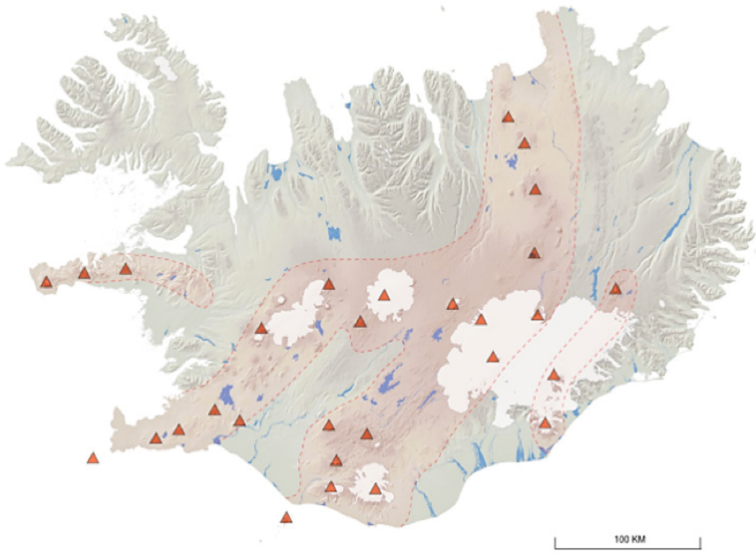
# Exploiting the outcome of FUTUREVOLC

Stakeholder workshop, 5 November 2015,
Hótel Örk, Hveragerði, SW-Iceland

This project is funded
by the European Union

Cover photos:
Top: Bárðarbunga 24th of October 2014, Photo: Þórdís Högnadóttir
Bottom: Eruption in Holuhraun 26th of October 2014, Photo: Ólafur Sigurjónsson

Layout and printing:
Pixel ehf.




Iceland's most active volcanoes marked with a triangle. Map from IMO.

## Why FUTUREVOLC?

On the 15th of April 2010 Europe was thrown into social and economic chaos as its air space was shut down due to volcanic ash in the air, with the closure lasting for several days. Many European businesses and citizens were deeply unhappy, but the cautious approach taken towards the hazard posed by the Eyjafjallajökull eruption demanded no less of a response. Decades of prior work had led scientists and engineers to a certain level of understanding of volcanic ash dispersal and its effects on aircraft engines, but in the white heat of an eruption there was very significant uncertainty about how, in practice, to respond. Since the turn of the century the term 'Earth System Science' had been used to highlight the interconnectivity between the various sub-disciplines in the study of processes involving the solid earth, the oceans and the atmosphere. The eruption in 2010 demonstrated just how important this interconnectivity is in today's technology-dependent society. A process of magma formation and movement that originated deep in the Earth's crust in a small region on an island in the mid-Atlantic lead to the onset of a moderate-sized volcanic eruption. This eruption was nevertheless capable of causing massive disruption right across Europe. The disruption was amplified by the need for a response that minimised the risk – that is, closing most of the air space based on computer models of estimated future ash dispersal. In turn the need for a cautious response was driven by gaps in our understanding of how to integrate the solid earth and atmospheric components on the 'Earth System', in an evolving real time situation. FutureVolc grew from a need for a more holistic approach to volcanic hazard estimation following the lessons from Eyjafjallajökull in 2010.

## Overview of the FUTUREVOLC Project

FutureVolc project is funded by the FP7 Environment Programme of the European Commission and aims to address the topic "Long-term monitoring experiment in geologically active regions of Europe prone to natural hazards: the Supersite concept". The project started 1 October 2012 and has a duration of 3.5 years, with 26 partners from countries representing academic, civil protection and industry groups. The supersite concept implies integration of space and ground based observations for improved monitoring and evaluation of volcanic hazards, and an open data policy. The project is led by University of Iceland together with the Icelandic Meteorological Office.

The main objectives of FutureVolc are to (i) establish an integrated volcanological monitoring system through European collaboration, (ii) develop new methods to evaluate volcanic crises, (iii) increase scientific understanding of magmatic processes and (iv) improve delivery of relevant information to civil protection and authorities. To reach these objectives the project combines broad European expertise in seismology, volcano deformation, volcanic gas and geochemistry, infrasound, eruption monitoring, physical volcanology, satellite studies of plumes, meteorology, ash dispersal forecasting, and civil protection. This European consortium leads the way for multi-national, multi-stakeholder volcanological collaboration with the aim of mitigating the effects of major eruptions at a European level that pose cross-border hazards.

During the project the largest effusive lava eruption in Iceland since 1783 occurred within the Bárðarbunga volcanic system from 31 August 2014 – 27 February 2015. It was preceded by major unrest, including seismic activity and ground deformation related to lateral injection of magma into the crust in a rifting event. A slow subsidence of the Bárðarbunga caldera occurred throughout the eruption, resulting in a caldera collapse of about 2 cubic kilometers. These events have influenced the project, and provided opportunities to test equipment and methods for analysis, derive new scientific understanding and improve our communication systems.

Fissure eruption within the Bárðarbunga volcanic system (2014-2015). Photo: Þórdís Högnadóttir.



## 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 World Organization of Volcano Observatories (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 FV 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 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 FV consortium.

FV 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 FV 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 FV will provide the in situ data.

The objectives of the FV data policy can be viewed in more detail at:

http://futurevolc.hi.is/data-policy

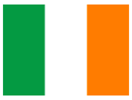
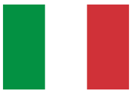
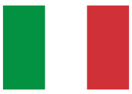
## Project structure

The FutureVolc project consists of ten work packages (WP) in total. The management of the whole project is provided through WP1, which oversees all aspects, receives feedback from all project components and facilitates appropriate progress of individual components and effective interaction between all work packages.

Five work packages (WPs 2, 3, 4, 9 and 10) interact strongly with all other packages:

- WP4 summarizes and provides the known eruptive behavior of volcanoes and thus provides the vital ground data for WP5 and subsequent WPs.
- WP2 is central to the project, dealing with the database development. In order to facilitate near-real time response and joint interpretation – data sharing is essential and needed from all WPs – a strong interaction is required between all of them.
- WP3 has an important role of providing communication and support for risk management across Europe. It ensures that all WPs combine to give effective warnings, and facilitates preparedness and response. It therefore ties in with and influences what is done in all subsequent WPs, drawing on the resources of WP2.
- WP9 receives input from all WPs through its demonstration of results and systems developed. It forms the basis for dissemination.
- WP10 coordinates dissemination and communication activities ensuring greater impact of the project results to all stakeholders

The bulk of the earth and atmospheric science work occurs in WP5 – WP8. Information from WP4 influences how volcanoes are monitored and how we search for evidence for long-term magma movements, leading to WP5. The output of long-term research and monitoring provided in WP5 influences how we monitor immediate pre-eruptive activity addressed in WP6. The output from WP6, on imminent eruptions provides the vital data that alerts and activates the multiple sensors applied in WP7 to evaluate the mass eruption rate in volcanic eruptions. For explosive eruptions, WP7 also provides as fast as possible further data of major importance for WP8 on magma composition and grain sizes, where it is used to assess the distribution of eruptive products.

| Institution | Nationality | Short description | Type |
|---|---|---|---|
| |  | Institute of Earth Sciences (IES), University of Iceland. Lead Scientist - Freysteinn Sigmundsson | Research institute |
| Icelandic Met Office |  | Icelandic Meteorological Office (IMO). Lead Scientist - Kristín S. Vogfjörd | Monitoring and research institute |
| UCD DUBLIN |  | University College Dublin National University Of Ireland, Dublin (NUID/UCD). Lead Scientist - Chris Bean | University |
| |  | University of Florence (UNIFI), Department of Earth Science. Lead Scientist - Maurizio Ripepe | University |
| BGS 1835 |  | British Geological Survey; Natural Environment Research Council (NERC/BGS). Lead Scientist - Susan Clare Loughlin | Research institute |
| UNIVERSITY OF LEEDS |  | University of Leeds School of Earth and Environment. Lead Scientist - Andy Hooper | University |
| CETEMPS |  | Centre of Excellence of the University of L'Aquila (CETEMPS) Lead Scientist - Frank S. Marzano | Research institute |
| CHALMERS UNIVERSITY OF TECHNOLOGY |  | Chalmers University of Technology (Chalmers) Department of Earth and Space Sciences Lead Scientist - Bo Galle | University |
| PHYSIKALISCH VULKANOLOGISCHES LABOR Universität Würzburg Germany |  | Physikalisch Vulkanologisches Labor, Universität Würzburg (UNI WUE), Institut für Geographie und Geologie Lead Scientist - Bernd Zimanowski | University and Research institute |

| Institution | Nationality | Short description | Type |
|---|---|---|---|
| NILU | | NILU-Norwegian Institute for Air Research (NILU)<br>Department for Atmospheric and Climate Research<br>Lead Scientist - Arve Kylling | Research institute |
| Ríkislögreglustjórinn Almannavarnadeild | | The Ministry of Interior, Iceland (NCIP)<br>National Commissioner of the Icelandic Police<br>Department of Civil Protection and Emergency Management<br>Lead Scientist - Víðir Reynisson | Civil Protection |
| University of Cambridge | | University of Cambridge (Cambridge)<br>Department of Earth Sciences<br>Lead Scientist - Robert S. White | University |
| GFZ Helmholtz Centre Potsdam | | Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum (GFZ)<br>Lead Scientist - Thomas R. Walter | National research centre |
| Uppsala Universitet | | Uppsala University (UU), Institute of Earth Sciences, Uppsala University<br>Lead Scientist - Ólafur Guðmundsson | University |
| Met Office | | UK Met Office (Met Office)<br>Lead Scientist - Claire Witham | Monitoring and research institution |
| Université de Genève | | University of Geneva (UNIGE), Unit of Geological Risk and Volcanology<br>Lead Scientist - Costanza Bonadonna | University |
| University of Bristol | | University of Bristol (UNIVBRIS), School of Earth Sciences<br>Lead Scientist - Jeremy Phillips | University |
| Universitatis Studiorum Panormitanae | | Università degli Studi Palermo (UNIPA), Dipartimento DiSTeM<br>Lead Scientist - Alessandro Aiuppa | University |

| Institution | Nationality | Short description | Type |
|---|---|---|---|
| NICARNICA | | Nicarnica Aviation<br>Lead Scientist - Fred Prata | SME |
| HIMET | | HIMET (HIMET), High Innovation in Meteorology and Environmental Technology<br>Lead Scientist - Errico Picciotti | SME |
| GURALP SYSTEMS | | Güralp Systems Limited (Güralp)<br>Lead Scientist - Cansun Güralp | SME |
| MIRACLE | | Miracle (Miracle)<br>Lead Scientist - Gunnar Bjarnason | SME |
| iTem .srl | | Item s.r.l. (iTEM)<br>Lead Scientist - Emanuele Marchetti | SME |
| UNIVERSITE BLAISE PASCAL CLERMONT-FERRAND UBP | | Blaise Pascal University, Clermont-Ferrand, France (Clermont), Laboratoire Magmas et Volcans<br>Lead Scientist - Olgeir Sigmarsson | University research institute |
| DLR | | German Aerospace Center - Deutsches Zentrum für Luft- und Raumfahrt (DLR), Remote Sensing Technology Institute (IMF)<br>Lead Scientist - Michael Eineder | Research institute |
| SAMSÝN | | SAMSYN<br>Lead Scientist - Kristinn Gudmundsson | SME |

The project is led by University of Iceland together with the Icelandic Meteorological Office. The Coordinator of the project is Dr Freysteinn Sigmundsson (UI). He is assisted in the day-to-day running of the project by a Project Manager Hrafnhildur Valdimarsdóttir (IMO), Financial Manager Sigurður Guðnason (UI) and the Management Team. The Management Team supports the Coordinator Consortium, Steering Group, General Assembly and Scientific Advisory Board and comprises expertise from UI, IMO & UCD.

The management team comprises of the following individuals:

Dr Aoife Braiden (UCD)
Dr Freysteinn Sigmundsson (UI)
Dr Kristín S. Vogfjörð (IMO)
Dr Magnús Tumi Guðmundsson (UI)
Dr Stéphanie Dumont (UI)
Hrafnhildur Valdimarsdóttir Legal Advisor (IMO)

An external, international expert Scientific Advisory Board (SAB) provides advice on the scientific and technological developments and in relation to n best practice/industry standards.

The Scientific Advisory Board comprises of the following individuals:

Dr Chris Newhall (Nanyang Technological University)
Dr Jean-Robert Grasso (Université Joseph Fourier)
Dr Charles Meertens (UNAVCO)

The Steering Group (SG) is the supervisory body for the execution of the project and has an overall responsibility for the scientific strategy and direction.



SG comprises of five persons from within the project. They are as follows:

Dr Fred Prata (NILU)
Dr Freysteinn Sigmundsson (UI)
Dr Kristín S. Vogfjörð (IMO)
Dr Maurizio Ripepe (UNIFI)
Dr Susan Clare Loughlin (BGS)

The General Assembly is the ultimate decision-making body of the Consortium and comprises each partner organisation. It meets at least once per year at project meetings.

Work package leaders are responsible for management of the respective Work Package, they are listed below:

| WP no | WP´s title | WP´s leader | Gender | Country | Partner |
|---|---|---|---|---|---|
| 1 | Project management and coordination | Freysteinn Sigmundsson | Male | Iceland | UI |
| 2 | Database development and programming | Ingvar Kristinsson | Male | Iceland | IMO |
| 3 | Impact and supporting risk management | Sue Loughlin | Female | UK | BGS |

| WP no | WP´s title | WP´s leader | Gender | Country | Partner |
|---|---|---|---|---|---|
| 4 | Evaluation of known Eruption Source Parameters | Evgenia Ilyinskaya | Female | Iceland | IMO |
| 5 | Long term magma tracking | Andy Hooper | Male | UK | UNIV LEEDS |
| 6 | Imminent eruptive activity, eruption onset and early warning | Kristín Vogfjörð | Female | Iceland | IMO |
| 7 | Determination and evolution of eruption source parameters | Magnús Tumi Guðmundsson | Male | Iceland | UI |
| 8 | Distribution and description of eruptive products | Arve Kylling | Male | Norway | NILU |
| 9 | Demonstration | Claire Witham | Female | UK | Met Office |
| 10 | Dissemination, outreach and exploitation of results | Aoife Braiden | Female | Ireland | UCD |



# WP1- Project management and coordination

## Objectives

The objectives of WP1 are to:

- Ensure efficient and effective management of the project to ensure all milestones and deliverables are met within the proposed timescale
- Ensure that the necessary resources are made available to carry out the aims and objectives of the project, and
- To coordinate communications internally within the consortium, between the consortium and European Commission and externally to stakeholders

## Description

The management of the project has been carried out by a team from University of Iceland (UI), Icelandic Meteorological Office (IMO) and University College Dublin. The coordinator is at UI, the lead project manager is based at IMO resulting in a successful close collaboration between the two institutes. The project is governed by a Steering Group, and a committee of Work Package leaders. Several IT resources have been utilized for the project management, most importantly the Basecamp project management software.

## Results/products

The management team has organized meetings, kept the FUTUREVOLC community updated, followed and recorded the project progress and ensured the delivery of the milestone and deliverable reports. FUTUREVOLC partners have used the FUTUREVOLC website, but also the social media, to communicate their main actions and results, in particular during the Bárðarbunga unrest and Holuhraun eruption which lasted over 6 months.

The FutureVolc consortium. Photo: Þórdís Högnadóttir.

## WP2: Database development and programming

### Objectives

The main objective of WP2 is to create a database system that fulfils the FutureVolc data policy, where different stakeholders can have access to, and are able to download, historical data, near real time data, and processed data related to Icelandic volcanoes in a standardised formats. Designated users will be able to share their data and scientific studies through the database system.

### Description

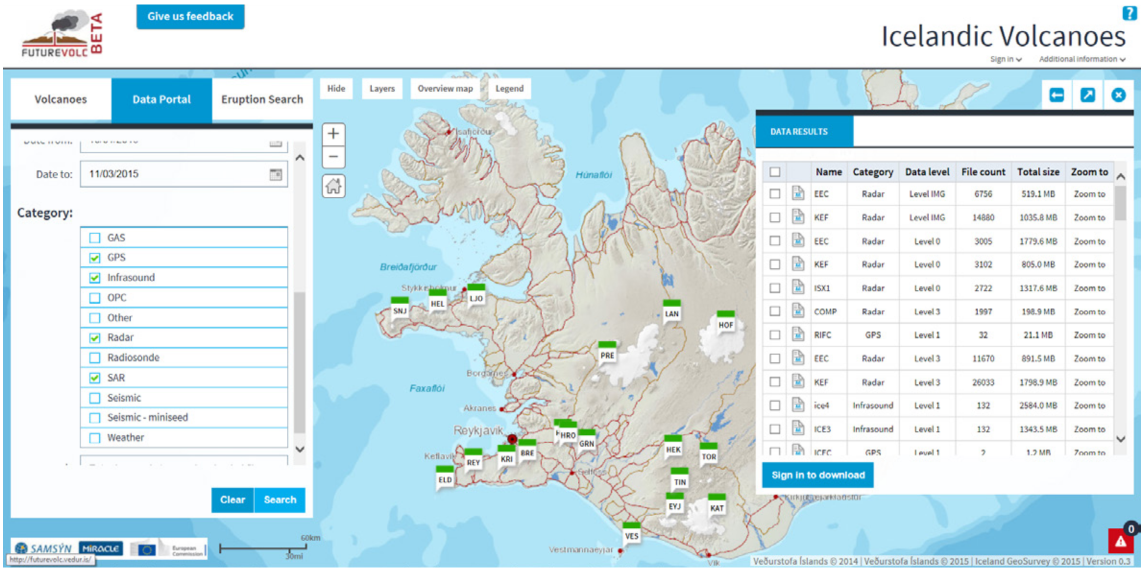
The International Volcanic Ash Task Force (IVATF), which was established by the ICAO (International Civil Aviation Organisation) in close coordination with the WMO (World Meteorological Organisation), encouraged organisations to improve the availability of, and access to, airborne volcanic ash detection data. This includes historical eruption data from Icelandic volcanoes, data from operational institutes, scientific institutes and universities. WP2 is addressing this request by establishing a bespoke web-portal for Icelandic volcanoes, which includes catalogue information and a data hub. Disseminating observation data, processed data and analyses made by experts related to Icelandic volcanoes to airliners, operational centres, research institutes, universities, civil protections etc. in an understandable form is a challenging task, whether it is during a period of volcanic unrest or quiescence. In response to this challenge partners involved in WP2 developed the Icelandic Volcanoes data-hub and catalogue web-portal which is now open in its first release version.

The work in WP2 was carried out in three main tasks. It started with requirement analysis where FutureVolc partners were requested to define their data and comment on defined use case scenarios. Based on this, the FutureVolc data sharing system was designed and developed in parallel to enable more interaction with users and obtain their input in the process. This made it easier for users to understand the expected output, and to comment and advice on the development of the FutureVolc system during its initial stages.

### Results/Products

The FutureVolc system comprises four main components: (i) user interface (website GIS based), (ii) databases storing mostly metadata and system configurations, (iii) shared domain data mostly stored within IMO file systems or databases and (iv) a service layer integrating the other components.

The final deliverable of WP2 is a web-portal for Icelandic Volcanoes. Scientific users will be able to download data and approved users can upload their data, information regarding studies and analyses. Operational users, such as airliners and civil protection, will be able to find information about the Icelandic Volcanoes (WP4) and download data and reports they require for their decision-making processes. At Icelandic Volcanoes the users have single point access for near real-time data, processed data and historical data related to Icelandic Volcanoes. The data are easy to find and registered users can




Web-portal displaying search result for data. futurevolc.hi.is

download the data and use according to the terms free of charge. The current address for the web-portal is: futurevolc.vedur.is



# WP3: Communications and supporting risk management

## Objectives

This work package focuses on optimising the interaction and transfer of information between responding scientists, Civil Protection, government departments, regulators, met services, private sector and other stakeholders, with the aim of establishing best practice at a national and international level.

The main objectives are to:

- Establish a framework for effective coordination and communication across Europe before, during and after volcanic unrest/eruption,
- Develop the state-of-the-art in crisis communication between scientists and civil protection agencies during volcanic crises including cross-border affected countries, and
- Establish lessons learned from past eruptions and analyse the risk management process on an on-going basis.

## Description

The eruptions of Eyjafjallajökull in 2010 and Grímsvötn in 2011 and their widespread impacts demonstrated the urgent need for awareness raising and good communication networks across Europe. In 2010, the reporting from Iceland was already excellent and enabled the rapid though adhoc response that followed across Europe. This work package aimed to enhance communications further so that the needs of a variety of different stakeholders in Iceland and across Europe were met.

The main research approach was to use questionnaires and interviews to assess lessons learned from the eruptions in 2010 and 2011, establish the needs of stakeholders, and then to apply new methods/techniques of communication. Subsequently further questionnaires investigated the value

Icelandic Coastguard helicopter and staff with scientists and technicians on November 11th, 2014.
Photo: Magnús Tumi Guðmundsson.



and efficacy of particular approaches and identified what communication methods are most valuable to stakeholders. The final stage is to consult end-users as to the impact of FUTUREVOLC and any outstanding requirements.

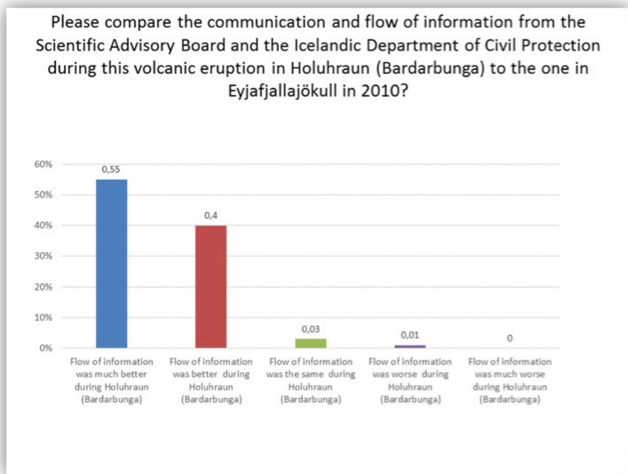
The research has been divided into a series of four tasks:

i. Forensic analysis of the lessons learned in the collection, collation, analysis and transfer of data, and national and international communication from recent Icelandic eruptions. This demonstrated some surprising results such as the lack of awareness about the value of monitoring and early warning for volcanic eruptions. The results enabled a targeted approach in subsequent tasks.

ii. Identification of appropriate response indicators of Icelandic volcanoes, with the aim to improve early warning systems and preparedness. This included establishing a new alert level system for aviation and the development of indicators to help ensure consistent scientific decision-making despite uncertainties.

iii. Improve communication of volcanic risk, which by operational partners has included enhanced reporting, visualisation and communication methodologies. For example, following the Holuhraun eruption, a questionnaire was distributed to the recipients of the Scientific Advisory Board Factsheet. The Factsheet was sent to 774 email addresses (397 in Icelandic and 377 in English). The survey reveals that the total circulation of the Factsheet was about 8000 recipients. Over 90% of responders believe communication and flow of information was either better or much better during Bárðarbunga in 2015 than in Eyjafjallajökull in 2010 and Grímsvötn in 2011.

iv. Consult end-users as to the impact of FutureVolc and any outstanding requirements. This will ensure that any outstanding matters can be taken forward beyond the project.




Communication and flow of information from the Science Advisory Board and the Icelandic Department of Civil Protection in the 2014-2015 Holuhraun eruption and the Eyjafjallajökull 2010 eruption.

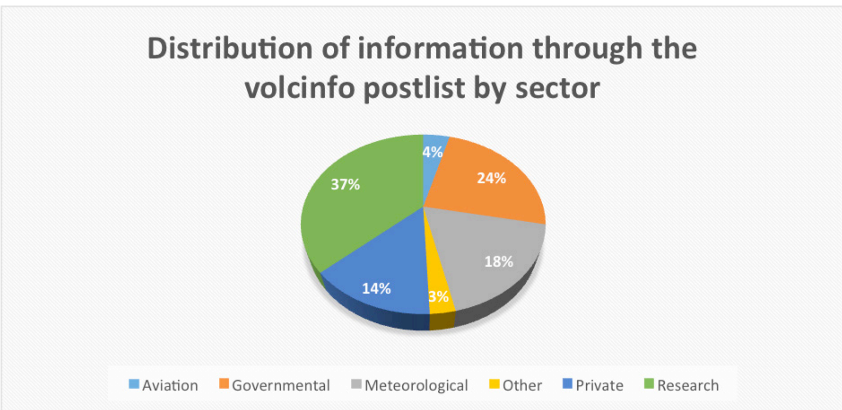
## Results/Products

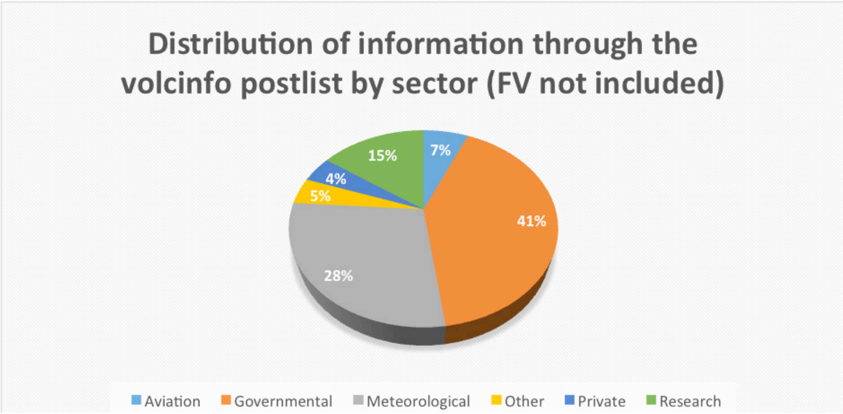
A series of reports has been produced containing 1) an analysis of lessons learned from the Eyjafjallajökull and Grímsvötn eruptions, 2) development of early warning systems, standards of information for EU and scenarios for major events, 3) a best practice report on communication and the next step is 4) a report on the impact of FutureVolc and the feedback of stakeholders. Questionnaire results so far have shown that, without doubt, communications from Icelandic agencies about the status of Icelandic volcanoes have been enhanced over the course of the project, as have communications within and between stakeholders across Europe.

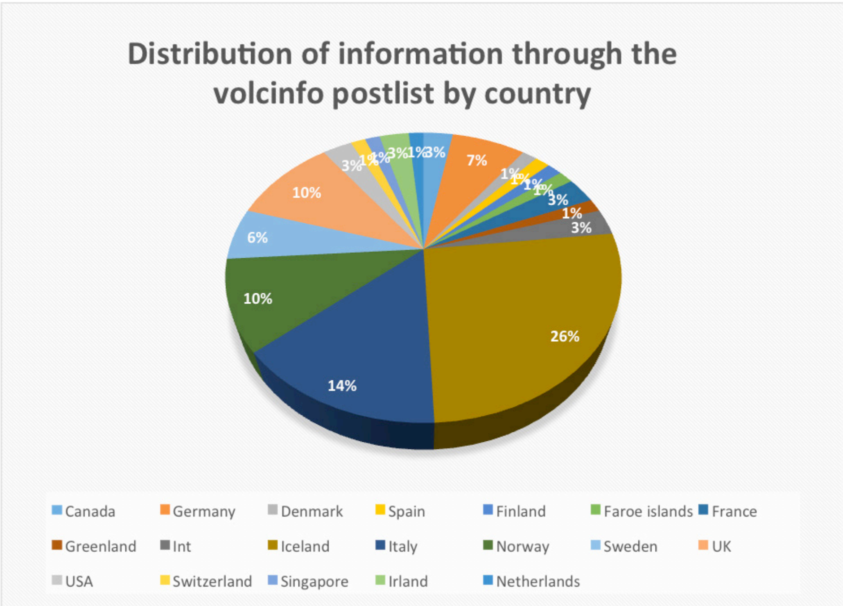
It was originally anticipated that exercises might be needed to test new methods but in fact a series of episodes of unrest and the Holuhraun eruption in 2014-2015 enabled new methods to be applied and tested in real-time, with real data and with existing communication systems.

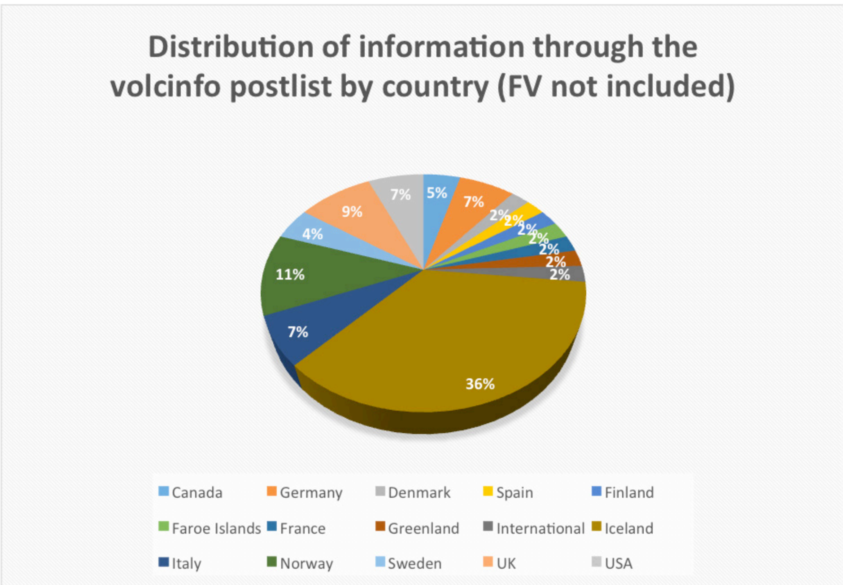
Specific communication tools produced in Iceland and supported by FutureVolc now include:

- An aviation color code system and map supported by rigorous scientific decision-making (Icelandic Meteorological Office) http://en.vedur.is/earthquakes-and-volcanism/volcanic-eruptions/
- The postlist receiving immediate communication regarding any aviation color code has been extended to additional contacts. More countries, institutions and sectors are now included.




Distribution of information through the volcinfo postlist by sector (FV not included)
7%
41%
28%
5%
4%
15%
Aviation
Governmental
Meteorological
Other
Private
Research


Distribution of information through the volcinfo postlist by country
7%
3%
3%
10%
6%
10%
14%
26%
Canada
Germany
Denmark
Spain
Finland
Faroe islands
France
Greenland
Int
Iceland
Italy
Norway
Sweden
UK
USA
Switzerland
Singapore
Irland
Netherlands


Distribution of information through the volcinfo postlist by country (FV not included)
7%
5%
7%
9%
4%
11%
7%
36%
Canada
Germany
Denmark
Spain
Finland
Faroe Islands
France
Greenland
International
Iceland
Italy
Norway
Sweden
UK
USA

- A daily Factsheet during eruptions compiled by the Scientific Advisory Board containing a range of information on status, monitoring, forecasts, recommendations, future scenarios and advice to the public, e.g. (see WP9) http://en.vedur.is/media/jar/Factsheet_Bardarbunga_20141031.pdf
- Weekly status reports to key stakeholders (including ERCC) (Icelandic Meteorological Office)
- Regular, complementary and consistent communications from three Icelandic institutions through a variety of media (e.g. web sites, social media, press) e.g. https://www.facebook.com/Almannavarnir/

# WP4: Evaluation of known eruption source parameters (Catalogue of Icelandic Volcanoes)

## Objectives

The main objective is to compile a catalogue of volcanoes in Iceland, outlining known history of activity, eruption frequency, magnitude and the characteristics of the volcanic products. The catalogue is an official publication (available as an open website) intended to serve as an accurate and up to date source of information about active volcanoes in Iceland and their characteristics.

## Description

Iceland has 32 active volcanic systems that have very varied activity in terms of eruption styles, eruptive environments, eruptive products and their distribution. Extensive research has taken place on Icelandic volcanism, and the results reported in scientific papers and other publications. We have worked on collating the current state of knowledge to create a comprehensive catalogue readily available to decision makers, stakeholders and the general public. Work on the Catalogue has been supported by the International Civil Aviation Organisation and forms a part of an integrated volcanic risk assessment project in Iceland (commenced in 2012), in addition to FutureVolc.



This work package is a collaborative effort between the Icelandic Meteorological Office (the national volcano observatory), the Institute of Earth Sciences at the University of Iceland, and the Icelandic Civil Protection, with contributions from a large number of specialists in Iceland and elsewhere.

## Results/Products

- The Catalogue of Icelandic Volcanoes is accessible at futurevolc.vedur.is (beta version).
- The 32 volcanic systems can be interactively searched and viewed according to their activity level, aviation colour code, most recent eruption year, or simply alphabetically. A volcanic system can be selected either from the list on the left hand side, or by being selected from the map.
- An overview of each volcanic system is given in a summary chapter ("Short Description"), followed by summary tables under "Central Volcano" and "Fissure Swarm". More in depth information is available from the relevant subchapters.
- Eruption source parameters for individual eruptions from the 4 most active volcanic systems (Bárðarbunga, Grímsvötn, Hekla and Katla which account for >80% of eruptions) can be accessed using the "Eruption Search" option. The search results are also downloadable.
- Detailed and interactive maps, including Holocene lava flows and tephra layers can be accessed under "Map layers". Information about tephra grain size for selected eruptions can also be viewed on the maps and downloaded.

Online Catalogue of Icelandic Volcanoes.

- New live webtool has been developed to help assess and understand the current level of activity ("Activity status"). The recent number of seismic events ('recent' being defined as either one day, one week, one month or one year) is compared with the 'background' (mean value 1991-2013). The seismic data used by this webtool is accessed directly from the IMO database.



# WP5: Long term magma tracking

## Objectives

The objectives of this WP are to:

- Track subsurface magma movements with high spatial and temporal resolution, with a focus on the most active volcanoes in Iceland,
- Quantify volatile emissions from volcanic systems, in order to verify models of magma source depth, migration, differentiation and interaction with hydrothermal systems, and
- Develop an integrated system that can be rolled out to volcanoes worldwide, for monitoring and tracking subsurface magma movements.

## Description

To achieve the overall objective of an integrated volcanological monitoring system, the movement of magma needs to be tracked while still in the ground. Before the project began, this was achieved in Iceland primarily through networks monitoring surface deformation and seismicity. There were also hydrological monitoring systems on rivers around Mýrdalsjökull and Vatnajökull, which measure basic properties of river water, such as temperature and electrical conductivity, but there were no permanent measurements of gas emissions. Automatic processing systems were in place for most, but not all, of the data being collected.

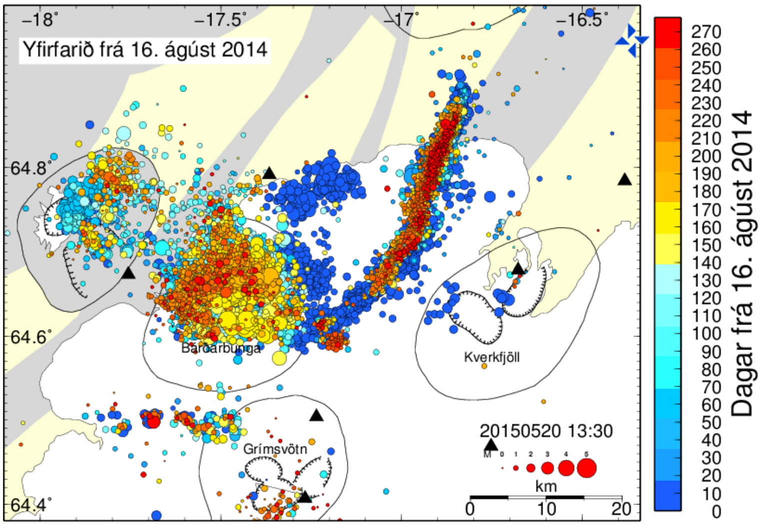
Specific aims of this WP were therefore to:

- Fill in data gaps by installing new monitoring instrumentation and systems,

- Develop near real-time processing software for data that are currently processed offline,
- Develop algorithms to automatically constrain models of magma movement using various combinations of data, and
- Carry out short-term studies to better constrain the accuracy of these models.

## Results/Products

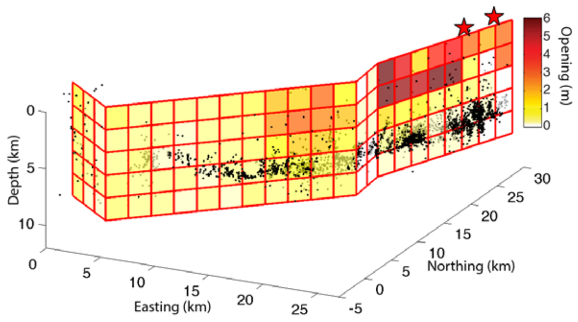
Eight new, temporary broadband seismic stations have been installed around Vatnajökull and three new, permanent GPS stations. In addition two permanent, broadband seismic stations were installed on rock outcrops inside the glacier and two sites with new glacial seismometers were developed and deployed on the Vatnajökull ice cap itself. The constraints provided by the additional data recorded by the glacier sites, as well as other rapid installations in and around the glacier during the 2014-2015 unrest and eruption in the Bárðarbunga volcanic system were crucial in the mapping of seismicity and therefore constraining the associated dyke intrusion in space and time. During and after the Bárðarbunga unrest, 16 new GPS sites where installed. These sites played a major role in constraining the deformation field of the dyke intrusion and the subsidence of the Bárðarbunga caldera, thus enabling the modelling of the magma migration and volume change. This monitoring has continued during the post eruptive period where the main focus has been to monitor possible re-inflation of Bárðarbunga.




Tracking of magma during dyke intrusion. Data indicates earthquakes recorded over 270 days from August.

For gas monitoring, two scanning UV-instruments and one MultiGas instrument have been installed. MultiGAS measurements of the concentrations of potentially toxic gases released from the subglacial flood at Sólheimajökull outlet glacier during the first week of July 2014 were provided to the Icelandic Civil Protection, and were used to help decide how long access to the affected area close to the river should be restricted.

In terms of new software, an automatic earthquake relative relocation system has been implemented, which proved its worth in mapping progress of magma migration during the Bárðarbunga rifting event. An automatic processing algorithm for InSAR data was also developed, and for the first time it was possible to map deformation associated with a rifting event in near real time using InSAR data in addition to the GPS data. A joint inversion tool was developed to jointly invert the relocated seismicity and deformation data and used to infer the progression of the Bárðarbunga dyke in terms of position, depth distribution and volume change. Once the eruption started at Holuhraun, rapid installation of equipment to measure gas was key for monitoring the local hazard in near real-time, using newly developed software for flexible downloading and evaluation of the Differential Optical Absorption Spectrometry (DOAS) data.




Model of dyke opening for the Bárðarbunga rifting episode, constrained by relocated seismicity (black dots) and deformation data from InSAR and GPS. From Sigmundsson et al. Nature, 2015.

Other data that were collected during the Bárðarbunga unrest include repeated elevation measurements using a combination of satellite SAR data, satellite stereo optical data and airborne radar altimetry data. These data were crucial to monitoring the remarkable slow collapse of the caldera. In addition, thermal signals observed outside the caldera provided evidence of short-lived, minor subglacial eruptions along the pathway of magma migration between Bárðarbunga and Holuhraun, where the eventual flood basalt eruption occurred in August-February. Additional tasks on schedule for the end of the project include constraining 3-D crustal velocity structure and source characterization of volcanic earthquakes.

## WP6: Imminent eruptive activity, eruption onset and early warning



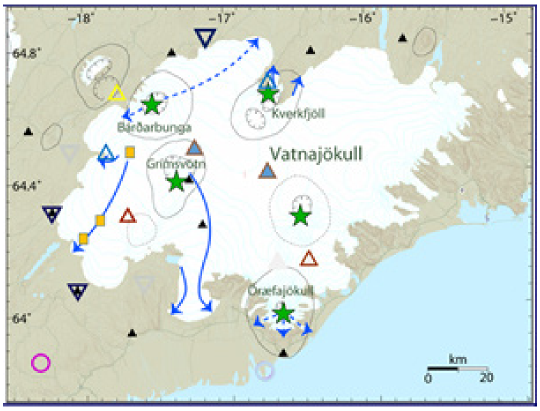
### Objectives

- To identify precursory geophysical and geochemical signals of an imminent eruption and characteristic signals associated with eruption onset.
- To distinguish the characteristics of the different seismic-tremor-generating processes at glacier-covered volcanoes, in order to minimize the number of false eruption alarms.
- To implement real-time, automatic processes for detecting the diagnostic changes in geophysical and acoustic signals signifying magma moving towards the surface.

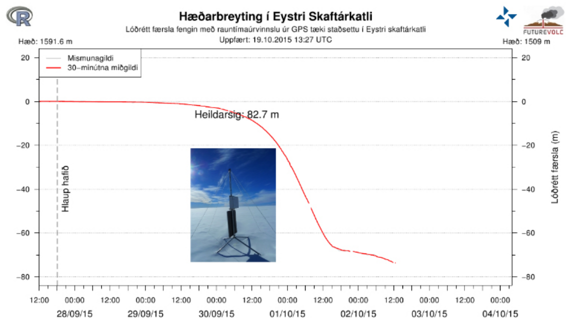
### Description

This work package considers the signals and processes associated with shallow magma migration, once it enters the final pre-eruptive stage with an emphasis on real-time analysis. The primary focus is to strengthen existing real-time monitoring and analysis systems at the Icelandic volcano supersite, incorporating new observations and processing of additional geophysical, geochemical and acoustic signals, to facilitate early warnings of an imminent eruption and detection of the onset of an eruption.

To implement this real-time monitoring for volcanoes in Vatnajökull ice cap, the sensitivity to their seismic signals required improvement. This was achieved through the four new, permanent seismic stations installed inside the glacier under WP5. This WP added two broadband seismic arrays west of the glacier margin to also enabled location and tracking of seismic tremor emanating from inside the glacier, and eventually allowed discrimination between the different tremor sources; volcanic eruption, hydrothermal explosion and subglacial floods (jökulhlaups). The tremor study included installation of three GPS receivers on the ice, two above the flood track from the eastern Skaftá cauldron and one in the cauldron itself. The cauldron installation included real-time data transmission and processing to enable early detection and warning of floods. To understand the composition and source of the seismic tremor, numerical modeling of the seismic wavefield was performed for sources at different depths under the Vatnajökull ice sheet, taking into account bedrock and ice surface topography.




(Left) a map of Vatnajökull glacier, showing volcanoes (stars), tracks of subglacial flood routes (arrows), seismic stations (triangles) and arrays (inverted triangles), as well as GPS stations (squares) monitoring the eastern Skaftá cauldron and its flood route, transmitting the cauldron elevation in real time for processing in near-real time at the supersite data center. (Right) Photo of Skaftárhlaup October 2015. Photo: Benedikt G. Ófeigsson.




(Left) the ~80 m subsidence measured at the Eastern Skaftá cauldron from 27/09 – 02/10 2015. The flood came out of the glacier shortly after midnight on 1 October. The inset shows the installation in the cauldron. (Right) photo of the cauldron from the surface. Photo: Magnús Tumi Guðmundsson.

To study and quantify the volatile emissions from glacier covered volcanoes (where the gases are dissolved in meltwater draining from the volcanoes) technologies were developed to enable continuous monitoring of element fluxes in glacial rivers issuing from the volcanoes, especially during jökulhlaups from subglacial, geothermal and volcanic areas.

## Products/results

The main products from this WP are:

- An electricity-free, cost-efficient, continuously recording geochemical (osmotic) sampler for monitoring element fluxes in floods from subglacial volcanic areas, developed to quantify emissions of volatile gases from volcanoes. The instrument was used to monitor subglacial floods from the two Skaftá cauldrons and the Bárðarbunga 2014 eruption. The methodology and results were published in an international peer reviewed article presenting the instrument construction and analysis of a jökulhlaup from the western Skaftá cauldron in 2014 (Morgan et al., 2015).
- Analysis of shallow microseismicity at Hekla volcano (Eibl et al., 2014). The persistent seismicity along the steepest slope on Hekla's northern flank, and near the summit is likely structurally controlled. It aligns parallel to the eruptive fissure along the summit and the

seismicity rate, and may act as a sensitive pre-eruptive 'stress gauge', possibly enabling earlier warnings (than the current 1-2 hours) for future Hekla eruptions.

- Analysis and identification of helicopter tremor recordings at Hekla volcano and Vatnajökull (Eibl et al., 2015). The distinguishing features of helicopter tremor are identified and described in order to assist the volcano seismologist when interpreting tremor signals in areas with significant helicopter traffic.
- Seismic analysis of a small hydrothermal explosion at Kverkfjöll volcano in 2013, incorporated in a multidisciplinary analysis of the event and submitted for (Montanaro et al., in review 2015). The explosion craters and ejected material were observed on the surface, making the tremor signal a possible calibration for other subglacial hydrothermal explosions, like the ones probably generated by the draining of meltwater from the Eastern Skaftá cauldron in 2015.
- Two 7-element seismic arrays installed outside the western margin of Vatnajökull glacier in 2013 with fully functioning, real-time data processing implemented during the project and a third temporary array installed during the Bárðarbunga 2014-2015 event, near the eruption site. Application of the three arrays to locate the sources of tremor recorded during the eruption, both at the eruption site and under the ice cauldrons, which formed on the ice surface during the first weeks of the unrest. Application of the two initial arrays to monitor and track the sources of tremor during the subglacial flood from the eastern Skaftá cauldron in September/October 2015. Slowness analyses of array signals provide a good indication of Earth surface processes beneath the glacier (as opposed to activity at depth in the geology).
- Numerical simulations of seismic tremor in the ice covered area of Vatnajökull, taking into account the surface topography and ice thickness, in order to model tremor generation by sources related to shallow magma movements and propagation along a glacier-covered path.
- Installation of two GPS receivers on the ice surface above the track of the subglacial floods from the Skaftá cauldrons and one receiver in the eastern Skaftá cauldron itself, transmitting data in real time. Automatic fast-track processing of the data and publishing of the cauldron elevation on IMO's web site. This installation enabled real-time monitoring and issuing of an early warning, two days before the subglacial eastern Skaftá flood emerged from Vatnajökull glacier on 1 October 2015. This early warning enabled farmers, the road authority and tourist managers to implement contingency plans and mitigate potential damage caused by the flood, which was the largest ever recorded Skaftá flood.

## WP7: Determination and evolution of eruption source parameters

### Objectives

The aim of WP7 is to provide systems that use the best available methods to determine the rate of magma flow from volcanic craters during eruptions. Specifically we have set up several instruments around key volcanoes in Iceland and implemented models defining the eruption rate from parameters we can measure. We are currently in the process of completing a multi-parameter system that can provide the eruption rate in near real-time for various types of eruptions.

### Description

The single most important parameter in determining the impact and possible hazards associated with a volcanic eruption is the rate of magma flow out of the crater. For an explosive eruption the eruption rate determines the height and size of the eruption plume, fallout of volcanic tephra, and the amount of ash that can be transported long distances and potentially disrupt air traffic. In a subglacial eruption the meltwater generation is determined by the eruption rate. In an eruption producing lava the eruption rate determines the length of the lava flow, the amount of gas produced and therefore the atmospheric pollution and potential health hazards. It is therefore of major importance to be able to estimate the eruption rate as fast and as accurately as possible. This is primary goal of WP7.

Five main tasks were designed to achieve the objectives of WP7:

i. **Development and implementation of new near-real time source monitoring systems.** This task was a major effort involving the setting up of new sensors around some of the most active volcanoes in Iceland, including Hekla, Katla and Grímsvötn. These sensors included infrasound, automated cameras, electric field sensors, radiosondes, tephra samplers and analysers, gas monitoring systems, radars, lightning detection networks and thermal cameras.

ii. **Field and air observations during volcanic eruptions.** This involved the establishment of a mobile field laboratory and development of protocols for aircraft observations during eruptions.

iii. **Plume model calibration and refinement.** This involved comparing information from recent eruptions in Iceland with simple models that people have used to relate plume height and eruption rate, and building a model that takes into account the effects of wind on volcanic plumes.

iv. **Interpretation and software development.** In this task information from microwaves transmitted and received by weather radars is used to estimate the mass of ash particles in a volcanic plume. In order to devise new ways of estimating the eruption source parameters, software is developed to use infrasound data as fully as possible to detect and analyse signals travelling through the atmosphere from erupting craters. Similar development takes place to analyse digital images from cameras, electric fields generated by eruptions, and study and validate models on tephra fallout of tephra from a plume.

v. **Multi-parameter system** (currently underway). In this task the information from all sensors in task 1 and the models developed in tasks 2-4 is combined to create a unique automated system that estimates the eruption rate of a volcano in near real-time.

Gro M. B. Pedersen and Stephanie Dumont (postdoctoral reserachers from the University of Iceland) collecting infrared images and time lapse video at the lava flow. Photo: Magnús Tumi Guðmundsson.

## Results/Products

The main products of WP7 are the 1) arrays of instruments that now monitor the most active Icelandic volcanoes, listed under task i; 2) the new software and models of volcanic plumes, tephra settling, grain size, interpretation of radar signals and images from cameras; 3) a new instrument to sample and analyze tephra in the field in real time, and 4) the multi-parameter system for very fast estimates of eruption rates during eruptions.

The monitoring systems set up in WP7 are to a large extent aimed at explosive eruptions, although both subglacial and effusive eruptions are also being analyzed. From August 2014 to February 2015 the largest eruption in Iceland in 230 years took place in Holuhraun in central Iceland, accompanied by the slow collapse of the Bárðarbunga caldera. The monitoring of these major events dominated the work relating to eruption monitoring in WP7. The main scientific efforts that have resulted from the work apart from the establishment of the sensor network include:

- Extensive measurements of gas emissions, including that of sulfur dioxide (SO2), took place during the eruption in Holuhraun using FutureVolc sensors. The dispersal of SO2 was also modelled. This required several field campaigns and provided vital information on total gas flux and pollution hazard.
- A major field campaign took place both on ground and from aircraft throughout the six months of the eruption to estimate the magma eruption rate. The extent of lava field was mapped using both airborne and satellite techniques. Thickness measurements for volume estimates were made from the air using aircraft altimetry and on the ground where lava margins were observed. At the time of writing, these methods provide the best estimate of the total volume of lava erupted. A detailed time series of geochemical data was obtained from samples collected throughout the eruption, using a mobile field laboratory established in FutureVolc.
- An experiment for calibration of various ash quantification sensors took place in Würzburg, Germany with participation of many FutureVolc partners. The results are useful for determination of how best to convert observed signals from a sensor to eruption rate.
- Extensive collaborations across WPs within FutureVolc took place during this major eruption in Iceland as it called for the efforts and expertise of many partners. This event involved lateral dyke formation, caldera collapse, formation of a large lava field and minor subglacial volcanic activity. It clearly illustrated the importance of a truly interdisciplinary approach in understanding complicated events.



The gas-rich plume of the eruption north of Vatnajökull in September 2014. Photo: Magnús Tumi Guðmundsson.

# WP8: Distribution and description of eruptive products

## Objectives

The objectives of WP8 are to provide quantitative information about volcanic eruptive products in the near and far-field during and after eruptions, to expand and refine existing methods for detection of eruptive products, and develop new measurement and retrieval methods for these quantities. To reach the objectives WP8 has used ground-based in situ measurements, ground- and satellite-based remote sensing, and radiative transfer and dispersion models.

## Description

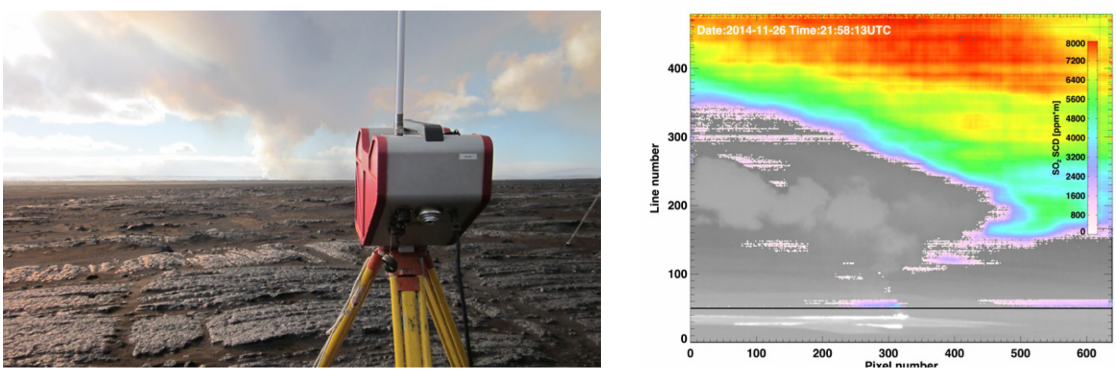
WP8 is divided into four tasks:

i. Satellite and air-borne techniques, which investigate the potential of space-borne microwave radiometry. For selected cases the synergy of satellite-borne microwave data with lightning, radar and dispersion model data is explored. Furthermore, sensitivity studies of ash concentration retrieval algorithms for satellite infrared (IR) measurements are made, the height and paths of eruptive plume features tracked and the time dependent changes in an eruptive cloud quantified through ground-based photogrammetric monitoring.

ii. Ground-based techniques, which includes building three multispectral IR cameras for operation in the Icelandic climate, and putting them into operational work. These cameras may provide cloud height and mass eruption rate. Furthermore, two weatherproof aerosol particle counters have been deployed and methods developed for automatic processing of data on ash suspension and re-suspension, and on volcanic aerosols in the atmospheric boundary layer in the near-field during and after eruptions.

iii. Dispersion model analysis which aims to increase our understanding of the behaviour of dispersion models and their uncertainties, specifically (i) the influence of meteorological data resolution and topographical resolution on model prediction of ash distribution; (ii) the influence of improved observations, as delivered by WP7 and WP8, on model prediction of ash distribution; (iii) the influence of near-vent model outputs from WP7, on model prediction of ash distribution.

iv. Synthesizing near and far-field data of eruptive products. This task utilizes the unique set of measurements and models simulations to construct a comprehensive dataset of the eruptive products in the near and far-fields from the satellite-based data, the ground-based data and the dispersion modelling for specific case studies.

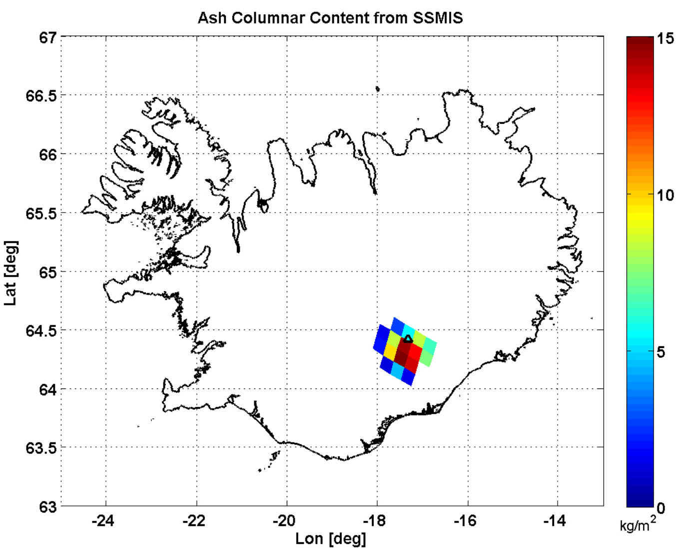



(Left) Infrared imaging camera (nicAIR-II) measuring close to the active lava from at Holuhraun. The camera was able to measure SO2 gas at relatively high frequency (~1 Hz) and estimate mass loadings and emission rates. (Right) Example of an SO2 retrieval from the Holuhrain gas plume. Mass loadings were extremely high (>5000 ppm*m) and in some places saturation occurred.

## Results/Products

The main products and results from WP8 are the instrumentation developed and delivered (optical particle counters (OPC) and infrared (IR) cameras), software developed, peer-reviewed articles and presentations at conferences, and milestone and deliverable reports. Main findings include:

- Space-borne microwave radiometer observations have, due to the sensitivity to the volcanic tephra, the potential to monitor the erupted plume in the proximity of the eruption vent where satellite-based infrared measurements are often saturated.
- An algorithm has been developed that can track identifiable features, and also map the velocity structure throughout the elevation of an eruption cloud. The algorithm was applied to a series of images from the 2010 eruption of Eyjafjallajökull and the results show a highly variable plume driven by intermittent explosions. The results indicate a high degree of spatial and temporal variability within the plume. Both the pulsating nature and fallout from the plume lead to characteristics different from those expected from standard integral plume models.
- Two Optical Particle Counters have been made operational, including an automated data processing tool, remote communication and data streaming to the FutureVolc database. The OPC measures the aerosol size distribution and number concentrations. The OPCs have been in operation at different locations in Iceland, including near the Holuhraun-Bárðarbunga eruption site north of Vatnajökull in 2014-2015.
- Three automated NicAIR II camera systems for the visualization and detection of volcanic ash and SO2 have been designed and built. Each system has a multispectral IR camera, a webcam, GPS and an internal clinometer to enable more accurate retrievals of plume geometry. The systems are housed in a custom-made weatherproof casing and were deployed during the Holuhraun-Bárðarbunga eruption 2014-2015.
- Software has been developed to reconstruct volcanic plume structure from images of mass column densities obtained from IR and ultraviolet (UV) cameras.
- The sensitivity of dispersion model forecasts to the numerical weather prediction model configuration has been investigated. The analyses on the sensitivities of model forecasts have improved our understanding of the behaviour of dispersion models and the uncertainties associated with the forecasts they produce. The best choice of weather prediction model depends on the altitude of the released material (ash or SO2), which is different for explosive and effusive eruptions. Dispersion model forecasts are also highly sensitive to the Particle




Estimated ash columnar content from the Special Sensor Microwave Imager Sounder (SSMIS). Data recorded 08:34 UTC, 21 May 2011, during the Grímsvötn eruption.

Size Distribution. Use of radar data from the 2011 eruption of Grímsvötn show that it cannot be relied upon for accurate height information on ash emission for this eruption. However, the development of new retrieval algorithms as part of the FUTUREVOLC project may help to resolve these uncertainties in future eruptions.

- Microwave model simulations have been performed to investigate the behavior of the observed space-based brightness temperatures and their variance with terrain emissivity, water vapor and ice concentration within the volcanic plume.
- The effect of ash particle shape on IR satellite measurements have been investigated and it was found that the assumption of mass-equivalent spheres for ash mass loading estimates will underestimate ash mass loading compared to morphologically complex inhomogeneous ash particles.

## WP9: Demonstration of futurevolc

### Objectives

The overall objective is to demonstrate to all stakeholders that the FutureVolc supersite is fulfilling the project's objectives and improving on current procedures. This involves testing the end-to-end FutureVolc "system" to ensure that it can be used in operational real-time capacity and showcasing the "system" as a model for future volcano supersites.

### Description



Fundamental to demonstrating that the FutureVolc project is working and having an influence on response activities in Iceland over all timescales is being able to show the "pull through" of new science into operations. What this means in practice for WP9 is:

- Facilitating work to determine how FutureVolc partners will support the Icelandic Met Office (IMO), University of Iceland and Iceland Civil Protection during a volcanic unrest or eruption situation.
- Ensuring that IMO, and the situation response in general, can make the best use of all data from FutureVolc partners and equipment.
- Ensuring FutureVolc partners can discuss multi-disciplinary data in near real time.
- Showcasing the Supersite concept to stakeholders and demonstrating a fully functioning system.

To achieve this, the main components of the work were to run 1-2 exercises during the course of the project and feedback lessons learnt and areas where improvements could be made. The unrest and eruption in the Bárðarbunga volcanic system from August 2014 – February 2015 provided a real-world test for the project from which further developments were identified. Other geothermal and volcanic activity in 2014 and 2015 provided additional demonstration of the impact of FutureVolc.

### Results/Products

In June 2014 an exercise, that considered an eruption at Hekla, was held to test alerting and communications between FutureVolc partners. Pre and post-exercise questionnaires were used to evaluate the exercise and new SMS and email alerts were introduced as a result of identified requirements. In August 2014, these were put to good use at the start of the unrest in the Bárðarbunga volcanic system and allowed partners to react quickly and mobilise data and field equipment. The subsequent eruption at Holuhraun led to a major amount of work for the FutureVolc partners and proved a real test of the consortium. FutureVolc equipment and expertise were vital to the response effort.

Three other events in 2014-2015 also allowed the capabilities introduced by FutureVolc to be tested, for both communications and the use of new monitoring equipment. These were flooding and gas emissions at Mýrdalsjökull in July 2014; a major rockslide within the Askja caldera in July 2014, causing a tsunami in Lake Öskjuvatn; and the Skaftá ice-cauldron jökulhlaup in September-October 2015. Each of these events has been reviewed and the findings show that FutureVolc has had a direct impact on all of the responses through the rapid utilisation of equipment installed both before and during the events.

> *"The early detection of this outburst flood (jökulhlaup) is a resounding success for FUTUREVOLC! We were delighted to be able to issue a three-day advanced warning of the oncoming flood, based on measurement and data-processing techniques developed in WP6. This is a leading example of how FUTUREVOLC has made direct contributions to volcanic monitoring in Iceland".*
>
> *Icelandic Meteorological Office, Hazard Monitoring Section*

Lessons learned from the exercise and real events have led to: the introduction of a FutureVolc blog site for sharing information and multidisciplinary scientific discussion; the implementation of a single email address for dissemination of daily updates from Iceland during events; development of field safety procedures, including purchase of additional equipment and new training/briefing materials; refined processes for centralised fieldwork coordination in Iceland; the ability to easily add new monitoring sites to the FutureVolc data hub. Much of the new monitoring data has been streamed directly to IMO during the course of the project, but in June 2015 the FUTUREVOLC data hub was publicly launched, allowing access to the project's data and the Catalogue of Icelandic Volcanoes.


Screen-shot of the FutureVolc blog site, which was created in the run up to Exercise 1 and has subsequently undergone development and improvement based on feedback.



# WP10: Dissemination, outreach and exploitation of results

## Objectives

The scientific and technological advances made in a project such as FutureVolc are of little impact unless the results are communicated effectively.

WP 10 aimed to:

- Disseminate scientific findings through high impact, peer reviewed publications, conference presentations and conference session organization and promote data sharing policies developed within the network.
- Disseminate scientific results to all stakeholders and improve communications between these groups.

- Promote science within the community, and to encourage future generations of scientists and researchers.
- Ensure researchers are trained to both undertake and develop scientific research and disseminate their work and results with the highest possible impact at all levels.
- Ensure smooth pathways for internal communication within the consortium, which will promote collaboration and lead to an open working environment for all partners beyond the FutureVolc project.

## Description

The focus of WP10 is to disseminate the results and outputs of FutureVolc and to ensure the activities and findings reach the widest possible audience and have the highest impact possible. Communications for FutureVolc has been differentiated into internal and external: internal communications are closely linked to WP1, 3 and 9 and include general interactions between partners. External communications are those that engage communities outside the project itself. The objectives of the WP were developed with a range of target audiences in mind; scientific communities, policy and decision makers and general public; each of these groups has been successfully engaged.

## Results/Products

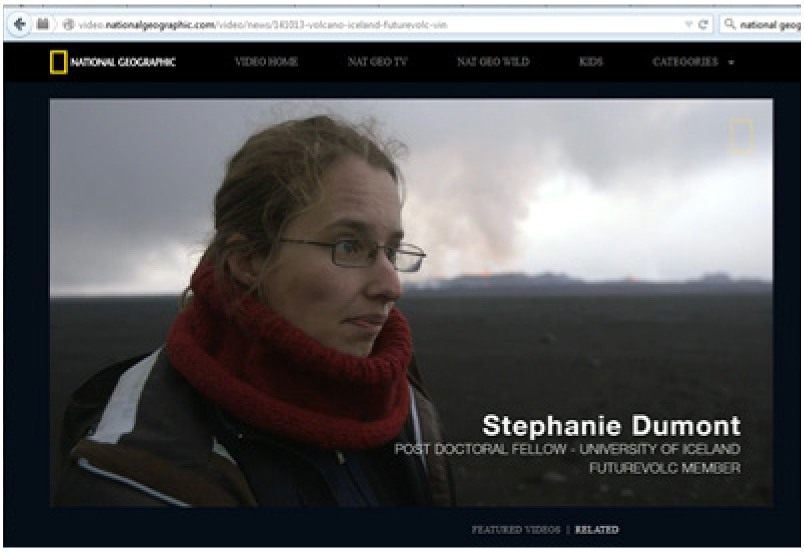
All partners have undertaken dissemination activities. Members of the FutureVolc team have published peer-reviewed scientific articles in high-impact international journals. In addition, team members have presented results at both international conferences and workshop sessions. The workshops have included representatives of relevant stakeholder groups (e.g. policy, volcano observatories, database managers, civil protection etc.) The involvement of these external partners has ensured focus and relevance of FutureVolc research. Beyond the scientific community and direct stakeholders, FutureVolc has made significant efforts to reach a wide, international, public audience. This has included public groups of all ages (e.g. from young school children to older generations) and backgrounds (e.g. farming communities to air travel operators). FutureVolc has also contributed to the professional training of academic researchers, observatory staff and technical support staff. In particular, the experience gained through deployment of equipment before and during the eruption in 2014-2015 has significantly increased the technical ability and problem solving skills of all participants.

Highlights of WP10 include:

- ~260 Public outreach articles or events including;
    - Two articles about the project and volcanoes were published in the Scholastic children's science magazines in USA; Science World and Superscience)
    - An interview and footage shown on the BBC of the team in Iceland carrying out fieldwork http://futurevolc.hi.is/bbc-news-futurevolc
    - A short segment about the FUTUREVOLC project on Euronews including an interview with Freysteinn Sigmundsson, Kristin Vogfjord and footage of the installation of infrasound equipment in Iceland by Maurizio Ripepe and the team from University of Florence http://futurevolc.hi.is/futurevolc-euronews
    - A short film available on the National Geographic website about the FUTUREVOLC project (published October 13th, 2014). http://video.nationalgeographic.com/video/news/141013-volcano-iceland-futurevolc-vin
    - A separate news article featuring FUTUREVOLC was also published on the National Geographic website on October 14th 2014

http://news.nationalgeographic.com/news/2014/10/141013-iceland-volcano-bardarbunga-lavascience/

- You Tube videos by consortium partners about the project including footage of deployment of monitoring equipment
- Numerous local and national interviews during the Bárðarbunga system eruption in 2014
- Regular presentations by members of the consortium to local groups and schools about the project and the scientific work being undertaken




Researcher, Dr Stephanie Dumont of Univeristy of Iceland being interviewed near the eruption site as part of the National Geographic online short film.

http://news.nationalgeographic.com/news/2014/10/141013-iceland-volcano-bardarbunga-lava-science/


Futurevolc video on You Tube https://www.youtube.com/watch?v=dmy_t7h5MwY

The IMO and Icelandic Civil Protection websites were used very effectively during the Bárðarbunga system eruption and were updated every day to inform the public, academic groups and decision makers in Iceland and further afield. This information was used, for example by the UCD group to;

- Plan and safely deploy additional instruments in the area to monitor the eruption
- Complement the seismic data streaming live to the Seismology Laboratory in Dublin
- Provide regular summaries to the Geological Survey of Ireland (the Government representative on the Office for Emergency Planning in Ireland) and
- Provide information to media outlets through informed interviews about the eruption and potential risks to the public and/or commercial interest groups.

Overall outputs from WP10 include;

- Approximately 160 conference presentations including large international meetings such as: American Geophysical Union (San Francisco), European Geoscientists Union (Vienna), International Association of Volcanology and Chemistry of the Earth's Interior (Japan), Cities on Volcanoes conference (Indonesia), Volcanic and Magmatic Studies Group (UK), ESA Fringe (Frascati, Italy), Global Risk Forum (Davos, Switzerland), Buenos Aires Volcanic Ash Advisory Centre and Aerolinas Argentina (Argentina), International Geoscience and Remote Sensing Symposium (Canada), Chemistry of Volcanic Gases (CCVG)/International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) (Chile)
- Approximately 70 stakeholder events including meetings with: Volcanic Ash Advisory Centres, members of the airline industry, World Meteorological Organisation, Salvation Army, Cascades Volcano Observatory USGS, Banff international Research Station, Colombian Geological Survey, Iceland interest groups, Icelandic Rescue Centre and Emergency Response Coordination Centre
- 27 peer reviewed publications (+ 6 further publications in press or in review) including articles published in: Nature, EOS, Annals of Geophysics, Journal of Volcanology and Geothermal Research, Geophysical Research Letters, Journal of Geophysical Research, Procedia Technology, Journal of Geophysics – Solid Earth, Bulletin of Volcanology, Geophysical Journal International, Journal of fluid Mechanics, Geochimica et Cosmochimica Acta, Earth and Planetary Science Letters.
- FutureVolc has also contributed to the professional training of academic researchers, observatory staff and technical support staff. In particular, the experience gained through deployment of equipment before and during the eruption in 2014, and the subsequent data handling, has significantly increased the technical ability and problem solving skills of all participants.

## The future

FutureVolc is now entering its final stages as it will be completed early in 2016. For volcano monitoring in Iceland FutureVolc has had a major impact. The large array of new sensors and systems made a huge difference in early warning capabilities and rapid interpretation of data during the most voluminous eruption for more than 200 years and the first caldera collapse in Iceland in modern times. However, although the gains are large, there is still some way to go. A major effort in FutureVolc has been the installation of sensors and development of methods to monitor and analyse explosive eruptions. Although the systems for explosive events have been installed they have not yet been put to the ultimate test of a real explosive eruption.

The sensor systems are fundamental for the advancement of volcano monitoring. However, the effect of FutureVolc on the participating groups is of no less importance. The project integrated different disciplinary communities and helped to develop a common language and understanding.

It has developed a common database with data from many disciplinary areas which needed to be integrated for effective real time response, in particular to ash laden eruptions. FutureVolc has also pointed the way for multi-disciplinary collaboration and integrated approaches to volcanic crises of the future. This legacy is perhaps FutureVolc's most important contribution to volcano science and risk mitigation.

Þorgils Ingvarsson at work. Photo: Baldur Bergsson futurevolc.vedur.is

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