

CEOS support to the Permanent Supersite “Iceland” of the GEO Geohazards Supersites and Natural Laboratories Initiative

October 28th, 2013

Background

The Geohazards Supersites and Natural Laboratories (GSLN) initiative of the Group on Earth Observations (GEO) aims at deepening knowledge and scientific understanding of geologic processes posing natural hazards. It is establishing a small number Permanent Supersites, which are regions of highest priority to the geohazards science community.

CEOS has agreed on a process for selecting these Supersites in the context of the GSLN initiative, whereby¹

1. Supersites are nominated to a “Scientific Advisory Committee” (SAC)
2. SAC reviews nominations and recommends to CEOS
3. CEOS Supersites Coordination Team (SCT) reviews proposals based on a set of criteria and recommends CEOS support, as appropriate,
4. CEOS SIT and Plenary confirm support to each Supersite.

This will be reviewed regularly every two years.

Recommendation of the CEOS Supersite Coordination Team

On October 15th, 2013 the SAC has recommended accepting Iceland as a Permanent Supersite based on the proposal attached.

The SCT recommends that CEOS support this Supersite and that the following resources are made available. The list below is indicative. Data will be made available free of charge on a best-effort basis. Individual license and access conditions may apply.

ASI	300 scenes / year until next review (2015); 500 scenes of past acquisitions	COSMO-Skymed	
CNES	2 coverage @ 2,5m 1 coverage per volcano per year (up to 40 in case of unrest)	SPOT-5 Pleiades	To be confirmed
CSA	160 scenes / year until next review (2015); Archive data	Radarsat-2	
DLR	250 scenes / year until next review (2015) plus 550 archive scenes	TerraSAR-X	
ESA	All available archive data Any available acquisition	ERS-1 / -2, ENVISAT-ASAR Sentinel-1, -2	
JAXA	tbd tbd	ALOS-2 ALOS-1, J-ERS	
NASA	Tbd Any available acquisition	ASTER EO-1	Awaiting confirmation

Required Action

The CEOS Plenary is requested to accept the proposed Iceland Supersite and approve the data commitments detailed above.

¹ Selection process for GEO Geohazard Supersites, A proposal of the Committee on Earth Observing Satellites, version 1.0, Sept. 6th 2012.

A.1 Proposal Title

Icelandic Volcanoes Supersite

A.2 Supersite Point-of-Contact (PoC)

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A.3 Core Supersite Team and organization

The core supersite team for Icelandic volcanoes is the consortium of the European Commission funded FUTUREVOLC project (see <http://www.futurevolc.hi.is>). The project addresses a call within the Environment program of the 7th Framework Programme of the European Commission (“ENV.2012.6.4-2 Long-term monitoring experiment in geologically active regions of Europe prone to natural hazards: the Supersite concept”). The full name of the project is “A European volcanological supersite in Iceland: a monitoring system and network for the future”. 26 partners are involved, with expertise on widely different aspects of volcano monitoring and science. The FUTUREVOLC partners are complemented with an extensive team of InSAR, GPS and deformation modelling experts from around the world (see A4, Other supersite research teams), most of which are working actively on monitoring and modelling crustal deformation in Iceland for the general purpose of advancing understanding of volcanic and tectonic process. The supersite point-of-contact will coordinate interaction with space agencies in close collaboration with Dr. Andy Hooper at University of Leeds, UK, with assistance of their research teams, and an advisory board to be appointed.

The FUTUREVOLC project has an open data policy (see further below) and will make available data mostly collected in-situ in the volcanic zones of Iceland, including GPS, seismic, thermal, and gas observations, as well as detailed observations of eruptions when they happen. The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) is the only space agency directly involved, with minor funding for generation of differential digital elevation models from time series of operational and experimental acquisitions from the TanDEM-X mission.

CEOS appointment of an Icelandic Volcanic supersite would complement in a unique manner the FUTUREVOLC project and help building access to extensive space and ground based data sets, openly available for scientific research. Data available through CEOS appointment would be immediately used for joint interpretation of available multi-disciplinary data on volcanic crisis, helping disaster managers as they are part of the FUTUREVOLC consortium (Icelandic civil protection authorities, who also provide information to civil protection authorities in other countries in case of an Icelandic eruption, the Icelandic Meteorological Office, issuing warnings for aviation in the North Atlantic

oceanic area, and the London Volcanic Ash Advisory of the UK Met Office, issuing ash advisories for air space closure for explosive eruptions.

Following is a list of institutions with names of scientists-in-charge for the FUTUREVOLC project, as well as their role in the project. For most of the institutions there is group of researchers involved. A broad spectrum of scientists is involved from all aspects of volcanology, including InSAR and crustal deformation specialists. Data made available from CEOS will be jointly interpreted with data from widely different sources to constrain the behaviour of volcanoes in as close to real-time as is feasible, by the FUTUREVOLC consortium. The core supersite team has thus excellent capacity to exploit not only the variety of space-based datasets, but also airborne and ground-based volcano monitoring data. The broad consortium has experience in merging multiple datasets to analyze subsurface processes, a key element of the FUTUREVOLC project. It is complemented by other supersite research teams with extensive experience of InSAR, including studies of volcanic processes in other areas of the world than Iceland. Through their involvement comparative studies of Icelandic deformation versus that taking place in other volcanic areas will allow the advancement of understanding of volcanic deformation processes in general.

University of Iceland (Freysteinn Sigmundsson): The Institute of Earth Sciences (IES) is a part of the Science Institute, a government-funded academic research organization, within University of Iceland. IES has 28 academic research and teaching faculty members, 6 technicians, 15 research assistants and postdocs and about 60 research students. Strong emphasis on volcanology at IES is reflected in the existence of the Nordic Volcanological Centre (Nordvulk), an integral part of IES and jointly funded by the Nordic Council of Ministers and the Icelandic Government. The centre funds 10 research and technical staff positions as well as 5-7 temporary research fellowships in volcanology. Monitoring and surveying techniques draw on experience from numerous seismic and volcanic crises in the last three decades, including the eruptions of Eyjafjallajökull in 2010 and Grímsvötn in 2011. Senior IES staff have an advisory role to the civil defense authorities in Iceland. The research group in volcanology includes 8 senior scientists that have participated in many internationally funded projects on volcanoes. The group has extensive experience in volcanological research, including volcano deformation, physical volcanology, tephrocronology, petrology, geochemistry and volcanic fluid chemistry.

Icelandic Meteorological Institute (Kristín Vogfjörð): The Icelandic Meteorological Office is responsible for monitoring, research, warnings and forecasts of all natural hazards in Iceland and has a long-term advisory role with the Icelandic Civil Protection. IMO is a designated state volcano observatory with respect to the International Civil Aviation Organization (ICAO). IMO operates the most extensive Earth systems monitoring networks in Iceland, including seismic (62), GPS (70 in collaboration with University of Iceland other institutions), and borehole strain meter (4) networks, weather stations (100+), hydrological stations (50+), permanent (2) and portable (2) weather radars, a radiosonde station for atmospheric observations and spectrometers (3+) to monitor volcanic gas discharge. IMO's expertise lies in real-time analysis of seismic signals, high-precision mapping of active faults and magma tracking through seismicity and analysis of atmospheric interaction with volcanic plumes. In FUTUREVOLC IMO will lead development of early-warning processes based on analysis of seismic signals from subglacial volcanoes and initiate the first permanent gas/volatiles-monitoring network in Iceland. IMO also has the important role of constructing and maintaining access to the multitude of

data collected in FUTUREVOLC. Data from IMO instruments will be important for event precursors, and to gauge the magnitude of events. During volcanic eruptions IMO data will help estimating the size of the eruption, the amount of material injected into the atmosphere, its vertical distribution and dispersion.

University College Dublin, Ireland (Chris Bean): The Geophysics Group at UCD was established in 1993 by Prof. Bean and develops innovative numerical tools for seismic wave propagation in fluid saturated, fractured media. These tools are based on discrete mechanics and allowing modelling of highly heterogeneous structures. The group also acquires high spatial resolution broad band field data on volcanoes, configured for LP source inversions.

University of Florence (Maurizio Ripepe): The Department of Earth Sciences of the University of Florence (UNIFI) is interested in near-source eruption dynamics by integrated geophysical parameters. UNIFI is a geophysical monitoring Center of the Italian Civil Protection running a permanent Observatory on the Stromboli volcano. UNIFI has expertise in developing infrasonic array real-time monitoring techniques as Early-Warning for the eruption onset and to retrieve eruption source parameter. In cooperation with several Research and Government Institutions has deployed permanent small-aperture infrasonic arrays on several active volcanoes in Italy, Japan, Montserrat, Iceland and Greece.

British Geological Survey (Susan Clare Loughlin): The British Geological Survey (BGS) is a public sector organisation and the UK's premier earth science centre, it provides impartial geologic advice to governments, industry, academia and the public. BGS managed the Montserrat Volcano Observatory (MVO) under contract to the Montserrat Government for twelve years and therefore is one of few organisations with operational experience of explosive eruptions. Expertise includes a wide range of ground- and space-based monitoring techniques, data analysis and research into volcanic processes. BGS updates the UK National Risk Register (volcanic risk) for UK Govt and provides advice to the UK Civil Contingencies Secretariat and Government Office for Science on volcanic hazard and risk.

University of Leeds, School of Earth and Environment (Andy Hooper and Tim Wright). Leeds researchers have been active in the field of radar interferometry (InSAR) since 1997 and have been at the forefront of developing the use of InSAR for measuring tectonic and volcanic deformation. The group has developed dedicated InSAR software packages, which have been made available to the scientific community, and today more than 300 users from all over the world use these softwares. Wright has led the international Afar Rift Consortium, investigating magmatic rifting and active volcanism in the best subaerial analogue for Iceland. Observations in Afar have been compared to those in Iceland, to understand the mechanism of volcanic rifting in general.

Centre of Excellence of the University of L'Aquila, Italy (Frank S. Marzano): Research and development on radar-based modelling and retrieval techniques and space-based microwave remote sensing of ash clouds.

Chalmers University of Technology, Sweden (Bo Galle): The Optical Remote Sensing group has a long experience in applying spectroscopic methods to environmental monitoring and research. This includes research related to stratospheric ozone depletion, urban air chemistry, biogenic climate gas emissions and industrial emissions. A special focus has been on development of methods to quantify

gaseous emissions from various sources. Development and implementation of Optical Remote Sensing instruments for gas monitoring on Icelandic volcanoes.

Physikalisch Vulkanologisches Labor, Universität Würzburg, Germany (Bernd Zimanowski)

Production, delivery, and implementation of 2 permanent and 3 mobile electrical field stations on selected Icelandic volcanoes (Grimsvötn, Katla, Hekla, Eyjafjallajökull). Calibration of the stations by laboratory experiments to magmatic compositions to be expected for future eruptions.

NILU-Norwegian Institute for Air Research (Arve Kylling): NILU has a long experience in the utilization of satellite and ground-based instruments to probe the Earth's atmosphere for the presence of volcanic ash and sulphur dioxide. Novel methods have been developed to estimate ash and sulphur dioxide concentrations from satellite and ground-based multi-spectral infrared (IR) measurements. These methods have been used to study the eruptive products from numerous volcanic eruptions.

The National Commissioner of the Icelandic Police, Department of Civil Protection and Emergency Management, Iceland (Víðir Reynisson): The DCPEM is the national competent authority on Civil Protection. The DCPEM is responsible for coordinating emergency response planning and for coordinating rescue and relief work in Iceland. Remotely sensed images and derivatives of such images construe an integral part in planning emergency response and in planning on-going rescue and relief operations. Remotely sensed images are used as a tool in informing the public about the effects of natural catastrophes.

University of Cambridge, UK (Robert S White): Deployment of seismometers, analysis of seismic data and development of new processing and modelling techniques. Leads a large research group at Cambridge University studying interaction of rifting and magmatism, influence of mantle plumes on volcanism, development of synthetic seismograms, hypocentral locations, moment tensor inversions and crustal structure

GFZ - Deutsches GeoForschungsZentrum, Potsdam, Germany (Thomas R. Walter): Deployment of cameras and use of imaging data to monitor the evolution of eruption source parameters. Camera recordings will be analyzed using computer vision methods, specific tasks are to explore digital image correlation and particle velocimetry algorithms.

Uppsala University, Sweden (Olafur Gudmundsson): A research group at Institute of Earth Sciences at Uppsala University explores methods of incorporating three-dimensional (3D) seismic velocity structure into improved earthquake locations. The group is also involved in tomographic studies at selected volcanoes in Iceland, that can assist interpretation of volcano behaviour and deformation.

Met Office, UK (Claire Witham): Home to the London Volcanic Ash Advisory Centre (VAAC) which has responsibility for the North Atlantic region, including Iceland, and issues Volcanic Ash Advisories (VAA) and Volcanic Ash Graphics (VAG) to air traffic control and civil aviation authorities to warn aviation about the presence of volcanic ash following eruptions in this region.

University of Geneva, Switzerland (Costanza Bonadonna): The Unit of Geological Risk and Volcanology of University of Geneva is equipped with dedicated facilities for the assessment of

volcanic hazards. Ongoing research includes characterization of tephra deposits, probability assessment of volcanic hazards, plume dynamics and ash particle sedimentation

University of Bristol (Jeremy Phillips): Ongoing research includes near-source plume dynamics and the interaction of plumes with the atmospheric wind, delivery of an operational model for ash injection height and flux into the atmosphere, providing input parameters for far-field dispersion modelling

Università degli Studi Palermo, Italy (Alessandro Aiuppa): Research work includes deployment of robust permanent/portable instruments for continuous volcanic gas monitoring, to creation of fully automated real-time data analysis scripts, and to quantitative interpretation of volcanic gas datasets from Icelandic volcanoes.

Nicarnica Aviation (Fred Prata): Nicarnica Aviation AS was formed in 2010 as a wholly owned subsidiary of Nicarnica AS with the exclusive rights and sole purpose of commercializing IR Imaging Technology for detecting volcanic ash and other hazards to the aviation industry. The company is a highly specialized company developing air-borne and ground-based IR imaging technologies to identify hazardous ash particles in the air. The company's technology comes from over 20 years of work by Nicarnica Co-Founder Dr. Fred Prata in the area of volcano observation.

HIMET, Italy (Errico Picciotti): HIMET s a spin-off company of the University of L'Aquila focusing on high innovation in meteorology and environmental technology. Involved in development of interfaces and data processors for radar-based data constraining eruption plumes.

Güralp Systems Limited, UK (Andrew Bell): A leading designer and manufacturer of seismological instruments, digitisers, acquisition modules and software. They will design, construct and advise on the installation of a new seismometer package, specifically for operation on glaciers, in order to improved the seismic coverage of Icelandic volcanoes.

Miracle, Iceland (Gunnar Bjarnason): One of the Iceland's leading companies in expertise on database centric platforms. They will lead design, development and implement the FUTUREVOLC database.

Item s.r.l., Italy (Emanuele Marchetti): Item s.r.l. works in applied optics, infrared reflectography, fiber optic technology and acoustic pressure sensors. Item s.r.l. is involved in volcanic ash detection and is modifying Pludix Doppler Radars to enhance volcanic ash monitoring in Italy for Civil Protection. In the framework of t he FUTUREVOLC Project, Item s.r.l. is developing a laser disdrometer specifically designed for volcanic ash detection.

Blaise Pascal University, France (Olgeir Sigmarsson): Home of the "Laboratoire Magmas et Volcans (LMV)". In Iceland involved in the development of compositional time series for the most active Icelandic volcano, Grímsvötn, and estimations of rates of magmatic processes.

German Aerospace Center - Deutsches Zentrum für Luft- und Raumfahrt (Michael Eineder): Within the FUTUREVOLC project responsible for generation of differential DEMs from time series of operational and experimental TanDEM-X acquisitions. Adaption of interferometric and SAR

processing chains and algorithms for optimized monitoring of deformations on volcano ice caps. Contribute to the evaluation, analysis and interpretation of observed height changes.

Samsyn, Iceland (Kristinn Gudmundsson): Samsyn is Icelandic leading company in geographic information systems (GIS), cartography and control-room systems for emergency response. Design, develop and implement the user interface on the FUTUREVOLC database, both for entering the data and to present the data for different user groups. The key focus will be on hazard managers.

A.4 Other Supersite Research Teams

Delft University of Technology, Netherlands (Ramon Hanssen): Department of Geoscience and Remote Sensing. DUT researchers have been active in the field of radar interferometry (InSAR) since 1995, and the current group working with InSAR is the largest in Europe. In recent years the group has been at the forefront of developing methodology and algorithms to estimate the deformation signal from extended time series of acquisitions. The group has developed dedicated InSAR software packages, which have been made available to the scientific community, and today approximately 1700 users from all over the world use these softwares. The department is also active in modelling deformation processes constrained by InSAR, GNSS and other geodetic data, including glacial isostatic adjustment, earthquakes and volcanism.

National Research Council (CNR), Italy (Eugenio Sansosti): CNR is the main public research entity in Italy with more than 100 Institutes grouped in 7 Departments. The Institute for Electromagnetic Sensing of the Environment (IREA) has a long-term experience in developing new techniques for SAR data processing, including the well known Small Baseline Subset (SBAS) technique for generating ground deformation time series. Eugenio Sansosti has coordinated several projects and researches on observation and modeling of active volcanoes by using SAR data. Since 2011, he has been the responsible for the SAR4Volcanoes project funded by the Italian Space Agency (ASI) for studying volcanoes through the use of COSMO-SkyMed data, which involved processing of more than 1,500 CSK images.

University of Plymouth, School of Geography, Earth and Environmental Sciences (Carolina Pagli): Carolina Pagli's research has focused on analysing the physical mechanisms responsible for crustal deformation, using InSAR and GPS, and in the development of models to explain the observations. She complements the application of geodetic techniques with analysis of seismicity and field investigations. Most of her research career has been devoted to studying volcanic and tectonic events in Iceland and Afar, the largest exposures above sea level of the Mid-oceanic ridge system. advancing the understanding of mechanics of rifting episodes and magmatic activity that takes place at divergent plate boundaries.

Penn State University, Department of Geoscience, USA (Peter LaFemina): Remote sensing and space geodetic data to investigate plate boundary zone deformation, including the earthquake cycle, magma-tectonic interactions and magmatic processes. Involved in operation of continuous and episodic GPS monitoring of Icelandic volcanoes and rifts.

University of Wisconsin, USA (Kurt Feigl): Home to researchers that combine innovative geophysical techniques, including specific advancements in InSAR analysis, volcanic processes and seismic analysis. Long-term involvement in studies of crustal deformation, and tectonic, geothermal and volcanic processes in Iceland.

KAUST - King Abdullah University of Science and Technology, Saudi Arabia (Sigurjón Jónsson): Extensive experience in applying InSAR to tectonic and volcanic deformation in Iceland and elsewhere. Operation of a network of continuous GPS stations in Northern Iceland and episodic GPS-measurements in Iceland.

University of Arizona, Department of Geosciences, USA (Rick Bennett): Area of expertise includes the field of high precision GPS geodesy and its many applications to the Earth Sciences. Rick Bennett serves on the Board of Directors for the non-profit corporation UNAVCO, a university-governed consortium facilitating geoscience research and education using geodesy. He was principal investigator on an NSF project that resulted in the deployment of more than a dozen continuous GPS stations in Iceland.

South Dakota School of Mines & Technology, USA (Tim Masterlark): Masterlark's research group focuses on developing FEM-based analyses and techniques for simulating deformation mechanisms of active volcanoes. More specifically, this group simulates transient rift behavior and magma migration and storage over volcanic eruption cycles. These simulations involve elastic, viscoelastic, thermoelastic, and poroelastic behavior resulting from internal or external loads. Active collaborations with Icelandic researchers.

University of Savoie, France (Thierry Villemin and Virgine Pinel): Long-term collaboration with Icelandic institutions on episodic and continuous GPS measurements, and modelling of deformation processes. Home of ISTerre, a laboratory specialized in the geophysical study of volcanoes, including seismic monitoring and deformation modeling, and EDYTEM, a laboratory developing research on the consequences of global warming in terms of deformation, erosion and sedimentation.

University of Leeds, School of Earth and Environment, UK (Tim Wright): Wright's research group has extensive experience working with InSAR on tectonic and volcanic problems worldwide, recently developing techniques for combining InSAR and GPS over large regions to study tectonic deformation. Wright has led the international Afar Rift Consortium, investigating magmatic rifting and active volcanism in the best subaerial analogue for Iceland. Observations in Afar have been compared to those in Iceland, to understand the mechanism of volcanic rifting in general.

University of Miami (Falk Amelung): Has over 15 years of experience in applying InSAR to active volcanoes and modeling deformation sources. Recent research has focused on deformation of basaltic ocean island volcanoes, including Hawaii and Galapagos.

Disaster Prevention Research Institute, Kyoto University, Japan (Yo Fukushima): Extensive experience in applying InSAR to volcano and earthquake deformation, the study of the physical processes that cause deformation, and geophysical inverse problems. Would be involved in comparative studies of Japanese and Icelandic volcanoes, in order to advance understanding of volcanic processes in general.

The National Land Survey of Iceland (Kolbeinn Árnason): A leading knowledge-based institute with the role of collecting, processing, preserving and disseminating spatial information about Iceland. The objective of the operation is to ensure that accessible and reliable topographical and geographical background information about Iceland is always available. Involved in continuous and episodic GPS-measurements. Tasks include: To develop and maintain vertical and geodetic reference systems of Iceland, to implement, maintain and disseminate digital spatial data layers in scale 1: 50 000, to provide access to data preserved by the institute, in particular high resolution (and very high resolution) satellite remote sensing data.

Bavarian Academy of Sciences and Humanities, Commission for Geodesy and Glaciology, Germany (Christof Völksen): Expertise in long time monitoring of continuous GNSS sites and evaluation of the deformation signals based on a critical geodetic deformation analysis. Research is based on the in-depth analysis of GNSS data (GPS/GLONASS) separating measurement errors and tectonic signals. Another focus is the analysis of coordinate time series as well as an expertise in the realization of geodetic reference systems and their maintenance. The academy is maintaining a continuous GNSS site close to the Krafla volcanic system. The research group has also access to a series of GNSS data observing the plate spreading in Northern Iceland. The interaction between glaciers, the environment and volcanic activity will be another focus of the group.

A.5 Supersite description and justification

Iceland with its 30+ active volcanic systems is capable of producing a very wide spectrum of volcanic activity. Frequent (one average every 2-5 years) and powerful eruptions can cause large closure of airspace as occurred during the Eyjafjallajökull summit eruption in 2010. The study area covers all the volcanic zones of Iceland, with special focus on the most active volcanoes in the Eastern Volcanic Zone of Iceland, including Katla, Grímsvötn, Hekla and Bárðarbunga, that are responsible for more than half of all eruptions in Iceland (see Figure 1). The richness of magmatic activity is due to Iceland's location on the Mid-Atlantic rift, which traverses the country from SW to NE spreading at a rate of 18-19 mm/yr. Interaction of the rift with a hot spot results in complicated plate dynamics with volcanoes in different tectonic settings (Figure 1). Since many of Iceland's volcanoes are located under ice caps explosive eruptions due to magma-ice interaction are common, often generating plumes exceeding 10-12 km in height and carrying fine-grained ash to great distances. The eruptions in Iceland range from being relatively small, posing limited local hazard, to major explosive eruptions and flood basalt outpourings of lava that can have catastrophic effects in Iceland and serious impact on Europe. The 1783-84 Laki eruption is the most recent event of this type (Thordarson and Self, 2003). About 80% of all Icelandic eruptions are explosive producing plumes that transport volcanic ash and gas to considerable distances (Thordarson and Larsen, 2007). Explosive eruptions in Iceland pose a risk to air traffic on a global scale due to the dispersal of airborne volcanic ash and gas. The impact of even small-moderate magnitude eruptions can be serious, as exemplified by the Eyjafjallajökull 2010 eruption. It lasted 39 days and led to widespread disruptions in aviation, most seriously from April 15th to 21st when 313 European airports (80% of the network) were totally disabled leading to the cancellation of more than 100.000 flights and disrupting the travel of more than 10 million passengers (Calleja, 2010). The financial damage from the eruption has been estimated as up to 5 billion US dollars (Oxford Economics, 2010). Serious as these economic losses are, the impact of much larger events, similar to the Laki eruption in 1783-4 that lasted for eight

months, would be much more severe. The eruption resulted in 15% of the population of Iceland perishing in a famine. A persistent sulphuric haze affected the whole northern hemisphere, resulting in crop failures and causing famine and increased mortality rates in Europe and America with tens of thousands of deaths attributed to the eruption outside Iceland (Witham and Oppenheimer, 2005; Trigo et al., 2010). Eruptions of comparable magnitude to Laki 1783-84 occur in Iceland once every 200-500 years (Thordarson and Larsen, 2007). For the reasons above, it is clear that the volcanic areas of Iceland pose widespread geological threats that are ideally suited for basic research of how volcanoes work, with the aim of reducing loss of life from volcanic disasters.

Magma movements in the volcano subsurface often lead to detectable signals prior to eruption. Increase in seismic activity is a primary signal of such volcanic unrest, recordable through a network of seismometers on the ground. In some cases, but not all, magma recharging of volcanoes leads to surface deformation of volcanic edifices, often ranging from several to tens of centimeters. This important type of precursor to volcanic activity can be studied by remote sensing, through InSAR. Observations and interpretation of deformation fields on volcanoes can reveal how much, and where, new magma is accumulating in the volcanic plumbing system. InSAR measurements can reveal relative deformation with ~10 mm accuracy, providing key information about the nature of volcanic unrest. There have been many successful InSAR studies, utilizing various radar satellites, of magma accumulation in the volcano subsurface; sometimes such events have preceded eruptions and in other cases no eruption has followed. The challenge remains to understand when volcanic unrest will lead to an eruption and when it will not. If an eruption occurs, InSAR studies of deformation can reveal co-eruptive deformation, which can be used to constrain the source of the magma, and the magma plumbing systems involved.

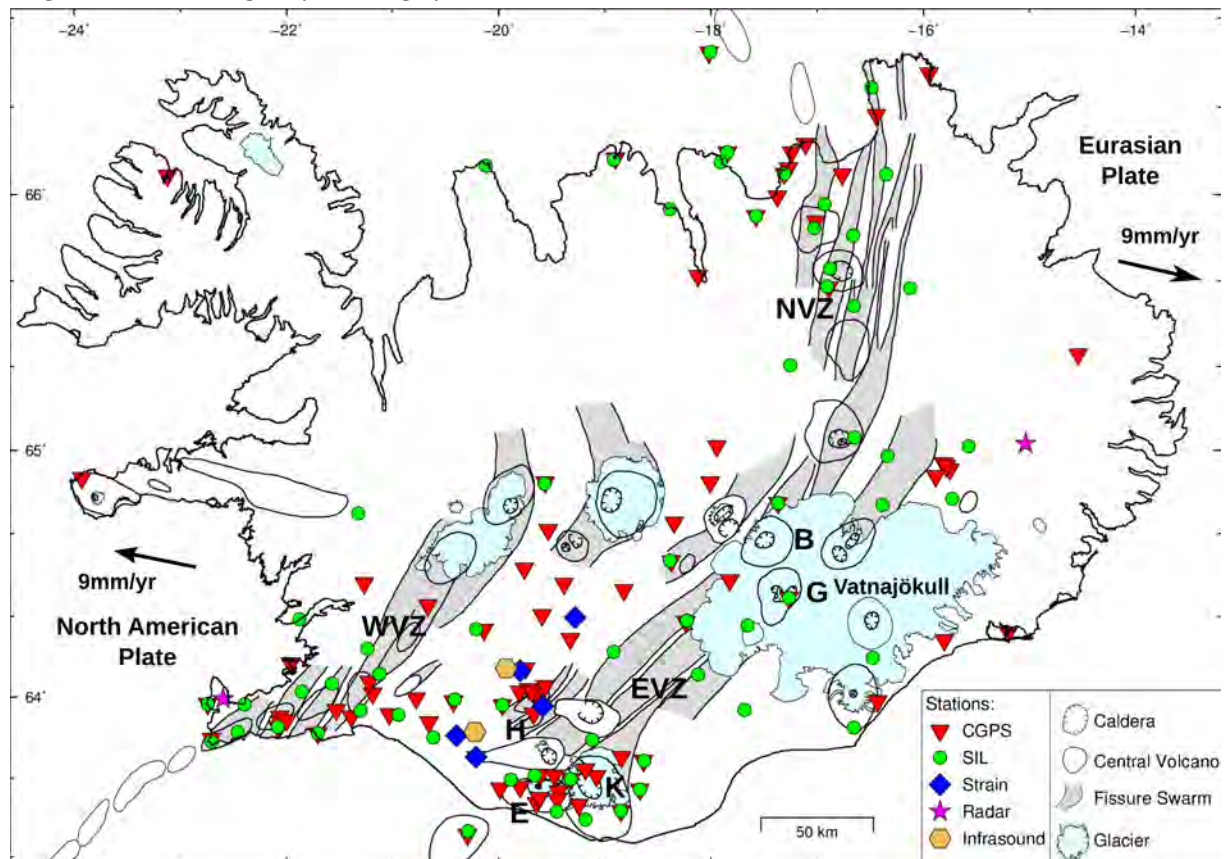


Figure 1. Iceland: volcanoes and present long-term monitoring stations (SIL = National seismic stations). The volcanic areas consist of volcanic systems, made of central volcanoes, calderas and fissure swarms. Western Eastern, and Northern volcanic zones marked (WVZ, EVZ, NVZ) are located on the divergent plate boundary between the North-American and Eurasian plates. Iceland's most active volcanoes are Grímsvötn (G) and Bárðarbunga (B) under the Vatnajökull ice cap, Katla (K) under Mýrdalsjökull ice cap, and Hekla (H). Eyjafjallajökull volcano is labelled E.

Access to in-situ data and main elements of the FUTUREVOLC data policy

Successful integration of space-based and in-situ data is a timely and important step towards the common goal of FUTUREVOLC and this CEOS GEO application, of improving geohazard monitoring and research. FUTUREVOLC will allow access to large and diverse data volumes, and when combined with CEOS appoint of Icelandic Volcanoes as a supersite there are obvious synergy effects. Under the coordination of the European Plate Observatory System (EPOS) and the U.S. institutions (U.S. Geological Survey and Unavco/Earthscope), the data providers of the FUTUREVOLC partnership are adopting the concept of a volcanic data supersite providing real-time data viewers as well as sophisticated data and tool sharing mechanisms. Users will gain access to the supersite data sharing facilities through a one time registration. Data will be stored at the supersite with the sole purpose of sharing it among registered users. Under special circumstances, private data storage space will be available to users, but a reasonable publication date will have to be provided for the data. Necessary measures will be taken to ensure safety of all data at the site, and the reliability of the site's services, and to protect it from abuse. Collaboration with the consortium is not mandatory, but recommended for scientists outside of the FUTUREVOLC consortium

FUTUREVOLC follows the GEO (Group on Earth Observations) recommendations on architecture and data management thereby following the vision set forth by GEOSS (the Global Earth Observation System of Systems).

The aim of the FUTUREVOLC project is to develop and implement a data access policy based on the GEO 2012-2015 work plan agreed during the GEO-VIII plenary meeting in Istanbul 2011. The European Plate Boundary Observatory (EPOS), which also serves as the co-lead of the GEO Supersites (<http://supersites.earthobservations.org>), will advise and guide the implementation of data sharing; CEOS will provide the space-based data, and FUTUREVOLC will provide the in situ data.

The objectives of the FUTUREVOLC data policy are:

To converge and harmonize observation methods and tools, to promote the use of standards and references, inter-calibration and data assimilation.

To enhance interoperability between participating organizations, including production of technical specifications for collecting, processing, storing, and disseminating shared data, metadata and data products.

To facilitate data management, information management, and common services, to promote the data sharing principles of the GEO Plenary, recognizing relevant international organizations,, national policies and legislation.

FUTUREVOLC defines three main data categories:

Real-time data streams. This category consists of various types of continuous data streams from well-established sensors. This type of data can be made available through links on a webpage, views on a webpage or, in certain circumstances, by direct streaming upon request. Data sources will include seismic stations, GPS stations, strain-meter stations, and Web-cams.

Near real-time data. Data in this category represents processed data that will be made available after a short delay, normally within a few hours of the source data creation. This data may be useful for numerical ash dispersion prediction and forecasting, monitoring of natural hazards, disaster relief, agriculture and homeland security to name a few examples. Data products, amongst others, are seismic data, GPS data, camera images of ongoing eruptions, and gas measurements. Data sources include geochemical sensors, meteorological stations, radiosondes, infrasound networks, lightning networks, electromagnetic sensors at volcanoes, the Icelandic radar network, and high-speed and time lapse cameras. This data will be made available via FTP and web services (see paragraph below on the FUTUREVOLC data hub).

Science products. For latency independent research and applications, long term studies and trend analyses, standard science products should be used. These are created using the best available ancillary, calibration and ephemeris information, and are an internally consistent, well-calibrated record of the Earth's geophysical properties. They may include InSAR and GPS processed results, ash dispersion model results, infrasound recordings and others. This type of data is subject to stringent quality controls and possibly manual curation to ensure the best possible quality for scientific research. The supersite will keep users informed on the progress of validating such data and regularly update publication schedules.

Work on the FUTUREVOLC data hub that will be hosted at the Icelandic Meteorological Office in Iceland has been initiated, and its establishment is one of initial priorities of the FUTUREVOLC project. It is foreseen that a part of the combined ground and space based data sets for the Icelandic Volcanoes supersite will be physically located outside of the main server for the FUTUREVOLC data hub, in particular space data from CEOS agencies contributing data through this proposal (if successful) that are interested in holding data on their own servers. These data will be integrated into the Iceland Supersite's data infrastructure through web services. The interfacing of servers and practical implementation of web services would be best carried out and implemented through a dialogue between CEOS agencies and the FUTUREVOLC team.

A.6 Current or future use of requested data

Almost a decade of experience with SAR interferometry for deformation measurements have shown that all SAR bands are extremely usable in Iceland. The lack of forests and dense vegetation in Iceland, combined with rocky landscapes and large lava fields make for excellent coherence throughout the country. Furthermore, Iceland has one of the largest density of active volcanoes in the world, as well as being an active rift zone and continuing uplift due to ice mass reduction. This makes Iceland a unique natural laboratory for crustal deformation studies using SAR data.

The principal objective of the requested data is to encourage basic research of volcano processes and other hazardous geological processes as a means of reducing the loss of life from geological disasters. Improved processing techniques and computing facilities allow for more data to be analysed, and yield better quality measurement results. Furthermore, improved repeat times of SAR satellites provides more extensive timeseries and shorter interval between measurements.

Time series of deformation will allow to study both precursory processes prior to eruptions as well as co-eruptive deformation. Long-term relatively slow time deformation requires long time-series, study of eruptions require short repeat intervals. For example, deformation associated with dike intrusions and fissure eruptions may take place over hours to days.

With CEOS appointment of Icelandic Volcanoes supersite we can more accurately determine what occurs during the period proceeding and following eruptions, better extract the time evolution of volcanic deformations, and use this information to produce more complex models of the volcanic systems.

The data will also bring us closer to near-real time processing of the SAR data. Together with the high repeat times of current satellites, InSAR could now be used not only as a study tool of the past, but also as a monitoring tool, similar to other techniques like seismic and GPS data. The high spatial coverage of InSAR would provide valuable insights into ongoing activity, and we foresee that early warning capabilities would greatly improve if such a system would come online. Setting up the processing algorithms and infrastructure to allow this near-real time processing of InSAR data is in fact an important part of the FUTUREVOLC project. A steady inflow of SAR data is required for the system to operate effectively, and the requested data in this proposal would greatly aid this goal.

Persistent deformation sources in Iceland outside ice caps will in particular be addressed with InSAR studies: They include: i) Most active volcanoes in Iceland partly or fully outside ice caps that provide the largest threat: Katla, Hekla, Bárðarbunga. The Grímsvötn volcano requires GPS-studies as it is almost fully ice covered, ii) Other actively deformation volcanic areas the can advance fundamental science: ii) Askja, Kverkfjöll, Krafla, Eyjafjallajökull, Reykjanes Peninsula volcanic area. These areas have been actively deforming, but eruption frequency is less than at others.

A.7 Schedule

The FUTUREVOLC project started 1 October 2012. Initial work has included efforts towards defining the requirements for data access, considering data format and storage structure for other supersites, UNAVCO data policy and implementation, EPOS e-science and data storage policy. Computer facilities and efficient data base are being established, as well as access routines. Data is expected to start to come on line in this future facility before end of 2013, starting with the best established data bases and data streams, like GPS and seismic data. The summer of 2013 has been used to reinforce ground monitoring in Iceland with various new equipment installations.

The acceptance of this proposal would allow an immediate boost in the application of InSAR on Icelandic volcanoes. The catalogue satellite data from past acquisitions asked for would be considered and analysed by the research groups of the researchers behind this proposal, including importantly their Ph.D. students and postdocs. The first significant amount of new acquisitions made

available through this proposal may be in the snow free period in Iceland in 2014, May – October. Prior to that the group of researchers will advance InSAR analyses techniques, and be ready to analyse the data delivered through this proposal in as close to real time as possible.

A.8 Detailed geographic region of interest

The Icelandic Volcanoes supersite covers the volcanic zones of Iceland, including its 30+ active volcanic systems. The aim of the supersite project is to combine ground based monitoring addressing activity within the volcanic zone with satellite observations of activity. InSAR observations are particularly important in this respect. Within the project, there is, focus on the most active and fastest deforming volcanoes that are considered to be most likely sites of unrest and/or eruptions in the coming decade. This includes a number of volcanoes deforming at rates of mm to cm per year in response to gradual magma movements and pressure changes in their roots, and plate movements. They are located in the Reykjanes Peninsula/Western Volcanic Zone, the Eastern Volcanic Zone and the Northern Volcanic Zone. The region of focused interest falls within the area indicated with polygon in Figure 2. Within this area, the main focus is on the most active volcanoes in Iceland, which are the Katla, Hekla, Grímsvötn and Bárðarbunga volcanoes.

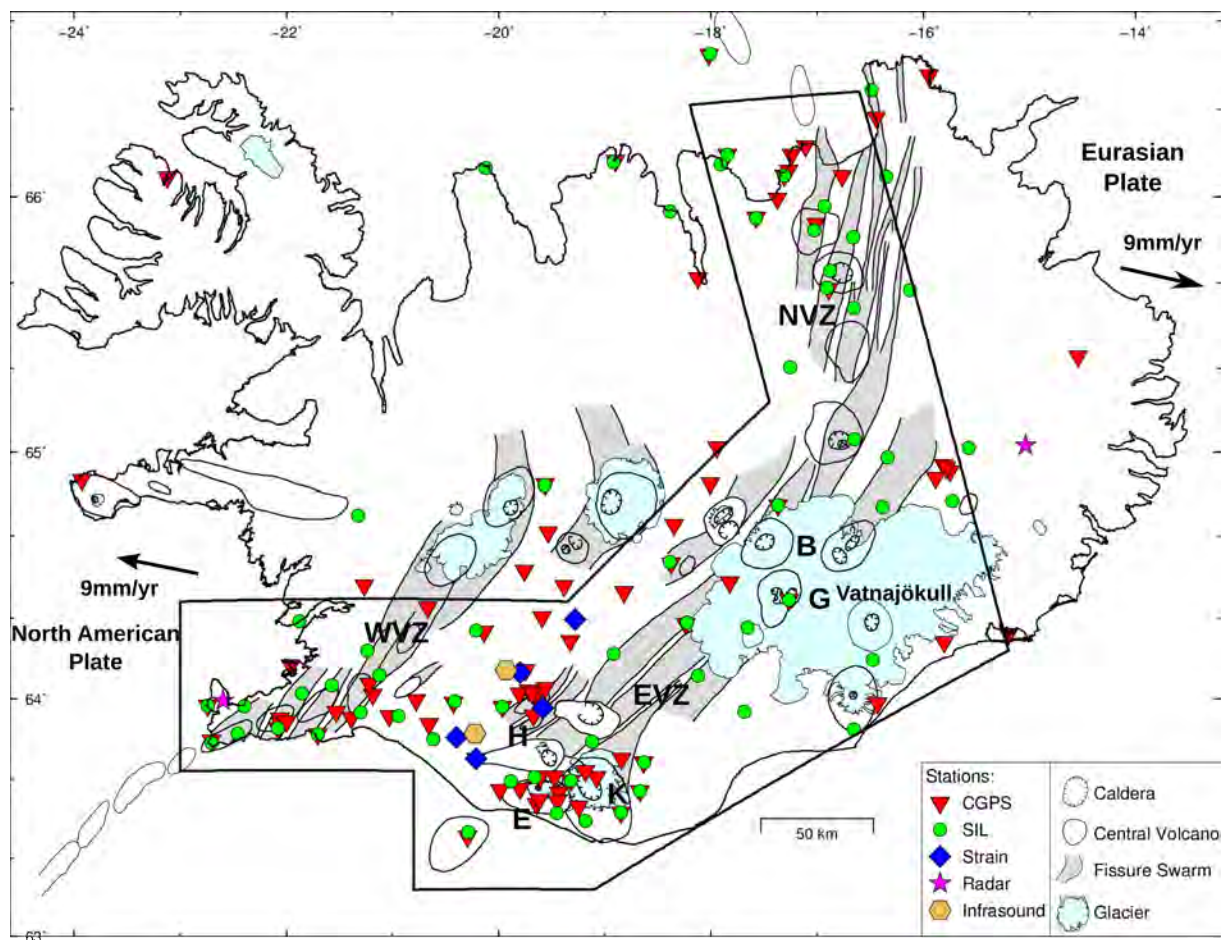


Figure 2. Polygon outlining the area of focused interest, overlaid on a map of the volcanic zones of Iceland and monitoring stations (same as Figure 1).

The polygon outlining the area of focused interest has the following coordinates:

-23.00 64.40
-23.00 63.70
-20.80 63.70
-20.80 63.20
-19.10 63.20
-15.20 64.20
-16.60 66.40
-18.20 66.35
-17.45 65.20
-19.35 64.40

A.9 Data requirements

Data suggested for this supersite proposal is primarily for InSAR studies, but includes other data constraining the dynamics of volcanoes as well. A large quantity of satellite data already freely open is not addressed in particular here, but rather we focus on data which would be most beneficial for a comprehensive study and monitoring program, for maximum scientific understanding of how volcanoes work, if made available through this CEOS proposal. These data will complement the available ground based in-situ data presently available and that will be made available through the FUTUREVOLC project.

Satellite data for InSAR studies

The suggested data to be delivered through this proposal includes an extensive set of InSAR images. The user requirements for InSAR acquisitions are to capture any long-term deformation that may take place at the most actively deforming and hazardous volcanoes in Iceland, as well as details of episodic activity.

Spatial coverage: The zone of highest interest straddles Iceland from southwest to northeast, spanning several hundred km. Within this zone there are several or more volcanoes that every year deform at rates of > 10 mm/yr and have movements detectable by InSAR. Acquisitions over this wide area would be optimal for an “Icelandic volcanoes” supersite. Therefore the suggested satellite acquisitions do cover the most active part of the volcanic zones of Iceland where persistent deformation has been detected, with the area of focused interest outlined in Figure 3.

Temporal coverage: Because of high latitudes, satellite acquisitions are focused in time on snow-free summer months. This is normally at maximum the time span from May to October, or half the year. Throughout mostly snow-free months we ask for a series of both ascending and descending images to update time series analysis of the most hazardous areas on a regular basis. During the snow free months, each location within the area of focused interest should be covered at intervals of 1-2 weeks in both ascending and descending modes. In the period of typical snow cover from November to end of April SAR images can still be useful to monitor large-scale changes at volcanoes. During non-

eruptive intervals this applies to glacially covered volcanoes where ice cauldrons exist in relation to geothermal activity, at the focus volcanoes of Katla, Grímsvötn and Bárðarbunga. One day interferograms from Cosmo-SkyMed tandem acquisition mode would also be useful all year to detect ice flow variations at these volcanoes.

Satellite coverage: Multiple acquisitions from multiple sensors increase the chances of resolving well the evolution of magma movements and pressure changes in the roots of volcanoes. Use of a mix of InSAR satellites is therefore most appropriate in Iceland to ensure sufficient spatial and temporal coverage of volcanoes, under different viewing and incidence angles. Accordingly, the goal is to have each of the InSAR satellites acquiring data over all the zone of interest, although with some difference in study focus. Many volcanic eruptions in Iceland had measurable precursory activity and accelerating ground inflation occurred before some eruptions as magma flows into a chamber or intrusive complexes. In order to successfully forecast and understand magmatic activity, and mitigate volcanic hazards, the dynamics of volcanoes need to be resolved at dense temporal scales in the medium and long-term.

DEMs: Scientific studies of the Icelandic volcanoes benefit in many ways from digital elevation models (DEM), both for InSAR analysis, but also for studies of the structures of volcanic edifices and their evolution, for example lava flows.

Surface change detection: During eruptions large scale surface changes (> meters) may occur on volcanoes, such as formation of lava flows or ice cauldron formation at sites of subglacial eruptions. Detailed measurements of evolution of such changes is important to understand the hazards involved and increase scientific understanding of the processes. In this respect, the SAR intensity (amplitude) data can very valuable to track the ongoing changes for maximum scientific understand of the processes taking place. Furthermore, high resolution InSAR imaging can also be important in this respect, in particular during eruptions or major unrest episodes.

A primary consideration, for the usage of data asked for in this proposal, is that we plan to use SAR images to produce maps of incremental deformation and average velocity. The InSAR time-series will show the evolving deformation pattern of the volcanoes, while average velocity maps will enable scientists to detect the prevailing mode of deformation. Sharp deformations from sudden magma movements will also be identified. These maps will provide a new understanding of the magmatic processes and will improve current models of the volcano plumbing systems. Dense satellite observations from multiple satellites help achieve these goals.

With the InSAR data requests in this proposal our aim is to move scientific InSAR deformation studies in Iceland from an opportunistic basis towards operational near-real time studies of Icelandic volcanoes, through development of a pilot project, and to ensure the full integration of space and ground based deformation studies for maximum benefits for the understanding of volcanic hazards in as close to real time as feasible. In the event that magma moves rapidly up to the shallow crust in and episodic intrusion, or an eruption occurs, changes may occur rapidly (seconds, minutes, hours). InSAR combined with the highest possible temporal resolution, combined with high-rate continuous

GPS observations and other ground based monitoring will then be of primary importance. A full integration of space and ground based monitoring is envisioned through this proposal.

The user requirements in terms of spatial, temporal and satellite coverage, and DEMs and surface change detection, listed above, form the primary considerations that can guide space agencies to what data they can and would like to make available through this proposal, and how CEOS can define meaningful resource commitments. To guide that process we list below suggestions and considerations regarding data from different InSAR satellites. We furthermore suggest the data requirements be reconsidered at regular intervals, dependent on progress and emphasis on research, availability of data from CEOS partners, and activity in Iceland. An extensive volcanic unrest or major volcanic eruption in Iceland would in particular call for revisions of satellite acquisitions plans.

Sentinel-1

The C-band SAR onboard the first Sentinel satellite of ESA, when operational, will provide crucial data for the study of Icelandic volcanoes. Anticipated open policy of freely available data acquired by Sentinel-1 satellites is critical. Downloading, and near-real time analysis, of all Iceland data available from Sentinel-1 is planned by the supersite deformation team.

TerraSAR-X: (up to 250 acquisitions per year suggested + catalogue of past Iceland images)

TerraSAR-X interferometry has proven to be very useful to monitor magma movements prior to and during the Eyjafjallajökull eruptions in 2010 [e.g. Sigmundsson, Hreinsdottir, Hooper et al., Intrusion triggering of the 2010 Eyjafjallajökull explosive eruption, *Nature*, 468, 426-430, 2010]. The acquisitions we ask for here are to conduct studies comparable to that of the Eyjafjallajökull 2010 eruptions but in an improved manner, and to combine TerraSAR-X data with other set of images. Importantly the aim is to conduct time series analysis of deformation (see Figure 3 for an example).

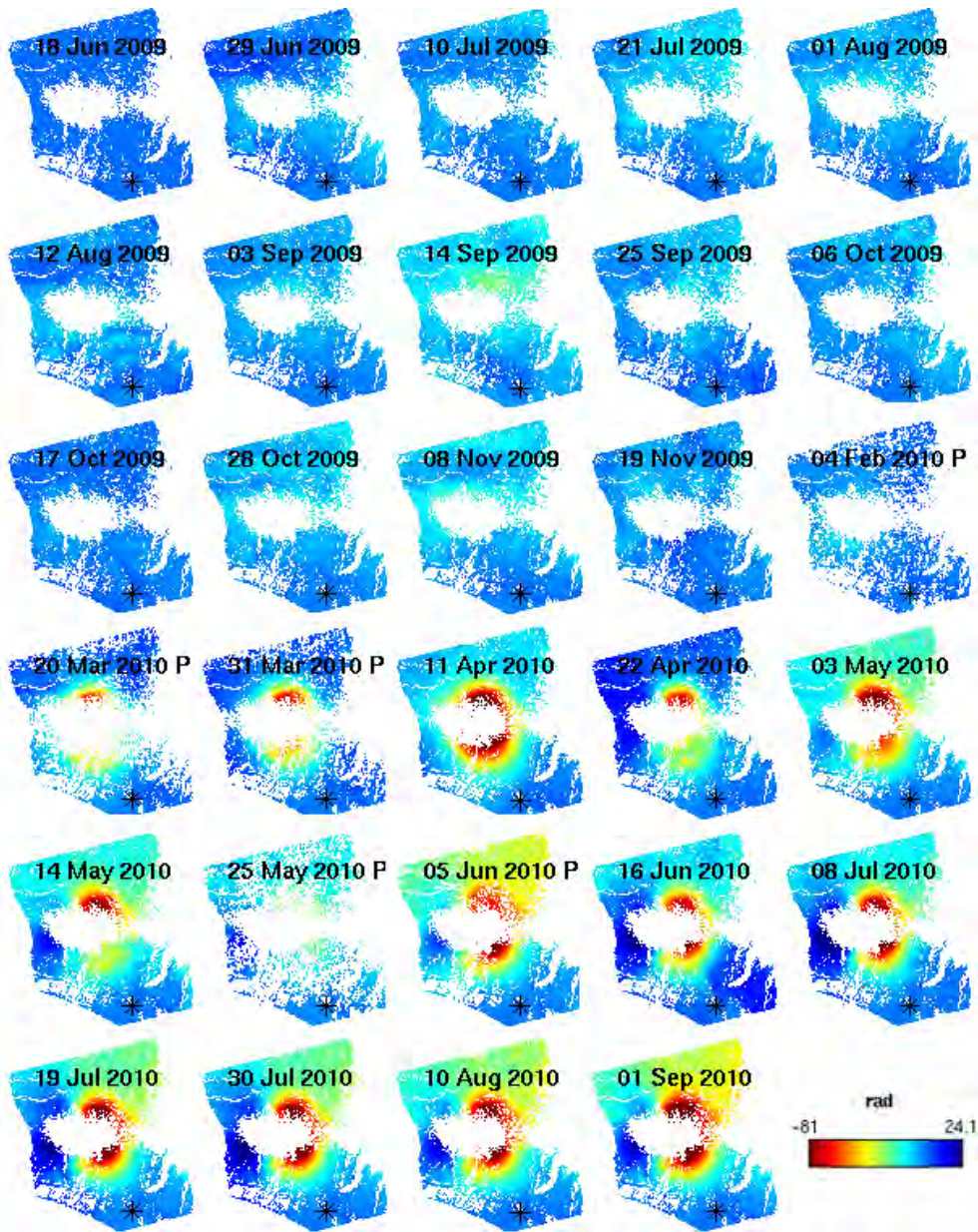


Figure 3. InSAR time series at Eyjafjallajökull volcano Iceland. Unwrapped timeseries of TSX interferograms showing the unwrapped cumulative deformation with respect to the first image (18 June 2009). In 2010, an effusive flank eruption occurred 20 March – 12 April, followed by the air-traffic disrupting eruption 14 April to end of May. During the activity and following, images were acquired in this track nearly every overpass, giving an outstanding overview of the evolution of the deformation throughout the two eruptive events. By acquiring timeseries like this continuously during the summer months over volcanoes, and processing them in near-real time, InSAR can be used both for improved understanding of volcanic processes and as a monitoring tool, providing early warning about events and their characteristics.

In past years data from various tracks and swaths of the TerraSAR-X satellite have been acquired over a substantial part of the volcanic zones of Iceland (Figure 4). This forms an important set of images to compare further acquisitions with. Therefore we ask for access through this supersite proposal to all

past Iceland acquisitions. An important set of these are stripmap images in HH polarization (strips 003-014). These include:

- 2009: 67 images
- 2010: 153 images
- 2011: 88 images
- 2012: 151 images
- 2013: 97 images

For future years, we ask for images, mostly in a strip-map mode, covering the volcanic zones, mostly in the time period from April to October each year. Acquisitions from about 25 different swaths cover the most active parts of the Icelandic volcanic zones in ascending and descending modes. With 11 days repeat time it is feasible to collect about 10 acquisitions from each swath per year, leading to a total of up to 250 suggested acquisitions per year. An important issue is to ensure sufficient priority to the Iceland image acquisitions by the supersite project partners; in past years there have been many cancellations of orders posed by University of Iceland, as well as many orders made by UNAVCO in 2013.

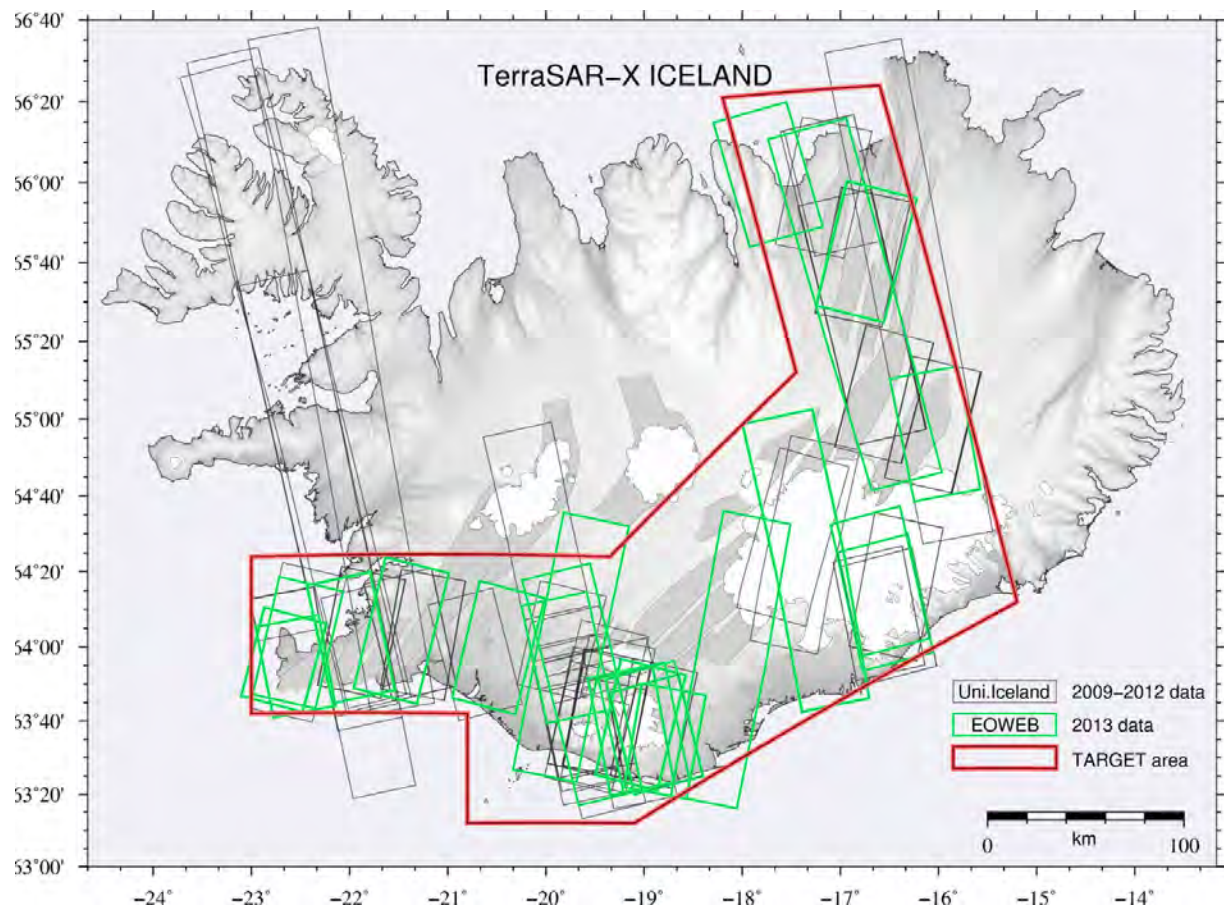


Figure 4: TerraSAR-X acquisitions over Iceland used in past for studies of volcanoes by University of Iceland and collaborators. The background map shows shaded relief together with fissure swarms (grey filled outline). Swaths shown in dark grey are images used by University of Iceland and collaborators in 2012 and earlier years (stored at University of Iceland), green swaths show data collected in 2013 up to the time of writing (29 August). The red polygon outlines the area of focused interest.

A revision to the TerraSAR-X acquisition plan over Iceland in case of an eruption could consider the acquisitions of Spot-light images for monitoring of large scale surface change in detail, taking into account though the need to continue strip-map imaging to form interferograms with earlier images. Spot-light images may be particularly to monitor evolution of large-scale changes of glaciers in case of subglacial eruptions.

TanDEM-X: (up to 36 bistatic pairs)

Repeated digital elevation models created from bistatic acquisitions of the TanDEM-X mission would be of great advantage for a number of applications; to create time series of height changes relating to cauldron formation; to quantify the volume of new craters and lava flows during eruptions; and to measure any strong ground deformation beneath the ice caps.

We suggest therefore frequent bistatic acquisitions over the ice cauldrons of the most hazardous volcanoes of Katla, Grímsvötn and Bárðarbunga. The long term time series of height change that can be generated from these data will be complimentary with the instantaneous velocities measured by Cosmo Skymed in tandem mode. In the ideal case a bistatic pair would be acquired once per month over each of the three volcanoes, giving 36 pairs per year. In the event of magma rising to shallow depths, or of an eruption, even more frequent bistatic acquisitions would be great scientific interest.

COSMO-SkyMed: (up to 350 acquisitions per year suggested + catalogue of past Iceland images)

The COSMO-SkyMed (CSK) constellation consists of 4 satellites, each equipped with a SAR instrument and with a repeat cycle of 16 days. Interferograms can be constructed by combining any acquisition from the constellation, making CSK the only SAR instrument currently capable of measuring ground motions with a revisit time as short as 1-4 days. Therefore CSK is an ideal satellite to measure fast changing ground deformations, such as caused by magma intrusions and eruptions. CSK data can thus provide critical temporally-dense measurements of crustal motions at Icelandic volcanoes that are experiencing unrest and that are capable of producing disruptive eruptions. Short revisit times will allow scientists to detect the complex dynamics of the Icelandic volcanoes and will facilitate identification of precursors to potentially disastrous eruptions. Furthermore, during eruptions such temporally dense observations can significantly help understanding and mapping the effects of eruptions, such as extents of lava flows.

Icelandic volcanoes have been imaged by CSK since 2009 and we plan to make use of past acquisitions as a basis for constructing a history of surface deformation. We request all the stripmap Himage (STR_HIMAGE) scenes (40 km wide) acquired over the most active volcanic zones of Iceland (black outline in Fig. 5) between 01 May and 30 October in 2009-2012, for a total of about ~600 scenes.

For future acquisitions, we suggest continued stripmap Himage acquisitions covering the same area of the most active volcanic zones (black outline in Figure 5) in both ascending and descending tracks, for

a total of ~18 tracks with a routine revisit time of 16 days mostly between 1 May and 30 October, corresponding to about 200 acquisitions per year in total (assuming an acquisition spanning the zone of interest in the flight direction of the satellite, along track, counts as one acquisition).

Additionally, we suggest selecting three volcanoes as targets for special studies (Hekla, Katla and Eyjafjallajökull). They would be monitored at temporal resolution of 8 days in 6 different tracks, giving about 70 additional scenes per year. In the occurrence of an important seismic-magmatic-tectonic crisis in Iceland we would like to request up to 30 extra images per year, whose revisit time may be as short as 1 day (“tandem-like” mode) depending on the surveillance level needed to manage the seismic-magmatic-tectonic risks and ensure the best possible constraints on progress of deformation, for e.g. improved imaging of magma movements.

Furthermore, we suggest to use the 1 day tandem mode acquisition capability (forming interferograms by combining CSK-2 and CSK-3) to acquire images over the focus volcanoes of Katla, Grímsvötn and Bárðarbunga in the winter period, to detect ice flow variation at ice cauldrons above subglacial geothermal areas. The interaction between glaciers and volcanoes is an important topic to understand volcanic processes at ice-capped volcanoes and the research teams behind this proposal would like to explore this aspect. If feasible, we ask for up to 50 acquisitions per year for this purpose.

The most active Icelandic volcano, Grímsvötn, as well as the highly hazardous Katla and Eyjafjallajökull are covered by glaciers. This has been a limitation for studying deformation as InSAR cannot detect crustal motions under the glaciated portions of the volcano. On the other hand, shallow magmatic intrusions, hydrothermal activity and subglacial eruptions can cause localized melting of the glaciers and the generation of ice cauldrons at its surface. We envisage that the frequent revisit time of CSK (up to 1 day revisit time) will be used to measure deformations of the ice surface that may occur when magma migrates to shallow levels and in the initial phases of eruptions, enabling scientists to quickly respond to an impending eruption. Interferometry will be attempted on the ice surface, or alternatively, careful comparison of amplitude images can reveal large scale changes at subglacial eruptive sites. In the occurrence of eruptions, coherence images will be used to map the evolving surface of lava flows and amplitude images will also be analysed to identify fault scarps, venting and fracturing in the vicinity of the eruptive sites where no direct observations could otherwise be made (http://www.asi.it/it/news/cosmoskymed_vigila_sul_risveglio_di_nabro).

Considering the X-band nature of CSK, the plan in this proposal is to focus on detailed studies of individual volcano deformation, rather than more regional deformation. Therefore the focus is on stripmap imaging rather than scan-SAR imaging.

The study of Icelandic volcanoes benefits in many ways from accurate digital elevation models (DEMs). If space agencies can provide these to the supersite project it would be very beneficial.



Figure 5. COSMO-SkyMed acquisitions in Iceland (pink rectangles) May-October 2010. The black outline marks the area where the presently most deforming and hazardous volcanoes are located.

Similarly as for the TerraSAR-X satellite, a revision to the COSMO-SkyMed acquisition plan over Iceland in case of an eruption could consider the acquisitions of Spot-light images for monitoring of large scale surface change in detail, taking into account though the need to continue strip-map imaging to form interferograms with earlier images.

Radarsat-2: (up to 160 acquisitions per year suggested + catalogue of past Iceland Radarsat images)

Radarsat-2 is the only mission currently operating in C-band for which data can be made available. Decorrelation in C-band is significantly reduced in the more vegetated areas compared to the X-band sensors (TerraSAR-X and COSMO-SkyMed), **increasing the expected coherence of the interferograms over long time-frames**. Although TerraSAR-X and COSMO-SkyMed compensate with their reduced repeat times, this is not always possible, for instance in spanning the winter months. Radarsat-2 therefore has an important role to play in extracting deformation, particularly in the more vegetated regions and to detect more regional deformation. Atmospheric perturbations and deformation show up in C-band data as fewer fringes than in X-band, making unwrapping of C-band images over large areas simpler, compared to X-band.

We ask for acquisitions in wide fine (WF) mode (150km*150 km) for testing utilization of fine beam interferograms of large areas centred on the plate boundary in Iceland. They can give an overview of plate boundary deformation and its interaction with volcanoes. Such interferograms can address the

issue of plate boundary deformation and uplift due to ongoing glaciation (due to global warming) and how these processes may trigger magmatic activity and eruptions. Iceland is covered by 4 ascending and 4 descending frames, corresponding to 120 images/yr (each frame 15 images/yr).

There have been successful studies of volcano deformation in Iceland with Radarsat [e.g., de Zeeuw-van Dalen E, Pedersen R, Hooper A, Sigmundsson F, Subsidence of Askja caldera 2000–2009: modelling of deformation processes at an extensional plate boundary, constrained by time series InSAR analysis. *J Volcanol Geotherm Res* 213–214:72–82, 2012.

doi:10.1016/j.jvolgeores.2011.11.004]. We would furthermore like to extend further these studies and ask for access to images acquired over Iceland with both Radarsat-1 and Radarsat-2. The incidence angle of Radarsat allows good resolution of both vertical and horizontal deformation, and is thus an important additional data set. To extend these studies, and start new time series of detailed volcano deformation, we ask for up to 40 additional images in higher resolution modes than WF.

The details of how data would be made available would best be found in a dialogue between the supersite and CSA, in the case of Radarsat-2 data, as explained in general at the end of chapter A.5.

ALOS-2: (200 acquisitions per year suggested + catalogue of past Iceland ALOS images)

The reduced decorrelation compared to C- or X-band means that L-band missions can capture deformation in vegetated areas that decorrelate rapidly. For example, data from ALOS gave a much more complete picture of the deformation associated with the 2008 earthquake sequence in the South Iceland Seismic Zone than data from Envisat. L-band also allows interferograms to be made between images with light snowfall in between, as the decorrelation effect of the snow has less impact at these frequencies. Data from ALOS-2 will therefore be an essential component for monitoring year-round deformation when the mission comes online.

Similarly as for the other satellites, we ask for the archive of all ALOS data from Iceland, in order to make time series analysis possible, and to compare to ALOS-2 images.

Future Missions

All of the satellites currently in operation have their own advantages, and combining data from all provides the best possible chance of capturing deformation associated with all of the different volcanic processes that can occur in Iceland. Future missions will also bring their own advantages, and we expect to extend the Supersite concept to include these new missions as they come on line. We specifically mention ALOS-2 above, as JAXA have already issued an Announcement of Opportunity, but other missions such as Sentinel-1 will also be very relevant.

Archive of additional SAR Data (all Iceland data suggested)

In addition to archived data from the satellites mentioned above, the archives of ERS-1, ERS-2, Envisat, JERS data over Iceland would be useful for the project.

The data can be analyzed with new and improved algorithms, allowing extraction of further information than past studies of magma movement. This would stimulate research on deformation processes, in particular for the creation of time series constraints on long-term deformation, magma movements and behavior of volcanoes.

Satellite data for other than InSAR studies

Satellite data freely available at no cost is not a particular topic of this proposal, except that space agencies would be encouraged to prioritize acquisitions over the Icelandic volcanic regions if acquisitions over Iceland compete with those in other areas.

For data not freely available, the research groups behind this proposal welcome a dialogue with CEOS partners on available imaging that can potentially be important to increase the scientific understanding of Icelandic volcanoes and their activity. We mention few suggestions below.

SPOT and Pleiades: (annual acquisitions over the volcanic regions of Iceland)

Orthorectified Spot Image's SPOTMaps products are good base to follow large-scale terrain change at Icelandic volcanoes, including eruptions. Similarly, images from the two Pleiades satellites, providing a new generation of high resolution optical images, would be very useful for this proposal.

Pleiades images would form an important geographic reference for visualization of other science outputs at the Icelandic Volcanoes supersite. They would also allow monitor of the large scale evolution of the landscape, or the formation of lava flows in case of an eruption. With submetric resolution (~0.5 m), they offer a unique opportunity to detect horizontal displacements of the Earth surface, similar to the SPOT images, but with a better sensitivity to small movements. The almost daily revisit capability allows measurements of temporal evolution with a very frequency, which is critical when used for surveying precursors of volcanic activity. The supersite team is interested in attempting to utilize optical images to monitor change on ice-covered volcanoes.

Images are required in highest resolution and with high-gain for resolving structures in lava-covered landscape of Icelandic volcanoes (very dark surface materials almost completely without any vegetation), or alternatively low-gain for resolving structures on ice caps. At least 1-2 acquisitions per year at each of the Icelandic volcanoes, some with high-gain and other with low-gain, and more focused acquisitions at selected volcanoes undergoing unrest would require over 40 acquisitions per year.

ASTER: (Images from eruptions, and prioritizing routine acquisitions at all times)

The high spatial resolution ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data allows large-scale changes on volcanoes to be routinely mapped, and the fine structure of eruption plumes and specifically the near vent situation to be studied.

Routine acquisitions over the Icelandic volcanoes are valuable to detect large-scale change like ice melt variations at glacially covered volcanoes, and unusual snow melt or lake ice melting during the winter period. Such changes can help evaluate the status of volcanoes. Prioritizing ASTER image acquisitions routinely over the volcanic zone of Iceland would thus be useful at all times.

The ASTER data collected during eruptions is very important. The data collected during the Eyjafjallajökull (2010) and Grímsvötn (2011) eruptions in Iceland allows comparisons with ash and SO₂ products from other satellite instruments, for example SEVIRI. The repeat time of ASTER makes it useful for following possible future events on Iceland.

ASTER is also useful for generating DEMs of volcanic landscapes and such data for use over Iceland's volcanoes is needed.

A.10 Available resources

Contribution to the FUTUREVOLC project from the European Commission (dependent on final decision from EC and signing) of 5.99 million Euros, in addition to contribution from individual partners

A.11 Additional comments

The research groups behind this proposal, including all the FUTUREVOLC partners, are interested in demonstrating the value of collaborative research on data from different ground and satellite sources. Highlighting the value of collaboration with the CEOS partners will be aimed for throughout the research planned with data delivered through this proposal, e.g. in publications, scientific presentations and on websites.