Final publishable summary report

1. Executive summary

During these three years of activities, APhoRISM completed all the tasks finalising the development of the two proposed methodologies: MACE, the Multi-platform volcanic Ash Cloud Estimation method, and APE, the A Priori information for Earthquake damage product method. Many efforts have been dedicated to analyse huge datasets coming from satellite sensors and ground data, with the objective to improve current products addressing emergency management in the field of volcanic eruptions and seismic events.

The ash cloud characterization maps (ash cloud mass, ash cloud detection, ash cloud optical depth, effective radius and mass loading, and volcanic cloud top height) have been generated for many different volcanic events (past and recent), trying to address exhaustive case studies, in different weather conditions, and with different types of Earth Observation (EO) data. A very detailed work has been performed to improve the estimation of all the single parameters that influence the final accuracy of the ash retrievals. MACE has been successfully implemented to integrate data acquired by Low Earth Orbit platforms, Geosynchronous Orbit platform, and ground sensors aiming at providing retrievals that are more accurate for delivering new products useful for the management of volcanic crises.

The seismic team of APhoRISM finalised the implementation of the APE method. The three years of activities have been focused on a deep screening of change detection methods with the objective to select the best performing damage proxy from EO data. A detailed review has been done, exploring several satellite-derived features that are sensitive to urban damage (e.g. textural parameters, Kullback-Leibler Divergence, Correlation indexes, etc.). Beside the analysis of satellite data, a lot of work has been dedicated to the identification of parameters suitable for defining soil instability and vulnerability scenario. The integration of geological data and buildings structural vulnerabilities have been tested as a priori information layers to improve damage mapping accuracy.

Two different types of damage maps have been generated: a damage map at single building scale, and a damage map at city block scale. The first type expresses the damage grade in the European Macroseismic Scale '98 (EMS98), and is able to discriminate between damage grade 5 (collapse) and less than 5. The second type of map provides information in terms of Collapse Ratio (i.e., numbers of collapsed buildings with respect the total numbers of buildings in a certain area) for each city block considered. Both products demonstrated that the implemented data fusion algorithms of APE increase the thematic accuracy of the map.

All the products generated with MACE and APE have been validated thanks to a specific work package that analysed all the project case studies. Ground truth (from in situ surveys) and independent data have been collected and compared to the EO derived products.

Finally, a market analysis and a business plan have been setup for looking at possible APhoRISM foreground exploitation. A potential market for volcanic products has been identified, and a market strategy for a possible service has been considered. As far as seismic products, a potential market in the domain of Insurance and Re-insurance companies has been identified, although damage products need a further development to make them more suitable insurance industry.

2. Summary description of project context and objectives

Satellite remote sensing has demonstrated to have unique capabilities in terms of spatial coverage, spatial density of measurements and synoptic view of the investigated area. In the same time ground based techniques are better suited for point measurements with high accuracy, and generally better time repetition, but generally ensure scarce density and limited coverage. Although the scientific and technical background are different, the scientists dealing with the use of satellite and ground data more and more agree that these two sources of data have to be used together. APhoRISM is a project

addressing the development of innovative products based on space and ground sensors and ground data to support the management and mitigation of the seismic and the volcanic risk.
The objective of the project was to demonstrate that satellite remote sensing data and ground data, appropriately managed by means of novel methods, can provide new and improved products to be used by the stakeholders for managing seismic and volcanic crisis. Stemming from a wider exploitation of available instruments, the project aims at achieving new performances in terms of accuracy and quality of information. In APhoRISM we propose two methods to combine in a fruitful way Earth Observation (EO) data from satellite and ground data. The first one regards the development of remote sensing methods for monitoring the volcanic crisis. The second one concerns the generation of products supporting seismic crises events. Concerning volcanic crisis, the outcome is the Multi-platform volcanic Ash Cloud Estimation (MACE) method (see for a detailed description Section 1.2.1.1). The MACE method exploits the complementarity between GEO (Geosynchronous Earth Orbit) sensor's platform, LEO (Low Earth Orbit) satellite sensors and ground measurements to improve the ash detection and retrieval and to fully characterise the volcanic ash clouds from source to the atmosphere. The basic idea behind the proposed method consists to meaningfully improve (calibrate and integrate), in a novel manner, the volcanic ash retrievals at the space–time scale of typical geostationary observations using both the LEO satellite estimations and in-situ data. The typical ash thermal infrared (TIR) retrieval will be integrated by using a wider spectral range from visible (VIS) to microwave (MW) and the ash detection will be extended also in case of cloudy atmosphere or steam plumes. As far as the seismic crisis is concerned, APhoRISM developed a procedure to deliver a damage map of the epicentral region of an earthquake addressing the detection, analysis and estimate of changes occurring to buildings and infrastructures (see a full description in Section 1.2.2.1 "A Priori information for Earthquake damage product (APE)"). The APE method obtains a damage map by integrating a-priori information and change detection products from satellite images taken before and after the earthquake. Different sources of a-priori information were investigated and processing methods specified in the form of an Algorithm Theoretical Base Document (ATBD). They include InSAR (Interferometric Synthetic Aperture Radar) time series measuring possible surface movements in and around the study area, information about the stability or subsidence of soil and about structural vulnerability of individual buildings (both a macroseismic and a mechanical approach were developed). The integration algorithm merges all these pieces of a-priori information with the detection of changes observed by EO sensors and, in addition, ground shake-map-derived seismological data. The resulting product is a Likelihood Index Damage Map (LIDaM), which represents a map of group of buildings or single buildings and infrastructures that are likely collapsed or strongly damaged.
The APhoRISM products are strongly oriented to the developments of innovative Copernicus products thanks to the exploitation of existing and upcoming sensor data and in-situ data in a novel manner. In particular, the methodologies proposed in APhoRISM are suitable to be implemented in the next generation of Earth observation ESA SENTINELS satellite systems. Despite the apparent different nature of the described methods, it is worth noting that most aspects, including the scientific background, related to the natural hazard and the disaster mitigation and management are common to the proposed products. Further links concern the wide use of multi-sensor and multiplatform satellite data, common algorithms for data managing, combination with ground data. Moreover, the APhoRISM products, for both seismic and volcanic themes, involve and address to the same user community, i.e. the Civil Protection Department, and both products are expected to be a step forward state of art in each framework. The methods and products of APhoRISM were tested in some selected regions prone to high seismic or volcanic risk and characterised by extensive settlements, presence of critical infrastructures and large availability of EO and in situ data.

3. Main S&T results/foregrounds

The section reports all the achievements of the project, addressing the user requirements and expected future work for exploiting APhoRISM foregrounds towards volcanic and seismic crises management services. The section is divided into two subparts, one related the volcanic theme, and one related to the seismic theme of the project.

a. Volcanic Products

Summary of the activities:

During the first period of the APhoRISM project (from M0 to M18) it has been given importance to the improvement of the procedures that are the base of the MACE approach, i.e. those connected with the volcanic ash cloud detection, retrieval of ash cloud optical depth, effective radius and mass loading, and with the volcanic cloud top height (VCTH) estimation, a parameter that deeply affects the retrievals.

The improvements sought for were aimed to reduce the need of supervision on the initial phases of an eruptive event, i.e. those corresponding to a possible volcanic ash cloud alert onset, and on the following tasks related to the monitoring of the cloud trajectory evolution.

The ash cloud detection based on the use of neural networks (NN) recently developed and applied for MODIS data to Mt. Etna (Sicily, Italy) has been generalised to cover a wider area, to define more classes for a better coverage of the different scenarios that can be met during the satellite image classification, and tested on SEVIRI data with promising results. Once the NN is trained and tested its application is straightforward, and the outcome is generated very quickly when new satellite images are available with an high hit rate and an interesting drop of false alarms. Moreover, the classification of the surface underling the volcanic ash cloud allows a significant reduction of the uncertainty on ash retrievals. Pixels identified as ashy by the NN can be suitably used as an ash cloud mask in further processing steps, reducing retrieval computation time and errors.

The ash cloud retrieval procedure used for the MODIS and SEVIRI image processing is based on the VPR procedure (see D3.1; Guerrieri et al., 2013; Pugnaghi et al., 2016). It uses the cloud mask generated by the NN detection and needs as input only the ash cloud altitude and temperature. The VPR retrievals have been compared with those obtained by other approaches to verify their accuracy. VPR is an excellent starting point for estimating the initial products, which then have to be integrated in the MACE method because it gives accurate results, is easy to use and extremely fast. During this first phase of the APhoRISM project, the procedure has been further improved (see D3.1 for details).

In addition to the improvement of the VPR procedure, the capability of the ground radar system (see D3.2; Corradini et al., 2016) to discriminate between the ash travelling horizontally and the ash fall out was preliminary investigated on a case study basis. The retrieval of the travelling ash layer based on radar measurement is important because it allows to constrain the volcanic ash thickness in the near source area and then to obtain the ash concentration from the volcanic ash mass derived by IR satellite estimates.

Being VCTH one of the most important parameter needed for the ash retrievals, a particular attention has been dedicated to improve the procedures for its determination. Among the common approaches based on dark pixels, the following of the ash centre of mass and the radar measurements, the parallax effect between GEO satellite-ground radar and GEO-LEO satellites measurements, have been also investigated (see D3.5; Corradini et al., 2016; Merucci et al., 2016).

The retrieval strategies of all the other LEO and ground based instruments involved in the MACE approach have been described in D3.1 and D3.3.

The activity of the second period of the APhoRISM project (from M18 to M37) was focused on the development of MACE approach, its test and validation on major eruptions selected either from recent or past representative events (see D3.4 and D3.5 for details).

D3.4 addresses the spatial collocation and geocoding on the SEVIRI reference grid of available datasets and ash products that is at the base of the MACE approach, applied to the event chosen as the first and main test and validation case for the project, i.e. the Mt Etna (Italy) lava fountain occurred on the 23.11.2013. The GEO-LEO, GEO-ground, and GEO-GEO data collocations were introduced showing the collocation results obtained by using SEVIRI as reference GEO instrument, and MODIS, radar and MVIRI datasets for the three cases respectively (see D3.4; Corradini et al., 2016; Merucci et al., 2016).

The general MACE architecture articulated in the four *collocation*, *pre-processing*, *integration* and *retrieval* phases has been thoroughly reviewed and applied to clear and cloudy sky conditions test cases during the second part of the project (see D3.5).

The collocation and geocoding initial phase with the SEVIRI reference dataset has been described for the 09:45 UTC MODIS image collected during the Mt. Etna 4.12.2015 eruptive event (GEO-LEO), and for the Radar X ground-based measurements (GEO-ground based) and the MVIRI images of the Mt. Etna 23.11.2013 lava fountain (GEO-GEO). The parallax correction for the different viewing angle of the sensors, and the temporal and spatial interpolation required to match the reference grid have been addressed and yielded to novel approaches for the ash cloud height estimation (Corradini et al., 2016; Merucci et al., 2016). The *pre-processing* phase has been explained using two images acquired by SEVIRI and MODIS sensors. The MODIS products were re-collocated to match the SEVIRI image with a cross-correlation technique that establishes which average displacement provides the highest correlation between the ash clouds seen by the two sensors. The *integration* phase has been addressed with a number of different modules and techniques considered better suited for the integration of different types of data. This is because there is currently no general recipe on how different datasets can be integrated in an optimal way, and the best approach varies from case to case. The parallax and ash cloud height modules affect the actual position of the cloud, and a weighted average module for the integration of the maps of the products have been discussed and applied to the recent Mt. Etna eruption occurred on the 4.12.2015. Novel products such as ash cloud concentration, total mass and total grain size distribution have been defined and applied for the test cases where the required supplementary datasets were available. In the retrieval phase, the improved and new products characterising the volcanic ash cloud (ash mass, effective radius, AOD, ash concentration, volcanic cloud height and thickness) are generated, and finally collocated again on the SEVIRI grid to account for the parallax effect due to the different viewing angles of the different sensors. The retrieval phase has been tested and verified by applying the MACE processing to the eruptions of volcanoes Etna (23.11.2013, 3-5.12.2015; Corradini et al., 2016; Merucci et al., 2016), Calbuco, Chile (24.4.2015; Marzano et al., 2017), Holuraun, Iceland (6.9.2014; de Michele et al., 2016) characterised by clear sky conditions and Etna (27.07.2001, 12.05.2011, and 23.11.2013), Eyjafjallajökull (8-9-11.05.2010; Picchiani et al., 2014) characterised by overcast weather (see D3.5). Additional results were obtained with novel techniques developed during the project, including TIR images classification based on Neural Networks, ash detection using SAR data, ash detection based on GPS data (Aranzulla et al., 2014), while recent approaches based on Radio Occultation measurements were considered for the ash cloud height assessment.

User Requirements and Achievements:

Table 1 and Table 2 show the DPC and VAAC user requirements (see D2.1) in which a column has been added to emphasize the achievements obtained during APhoRISM . These user requirements are common to all the different integrated ash products (ash mass, effective radius, AOD @550 nm, concentration, VCTH and detection).

PRODUCT	ASH CLOUDS CHARACTERISTICS	***APhoRISM Achievements***
FIELD of USE	CRISIS	
SPECIFIC QUESTIONS related to the proposed PRODUCTS		
Expected BENEFITS from the proposed products		
What are the benefits? Areas, methods, improved?	General improving of the National early warning system by the integration between ground based and EO data. Near real time mapping of the crisis areas during the event.	*The improvements of the MACE integrated products have described analyzing the different test cases (see D3.5). They are related to the improvement of the accuracy and the generation of new products.* *Moreover also the products generation in near real time has been shown (every 15 minutes).*
Benefits for populations?	Near real time mitigation actions for safeguard of population. General advancing of the decision support system of the Civil Protection Authorities	*The main advance in support the decision of the Civil Protection and Authorities is linked to the production of improved and new products that can be used in near real time (see for example the ash concentration maps).* *Moreover the improvement of the source characterization lead to an improvement of the ash cloud forecast, extremely important to mitigate the effect of the eruptions.*
Expected minimum time performances	Crisis: 6-12 hours based on most frequent data availability	*Done*

Expected optimum time performances	Rapid availability of the products, need to be improved space systems both for space and ground segments in order to became operative. Crisis: 15 minutes	*The results obtained during the project demonstrate the ability to deliver the ash integrated products every 15 minutes (the time frame of the SEVIRI images)*
Delivery time frequency **Time frame between the first product delivery and its updating**	Crisis: 15 minutes	*Done, see above*
Delay **Between the ordering and the disposal**	6 – 24 hours after the event	*Done, see above*
Preferred Volcanic ash product	Ash Mass/Concentration/Altitude	*The test cases analyzed during APhoRISM shows the ability of MACE to produce Ash Mass/Concentration/Altitude maps integrated and improved products. In particular during APhoRISM two novel procedures have been developed for the VCTH retrieval maps using GEO and LEO satellite systems.* *(ref: D3.4; D3.5; Corradini et al., 2016; Merucci et al., 2016; Marzano et al., 2017)*
Delivery mode	Format: cartographic, raster, vector Communication protocol: web and download Time frame: regular basis and one shot under crisis.	*Done*

Table 1. DPC User Requirements and Achievements during APhoRISM

PRODUCT	ASH CLOUDS CHARACTERISTICS	***APhoRISM Achievements***
FIELD of USE	CRISIS	
SPECIFIC QUESTIONS related to the proposed PRODUCTS		
Expected BENEFITS from the proposed products		
What are the benefits? Areas, methods, improved?	General improving of the real time monitoring system by the integration between ground based and EO data.	*The improvements of the MACE integrated products have described analyzing the different test cases (see D3.5). They are related to the improvement of the accuracy and the generation of new products in near real time.*
Benefits for aviation?	General advancing of the decision support system	*The advancing of the decision support system is due to the generation of near real time improved volcanic cloud products and source characterization. In particular, this latter lead to an improvement of the ash cloud forecast, basic for decision makers.*
Expected minimum time performances	15-60 minutes	*Done*
Expected optimum time performances	Less than 15 minutes	*The test cases proposed show the ability of MACE to deliver the integrated products every 15 minutes. In the Northern hemisphere SEVIRI can be also used in rapid scan mode (i.e. one image every 5 minutes), but this configuration has not been tested.*
Delivery time frequency **Time frame between the first product delivery and its updating**	15 – 30 minutes	*Done (see D3.4; D3.5)*
Delay **Between the ordering and the disposal**	15 – 60 minutes	*Done (see D3.4; D3.5)*
Expected minimum spatial resolution	SEVIRI spatial resolution	*3x3 km^2, sub satellite point*
Expected optimum spatial resolution	1 km	*This spatial resolution will be obtained with the (Meteosat Third Generation (MTG), that will be launched in 2022.*

Expected minimum vertical resolution	None	*N/A*
Expected optimum vertical resolution	0.5 km	*For the Volcanic Cloud Top Height (VCTH) the uncertainty is about +/- 1 km*
Preferred Volcanic ash product	Ash Mass/Concentration/Altitude	*Done (see D3.5; Corradini et al., 2016; Merucci et al., 2016)*
Delivery mode	Format: images (GIF, BMP, TIFF etc.), Binary (Netcdf etc.) Communication protocol: web and download Time frame: regular basis and one shot under crisis.	*Done*

Table 2. VAAC User Requirements and Achievements during APhoRISM

MACE products Validation

As detailed in D5.4 all the MACE products have been validated by considering different test cases. The validation procedure consists in comparing the quantitative improvement achieved using the new integrated approach, MACE, with respect to the conventional ones mainly based on different systems and/or models. In some cases, although we tackle with the difficulty of disposing of ground truth for the estimated parameters, as frequently discussed during the project, we succeed in validating the results comparing the products with independent measurements from other techniques, or estimates obtained through consolidated models or methodologies. This aspect represents probably the main issue of the validation activities, which demanded for each case a specific approach. Despite this challenge, the quantitative improvement of the new products with respect to the state of the art is generally demonstrated. The results reported in this document mainly consists in a comparison of the results available through a standard way with respect to that obtained with the integrated approach.
The validation is discussed analysing events where the retrieval tools are applied both with clear sky and cloudy sky conditions. The number of analysed events is greater than that initially scheduled in the DOW because during the project duration some new interesting events took place. Among the selected sites the Etna Volcano outstands, being one of the world's most active volcanoes with a significant set of sensors often available during the main events.

As discussed in the reference documents dedicated to the generation of the products, the detection of volcanic clouds, and the retrieval of ash parameters using “standard procedures”, i.e. based on optical data, can be significantly affected by the presence of meteorological cloud, reducing the reliability of the proposed techniques. The outstanding innovative issue of MACE is the integration of sensors or

techniques also to overcome this limit. For this reason, and in agreement with the D3.5, the volcanic product outcomes, including this report about validation, have been separated in two different cases according to the sky conditions.
All the MACE integrated products, measurement units, accuracy, processing and delivery time are reported in Table 3. The accuracy is estimated according to D3.4, Picchiani et al., 2014, Corradini et al., 2016, Merucci et al., 2016, Marzano et al., 2017.

Product name	Product Description	Meas. Unit	Format	Accuracy	Processing Time	Delivery Time
RET-ASHM	Ash Mass map	t/km^2	Binary, txt, JPG etc.	30%	10 min	15 min
RET-ASHR	Ash Effective Radius	μm	Binary, txt, JPG etc.	30%	10 min	15 min
RET-ASHA	Ash AOD at 0.55 □m	-	Binary, txt, JPG etc.	30%	10 min	15 min
RET-ASHC	Ash Concentration map	mg/m^3	Binary, txt, JPG etc.	30%	10 min	15 min
RET-ASHH	Ash Height map	km	Binary, txt, JPG etc.	30%	10 min	15 min
RET-ASHD	Ash Detection map	-	Binary, txt, JPG etc.	Improved in clear sky conditions	10 min	15 min

Table 3. MACE integrated products, measurements unit, accuracy, processing, and delivery time.

Limitations of products and methods:

The experience done so far with the volcanic ash products integration clearly indicates that currently there is no general recipe applicable on every product and every different dataset. The methods applied to perform the integration and described here, and in the preceding WP3 deliverables, have been studied for each product considering a number of dependencies that all have an effect on the final result. As addressed in deliverable D3.4, the projection of different datasets on the same coordinates system implies an interpolation, and this step introduces artefacts that depend on the specific interpolation method that is used. Therefore the error introduced by the adopted interpolation scheme should be estimated to evaluate its impact on the MACE processing workflow and on the final result. Similar issues are related to the different product data types. For instance the ash cloud top height could be either expressed as the average height for the whole volcanic cloud, as a variable number of geo-referenced VCTH assessments (i.e. as a sparse map of VCTH values), or as a geo-referenced dense matrix of VCTH values retrieved on the whole region where the volcanic cloud is detected. These representations depend on the adopted VCTH retrieval scheme, and have different effects on the retrieval of other parameters (such as the mass, the effective radius or the aerosol optical depth of the ash cloud) that should be evaluated in each case. Along with the spatial resolution, the acquisition repetition cycle has its own impact on the integrated result that varies for each instrument (either space- or, when available, ground-based). This impact requires to be studied in detail in each case, as it has been done during the APhoRISM project.

MACE operational scenario and perspectives for the future:

Concerning the sensors aboard geostationary platforms, the foreseen evolution of the Earth Observation (EO) capability will soon allow remarkable improvements on spatial resolution and acquisition frequency with continuous and global coverage. These technological advances will generate an increased data flow (see the D3.4 deliverable and Merucci et al., 2016) with the consequent need to process and integrate this wealth of high quality EO data. The MACE approach has been defined with SEVIRI as a base geostationary instrument and therefore appears limited to the Europe and Africa region. However, as already remarked, it can be applied relying on any similar geostationary instrument, allowing the different Earth sectors complete coverage for an effective and global monitoring (see Figure 1).

The different sources of information have also different temporal resolutions. The different acquisition times have an impact on the integrated result that varies for each satellite or ground-based instrument. However, the actual and foreseen evolution of the GEO Earth observation capability, allows meaningful improvements on temporal collocation between different measurements. The new generation of HIMAWARI-class instruments, will have a repetition time of 10 minutes for all the hemisphere compared to the current SEVIRI full disk acquisition cycle of 15 minutes. Moreover, the SEVIRI "Rapid Scan Mode" allows a 5 minutes repetition cycle on the Northern hemisphere and similar features in the new sensors will improve the repetition cycle accordingly. The availability of GEO images in such a short time interval will provide GEO datasets increasingly closer in time to LEO and ground-based measurements. This will reduce the unavoidable inaccuracies due to the acquisition time mismatch between different measurements, as well as the error induced by the interpolation procedures used to correct for these acquisition time differences.

From the MACE perspective, these technological improvements of the EO instrumentation temporal resolution will naturally yield to the improvement of the GEO, LEO and ground-based measurements integration.

- A different approach need to be set up when only GEO -SEVIRI observation is available. In this case parallax need to be compensated using the vertical thermal profile coming, for example, from radiosoundings or forecast model outputs.
- So far, the main hypothesis made in the parallax compensation procedure is that the plume altitude is constant along its extension. This can be in general not true especially if the plume is detected over a path of several kilometers. In this case a refined procedure to take into account the spatial variations of the plume altitude might be investigated.

As the GEO-GEO section shows, the 23 November 2013 test case can be used to demonstrate the feasibility of this scheme of ACTH estimation based on GEO-GEO image pairs, and to investigate the advantage and drawbacks with currently available datasets. MVIRI sensor has a poor spatial and spectral resolution. However, in the near future the situation will improve significantly (see Figure1). The new generation multispectral sensors - i.e. Flexible Combined Imager on MTG-I, Advanced Baseline Imager, Advanced Himawari Imager, Advanced Geostationary Radiation Imager, Electro-

GOMS Imager for Electro M (MSU-GSM) - on board geostationary platforms will have many more bands and a thermal infrared spatial resolution comparable to that currently achieved by the SEVIRI HRV visible channel (http://www.wmo-sat.info/oscar/). After year 2020 is expected that all sectors will be covered with redundancy by third generation imagers, except sector 180°± 30° which lacks backup. Nevertheless, even this latter sector will be partially covered by instruments on board the Himawari and GOES-W platforms (see Figure 1).

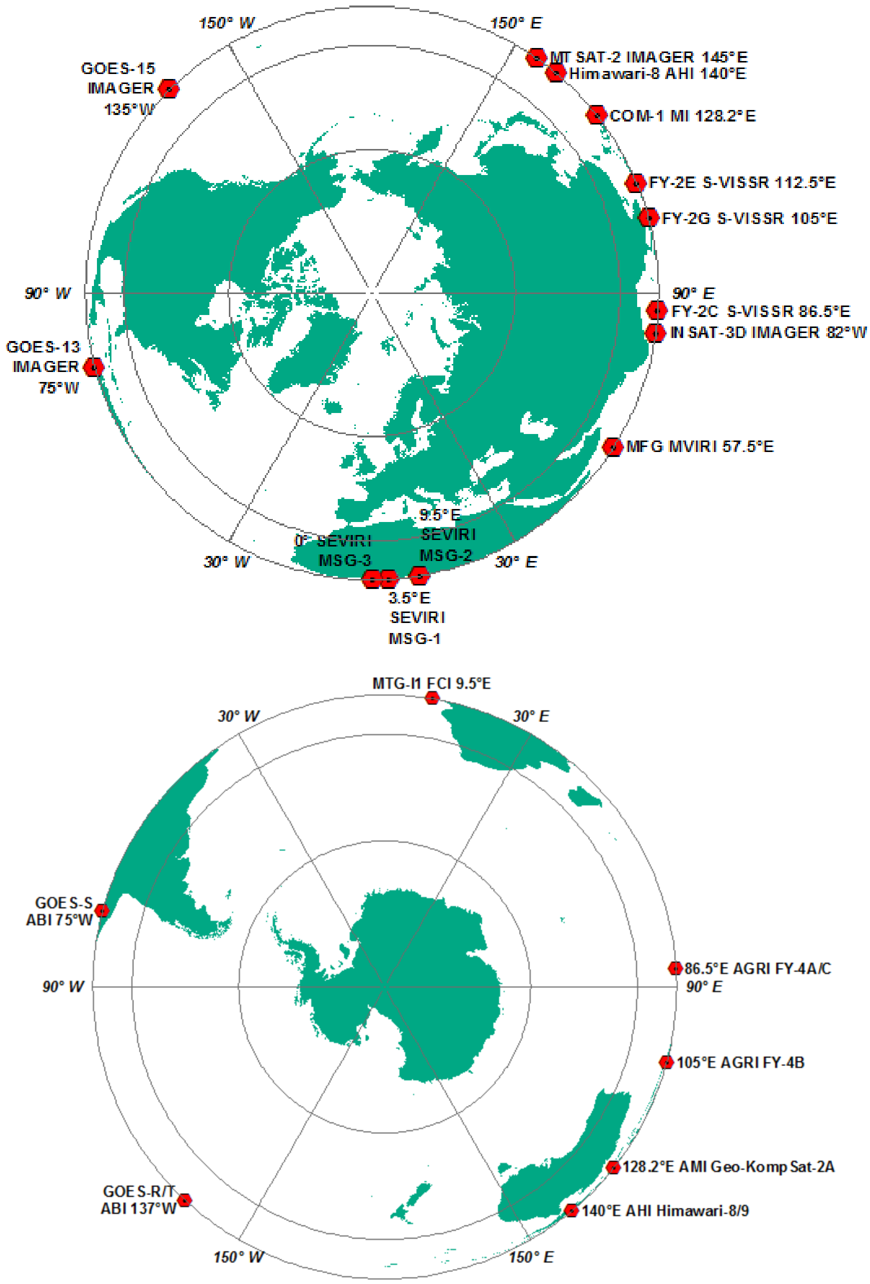


Figure 1. In the upper panel the Northern hemisphere image shows the currently operational geostationary satellites. In the lower panel the Southern hemisphere the implementation of Earth Observation satellites planned by year 2020 (based on http://www.wmo-sat.info/oscar/observingmissions/view/2 data).

The GEO VIS/IR imagery will benefit from ever-improving sensor spatial and spectral resolutions, acquisition repetition cycles, and differences in angle of view between the sensors. All these improvements will enable full advantage to be taken of the proposed method both day and night for effective monitoring of volcanic clouds on a global scale.
Moreover, latest researches show the possibility to use the GNSS Radio Occultation (GNSS-RO) measurements for the Volcanic Cloud Top Height (VCTH) retrievals. The results obtained from this technique, will be compared with the results obtained from the MACE integration.
The GPS Radio Occultation (RO) technique [Kursinki et al., 1997] enables measurement of atmospheric density structure in any meteorological condition (since the radiowave signal is not affected by clouds). They can be used in remote areas and during extreme atmospheric events with high vertical resolution and accuracy [Steiner et al., 2013] and improving the poor temporal resolution and coverage given by the lidars and radars on board of satellites. Several RO missions are on-going such as the Constellation Observing System for Meteorology, Ionosphere and Climate – COSMIC [Anthes et al., 2008], the MetOp [Von Engeln et al., 2011], the Satélite de Aplicaciones Científicas - SAC-D [Hajj et al., 2004], and the Gravity Recovery And Climate Experiment – GRACE [Beyerle et al., 2005], providing at the moment a total of about 3.000 profiles per day. In a few months the new COSMIC-2 constellation will be also available increasing the number of occultation to more than 12.000 per day and providing unprecedented coverage in space and time for monitoring the atmosphere allowing to detect the thermal structure impacts of volcanic eruptions and their cloud dispersions at any stage.
The GPS RO has already been used for detecting the volcanic eruption cloud altitude [Biondi et al., 2016] and for detecting the impact of the eruption in the atmospheric thermal structure [Wang et al., 2009; Okazaki and Heki, 2012; Biondi et al., 2016] with promising perspectives. The vertical resolution of the ROs (of the order of 100 m in the troposphere) allows to detect variations of atmospheric parameters in shallow layers of the troposphere and the use of the bending angle provides fundamental information on the atmospheric density without being affected by any model or retrieval. Due to their independence from weather conditions and to their high vertical resolution, RO observations can contribute to improved detection and monitoring of volcanic clouds and support the warning systems. The high accuracy and vertical resolution of RO observations for detecting the tropopause with global coverage will also help to understand whether eruptions overshoot into the stratosphere and contribute to short-term climate variability.
Reference climatologies for bending angle and temperature were obtained by Biondi et al. [2016] by averaging all RO profiles collected in the period 2001 to 2012 to monthly means on a 1° x 1° grid in latitude and longitude, using a resolution of 5° x 5° around each grid point (i.e., grid cell size of about 500 km extension). Vertically, the climatology is set up at a sampling grid of 100 meters covering the full troposphere and stratosphere. Constructed this way, the reference climatology is available with global coverage on a 1° x 1° x 100 m (latitude x longitude x altitude) sampling grid, for both bending angle and temperature. It can be used to extract a collocated long-term mean climatological profile at any desired RO event location, where the extracted profile can then serve as reference to compute an anomaly profile.

The cloud top altitude has been evaluated by using the bending angle anomaly: the bending angle anomaly is computed by referring each selected individual RO bending angle profile in the volcanic cloud area to the RO reference climatology profile extracted for the same location from the global RO bending angle reference climatology of the applicable month. Then the anomaly has been normalized with respect to the reference climatology profile in order to obtain a fractional (percentage) anomaly profile. The cloud top altitude is represented as pronounced spike in the vertical bending angle anomaly structure. The criterion chosen for cloud top detection is a bending angle anomaly deviation larger than 3% within a 2 km altitude range.

Summarizing, in APhoRISM have been developed integrated ash monitoring products, of improved quality, used for nowcasting and to feed the VATD models for improved volcanic cloud forecasts. Figure 2 shows the ash ground deposit obtained using ash dispersion model initialized with MACE products.

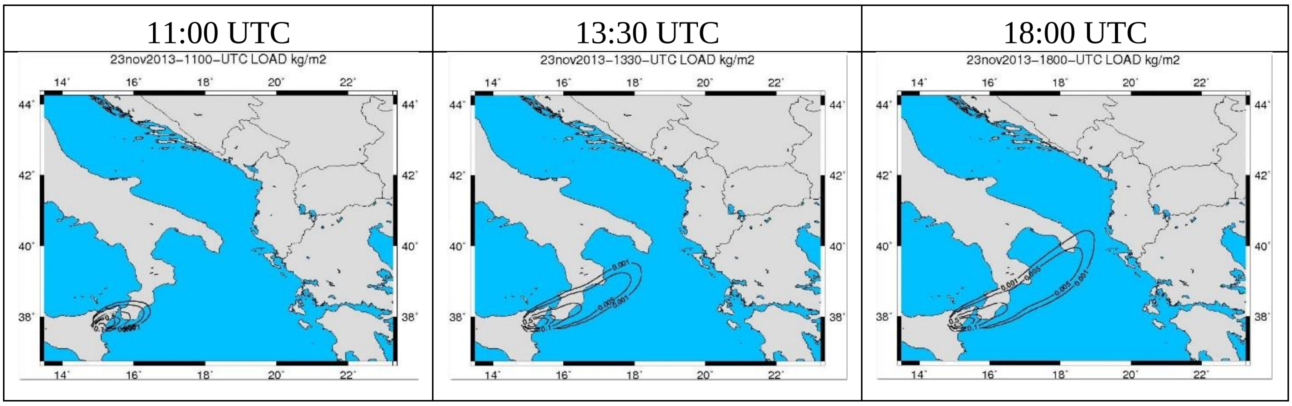


Figure 2. Ash ground deposit obtained using ash dispersion model initialized with MACE products.

Moreover with the MACE products it is possible to effectively monitor volcanic ash cloud impact on critical air infrastructures such airports and air routes greatly enhancing the reliability and the TRL of our initial products. Considering the validation of MACE products carried out in WP5, the TRL of the current development stage of the products can be assessed between TRL 6 and TRL 7 (technology validated and demonstrated in relevant environment respectively). Further development of the MACE approach will be the implementation of the system prototype and the demonstration of its capability in operational environments in order to achieve a full TRL 7. This is particularly referred to the ash cloud detection and top height map products (RET-ASHD and RET-ASHH) which define the extension and altitude of the cloud, and the ash cloud mass and concentration map products (RET-ASHM and RET-ASHC) that quantify and geolocate the ash mass burden and the ash concentration. Among the six integrated MACE products, these four are the most directly usable as a novel combined information base for decision support related to air space safety, answering to the basic questions on whether an when a volcanic ash cloud is detected, where is located, how high it is, how much ash it carries, and which is its ash concentration. Figure 3 shows an example of the air infrastructures close to Mt. Etna that can be affected by the volcano eruptions.

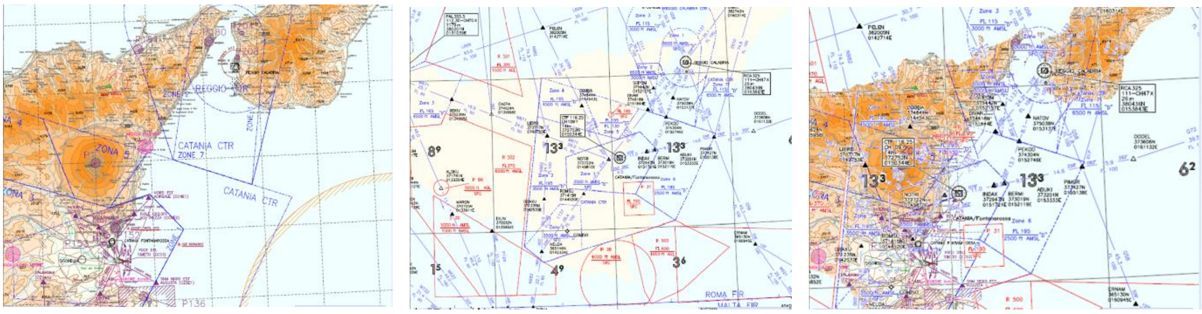


Figure 3. Air infrastructures close to Mt. Etna that can be affected by the volcano eruptions.

The possibility to protect the MACE foreground in terms of IPRs is currently considered for original and unpublished results and methods to investigate and prepare its possible future commercial exploitation.

b. Seismic Products

Summary of the activities:

Three main parts can be summarised about the activities performed towards the implementation of APE method and the generation of the associated products, that are:

1) Map of damage at single building scale
2) Map of damage at city block (group of buildings) scale.

The first part was devoted to the study of the data for the realisation of the a-priori information layer. Tests and analyses were carried out to study the capabilities of some soil instability factors to provide earthquake damage proxy. The effects and possible relations with damage were analysed considering (see deliverable D4.1):

- ground velocity maps, coming from multi-temporal InSAR
- soil seismic amplification factors, through the inclusion of seismic microzonation data
- soil resonant periods
- liquefaction susceptibility
- landslides susceptibility

Efforts were spent to include the structural vulnerability of the buildings: macroseismic and mechanical models for damage probability estimation were implemented. Structural vulnerability and soil instability indexes were used to constitute the so-called ***vulnerability scenario*** of APE, that represents the a-priori information layer.

The second part was focussed on a deep re-analysis of change detection methods for medium resolution (MR) and very high resolution (VHR) satellite data, for both optical and SAR sensors. For the selected test sites we performed a detailed work for selecting the best performing change indexes. The sensitivity with respect to damage was considered by taking into account reference damage maps obtained from in situ surveys. The change detection methods comprise algorithms for the calculation of Normalised Change Difference, Image Ratio, Kullback-Leibler divergence and Mutual Information (coming from the Information Theory), phase coherence difference, intensity correlation

difference, and also textural parameters such as, Energy, Correlation, Homogeneity, Contrast, and Entropy. Details are given in deliverable D4.2.
All these change features were exploited considering an object based approach. Indeed, the changes in the urban environment were estimated, not pixel by pixel, but by considering polygons corresponding to groups of buildings or single buildings, for MR and VHR data exploitation, respectively.
Besides that, a method based on coherence loss on Persistent Scatterers was tested. Some interesting results were obtained even if interferometric coherence is influenced by many factors not related to damage. Therefore, it is still not a reliable approach.

The third part of the seismic activities was the implementation of the data fusion algorithm. The work aimed at integrating satellite change features with the above mentioned a-priori information set. A Naïve Bayesian approach and a Support Vector Machine algorithm were tested to generate the final damage map for the selected case studies. As far as the MR data are concerned, a new data fusion method was implemented. The work was aimed at creating a non-supervised classification algorithm. The method is called Features Stepwise Thresholding (FST) classification algorithm (see deliverable D5.3 for a detailed description of the method).

User Requirements, Achievements and Limitations

Figure 4 shows the damage maps at single building scale and group of buildings scale that were generated by using the APhoRISM developed methodologies. The upper panel reports the damage map obtained by applying the APE method for the case study of L'Aquila 2009 earthquake. The lower panel shows the damage map generated by using the FST algorithm for the Haitian earthquake that hit the city of Port-au-Prince.

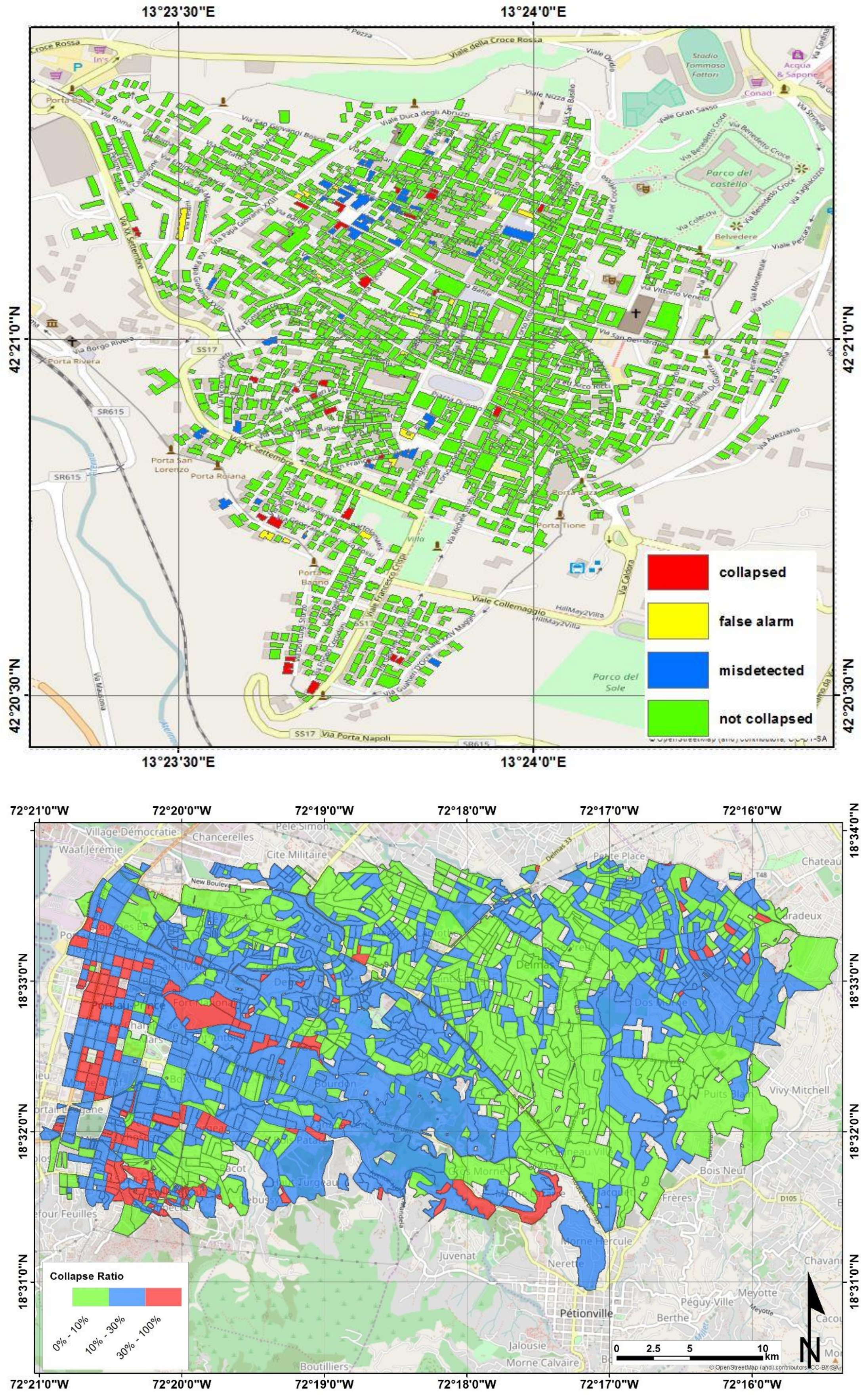


Figure 4. Damage map resulting for the case study of L'Aquila 2009 earthquake (upper panel), and Haiti 2010 earthquake (lower panel).

Tables 4 and 5 report the user requirements collected during the project lifetime. The reference user involved in the definition of the requirements is the Italian Civil Protection Department (DPC). The third column of tables briefly reports what APhoRISM achieved considering the work done during test and validation of the APE products.

Product: Damage maps at the scale of group of buildings		
Description	***Requirements***	***Achievements***
Expected BENEFITS from the proposed products What are the benefits? Areas, methods, improved? Benefits for populations?	Support to Civil Protection activities for the emergency management in the first hours after the mainshock in case of large epicentral areas. Fast identification of strongly damaged urban areas, mainly if in remote zones, difficult to reach. Assess status of strategic transportation networks (roads, bridges, railways) and lifelines. Improve the approaches with respect to state of art	The generated products at city block scale allow the identification of the most damaged areas in an urban environment. The spatial pattern of damage was demonstrated to be similar to the ground truth in the selected case studies The implemented data fusion algorithms, i.e., Naïve Bayesian, SVM, and especially the novel FST, were quite fast to provide a rapid response. The exploitation of change features and the FST algorithm are new. The investigation demonstrated that the use of both SAR and optical data together performs better than the single sensor damage map.
Expected content	The map of damage distribution at the scale of groups of buildings should be organized in at least three classes of heavy damage distribution in a given area. For instance: Class 1, from 0 to 10% buildings collapsed or strongly damaged; Class 2, from 10 to 30% buildings collapsed or strongly damaged; Class 3, above 30% buildings collapsed or strongly damaged	The content of damage map agrees to the expected one. Damage maps refer to three collapse ratio classes. They were validated considering the suggested class definition

Expected minimum performances	Scale of products: 1:10,000 Delivery time: a damage map is useful if available to the decision-maker within 12 hours from the event Accuracy: 75%	The scale is achieved Delivery time is strongly dependent from the latency time from the event and the satellite image availability to the product provider. Final map can be delivered within 4 hours after data availability The accuracy (overall accuracy) was estimated about 62%
Expected optimum performances	Scale of products: 1:5,000 Delivery time: a damage map is useful if available to the decision-maker within 6 hours Accuracy: 90%	The scale is achieved Delivery time is strongly dependent from the latency time from the event and the satellite image availability to the product provider. Final map can be delivered within 4 hours after data availability The accuracy (overall accuracy) was estimated about 62%
Delivery frequency Time frame between the first product delivery and its updating	During an emergency, an update of such products is expected every 12 hours.	No tests were done to assess this requirement, as the repeat cycle of the presently operative satellites does not match this requirement. A multi-platform approach as well as new constellations are the keys.
Delay Between the ordering and the disposal	The delivery can be released within no more than 6 hours from ordering.	No test were done to assess this requirement (see above).
Delivery format	Format: cartographic GIS, raster, vector (preferred)	Vector file is provided (ESRI shapefile)
Delivery mode	Communication protocol: web (webservices), ftp Time frame: one-two shots under crisis.	ftp transfer can be easily setup directly to the user

Table 4. User requirements and APhoRISM achievements for damage maps at the scale of group of buildings.

Product: Damage maps at individual building scale		
Description	***Requirements***	***Achievements***
Expected BENEFITS from the proposed products/services What are the benefits? Areas, methods, improved? Benefits for populations?	Support to Civil Protection activities for the emergency management in the first hours after the mainshock. Fast identification of highly affected buildings in damaged urban areas, mainly if in remote areas difficult to reach. Rapid analysis of the overall situation in wide areas around the epicenter. Status detection of specific points of the strategic transportation networks (roads, bridges, railways) and lifelines. Improve the approaches with respect to state of art	The generated products at single building scale allow the identification of the most damaged buildings The implemented data fusion algorithms, i.e., Naïve Bayesian, SVM, and the novel data integration approach, were quite fast to provide a rapid response. The implemented data fusion algorithms, Naïve Bayesian and SVM demonstrated that the integration between satellite data and structural vulnerability of buildings improve the accuracy of the products. The exploitation of change features and the data integration algorithm are new. An improved map of damage was obtained thanks to the use of VHR SAR and Optical data through innovative segmentation algorithms
Expected content	The map of damage at individual building scale should be organized in at least three classes, each one related to the EMS98 scale: class of buildings with EMS98 level 1 to 3 (C1), class of buildings with EMS98 level 4 (C2), and class of buildings with EMS98 level 5 (C3).	The best performance in terms of accuracy can be obtained by generating a 2-class EMS damage map: building with damage grade 5, and buildings with damage grade less than 5.
Expected minimum performances	Scale of products: 1:5,000 Delivery time: a damage map is useful if available to the decision-maker within 12 hours from the event.	The scale is achieved Delivery time is strongly dependent from the latency time from the event and the satellite image availability to the product provider. Final map can be delivered within 4 hours after data availability The accuracy (overall accuracy) was estimated between 76% and 96%

Expected optimum performances	Scale of products: 1:1,000 Delivery time: a damage map is useful if available to the decision-maker within 6 hours from the event	The scale is achieved Delivery time is strongly dependent from the latency time from the event and the satellite image availability to the product provider. Final map can be delivered within 4 hours after data availability The accuracy (overall accuracy) was estimated between 76% and 95%
Delivery frequency Time frame between the first product delivery and its updating	During an emergency, an update of such products is expected every 12 hours.	No tests were done to assess this requirement, as the repeat cycle of the presently operative VHR satellites is far from matching this requirement. A multi-platform approach as well as new constellations are the keys.
Delay Between the ordering and the disposal	The delivery can be released within no more than 6 hours from ordering.	No test were done to assess this requirement (see above).
Delivery format	Format: cartographic GIS, raster, vector (preferred)	Vector file is provided (ESRI shapefile)
Delivery mode	Communication protocol : web (webservices), ftp Time frame: one-two shots under crisis.	ftp transfer can be easily setup directly to the user

Table 5. User requirements and APhoRISM achievements for damage maps at t individual building scale.

After the three years of APhoRISM project, some conclusions can be drawn.
For the a-priori information layer of the APE method we found that:

- The instability indexes demonstrated not related to damage. For the selected case studies, the ground deformation rate obtained from InSAR multi-temporal techniques did not show relation to the occurred damage. Some other indexes were defined but still there are no evidence, from these studies, of direct impact on the assessment of damage;
- Co-seismic displacement from differential interferometry, in particular the interferometric phase slope, is another parameter that has no clear contribution in the damage assessment, even if some correlations were found when considering seismic intensity at municipality scale
- High resolution shakemaps derived thanks to microzonation data, do not show high sensitivity to damage, probably because peak ground acceleration pattern has resolution not comparable to the scale of APE products;
- Other geological parameters, such us the liquefaction and landslide susceptibilities need further investigations (i.e. more test cases) to assess their role as damage proxies. The only geological quantity that demonstrated a (slight) sensitivity to the damage is the soil oscillation period.

As far as the damage mapping at single building scale, we can conclude that:

- the structural module helps reducing the false alarms when the satellite image classification is not as good as it can be;
- limited quality of pre-processing (e.g. co-registration of optical data) or lack of a suitable training set to optimize the likelihood estimation, strongly affect the image classification results;
- damage map in EMS98 scale can be done with an acceptable overall accuracy only by discriminating between damage grade equal to 5 and less than 5 (two classes). Additional damage grades do not allow to reach e reasonable accuracy
- the accuracy of EO derive map is comparable to the accuracy that can be reached when comparing different ground truths.

Concerning the damage mapping at city block scale, we found that:

- fusion of optical and SAR data improve the classification accuracy with respect the single type sensor products;
- the definition of collapse-ratio classes affects the accuracy;
- the spatial distribution of damaged city blocks are consistent with the ground truth survey even if overall accuracy is not very high and k-coefficient is quite low.

Both types of products are characterised by satisfactory overall accuracies (higher than 75% and 60% for the VHR and MR data, respectively), but looking at the values of the K-coefficients it can be noticed that these values are quite low (maximum around 0.3 for both types of products). Indeed, even if we have globally good results, the omission and commission errors are still not negligible. First, the dispersion of EO parameters is quite high for the same class of damage. Moreover, we found that many errors cannot be avoided when changes in the objects of the scene are not visible from satellite data even for a photointerpreter. Typical examples of miss detections are the pancake effect (the collapse of one or more floors whilst roof remains intact) or case of a building destroyed inside, whose roof is only slightly damaged. On the other side, false alarms are caused by modification of some buildings after renovations or strong geometric distortions due to very different viewing angle of optical sensors. As observed, these false alarms are mitigated by using structural vulnerability, but some positive effects can also be obtained if:

- updated pre-event images are available
- pre and post-earthquake images have very similar and quasi-nadiral view
- fusion with SAR data which are less sensitive to viewing geometry

APE operational scenario and perspective for the future:

From the operational point of view, APE methods and the developed algorithms are not so far from being ready in the framework of emergency response services. The automatic procedures of APE can generate products rapidly, allowing a fast delivery to the stakeholders involved in the emergency management. In the future, the quality of the products are expected to improve for several reasons. A major factor is the technological developments of satellite sensors in terms of resolution and number of bands. Another major factor is the increasing number of missions based on platform constellations (see for example ESA Sentinels) that will improve accuracy (i.e., change detection) and especially response time. A multi-mission approach is therefore recommended for a better exploitation of earth observation in this field, which was already envisaged in the APE algorithm development (e.g., non-parametric methods, incremental feature vector). It also foresees an easy access to the satellite archive and programming of the mission operation according to disaster management needs. Indeed, we expect to have much more updated imagery, regularly acquired, with revisiting time shorter than the present day that will allow reducing delay from event occurrence and images acquisition and delivery. This latter is presently the main drawback on the use of remote sensing data for emergency purposes. Another important factor is the opportunity to collect in a unique system an historical sequence of case studies in order to create a database of “change feature signatures”, eventually depending on the characteristics of the hit area. This will allow to select properly the likelihoods (as for Bayesian classification) or support vectors (as for SVM), shortening the training phase to deliver more rapidly products with comparable quality.

Besides satellite data access, the APhoRISM project also demonstrated the importance to set up an operational system able to easy access ancillary data, like urban maps, geological data and so on. This call for an Open Data policy at international level, essential for managing disastrous event both at national and especially supranational scale. In fact, at the moment, detailed geological data and buildings vulnerabilities, and in general all the non EO datasets that constitute the a-priori information of APE, are not easy collectable in any site and country, therefore APE encouraging results cannot be assessed easily. In the project, the role of the vulnerability scenario was addressed, but its potential impact has to be further investigated. Even if APhoRISM did not assess a clear link of some geological quantities with respect to damage, as the case studies were selected in areas quite stable in this respect, further studies should be conducted, considering additional case studies, to examine and to investigate on the role of instability indexes with the aim to provide pre-earthquake vulnerability. Although vulnerability assessment was not a final objective of the project, APhoRISM made investigations and produced some by-products in this respect that are worth to be prosecuted.

Finally, APhoRISM provided some hints on the approaches that should be followed to collect ground data after an event. Although this is a topic largely addressed by earthquake engineers, civil protection institutions and many others, if we want to promote the use of satellite it is important also to collect ground data that can be compared with the satellite products. For instance, it was stressed the importance to collect data associated to map objects (e.g., labelling polygons of a common GIS layer, rather than filling forms on paper), to consider a damage grade scale comparable to what the satellite can detect (eventually in addition to the standards presently established). This is important to make the final user able to take advantage from the potential of earth observations, notwithstanding their well-known limitations. A damage grade scale in some way linked to the satellite capabilities is a key for a more effective exploitation of earth observation.

4. The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

The work done in APhoRISM highlighted that both APE and MACE methodologies and the connected possible services can impact at social and economic level.

APhoRISM methods and products have their major impact in the domain of the emergency response and management. This is demonstrated by the interest expressed by Civil Protection actors, that actively defined their requirements in terms of both thematic accuracy and service performances. Fast and accurate maps of damage as well as the ash characterisations data provided by the novel methods of APhoRISM , can improve general safety and emergency management, adding new solutions to be integrated in the current Emergency Mapping Services of Copernicus.

As far as the MACE is concerned, on the base of Stakeholders analysis, the domain Service Model and corresponding Value chains in the Air Transportation Industry dealt with D6.1 Stakeholders data collection and collation, it's clear how the main marketing target of MACE methods are Volcanic Ash Advisory Centres (VAACs) organizations. Additional targets are the ANSPs, Airlines, Airport authorities, International authorities and Regulators and Technology provides (e.g. Airbus, BAE, Boing and Selex ES). MACE method and related services can offer advantages thanks to innovative satellite remote sensing and in-situ data mixed, to support specific algorithms and instrumentations to end-users. MACE offering is split among pilot, near future and future services according to the market target needs.

Consortium assessment and business SWOT analysis report several strengths in: long experience in R&D projects in matter of Emergency of natural disasters; high skill and European reference point for Geophysics and Volcanology; consolidated skills in the domain of human capital, and a good industrial component able to technology transfer to the market and marketing portfolio services. Vice versa, there are some weakness can should be mitigated such as: lack of aeronautics players (e.g. ANSP, ATM…) in the consortium and necessity of external support of meteorological domain player, for merging remote sensing data with weather forecast.

Business rollout is planned in three steps; in a first step, the project team in charge of promotion and commercialization of MACE products must put in place an action to engage the key customers such as VAACs, IAVW. At this stage the offering must provide them with the added value of innovative maps. Second step of product launch, that begins after 1 year, it envisages to move with try & buy promotion policy and cost base price policy on main targets with the goal to cover up to 10% of this market. After the adoption of MACE products by key customers, the promotion strategy will move to the secondary market target; market growth strategy will move from product development to market development, with the purpose to achieve a market share of 45%. Last step will cover the indirect sales channel setup in vertical market to enlarge the market penetration and collect new end-user requirements that may arise thanks to the MACE brand.

In conclusions, some improvements on business model of MACE products, could be put in place considering that:

- Business model could take advantage from INGV direct involvement as service provider. Synergy with the ongoing earthquake information services provided by the Surveillance Room could reduce costs of operations significantly.
- Cost of operations could decrease if the cloud computing facility approach (server utilization renting) to be pursued.
- Using INGV infrastructure (Surveillance Room) there will be lower costs for the processing of MACE products. It allows to pursue a sales strategy to the scientific community as free of

charge, while on monthly fee base to industry players. Revenues from the sale of products could be reinvested in scientific research through the recruitment of new researchers.

Looking to the future it is suggested to turn on an initiative to a large demonstration action to the market. Thanks to maturity and quality of the products (TRL 6/7), this initiative could be conducted, using EC tools, for instance, Fast Track to Innovation calls, dedicated to products and services ready for the market in 24/36 months. Alternatively, by national innovation programme such as PON / POR (Piano Operativo Nazionale or Regionale) or ASI (Agenzia Spaziale Italiana) funds.

Concerning seismic products of APhoRISM, the analysis of the market identified a potential impact in the domain of Insurance and Re-insurance companies.

Following the Insurance Europe Association – CEA, report of 2014, the European non-life premiums market with its three main business lines of motor, health and property amounted to € 446bn in 2013. Property premiums in 2013 suffered a decline, estimated at -1.4% at constant exchange rates, owing to a substantial fall in premiums in the UK and France compared with the year before. The Spanish property insurance segment remained competitive despite the difficult economic situation, showing an ability to adapt to market conditions. Germany's property and casualty market saw an increase in premiums, partly prompted by the damage caused by natural catastrophes in the course of the year.

Generally, earthquake risk is covered by Property (non-life) premiums and sold generally by private insurers worldwide with a quite different diffusion depending on country regulations - as already saw for Italy, Japan and Australia, where the risk owner is in charge of Government or is balanced with Insurance and Financial market operators.

APE method and related services can offer an advantage by using satellite data in the earthquakes damage estimation that are not yet present in the currently used methods. In addition, the use of satellite images integrated with geological and structural data will allow performing analysis that can help Insurance industry in identifying built-up areas prone to seismic hazard, characterise the local vulnerability and seismic reposnse (see definition of vulnerability scenario) .

Consortium assessment and business SWOT analysis report several strengths: long experience in R&D projects in matter of Emergency of natural disasters, Earthquake; consolidated skills in the domain of human capital, and a good industrial component able to technology transfer to the market and marketing portfolio services. Viceversa, there are some weakness can should be mitigating such as: lack of Insurance and Emergency players in the consortium and necessity of external support of disaster management system technology, such as decision system support tools..

Regarding APE service market forecast, due to the competition with current risk analysis models the market penetration is forecast from 30% to 40% of Insurance and Civil Protection EU organization. However, recent seismic events occurred in Italy have consolidated a tendency on part of citizens, to protect their homes even for natural disasters.

Italy is one of the countries in which the cost of damages to natural disasters such as earthquakes, fall on the entire community and is therefore the responsibility of the government to compensate the people who have suffered damage and lost their homes (Model 1. As reported in D6.1 paragraph 2.3.2 Insurance Service Model). It was considered useful for the purposes of the project, take into account, this market potential and study their evolution in terms of both demand and supply.

Conclusions: the result of the potential market, suggests the following elements of reflection; them can be future actions with the aim to continue the development of the APE products:

- APE products need a further development to make them more suitable for insurance industry.

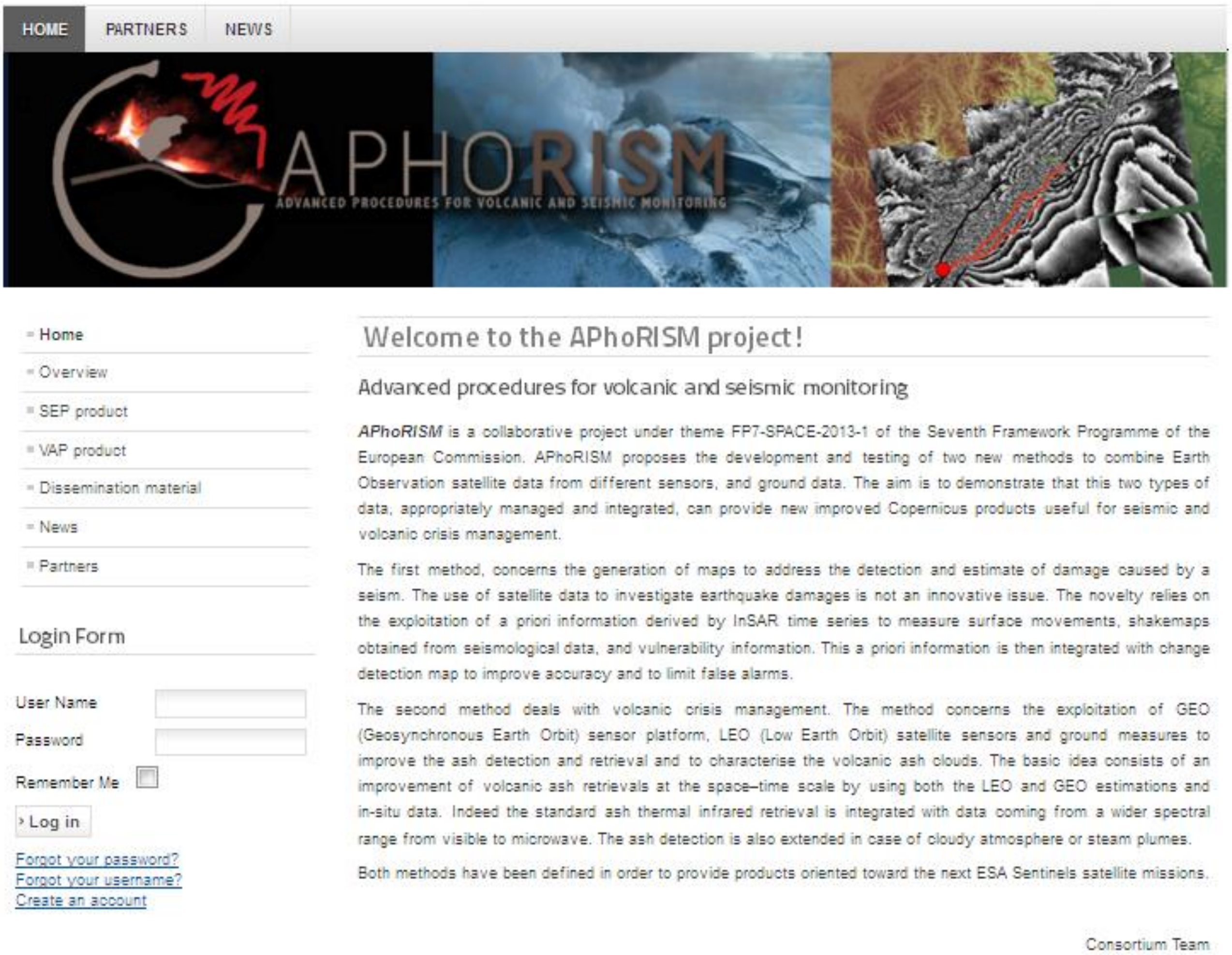
- There are the conditions for a sustainable business with a potential market.
- The home owners are increasingly aware to purchase instruments that protect the property in case of natural disasters.

Financial tools, in support of APE products development, could be H2020 Innovation Action, dedicate to development of products and services to the benefit of citizen with an intermediate TRL. This project, following the next EO calls and topics will necessarily have to involve the Insurance industry with the purpose to support to risk assessment phase to fix the value of the insurance premium.

5. Address of the project public website and illustrations

Project Logo:

Project website (home page): http://www.aphorism-project.eu/



Brochure (last issue):

APhoRISM is a collaborative project under the theme FP7-SPACE-2013-1 of the Seventh Framework Programme of the European Union. It proposes the development and testing of two new methods to combine different types of Earth Observation satellite data and ground data. The aim of *APhoRISM* is to demonstrate that an appropriate management and integration of satellite and ground data can provide new improved products useful for seismic and volcanic crisis management. In particular, the project is focused on two types of products: one is related to the volcanic ash mapping, and the other concerns the earthquake damage mapping.

GAMMA REMOTE SENSING

SAPIENZA Università di Roma

INGV

Alma Sistemi sas Consulting for Space

CTTC

UNIVERSITY OF OXFORD

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APHORISM ADVANCED PROCEDURES FOR VOLCANIC AND SEISMIC MONITORING

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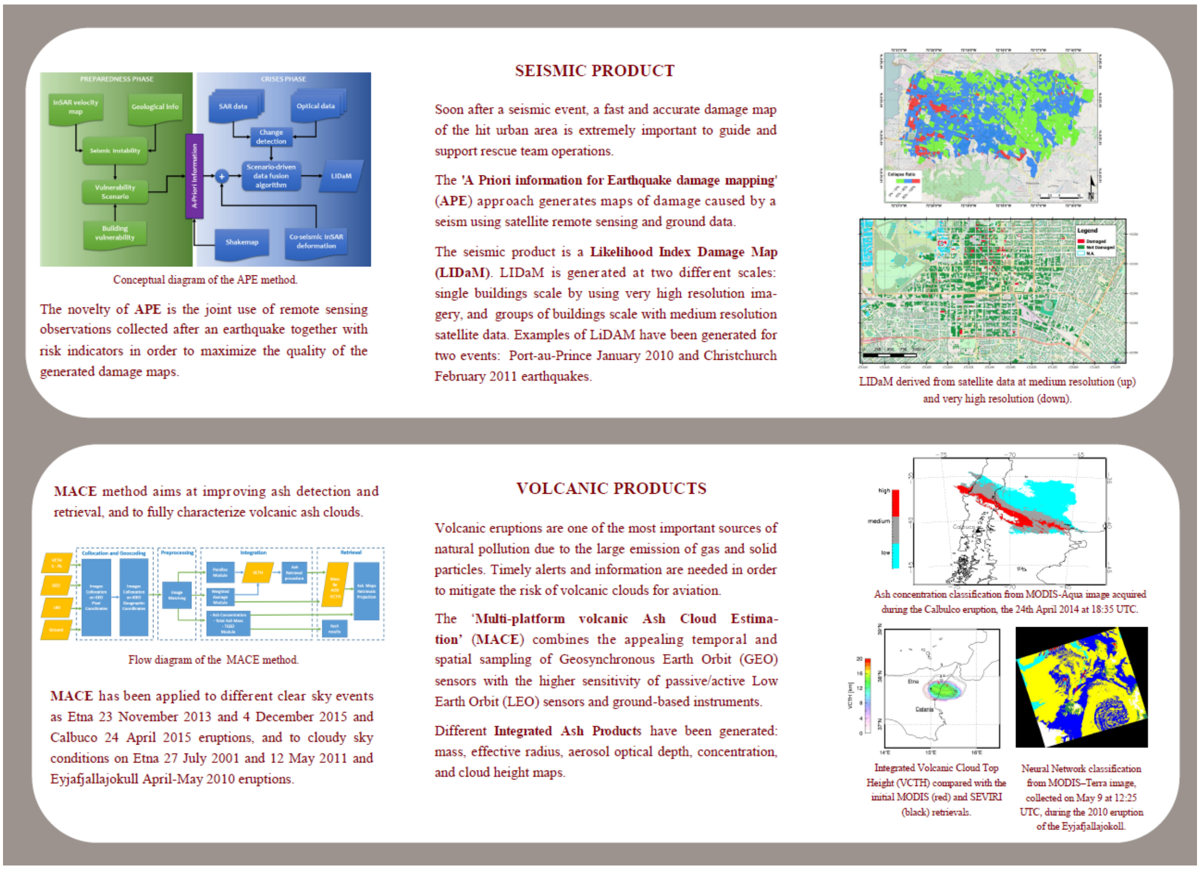
The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 606738.

APHORISM

ADVANCED PROCEDURES FOR VOLCANIC AND SEISMIC MONITORING



Conceptual diagram of the APE method.

The novelty of **APE** is the joint use of remote sensing observations collected after an earthquake together with risk indicators in order to maximize the quality of the generated damage maps.

SEISMIC PRODUCT

Soon after a seismic event, a fast and accurate damage map of the hit urban area is extremely important to guide and support rescue team operations.

The **'A Priori information for Earthquake damage mapping'** (**APE**) approach generates maps of damage caused by a seism using satellite remote sensing and ground data.

The seismic product is a **Likelihood Index Damage Map** (**LIDaM**). LIDaM is generated at two different scales: single buildings scale by using very high resolution imagery, and groups of buildings scale with medium resolution satellite data. Examples of LiDAM have been generated for two events: Port-au-Prince January 2010 and Christchurch February 2011 earthquakes.

LIDaM derived from satellite data at medium resolution (up) and very high resolution (down).

MACE method aims at improving ash detection and retrieval, and to fully characterize volcanic ash clouds.

Flow diagram of the MACE method.

MACE has been applied to different clear sky events as Etna 23 November 2013 and 4 December 2015 and Calbuco 24 April 2015 eruptions, and to cloudy sky conditions on Etna 27 July 2001 and 12 May 2011 and Eyjafjallajokull April-May 2010 eruptions.

VOLCANIC PRODUCTS

Volcanic eruptions are one of the most important sources of natural pollution due to the large emission of gas and solid particles. Timely alerts and information are needed in order to mitigate the risk of volcanic clouds for aviation.

The **'Multi-platform volcanic Ash Cloud Estimation'** (**MACE**) combines the appealing temporal and spatial sampling of Geosynchronous Earth Orbit (GEO) sensors with the higher sensitivity of passive/active Low Earth Orbit (LEO) sensors and ground-based instruments.

Different **Integrated Ash Products** have been generated: mass, effective radius, aerosol optical depth, concentration, and cloud height maps.

Ash concentration classification from MODIS-Aqua image acquired during the Calbulco eruption, the 24th April 2014 at 18:35 UTC.

Integrated Volcanic Cloud Top Height (VCTH) compared with the initial MODIS (red) and SEVIRI (black) retrievals.

Neural Network classification from MODIS–Terra image, collected on May 9 at 12:25 UTC, during the 2010 eruption of the Eyjafjallajokull.