# LAMPRE FINAL REPORT

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# 1 FINAL PUBLISHABLE SUMMARY REPORT

## 1.1 EXECUTIVE SUMMARY

**LAMPRE – LAndslide Modelling and tools for vulnerability assessment Preparedness and REcovery management**, was a two-year collaborative project funded by the European Commission (EC) under the FP7-SPACE-2011 call. The scope of LAMPRE was to execute innovative research and technological development to increase the EC Copernicus programme (formerly GMES – Global Monitoring for Environment and Security) to cope with triggered landslide events and their consequences, in Europe and elsewhere.

LAMPRE integrated satellite data and technologies with ground data, information and technologies to enhance landslide risk mitigation and preparedness efforts, and post-event landslide recovery and reconstruction actions in landslide vulnerable regions. This was achieved improving general and specific abilities to detect and map landslides, to assess landslide susceptibility, to model the kinematics of landslides and anticipate their behaviour, and to evaluate the potential impact of triggered landslide events on road networks.

LAMPRE designed and tested **seven products and services** in different geographical areas and geological, climatic and physiographical conditions. The portfolio of products and services offered by LAMPRE includes landslide inventory maps (LIM), event landslide inventory maps (ELIM), tools for landslide susceptibility models and maps (LSMM) and for determining the statistics on landslide size (LStats), three-dimensional surface deformation models (3DSDM), and landslide-road impact models (LRIM). In addition, LAMPRE has assembled landslide teaching materials and educational resources aimed at non-experts (LEdu).

The maturity of the LAMPRE products and services was evaluated considering the level of automation, the reliability, and the generality of the products and services. Automation measures the amount of human effort required to prepare a product; reliability depends on the effort needed for the full exploitation of a product; and generality sizes the effort required to produce the same product in a different area. LSMM and LStats were found mature products, ready for exploitation and marketing. ELIM and LIM were also ranked mature products, and almost ready for exploitation and marketing. Other products and services are less mature and require further efforts.

The potential demand for the LAMPRE products and services was investigated for various user segments, including emergency, insurance, transportation, construction, meteorology, science, and the media, and three service delivery strategies were designed for the commercialization of the LAMPRE products and the services. Lastly, LAMPRE has investigated cooperation opportunities and European funding frameworks to complete pending actions needed for all the products and the services to be taken to the market profitably.

# 2 SUMMARY DESCRIPTION

A **landslide** is the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity. Different natural phenomena cause landslides, including intense or prolonged rainfall, earthquakes, rapid snowmelt, and volcanic activity. Human actions also cause landslides, including excavations, overloading, construction works, leakage from water or sewage lines, irrigation, deforestation, and traffic. Landslides can involve flowing, sliding, toppling, or falling, and many landslides exhibit a combination of two or more types of movements. The diversity of the landslide phenomena makes it difficult to define a single method to detect and map the landslides, to model the landslide kinematics, to evaluate landslide susceptibility and hazard, and to anticipate the impact that landslides may have on the built-up environment or on transportation networks.

Landslides are present in all continents, and play an important role in the evolution of landscapes. They also represent a serious hazard in many areas of the world. In Italy, landslides have caused more than 3000 casualties, and 150,000 homeless and evacuees in the 50-year period 1965 – 2014[1]. Landslides are not an Italian (or Mediterranean) problem only. In the 7-year period 2004-2010, landslides have killed more than 32,000 people globally[2]; and this figure is an underestimate. Despite their importance and the severe risk posed by landslides, systematic and standardized information on the type, abundance, and distribution of landslides is lacking almost everywhere in the world[3]. This limits the ability to detect and map landslides, to enhance landslide risk mitigation and preparedness efforts, and post-event recovery and reconstruction actions.

LAMPRE executed innovative research and technological development activities to increase the Copernicus programme (formerly GMES – Global Monitoring for Environment and Security) capacity to cope with triggered landslide events and their consequences, in Europe and elsewhere. More specifically, LAMPRE has **advanced the ability to use satellite imagery and remote sensing technologies**, in combination with surface and sub-surface information, data and technologies, **to improve existing capacities to detect and map landslides, to determine landslide susceptibility, and to model the kinematics and the expected impact of landslides**.

LAMPRE has obtained significant scientific and technological advancements. The **scientific advancements** include better methods for the visual (manual) and the semi-automatic production of landslide inventory and event landslide inventory maps, from optical satellite images. LAMPRE experimented the use of 3D enhanced Normalized Differential Vegetation Index (NDVI) images for the visual interpretation of stereoscopic satellite imagery for the identification of event landslides. The new technique allows detecting and mapping landslides that were not visible in standard

1 http://polaris.irpi.cnr.it/report/
2 Petley, 2012. Global patterns of loss of life from landslides. Geology 40(10), 927-930, doi:10.1130/G33217.1.
3 Guzzetti et al., 2012. Landslide inventory maps: New tools for an old problem. Earth-Science Reviews 112, 42-66, doi:10.1016/j.earscirev.2012.02.001.

RGB images (e.g., in shadow areas), contributing to improve the quality and completeness of event landslide inventory maps.

Research executed by LAMPRE advanced existing probabilistic segmentation frameworks that exploit contextual geo-environmental information (including e.g., a slope map obtained from a digital elevation model (DEM) or a landslide susceptibility zonation) for the accurate, semi-automatic detection and mapping of landslides from high and very-high resolution optical (multispectral), post-event satellite imagery. A significant scientific advancement obtained by LAMPRE consists in a new type of landslide inventory map that shows the probability that each part of a territory (e.g., each pixel) is (or is not) a landslide. We expect this new type of inventory to be useful for susceptibility and hazard modelling and zonation.

The LAMPRE **technological developments** advanced the ability to determine landslide susceptibility and to obtain accurate statistics of landslide size, to construct finite element models (FEM) to predict the future behaviour of landslides, and to model the impact of event landslides on transportation networks. New software tools developed by LAMPRE can now be used to construct and validate landslide susceptibility models, and to determine accurate statistics of landslide size (area), using statistical methods. We expect that this will contribute to define standards for landslide susceptibility and hazard zonation.

LAMPRE has advanced the ability to model the kinematics of slow-moving landslides using Finite Element Models (FEM), or other similar stress-strain models. The innovation experimented in LAMPRE consisted in using time series of surface deformations obtained through advanced DInSAR processing of satellite SAR data to constrain the FEM model. Lastly, LAMPRE has experimented an innovative model that exploits existing knowledge on the statistical distribution of landslide size and GIS technology to prepare realistic scenarios of the possible impact of a population of event-triggered landslides on road network.

LAMPRE has developed a portfolio of seven **landslide products & services**, including:

- Landslide inventory maps (LIM),
- Event landslide inventory maps (ELIM),
- Landslide susceptibility models and maps (LSMM),
- Statistics on landslide size (LStats),
- 3D Surface deformation models (3DSDM),
- Landslide-Road impact models (LRIM), and
- Teaching materials and educational resources (LEdu).

A **landslide inventory map** (LIM) shows the location, extent and type of landslides that have left discernable features in a region. LAMPRE can prepare a new LIM, or update an existing LIM, anywhere stereoscopic satellite imagery or aerial photographs of adequate quality is available. An **event landslide inventory map** (ELIM) is a type of inventory that shows the location and extent of landslides caused by a single trigger e.g., an intense rainfall event, a period of prolonged rainfall, a rapid snowmelt event, or an earthquake. LAMPRE can rapidly prepare an ELIM anywhere recent landslides have left signs that were captured by post-event, optical (multispectral) satellite images.

A landslide susceptibility model and the associated terrain zonation is a type of forecast of where landslides are expected in a region, based on local terrain and environmental conditions. LAMPRE developed software for **landslide susceptibility modelling** and validation (LSMM) adopting statistical classification methods. The software allows preparing susceptibility modes in areas of a wide range of sizes (from local studies to regional or national studies), using different type of terrain mapping units. LAMPRE has also developed software to determine accurate **statistics of landslide areas** (Lstats) starting from information on the size (area) of landslides available from a digital landslide inventory in a GIS.

3D **surface deformation models** (3DSDM) are useful to anticipate, in space and time, the kinematics of slow-moving landslides. The innovative LAMPRE 3DSDM product allows preparing surface deformation models for slow-moving landslides anywhere adequate time-series of surface and sub-surface displacements are available, together with topographic, geological, geotechnical, and groundwater information.

It is known that heavy rainfall, earthquakes or rapid snowmelt events may cause many landslides across a region, and some of the triggered landslides may block the roads making it difficult to move about a region. LAMPRE has developed an innovative modelling tool (LRIM) to construct and examine realistic scenarios of the possible **impact of event-triggered landslides on a road network**.

Lastly, LAMPRE has organized a number of **teaching materials** and **educational resources**, including talks, practicals, and a landslide FAQ, to help non-experts to better understand landslides and their potential impacts and hazardousness (LEdu). The teaching materials are available from the LAMPRE web site (http://www.lampre-project.edu).

All the LAMPRE products and services exploit, directly or indirectly, Earth Observation (EO) data and technologies to improve existing capabilities to detect, map, and model landslides and their expected impact. With this respect, the **products and services offered by LAMPRE complement existing products and services** for landslide detection and mapping, for landslide susceptibility and hazard modelling, and for landslide monitoring and forecasting.

Testing and validation of the products and services was a primary concern of LAMPRE. These activities were conducted in a range of geographical, climatic and physiographic regions in three continents, with the active involvement of a number of end users. The number and geographical locations of the test sites, the variety of the tests performed, and the number of users and stakeholders directly or indirectly involved in the use and the evaluation of the LAMPRE products and services, guarantee that the proposed tools (techniques, methods, software) are robust, and that the LAMPRE products and services are applicable to a large range of geographical, geological, and climatic settings, and in different societal and organizational settings.

LAMPRE evaluated the **maturity** of its products and services considering three contributing factors i.e., the level of automation, the reliability, and the generality of the individual products and services. In this context, automation measured the amount of human effort required to prepare a product, reliability depended on the effort needed for the full exploitation of a product, and generality sized the effort required to produce the same product in a different area. In the LAMPRE portfolio, the LSMM and LStats software tools were ranked mature products ready for exploitation and marketing. LIM, ELIM and LEdu were also ranked mature products, and about ready for exploitation and marketing. Other products and services were measured somewhat less mature, and will require further efforts to be exploited bt stakeholders and marketed successfully.

Possible demand trends for the portfolio of the LAMPRE products and services were assessed for seven user segments, including **emergency**, represented by Civil Protection Agencies, **insurance** and re-insurance, **transportation**, **construction**, planning, and development authorities, **meteorology**, **scientific** research community, and **media** and other communities. Interviews of potential users and stakeholders in these sectors were used to determine the attractiveness of the LAMPRE products and services in the seven market segments. Based on the insights gathered on willingness to pay, procurement methods in each segment, and possible business integration drivers, LAMPRE identified three service delivery methods, including:

- Offering standardized products on a dedicated platform,
- Tailoring the products & services to the needs of specific users, and
- Integrating the products and services into mass-market applications.

LAMPRE assessed the economics of each product in its portfolio based on high-level assumptions, recognizing that the cost assessment would need to be further refined. A business model for the platform portal was established assuming that European (e.g., DG-ECHO) or national Civil Protection organizations would finance the initial content, and that the service would be maintained and updated by a service provider in exchange of exclusivity for exploiting the products and services in other markets. We maintain that, for a marginal investment, the European Commission could stimulate the downstream market and create capacity at many European CPAs. A partnership should provide a win-win for all parties. Service Provider(s) get market access in exchange of a commitment to maintain the LIM database up-to-date. The European Commission builds capacity for the CPA's and stimulates the EO market to reach out to new segments for further growth. CPA's can rely on an up-to-date landslide database and get free access to basic products and preferential rates for higher accuracy products. R&D centres can use the platform as a centre of excellence to increase awareness of the landslide issues and of the usefulness of additional research to reduce risk to populations, and private and public properties.

# 3 MAIN S&T RESULTS AND FOREGROUNDS

LAMPRE has obtained different results, including a set of **seven products & services** (P&S) and specific **scientific and technological** (S&T) advancements for the detection and mapping of landslides, the advanced modelling of landslides, and the evaluation of the vulnerability to landslides of infrastructural (road) networks. In the followings, we first describe the P&S designed by LAMPRE. Next, we summarize test and validation actions performed by LAMPRE. This will be followed by a description of the main S&T advancements of LAMPRE.

## 3.1 LAMPRE Products & Services

LAMPRE has designed and tested a set of **products & services** (P&S) useful for the **detection and mapping of landslides**, and the design of tools for **vulnerability assessment** for the preparedness and mitigation and for the response and recovery phases of a typical civil protection cycle. As a result, the portfolio of P&S offered by LAMPRE includes:

- Landslide inventory maps (LIM),
- Event landslide inventory maps (ELIM),
- Landslide susceptibility models and maps (LSMM),
- Statistics on landslide size (LStats),
- 3D Surface deformation models (3DSDM),
- Landslide-Road impact models (LRIM), and
- Teaching materials and educational resources (LEdu).

LAMPRE makes a distinction between a **product** and a **service**. A single application of one of the “tools” (techniques, methods, software) developed by LAMPRE results in a **product**. Repeated applications in the same general area or in different areas of the same tool (or set of tools) represent a **service**. A service can prepare single or multiple sets of products. A landslide inventory map prepared through the visual interpretation of stereoscopic satellite images, and a landslide inventory map prepared exploiting post-event optical satellite imagery and one of the techniques developed by LAMPRE, are examples of LAMPRE products. LAMPRE can update routinely (e.g., every season, or year) existing landslide inventory maps through the visual interpretation of stereoscopic satellite images to produce multi-temporal inventories, or it can prepare event inventory maps shorty after each landslide-triggering event. These are examples of services that LAMPRE can provide.

LAMPRE has advanced the ability to use satellite imagery and remote sensing technologies to improve existing capacities to detect and map landslides, to determine landslide susceptibility, and to model the impact of landslides. With this respect, the **LAMPRE P&S are complementary to existing products and services** for landslide detection, mapping, and modelling, including the Copernicus products and services.

Below, we describe the seven P&S offered by LAMPRE. For each product or service, we first illustrate what each product is or does, when and where it can be prepared, and when it can be prepared and how long it may take.

The **first** LAMPRE product is called **Landslide Inventory Map** (LIM) (Figure 1). A landslide inventory map is the simplest form of landslide cartography, and it shows the location, extent and type of landslides that have left discernable features in a region. LAMPRE can prepare a new LIM, or update an existing LIM, anywhere stereoscopic satellite imagery or aerial photographs of adequate quality is available, and it can prepare the LIM whenever the new images are made available for an area of interest. The time required for the production of a new LIM, or to update an existing inventory, depends on the extent and complexity of the area, the number of landslides that have to be recognized and mapped, and the experience of the interpreters. LAMPRE prepares LIMs at typical scales ranging from 1:25,000 (smaller scale) to 1:10,000 (larger scale) in periods ranging from days to months, depending on the extent and complexity of the study area. LAMPRE delivers the LIM in digital raster and vector formats.

LIM

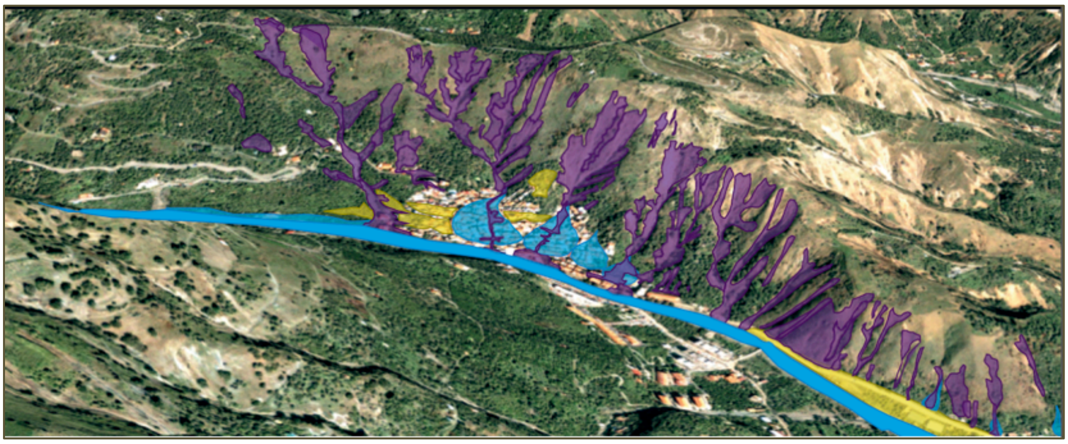

Figure 1 - Giampilieri, Messina, Sicily. 3D view of landslide inventory map superimposed on a very-high resolution satellite image taken shortly after a rainfall triggering landslide event on 1 October 2009. Landslides shown in violet, alluvial deposits in light blue, terraces in yellow.

The **second** LAMPRE product is called **Event Landslide Inventory Map** (ELIM) (Figure 2). An event landslide inventory shows the location and extent of the landslides caused by a single trigger, which can be an intense rainfall event, a period of prolonged rainfall, a rapid snowmelt event, or an earthquake. LAMPRE can prepare an ELIM anywhere recent landslides have left signs that were captured by optical (multispectral) satellite images. An ELIM can be prepared in periods ranging from few hours to some day after the triggering event, provided that adequate of the high resolution (HR) or very-high resolution (VHR) optical satellite imagery is taken shortly after the event, and is made available to LAMPRE.

LAMPRE prepares ELIMs at scales ranging from 1:25,000 (smaller scale) to 1:5000 (larger scale) using post-event satellite images, and delivers the new event inventory maps in digital raster and vector formats.

ELIM

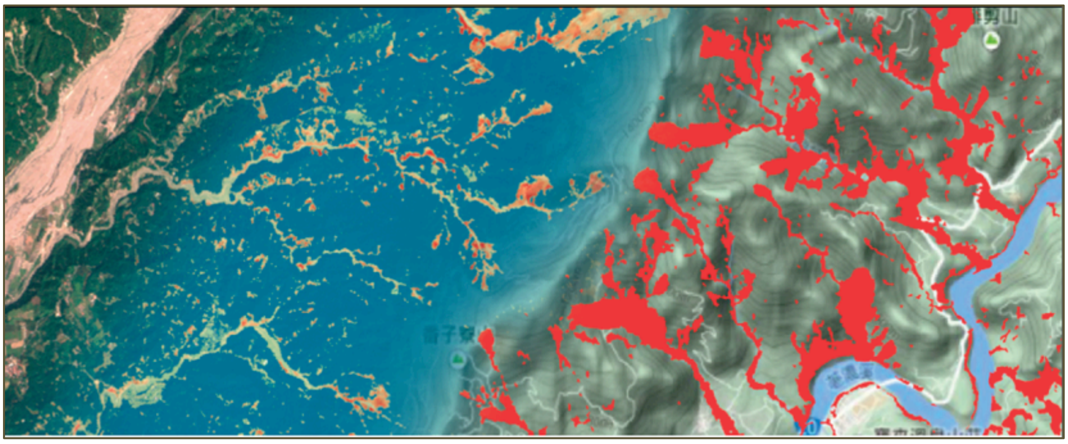

Figure 2 - Kaopin (Kaohsiung, Taiwan). On the left, the picture shows a FORMOSAT-2 satellite image taken on 14 August 2009 shortly after typhoon Morakot hit the area triggering many landslides and a landslide probability map obtained from the satellite image, on the right, the corresponding event inventory map on a Google Physical map.

The LIMs and ELIMs prepared by LAMPRE through the visual interpretation of stereoscopic satellite images and the semi-automatic analysis of multispectral satellite images can be combined to produce seasonal and multi-temporal landslide inventory maps, where a seasonal landslide inventory shows landslides occurred in an area during a season (e.g., the autumn) or a few seasons (e.g., the wet period from October to May), and a multi-temporal inventory shows landslides occurred in a longer period that may cover a few years or decades.

The **third** LAMPRE product is called **Landslide Susceptibility Model and Map** (LSMM) (Figure 3). Landslide susceptibility is the propensity of a landscape to generate (or not generate) landslides, based on the local terrain conditions including e.g., the morphological, geological, and structural settings, or the land cover and land use types. In probabilistic language, landslide susceptibility is the geographical probability of landslide occurrence i.e., the spatial component of landslide hazard. In this context, a landslide susceptibility model and the associated terrain zonation are a forecast of **where** landslides are expected (and not expected) to occur in a region.

LAMPRE has developed software for landslide susceptibility modelling adopting statistical classification methods. The software is written in the R language for statistical computing and graphics (http://www.r-project.org/), and can be used anywhere adequate information on the location of pre-existing (known) landslides, and information on the morphological, geological, and land use setting is available. The landslide information required for the susceptibility modelling can be obtained from a LIM produced by LAMPRE (Figure 1), and the susceptibility zonation can be validated against landslide information shown in an event landslide inventory, that can also be prepared by LAMPRE (Figure 2).

LAMPRE prepares LSMMs at scales ranging from 1:100,000 (smaller scale) to 1:25,000 (larger scale), in periods ranging from hours to days, where the landslide inventory and terrain (e.g., morphological, geological, land use) data are available. The quality of the landslide and terrain information controls the quality of the LSMMs.

LSMM

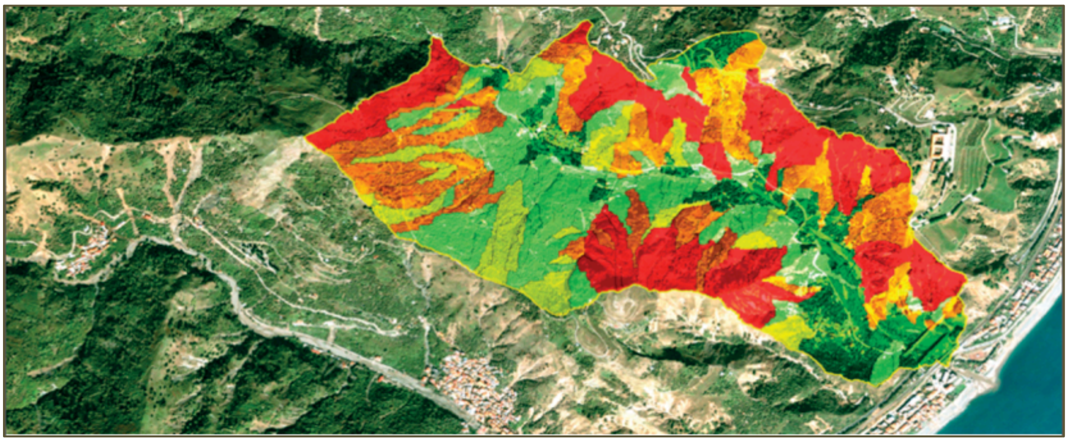

Figure 3 - Messina (Sicily, Italy). Coloured areas show a landslide susceptibility zonation superimposed on a very-high resolution satellite image taken shortly after a destructive landslide event. Red areas are expected to be prone to landslides and green areas are not expected to be prone to landslides.

The **fourth** LAMPRE product is called **Landslide Statistics** (LStats) (Figure 4). It is known that the number (or frequency, or probability) of landslides of a given size (area, volume) follows simple statistical laws. For small landslides, the non-cumulative probability (or frequency) of the landslides increases with the area of the slope failure up to a maximum value (known in the technical literature as the "rollover") after which the probability (or frequency) decreases rapidly with increasing landslide size following a power law trend. It is also recognized that the non-cumulative probability of landslide area can be approximated by a double-Pareto or an inverse-Gamma function. Similarly, the non-cumulative distribution of the volume of landslides obeys a negative power law, with the scaling exponent of the power law model a function of the landslide type.

Knowing the statistics of landslide size has multiple applications, including the probabilistic assessment of landslide hazard, the construction of vulnerability scenarios to event landslides, landslide risk modelling, and erosion and landscape modelling. However, obtaining accurate definitions of the statistics of landslide size, including the uncertainty associated to the probability (or frequency) estimates, is not trivial.

LAMPRE has developed software to determine accurate statistics of landslide areas, starting from information on the size (area) of each landslide readily available from a digital landslide inventory map in a GIS. Using the new software, LAMPRE can determine the landslide statistics anywhere information on the area of the landslides is available. This information can be obtained from good quality landslide inventory maps (LIM) or event inventory maps (ELIM). The landslide statistics prepared by

LAMPRE can also be used to evaluate the quality of new or existing LIMs or ELIMs. The statistics can be prepared or updated in hours whenever a new inventory is prepared after a landslide-triggering event, and is made available for the analysis. The quality of the obtained statistics depends on the quality and completeness of the original landslide inventory.

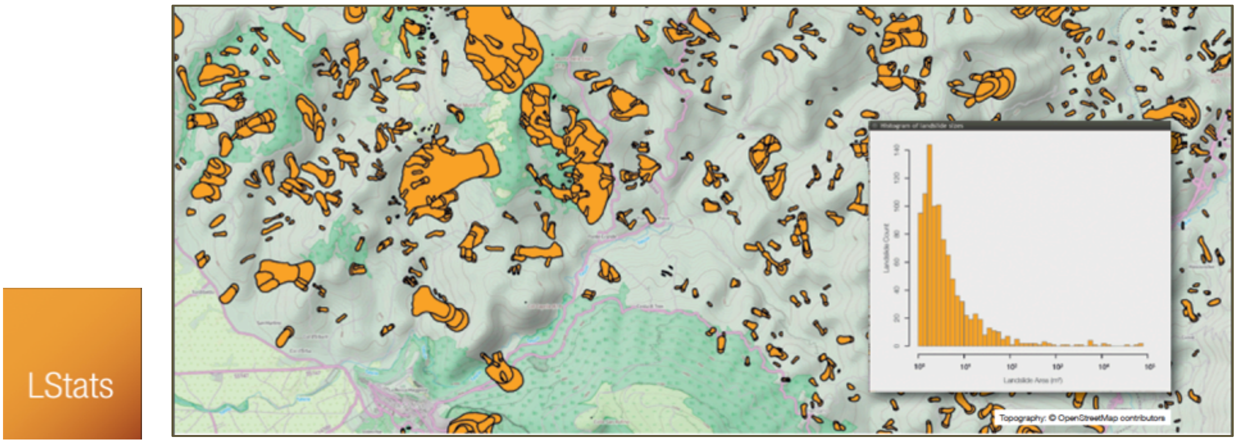


Figure 4 - Assisi (Umbria, Italy). Landslide inventory map showing geographical distribution and area of landslides. Like in other landscapes, landslides in this area have a range of sizes, from very small to very large, and small landslides are much more common than large ones.

The **fifth** LAMPRE product is called **3D Surface Deformation Model** (3DSDM) (Figure 5). To study the kinematics of single, slow-moving landslides, it is good practice to construct Finite Element Models (FEMs), or other similar stress-strain models, where a FEM is a numerical representation of the stress-strain behaviour of a slope that can be used to predict the kinematical behaviour of a landslide. A limitation of FEMs is that the models are data-intensive, and can be prepared only where adequate time-series of surface displacements and geo-information are available. An innovation of the LAMPRE 3DSDM consists in the fact that the time series of surface deformation are obtained through advanced DInSAR processing of satellite SAR data.

LAMPRE has advanced the construction of 3D FEMs for active, slow moving landslides. To prepare a 3DSDM, LAMPRE combines advanced space-borne DInSAR products, in-situ surface and sub-surface monitoring data, and geological, geotechnical and groundwater information. With this respect, the 3DSDM acts as an integrator of information, data, and measurements obtained from multiple sources.

The methods developed by LAMPRE allow preparing 3DSDM for slow-moving landslides anywhere adequate time-series of surface and sub-surface displacements are available, together with topographic, geological, geotechnical, and groundwater information. The LAMPRE 3DSDM is applicable to landslides of different sizes, are well suited to study (and predict) their temporal behaviour in urban and sub-urban areas and for landslides affecting infrastructures, and works best where continuous monitoring devices are available. LAMPRE can prepare the

3DSDM of a slow-moving active landslide in a few to several weeks, provided that sufficient information of adequate quality is available. The updating of a calibrated 3DSDM requires from a few hours to a few days, when new measurements become available. The output of the LAMPRE 3DSDM consists of digital graphs, tables, cross sections, contour maps, and 3D plots.

3DSDM

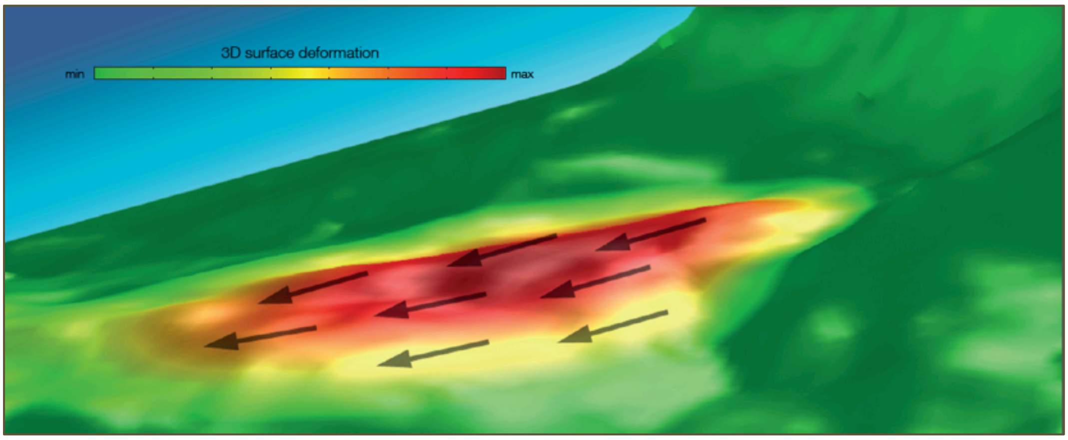


Figure 5 - El Portalet (Huesca, Spain). 3D Finite Element model for an active landslide. Perspective view of a model predicting landslide velocity obtained from a 3D finite element analysis calibrated exploiting space-based Differential SAR Interferometry (DInSAR) products and ground-based inclinometer data.

The **sixth** LAMPRE product is called **Landslide-Road Impact Model** (LRIM) (Figure 6). Triggers such as heavy rainfall, earthquakes or rapid snowmelt events may cause many landslides across a region within minutes to weeks of the event. Some of these landslides may block the transportation network, making it difficult to move about a region. LAMPRE has developed software to construct realistic scenarios of the possible impact of a population of event-triggered landslides on an existing or planned road network.

The LRIM modelling tool experimented by LAMPRE can be used to construct and explore different scenarios of regional road network disruption by event triggering landslides. Specifically, LRIM can be used to prepare vulnerability scenarios anywhere triggered landslide events occur, and where information on the road network, the landslide susceptibility, and a digital representation of topography (a DEM) is available. The landslide susceptibility assessment required by LRIM can be prepared using the LAMPRE LSMM software (Figure 3). LRIM does not require an inventory of real landslides to perform the simulations. Synthetic landslides are drawn from a known non-cumulative distribution of landslide area. However, where a LIM or an ELIM exist or can be prepared for an area, the inventories can be used to construct region-specific statistics of landslide area (using the LSTAT software, Figure 4), which can then be used by LRIM for the vulnerability modelling.

LAMPRE can construct the vulnerability models before, during, and after a triggered landslide event, in periods raging from a few hours to a few days, depending on the size and complexity of the area, and the number of simulations required. The scale of the LRIM simulation range from 1:100,000 (smaller scale) to 1:10,000 (larger scale).

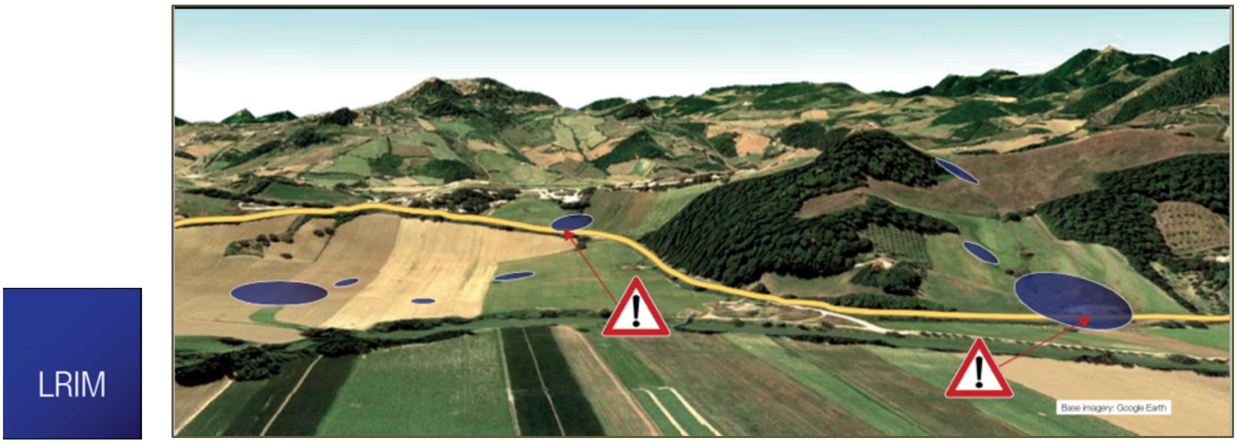


Figure 6 - Collazzone (Umbria, Italy). Landslide-Road Impact Model (LRIM) simulated landslides (blue) and resulting road network blockages (red triangles).

The **seventh** LAMPRE product consists in **teaching materials and educational resources** to help **non-experts** to better understand landslides and their potential impacts and hazardousness (LEDU) (Figure 7). It is recognized that information on natural and human hazards fosters safety and contribute to increasing resilience. With this respect, an informed society is a safer, and more resilient society. Unfortunately, information on landslides is scarce in many areas of the World, including areas where landslides are frequent and abundant. LAMPRE recognizes that there is an urgent need to disseminate information on landslides and their vulnerability. To contribute to fulfil this need, LAMPRE has prepared, organized materials and information on landslides and the vulnerability to landslides. The materials represent the basis for custom-made educational activities that can be created by LAMPRE. The LAMPRE educational services are intended for **non-experts** interested in learning more about landslides, triggered landslide events, and the potential impact of landslides, including the general public, students, teachers and decision makers. In addition, LAMPRE can provide specific training on its other products and services, on demand.

LAMPRE Educational (LEdu) resources include:

- LAMPRE Landslide talks and workshops explaining the basics of landslides and triggered landslide events.
- Webcast versions of these talks are 45 and 3 minutes.
- A LAMPRE Google Earth Practical for the identification of landslides.
- A LAMPRE Interactive Presentation on landslides and triggered landslide events.
- A set of 25 LAMPRE Landslide Frequently Asked Questions.

- A web site with all the above activities, plus a set of web links to (i) general landslide information, (ii) landslide videos and photos, (iii) landslide activities and teaching.

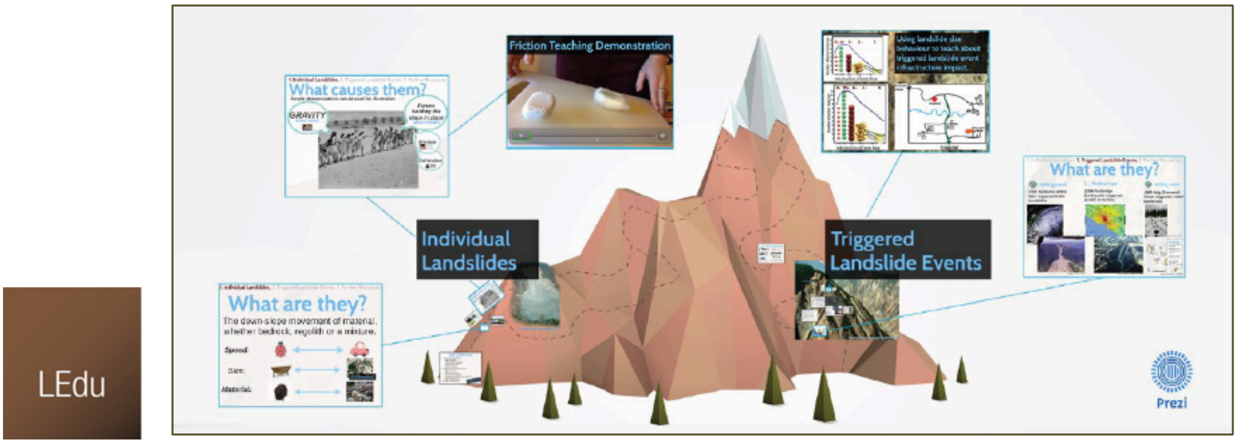


Figure 7 - A LAMPRE Interactive Presentation on landslides & triggered landslide events, for students, teachers and the general public. Credits: Large centre mountain (Prezi, 2014).

The LAMPRE P&S were designed and developed considering, and are now offered to, five main types of users. These include: (a) Civil protection authorities (CPA), (b) Planning and development offices and authorities, (c) Transport and utility managers and authorities, (d) Agriculture and forest managers and authorities, and (e) Research scientists. Despite the fact that the LAMPRE P&S were designed considering specifically the above users (and chiefly CPAs), other users may benefit from the LAMPRE P&S, including (but not limited to) insurance and re-insurance companies, construction and mining companies, and weather services.

Below we list what we consider some of the potential applications of the LAMPRE P&S for the main classes of users.

**Civil Protection Authorities** can use LIMs and ELIMs prepared by LAMPRE in the aftermath of an event for improved rescue and recovery operations. CPAs can use LSMMs in landslide regional or national early warning systems, and to improve their response capacity, LStats to anticipate the sizes of the landslides caused by an intense or prolonged rainfall, an earthquake, or a rapid snowmelt event, and 3DSDM to anticipate the behaviour of slow-moving landslides for early warning and improved vulnerability and risk analyses. Finally, CPAs can use LRIM to prepare scenarios of network impact of different sized triggered landslide events, and to help estimating the potential resources that might be needed to cope with a landslide-triggering event.

**Planning and development authorities** may use LIMs to identify areas affected by landslides and ELIMs to identify areas recently affected by landslides, and so that dangerous areas can be avoided by new constructions and developments, or constructions are made properly. They may use LSMMs to identify landslide prone areas and to zone their territory accordingly, and LStats to anticipate the size and the number of the expected landslides. They may use 3DSDMs to construct landslide scenarios for improved planning, and to investigate the efficacy of existing and planned remedial and mitigation measurements, and LRIM to identify potentially vulnerable transportation and utility network scenarios and to plan appropriate redundancies.

**Transportation authorities & utility managers** may use LIMs and ELIMs to evaluate the impact of landslides on their transportation and utility networks, and may use LSMMs to predict the potential impact of landslides on transportation or utility network, and for the design of improved maintenance and mitigation strategies. They may use 3DSDMs to anticipate the impact of slow-moving landslides on sections of their transportation or utility networks, and they are a primary user of LRIM that they can exploit to model potential overall road distance unavailable in the road network, and to plan appropriate redundancies in the road networks.

**Agricultural & forest offices and agencies** may use LIMs and ELIMs to evaluate the impact of landslides on agricultural areas, crops, and forests. They may use LSMMs to identify landslide prone areas, and LStats to evaluate the potential vulnerability of crops and forests to event landslides, for improved agricultural and forest management. They may also use LRIM to model potentially vulnerable road network scenarios in forests, and 3DSDM to assess the impact of slow-moving landslides on crops and forests.

**Scientists** may use LIMs for erosional studies and to determine the statistics of landslide areas, and ELIMs to prepare multi-temporal inventories, also useful for erosional studies, and to determine the statistics of landslide areas. They may use LStats for erosional studies and landscape modelling, and to evaluate the quality of landslide inventory maps, and LSMM to predict the expected climate and environmental changes on landslide abundance and activity. They can also use 3DSDMs to understand the kinematics of landslides in a changing climate, and LRIM to simulate the potential impact of landslides, and other types of hazards, on different kinds of infrastructure networks. All the tools and techniques developed by LAMPRE may also be useful for new studies on multi-hazards, and to investigate the inter-dependencies among the hazards.

The LAMPRE educational P&S (LEdu) can be used by all types of users, for different scopes and to meet a variety of demands.

## 3.2 Testing and Validation of the Products & Services

Testing and validation of the P&S was a primary concern and represented an essential part of LAMPRE. These important activities were conducted through three sets of complementary actions.

LAMPRE reviewed existing validation methods for the production and use of landslide products and services, including the production and use of landslide inventory maps (LIM, ELIM), and landslide susceptibility, hazard and impact models. The analysis revealed a general lack of consolidated, objective and reproducible methods for the evaluation of landslide products and services. Based on this review, LAMPRE has proposed specific criteria and associated procedures for the validation of the LAMPRE products and services (P&S). This is a preliminary – yet necessary – step towards the definition of standards. The proposed criteria and procedures were discussed amongst the LAMPRE partners and with relevant stakeholders, and were refined and updated considering the experience gained in the project.

LAMPRE P&S were prepared / tested in eight different sites in three continents, including three sites in Italy (Liguria, Umbria, and Sicily), two sites in Spain (Mallorca and El Portalet), one site in Switzerland (Matter Valley), one site in Costa Rica, Central America, and one site in Taiwan (Kaopin), Asia (Table 1). Inspection of the Table 1 reveals that not all the P&S were prepared in all the test sites. This has multiple reasons. On the one side, it was not of interest to test all the products on all test sites, and the products were prepared and tested where they were meaningful and potentially relevant to local users and stakeholders. Some of the products (e.g., 3DSDM, LRIM) required specific information and data that were not available in all the LAMPRE sites. Data availability limited the testing of these products. The time, financial, and human resources available to the project were limited, and did not allow for more widespread and compressive testing and validation of the products and services. However, we note that the LRIM was tested in two additional areas outside the main LAMPRE test sites, including in an area in Southern California and in an area in southern Taiwan.

Table 1 – LAMPRE products (rows) and main test sites (columns) where the products were tested. Not all the products were prepared for all the test sites.

| | Mallorca | Portalet | Liguria | Umbria | Sicily | Matter Valley | Taiwan | Costa Rica |
|---|---|---|---|---|---|---|---|---|
| LIM | | | ✔ | ✔ | ✔ | | ✔ | ✔ |
| ELIM | | | ✔ | ✔ | | | ✔ | ✔ |
| LSMM | ✔ | | | ✔ | ✔ | | | ✔ |
| LSTAS | | | | ✔ | ✔ | | ✔ | ✔ |
| 3DSDM | | ✔ | | ✔ | | | | |
| LRIM | | | | ✔ | | ✔ | | |

Selected users experimented some of the LAMPRE P&S. In Spain, the Mallorca Regional Council, Department for Roads and Highways, used landslide models prepared by LAMPRE to evaluate the possible impact of rock falls on their road network. The Geological Survey of Israel used the LSTAT software to determine accurate statistics of the area of a population of submarine landslides off shore the coast of Israel. In Costa Rica, local authorities used and evaluated positively LAMPRE products prepared for their area of interest,

We maintain that the number and geographical locations of the LAMPRE test sites, the variety of the tests performed, and the number of users and stakeholders directly or indirectly involved in the use and the evaluation of the LAMPRE P&S guarantee that the proposed tools (techniques, methods, software) are robust, and that the LAMPRE P&S are applicable to a large range of geographical, geological, and climatic settings, and in different societal and organizational settings.

## 3.3 SCIENTIFIC & TECHNOLOGICAL ADVANCEMENTS

LAMPRE obtained significant scientific and technological (S&T) advancements in different fields, including: (i) the production of landslide inventory maps (LIM) and event landslide inventory maps (ELIM), (ii) landslide susceptibility models and associated terrain zonations, (iii) the determination of accurate landslide statistics (LStats), (iv) landslide impact modelling (LRIM), and (v) the 3D modelling of deep-seated, slow moving, active landslides (3DSDM).

### *3.3.1 IMPROVED LANDSLIDE MAPPING*

#### *3.3.1.1 VISUAL DETECTION AND MAPPING OF LANDSLIDES*

Research focused on mitigating the effects of shadows in optical satellite images.

LIMs and ELIMs are prepared chiefly through visual interpretation of aerial and satellite stereoscopic images. The visual interpretation of stereoscopic images for landslide recognition requires experience, training, a systematic methodology, and well-defined interpretation criteria. The interpreter detects and classifies landslide visually based on the recognition of photographic characteristics including shape, size, colour, tone, mottling, texture, pattern of objects, site topography, and local setting. In places, key photographic characteristics are reduced (degraded) by the presence of shadows, which may result from local terrain conditions (e.g., in deep and narrow valleys) and by a poor illumination (e.g., during the autumn and winter seasons). Where present, shadows result in a reduced spectral signal in all bands. In the shadowed (dark) areas, the interpreter cannot recognize the photographic / topographic signature typical of the landslides. Lack of contrast in shadowed (dark) areas limits the ability of the interpreter to recognize landslides.

LAMPRE experimented the use of 3D enhanced Normalized Differential Vegetation Index (NDVI) images for the visual interpretation of stereoscopic satellite imagery for the identification of landslides. The new procedure tested by LAMPRE obtains first the NDVI from the original stereo satellite images that, in shadowed areas, exhibit a typical bimodal distribution, with the a mode (peak) centred on the lower NDVI values representing the shadow areas, and a mode centred on the higher NDVI values representing illuminated (non shadowed) areas. To exploit the information in the first peak (shadow areas) enhancing the image contrast in the shadowed areas, a piecewise linear stretch is applied, which involves the identification of a number of linear expansive brightness ranges. Figure 8 shows that landslide features not visible in the original RGB image (left), and in the standard NDVI (centre) image, are clearly recognizable and can be readily mapped in the modified (enhanced) NDVI image (right).

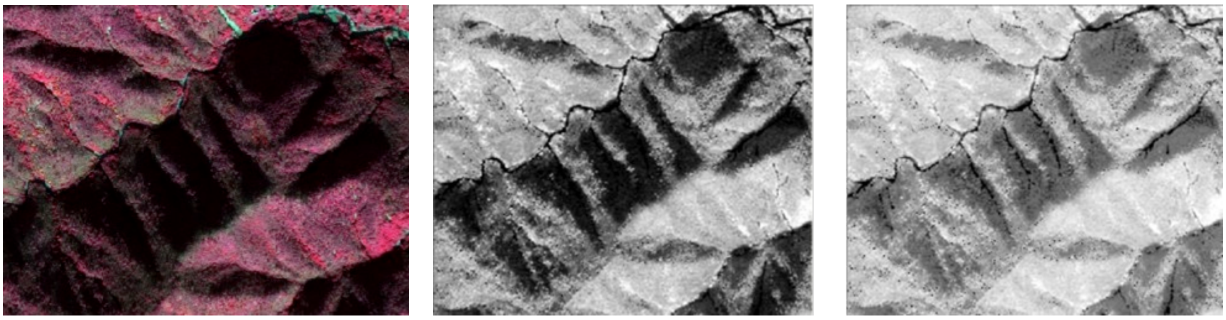

Figure 8 - NDVI histogram enhancing. From left to right: (i) original RGB (NIR-Red-Green) WordView II image, (ii) NDVI image, and (iii) enhanced NDVI image.

#### 3.3.1.2 SEMI-AUTOMATIC MAPPING OF LANDSLIDES

Research focused on advancing probabilistic frameworks that exploit contextual geo-environmental information for the accurate detection and mapping of landslides.

Production of landslide inventory maps (LIM) and event landslide inventory maps (ELIM) through the visual interpretation of stereoscopic images requires experienced investigators, and long periods of time, hampering the systematic production of the maps. This is why there is mounting interest for methods for the semi-automatic detection and mapping of landslides from optical (multi-spectral) satellite images, and other types of remote sensing information. The semi-automatic classification of landslides from satellite images is a type of classification problem, where a classification tool exploits the quantitative, multispectral information stored in a satellite image to separate landslide areas from non-landslide areas. From a spectral point of view, landslides are a type of land cover class (like, e.g., build-up areas, forests, water). The difficulty in the accurate recognition and classification of landslides from the satellite imagery results from the complex tridimensional nature of the landslides, and the spectral similarity of the "landslide" class with other classes present in a hilly or mountainous landscape where landslides occur, including bare soil, ploughed fields, and human-made elements (e.g., dirt roads, quarries, dump sites). Lack of adequate spectral information to discriminate landslides from other land cover classes can result in erroneous class membership assignments, and typically in the overestimation of the "landslide" class (i.e., false (landslide) positives).

LAMPRE addressed the problem of the classification errors exploiting geo-environmental contextual information through specifically designed filters (weights). Two probabilistic frameworks were experimented: (i) an independent modelling framework, and (ii) a Bayesian framework. Both frameworks start by transforming the available optical satellite image in a derived image (or map) showing the "probability of landslide presence". This probability is obtained from the spectral signal captured by the satellite image, using the known or expected landslide spectral response measured in specific regions of interest (ROI). Next, both frameworks exploit information on landslide susceptibility (i.e., the spatial probability of landslide occurrence) to identify non-landslide areas that exhibit landslide-like spectroscopy. The two methods differ in the way they use the filters (weights). For the independent modelling framework, the probability of landslide presence and the probability of landslide occurrence are assumed independent, and the combined result is a conceptually new probabilistic landslide inventory map, which includes a measure of the uncertainty. Figure 9 shows the result of the application of the independent framework to a Formosat II image captured over the Kaopin area, southern Taiwan, two months after the devastating 2009 typhoon Morakot.

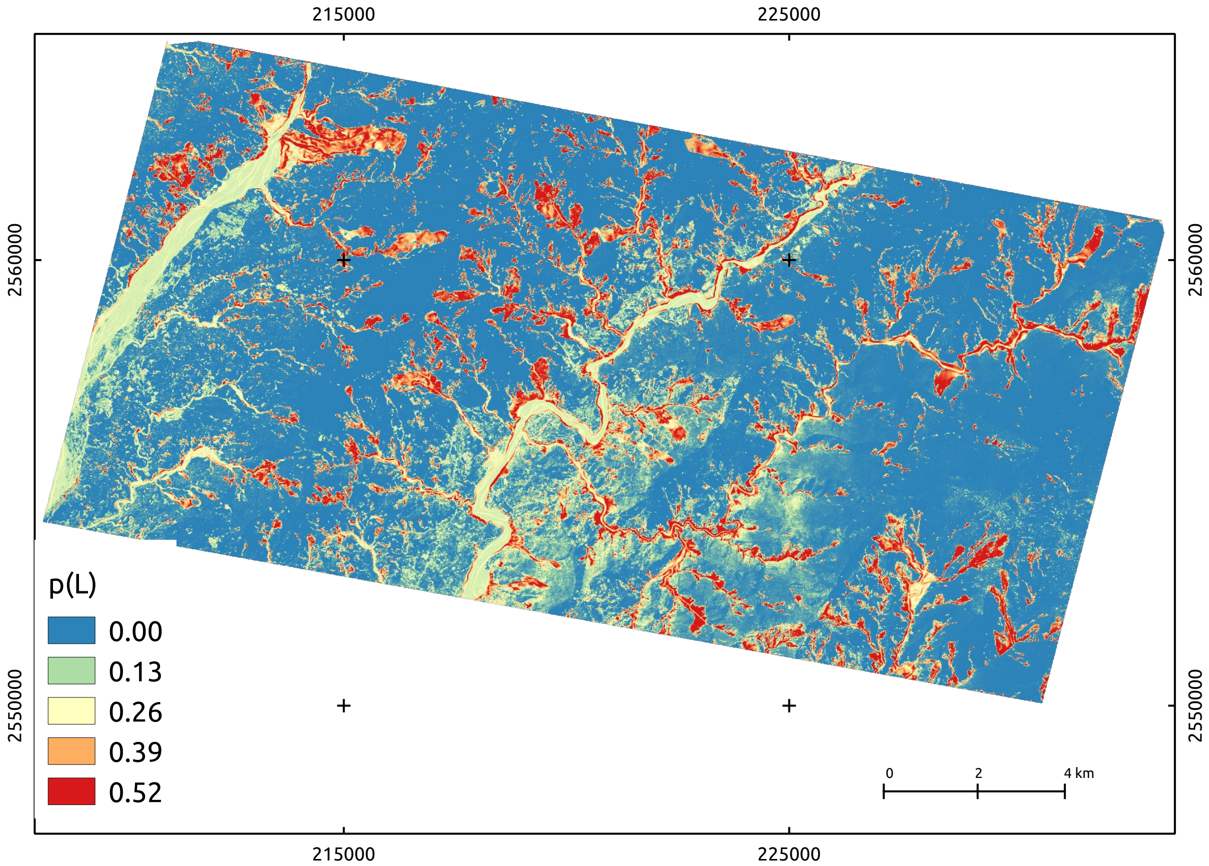


Figure 9 – Map showing the probability of landslide presence, from high (red) to low (blue), obtained through the semi-automatic classification of a Formosat II optical image. Mapped landslides were caused by typhoon Morakot in august 2009 in southern Taiwan.

In the Bayesian modelling framework, the map of the probability of the (known or inferred) landslide occurrence (i.e., landslide susceptibility) is used to condition the a priori probability of landslide presence obtained from the satellite image. Through a stepwise exploitation of geo-environmental information, in the same Kaopin area, southern Taiwan, the Bayesian probabilistic framework separated landslide areas from non-landslide areas, and classified the landslides internally in source areas and transport and depositional areas. The ability to classify landslides internally (as source and run our areas) is important for the estimation of the magnitude the landslide event, measure by the number of the triggered landslides. Figure 10 shows the result of the application of Bayesian modelling framework in the Kaopin area, southern Taiwan.

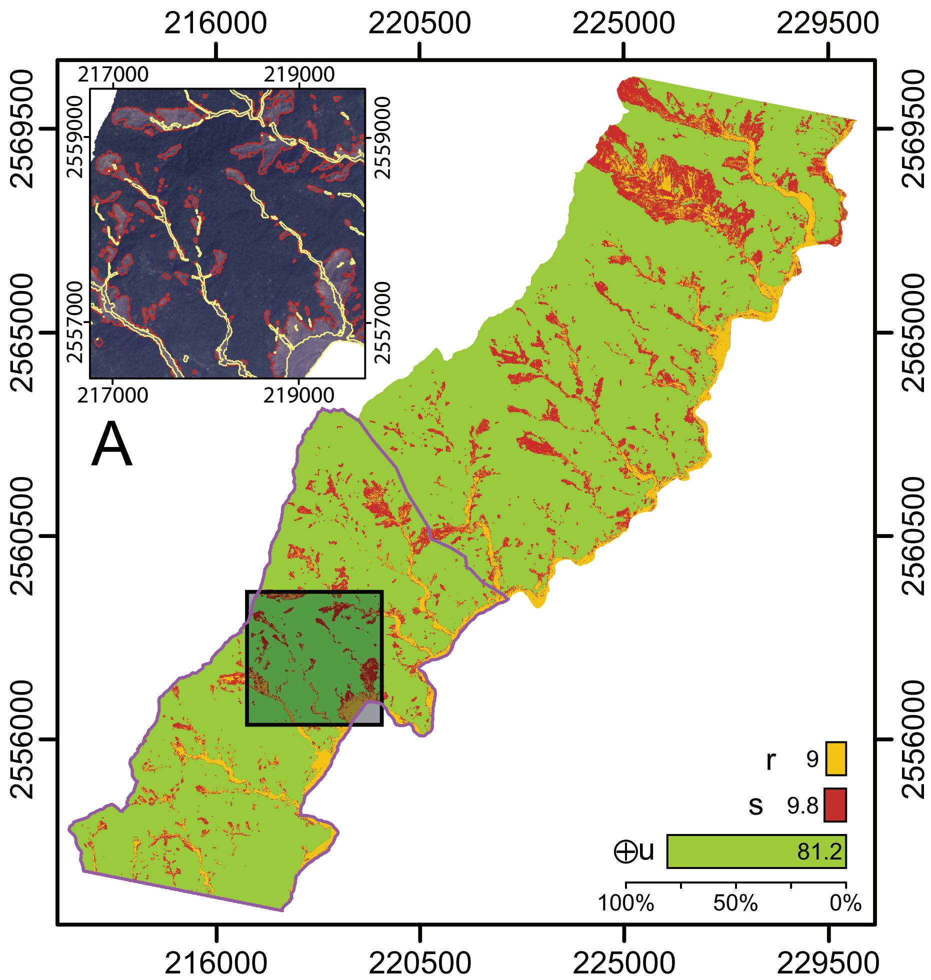


Figure 10 - Result of a Bayesian semi-automatic classification of event landslides caused by typhoon Morakot in august 2009 in southern Taiwan. Legend: Red, landslide source areas. Yellow landslide run out areas. Green stable areas. Inset shows a portion of the classification overlaid on the Formosat II optical image used for the classification.

### 3.3.2 LANDSLIDE MODELLING

LAMPRE technological developments have advanced the ability to determine landslide susceptibility and to obtain accurate statistics of landslide size, to model the impact of event landslides on transportation networks, and to construct finite element models (FEM) to predict the future behaviour of landslides.

#### 3.3.2.1 LANDSLIDE SUSCEPTIBILITY MODELLING

Landslide susceptibility is the propensity of a landscape to generate (or not generate) landslides. In mathematical language it is the spatial probability of landslide occurrence, given a set of geo-environmental variables. A large literature exists on methods and techniques to evaluate landslide susceptibility. A problem with the current operational (practical) production and use of landslide susceptibility models and maps lays in the lack of standards and common methods and tools for landslide susceptibility modelling an terrain zonation.

To fill this gap, LAMPRE has developed and tested new SW for regional landslide susceptibility modelling adopting standard statistical classification techniques. The SW logical framework is organized in five steps: (i) data preparation and input, (ii) production of single susceptibility models and maps, (iii) combination of the single models into “optimal” combined models and maps, (iv) evaluation of the single and the combined (optimal) susceptibility models and maps, and (v) evaluation of the uncertainty associated to the single and the combined models and maps.

The LAMPRE susceptibility modelling SW can use different types of mapping units, including grid cells, slope units, geomorphological units, hydrological units, and administrative units. For each mapping unit, the SW requires (i) a binary grouping (dependent) variable to mark the absence (0) or presence (1) of landslides in the mapping unit, and (ii) a set of explanatory (independent) variables, including e.g., morphometric, lithological, geological, land use / cover variables. The SW implements different multivariate statistical classification methods, including linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), logistic regression (LRM), and a self-optimizing neural network (NNM). Other statistical classification methods can be added.

To combine the results of different, single landslide zonations into “optimal” (combined) zonations, the SW exploits a logistic regression approach. For the purpose, the SW uses the presence (1) or absence (0) of landslides in each mapping unit as the grouping variable, and the probabilistic susceptibility predictions obtained with the single susceptibility models as the explanatory (independent) variables.

From a user perspective, use of the SW begins with a model-training phase and ends with a model-validation phase. In the training phase, the SW determines the relationships between the dependent (presence / absence of landslides) and the set of the independent geo-environmental variables. In the validation phase, the established relationships are verified, adopting a number of different validation scenarios. The SW provides the user a set of procedures to evaluate dependency among the explanatory variables (which should be avoided), to measure the model prediction skills (i.e., the ability of the model to match the original input data), to evaluate the temporal and spatial performance of the susceptibility zonations (i.e., the ability of the model to predict new, independent landslide information), to determine and evaluate the model errors, and to measure the uncertainty related to the susceptibility estimates.

Figure 11 portrays an example of a regional scale landslide susceptibility zonation for the Umbria Region, central Italy. The susceptibility zonation was prepared using the landslide susceptibility SW tool designed by LAMPRE.

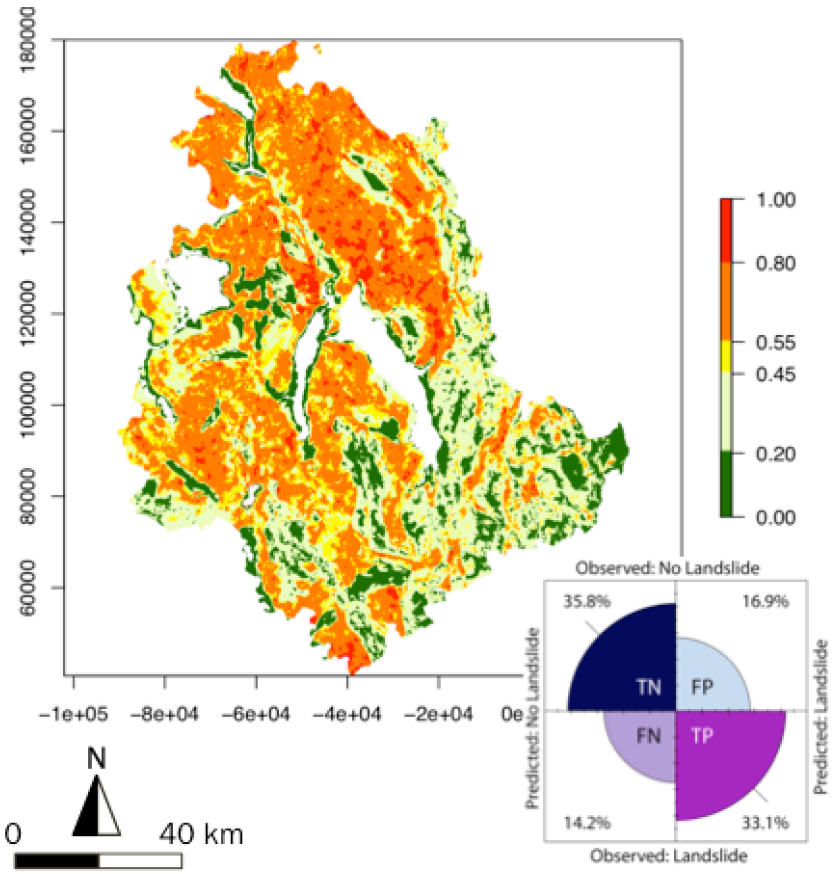


Figure 11 – Landslide susceptibility map for the Umbria Region, central Italy, prepared using the SW tool for landslide susceptibility modelling designed by LAMPRE.

#### 3.3.2.2 LANDSLIDE SIZE MODELLING

The assessment of the risk posed by populations of landslides over large regions requires estimation of landslide hazard, and hence the probability of a landslide of a given size occurring. The size of a landslide is often taken to be its area, and is commonly considered to be a proxy of landslide magnitude. Landslide area is preferred to volume since it can be measured accurately. LAMPRE developed the LStats SW for the accurate determination of the statistics of landslide area. Written in the R language for statistical computing and graphics (http://www.r-project.org/), the SW tool implements parametric and non-parametric approaches to estimate the probability density of landslide area, including (i) Histogram Density Estimation (HDE), (ii) Kernel Density Estimation (KDE), and (iii) Maximum Likelihood Estimation (MLE). Each of the implemented approaches exploits different optimization procedures; thus can give slightly different results.

LAMPRE developed two versions of the SW: a “base” version and an “advanced” version. In its “base” version, for each parameter of the distribution the SW tool gives an estimate of its value, standard error, the estimated error variance, and the correlations among the parameters. The "advanced" version integrates the following additional features: (i) the bootstrapped parameter uncertainty estimation, for a more significant statistical comparison of the obtained probability distribution parameters, (ii) the bootstrapped Kolmogorov–Smirnov test (KS test) to serve as a "goodness of fit" test providing a measure of the suitability of the different distribution types, (iii) an improved version of the cumulative density function calculation, (iv) an improved use of shape files, allowing the automatic landslide size calculation, and (v) an improved output version, allowing the calculation of the probability density. The type of output is differentiated in the two software versions. Different interfaces were prepared for the two versions integrating different specifications, namely: (i) a batch script interface fir the "advanced" version, and (ii) a Web Processing Service (WPS) interface for the "base" version. Figure 12 portrays three computed probability density functions for landslide areas obtained from an event landslide inventory in Taiwan using the LStats SW tool designed by LAMPRE.

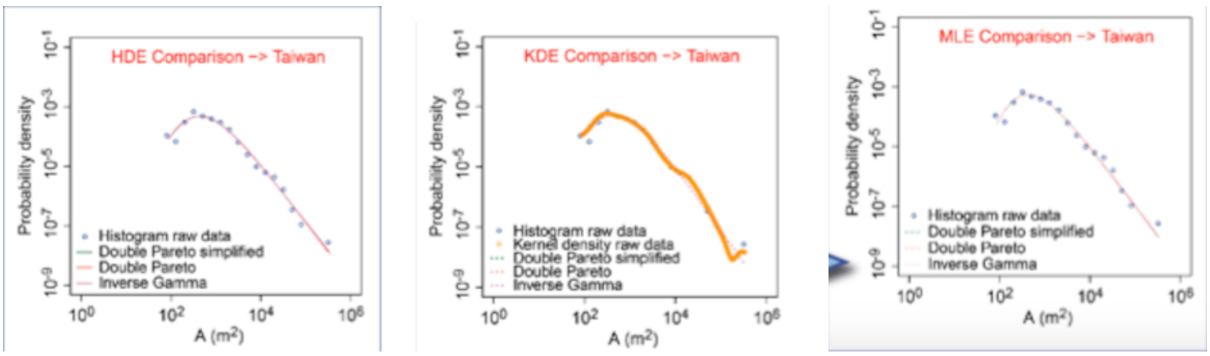


Figure 12 – Probability density functions of landslide areas for an event landslide inventory in Taiwan obtained using the LStats SW. Left, Histogram Density Estimation (HDE). Centre, Kernel Density Estimation (KDE). Right, Maximum Likelihood Estimation (MLE).

#### 3.3.2.3 *LANDSLIDE ROAD IMPACT MODELLING*

In medium to high topographic regions, triggered landslide events are known to pose a severe threat to infrastructures, livelihoods, and public and private assets. A triggered landslide event includes all of the landslides resulting from one triggering event, such as an earthquake, a heavy or prolonged rainfall, or a rapid snowmelt event. Depending on the location and trigger, a triggered landslide event may include just a few landslides to tens of thousands of landslides, occurring across the impacted region within a short time (e.g., minutes to days). If a number of roads is blocked by landslides simultaneously, this can make it difficult to move about a region by road, and conduct rescue and recovery operations effectively. In extreme cases, people may become entirely isolated for days to weeks.

LAMPRE studied and developed a Landslide-Road Impact Model (LRIM) to explore different potential scenarios of regional road network disruption by different numbers of landslides. The model considers triggered landslide events, where the impact of multiple landslides on the road network can at times be greater than adding up the impact of individual landslides on specific roads. The method generates repetitively synthetic triggered event landslide inventory maps for a given magnitude chosen by the user, where the number of landslides resulting from the trigger measures the magnitude of the event. Number and dimension of the landslides in the inventory maps are obtained from statistical distributions developed to describe the general behaviour of landslides based on events of the past. Synthetic landslides are then dropped on the landscape according to the local characteristics of susceptibility. The synthetic landslide inventory maps created in the model are then overlaid with the road network to identify where road blockages occur, and where landslides are within predefined distances (e.g., 50, 100 m) of the road. By repeating the process many times, different scenarios of impact can be evaluated and plan accordingly. The road model benefits of the software prepared by LAMPRE and delivered to the community to estimate landslide statistics (LStats) and susceptibility (LSMM).

Figure 13 shows the overlap between one of the simulated event landslide inventory map and the road network in the Collazzone area, Umbria, central Italy. In the inset, a potential intersection between a road and a synthetic landslide that might result in a road damage or blockage.

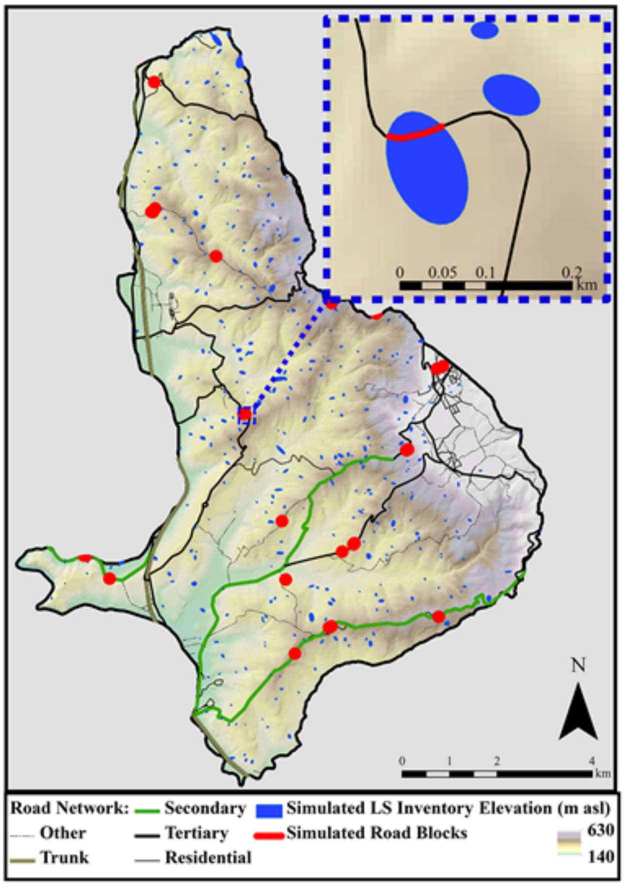


Figure 13 – One of hundreds of synthetic triggered landslide event inventory maps prepared by the Landslide Road Impact Model (LRIM). In this example, 413 landslides were dropped across the 79-$km^2$ Collazzone area, Umbria, central Italy.

#### 3.3.2.4 ADVANCED MODELLING OF SLOW MOVING ACTIVE LANDSLIDES

LAMPRE technological advancements for the investigation of single landslides or unstable slopes focused on the characterization and the interpretation of three-dimensional (3D) surface deformations caused by active, slow moving, deep-seated landslides. The topic is crucial for the analysis of unstable slopes and the potential prediction of the kinematical behaviour of the landslide.

LAMPRE integrated in a novel Finite Element (FE) numerical modelling scheme the intrinsic complexities of the environment, such as topography, the geological and geomorphological settings, the geo-mechanical characteristics of the geo-materials, and the time-dependent processes constrained by DInSAR measurements of landslide surface displacements, together with in situ data and measurements. For the El Portalet landslide, in the Spanish Pyrenees, the sub-surface deformation measurements were obtained exploiting an innovative Automated Inclinometric System (AIS) designed for the semi-continuous measurements of the deep deformations. In LAMPRE, FE analyses of the 3D models included a forward analysis, to constraint initially the model using existing field data and geomorphological inference, and an inverse analysis to further constrain the model parameters using the DInSAR deformation data through a minimization of the error between the calculations and the measurements. In this perspective, the potentiality of ©COMSOL Multiphysics FE modelling tool was combined in LAMPRE with Monte Carlo optimization procedures to obtain and interpret the ground deformations measured in the landslide area. Optimization of the model parameters was performed combining ©COMSOL Multiphysics in a Genetic Algorithm scheme to search for the best-fitting model parameters that minimize the root-mean-square of the difference between the DInSAR-measured and the FE-calculated displacements. The landslide shear band was simulated in the FE model using the information available for the corresponding depth (i.e., using inclinometer profiles and geophysical data). Different soil constitutive models (elasto-plastic, poro-elastic, creep) were tested searching the most appropriate soil model to characterize the geo-mechanical behaviour of the landslide. The results of the FE model allowed obtaining the 3D components of the surface displacement field, and to prepare a 3D surface velocity map for the landslide area (Figure 14).

The 3D FE modelling benefited from advancements obtained in LAMPRE concerning innovative DInSAR processing for land surface displacements measurement. A new algorithm tested in LAMPRE increases the density of radar measurements (i.e., the number of coherent scatterers which can be exploited for measuring motions), allowing for an improved understanding of the landslide dynamics. The new algorithm addresses the problem of the temporal decorrelation of the SAR signal, typical of landslide environments, and of the resulting loss of reliable measurement points. The algorithm combines the SAR image amplitude statistics approach and the phase coherence stability approach adopting an innovative de-noising filtering strategy to reduce the additive Gaussian noise. The filter improves the interferometric phase quality without loosing resolution.

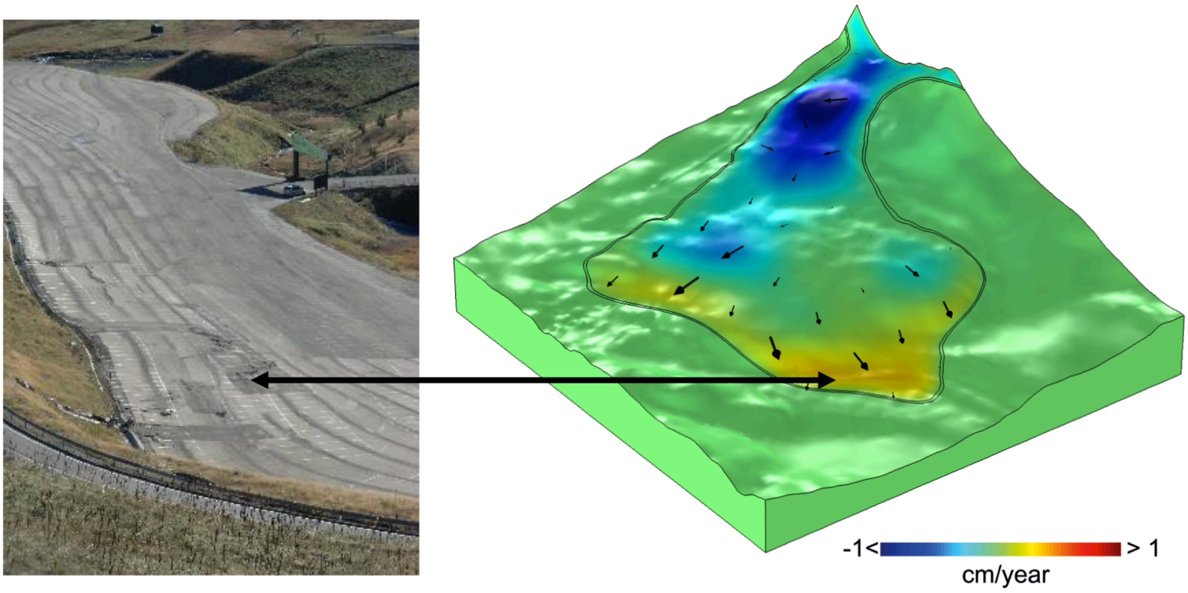


Figure 14 – Right: Deformation velocity map obtained from the 3-D finite element model of the deep-seated El Portalet landslide, Spanish Pyrenees. Arrows show modelled horizontal displacements. Colours show modelled vertical motion (velocity). Left: Parkin lot deformed by the active El Portalet landslide.

The new method exploits the innovative Non-Local Interferometric SAR (NL-InSAR) filtering technique, in the SPN advanced PSI processing chain. The methodology allows to vary the number of looks pixel-by-pixel, depending on the number of similar patches found in a search window around the examined pixel, and preserves the resolution over point-like scatters averaging only homogenous regions with predominance of distributed scatters. Adaptive coherent threshold selection criteria are also used to select the optimum InSAR pairs, to improve the detection of coherent scatters in long-term stacks of SAR data. The combination of the two solutions proves important to improve the density of the measurement points in highly decorrelated environments, and provides more valuable short- and long-term solutions for slow-moving, active slopes.

Figure 15 shows a comparison of the total (cumulated) displacement along the satellite line-of-sight (LOS) for a TerraSAR-X data set using the full-resolution approach without any filtering (left), the coherence stability approach within a 5 × 5 boxcar sliding window (center), and the innovative NL-InSAR filtering technique experimented in LAMPRE (right). All approaches retrieve the same displacement trends, but with significantly different densities of the point scatterers. Specifically, PSI results based on the innovative NL-InSAR filtering results in a threefold increase in the number of the persistent scatterers (bare soil, roads, rocks), compared to standard ("classical") PSI approaches.

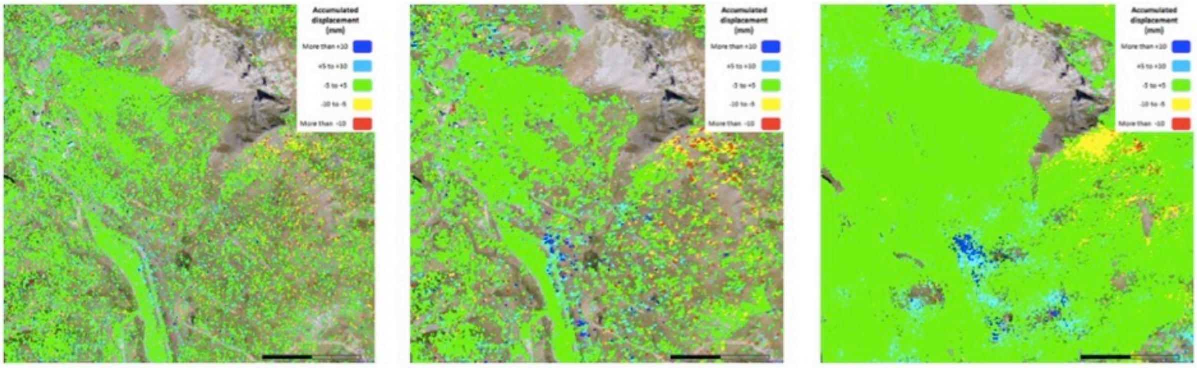

Figure 15 - PSI displacement results along satellite line-of-sight (LOS) for a TerraSAR-X dataset using (left) full-resolution PSI processing, (centre) after applying a 5 × 5 boxcar window, and (left) after applying the innovative NL-InSAR filtering technique.

# 4 POTENTIAL IMPACT

LAMPRE has developed new products & services (P&S) that enhance landslide risk mitigation and preparedness efforts and post-event landslide recovery and reconstruction activities in landslide-prone regions. The LAMPRE P&S improve and expand existing capacities to detect and map landslides accurately and timely, to assess and forecast the impact of triggered landslide events on vulnerable elements, and to model landscape changes caused by slope failures. The new LAMPRE P&S are potentially relevant to the effective implementation of the EU Strategy for the prevention, preparedness and response to natural hazards (chiefly landslides) for the protection of the population, of private and public property, of structures and infrastructures, and of the environment. With this respect, the results of LAMPRE are of broad scientific, technological and societal interest. The advancements obtained in LAMPRE are also potentially relevant to the implementation of the EU Soil Thematic Strategy, and to the design of novel Copernicus (previously known as GMES, Global Monitoring for Environment and Security) landslide services based on images taken by the innovative European Space Agency (ESA) Sentinel-1 (radar) and Sentinel-2 (optical) satellites. In addition, if properly and effectively integrated within the portfolio of existing solutions offered by service providers, the LAMPRE P&S can reach the market and can be offered to the private sector.

## 4.1 Technological Readiness Level

In any R&D endeavour there are phases of development that define different levels of maturity for the technology developed / exploited, and the products and services offered to the market. For an endeavour to be successful, it is important to evaluate the maturity of the technology, products and services, and to identify pending actions, including additional R&D activities, required to reach the level of maturity necessary to allow a product or service to be exploitable, and marketable.

LAMPRE proposed a new approach to the old problem of detecting and mapping landslides. The new approach promises to reduce the response time (from days to hours) required for the production of LIM and ELIM, maintaining (and improving locally) the quality of the inventory maps. LAMPRE developed innovative tools to improve the production of landslide susceptibility and landslide hazard models and maps, at different geographical scales. The SW tools offered by LAMPRE are a significant step towards a much-needed standardization in the production of landslide susceptibility and hazard assessments, and promise to reduce significantly the time required for landslide susceptibility and hazard modelling. Finally, LAMPRE introduced new concepts for the continuous modelling of single active landslides or unstable slopes, and for the construction of realistic vulnerability scenarios of the possible impact of event-triggered landslides on transportation networks. These new concepts promise to change profoundly the way users cope with the impact of landslides on single structures and on large and complex infrastructural networks.

In this context, it is important to understand the **level of maturity** of the technology and of the P&S offered by LAMPRE. This is necessary to identify the advantages and weaknesses of the new P&S compared to competing products and services, offered e.g. by the Copernicus Core services. It is equally important to recognize the additional efforts necessary to bring the P&S to a level of maturity sufficient for their successful commercial exploitation.

LAMPRE performed an analysis of the Technological Readiness Level (TRL) of all its P&S, namely:

- Landslide inventory maps (LIM),
- Event landslide inventory maps (ELIM),
- Landslide susceptibility models and maps (LSMM),
- Statistics on landslide size (LStats),
- 3D Surface deformation models (3DSDM),
- Landslide-Road impact models (LRIM), and
- Teaching materials and educational resources (LEdu).

The main advantages promised by the new LAMPRE P&S consist in: (i) a reduction of the time (and costs) required for the production of landslide maps and models, which is particularly important for users that operate in emergency situations (including CPAs), (ii) an improved standardization of the results obtained, which is important to many users, and contributes to building confidence and thrust on the P&S, and (iii) the possibility to prepare landslide maps and models over large areas, maintaining (and locally improving) the quality (e.g., resolution, completeness, thematic accuracy) of the maps, models, and assessments.

For the TRL analysis, the LAMPRE P&S were classified in three groups:

- P&S used to prepare landslide maps, including inventory (LIM) and event inventory (ELIM) maps. These P&S focus on the detection and accurate mapping of landslides, determining their geographical location, size, type and (possibly) internal subdivisions.
- P&S designed to model landslides exploiting statistical, probabilistic, geo-mechanical, geomorphological, geographical (GIS) modelling tools and concepts. These include SW for modelling landslide susceptibility (LSMM) and the statistics of landslide size (LStats), a framework for the integrated 3D monitoring & modelling of active landslides (3DSDM), and a new modelling approach to build impact scenarios of event triggered landslides on transportation networks (LRIM). These P&S focus on the production of new and innovative information useful to better characterise a landslide problem at a broad range of geographical and temporal scales.
- An educational service that provides materials useful to help non-experts to understand landslides and their potential impacts and hazardousness. The educational service complements all the other LAMPRE P&S.

The LAMPRE P&S have defined initial requirements, and need specific input data and information, which can be provided by another LAMPRE P&S, or can be obtained from independent sources. For example, an ELIM can be used to update an existing LIM. The landslide information shown in a LIM can be exploited by

LSMM to prepare a susceptibility zonation, and the landslide information in an ELIM can be used by LSMM to validate a susceptibility zonation, and by LStats to obtain accurate statistics of landslide size for a new event. The LRIM tool can exploit landslide statistics prepared by LStats, and susceptibility information produced by LSMM. In a large region prone to landslides, 3DSDM can be performed at sites identified as particularly critical by LSMM. The quality of the new LAMPRE P&S (maps, models, assessments) depends on the quality (accuracy, completeness, significance) of the available input data and information. For the TRL analysis, we assumed that all the initial requirements are met, and all the necessary data and information are available.

To establish maturity, we use a TRL scale that measures the readiness of a technology, product or service in nine levels, from TRL 1 (lowest maturity) to TRL 9 (highest maturity) (Table 2). The nine levels follow EC H2020 general indications to decide on the technological characteristics (and maturity) of EC funded projects. We note that no clear / unique definition exists for the different maturity levels, and that the EC specific adaptations listed in Table 2 focus on single technologies, and do not address fully all aspects of research/technological solutions required by the interactions of different technologies. Therefore, the scheme is generic and open to interpretation. Further, for our TRL analysis we adopted a "technological" perspective, which was considered more suited than a "market" perspective, since the later would require analyses and information that were not performed or that were not available to the project.

Table 2 - Technology Readiness Levels (TRL) for EC H2020 funded projects.

| TRL Scale | Description |
|---|---|
| TRL 1 | Basic principles observed |
| TRL 2 | Technology concept formulated |
| TRL 3 | Experimental proof of concept |
| TRL 4 | Technology validated in laboratory |
| TRL 5 | Technology validated in relevant environment |
| TRL 6 | Technology demonstrated in relevant environment |
| TRL 7 | System prototype demonstration in operational environment |
| TRL 8 | System complete & qualified |
| TRL 9 | Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space) |

We base the assessment of the "maturity" of the LAMPRE P&S on three metrics:

- **Automation** [from 0 to 4], which measures the level of automation reached by the P&S. It also measures, and depends on, the amount of human effort required to prepare the product. The lowest level of automation [0] is attributed when all the steps in the process are manual, or need to be performed manually by an operator (largest effort). The highest level of automation [4] is attributed when all the steps in the process are automatic, once the necessary parameters / variables are set by the operator (lowest effort).

- **Reliability** [from 0 to 3], which measures the level of reliability of the P&S that depends on the effort required for the full exploitation of the P&S. The lowest level of reliability [0] is attributed when a significant effort is required by the user to exploit the P&S. The highest level of reliability [3] is attributed when little effort is required by the user to exploit the P&S.
- **Generality** [from 0 to 3], which measures the effort required to produce the same type of product, or to offer the same service in a different area. The lowest level of generality [0] is attributed to a P&S that requires a significant tailoring effort to adapt the P&S. The highest level of generality [3] is attributed to a P&S that can be produced in a different area without any additional tailoring effort.

For the TRL analysis, we consider the three metrics (automation, reliability, generality) independent. This is a simplification, as links exists between the three metrics. As an example, a very large automation is achieved for P&S that are also very general, and require little (or nil) tailoring effort. We further acknowledge that reliability depends on the user of the P&S, and its intrinsic ability to exploit the LAMPRE P&S. In general, a highly skilled user will find the LAMPRE P&S more reliable that a less skilled user.

To obtain the final "maturity" (TRL) level for each P&S the three single scores are summed. The results for the seven LAMPRE P&S are listed in Table 3 where, for each P&S the automation, reliability and generality scores are mean values obtained by averaging the scores given by individuals working for four LAMPRE partners (ALTA, CNR, IGME, UNIFI).

The largest scores (higher maturity) were obtained for the LSMM (TRL = 8) and LStats (TRL = 8) SW tools, and the lowest score for the 3DSDM integrated monitoring & modelling framework (TRL = 4) and the LRIM impact modelling tool (TRL = 4), which remain experimental. Large score were also obtained for the LAMPRE education services (LEdu, TRL = 7), and the mapping P&S (ELIM, TRL = 7 and LIM, TRL = 6).

Based on the results of the "maturity" analysis (Table 3) three main groups of P&S can be singled out, namely:

- LSMM and LStats SW tools, for which the prototype demonstration was completed successfully in an operational environment so that they are considered qualified. These two P&S are ready for exploitation and marketing.
- Production of LIM and ELIM was demonstrated in relevant environments, and a prototype demonstration was completed successfully in an operational environment for the ELIM. The two P&S are almost ready for exploitation and marketing.

- The 3DSDM and LRIM modelling tools were validated on a limited number of test cases (laboratory tests). Some additional effort remains to bring the two products to a TRL sufficient for exploitation and marketing.
- The LEdu educational LAMPRE P&S is peculiar, and based on its TRL score can be considered ready for exploitation.

Table 3 - Resulting P&S evaluation from LAMPRE technical partners used for deriving the products' maturity level.

| | AUTOMATION [0 - 4] | RELIABILITY [0 - 3] | GENERALITY [0 - 3] | TRL INDEX | POSITIONAL INDEX |
|---|---|---|---|---|---|
| LIM | 1 | 3 | 2 | 6 | 132 |
| ELIM | 3 | 2 | 2 | 7 | 322 |
| LSMM | 3 | 2 | 3 | 8 | 323 |
| LSTAS | 3 | 2 | 3 | 8 | 323 |
| 3DSDM | 1 | 3 | 1 | 4 | 131 |
| LRIM | 2 | 1 | 1 | 4 | 211 |
| LEDU | 3 | 2 | 2 | 7 | 322 |

A problem with the adopted scoring scheme is that the final index does not convey information on the values of the single metrics. As an example, a TRL of 6 can be the result of automation = 1, reliability = 2 and generality = 3, or automation = 4, reliability = 2 and generality = 0, which are clearly very different conditions. This limits the use of the TRL score to decide in which of the three categories effort should be placed to enhance the readiness level of the P&S. This is useful for a information for a service provider that may want to invest in the exploitation and further development of the LAMPRE P&S.

In an attempt to cope with the problem, we introduced an additional "readiness" indicator based on a "positional" index (right column in Tale 3). The positional index also uses a single code to show the readiness level of a P&S, but the code maintains the information of the three metrics (automation, reliability, generality) separated. In the positional index, the first (left) digit indicates the score for the automation criterion, the second (central) digit gives the score for the reliability criterion, and the third (right) digit gives the score for the generality criterion. This alternative scheme has two main advantages. First, it allows determining what score is weak and what score is strong. This is important information to decide on where to allocate R&D and other efforts. Second, it allows to consider the different relevance of the three scores. In our case, being "automatic" is considered more relevant than "reliable", or "general". But different combinations are possible, depending on the scope of the evaluation. For example, if the scope of a business is to open new market opportunities in a geographical area or Country, from a market perspective a more "general" product (large value for the third digit) is better (more promising) than a more "automatic" product. However, since the scope of our "readiness" analysis was technical (and not strictly commercial) we maintain that the adopted classification scheme is suitable.

Based on the readiness level given by the positional index, the following specific considerations can be made on the seven LAMPRE P&S:

- For LIM, a significant effort is required to increase automation, reducing the manual activities, which are significant. The amount of work performed by human interpreters remains large, and the experience of the investigators conditions the quality of the results. The level of automation can be increased moving toward a more systematic use of satellite stereoscopic images. The experience of the investigators can be augmented with training.
- For ELIM, the level of automation is already high but can be further improved. Moderate efforts are required to augment the reliability and the generality of the ELIM. The later may be achieved by simply testing the proposed methodologies in additional and different geographical areas.
- For LSMM and LStats, the maturity of the P&S is already significant, minor further efforts can improve the level of automation (e.g., better exploiting modern GIS and statistical computing technologies) and the reliability of the models.
- The maturity of LRIM remains low, for all the three considered metrics, and significant efforts are need to improve automation, to increase the model reliability, and to enhance the generality of the modelling results. The later can be achieved by testing the LRIM approach in several geographical areas and using different transport and infrastructural networks. Further analyses are also needed to compare the result of the LRIM against independent information of the impact of triggered landslide events on transportation networks.
- The maturity of 3DSDM is also comparatively low. Although very promising, efforts are needed to improve significantly the automation of the proposed modelling tools. Despite the fact that the 3DSDM were tested successfully in two real test cases, and compared against other technologies, set-up of the 3D sub-soil geometry for getting the appropriate single element network to run the forward simulations remains difficult. The configuration of the network is done manually, and requires expertise. Additionally, the results of the simulations are very sensitive to small changes in the network. These problems require further R&D efforts and specific training of the investigators.
- For LEdu, the maturity of the P&S is high. Efforts should be bade to improve the reliability and the generality of the available P&S. Exploiting the existing P&S in additional geographical areas, and considering new potential users can achieve this result.

## 4.2 SUSTAINABILITY AND TAKE UP

The objectives of the sustainability assessment were:

- to determine the economic sustainability of LAMPRE as a component of a larger (upstream or downstream) service, encouraging its uptake by a wide user community,
- to understand complementarities between LAMPRE and other services (e.g., DORIS http://www.doris-project.eu) in the wider Copernicus framework, and
- to explore the possibility to establish cooperation and clustering opportunities based on the adoption of the LAMPRE P&S with other projects and actors.

An internal survey helped determine the common vision and mission of LAMPRE, and identify common, long-term goals for consortium members. For each of the seven LAMPRE P&S, attributes were analysed to determine the ease of adoption and the costs to serve the various user segments (Table 4). P&S with a high richness and high ease of integration, and low to medium costs are expected to have the highest chance for take up.

Table 4 - The LAMPRE products & services considered for take up and sustainability in a service, and their main characteristics.

| Attributes | LIM | ELIM | LSMM | 3DSDM | LStat | LRIM |
|---|---|---|---|---|---|---|
| EO Satellite images | Opt VHR | Opt. (V)HR images | Opt (V)HR | SAR (DInSaR) | No | Opt (V)HR (via LSMM) |
| Critical Inputs | Stereo images | Fresh images | Quality LSI / LIM | Continuous monitoring | Quality LSI / LIM / ELIM | LStat, DEM, road maps |
| Rich multiple inputs | No | No | Yes | Yes | No | Yes |
| Expert reliance | Yes | No | For validation | No | No | No |
| Quick Pace | Days to Month | Hrs to Days | Hrs to Days | No: Weeks | Min to Hrs | Hrs to Days |
| Restrictions | Changes of land cover | Clouds + Vegetation | - | Low mobility LS | Low mobility LS | - |
| Purpose | Identification of affected areas | Impact assessment | Prediction probabilistic | Prediction geo-mechan. models | Prediction | Impact simulation |
| Possible Validation | - | - | YES | - | - | - |
| Areas covered | Med to small | Med to very small | Large to Med | Very small | Large | Large to Med |
| Expected Costs | HIGH | MEDIUM | MEDIUM | HIGH | LOW | MEDIUM |
| Ease of Integration | HIGH | HIGH | HIGH | MEDIUM | LOW | MEDIUM |
| Product Richness | MEDIUM | MEDIUM | HIGH | HIGH | LOW | HIGH |

The unequal and widespread distribution of the landslide problem across Europe and the world leads to various responses from local authorities, and a fragmented demand for P&S from authorities, business, and the public. Awareness for landslide issues is highest in mountainous regions that have been affected by recent events. In addition, at the European level, it can be noted that the level of spending into value added landslide services is very small, in the order of a few million Euros.

The business case for LAMPRE addressed the following questions:

- What are the segments that could be attractive for LAMPRE P&S?
- How large is the opportunity in each segment?
- Is there an opportunity to engage into sustained activities in the short term?
- How each segment should be approach to market LAMPRE P&S?

- What is the best go-to-market and operating model for each segment?
- What are the next steps for consortium members?

Demand trends for LAMPRE P&S were assessed for seven user segments, including **emergency**, represented by Civil Protection Agencies, **insurance**, **transportation**, **construction** planning and development authorities, **meteorology**, **scientific** research community, and **media** and other communities. We conducted interviews of potential users to test the attractiveness of LAMPRE in these segments. Based on the insights gathered and on desk research, including on willingness to pay, procurement methods in each segment, and possible business integration drivers, we derived the service delivery methods that would be best for each segment. We also looked into a case study on how similar research on avalanche risk assessment has been spun off into an operational service.

The **Institutions drive** the **emergency segment**. Users include public authorities for prevention and post event response. All products are relevant, but in particular LIM and ELIM for impact assessment, LSMM for zoning, and 3DSDM for detailed analyses of critical slopes. The later is more costly to produce. The business model split roles between institutions and service providers, responding to request from CPAs. Research institutes would continue providing ad-hoc analyses, with experimental improvement in specific areas. The challenge for the operating model addressing this segment is the lack of budget and procurement commitment from CPAs. One approach would be the syndication of needs at national or European level, to recognise that risks unevenly spread could be managed and funded in a coordinated manner. Another challenge is that costs per product cannot be estimated precisely, as P&S require expert inputs that may vary depending on multiple factors. An approach is to consolidate all such procurement at the European level to achieve economies of scale, at least for the most automated part of the service. The market opportunity cannot be confirmed until budgets are better known. The SWOT analysis identified a gap at European and national levels of a budget assessment based on past events, risks, and response levels.

The **land management segment comprises a variety of users**, including municipalities for urban planning, enterprises (public and private) that need to maintain monitoring and risk assessment capabilities in order to protect infrastructure, and assess damage to quickly restore operations. It also includes (re)insurance companies providing insurance coverage on the basis of risks models. These users would be primarily offered LIM, LSMM and LStat, and in some cases 3DSDM and LRIM. The cost effective approach implies a total autonomy of service providers, and a focus on P&S that require little expert judgment. It implies that all relevant IPR are transferred to one or two service provider members of the LAMPRE project. The SWOT analysis identified gaps in the workflow integration leading to a low acceptance by commercial and institutional users. A gap exists in the ability of the consortium members to promoting the P&S to a large pool of users across multiple countries. To ensure take-up, it was concluded that catalogues and inventories should be promoted to end-users e.g., availability of prior assessments should be visible eon a user portal. Transparency should help stimulate demand.

**Enterprises** and **individuals** looking for high level aggregate risk information for decision making represent another opportunity for LAMPRE. Service provision would primarily focus on LIM, LSMM, LStat and to some extent ELIM. Risk information services would leverage market access of established value chains. Two examples were assessed. First, meteorological service providers, which are already integrating natural hazards information in their forecasts and reports. These providers have already developed mobile applications with a revenue model based on “freemium” and advertisement. One service provider of the LAMPRE consortium would provide a continuous service to one of the Meteo service providers. Other products could be developed on the basis of LSMM, in particular to automate the production of susceptibility maps. Several candidates of Meteo service providers were identified. Second, information portals either local (large municipalities touristic areas), or thematic portals (e.g. GeoHazard App). These Meteo service providers and portals generate their revenue from web traffic/referrals, advertisement, and paid subscriptions. Regularly updated automated software provides the basis for the service initially, augmented with value adding LSMM assessment, in particular for local instances of these applications.

Table 5 summarizes the fit of the LAMPRE P&S. LIM and LSMM are expected to be the most popular P&S, and more technical P&S such as LStats and 3DSDM will be attractive to fewer segments. LIM and LSMM P&S are of interest to all segments, and can be established once for all regions of interests. LStats is reserved for specialists such as modellers among scientists, CPA’s development teams, and the insurance companies modelling labs. 3DSDM attracts planning and development authorities, and construction companies.

Table 5 – The LAMPRE products by market segment.

| Segment | Product Fit | | | | | | Willingness to pay | Details |
|---|---|---|---|---|---|---|---|---|
| | LIM | ELIM | LSMM | 3DSDM | LSTAT | LRIM | | |
| Civil Protection Agencies | Fit possible | Fit possible | Fit possible | Fit possible | Fit possible | Fit possible | ◔ | • Strong interest in products<br>• Currently un-clarity on budget |
| Planning & Development Authorities | Fit possible | Very limited fit | Fit possible | Fit possible | Very limited fit | Fit if provided with service | ◕ | • Construction has high budgets<br>• Landslide risk assessed for projects |
| Transport & Utilities | Fit possible | Fit possible | Fit possible | Fit if provided with service | Fit if provided with service | Fit possible | ◑ | • Landslides pose considerable risk<br>• Monitoring often done by CPAs |
| Agriculture & Forest | Fit possible | Fit if provided with service | Very limited fit | Fit if provided with service | Fit if provided with service | Fit if provided with service | ○ | • No immediate cost impact from risk<br>• No direct demand or budget |
| Scientists | Fit possible | Fit possible | Fit possible | Fit possible | Fit possible | Fit if provided with service | ○ | • High interest in landslide data<br>• No direct budget |
| General public | Fit possible | Very limited fit | Fit possible | Fit if provided with service | Fit if provided with service | Fit if provided with service | ◔ | • Interest in low level information<br>• Low budget but large market |
| Weather platforms | Fit possible | Fit if provided with service | Fit possible | Very limited fit | Very limited fit | Fit possible | ◑ | • Possible landslide info. distributor<br>• Monetization through advertisement |
| Insurance | Fit possible | Very limited fit | Very limited fit | Fit if provided with service | Fit possible | Very limited fit | ◔ | • Demand for use in statistical risk models |

Fit possible ■ Fit if provided with service ■ Very limited fit ■

The seven LAMPRE products can be marketed using three service delivery approaches. P&S were allocated to each delivery method:

- Offering standardized products on a **platform** will allow for multiple usages by product and stimulate demand growth. The platform is a way to consolidate information, services, and generate awareness for landslide issue (in particular for municipalities, engineering companies, schools), and research. The platform can be extended to offer LEdu products.
- A **tailored P&S** avenue is no different to what service providers already do with their product line. However, this service provision leverages IPR developed under LAMPRE, and provides a richer portfolio of services.
- A third approach service levels need to be carefully assessed as the products should be simple enough to be integrated into **mass market applications**, and refreshed often enough to provide a value added that can be monetised by the third party accessing LAMPRE database.

The economics of each product were assessed based on high-level assumptions, in recognition that the cost assessment would need to be refined as P&S reach a higher maturity (TRL 8). A business model for the platform portal was established on the basis that CPAs or e.g., DG-ECHO would finance the initial content, and that the service would be maintained and updated by a service provider, in exchange of IPR and exclusivity for exploiting the LAMPRE P&S in other markets. The cost of the initial content (i.e., the number of LIM and 3DSDM products to populate the portal) was assessed. Under a PPP scheme, the potential revenues for a service provider were modelled to determine at which point the service provider would break even.

A SWOT analysis on the business case was executed to give an understanding of the gaps LAMPRE should tackle as an organisation or consortium before going to market. This was a key input to the roadmap. All key participants reviewed the roadmap. The key elements of the roadmap were established for each of the considered go-to-market approaches, in the area of product refinement, service set-up, and commercialisation. For each delivery method, the P&S may need to be refined to reach a sufficient TRL. The service needs to be established with a repeatable process with well identifiable sources for all segments and geographies being served. Finally, commercial activities are required to set up a commercial interface including SLAs, and billing and marketing / promotion processes. The roadmap was presented with a recommended timeline to ensure service availability within 12 to 18 months. Table 6 summarizes the high level roadmap for establishing the LAMPRE service platform.

To prepare for the execution of the roadmap, LAMPRE partners have considered taking specific actions, including setting up a frame cooperation agreement among themselves, and identifying a wide range of EU financial instruments to co-financing, and engaging into P&S refinement, detailed service specifications, and commercialisation actions to implement the above business model. Scenarios for moving forward LAMPRE were identified considering the interdependency of natural hazards and synergies with existing Copernicus-related projects. Different EU programmes (e.g., H2020, COSME, Interreg Europe, Central Europe, ETC MED) financing cooperation and cluster opportunities between projects and/or partner organizations were identified, and considered. A list of the potentially exploitable scenarios includes:

Table 6 – LAMPRE Mass Market Services roadmap.

| PLATFORM DATABASE | STANDARDIZED DATABASE OF LANDSLIDES AND SUSCEPTIBILITY |
|---|---|
| Product | Create a database capable of capturing the output of all LAMPRE P&S in one place.<br>Standardize technical specifications of the products for multiple usage allowing for scale deployment and resource budgeting, automate process as much as possible.<br>Populate database starting in high-risk areas; within the first year of all high-risk areas in Europe should be covered.<br>Leverage LEdu P&S in the creation of a general landslide information platform. |
| Service | Set up central server for landslide database and information site.<br>Create a user-friendly portal for CPAs and other stakeholders to access the database – test interface with the stakeholders.<br>Set up processes to continuously update database with new landslide information.<br>Search for a suitable service provider with the breath to roll out and maintain the database in Europe.<br>Leverage universities, scientists and media to contribute t and benefit from the general landslide information platform. |
| Commercial | Cost assessment of required budget to create database with European coverage.<br>Establish contact to key stakeholders for promotion of new database and feedback on usability of interface.<br>Request of funding for the investment of creating the database to European Commission.<br>Establish pricing mechanism based on costs and stakeholders ability to pay (low cost / free for government bodies, subscription system fro commercial users). |

- Aggregation of organizations (in particular SMEs) exploiting on-going and future calls from H2020 or COSME (for example toward new industrial value chains) or European Structural & Investment Funds (ESIF), with focus on geo-spatial technologies for emergency management and land management.
- Aggregation of EU funded projects, exploiting funding opportunities from H2020. This encompasses: Strengthening the prototyped P&S of LAMPRE by integrating these with other technologies and features in view of achieving greater impact and efficiency, through coordinated actions/operations toward a pan-European service for landslides. (ii) Linking successive projects that build on each other focusing on single (e.g., DORIS & LAMPRE) or multiple hazards (within the Copernicus projects). (iii) Linking parallel projects that complement each other (for approach, expertise, gaps to be filled in, extension of existing platforms), such as the PREFER, PHAROS, LAMPRE (landslides and forest fire) and APHORISM, SENSUM, LAMPRE (seismic, volcanoes and landslides).

# 5 USE AND DISSEMINATION OF FOREGROUND

## 5.1 DISSEMINATION MEASURES

LAMPRE executed a diversified programme of dissemination and outreach activities based on a plan organized in two years. During the first year, the activities focused on establishing a strategy for the optimal promotion of the LAMPRE products and service (P&S) to a wide audience of potential users. This included the identification of the main groups of potential interested users to be targeted by the dissemination and outreach activities (Figure 16). During the second year, most of the dissemination and outreach activities were executed, including the design and production of specific leaflets for the seven LAMPRE P&S, and on-site presentations and field tests of the LAMPRE P&S to specific, interested users.


Figure 16 – Main groups of possible interested users targeted by the LAMPRE dissemination and outreach activities.

Dissemination in LAMPRE was designed with two major, user-oriented objectives. The first objective consisted in **increasing the awareness** on LAMPRE, its activities, the results obtained, and the P&S. The second objective aimed at **improving the understanding** of the scientific and technological advancements made by LAMPRE, and the technical specifications of the LAMPRE P&S.

Different means and media were used for dissemination, including online activities through the project web site, printed materials (flyers, brochures, product leaflets, a poster), publication in peer-reviewed scientific journals, interactive (personal) presentations and discussions at close-doors and public events.

The LAMPRE web site (**http://www.lampre-project.eu/**) was a dynamic platform used to inform a diversified audience on the project activities, including the LAMPRE educational activities, and the P&S offered by LAMPRE. Organized in five sections (News & Events, About LAMPRE, Knowledge & Results, Beneficiaries, LAMPRE Educational), the web site provided background information on the project objectives, the consortium members and their expertizes, the project test sites, the individual P&S and their technical characteristics. The web site also published news and events related to the project, and on promotional activities. A specific, password protected, section of the web site was used to organize and exchange working documents and materials among the project partners.

The main scientific and technological results obtained by LAMPRE were presented at a number of national and international, general and specific (thematic) conferences, congresses, and workshops, including General Assemblies of the European Geosciences Union (EGU), in 2014 and 2015, and Fall Meetings of the American Geophysical Union (AGU), in 2013 and 2014. The most relevant scientific results were published in nine papers in international, peer-reviewed journals. Other papers are under review or in preparation, and will be published during the year or in the next year.

LAMPRE participated to private and public networking events, including the Supersites Coordination Workshop organized by the EC in June 2013 in Brussels, the European Space Solutions conference held in June 2014 in Prague, and the Copernicus Emergency Projects Workshop in December 2014 in Brussels. LAMPRE contributed to a number of public outreach events, including the NEREUS Space4You Conference held in Bari in February 2014, the Space Research Conference held in Rome in September 2014, and the European Space Expo held in Genoa in October 2014. LAMPRE will participate to the European Civil Protection Forum 2015, held in Brussels in May 2015.

LAMPRE printed dissemination materials included flyers, brochures, product leaflets and folders and a poster. Following specific recommendations from the LAMPRE Steering Committee and the Stakeholder User Group (SUG), a set of leaflets were prepared to describe the LAMPRE P&S. The leaflets, produced in four languages (English, Spanish, Italian, Chinese) present in a clear and simple language **what** each LAMPRE P&S is or does, **where** and **when** it can be produced, and **who** are the main users of the P&S. The leaflets can be downloaded from the project we site.

LAMPRE has organized a number of **targeted dissemination events**. Some of these events were aimed at informing the project Stakeholder User Group (SUG). The LAMPRE SUG was aggregated at the beginning of the project to expose a qualified audience of existing and potential end users and stakeholders from twelve different Institutions to the results of LAMPRE, facilitating the up take of the project results, and to obtain from the same users and stakeholders feedback to improve the quality and usability of the P&S designed and delivered by LAMPRE. Three specific events were organized for the SUG. The first event was held in London in February 2014, hosted by King's College London. The second event was held in Genoa in October 2014, hosted by the Regional Civil Protection Office. The second meeting provided an opportunity to visit the Cinque Terre area, a UNESCO world-heritage site disrupted by landslides and flash floods in October 2011, and where LAMPRE had produced a post-event ELIM. The last meeting of the SUG was held in February 2015, at the Research Executive Agency in Brussels. During this meeting the SUG members expressed their opinions and provided a final feedback on the lessons learnt and on the P&S delivered by LAMPRE.

Other LAMPRE outreach events consisted in the organization of **training activities**. These events consisted in 2- to 5-day sessions with general presentations, technical lessons, tutorial and hands-on practicals that allowed a selected number of users to learn about and experiment with the LAMPRE P&S. These events were organized at the Geological Survey of Israel, in Jerusalem in May 2014, at the Road Maintenance Service of Mallorca, Mallorca in June 2014, at the Istituto Geologico Y Minero de Espana, in Madrid in June 2014, and at the University of Costa Rica, in San José in January 2015.

Lastly, LAMPRE has organized a Final Conference held in Brussels in February 2015, and hosted (and co-organized) by the Royal Belgian Institute of Natural Sciences, at their Museum. The event, co-organized also by EuroGeoSurveys, the not-for-profit organization of the Geological Surveys of Europe, served the purpose of informing representatives from more than 20 national Geological Surveys in Europe on the results achieved by LAMPRE, and of the availability of the LAMPRE P&S.

## 5.2 EXPLOITABLE FOREGROUND

LAMPRE has developed a portfolio of P&S that can be taken to the market, pending a few actions to take the P&S into fully marketable services. We maintain that, for a marginal investment, the European Commission could stimulate the downstream market and create capacity at many European CPAs. This PPP should provide a win-win for all parties. The **Service Provider**(s) get market access in exchange of a commitment to maintain the LIM database up-to-date. The **European Commission** is building capacity for the CPA's and stimulates the EO market to reach out to new segments for further growth. **CPA**'s can rely on an up-to-date LIM database and get free access to basic products and preferential rates for higher accuracy products. **R&D centres** can use the platform as a centre of excellence to increase awareness of the landslide issues and of the usefulness of additional research to reduce risk to populations.

### 5.2.1 COMMERCIAL EXPLOITATION OF LAMPRE P&S (EC CONFIDENTIAL)

Outside the CPA segment, LAMPRE estimates the potential take up to be €11.8 million per year within a few years of initial operations broken down as follows: (i) Insurance segment, €0.5 million, (ii) General public (via weather platform), €0.5 million, (iii) Transport segment (direct, and via weather platform), €5 million, (iv) Construction segment, €5.7 million, and (v) Education segment, €0.1 million. The CPA segment could represent between €4.5 and € 6.0 million, bringing the total opportunity to €16.3 to €17.8 million per year. In comparison, the overall value added services market for geological services, crisis, vulnerability, and land motion represents about €115 million[4] in 2015.

[4] Source: EARSC survey 2013, Euroconsult, Strategy& analysis, assuming constant CAGRs since 2012.

The business plan hinges on key parameters, and optional measures. The parameters include the initial funding level, which influences the richness of the content of the initial database, to make it useful from start. The level of subscriptions and the number of communities using LAMPRE will influence the resources available to continue fund the basic database. We expect that the service should be offered for free to the CPAs, as these institutions are likely not able to pay and have their own expertise. How often the database should be updated to maintain relevance to public users will also drive the business case. Customer revenues would help the service providers to capitalise on their investment. Finally, the level of additional funding will drive the effort to bring 3DSDM and LRIM at a higher TRL, and to generate a derivative of LRIM for e.g., railway operators.

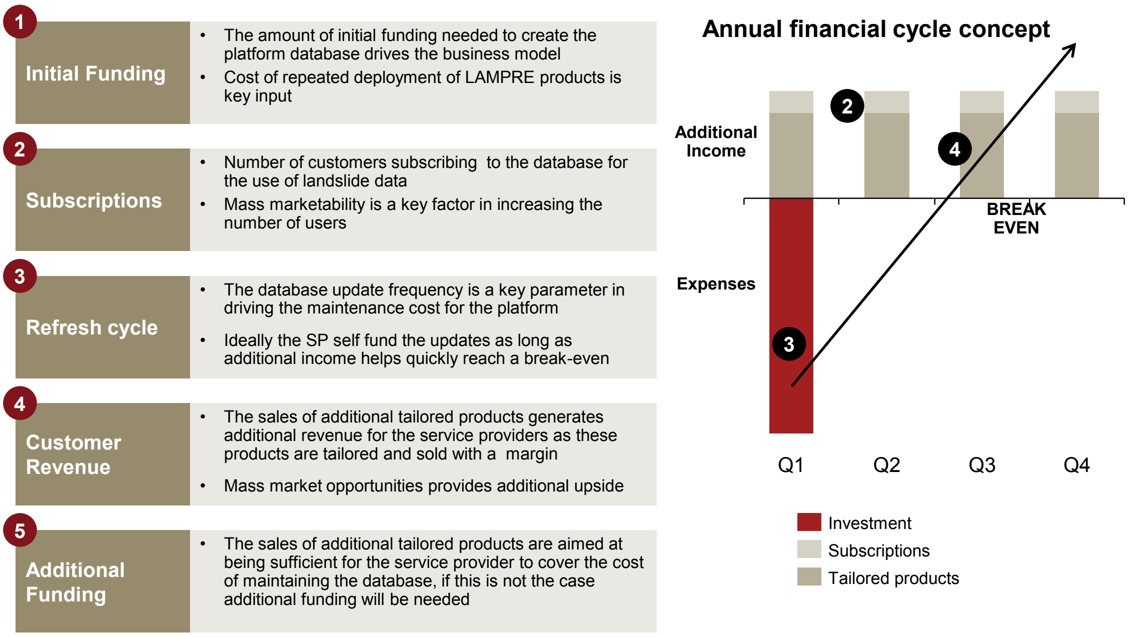


Figure 17 – LAMPRE Business Model Parameters.

In the **first go-to-market approach**, a value added service provider develops and maintains a portal platform hosting the LIM/LSMM and LStats. The business model assumes that the platform portal and first initial content is financed through external funding. This initial content would represent 10 European regions at 1:100,000 (i.e., regions of 60 km × 80 km). A more ambitious assumption for the initial content would consider 50 regions. The service provider would not invest in the portal, but it would guarantee keeping the platform running and up to date with new content, on the basis of LIM or LSMM add-ons on a regular basis (e.g., three additions per year).

In the **second go-to-market approach**, the focus is on service provision by service providers. It consists in developing further the line of P&S to address railway and other situations, and to create pilot assessments together with key target customers in engineering companies, road operators, railway network operators. Most complex pilots are estimated to cost €300,000 to €400,000, allowing development of process integration at the customer. It is suggested to start with one pilot implementation co-financed by the customer.

In the **third go-to-market approach**, the focus is on monetising the products through mass-market applications. The approach is most effective when combined with the first approach, to leverage the platform as a consistent source of information. This go-to-market approach requires the development of an interface specific to the partner retained. Depending on the agreement, this could be financed through the deal with the data distributor.

To prepare for the execution of this roadmap, the LAMPRE consortium partners are considering taking the following three main actions.

First, **setting–up a frame cooperation agreement**. This action is lead by CNR, ALTAMIRA and IGME.

Second, **identifying a wide range of EU financial instruments to co-financing**, including (i) the advancement of LAMPRE products in the TRL path (such as H2020 and COSME), (ii) the implementation of the P&S at regional and local levels through European Territorial Cooperation programmes (e.g., the Interreg Europe Programme, the ETC MED Programme, the Central Europe Programme), (iii) the possibility to integrate P&S of different Copernicus-derived projects through cooperation and clustering programmes, and (iv) the possibility to develop novel public-private partnership (through PPP and P2P instruments) which support the uptake of LAMPRE products and services by regional and local authorities. Some early meetings have been occurring after the Final Conference between ALTAMIRA, CNR, UP and the coordinators of other Copernicus projects (e.g., PHAROS, PREFER), discussing cooperation scenarios and financial mechanisms already identified. This action is lead by CNR, UP, ALTAMIRA and IGME.

Third, contracting the **set-up of the P&S refinement**, detailed service specifications, and commercialisation actions required to implementing the proposed business model. For a marginal investment of €500,000 at the minimum, the European Commission could stimulate the downstream market, and create capacity at many European CPAs.

### 5.2.2 OPPORTUNITIES TO EXPAND MARKETABILITY OF LAMPRE P&S

LAMPRE has investigated cooperation and funding frameworks that could help completing some of the pending actions needed for the P&S to be taken to the market profitably. For the purpose, existing and foresee programmes of the European Commission (EC) and of the European Space Agency (ESA) were examined.

Two potential frameworks for collaboration between current FP7 projects were identified. Both frameworks may allow the enhancement of LSMM and ELIM to consider different triggering factors. The first framework envisions collaboration between LAMPRE and the PREFER (http://www.prefer-copernicus.eu/) and PHAROS (http://www.pharos-fp7.eu/) FP7 projects, and aims at studying interactions between forest fires, erosion and landslides for improved susceptibility models and triggering events. The activity will allow the development of an in-depth study of how combining burn scars and vegetation recovery information as an indicator of change of the land cover (and properties) would result in new methods to improve the susceptibility analysis and therefore improved risk assessment over burned areas followed by intense rainfall events. The second framework envisions collaboration between LAMPRE and the APHORISM (http://www.aphorism-project.eu/) and SENSUM (http://www.sensum-project.eu/) FP7 projects for studying multi-hazards interactions and cascade events related to earthquakes, volcanic hazards and landslides in different geographical areas and geological settings.

The UNIFI, IGME, CNR and DPC LAMPRE partners, together with other Institutions, have responded to EC ECHO call Sentinel for Geohazards regional monitoring and forecasting, proposing the SAFETY project. The project proposes the possible exploitation of various P&S, including some of the P&S developed by LAMPRE, to enhance multi-risk mitigation actions performed by CPAs, with a focus on urban areas.

ALTAMIRA and CNR have together taken results and technological developments obtained by LAMPRE into new project proposals for the European Space Agency. Two of these proposals were accepted, and development of the new projects is under way. The first project - land cover change detection and monitoring methodologies based on the combined use of S1&2 for natural resources and hazard management - aims at developing new methods for the “fusion” of ESA Sentinel-1 (radar) and Sentinel-2 (optical) data for improved mapping of event landslides and floods. The idea of the project is to further expand the semi-automatic change detection methods developed and used in LAMPRE for the detection of event landslides and inundated areas using EO data. The MEMpHIS - Multi Scale and Multi Hazard Mapping Space based Solutions project is experimenting the migration of some of the LAMPRE products as services delivered by the ESA Geo-Hazard Thematic Exploitation Platform (TEP), for the production of landslide and hazard maps. The project considers the combination of LAMPRE (mainly with optical data) and DORIS (mainly with SAR data) solutions for improved landslide mapping and zonation, and the interactions and chain effects between landslides and other natural hazards.