Present day in-situ monitoring networks of volcanic and seismic hazards in Iceland and FUTUREVOLC

Freysteinn Sigmundsson (fs@hi.is), Kristín Vogfjörð (vogfjord@vedur.is), Benedikt G. Ófeigsson (bgo@vedur.is), Sigrún Hreinsdóttir (runa@hi.is), Matthew J. Roberts (matthew@vedur.is), Maurizio Ripepe (maurizio.ripepe@unifi.it), Magnús T. Guðmundsson (mtg@hi.is) and the FUTUREVOLC team

Memorandum 19 March 2013, describing in-situ monitoring networks in Iceland and future plans, based on the FUTUREVOLC proposal and compilation of present resources.

Iceland is a high volcanic-risk area at an international level because its 30+ active volcanic systems generate relatively frequent and powerful eruptions. Closures of parts of the European airspace occurred in the explosive eruptions of Eyjafjallajökull in 2010 and Grímsvötn in 2011, with some disruption as well in smaller eruptions in 1991, 1998, 2000 and 2004. Iceland is capable of producing a wide spectrum of volcanic activity. This richness of magmatic activity is due to Iceland's location on the Mid-Atlantic rift, spreading at a rate of 18-20 mm/yr. Interaction of the rift with a hot spot results in complicated plate dynamics with volcanoes in different tectonic settings (Figure 1). Many volcanoes are located under ice caps leading to phreatomagmatic eruptions, often generating plumes exceeding 10-12 km in height and carrying fine-grained ash to great distances. Seismic hazards are high in Iceland, in particular in the South Iceland Seismic Zone linking the Western and Eastern Volcanic Zones and at the Tjörnes Fracture Zone in north Iceland linking the Northern Volcanic Zone and the offshore Kolbeinsey Ridge. Series of up to M7 earthquake occur in these zones.

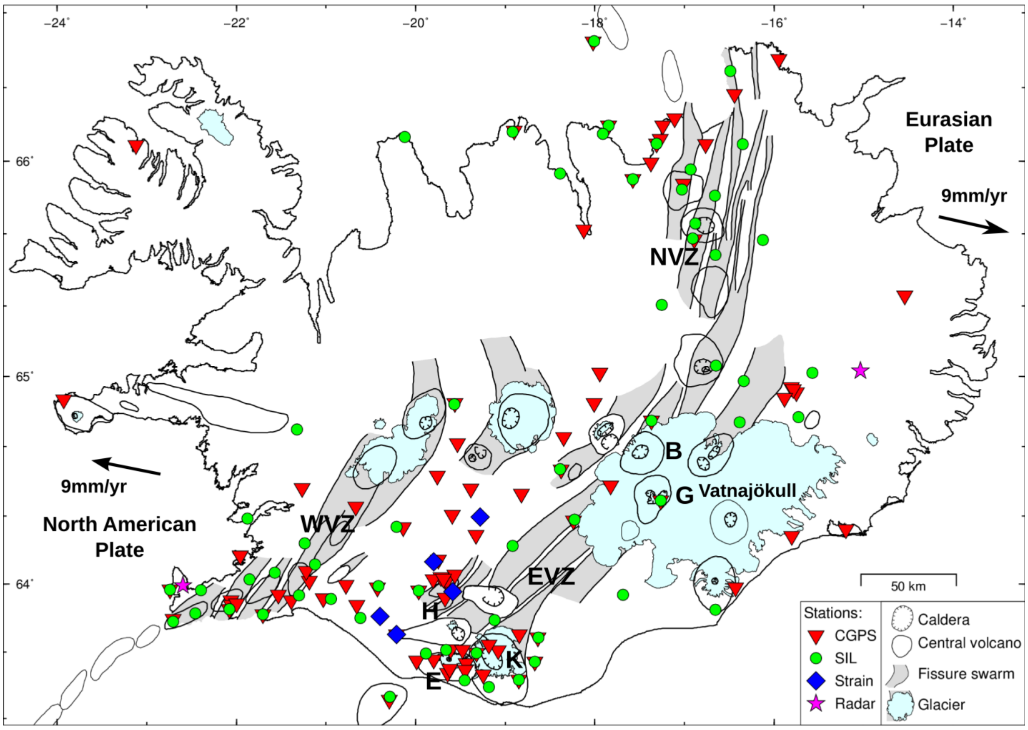

Figure 1. Iceland: volcanoes and present long-term monitoring stations. The volcanic areas consist of volcanic systems, made of central volcanoes, calderas and fissure swarms. Western Eastern, and Northern volcanic zones marked (WVZ, EVZ, NVZ) are located on the divergent plate boundary between the North-American 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 vocano is labelled E.

The Icelandic Meteorological Office (IMO) leads long-term monitoring of geohazards in Iceland and is responsible for maintaining instrument networks for this purpose.

http://en.vedur.is/

IMO has extensive collaboration with a number of Icelandic and international research groups, including the Institute of Earth Sciences (IES), University of Iceland.

http://earthice.hi.is/

In-situ instrumentation to monitor geological hazards in Iceland includes seismic, GPS, strain, hydrological, radar, infrasound networks, and scanning DOAS spectrometers.

Long term monitoring networks form the basis for the FUTUREVOLC project:

http://www.futurevolc.hi.is/

IMO is Iceland's leading partner in the EPOS project (PI for Iceland is Kristín Vogfjörð). Permanent networks included in EPOS are described in the EPOS RIDE data base (Research Infrastructure Metadata base for EPOS):

http://www.epos-eu.org/ride/

Selecting a country filter and Iceland gives an overview of the in-situ networks described in EPOS RIDE. Information on the networks is found by selecting the relevant network (the GPS network is divided into 3 parts)

Seismic results

The national seismic network is named the SIL network. Present seismic stations are shown as green dots on Figure 1.1. This network has been operated by the IMO since 1990s, initiated from a Nordic project covering the South Iceland Seismic Zone in the 1990s but has expanded to cover all of Iceland. This network is complemented with various temporary and permanent seismic installations in Iceland, e.g. by IES, University of Uppsala, Sweden, University of Cambridge, UK, and British Geological Survey (BGS). Data from stations from temporary networks are in some cases transmitted directly in real time to IMO and included in near real-time analysis.

A map of the seismic SIL stations can be found at:

http://hraun.vedur.is/ja/skjalftar/silstn.html

Processed results from the SIL network are available from IMO in various forms – some with description in Icelandic.

Link containing the automatic locations from the SIL network for the last 48 hours – NOT manually checked.
(kort = map, tafla = list of earthquakes):

http://www.vedur.is/skjalftar-og-eldgos/jardskjalftar/#view=map

Summary of weekly activity – revised earthquake locations:

http://hraun.vedur.is/ja/viku/

A folder holds information for each year (e.g. folder 2013 holds information regarding seismicity in 2013.). Subfolder for each week (Icelandic vika) shows maps for activity each week, based on list of earthquakes that have been manually checked.

Naming convention is the following:
http://hraun.vedur.is/ja/viku/yyyy/vika_ww/listi
where yyyy is a year and ww=number of week in that year.

Example:
http://hraun.vedur.is/ja/viku/2013/vika_10/

A list of manually checked earthquakes for that respective week is found at:

http://hraun.vedur.is/ja/viku/2013/vika_10/listi

Alert maps and shake maps can be accessed through

http://hraun.vedur.is/ja/alert/

There are two links

Alert maps:
Reveals a list of earthquakes. By clicking on items in the list three maps for each event are shown. From left: time of peak ground velocity (PGV), amplitude of PGV, and onset time of P-wave arrival.

Shake Maps:
Reveals a list of shake maps. They are drawn with the USGS ShakeMap software receiving PGV and peak ground acceleration information for the SIL stations, and using PGV and PGA attenuation relations as well as Intensity (PGV, PGA) derived for seismic wave propagation in Iceland.

Continuous GPS results

The present stations of the national GPS network (ISGPS) are shown as red triangles on Figure 1. The build-up of continuous GPS monitoring in Iceland has been accomplished by various international collaborative projects. Eventually the build up of these “sub-networks” has formed a network of close to 80 stations distributed along the volcanically and seismically active zones in Iceland. Several universities and institutions, with the support of research funds, have contributed to the build up of the network. Among the main contributors are University of Iceland, University of Arizona, Penn State University, Savoie Universiy in France, ETH in Zürich and King Abdulla University, KAUST, in Saudi Arabia and Bavarian Academy of Sciences and Humanities, Germany. Power companies Landsvirkjun, Orkuveita Reykjavikur and HS Orka, as well as the National Land survey of Iceland have also contributed.

There are two IGS (International Geodetic Service) GPS stations in Iceland, Hofn (HOFN) and Reykjavik (REYK):

http://igscb.jpl.nasa.gov/

Data from these stations are analyzed by many international agencies and are included in the global ITRF velocity field

http://itrf.ensg.ign.fr/ITRF_solutions/2008

Data from the many international collaborative GPS-monitoring projects in Iceland are analyzed by various agencies. Results from daily analysis of all continuous GPS sites in Iceland are available at IES and IMO.

Sigrún Hreinsdóttir at IES maintains a site with updated detrended time series from all stations:

http://strokkur.raunvis.hi.is/gps/

This sites includes a description of the data and time series. The detrended time series are particularly useful to check for deviations of displacement patterns from previous trends, such as due to magma movements in volcanoes.

IMO (contact person Benedikt G. Ófeigsson) present raw time series (not detrended) in the ITRF2008 reference frame at:

http://gps.vedur.is/

The site (under construction) includes also station map as well as some background information. The time series also reveal anomalous displacement patterns, but background velocities in ITRF2008 reference frame have to be considered as well as annual cycles in derived movements.

Strain results

A network of borehole strainmeters (Sacks-Evertson borehole dilatometers) is operated by IMO (contact person Matthew J. Roberts) in collaboration with the Carnegie Institution of Washington (CIW). Data streams (uncorrected) from four strainmeters are displayed at:

http://hraun.vedur.is/ja/strain/1sec/index.html

These have proven successful to detect immediate precursory signals to eruptions of the Hekla volcano. A real-time monitoring of strain and seismicity at Hekla is displayed at:

http://hraun.vedur.is/ja/hekla/borholu_thensla.html

Infrasound result

On active volcanoes, volumetric sources rapidly expanding in the atmosphere produce infrasound providing valuable insights into eruption dynamics and into the state of volcanic activity in general.

Explosive activity in Iceland is monitored by a 4-element infrasonic array with a triangular geometry and an aperture (maximum distance between two elements) of ~120 m. The array is operating in Gunnarsholt South Iceland and each element is equipped with differential pressure transducer with a sensitivity of 25 mV/Pa in the frequency band 0.001-50 Hz and a noise level of 10-2 Pa. Infrasound is recorded on site at 100 Hz and 24 bits and transmitted via Internet link both to the Icelandic Meteorological Office (IMO) and the Department of Earth Science of University of Florenze, Italy (UNIFI).

Location of the infrasonic source is performed by array multi-channel semblance analysis applied on a grid-searching procedure to identify in real-time signals from noise in terms of propagation back-azimuth and apparent velocity. Data and source location are visible in real-time at:

http://lgs.geo.unifi.it/iceland

Infrasonic monitoring allows for real-time determination of parameters such as onset, duration and intensity of the eruption. Data collected during the Eyjafjallajökull 2010 eruption indicate that infrasound could be used to calculate mass eruption rate and plume height in real-time

Contact person is Maurizio Ripepe (UNIFI).

Real-time hydrological data

Many of the volcanoes in Iceland are glacially covered. For these, the monitoring of the rivers emanating from the overlying ice caps is of particular importance. IMO runs a country-wide network of sensors for river flow:

http://vmkerfi.vedur.is/vatn/vdv_gmap.php

http://vmkerfi.vedur.is/vatn/direct_login.php?id=430408

Contact person is Matthew J. Roberts at IMO

In case of unrest:

In case of eruptions, daily situation reports will be (as they have been in the past) prepared jointly by IMO and IES, outlining the situation, explaining signals observed with the in-situ monitoring networks and other available information.

FUTREVOLC - Progress beyond the state-of-the-art

Monitoring systems

The seismic work in FUTUREVOLC relies on the existing permanent networks. With many of the most active volcanoes in Iceland located under ice caps, like Mýrdalsjökull and Vatnajökull (see Fig. 2), extending the networks to close proximity to the volcanoes has not been possible, except on the occational rock outcrop (nunatak) in the ice. Many of these volcanoes are therefore undermonitored. However to enter into the glacies with the monitoring networks will require significant strides to be made, because in addition to technological developments of the instruments themselves, several problems will need to be overcome to allow instrument operation in the harsh glacier environment. This will be the task of one of the FUTUREVOLC partners, Guralp Systems Ltd. who will develop a seismic instrument in the project suitable for deployment in the ice. Close monitoring of the subglacial volcanoes will increase their monitoring level and enable tracking magma movements through migration of microseismicity and through detailed analysis of earthquake source mechanisms. The emphasis will be on real-time processing of detected signals for early warning of volcanic eruption. Accuracy of the earthquake locations is dependent on the ability to properly represent the heterogeneous crustal structure at volcanoes. Therefore by including 3D velocity models in the location procedures, the resolution of the seismicity mapping could be significantly improved.

Seismic tremor is also a common sign of activity and unrest in volcanoes and generally accompanies eruptions. Understanding the physical processes generating seismic tremor and discriminating the different characteristis of each one can improve the monitoring potential of volcanoes and decrease the number of false alarms. Subglacial floods issue from regions in the Vatnajökull ice cap on average every other year and a few floods have come from Katla in Mýrdalsjökull (Fig. 2), making them ideal candidates for the project's journey into the glaciers to study the sources of tremor. Two seismic arrays will be installed at the glaciers edge to locate and track the sources of tremor. Floods from Grímsvötn, Katla and Eyjafjallajökull volcanoes as well as floods from the Skaftárkatlar ice cauldrons are also known (Fig. 2) and recent volcanic eruptions at Hekla, Eyjafjallajökull and Grímsvötn have been generous sources of volcanic tremor.

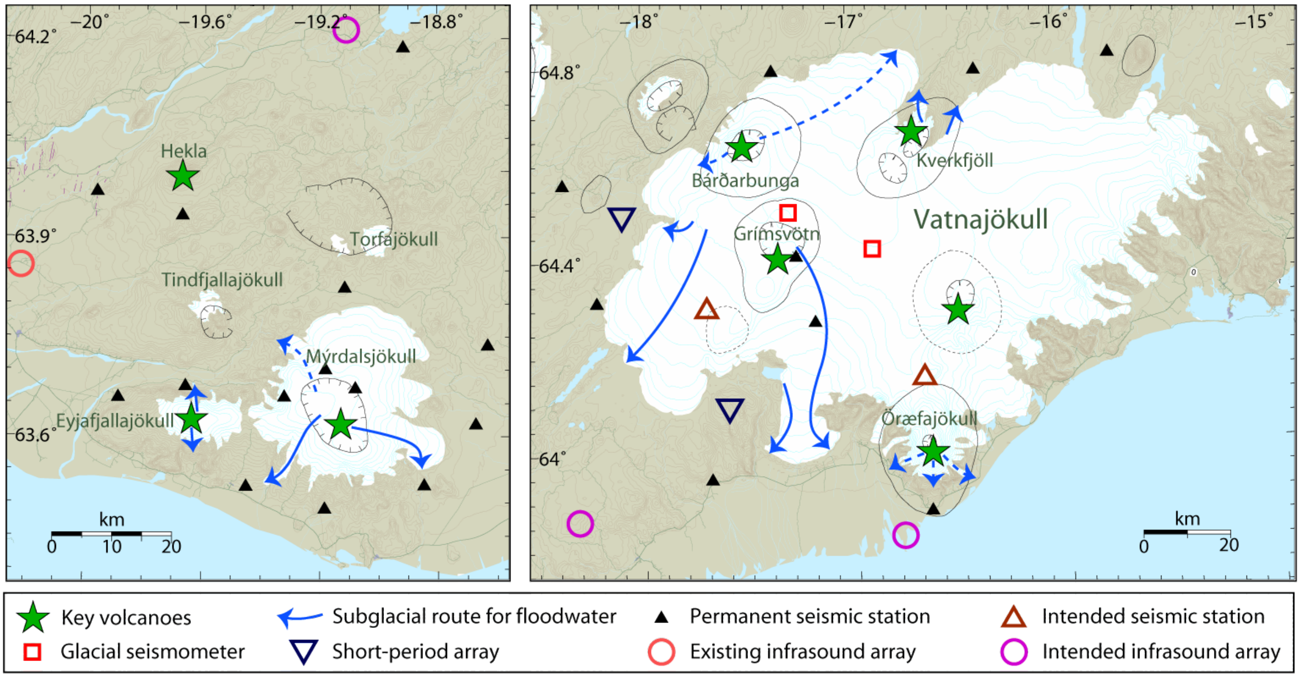

Figure. 1.2 Left: Locations of the volcanoes Eyjafjallajökull, Hekla, and Katla (beneath Mýrdalsjökull) in southern Iceland. Right: Map of the Vatnajökull ice-cap in southeast Iceland. Existing and planned monitoring sites are shown on the maps, including the routing of floodwater from several known subglacial sources.

Volcanic volatiles dissolved in glacial rivers, sourced from the volcanes are presently inadequatley monitored and their potential for advance warning of increased volcanic activity will be examined in the project. The chemical analysis work of glacier waters will focus on Katla volcano in the Mýrdalsjökull glacier, taking advantage of, and adding to, the existing river monitoring networks at Mýrdalsjökull, currently monitoring temperature and electrical conductivity in addition to the river stage. Increased activity and repeated floods from Katla since 2011 make this volcano a good site for testing the new observation- and analysis systems of river water.

The infrasound work makes use of partner UNIFI's (University of Florence, Italy) current 4-channel infrasound array near Hekla, Eyjafjallajökull and Katla volcanoes, with the addition of three similar arrays installed in other locations under WP7 by partner UNIFI. The borehole strain network is focused near Hekla volcano, with the most recent installation in 2010, 5 km from the volcano. An additional installation, through collaboration with CIW and the BGS (British Gelogical Survey) is planned near Katla in 2012. The strain analysis will therefore be focused on Hekla and possibly Katla volcanoes. Real-time data from the existing tilt meter operated on the caldera rim of Grímsvötn and an additional tilt meter to be installed at Hekla in 2012 will be utilized in processes developed for these two volcanoes. The GPS network monitors volcanoes, like Hekla with high resolution, while the ice covered volcanoes are less well monitored at present. Efforts will go towards installing GPS instruments on rock outcrops in the Vatnajökull glacier to improve resolution there also. Real-time data from an existing tilt meter operated on the caldera rim of Grímsvötn and an additional tilt meter to be installed at Hekla in 2012 will, together with the high-rate GPS data enable near-real time processing and analysis of geodetic data, to be incorporated with other monitoring systems utilized and developed.

Subglacial eruptions and events

Floods caused by geothermal and volcanic activity is the most frequent volcanic hazard in Iceland and large subglacial eruptions can cause catastrophic floods. Over 50% of all eruptions in Iceland occur within glaciers and start off as subglacial. However, determining the onset of subglacial eruptions presents very significant challenges. Onset detection is exclusively dependent on geophysical signals, which, currently, are not fully understood. Past Icelandic eruptions demonstrate that there are strong seismic signals associated with volcano driven subglacial processes, but at present it is problematic to unequivocally distinguish between volcanic signals at the magma/lava interface, and those associated with flowing melt water or boiling. Hence the challenge is to distinguish between magma/lava movement, boiling hydrothermal systems, water flow and moving ice.

Subaerial eruptions

Even if volcanoes are not covered by glaciers, bad weather (blizzards, dense clouds) can mean that, visually, weak eruptions may go undetected for a few hours emphasising the need for real time detection of changes in geophysical parameters. Even when such changes are detected the exact location of an eruption and length of eruptive vent/fissure may not be known. Onset of open-vent eruption can be detected by infrasound observations. The presence of infrasound arrays in Iceland, strengthens the possibility of instrumentally detecting eruption onset, when visual observations are prevented.

Determination and evolution of eruption source parameters

Recent eruptions in Iceland (Eyjafjallajökull 2010, Grímsvötn 2011; Figure 1.3) and in South America (Chaiten 2008, Puyehue 2011) demonstrated the large impact that explosive, ash-producing eruptions can have on aviation, even though none of these events can be classified as major. Eyjafjallajökull 2010 caused unprecedented disruption to global air traffic while the ash from Puyehue circumvented the globe disrupting aviation in Australia and New Zealand, after travelling across the South Atlantic and Indian Oceans (Smithsonian, 2011). To make forecasts, sophisticated atmospheric dispersion models such as the NAME model of the UK Met Office are applied. However, the accuracy of the dispersal predictions depends critically on the model input. The most important and critical input is the mass eruption rate (the source term). Determination of this term is highly uncertain, and an estimate is usually obtained from a simple nonlinear empirically-derived power law relating the plume height with eruption rate. Other meteorological factors that may influence the plume are usually not taken into account although theories exist describing the effects of wind on plume height. More accurate methods for determining the mass eruption rate in order to make further improvements in the prediction capability of VAACs possible are a priority.

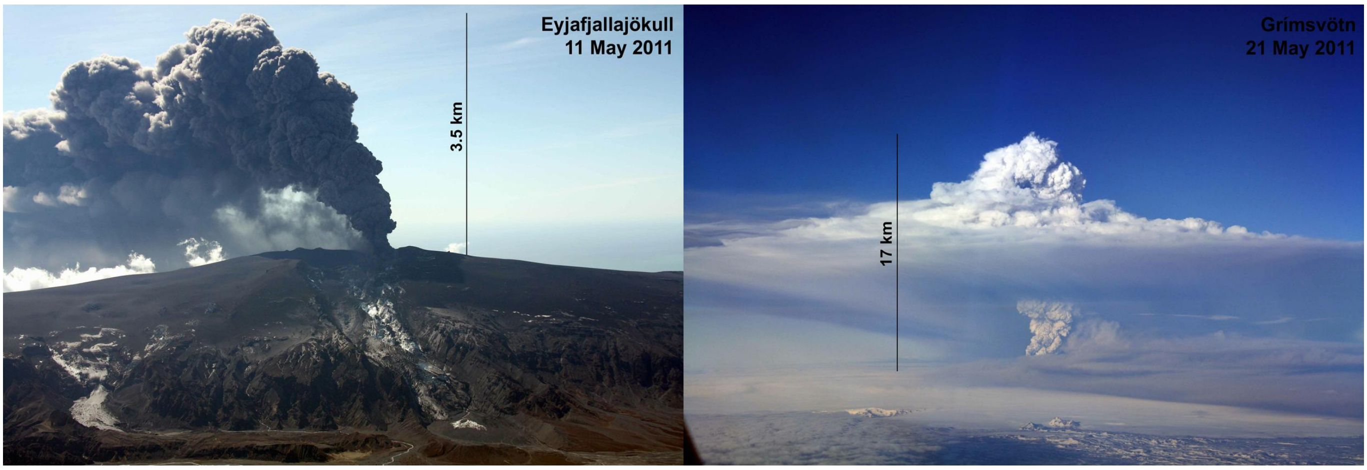

Figure 3. The eruption plumes of Eyjafjallajökull in 2010 (left) and Grímsvötn 2011. The difference in magnitute is apparent from the much larger dimensions of the Grímsvötn eruption.

It is the aim of FUTUREVOLC to address the issue of improving the estimates of the mass eruption rate in explosive eruptions in a decisive way through a multi-parameter approach. To achieve this, a variety of sensors will be implemented and combine into a unique system that estimates mass flow rate from a volcano in near real time to real time. One of the two largest work packages of the project is dedicated to this problem (workpackage 7; WP7). Emphasis will be on real time sensors (an array of radars, lightning detection systems, infrasound, optical cameras, electrical field sensors, tephra samplers, gas analyser systems) and their pre-eruption calibration, since the eruption source parameters can be highly variable with time, with significant changes occurring at time scales of minutes to hours. It is expected real time estimates of mass eruption rate can be achieved in all cases of significant explosive eruptions, which would account for 80% of all eruptions in Iceland, and near real time estimates of fully subglacial or effusive eruptions. A mobile laboratory will be taken out into the field in the event of an eruption to analyse the chemistry of the erupting magma and characterize grain sizes. The system to be developed will be a major advancement in the science of explosive volcanism requiring a wide range of expertise. Efforts from 15 of the partners of the consortium are required, including three SMEs, the development of new equipment and the merging of the various data into a unique single system. This new system will lead to more accurate input into atmospheric dispersion models, benefitting both local populations and risk assessment for aviation on a regional scale. The work on the mass eruption rate in WP7 is used as key input for the dispersal studies in WP8.

Transport of volcanic emissions

The emissions from volcanoes include gases, aerosol and silicate particles. Airborne aerosol injected into the atmosphere pose hazards to aviation. The ocean productivity may increase due to iron supplied by ash fallout. The increase ocean productivity may lead to a reduction of atmospheric carbon dioxide. Once into the stratosphere the volcanic aerosol impacts atmospheric chemical cycles and the solar and terrestrial radiation budgets, and thus influences the climate.

Winds can transport the ash and gases from eruptions rapidly and in multiple directions depending on the wind speed. Within the jet stream, wind speeds may easily reach 100 ms^{-1} (360 km hr^{-1}) so that transport over long distances in a few hours is possible. The long-range influence of volcanic clouds requires a global observational perspective that can only be achieved by space-based (satellite) measurements. The Meteosat Second Generation Spin Enhanced Visible and Infrared Imager (MSG-SEVIRI) allows ash to be detected and followed day and night at 15 min. temporal resolution. During the recent Eyjafjallajökull eruption the combination of satellite data and a Langrangian transport model by an inversion scheme allowed the determination of time- and height-resolved volcanic ash emissions. However, an urgent need for measurements of the time-varying vertical source strength has been identified. This may be achieved by near-field measurement of ash and gas concentrations utilizing multi-spectral IR cameras allowing the retrieval of ash particle size, mass and optical depth.

Ground-based microwave radar systems can have a valuable role in volcanic ash cloud monitoring as evidenced by available radar imagery. These systems represent one of the best methods for real-time and areal monitoring of a volcano eruption, in terms of its intensity and dynamics. The possibility of monitoring 24 hours a day, in all weather conditions, at a fairly high spatial resolution (less than few hundreds of meters) and every few minutes after and during the eruption is the major advantage of using ground-based microwave radar systems. They can provide data for determining the ash volume, total mass and height of eruption clouds. There are still several open issues about microwave weather radar capabilities to detect and quantitatively retrieve ash cloud parameters. A major impairment in the exploitation of microwave weather radars for volcanic eruption monitoring is due to the exclusive use of operational weather radars for clouds and precipitation observation. Several unknowns may also condition the accuracy of radar products, most of them related to microphysical variability of ash clouds due to particle size distribution, shape and dielectric composition. These issues will be addressed in the project (WP7) to enhance the use of radars in ash cloud detection and characterization.

Satellite measurements play a key role in providing continuous measurements of ash mass loadings which in turn may be used to constrain dispersion model forecasts and assist aviation planners. Sophisticated ash retrieval algorithms have been developed but these lack vital validation data that can come from detailed ground-based measurements. In FUTUREVOLC the combination of ground-based measurements with satellite data and dispersion model forecasting will constitute the most powerful tool available for providing advanced warnings to aviation and health authorities about volcanic ash and gas transportation. Further improvement of satellite volcanic ash retrieval algorithms can be achieved by combining dispersion modeling with a state-of-the-art radiative transfer model.

Viewing of a volcano by several multi-spectral IR from several directions will allow the collection of 4-D (3 space and time) data. In combination with new data retrieval methodologies this will provide unique data on the time-varying vertical source strength. During the Eyjafjallajökull event and also in the past, atmospheric transport models have shown substantial skill in calculating ash dispersion. Still there are important open questions that need to be addressed in order to forecast ash dispersion, the resulting atmospheric ash concentrations and the associated uncertainties in the most reliable way. This includes improved knowledge about source emissions, and knowledge about the uncertainties in meteorological data. These issues will be addressed by FUTUREVOLC.

Volcanic degassing

From a gas monitoring perspective, Iceland is one of the least explored volcanic realms on the planet, with very few data on high-temperature magmatic gas emissions having been available until the Eyjafjallajökull eruption in 2010. Even during the Eyjafjallajökull eruption, gas data have only sporadically been taken, and only after the eruption onset; therefore, pre-eruptive degassing features, which may help to constrain modes and rates of magma storage and ascent in the upper crust, are virtually still un-characterised. The recent advent and wide diffusion in the volcanological community of new fully automated in-situ and remote instruments for gas monitoring, which FUTUREVOLC is planned to permanently use in Iceland for the very first time, promise to contribute to a decisive progress in monitoring of magmatic gas compositional features and fluxes over the country.

Trans-border communications and networks

Worldwide the focus of trans-border communications has been focused on the issue of ash. National volcano observatories (eg Iceland Met Office) are required (by ICAO) to update the regional VAAC about the progress of any eruption and in particular the height of the ash plume. The height of the plume is used to assess empirically the eruption rate. In this project we develop this much further and intend the London VAAC to receive much more advanced information and data from the FUTUREVOLC community in close to real-time. For example we plan to supply detailed ash plume height assessments from multiple sources with quantified uncertainty (WP7), we aim to provide this information as a time series to enable the London VAAC to modify their model to account for fluctuations. We aim to provide an assessment of grainsize distribution as rapidly as possible as well as an assessment of likely magma eruption rate and gas content of the plume. The FUTUREVOLC team will rapidly integrate data and information across disciplines to provide the best and most appropriate information in a timely manner. It will not just be the VAAC that receives information, we will develop further the needs of trans-border governments who require close to real-time information on ash composition, leachates and gas flux in order to consider any environmental or health impacts further afield than Iceland. The engagement of scientists from across Europe in FUTUREVOLC and the communications within the team that we envisage also ensures that we promote the IAVCEI protocol (IAVCEI 1999) 'single message' about the volcanic hazard across Europe to the media and on websites. The check lists and best practice that we devise in FUTUREVOLC will in particular concentrate on enhancing the already strong science-Civil Protection links in Iceland and promoting Best Practice in this area across Europe and potentially elsewhere. For example, checklists and Best Practice guidelines may be applicable for future eruptions in Greece where there is currently no experience of managing a volcanic crisis. We will have links with projects working on reducing risk and increasing resilience to volcanic risk worldwide for sharing knowledge in this rapidly expanding field of international communication and cooperation.

Space observations

Interferometric analysis of SAR data (InSAR) is one of the key tools for space-based monitoring of volcanoes. Identification of Iceland as a GEO supersite would be make possible the full integration of space observations with the in-situ measurements described above, and the advances in the state-of-the-art monitoring that the FUTUREVOLC plans to deliver.

FUTUREVOLC Data policy

All FUTUREVOLC partners agree that successful integration of space-based and in-situ data is a timely and important step towards their common goal of improving geohazard monitoring and research. FUTUREVOLC will allow access to large and diverse data volumes, hitherto unprecedented at volcano observatories or at WOVO (http://www.wovo.org/). Data will be provided to the WOVOdat project which is building a database of global monitoring data. Under coordination of the Committee on Earth Observation Satellites (CEOS), nearly all satellite data providers have already established procedures and means for electronic data provision, some of which are included in the FUTUREVOLC e-infrastructure. 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 (similar to GEBCO, the General Bathymetric chart of the Oceans). 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 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.

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.

To ensure reliability of data and to protect the supersite from misuse, The FUTUREVOLC partners will devise specific rules and procedures that must be followed when uploading data to the supersite. Rules and procedures may differ for FUTUREVOLC partners and external users.The partners will develop a plan containing a full list of both the real and near-real time datasets that will be shared at the supersite, how they are produced, data limitations, sharing details, presentation and a release schedule for each dataset before the launch of the project. Both the plan and the schedule will be regularly revised and updated during the lifetime of the project.

The whole point of storing data at the supersite is to share it among registered users. Therefore all datasets will be shared among all registered users immediately after they are stored at the supersite. Otherwise their publication date will be posted at the supersite, citing reasons for delay.

<u>Data hub and management</u>

The aim is to develop a data sharing system where seismic, volcanological, meterological and other data will be stored and made accessible according to the FUTUREVOLC data distribution policy and agreements. To ensure data availability, the data stored at the supersite will be backed up at the IMO and access redundancy secured both locally and internationally.

Notes and confines of full data availability at the data hub:

Data will be stored long-term at the FUTUREVOLC supersite but some data may at some point be subject to compression and/or relocation from its orignal storage point, possibly affecting availability temporarily. The FUTUREVOLC partners will devise and publish a timeplan detailing any datasets subject to such changes.

Other limitations on data availability include:

Excessive storage requirements: Specific long term data, such as data from cameras that record up to 15 GB per minute, are for technical reasons available in full temporal and spatial resolution upon request on hard disk, or de-sampled in near real time at the cost of reproduction.

Qualification and first-publish requirements: Doctoral dissertations and other qualification theses, dependent on first publication of data might lead to conflicts with open data policy, warranting a limited retardation period. Project partners need to request and justify the retardation period, which will be annually reviewed and decided on by the external advisory board.

Quality checks of new data products: The quality of available data products will be clearly indicated on the web interface; i.e. data are available at different quality levels (raw data unverified, verified, manually curated, and analyzed).