (GSNL) initiative, established to improve the utilization of EOs for disaster risk management. This initiative is designed to support first responders and risk managers by providing effective tools to rapidly map damages and impacts during rescue operations following disasters. The GSNL utilizes a voluntary international partnership that aims to improve, through an Open Science approach, geophysical scientific research and geohazard assessment in support of Disaster Risk Reduction. The GSNL goal is pursued by promoting broad international scientific collaboration and open access to a variety of space- and ground-based data, focusing on areas with scientific knowledge gaps and high-risk levels, commonly known as the Supersites and the Natural Laboratories. For these areas, a joint effort is carried out: the space agencies provide satellite imagery at no cost for scientific use, the monitoring agencies provide access to ground-based data, and the global scientific community exploits these data to generate state of the art scientific results. The coordination of each Supersite is normally attributed to local geohazard scientific institutions and researchers, which are already operationally providing authoritative geohazard information to support the decision-makers. This process ensures that the new knowledge generated by the wider scientific community is rapidly taken up by the stakeholders to benefit hazard assessment, disaster monitoring, and response actions.

8. Optical satellite imagery for earthquake damage assessment

Gareth Crisford, EARTH-i

The number of natural disasters has quadrupled in the last 30 years. Earthquakes and other catastrophes have a devastating impact on communities and the built environment such as homes, businesses, and infrastructure. EO images acquired from space offer a quick and unbiased view of the situation on the ground from over 500 km above.

Very high-resolution imagery offers the ability to capture wide area images at resolutions of up to 40 cm. These full colour, high-resolution images can help insurers gain an overview to understand the scale of the insured losses over areas affected. Satellite imagery can now be delivered faster than ever, with some satellite providers moving towards near real-time data as a reality. During a disaster, when time is critical, having this information fast can mean that insurance companies can react quickly and allow for the right level of capital to be set aside. Another benefit is that early damage assessments also give agencies, such as aid, the power to deploy the appropriate resources to the areas that need it the most.

Earth-i regularly tasks satellites to acquire data over areas that have been affected by natural disasters, such as earthquakes (Figure 7). Regular image capture, which is most effectively done with a constellation of satellites, allows for an even deeper understanding of the changing situation on the ground (Figure 8). Analytics software can use satellite data to run automatic change detection and mapping solutions to provide more information and keep everyone informed.

However, still satellite imagery has its limitations, which is why video capability from space is being explored. Earlier this year, Earth-i announced that they will be launching and operating their own constellation of small satellites offering 1 m resolution video capability, in addition to still imagery. Earth-i will be the first company to offer full colour, full motion video. Earth-i have been exploring the capabilities that video data will unlock.

Capturing video data over an area of interest from many angles will allow for 3D modelling to be carried out after just one pass of the satellite. This is a huge improvement on the best available now which is two to three still images. These 3D models will allow for greater understanding of current situational awareness. This multi-look view can enable insurers not just have a 'top-down' view, but they could potentially explore damage to the sides of buildings. The same technique can be applied for monitoring and mapping access roads and ensuring they are clear and roadworthy.

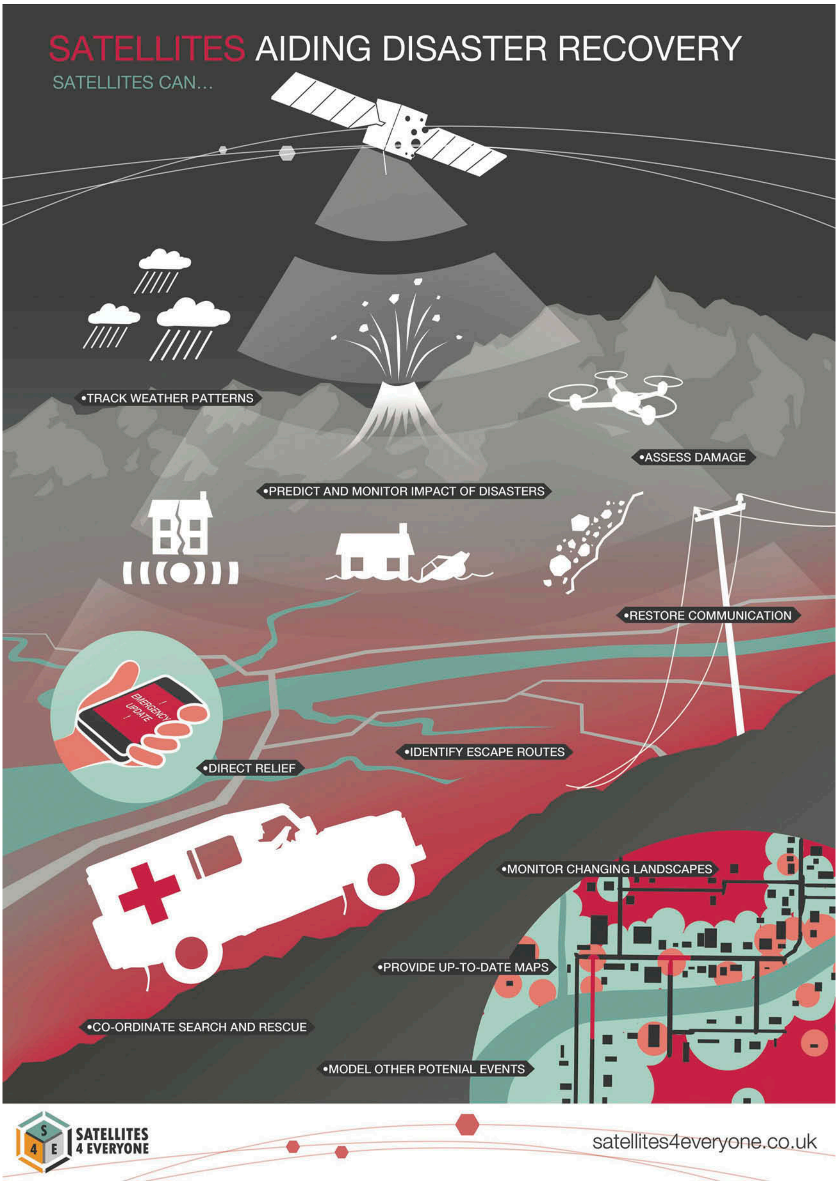

Figure 7. Satellites Aiding Disaster Recovery ©Satellites4Everyone.

As a company, Earth-i is still exploring the solutions that can be extracted from full motion video from space and are collecting the views of insurance professionals to discuss applications that could be extracted from this data. If you have an interest in this subject, please get in touch directly to be included.

(a) (b)

Figure 8. (*a*) Before and (*b*) after the August 2016 Earthquake – Amatrice, Italy.

9. Mckenzie intelligence services: near real-time reporting on natural catastrophes

Forbes McKenzie, McKenzie Intelligence Services

McKenzie Intelligence Services (MIS) delivers near real-time reporting on Natural Catastrophes. Were an earthquake that directly affected the Los Angeles (LA) basin to occur, Lloyd's of London would send MIS a request for information regarding the impact of the earthquake.

Hand in hand with Lloyd's of London (Lloyd's Market Association 2017), MIS has created an Intelligence Collection Plan and geospatially referenced key infrastructure for the wider conurbation of LA. Like in Houston post Hurricane Harvey, it is assumed that federal laws will preclude the use of commercial Drones and air breathing platforms. Therefore, the Intelligence Collection Plan leans very heavily on space-based remote-sensing solutions to achieve its primary objectives.

The key Intelligence outputs are

- very early vector overlays of graded damage to inform Exposure Management teams,
- detailed overlays of properties in detail to make quick payments on individual properties,
- life cycle event timeline for the reinsurance customers.

All Intelligence is delivered via the thousand-user Lloyd's market portal & eco-system of www.mis-intel.com.

Remote-sensing solutions will be based on the data that are on time rather than the best data late. Typically, MIS uses Planet, Airbus, and Digital Globe and has a very effective relationship with CGG's NPA Satellite Mapping group.

MIS also captures data from the Internet of Things, Landsat, Copernicus, NOAA data and maximizes scalable computing science and machine learning. Processing continental data sets involving multispectral/synthetic aperture radar data on ERDAS Imagine and Remote View is routine and MIS will extract as much as it can via AI led image analysis techniques before passing to ex-Military Imagery Analysts – who will conduct hand/eye detailed damage assessments.

Damage assessments start at a quick very low fidelity and are based on structural damage scales at Zip code level before maturing into individual properties at a fine scale.

Reference

Lloyds's Market Association. 2017. "Claims Imagery & Intelligence Service: MIS Portal Demonstration." Accessed 20 November 2017. http://www.lmalloyds.com/LMA/Events/LMA___market_events/Claims_Imagery___Intelligence_Service_Launch_17July2017_E17085.aspx.

10. Summary

The event co-chairs – Chris Ewing (AGI/Aon Benfield Impact Forecasting), Tina Thomson (RSPSoc/MS Amlin), William Forde (RMS), Matthew Foote (ArgoGlobal) and Richard Teeuw (RSPSoc/University of Portsmouth)

Within the earthquake science and insurance community, the event aimed to

(1) explore scientific findings following the latest USGS science updates and catastrophe model releases, factoring in earth observation and its significance in earthquake modelling;
(2) identify the application of the findings in terms of disaster response and loss assessment, as highly relevant to the insurance industry; and
(3) discuss resilience and disaster risk reduction.

In summary, the event showcased a wide range of studies and the role of earth observation in

(1) the understanding of seismic hazard, in particular the advancement of InSAR, lidar, and GPS technologies for geodetic deformation models such as measuring fine-scale faulting and earthquake deformation features, important for identifying the time-dependent earthquake processes;
(2) disaster risk reduction, such as work by the World Bank and the Sendai Framework as adopted by the UN Member states; and

(3) rapid earthquake damage/loss assessment and response as required by national and regional governments, agencies, and the insurance industry.

RSPSoc, RGS, and AGI plan to enable closer links between the Earth observation and GIS communities with the insurance sector and disaster risk reduction sphere. Through events like this, we can build future resilience to earthquakes through the use of geospatial technologies. We hope this report has provided impetus for future research and collaboration on the use of these technologies for the quantification of earthquake risk.

Notes

1. http://www.rspsoc.org.uk/index.php/special-interest-groups/disaster-management.html.
2. http://www.agi.org.uk/agi-groups/special-interest-groups/insurance.
3. http://www.rgs.org.
4. http://www.rms.com.
5. http://impactforecasting.com.
6. https://www.msamlin.com.

Acknowledgements

The event was a joint venture between learned Societies whose interest is to educate and bridge the gaps between science, government, and industry:

The Remote Sensing and Photogrammetry Society (RSPSoc)[1] is the UK's leading Society for remote sensing and photogrammetry and their application to education, science, research, industry, commerce, and the public service. Its Disaster Management Special Interest Group (SIG) aims to promote best practice and innovative applications in the use of remote sensing and photogrammetry in all aspects of disaster management, both pre-disaster (e.g. disaster preparedness; hazard, vulnerability/exposure, and risk assessment) and post-disaster (e.g. crisis response, damage estimation, and disaster recovery.

The mission of the Association for Geographic Information (AGI)[2] is to maximize the use of geographic information for the benefit of the citizen, good governance, and commerce. Its Insurance and Risk SIG provides a forum to discuss and explore the use of geographic information and geospatial technologies within the insurance and risk sectors.

Thanks to the Royal Geographical Society,[3] the event was accredited as Continuing Professional Development (CPD) to the Chartered Geographer (CGeog), which is the only internationally recognized professional accreditation for those with competence, experience, and professionalism in the use of geographical knowledge, understanding, and skills in the workplace.

Lastly, the event would not have been possible without the financial support from peers in the insurance and catastrophe risk modelling industries:

Risk Management Solutions' (RMS)[4] catastrophe models, technology, and services provide (re) insurers, brokers, capital markets, and corporations a secure foundation to build balanced and profitable portfolios, and to help governments and other public agencies support the well-being of the public they serve. Through a combination of rigorous science, innovative technologies, and the collective expertise and commitment of a global team, RMS supports some of the leading industries driving today's global economy.

Impact Forecasting[5] provides risk insights for the peak risk zones around the globe, as well as for the emerging markets. This allows insurers to place effective reinsurance programmes and manage capital based on more accurate model results. Impact Forecasting partners with academic and industry organisations around the world to incorporate the latest research into all of our catastrophe models.

MS Amlin[6] provide insurance in Property & Casualty and Marine & Aviation, and Reinsurance for other insurers. MS Amlin extends back over 300 years and today is part of the top 10 global insurance group MS&AD group. The company offers expertise in underwriting and claims, with both technical capability and deep knowledge of the areas it insures. By putting people first and creating strong, balanced working relationships, MS Amlin continues to become a stronger partner for its clients. It's a virtuous cycle, and in today's complex and integrated world, it matters more than ever.

Disclosure statement

No potential conflict of interest was reported by the authors.