# DEVELOPING ENLARGED ACTIONS FOR SATELLITE EO & SEISMIC HAZARDS: ANNEXES.

**30 October, 2013. CEOS Seismic Hazards Thematic Team.**

This document complements the CEOS DRM Proposal Draft concerning Seismic Hazards. The proposal provides ideas concerning how to accelerate the utilisation of Satellite EO for seismic and possibly other geohazards.

There are 15 Annexes to this document.

- Annex 1: analysis of user requirements
- Annex 2: assessment of relevant activities, gaps and priorities
- Annex 3: overview of the GSNL
- Annex 4: overview of SSARA
- Annex 5: overview of ESA's SSEP proposal
- Annex 6: overview of the INSAR based GSRM initiative
- Annex 7: overview of Advanced Rapid Imaging and Analysis Project (NASA/JPL)
- Annex 8: overview of SIGRIS (ASI/INGV)
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- Annex 10: overview of COOPEUS
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- Annex 15: high level observation modes concerning seismic risks

**These annexes are open, each of them can be edited. In particular Annex 2 concerning the state of development of relevant activities can be expanded according to the input from the CEOS DRM Thematic team.**

## Annex 1: analysis of user requirements:

This Annex provides an Analysis of requirements from users & practitioners from the seismic hazard risk management community.

*1.1) Overview of User community:*

Users and their information needs with regards to seismic risk: National and regional civil protection agencies, seismological centres and national and local authorities in charge of seismic risk management activities are all concerned with the phases of preparedness/mitigation, early warning, response, recovery, rehabilitation and reconstruction. The insurance and reinsurance industries also have a strong interest in quantifying seismic risk.

Beyond operational users with a mandate in seismic risk management, there is a range of geoscience users focused on the scientific use of data with the main goal of understanding the physics of earthquakes thereby improving our ability to characterize, understand, and model seismic risk. The needs of these user groups can be broken into the following three categories of activity: (i) long-term seismic risk estimation; (ii) emergency response, and (iii) scientific research. Below, we describe the needs in these different areas, and the potential contribution of information from EO.

The table below considers the goals of the improved use of EO data in **Seismic Risk Management (SRM)** and the relevant user communities. Note that, differently from other hazards (e.g. floods, landslides) no predictive activities are part of this cycle, and the Warning and Crisis phase is in practice only dealing with Crisis management.

| Risk management phases | Goals of SRM | Activities | Actors involved |
|---|---|---|---|
| **Assessment and Prevention** | ***Seismic hazard assessment*** | Estimate of ground motions due to seismic shaking in a certain area and within a certain period of time. Involves the analysis of various data sets: seismological (instrumental, historical), geological (*active fault maps and parameters*), and geodetic (*rates of strain accumulation in the region*). | Scientific institutions (VA), public administrations (users) |
| | ***Vulnerability assessment*** | Estimate the vulnerability of man-made structures to seismic shaking. Involves an analysis of the *structural weaknesses of the built environment* and of its resistance to earthquakes, as well as the analysis of the capacity of the society to cope and overcome the disaster. | Scientific institutions (VA), public administrations (users), private sector (VA & users) |
| | ***Mitigation*** | Policies and technical strategies to reduce the effects of earthquakes, usually in the long term. It is based on seismic and vulnerability assessments, and involves different actions, e.g. implementing strict building and urban planning codes and enforcing abidance to these rules. | Public administrations (VA), private sector (users) |
| | ***Preparedness*** | All activities aiming to reduce the impact of earthquakes on people. It consists of *planning response and recovery measures*, and of training the managers and the population to respond effectively to the earthquake emergency. | Public administrations (VA & users), |

| | | | |
|---|---|---|---|
| Warning and Crisis | ***Earthquake damage assessment*** | Estimate of the effects of the earthquake on the people and on the built and natural environment.<br>*Early damage assessment* is a less precise inventory useful during the first 2-3 (sometimes more) days from the main shock (and further large aftershocks) to direct rescue and relief operations.<br>Precise damage assessment is the longer process of structural classification of building damage, e.g. for insurance and compensation payments. | Scientific institutions (VA), public administrations (users), private sector (users) |
| | ***Earthquake scenario definition*** | Consists of all activities for the analysis of the physical scenario for the seismic sequence. E.g. *location and assessment of the seismic source, assessment of risk of possible triggering of other shocks on nearby faults, mapping of ground deformation and surface faulting, mapping of triggered gravitational mass movements,* etc.<br>The first scenario is delivered within 1-2 weeks, but may be eventually refined by detailed scientific studies for the next several years. | Scientific institutions (VA), public administrations (users) |
| | ***Earthquake response*** | *Implementation of plans for search and rescue, medical aid, evacuation, sanitary risk reduction*, etc. Normally lasts a few months. | Public administrations (VA & users) |

*VA: Value Adders*

In italic, the activities to which EO data can contribute. The Charter is already providing EO-based products for some of such activities, mainly for damage assessment and response. Similar services were developed by projects as SAFER and are provided by GIO.

*1.2) High level user requirements:*

Based on the priorities defined at the 2012 International Forum on Satellite EO and Geohazards the seismic community has set out a vision of the EO contribution to an operational global seismic risk program. In 5 to 10 years' time, EO could provide fundamental new observations of the seismic belts - around 15% of the land surface – and improved understanding of seismic events through the work of the GSNL.

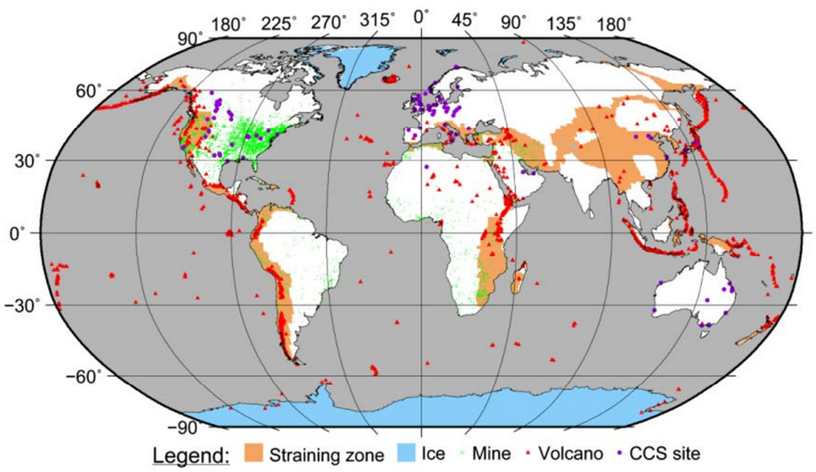


Figure 1. Straining areas (seismic belts) and volcanoes of the world. The areas coloured orange have strain rates higher than 10-9 yr-1 in the global strain rate model derived from global navigation satellite system (GNSS) data (Kreemer et al., 2003). Figure from the GSNL Strategic Plan 2012. Concerning the INSAR based Global Strain Mapping see Annex 5.

As proposed by the seismic community, a satellite EO based programme will enable:

1. *Development of a high resolution global strain rate model (GSRM) at high spatial resolution incorporating deformation constraints from GNSS and InSAR.* InSAR allows essentially continuous observations of the seismic belts worldwide with near-uniform quality.

2. *New regional or global maps of active visible faults*, incorporating the latest results from the geomorphological analysis of high resolution optical imagery and digital topography data.

3. *The creation of a new global seismic hazard map* based on 1 and 2.

4. *To continue the GSNL* and provide precise measurements, including frequent acquisitions with multiple SAR sensors, over geographically focused areas to ensure strain rate measurements of unprecedented accuracy. The GSNL are supported by numerous partners including GEO, ESA, JAXA, NASA, DLR, ASI, CSA, NSF, UNAVCO and EPOS.

5. *Rapid response to earthquakes*, including:

(a) Automatic rapid estimation of earthquake damage using high-resolution optical and radar imagery, and InSAR coherence using available capacities such as the Charter.

(b) Automatic rapid creation and web-publication of co-seismic interferograms (wrapped and unwrapped) from all available sensors.

(c) For non-specialist end users, products derived from the interferograms, such as phase gradient maps, combined with critical infrastructure data, could be produced.

(d) (Semi-) automatic fault modelling – rapid production and web-publication of fault parameters using simple, consistent techniques.

(e) Prediction of damage distribution using this fault model.

(f) Rapid calculation of Coulomb Stress changes on neighbouring faults to assess likely locations of aftershocks or triggered earthquakes. The fault model in (d) would be used initially, along with any data on historical seismicity (e.g. from USGS archives).
(g) Collection of InSAR data to support fundamental research on earthquake fault mechanics using observations of the early post-seismic phase. These observations (hours to days after the event) are now possible thanks to the multiple sensors available to the GSNL.

6. *A long-term response to earthquakes* that involves acquiring radar data for years to decades after an earthquake in order to measure post-seismic deformation.

*1.3)Analysis of requirements*

To meet the ambitious vision outlined on a 5 to 10 year time scale requires a concerted effort from both EO data providers and scientists or value adding companies developing tools to exploit the EO data. The initiative should be user-driven to ensure that the results provided are utilised to increase resilience to earthquake hazards.

1.3.1) Requirements for EO data providers:

The main areas of the 5 to 10 year vision where activities are critically dependent on EO data providers are for the goals of mapping tectonic strain, mapping faults, and for rapid response to earthquakes. Specific recommendations include:

*For mapping strain:*
Mapping tectonic strain with the required accuracy to be useful for seismic hazard estimation requires regular repeated radar acquisitions over long time periods, ideally in several different viewing geometries. No single planned mission meets all the requirements, but upcoming missions, notably Sentinel-1A/B, ALOS-2 and the RCM, have the potential to collectively fulfil the objective. In order to achieve this:

- Planned radar missions should acquire data as often as possible in the world's seismic belts. The surface area with strain rates higher than 10-8 yr-1 is ~3.55% of the imageable Earth surface (between +/-80 degrees). The entire seismic belts, including the lower straining areas, cover ~15% of the earth's land surface.
- Radar missions should build uniform catalogues in single modes of acquisition for long periods of time. Missions should have background missions that build up large, uniform catalogues over the seismic belts. This will ensure accurate deformation rates can be recovered.
- Radar missions should acquire data with multiple viewing geometries (ascending and descending). To ensure that faults with all geometries can be viewed, single missions (e.g. Sentinel-1A/B) should acquire data in ascending and descending modes. Space agencies should coordinate efforts to ensure a range of viewing geometries are acquired in the future.
- Data should be made available for this task. Ideally, satellites should have a free and open data policy that would allow multiple users to work on this task. Multi-sensor imagery should be available with unified metadata through a convenient e-infrastructure following the example of the GSNL to facilitate joint analysis of thousands of radar data.

*For global fault mapping*:
Mapping faults using EO data requires high-resolution optical imagery and digital topography. Specifically:

- High-resolution (1 m or better) optical imagery should be made available at reasonable cost for all tectonic zones for the purposes of seismic hazard investigation. Currently the costs for finding faults across large regions using tectonic geomorphology from EO data are prohibitive for individual scientists or civil protection agencies.
- High-resolution (10 m or better) digital topography should be made available at reasonable cost for all tectonic zones for the purposes of seismic hazard investigation. New missions are capable of producing high-resolution topographic models using optical stereo matching or InSAR. Space agencies should consider making these available at reasonable cost for large regions for investigations into seismic hazard.

*For rapid response to earthquakes:*
The rapid acquisition of post-event data is critical. The impact of EO data for damage assessment is highest in the immediate aftermath of an earthquake, and its use would be facilitated by:

- Immediate tasking of radar and optical satellites for acquisition of post-event data. In some cases this will require special intervention to ensure imagery is acquired. In others, with suitable background missions, this objective should be straightforward to meet.
- Opening of archive data for the area of the earthquake. For change detection work using optical or radar data, pre-event imagery is as critical as post-event imagery.
- Rapid delivery of EO products to all potential users. This could be facilitated through the development and standardisation of the GSNL's "event supersites", for example, to ensure that all potential users of the EO data have rapid access to the best possible pre- and post-event data.

1.3.2) Requirements from scientists, civil protection agencies and value adding companies

To meet the objectives, considerable effort is required on the part of scientists, civil protection agencies and value adding companies. Specifically, the following tasks are required:

*For strain mapping:*

- Further development and optimisation of automated time series methods. To map strain using InSAR first requires producing the best possible deformation maps for individual radar tracks. If we are to achieve this regionally or even globally, considerable effort will be required in automating this process and conducting quality control with existing methods. Particular attention will need to be paid to phase unwrapping errors, orbital errors, corrections for tropospheric and ionospheric noise, and other geophysical corrections (such as earth tides). These are particularly important at the long spatial scales (~100 km) that are required for mapping tectonic strain.
- Testing and further development of methods for integrating GNSS and InSAR to map strain over large regions. Integrating observations from multiple satellites with different viewing geometries with ground-based GNSS observations is critical for producing a uniform product comparable to the existing, low-resolution global strain rate map, derived from GNSS. Further work is required to test and improve on existing algorithms.

- Organisation and planning is required if this task is to be completed. The processing involved represents a considerable task, which should not be underestimated. It will require dedicated operational staff and computing resources.

*For mapping active faults:*

- Further development of observational strategies. Mapping tectonic faults using EO data, particularly those that are blind at the surface, is becoming more routine, but methods are developing all the time. Further research is required in this area. Training of scientists and civil protection agencies is needed. Mapping faults across large regions or even globally would require a huge effort. Many of the methods used in tectonic geomorphology for identifying faults are now fairly routine, but specialist training is required to roll out these methods to a wider range of scientists in research establishments or civil protection agencies.
- Organisation and planning is required if this task is to be completed. Like strain mapping, this is a considerable task that would require some central coordination if a uniform global product is to be produced.

*For mapping seismic hazard:*

- Development and testing of methods for incorporating tectonic strain into seismic hazard maps. Methods have been proposed but need further testing and development.

*For rapid response to earthquakes:*

- Development and testing of methods for automatic rapid damage assessment using optical and/or radar imagery. Considerable progress has been made in this area, but further work is required to refine and automate existing algorithms.
- Development of automated algorithms and systems for rapid production and web delivery of co-seismic interferograms and derived products. At present, co-seismic interferograms and derived products are produced by the community and posted on 'event supersites' after significant events. This could be automated and products could be delivered via, for example, the USGS earthquake portal.
- Development and testing of automated geodetic source modelling routines. Numerous inversion schemes exist that are capable of creating source models after earthquakes. Few of these are automated, but there are no real barriers to this.
- Development of derived products from geodetic source models. Once the geodetic source models exist, creating derived products, such as predicted damage distributions or stress change maps, is relatively straightforward. Nevertheless, effort is required in developing, testing and automating these methods.

*For advancement of earthquake science:*

The goals in earthquake science are too numerous to list here, but one issue merits highlighting: modelling. In the past 20 years, data have outstripped model development when it comes to the earthquake loading cycle. There is not a self-consistent model that can explain co-seismic, post-seismic, and inter-seismic deformation that is accepted by the community, and this goal may be years away, in stark contrast with the climate community for example. Huge effort is required to support the modelling of geodetic data in order to better understand the physics of earthquakes.

1.3.3) Constraints and challenges:

To achieve the ambitious objectives set out will require considerable coordination and focused effort from the international community currently engaged in the use of EO for seismic risk. One of the challenges is that many scientific users of EO have, to date, been primarily focused on using EO for furthering understanding of the fundamental processes associated with earthquakes, rather than in creating new products or services that could have immediate practical implementation. These scientists need to be engaged with value-added companies and end users to deliver the services described here.

Products and services derived from EO will only ever be one component of an array of tools and data sets available to those responsible for managing seismic risk. The authors of this chapter believe there is scope for increasing the uptake and effective use of EO by the end user community and have highlighted several issues that need addressing:

- Lack of acceptance of EO data. Many of the technologies used in creating EO products that could be used by seismic risk practitioners are relatively new. Although methods have been validated in numerous scientific studies, further work is required in demonstrating the validity of products derived from EO, and in delivering robust uncertainty estimates.
- Lack of expertise. Most end users are not experts in EO data processing and interpretation. Considerable effort is required in creating products and services that are straightforward to use, and in building EO analysis capacity through targeted training to end users.
- High cost of many data products. Many civil protection agencies, particularly in developing countries, cannot afford to purchase EO-derived products, such as PSI deformation maps. Alternative funding models need to be considered if such products are to be widely used.

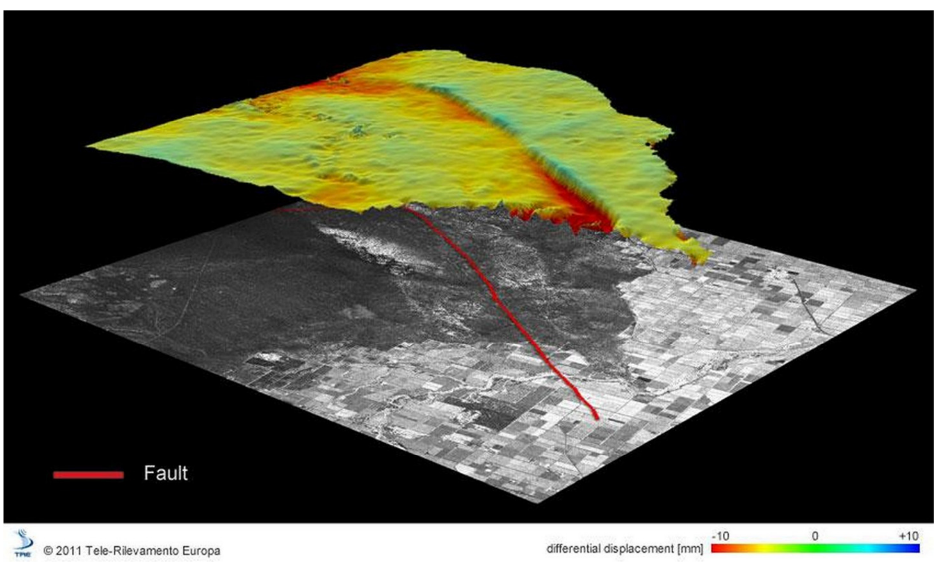


Figure 2. Example of a differential fault displacement map processed by Tele-Rilevamento Europa showing the ground displacement due to a tectonic event on Superstition Hills fault, California, in October 2006 using Radarsat-1 data of 28 Aug 2006 and 21 Sep 2006. Background image: multi image reflectivity map.

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## Annex 2: assessment of relevant activities, gaps and priorities:

The pilot set its objectives based on priorities elaborated through an open review process in the framework of the International Forum on Satellite EO and Geohazard (see Annexes 1 & 2). The three objectives are:

A. **Support the generation of globally self-consistent strain rate estimates and the mapping of active faults at the global scale by providing EO InSAR and optical data and processing capacities to existing initiatives, such as the iGSRM**

*[Wide extent satellite observations]*

B. **Support and continue the GSNL for seismic hazards and volcanoes**

*[Satellite observations focused on supersites]*

C. **Develop and demonstrate advanced science products for rapid earthquake response.**

*[Observation of earthquakes with M>5.8]*

In addition, the CEOS DRM activity on seismic hazards will promote the International Charter Space & Major for crisis mapping/damage assessment in the immediate response to earthquakes, offering information and facilitating access for interested communities.

*1) State of development concerning global EO based seismic hazard mapping:*

Today, the only comprehensive global seismic hazard map is that generated by the Global Seismic Hazard Assessment Program. The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/ISDR). The GSHAP project terminated in 1999. The GSHAP Global Seismic Hazard Map has been compiled by joining the regional maps produced for different GSHAP regions and test areas.

*Developments foreseen/on-going with GEM:*

A new effort is underway to map earthquake risk through the Global Earthquake Model (GEM, http://www.globalquakemodel.org) an international initiative looking at hazard modelling, hazard exposure and vulnerability. On exposure and vulnerability and the elaboration of risk scenarios the contribution of GEM can be very valuable; concerning exposure, Satellite EO is a source of information and GEM have started to approach the GSNL. Hazard modelling in GEM currently does not consider using Satellite EO i.e. GEM will not use Earth observation data in the short term. GEM is developing a strain rate model. The Global Strain Rate Map project II-8, initiated in 1998 by the International Lithosphere Program (ILP), provides constraints for understanding continental dynamics and for quantifying seismic hazards in general. To date, the Global Strain Rate Map (GSRM) model is a numerical velocity gradient tensor field solution (i.e., spatial variations of horizontal strain rate tensor components and rotation rates) for the entire Earth surface [Kreemer et al., 2003 'an integrated global model of present-day plate motions and plate boundary deformation,Geophys. J. Int., 154, 8–34]. The model consists of a grid with 51 rigid plates/blocks and~142,000 deforming cells of 0.2º by 0.25º; it provides an estimate of the horizontal strain rates, rotation rates, and velocity fields for the diffuse plate boundary zones as well as an estimate of the motions of the spherical caps. This is one of the first successful models of its kind that includes the kinematics of plate boundary zones in the description of global plate kinematics. The vast majority of the data used to obtain this model come from horizontal velocity measurements obtained using Global Positioning System (GPS).

The EUCENTRE is a Research Centre on Seismic Engineering, co-located with the Engineering Campus of the University of Pavia, Italy. The Aerospace Section of the EUCENTRE addresses issues related to aerospace support in the analysis and risk management, especially regarding seismic risk. The Section Head, Fabio Dell'Acqua, is the PoC for Component C2 on Geohazards, of Task Di-01 "Disasters" in GEO WP 2012-2015. GEO Supersites are declared in Component C2, as mentioned in the introduction to this document. The EUCENTRE has strong links with the GEM (Global Earthquake Model), also located in Pavia, Italy, and will be a partner in the pilot.

*Developments foreseen/on-going with the iGSRM:*

Some scientists have proposed the use of satellite-borne SAR to map global strain at high spatial resolution incorporating deformation constraints form both GNSS and InSAR. InSAR observations would allow for global terrestrial observations of near uniform quality with a large number of points of reference and thus allow the generation of a very accurate strain model, although the number of imaged scenes is quite high. Testing this approach on a given geographic area, such as the part of the Alpine-Himilayan belt would allow validation of the methodologies employed and comparison with other measurement models.

The Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics COMET+ (http://comet.nerc.ac.uk/) was formed from its predecessor, the Centre for the Observation and Modelling of Earthquakes and Tectonics (COMET), one of the six original NERC Earth Observation Centres of Excellence, when its investigators became members of the Dynamic Earth and Geohazards research group in the National Centre of Earth Observation in 2008. At that time, its remit was broadened to include volcanological research. The COMET+ team is currently planning to investigate the elaboration of a Global Strain Rate Model or Map using advanced space-borne INSAR – the so called iGSRM - and made a 3.5million Euro proposal to NERC. This is described in Annex 5.

There are other science teams working on similar approaches.

As opposed to the geohazard supersites (GSNL, see 2.2) the aim of the iGSRM is to map terrain motion over large surfaces, the target is 15% of land surface; that will imply to provide the minimum necessary datastacks over very extended regions as opposed to the GSNL that have the aim to provide many INSAR observations and non EO data over a discrete series of sites with limited extent. Because of this constraint EO systems providing large coverage and repeat observations will be needed and the EO missions that will primarily contribute to the iGSRM are Sentinel-1, ALOS-2 and possibly RCM.

The challenges the iGSRM has to face concerns the ingestion of large quantities of large volume files alongside with the processing of such data (using both conventional INSAR and the PSI).

In view of the large processing effort planned it is to be noted that the capacity of Catapult/CEMs of Harwell (UK) has been foreseen by COMET+. In addition it is noted that the German collaborative ground segment could play a role given the capabilities they foresee (with a clear mention of INSAR capabilities).

As indicated in the description of the GEM initiative there are other initiatives – not based on Satellite EO - concerning the estimation of strain rates at global scale. Concerned an EO based solution like the iGSRM, while it has the merit of allowing measurements at global scale including remote parts of the seismic belt where in siutu data are not available, it needs to demonstrated whether using INSAR the strain rate estimates are suitable for deriving the accurate hazard information.

*Developments foreseen/on-going with EPOS (Europe):*

The strategic project EPOS (European Plate Observing System) is coordinated from Italy through the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and has the aim to coordinate Research Infrastructure and e-science for Data and Observatories on Earthquakes, Volcanoes, Surface Dynamics and Tectonics. Originally, the EPOS project was limited to using in situ data. More recently, the need to augment these data with valuable satellite EO has been recognized. The working group WG8 ‘Satellite Information Data’ is the link between the EO data community, composed of the EO data providers and EO product providers, and the in situ data community. EPOS won't develop EO based activities but they are key concerning the adoption of solutions concerning seismic users at European level.

*2) State of development concerning the Geohazard Supersites and Natural Laboratories (GSNL):*

As currently structured, the GSNL are an on-line catalogue of metadata with links to repositories (supersites.earthobservations.org) providing large volumes of freely available SAR data for scientific analysis of geohazard risk. EO data made available through the GSNL are available to all (upon request for some of the EO sources, systematically for other EO sources).

The structure is by its own definition “free-form”, encouraging an open policy with multiple formats and few constraints. Metadata are organised by supersite, and are currently presented without geographic interface or display query, or shape files, although this is under development. Data are in fact still in their own archives, which can be accessed through the virtual archive (e.g. ESA data: eo-virtual-archive4.esa.int), a Cloud solution providing Storage-as-a-Service for storing the data and coupled with complementary services: user authentication and authorization; data discovery implementing simple interfaces such as OpenSearch and results in Atom, RDF and KML format; data access via common web protocols such as HTTP(s). Other EO sources such as TerraSAR-X are not available via the virtual archive; TerraSAR-X data for the selected Supersites is currently available according to site-specific mechanisms and will be searchable by an HMA CSW and downloadable from an https server. Similarly a license agreement (restricted to scientific use cases) must be signed with ASI for access to Cosmo data. Ultimately, the GSNL aims at setting up a common search and access interface.

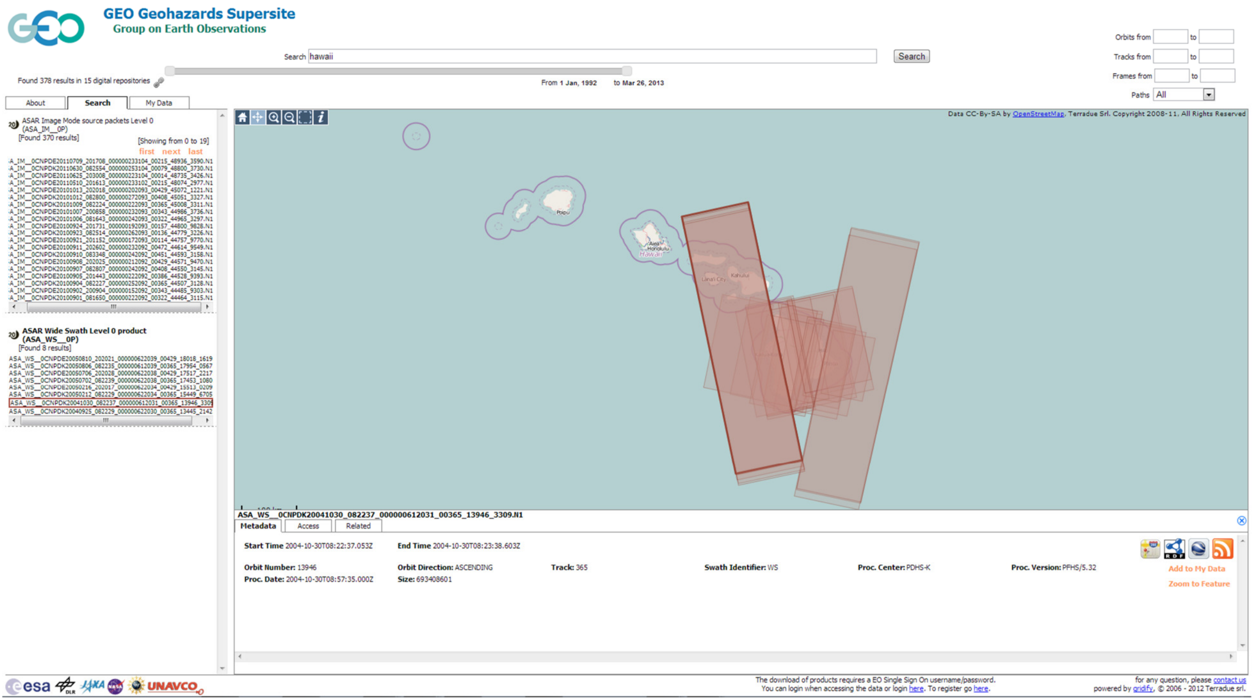



Figure 3. Illustration of the virtual archive used by the GSNL to access ESA missions data.

On the user side, there is no user obligation or commitment. There is no formal user login process, and no clear listing of users. The GSNL lacks a clear and transparent management structure and long-term vision for sustainable service provision to the solid earth science community. On the other hand, the GSNL have built considerable momentum since inception in 2007, and have established an international precedent for large volumes of freely available SAR data for scientific analysis of geohazard risk.

What the GSNL currently provides can be characterised as follows:

- The GSNL is not an upon request service and applies plans defined by the GSNL research teams
- A web site (supersites.earthobservations.org/)
- The web site does not comprise any geographic interface to display, query or get data, although plans for this in the future exist, including a possible portal
- A repository of data today focused on ESA data (eo-virtual-archive4.esa.int)
- The GSNL provides data freely & openly and there is no SLA, meaning no obligation for users. It is using a basic registration (using simple credentials via SSO) to identify / track users and download activities but simple products are available for download without registration.
- The GSNL has a list of sites but they are not described as geographic features (e.g. no shapefiles)
- The GSNL does not have a pre-defined list of users
- There is no clear mechanism to federate them apart from the SAC
- The GSNL does not have an exploitation platform to allow processing
- The GSNL includes non EO data such as GNSS data. The willingness of sites to contribute in-situ data is an evaluation criteria in the selection process. (Determine portion of the supersites that are non EO data)

The GSNL are involving, with significant new input from CEOS. Many of the issues identified are being addressed through CEOS and a significant restructuring should be completed by end 2013. This restructuring offers ESA an opportunity to influence improve the basic function of the GSNL.

*Developments foreseen/on-going at ESA:*

The development of the EO pilot of Helix Nebula 'SSEP' is being led by Logica with Terradue. It began in June 2012, with a forecast end in January 2014. Budget: circa 300kEuro. The focus of this project is on space data only. It includes INSAR processing with the SBAS chain of CNR IREA, the INSAR chain of GAMMA, the GMTSAR toolbox of Univ. Miami. The project will be tested with beta users. ESA also started the E-CEO project to test e-infrastructures in the area of INSAR with CNR IREA. Details are provided at: https://wiki.services.eoportal.org/tiki-index.php?page=SSEP.

What the SSEP provides comprises of:

1. Hosting & dissemination of data on the cloud
2. Processing services (the INSAR modules of GAMMA, CNR IREA and the GMTSAR, NEST modules)
3. Virtual machines (cloud as a platform)

Only 1) is available to the GSNL today (concerning ESA data only). To use the SSEP users need to submit a request to be selected and awarded quotas.

*3) State of development concerning a rapid response to earthquakes:*

Concerning the rapid response to earthquakes, the concrete objectives of user community is given in Annex 1 page 5 with seven items 5.a) to 5.g). A roadmap to address them requires to set priorities. It is suggested to first address 5.a), 5.b) and 5.g). The scientific community will develop tools and services to deliver 5c to 5f.

The rapid response considered is a rapid generation of InSAR products, which are not currently covered by the Charter. The Charter provides rapid access to imagery for response, typically VHR & HR Optical and SAR imagery to support crisis mapping, damage assessment and background /reference mapping. The scenarios of the Charter are hazard type specific and are based on sensor options tuned to optimize the sensitivity to the bio-geo-physical parameters of interest and to ensure the most rapid access. This is different from the observational requirements of InSAR concerning the GSNL that are based on times series with a fixed geometry to allow interferometric correlation; this criteria is higher priority than the rapidity of the next acquisition i.e. rather than the first possible acquisition an InSAR scenario will identify the next acquisition with the right viewing angle / sub-swath and polarization (w.r.t. the data ex archive).

Because we do not know in advance where damaging earthquakes will occur, for a rapid InSAR response to be effective, a regular background set of radar acquisitions must be made for all the tectonic areas, not just the GSNLs. For those missions associated with the iGSRM, the archive will be available. If other satellites are to be useful for this objective, they would need to have images available in the archive from which interferometric pairs could be formed. The frequency of revisits for a useful background mission would depend on the background coherence.

Overall the CEOS DRM objectives associated to them are:

C. Develop a rapid response to earthquakes (supersite extension, concerns the supply of EO data to support seismology rather than disaster response). The generation of InSAR products for earthquake response can be considered a function provided by the GSNL.
D. Rely on the International Charter to supply EO data for crisis mapping/damage assessment for the immediate response to geohazards.

*As far as long-term response to earthquakes is concerned:* Long-term research over years and decades to acquire data and analyse decadal post-seismic deformation is not clearly available to the international research community, and can only be found through dedicated searches on a case-by-case basis. This can be addressed by the GSNL for their sites i.e. for a limited series of sites.

## Annex 3: overview of the GSNL

"The Supersites have data for the study of natural hazards in geologically active regions, including information from Synthetic Aperture Radar (SAR), GPS crustal deformation measurements, and earthquakes. The data are provided in the spirit of GEO, ESA, NASA and the National Science Foundation (NSF), that easy access to Earth science data will promote their use and advance scientific research, ultimately leading to reduced loss of life from natural hazards."[1]

The GSNL differentiate four types of Supersites[2]:

- Permanent Supersites
  - Highest priority
  - Threat to humans and/or critical facilities
  - Scientific investigations aim at understanding processes

- Candidate Supersites
  - … are Permanent Supersites under development.

- Event Supersites
  - Recently affected by major geological event
  - important and rare opportunity for scientific investigation
  - Substantial scientific interest internationally

- Natural Laboratories
  - Potentially larger areas
  - Potentially less densely monitored

As currently structured, the GSNL are providing large volumes of freely available SAR data for scientific analysis of geohazard risk. Supersites are assumed to provide several EO sources and in situ data and Natural Laboratories concern sites for which a space agency contributors provides an EO data collection. For Supersites, Event sites and Natural Laboratories the EO data are available to all (upon request for some of the EO sources, systematically for other EO sources).

A selection process for new Supersites has been agreed (see http://supersites.earthobservations.org/CEOS_SelectionProcessProposal.pdf ) .

The GSNL Scientific Advisory Committee is responsible for proposing permanent supersites and natural laboratories, according to the following criteria:
**"**Potential Supersites will be selected according to three criteria.

1) *GEOSS commitment of local monitoring agency.* This includes (i) the willingness to contribute in-situ data to GEOSS, (ii) the likelihood that the data and data products will flow into geohazard assessment, and (iii) efficient communication with task leadership (e.g. articulating data requirement, providing feedback about satellite data use in particular for crisis situations, etc).

[1] From GSNL homepage at supersites.earthobservations.org
[2] http://supersites.earthobservations.org/Supersites_Definitions_final.pdf

2) *Vulnerability of population.* As laid out in the original White Paper, geohazard sites with significant populations exposed to geohazards are of higher relevance than unpopulated areas.
3) *Potential for new scientific results*. Sites with a high likelihood for new scientific results are of higher relevance because we need to demonstrate to CEOS that the satellite resources are well used.
4) *Geographical distribution*. We aim for 1 or 2 Supersites for each country of each proposed natural laboratory.

The GSNL SAC propose to rate the sites according to the three criteria. For each site a total of 10 points is available: 4 for the GEOSS involvement, 3 for the potential of new scientific results, and 3 for vulnerability. Higher numbers indicate better rating. For GEOSS commitment points are given for the provision of information (1 pt for returning the questionnaire) and for the contribution of seismic and GPS data (3 pts)."[3]

To date (April 2013) one Permanent Supersite has been confirmed (Hawaii). A second one has been proposed (Iceland) and is currently reviewed by CEOS. In addition, the are more recent supersite proposals covering Italian volcanoes, Ecuadorian volcanoes, New Zealand volcanoes, Piton de la Fournaise, and the Marmara Sea.

A number of initial supersites were chosen prior to agreeing on a selection procedure, which are expected to be reviewed and formally proposed in the near future. According to the GSNL homepage, these sites are:

Earthquake Supersites

- Istanbul, Turkey
- Tokyo, Japan
- Los Angeles, USA
- Vancouver and Seattle, Canada and USA

Volcano Supersites

- Campi Flegreii and Vesuvius, Italy
- Mt Etna, Italy
- Hawaiian volcanoes, USA

Event Supersites include:

- Tohoku-oki
- Chile
- Haiti
- Wenchuan, China

In addition to the Event Supersites, there are smaller scale events ("other events") for which the GSNL keep data:

- Van, Turkey
- Baja California, Mexico
- Yushu, China
- Eyjafjallajökul, Iceland
- l'Aquila, Italy

[3] Ibidem.


Figure 5. Overview of the GSNL sites according to supersites.earthobservations.org.

In addition to the supersites, GSNL has designated certain areas as Natural Laboratories. "Natural Laboratories are geographic regions in one or several countries characterized by relevant geohazards and a coherent tectonic setting. They are similar to Permanent Supersites but cover larger regions and are less densely monitored. They are subject to investigations aimed at broadening the scientific understanding of the causative processes and at narrowing the uncertainty in geohazard assessment. Natural Laboratories provide a framework for regional collaborations in order to promote transnational access and collaborative temporary experiments for implementing the existing observing systems. Data providers and end users would share data and products, and coordinate research and studies at regional level including activities for testing and validating new techniques, technologies and sensors.
Natural laboratories are not limited in time and will normally exist during the lifetime of the related activities or organizations and beyond that as applicable."[4]

The following Natural Laboratories are under discussion. For many, ESA data are readily available for download from EOLI SA.

- Japan Natural Laboratory.
- Turkey Natural Laboratory.
- Iceland Natural Laboratory.
- Gulf of Corinth Corinth Rift Laboratory. For access to in-situ data see The Corinth Rift Laboratory (CRL).
- Western North America: see the Earthscope Area Natural Laboratory, and the University of Utah's Research on the Yellowstone-Teton-Snake River Plain Region.
- Ocean Island volcanoes: Hawaii (see Hawaii Supersite), Piton de la Fournaise, Galapagos, Cape Verdes, and the Canary Islands.
- Southeast Asia
- Latin America (Central-Southern Andes, Northern Andes, Caribbean)
- Mexico

[4] Definition from GSNL "Supersites Definitions" document, available at www.earthobservations.org

- Alaska North Pacific Ring of Fire (Aleutians, Kamchatka, Kuriles)
- Middle East
- East African Rift
- Central Asia (Tibet , etc.)

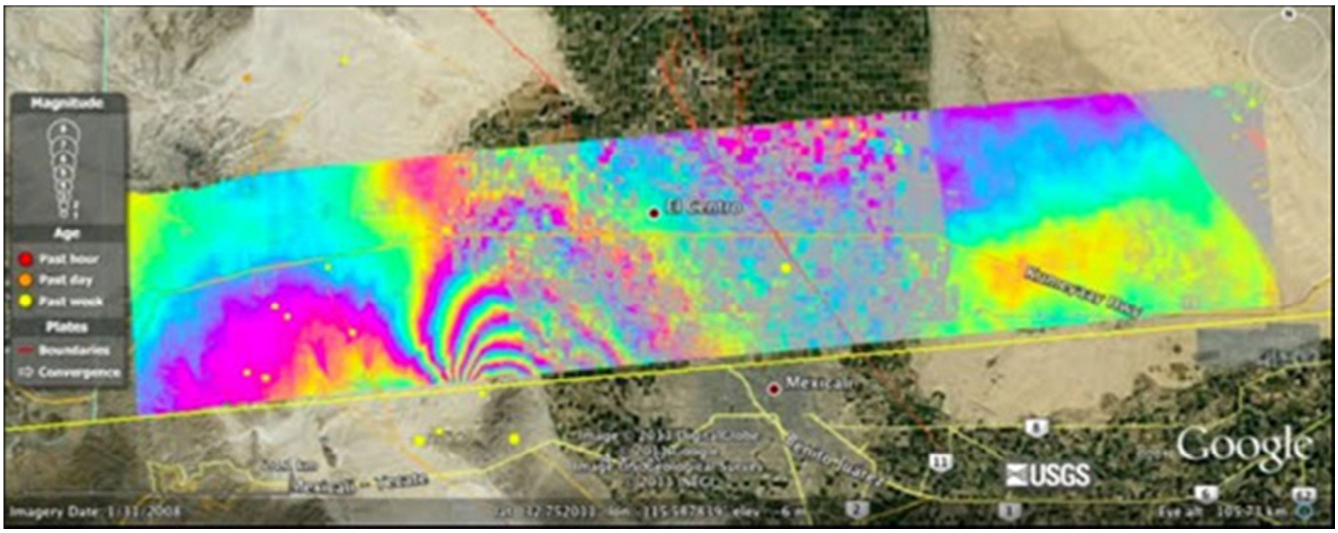
It should be noted that discussions with the GEO Secretariat, which assumes the role of Secretary for the GSNL Steering Committee and Science Advisory Committee, indicated that a new GSNL website is planned, and that the list of supersites is being revised. A new requirement of endorsement by the CEOS Plenary has been imposed, meaning at this time there is only one official supersite: Hawaii. At the next CEOS Plenary in late 2013, GSNL is expected to present further sites for endorsement: Turkey (NAFZ), Los Angeles (San Andreas Fault), Iceland and Italian volcanoes. There is still discussion within the GSNL community to understand how many supersites would be an ideal number.

The GSNL Scientific Advisory Committee is chaired by Falk Amelung of CSTARS (University of Miami) and aims to be representative of both hazards and regions. Its current members are: Tim Ahern of IRIS, USA; Falk Amelung of Univ. Of Miami, USA; Massimo Cocco of INGV, Italy; Florian Haslinger of ETH, Switzerland; Chuck Meertens of UNAVCO, USA; Hisao Ito of JAMSTEC, Japan; John Townend of Univ. of Auckland, New Zealand; Susanna Zerbini of WEGENER, Italy.

A separate body made up of space agency representatives, the Steering Committee, has as secretary the GEO Secretariat. Its members are: DLR (chair): J. Hoffmann, CSA: C. Giguère, ASI: S. Zoffoli, JAXA: Kazuo Umezawa and Shizu Yabe, CNES: S. Hosford, ESA: Wolfgang Lengert, NASA: Francis Lindsay.

## Annex 4: overview of SSARA (Seamless Synthetic Aperture Radar Archive)

“The ASF and UNAVCO are pleased to announce the release of a beta SSARA Federated API. Using this single access point, users will soon be able to search for SAR images archived at both ASF and UNAVCO. To interact with this beta federated querier please visit the Interactive API Tool for Accessing Synthetic Aperture Radar Data and select the "SSARA Federated API Query" tab. For further usage details on the SSARA Federated and ASF API visit http://www.asf.alaska.edu/program/sdc/asf_api.

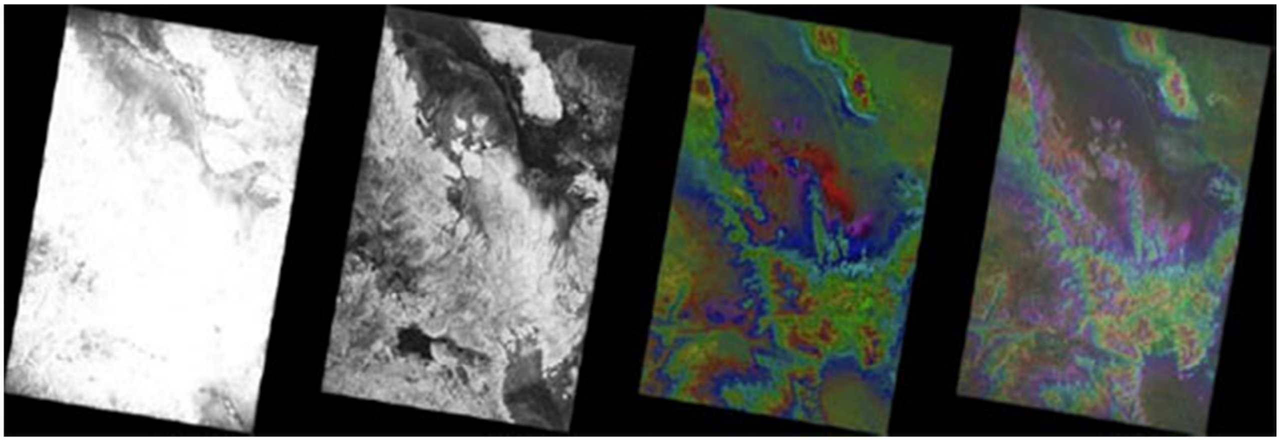



*NASA UAVSAR interferogram showing deformation from the 2010 Mw 7.2 earthquake in Baja California, Mexico. Fringe contours of deformation are 11.9 cm each showing up to 80 cm of motion. Enhanced access to UAVSAR interferograms is one objective of our project.*

UNAVCO/WInSAR, the Alaska Satellite Facility (ASF), and the Jet Propulsion Laboratory (JPL) are collaborating in an information technology and data management development project to design and implement a seamless distributed access system for Synthetic Aperture Radar (SAR) data and derived interferometric data products. A seamless SAR archive will increase the accessibility and the utility of SAR science data to solid Earth and cryospheric science researchers.

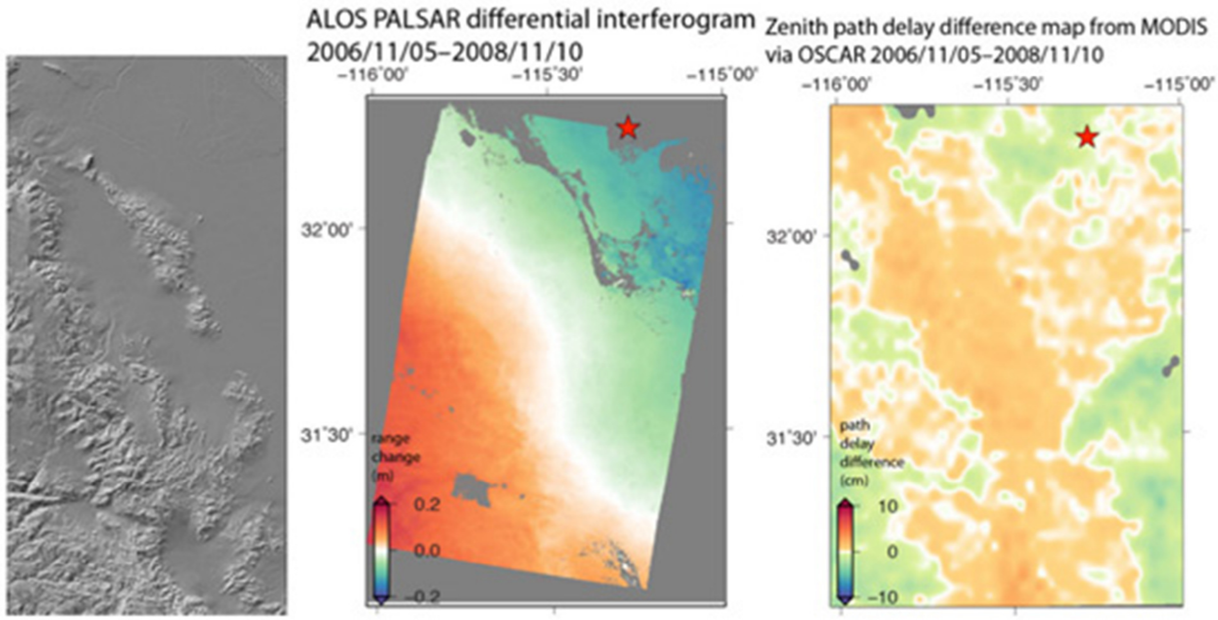

*An example of the URSA baseline plot. Users are provided with the capability to observe the perpendicular and temporal baseline distribution of an InSAR stack based on the selection of a desired master, filter granules, and select granules to order.*

Specifically, the project will provide simple web services tools to more seamlessly and effectively exchange and share SAR metadata, data and archived and on-demand derived products between the distributed archives, individual users, and key information technology development systems such as the NASA/JPL ARIA projects that provide higher level resources for geodetic data processing, data assimilation and modeling, and integrative analysis for scientific research and hazards applications. The proposed seamless SAR archive will significantly enhance mature IT capabilities at ASFs NASA-supported DAAC, the GEO Supersites archive, supported operationally by UNAVCO, and UNAVCO's WInSAR and EarthScope archives that are supported by NASA, NSF, and the USGS in close collaboration with ESA/ESRIN.



*ALOS-PALSAR amplitude image, coherence image, interferogram, and interferogram overlaid on the amplitude of the master image (left to right). Master image: acquired 2006-11-05. Slave image acquired 2008- 11-10 over Baja, California, Mexico. The copyright for the scenes used to create this image (and those below) is held by the Japan Aerospace Exploration Agency/Ministry of Economy, Trade and Industry*

As part of the proposed effort, data/product standard formats and new QC/QA definitions will be developed and implemented to streamline data usage and enable advanced query capability. The seamless SAR archive will provide users with simple browser and web service API access tools to view and retrieve SAR data from multiple archives, to place their tasking requests, to order data, and to report results back to data providers; to make a larger pool of data available to scientific data users; and to encourage broader national and international use of SAR data. The new ACCESS-developed tools will help overcome current obstacles including heterogeneous archive access protocols and data/product formats, data provider access policy constraints, and an increasingly broad and diverse selection of SAR data that now includes ESA/ERS/ENVISAT (and upcoming Sentinel mission), CSA/Radarsat, JAXA/ALOS-PALSAR, DLR/TerraSAR-X satellite data and NASA/UAVSAR aircraft SAR data. The list will continue to expand with NASA/DESDynI further increasing the need to efficiently discover, access, retrieve, distribute, and process huge quantities of new and diverse data.




*To facilitate terrain corrections, the proposed NSAR project will provide InSAR-ready topographic data through OpenTopography. Shown in (a) above is the terrain correction (EGM96 removed) via GMTSAR from NASA SRTM data. The terrain corrected differential interferogram unwrapped phase in (b) from the same ALOS-PALSAR pair was processed using ROI_PAC. Red star shows epicenter of April 2010 Mw 7.2 earthquake. The apparent range change variation is 30 cm. (c) shows the zenith path delay difference from OSCAR ODIS zenith path delay maps. The path delay difference map shows no large gradient due to the troposphere in this case. The ASF URSA catalog reports very high values for the Faraday rotation in the ionosphere for these two scenes, which would be consistent with large ionospheric delays. The NSAR project will standardize product and corrections/QC formats and facilitate this type of product quality evaluation and access to products critical to the interpretation of interferograms for earth surface motions and deformation.*

**Project Objectives:**

1. Develop and implement a federated metadata query and data and data product download capability from distributed airborne (NASA UAVSAR) and spaceborne SAR archives at ASF and UNAVCO/WInSAR.

2. Define and make available new QC parameters and products that will enhance the usability of data and data products from these existing NASA-funded collections.

3. Implement a web services enabled terrain correction service for interferometry (InSAR) using NASA SRTM data at SDSC.

4. Enhance ASF InSAR processing service to access distributed data collections, utilize terrain correction service, and generate enhanced QC products.

Establish processed data products archive."

- From www.asf.alaska.edu

## Annex 5: overview of ESA's SSEP proposal

With the advent of big data exploitation scenarios, the concept of "User Exploitation Platforms" (UEP) is increasingly presented as one of the potential solutions to *enable* access to and exploitation of large volumes of data, including the sentinels. As a first step to a wider strategy on UEP, we propose a User Exploitation Platform in support of the Geohazards community, progressively extending the capabilities of the SuperSites Exploitation Platform (SSEP) to a full-fledged "Global Strain Exploitation Platform" (GSEP) addressing the wider needs of the community.

The legacy model for data access and exploitation underlying the Envisat/ERS-era scenarios foresaw a simple model of data distribution. Data was distributed to whatever users required them, either by ordering or simple on-line access, and the exploitation work (and further processing) would take place at the user's premises, typically on the user's proprietary infrastructure. In short, data was transferred many times, replicated and processed in many places.  Collaborative work was not intrinsically supported.

The increasing volume of Earth Science observation becoming available drives the rationale for UEP. In particular, the new generation of Earth Observation (EO) satellites such as Sentinels will deliver Terabytes per day; Petabytes per year, and users require high-speed network connections (e.g. GEANT) – including the last mile to the user; huge data storage; and massive processing power. So also for certain geophysical applications – interferometry on large stacks is an example close to home. Consequently, user applications and assimilators of data (geophysical models, decision support systems, scientific algorithms etc.) will be able to handle the required data supply only if supported within big, sustained, and well-resourced organizational set-ups. The cost of procuring and operating the required infrastructure will be prohibitive to many.

The concept of UEP is based on an alternative paradigm: The cardinal idea is to facilitate data access and exploitation by moving the scientist's 'desktop' (and associated software) to the data, rather than moving the data to the scientists, thereby enabling ultra-fast data access and processing, and finally transferring a few Megabytes of results rather than several Terra/Petabytes of raw data to the user.

The platform delivers a complete work environment for its' users, and as such corresponds to the 'place' where exploitation work is done. Scientists access a platform work environment where they find data and processing capabilities, as opposed to downloading, replicating, and processing the data 'at home'. As a slightly reductive definition (but sufficient to illustrate the concept), a User Exploitation Platform corresponds to a Virtual Environment bringing together data, computing resources, tools (also third-party), workflows, documentation and support, all through an integrated user interface.

In the particular case of the GeoHazards community, a UEP would ideally include *inter alia* remote sensing and in-situ data from several sources (extension of the supersites data collections), combined with data discovery and InSAR processing capabilities (such as InSAR, GAMMA, SBAS, visualisation tools, MatLab etc.), a scientific social networking platform with collaborative capabilities, and would give access to the scalable ICT resources required for processing.

ESA has already developed a first demonstration of UEP focusing on the super site Geohazards community: the “Supersites Exploitation Platform” (SSEP).

SSEP is an e-infrastructure developed by ESA to enable discovery, access, mining and exploitation of EO data in support of the Solid Earth Science community, with a particular focus on the ‘Geohazard Super Sites’. The application is developed as the ESA flagship contribution to the Helix Nebula initiative (helix-nebula.eu), targets the European Science Cloud, and was based on the GEO Geohazards Supersites and National Laboratories web site, archive, and community.

The SSEP capability can be used as a critical building block of a distributed global e-infrastructure for Geohazards, providing scientists with a new way to use and share multiple heterogeneous data sets from federated data providers across communities and observing systems (e.g. EO, seismic, GPS).

The SSEP v1.0 demonstrator is at present in beta testing with a limited user community and provides:

- A virtual workbench where scientists can work, manipulate ESA EO data (supersite archive subset) as if they were in their office. The current workbench for SSEP 1.0 is hosted on a Cloud provider in Geneva offering co-location of data storage and cloud processing.
- Virtual data archive including ERS and Envisat SAR archive (supersites coverage), with a web-based interface to easily discover and access data
- Cloud processing on demand provided by commercial cloud providers, and scalable on demand.
- Third party software / workflows for SAR processing, including open-source (e.g. ESA toolbox, CNR SBAS) and commercial providers (e.g. Gamma)

The SSEP v2.0 (2013): to be started shortly is an activity aimed at the incremental evolution of the general capabilities of the application. This development targets the following:

- Extension of VM to include a development environment (CIOP Toolbox) for the development and deployment of new processing services on the platform
- Piloting integration with cloud brokering services to allow interfaces to several cloud providers, allow users to select ICT provider and thus avoid vendor lock-in
- New features allowing for the publication of processing results directly on the Cloud, i.e. dropbox.
- Dynamic provisioning of cloud resources, including sizing of clusters based on processing request load
- Layered administration, so that data ingestion and processing services related to the SuperSites could be safely delegated to administrators independent of the operation of the application and infrastructure

Following the SSEP v1.0 & v2.0 demonstrators, ESA is proposing the SSEP v3.0 (2013) to provide a rapidly available evolution of SSEP, with the principal purpose to build a research test bed environment for the geohazard risks community . This application will be operated for a period limited to one year after deployment, for outreach and pre-operation testing purposes, after which the GSEP should become operational. The principal targets of this activity are as follows:

- Integrate additional data: Access to VA4 and GPS data through integration with the SSARA API (pending agreements with data owners and alignment with relevant data policies); integration of the Envisat / ERS (A)SAR coverage dataset for big data collections concerning tectonic analysis e.g. strain rate assessment, active faults mapping, etc; catalogue integration (accessible through GUI); GlusterFS integration. In addition, the application will incrementally integrate relevant Sentinel-1 data (if in line with the Copernicus Regulation under preparation by the European Union and corresponding relevant data policy)
- Integrate new tools / capabilities: Consistency / feasibility analysis of processing scenario over identified dataset (implementation of persistent DB); extended visualization tools; integration of modeling tools; GMTSAR software (in addition to the SBAS and GAMMA softwares)

## Annex 6: overview of the INSAR-based GSRM initiative (iGSRM)

Tim Wright (COMET, University of Leeds) is leading an international effort to build a strain rate model constrained by GPS and InSAR for the Earth's tectonic belts. Funding in the UK has been secured for 2013-2018 from the Natural Environmental Research Council through the Centre for the Observation and Modelling of Volcanoes, Earthquakes and Tectonics (COMET+) and a large grant, "Looking inside the Continents from Space" (LICS; PIs Parsons and Wright). The current funding should be sufficient to build the strain map for the entire Alpine-Himalayan Belt and East African Rift. Other partners are being sought to expand the global coverage.

The excerpt below, from the LICS proposal explains the approach:
"Despite the success of InSAR to date, only a small proportion of the world's faults systems have InSAR measurements of interseismic deformation. Intermittent acquisitions with sometimes long intervals between them, and large variations in orbital position, mean that often there is not the sufficiently large number of high-quality interferograms required to properly mitigate the various error sources. However, in mid-to-late 2013, ESA will launch Sentinel-1A, a new radar satellite, followed 18 months later by an identical spacecraft Sentinel-1B, as part of the European Commission's Global Monitoring for Environment and Security (GMES) programme. Should either satellite fail, a spare will be available; the programme is planned for 20 years.[5] After an initial year of commissioning and ramping up, every point in the tectonic belts will be observed twice in each 12-day repeat cycle (on ascending and descending passes); every 3 days on average after the second satellite is launched. The shorter repeat times and tighter orbital control and regular acquisitions for Sentinel-1 data will markedly improve the coherence of interferograms relative to previous satellite missions and allow time-series InSAR methods to be automated.

"Aims and Objectives
"We aim to produce radically-improved estimates of time-dependent surface deformation in the Alpine-Himalayan Belt and East African Rift using radar data from Sentinel-1. We will use these to better characterise the seismic hazard for the region and to determine the appropriate dynamical models that describe the observed deformation.
"The proposal's specific objectives are grouped into three interlinked themes:

A. To make a fundamental advance in the measurement of tectonic deformation at high spatial resolution, utilising new data from the Sentinel-1 mission, by

5. Developing time-series methods and algorithms for their routine application across large regions using data from Sentinel-1.
6. Assimilating constraints from numerical weather prediction models to reduce the impact of atmospheric noise.
7. Improving the orbital model for Sentinel-1 to eliminate significant long-wavelength orbital errors.

B. To improve assessment of seismic hazard in the Alpine-Himalayan belt by

4. Constructing high-resolution velocity and strain-rate fields for the region.

[5] Other back-up data will also be available from Canada's RSAT Constellation Mission, beginning in 2016.

5. Using high-resolution imagery and elevation models to map unknown faults.
6. Assessing time-dependent hazard following major earthquakes.

C. To understand how the continents deform in space and time, and how this is controlled by the strength distribution in the lithosphere, by

7. Modelling observations of time-dependent earthquake cycle deformation to constrain the rheology of fault zones.
8. Testing competing hypotheses about continental collision using 3-dimensional numerical models with new constraints on rheological variations.
9. Establishing the factors that control the mechanism of continental extension in the East African Rift.

The project will deliver fundamental new data sets that will have wide academic and non-academic impact. We expect the new views that will emerge on continental tectonics from this effort to influence strongly the scientific agenda for the coming decades."

## Annex 7: overview of Advanced Rapid Imaging and Analysis Project (NASA/JPL)

When an earthquake occurs, seismic data provide an initial estimate of magnitude and location. However, for large earthquakes, we can improve our situational awareness once we know the full extent of the rupture — large earthquakes result from several 100's of kilometers of fault breaking, not just a point on the map corresponding to the epicenter. Rapid GPS and InSAR measurements from impacted regions combined with modeling can often tell us where and how much a fault ruptured, constraining these values more reliably than is possible using seismic data alone. Determining the geometry of the ruptured fault is critical for improving rapid estimates of the distribution and intensity of earthquake shaking (e.g., ShakeMaps). Accurate seismic shaking information is necessary for post-event fatality and loss estimates in support of recovery efforts.

The Advanced Rapid Imaging and Analysis (ARIA) project is collaboration between the Jet Propulsion Laboratory, which is operated under contract with NASA by the California Institute of Technology (Caltech), and the Caltech Division of Geological and Planetary Sciences (http://aria.jpl.nasa.gov). A prototype data system has been built that automates the generation of geodetic imaging products, including coseismic deformation and damage proxy maps, from SAR imagery and GPS data. We have recently developed algorithms for using SAR data to identify regions that have experienced damage. Integrating these SAR-based damage proxy maps into existing loss estimation models could give responders more accurate information on economic losses, estimated fatalities. The ARIA geodetic coseismic deformation products are then used along with seismic waveforms for modeling the distribution of slip on finite faults that ruptured in the earthquakes. New development is underway to include analysis of high-resolution optical imagery to measure coseismic deformation and estimate damage. The ARIA project is also working on monitoring hazards with SAR and GPS data, especially volcanic hazards, by time series analysis of InSAR and GPS data.

The ARIA group has recently started a new collaboration with the US Geological Survey (USGS) National Earthquake Information Center (NEIC) called Rapid Earthquake Products from Analysis & Imaging for Response (REPAIR), which is funded under the NASA Disasters Applications program. The USGS NEIC has the national mandate to provide timely, accurate, and complete information on global seismicity. For larger events, the Prompt Assessment of Global Earthquakes for Response (PAGER) system provides fatality and economic loss impact estimates. These PAGER estimates are generated rapidly following a large event, and are updated as more data constraining the shaking distribution of the earthquake become available. The PAGER estimates are often the first earth observation-based models for how much damage has been caused by a significant earthquake, and it can take days to weeks for agencies to construct synoptic pictures of damage that are more detailed than the PAGER estimates. The ARIA group is working with the USGS to extend the fault modeling algorithms already in use at the NEIC so that they enable combined modeling of geodetic and seismic data to improve the accuracy of the earthquake fault location, fault slip and improve predicted shaking estimates. ARIA will also develop algorithms for using SAR-based damage proxy maps in PAGER loss estimates that are used to assess population areas at risk from an earthquake. These REPAIR integrated products can be used to enhance the information available to response and recovery agencies, by giving a more accurate inventory of regions most affected by the shaking. ARIA and the USGS NEIC will jointly develop the REPAIR modeling algorithms and the resulting products to aid situational awareness and decision support.

## Annex 8: overview of SIGRIS (ASI/INGV)

The 2007-2011 ASI-SIGRIS project (www.sigris.it) was funded by ASI (partially co-funded by INGV), to develop and demonstrate pre-operational services, based on Earth Observation data integrated with in-situ data, in support of Seismic Risk Management.

The project developed an infrastructure, the SIGRIS system, through which 10 different information products of high scientific content could be generated, validated and delivered to the institutional User: the Italian Civil Protection Department (DPC).

The SIGRIS system was developed by a team of 6 italian organizations from the research and industrial sectors, led by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and the Advanced Computer Systems sme (ACS). It was implemented using a user-driven approach, based on requirements set by the scientific and operational components of the National Civil Protection Service.

Presently the SIGRIS system is installed at the INGV headquarters, in Rome; it is operated by INGV researchers under support of ASI which provides satellite data for the emergency operations.

The system architecture was devised according to the following general requirements:

- near-real time service provision, and rapid product generation and delivery (for the Crisis service);
- standardized framework for value added product generation and delivery,
- integration of satellite and ground data using state-of-the-art geophysical modeling techniques,
- flexibility to incorporate new models and algorithms.

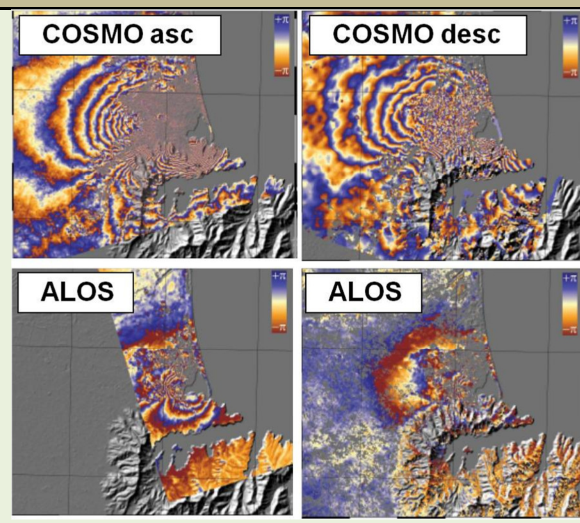
The main components developed to fulfill the above requirements, are: the Archive module, the Processing modules, the GIS interface platform, the Validation tools, the Dissemination module. The system has a storage capacity for 12 Gb of image data (scalable), a total RAM capacity of 500 Gb, and dedicated workspaces for 3 simultaneous operators.

SIGRIS can provide two main services: the Knowledge & Prevention and the Crisis services.

For the K&P service (Routine mode) 5 different scientific products are generated using mainly SAR and GPS data (see http://www.sigris.it/index.php?option=com_content&view=article&id=103&Itemid=82). These products support the Knowledge & Prevention activities of seismic risk management, and specifically they are meant to support the Seismic Hazard Assessment, by characterizing the crustal strain field in seismotectonic areas and modeling its possible sources. These products have been demonstrated for four test sites in Italy and a site in Iran.

For the Crisis service, the occurrence of earthquakes with M > 5.8 triggers the generation of 5 more products, which are used to support the emergency management. Products as co-seismic deformation maps, seismic source models, map of earthquake effects on the human and natural environment, are generated with strict time constraints, using SAR and high-resolution optical data. We demonstrated the SIGRIS system for five seismic sequences worldwide, including the 2009 L'Aquila sequence and the 2010 Darfield/Christchurch sequence.

Figure 6. INGV-provided value-added products

<table>
<tr><th colspan="2">Examples of value added products provided by INGV for the pilot</th></tr>
<tr><td>Co-seismic ground displacement maps</td><td>
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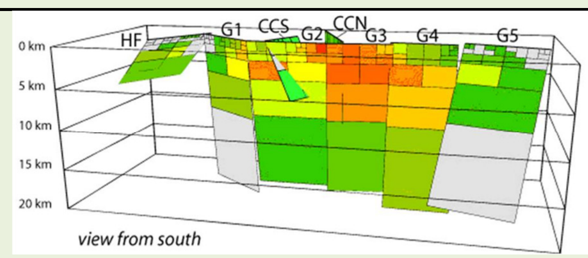
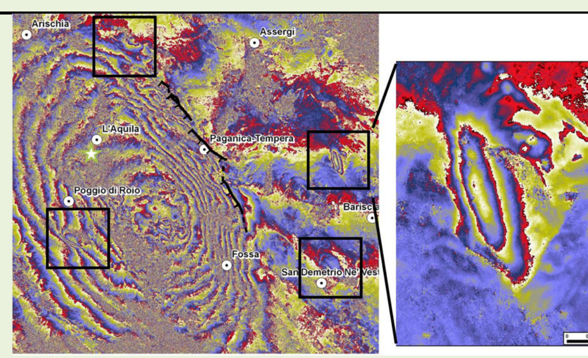
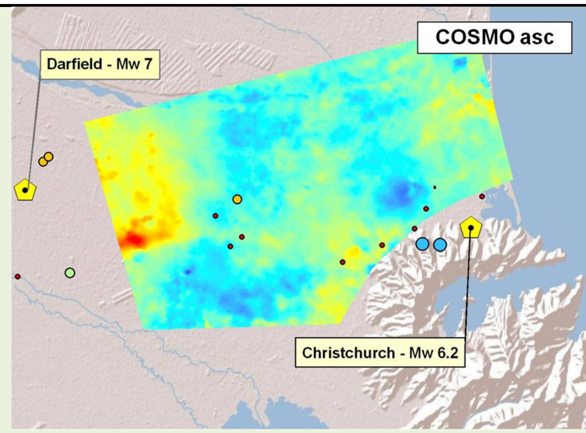
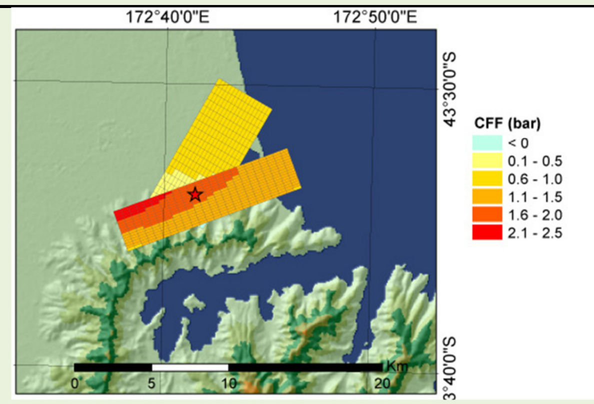
<tr><td>Seismic source models</td><td>
</td></tr>
<tr><td>Maps of geological surface effects (landslides, liquefactions, fault scarps, etc.)</td><td>
</td></tr>
</table>

| | |
|---|---|
| Post-seismic ground velocity maps |  |
| Coulomb stress change models on neighboring faults |  |

The system is able to process large datasets of optical and SAR images from commercial and scientific platforms (Quickbird, Ikonos, EROS, ERS, ENVISAT, ALOS and COSMO-SkyMed). EO data analysis, modeling and interpretations are carried out using also data from ground-based network and geological data. Before dissemination to the user, the final products are always validated using predefined procedures.

The main lesson learnt from the SIGRIS pilot project is that, for a sustainable provision of operational services, a constant flow of EO data is needed with short revisit times and over rather large areas, at no or little cost. For the SAR data in Italy this is provided by ASI in the framework of the MapItaly acquisition plan. For other seismically active areas of the world, since there is at present no organic acquisition plan for seismic risk monitoring, possible uses are limited. Although SIGRIS is able to generate products for any area of the world (with limitations due to the availability of in-situ data), its full exploitation at this scale will have to wait for the global coverage provided by Sentinel 1 data.

Presently the SIGRIS system is activated for all national crises and for some global events. In the latter case, even if there is no pre-event image archive, COSMO-SkyMed satellite tasking is requested to cover the post-seismic period (e.g. April 2013 Iran earthquakes).

## Annex 9: overview of EPOS

http://www.epos-eu.org

The European Plate Observing System (EPOS) is the integrated solid Earth Sciences research infrastructure approved by the **European Strategy Forum on Research Infrastructures** (ESFRI) and included in the **ESFRI Roadmap** in December 2008. EPOS is a long-term integration plan of national existing RIs.

***Why***

The goal of EPOS is to promote and make possible innovative approaches for a better understanding of the physical processes controlling earthquakes, volcanic eruptions, unrest episodes and tsunamis as well as those driving tectonics and Earth surface dynamics. Integration of the existing national and trans-national RIs will increase access and use of the multidisciplinary data recorded by the solid Earth monitoring networks, acquired in laboratory experiments and/or produced by computational simulations. Establishment of EPOS will foster worldwide interoperability in Earth Sciences and provide services to a broad community of users

***To Whom***

EPOS is aimed at a broad stakeholders community including European and Mediterranean countries. We have identified the following stakeholders categories:

1. Geoscience data providers.
2. Scientific user community (including Academia).
3. National research organisations & funding agencies.
4. Data and services providers and users outside the research community (incl. industry).

Several thousands of researchers in Earth sciences will benefit from the services provided by EPOS, fostering major advances in the understanding of the processes occurring in the dynamic Earth.

## Annex 10: overview of COOPEUS

www.coopeus.eu

STRENGTHENING THE COOPERATION BETWEEN THE US AND THE EU IN THE FIELD OF ENVIRONMENTAL RESEARCH INFRASTRUCTURES

Developing world-class research infrastructures for environmental research is one of the top priorities of the European Union Research Policies.

The COOPEUS project, funded under the Research Infrastructures action of the 7th Framework Programme for Research and Innovation of the EU, shall bring together scientists and users being involved in Europe's major environmental related research infrastructure projects, i.e. EISCAT, EPOS, LifeWATCH, EMSO, and ICOS, with their US counterparts that are responsible for the NSF funded projects AMISR, EARTHSCOPE, DataONE, OOI and NEON.

The intention is that by interlinking these activities new synergies are generated that will stimulate the creation of a truly global integration of existing infrastructures. The key of this integration process will be the efficient access to and the open sharing of data and information produced by the environmental research infrastructures. This important crosscutting infrastructure category is subject to rapid changes, driven almost entirely outside the field of environmental sciences. Trends in this area include growing collaborations between computer and environmental scientists, leading to the emergence of a new class of scientific activity structured around networked access to observational information. Therefore links to running projects like ENVRI in Europe or EARTHCUBE in the US who are developing relevant architectures are indispensable. Considering this perspective the COOPEUS project will serve as a testbed for new standards and methods.

**COOPEUS has a solid earth dynamics component:**

The goal of integrating seismic stations into a coherent network is to promote and make possible innovative approaches for a better understanding of the physical processes controlling earthquakes, volcanic eruptions, unrest episodes and tsunamis as well as those driving tectonics and Earth surface dynamics. Integration of the existing national and trans-national research infrastructures will increase access and use of the multidisciplinary data recorded by the solid Earth monitoring networks, acquired in laboratory experiments and/or produced by computational simulations. Bringing the initiatives EPOS, ORFEUS, Earthscope, IRIS and UNAVCO together will foster worldwide interoperability in Earth Sciences and provide services to a broad community of users.

**SOLID EARTH DYNAMICS points of contact:** EPOS (INGV – Massimo Cocco; massimo.cocco@ingv.it ), ORFEUS (KNMI – Torild van Eck; Torild.van.Eck@knmi.nl ), IRIS (Tim Ahern; tim@iris.washington.edu ), UNAVCO (Charles Meertens; chuckm@unavco.org ).

## Annex 11: overview of International Charter seismic activities

The Charter website provides a summary overview of how the Charter works: http://www.disasterscharter.org/home

The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each member agency has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property.

The International Charter provides a mechanism to obtain satellite EO data and value-added products (but not interferometric data and products) for two weeks following a major seismic event if the Charter is activated by an authorised user.

## Annex 12: overview of RASOR (CIMA Foundation)

EC FP7, Call SPACE

Project selected for funding, to start in November 2013

The RASOR project aims to develop tools for fast and reliable multi-hazard risk assessment, applicable to several natural hazards worldwide and fit for usage in all phases of the disaster management cycle.

The services offered by RASOR tools will be able to produce detailed and accurate risk information within minutes of computing time and without the need for costly and time consuming local ground data. This is achieved by using the latest generation of satellite data and related technology such as Digital Terrain Models (DTMs), Digital Elevation Models (DEMs) and land use information.

The RASOR tools supports all phases of the disaster management cycle:

- **Prevention phase**: Risk prevention and mitigation are traditionally based on risk analyses. Since RASOR can be applied worldwide, it will offer a benchmark for all local risk assessments. RASOR can also be used as a first step of a two-stage risk assessment, identifying areas, locations and scenarios that require special attention in the second, more detailed step. In data-poor regions, such as developing countries, RASOR may be the only reliable source of risk information available.
- **Preparedness phase**: Similar to its applications in the prevention phase, the rapid risk assessment tools offered by RASOR can help to establish contingency plans and prepare response actions. In data-rich regions, RASOR can act as a first step in a course-to-fine approach. In data-poor regions, RASOR may be the only available source of information to prepare for natural disasters.
- **Response phase**: During the response phase, detailed and reliable risk information is extremely valuable, for example for selecting emergency measures that should minimize the damage and for NGO's sending aid to people. A risk assessment can help to direct special precautions during unexpected and sudden events taking place as a disaster evolves. Being rapid is all the more important in such situations.
- **Recovery phase**: Immediately after the disaster has taken place, the RASOR tools can provide a first damage estimate and outline the affected areas. This type of information can be used by insurers and governments for financial negotiations and for planning of restoration work.

All these applications require that the risk information is readily available, reliable and accurate. The RASOR tools will offer this quality by combining a number of global data sources.

In order to maximise the usefulness of RASOR disaster support tools, it is essential that they be developed using a multi-hazard approach. This is critical because the same civil protection authorities consider floods and fires, landslides and earthquakes over a given geographic area. The availability of a single tool that can serve as a platform to address multiple hazards is a significant advantage. It is also important that the tool be standardised to consider different areas without the need for tailoring. This allows international organisations such as the World Bank, the UN or the European Commission to provide support to countries unable to address risk due to capacity or development challenges.

A single tool with standard input data that functions accurately on a global basis would provide the international disaster management community with currently unavailable insight into risk exposure in developing nations where populations are most vulnerable, and could be used to support development decisions for project funding, optimize emergency response and help minimizing the damage of imminent disasters. Such a tool will enhance understanding of risk, as evidence by the support the concept has found in the prospective user community. It may also serve as the basis for commercial services that will generate benefits for European industry and NGO's at both the SME and larger levels.

**RASOR Objectives**

RASOR will create an on-line platform to manage risk in real time using space and in-situ data sets.

The RASOR decision support tool will enable:

- Rapid spatialisation of assets and critical infrastructure without pre-existing or proprietary local data sets;
- Analysis of hazard exposure and extent;
- Support to analysis of risk elements for a broad range of hazards including flooding, storm surge, earthquakes, landslides and volcanoes, and ability to rapidly overlay data from other sources on other hazards such as drought, wildfires or windstorms;
- Mapping of vulnerabilities in near-real time;
- Estimation of likelihood of occurrence for certain key disaster types (e.g. flooding, geohazards);
- Ability to import other hazard data as overlays when available (e.g. fire, tsunami);
- Identification of specific areas at risk;
- Management support using multi-hazard approach;

- Support to the full cycle of disaster management for civil authorities – mitigation, warning, response and recovery, with specific emphasis on vulnerability and risk assessment for prevention, preparedness, emergency response and recovery.

**RASOR partnership**

| | |
|---|---|
| CIMA Research Foundation (CIMA) | Italy |
| Athena Global Europe (AG) | France |
| Acrotec (ACR) | Italy |
| SERTIT (UNISTRA) | France |
| Deltares (DLT) | Netherlands |
| EUCentre (EUC) | Italy |
| German Aerospace Center (DLR) | Germany |
| INGV | Italy |
| National Observatory of Athens (NOA) | Greece |
| Altamira Information | Spain |

**RASOR Users**

| | |
|---|---|
| Caribbean Institute for Meteorology & Hydrology (CIMH) | CARICOM |
| Indonesia Ministry of Public Works – Research Center for Water Resources (RCWC) | Indonesia |
| Munich Reinsurance | Germany |
| Italy National Civil Protection Department (DPC) | Italy |
| UNITAR’S Operational Satellite Applications Programme (UNOSAT) | International Organisation |
| World Bank (WB) | International Organisation |
| UN International Strategy for Disaster Reduction (UNISDR) | International Organisation |

## Annex 13: overview of ISTerre

The ISTerre group is focusing on measuring and characterizing the deformation associated with active faults, during a seismic cycle or accumulated in successive seismic cycles. We put particular emphasis on the study of transient phenomena of low amplitude but not negligible in the energy balance of the seismic cycle, such as slow slip events.

The heart of our skills is essentially space geodesy (InSAR, GPS), supplemented by components in source seismology, neotectonic and modeling, allowing a joint analysis of geodetic and seismological observations that takes into account the seismotectonic context. Our studies cover a broad spectrum of lithospheric deformation, from large earthquakes to low aseismic slip, in subduction zones as well as intracontinental areas (Chile, Mexico, Guatemala, Taiwan, Tibet, Himalaya).

In InSAR, our recent research activities include the analysis of the relationships in space and time between coseismic slip distribution, interseismic coupling, morphological and mechanical properties of faults, and rheological properties of the lithosphere. Methodological developments have been proposed to improve measurements of low deformation signal at various spatial wavelengths and not necessarily linear in time (the spatio-temporal evolution of interseismic deformation in particular). We have developed the NSBAS software, based on ROI_PAC (JPL/Caltech), that allows to process large SAR data stacks for InSAR time series analysis, and provides averaged Line Of Sight velocity maps. The software includes a variety of possible corrections (DEM errors, atmospheric delays, ...) that made possible the extraction of refined averaged LOS velocity maps across low coherence, mountainous areas. Some parts are included in the GIAnT software. A parallel version adapted to cluster and cloud infrastructures, and further methodological improvments to process large areas and data sets are being developped.

Our main current fundings come from Agence Nationale pour la Recherche (ANR), Centre National des Etudes Spatiales (CNES, TOSCA program), Institut des Sciences de l’Univers et Centre National pour la Recherche Scientifique (INSU/CNRS, PNTS and MASTODONS programs).

## Annex 14: synthesis of geographic priorities for seismic hazards:

- *Priorities for the iGSRM:*

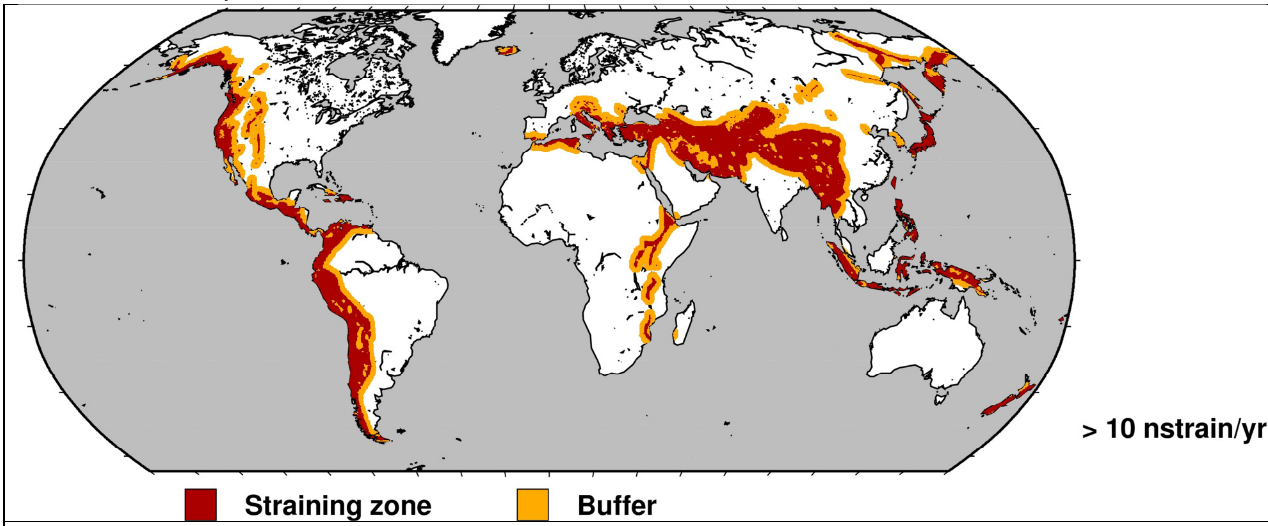



**Figure 7a).** Map showing actively deforming regions worldwide taken from the GPS Global Strain Rate Model v2.0 (http://gsrm2.unavco.org/). Deformation rate is defined in terms of the 2nd invariant of the strain rate tensor, and is based on global GNSS measurements. Regions that are deforming above a threshold rate of 10 nanostrains ($10^{-8}$) per year are coloured dark red. A 200 km buffer (orange) is also required to ensure data continuity and to constrain orbital uncertainties.

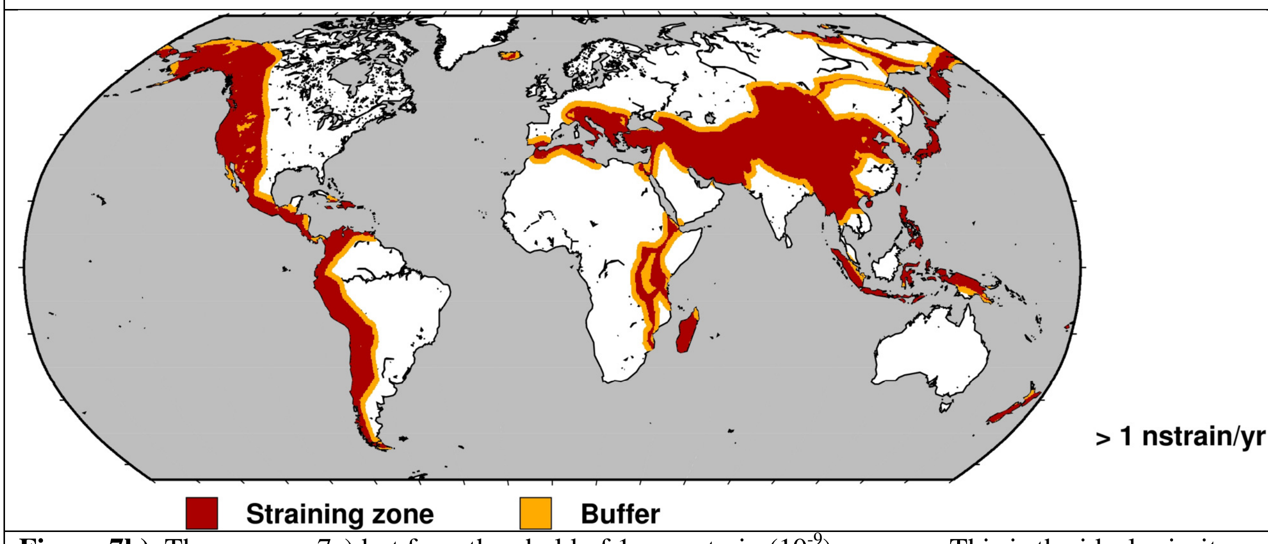



**Figure 7b).** The same as 7a) but for a threshold of 1 nanostrain ($10^{-9}$) per year. This is the ideal priority area for iGSRM but the area outlined in 7a is acceptable.

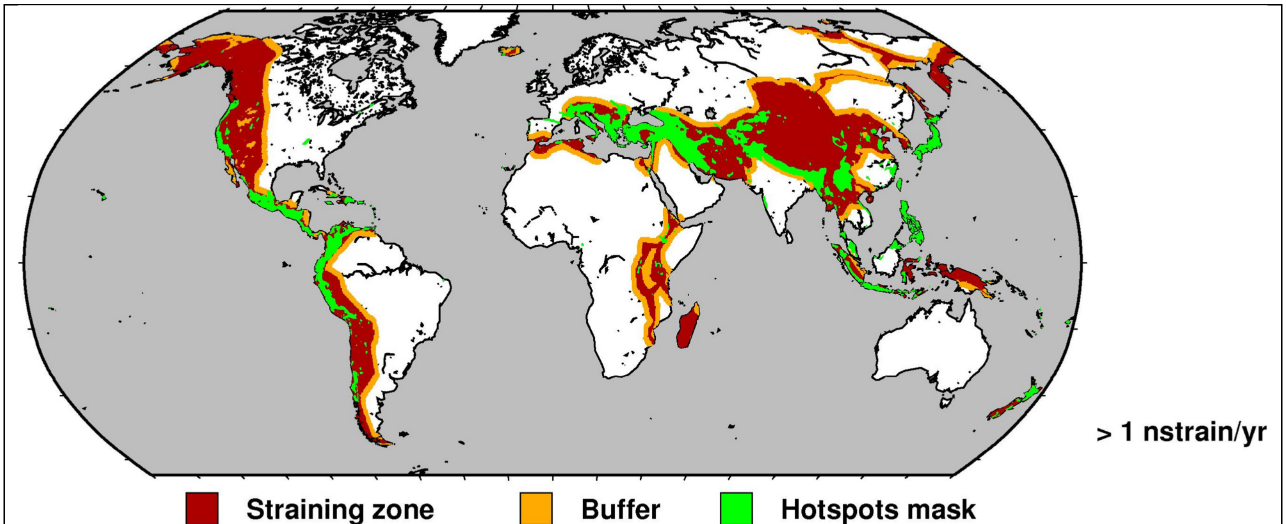



**Figure 7c).** The same as 7b) but showing the priority areas defined by GMES emergency management services in green (labelled 'hotspots mask' shapefile). These are based on the analysis of data taken from a collaborative study performed by the Columbia University and the World Bank, entitled *Natural Disaster Hotspots: A Global Risk Analysis* and provided by the Center for International Earth Science Information Network (CIESIN). This is based on the requirements gathered in 2010 from user organisations of GMES SAFER, GSE RESPOND and GSE Terrafirma projects for prioritizing where strategic EO dataset should be collected in anticipation, primarily for disaster response. This smaller area covers only 34% of the 10 nanostrains area, and 23% of the 1 nanostrains area. It excludes ~60% of earthquake deaths since 1900.

Tectonic strain and earthquake hazard is broadly distributed in the continents, with Earthquakes occurring at large distances from nominal plate boundaries. The red areas in figure 7a) to 7c) above show the regions of the world straining above 10 nanostrains/year (7a) and 1 nano/strains/year (7b), as estimated using the existing, low-resolution global strain rate model (version 2; http://gsrm2.unavco.org/). The 10 nanostrains/year region (7a) encompasses 96% of historic earthquake deaths that have occurred since 1900 and is an acceptable coverage for iGSRM.

InSAR data can be used, in conjunction with GNSS, to build a global strain rate model at high resolution, even in areas where the density of ground-based GNSS instruments is low. To achieve this aim, particularly in low straining areas, regular, systematic acquisitions are required for long time periods. For example, to achieve an accuracy of 10 nanonstrains/year, equivalent to 1 mm/yr over length scales of 100 km, requires acquisitions every 12 days for 5 years.

Concerning Satellite EO coverage a realistic target is to ensure coverage of all regions with strain values above 10 nanostrains/yr. We recommend that space agencies acquire data for the entire area deforming at 10 nanostrains per year or higher with a 200 km buffer, designed to ensure data continuity. It is essential that these acquisitions start as soon as possible for the entire area, as long time series are required, particularly in areas with the lowest strain rates.

Although systematic acquisitions for all the straining zones are required, for the pilot proposal we aim to deliver results for validation sites in Turkey and California, where data from multiple missions should be acquired, and strain maps for several larger regions of focus, including Turkey, the Himalayas, and the Andes, where single mission data sets are sufficient (shapefiles provided).

- *Priorities for the GSNL:*

The Geohazard Supersites initiative has supersites, natural laboratories and event sites. As far as supersites are concerned, the following have been accepted by the GSNL Scientific Advisory Committee (SAC): the **Iceland Volcanoes** and **Hawaii** (see http://www.earthobservations.org/gsnl_prop.php) the latter being formally approved by the CEOS Plenary in 2012, and the Iceland site to be considered by the CEOS Plenary in 2013.

There are 2 new Supersites proposals under submission to the GSNL SAC prior to potential evaluation by the CEOS Supersite Coordination Team (SCT) for approval at the CEOS Plenary:

1) **Istanbul (Marmara Sea)** (e.g., FP7' project MarSite, http://marsite.eu/)

**2) Italian Volcanoes** (Mount Somma, Campi Phlegreii, and Etna) (e.g., FP7' project Mediterranean Supersite Volcanoes (MED-SUV) http://www.med-suv.eu/)

Potentially the GSNL could have 4 sites as fully operational supersites by the end of 2014. There are other potential sites in elaboration, including as of October 2013 the following additional sites:

1. Ecuadorian volcanoes

2. New Zealand volcanoes

3. Piton de la Fournaise

*The priority for the GSNL is to complete the selection process for the sites currently under development. On the CEOS site developments are under way to enable a coordinated search and access for contributed data.*

The GSNL also maintains the following Event Supersites:

- Haiti
- Tohoku-oki
- Chile
- Wenchuan, China


- *Priorities for the rapid response to earthquakes:*

Most earthquakes occur within the straining areas (seismic belts) shown in Figure 7. However, occasional damaging earthquakes occur outside these regions. In addition to the regular acquisitions in the seismic belts, we require occasional acquisitions outside these belts to ensure that prior imagery is always available. The target areas cannot be planned precisely, but covering the seismic belts systematically should ensure that imagery prior to the earthquakes is available.

After an earthquake, data is required rapidly and frequently for the scientific and societal response to earthquakes. All data from all missions is valuable, even if prior imagery is not available. Effort should be made to ensure, where possible, that time series acquired following events are in modes that are compatible with interferometry.

## Annex 15: High level observation modes concerning seismic risks:

The observation modes for Satellite EO applications concerning seismic hazards can be summarized as follows (letters referring to objectives of seismic pilot):

| Objective | Sensor | Observation requirement | Other requirements | Area expected to be covered | Approximate frames per year |
|---|---|---|---|---|---|
| **A (interseismic strain mapping)** | HR SAR (L-band, ALOS-2) | Continuous observations in ascending and descending mode (9 acquisitions/year). In priority in vegetated areas showing strong deformation rate. | InSAR mode | Himalayan belt, eastern border of the Andes, South Chile subduction zone (South of -33S). To be extended to the eastern Himalayan syntaxis. | Descending ScanSAR mode:<br>Himalaya: 200 frames<br>Andes: 200 frames<br>South Chile: 100 frames<br>Ascending stripmap:<br>Himalaya: 1500 frames<br>Andes: 1500 frames<br>South Chile: 1000 frames |
| **A (interseismic strain mapping)** | HR SAR (Radarsat, Sentinel-1) | Continuous observations of descending and ascending modes, repeat coverage (30 acquisition/yr). Intensive observations in areas showing strong transients. | | East African rift area, Central and South America subduction zones (only Mexico, Peru), North Tibet | East African rift : 800 frames<br>Central Am.: 600 frames<br>South America: 1500 frames |
| **A (interseismic strain mapping)** | HR SAR (Sentinel-1) | Continuous observations of descending and ascending modes, repeat coverage (30 acquisitions/yr). The goal is to extend and guarantee observations to all seismic belts. | | Turkey to Iran seismic belt, Tibet, South American subduction zone | Turkey to Iran: 1000 frames<br>Tibet : 800 frames<br>South America : 800 frames |
| **A (transient deformation and creep on focused areas)** | VHR SAR (TerraSAR X, COSMO-SkyMed | For this objective, the smaller swath width limits VHR usage in situation where HR data cannot be acquired or where further viewing geometries are needed to better resolve the deformation field. | 1-3 images/ month, depending on temporal decorrelation<br>InSAR mode | Max ~100 x 300km for each test site.<br>~100 x 300km for each test site: two in Turkey, one in Tibet | Tibet : 500 frames<br>Turkey : 1500 frames |
| **A (transient deformation and creep on focused areas)** | VHR optical<br>(Pleiades) | High revisit time in ascending and descending mode, focused on main creeping segments of faults.<br>Strain measurement on fault creep segments by image correlation. | 1 coverage per year | Two test sites in Turkey along the North Anatolian Fault | 400km by 100km wide area |
| **A (fault mapping)** | HR/VHR Optical<br>(SPOT-5, Pleiades) | Archive images (no more than one year old), panchromatic or true colour composite.<br>HR for fault recognition<br>VHR for detailed offsets mapping, historic earthquake recognition. | VHR Stereo coverage along faults<br>HR: coverage of wide areas | VHR only on 20 km wide strips elongated along faults<br>Turkey to Iran<br>Andes<br>Tibet | TBD |
| **B, C (post-seismic deformation mapping)** | HR SAR (Radarsat, Sentinel-1, ALOS-2) | Descending and ascending repeat coverage of critical faults surrounding the mainshock epicentral area. | More than 3 images/month, NRT delivery, InSAR mode | Max ~400 x 200km for each test site (depends also on mainshock magnitude and tectonic setting) | Varies with satellite, maximum around few tens of frames (per revisit time) |
| | VHR SAR (TerraSAR X, COSMO-SkyMed) | Used to cover smaller faults than HR SAR. Descending and ascending repeat coverage of critical faults surrounding the mainshock epicentral area. | Shortest possible revisit time, up to 5 images/month, NRT delivery, InSAR mode | Max ~400 x 200km for each test site (depends also on mainshock magnitude and tectonic setting) | Max ~24 frames, average ~8 frames (per revisit time) |
| **B, C (co-seismic deformation mapping)** | HR SAR (Radarsat, Sentinel-1, ALOS-2) | Descending and ascending coverage of the mainshock epicentral area. All archive images younger than one year, and 4-6 acquisitions following the event. | NRT delivery, InSAR mode | Max ~400 x 200km for each test site (depends also on mainshock magnitude and tectonic | Varies with satellite, on average around ten frames (per revisit time) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | setting) | |
| | VHR SAR (TerraSAR X, COSMO-SkyMed) | Used to cover smaller faults than HR SAR. Descending and ascending coverage of the mainshock epicentral area. All archive images younger than one year, and 4-6 acquisitions following the event. | NRT delivery, InSAR mode | Max ~400 x 200km for each test site (depends also on mainshock magnitude and tectonic setting) | Max ~24 frames, average ~8 frames (per revisit time) |
| **B, C (surface fracture mapping)** | VHR Optical | Pre- and post-event imagery at resolutions better than 1m. No later than 4 days after the event. | NRT delivery. Stereo coverage is preferred. | Max ~150 x 20km for each test site (depends also on mainshock magnitude and tectonic setting) | Varies with satellite, on average around ten scenes |