2nd IUGG-WMO workshop on Ash dispersal forecast and civil aviation

World Meteorological Organization
Geneva, 18-20 November 2013

Program and Book of Abstracts

Photograph courtesy of J. Elíasson.

Document contents

2nd IUGG-WMO workshop on Ash dispersal forecast and civil aviation
World Meteorological Organization, Geneva, Nov. 18-20, 2013
Presentation

Presentation by the Organizing Committee

Dear Workshop participants,

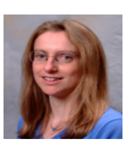
After the 2010 Eyjafjallajökull eruption in Iceland we felt the necessity for the tephra-dispersal community to revise monitoring and forecasting methodologies and provide a more robust and reliable response to the social needs. In particular, we felt the urgency for a new integrated strategy, based on the collaboration amongst the volcanological and meteorological communities and the International Civil Aviation Organization in order to ensure that both the scientific knowledge and aviation safety aspects are considered. The first IUGG-WMO workshop on "Ash dispersal forecast and civil aviation" that took place in Geneva on 18-20 October 2010 promoted stronger interactions between the volcanological and the operational forecasting communities and the resulting outcomes served as a "road-map" for on-going research. After three years, the second IUGG-WMO workshop aims at optimizing the scientific and operational advances since 2010 and will focus on the following specific objectives:

- To review and institutionalize the interaction between meteorological, atmospheric, volcanological, modelling and remote sensing communities.
- To develop strategies for a closer working relationship and further collaboration between the aviation industry and the scientific community.
- To document progress from the first IUGG-WMO workshop.
- To identify best practice modelling strategies to support operational implementation.
- To identify and develop concepts to address current challenges.

We are happy to welcome you to this second IUGG-WMO workshop on "Ash dispersal forecast and civil aviation" and we thank you in advance for your contribution that will help design improved forecasting strategies and build a stronger tephra-dispersal community.

Costanza Bonadonna
University of Geneva
Switzerland

Arnau Folch
Barcelona Supercomputing Center
Spain



Sue Loughlin
British Geological Survey
U.K.

Matthew Hort
London VAAC
U.K.

Peter Webley
University of Alaska Fairbanks
USA

Herbert Puempel
World Meteorological Organization
Switzerland

Acknowledgements

The Organizing Committee would like to thank our sponsors that made this workshop possible, and, in particular, the:

- International Union of Geodesy and Geophysics (IUGG),
- International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI),
- World Meteorological Organization (WMO),
- University of Geneva (Rectorate and Faculty of Science),
- British Geological Survey (BGS),
- UK Met Office.

WORKSHOP PROGRAM

Monday, 18 November 2013 (Room C1, WMO)

08:00-08:30		**Registration and Welcome Coffee**	
08:30-09:00		**Workshop opening ceremony** Representatives from WMO (H. Puempel; WMO; Chief, Aeronautical Meteorology Division), ICAO (G. Brock; ICAO, Meteorology Section), University of Geneva (Ll. Fontboté; Vice Dean of Faculty of Science)	
		Session 1A . Progress since 2010 and ongoing projects (Conveners: A. Folch, H. Puempel)	
09:00-09:15		S. Loughlin (BGS, UK) **Introduction to the session**	
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09:45-10:00	O1.1-03	S. Loughlin (BGS, UK) Summary of volcanology projects since 2010	pg. 14
10:00-10:15	O1.1-04	I. Lisk (WMO, UK) Volcanoes and Aviation - Detection, Prediction and Expectation	pg. 15
10:15-10:30	O1.1-05	R. Clarkson (Rolls Royce, UK) The Impact Volcanic Ash has on Jet Engines - Latest Understanding	pg. 16
10:30-11:00		**Coffee Break**	
11:00-11:15	O1.1-06	L. Clarisse (ULB, Belgium) The Support to Aviation Control Service, an overview and recent developments	pg. 17

11:15-11:30	O1.1-07	A. Haefele (MeteoSwiss, Switzerland) A European network for ground based profiling of wind and aerosols E-PROFILE	pg. 18
11:30-11:45	O1.1-08	F. Prata (NILU, Norway) The Volcanic Ash Strategic initiative Team-VAST: Advanced satellite retrievals of volcanic ash and SO_2	pg. 19
11:45-12:00	O1.1-09	F. Ferrucci (The Open University, Milton Keynes, U.K.) Real-time global volcano monitoring by geostationary and polar orbiting payloads	pg. 20
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12:15-12:30	O1.1-11	S. Mobbs (Leeds University, UK) Observing and Modelling Near- to Far-Field Plume Processes: Update on the VANAHEIM Project	pg. 22
12:30-12:45	O1.1-12	A. Neri (INGV, Italy) The contributions of the EU-funded MEDiterranean SUpersite Volcanoes (MED-SUV) project to the assessment of volcanic ash hazard	pg. 23
12:45-13:00	O1.1-13	M. Gudmundsson (University of Iceland, Iceland) FUTUREVOLC: A European supersite project on an integrated monitoring network for Icelandic eruptions	pg. 24
13:00-14:15		**Lunch (WMO cafeteria)**	
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14:45-15:00	O1.2-02	C. Davis (Wellington VAAC, New Zealand) The eruption of Mt. Tongariro on August 6th 2012: Operational response and dispersion modelling challenges	pg. 26
15:00-15:15	O1.2-03	S. Osores (SMN on behalf of VAAC Buenos Aires, Argentina) The Puyehue-Cordón Caulle re-suspended volcanic ash event	pg. 27

15:15-15:30	O1.2-04	N. Ek (Montreal VAAC, Canada) A Case Study of Atmospheric Transport and Dispersion Sensitivity: Implications for Volcanic Ash Modelling	pg. 28
15:30-15:45	O1.2-05	N. Asencio (Toulouse VAAC, France) MOCAGE Accident description and operational use	pg. 29
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17:15-17:30	O1.2-10	C. Newhall (WOVO) A view from the volcano observatory	pg. 34
17:30-17:45	O1.2-11	P. Webley (AVO, USA) Lessons learned from North Pacific Volcanoes: AVO, KVERT and SVERT	pg. 35
17:45-18:00	O1.2-12	M. Coltelli (INGV, Catania, Italy) The 2011-2013 lava fountains of Mt. Etna forming volcanic ash clouds have represented a test case for observatory operations in support to aviation safety management	pg. 36
18:00-18:15	O1.2-13	S. Karlsdóttir (IMO, Iceland) Monitoring volcanoes in Iceland; an update	pg. 37
18:15-18:30		**Closing of first day of conference**	
18:30-20:30		**Ice breaker/Poster session (ground floor bar area)**	

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Tuesday, 19 November 2013 (Room C1, WMO)

		Session 2A. Characterization of Eruption Source Parameters (Conveners: C. Bonadonna, S. Loughlin)	
08:30-08:45		P. Webley (University of Alaska Fairbanks, USA) **Introduction to the session**	
08:45-09:00	O2.1-01	A. Höskuldsson (University of Iceland, Iceland) FUTUREVOLC real-time tephra sampling: a state-of-the-art mobile laboratory to characterize eruptive dynamics and enhance ash-dispersal forecasting	pg. 38
09:00-09:15	O2.1-02	S. Valade (University of Florence, Italy) Ground-based imaging of volcanic plumes for mass flux	pg. 39
09:15-09:30	O2.1-03	F. Marzano (Roma University, Italy) Remote Sensing of Volcanic Ash Plumes Using Microwave Scanning Weather Radars	pg. 40
09:30-09:45	O2.1-04	L. Mona (CNR Potenza, Italy) Four-dimensional distribution of the 2010 Eyjafjallajökull volcanic cloud over Europe observed by EARLINET	pg. 41
09:45-10:00	O2.1-05	M. Ripepe (University of Florence, Italy) Characterization of eruption source parameters through infrasound	pg. 42
10:00-10:15	O2.1-06	M. Pavolonis (NOAA/NESDIS, USA) Development of a System for Quantitatively Analysing Volcanic Clouds	pg. 43
10:15-10:30	O2.1-07	M. Watson (Bristol University, UK) Detection and quantification of volcanogenic sulphur dioxide using orbital, sub-orbital and ground-based instrumentation	pg. 44
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11:30-11:45	O2.1-10	K. Weber (University of Dusseldorf, Germany) Airborne in-situ measurements in volcanic plumes with light aircraft - examples of research flights during eruptions of Eyjfjallajökull, Grimsvötn, Etna, Stromboli and Sakurajima volcano	pg. 47

11:45-12:00	O2.1-11	R. Meerkötter (DLR, Germany) VolcATS – Volcanic ash impact on the Air Transport System	pg. 48
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12:15-12:30	O2.1-13	Y. Suzuki (Tokyo University, Japan) 3D numerical simulation of volcanic plume dynamics and ash dispersal	pg. 50
12:30-12:45	O2.1-14	C. Connor (USF, USA) Eruption frequency and ESP uncertainty	pg. 51
12:45-13:00	O2.1-15	L. Mastin (USGS, USA) Compilation of a global eruption dataset with source parameters and observations for model validation	pg. 52
13:00-14:15		**Lunch (WMO cafeteria)**	
		Session 2B. Characterization of Eruption Source Parameters	
14:30-16:00		**Break-out sessions** List of groups for break-out sessions will be provided at the meeting	
16:00-16:30		**Coffee Break**	
16:30-18:00		**Plenary discussion** Mediators: Organizing committee	
18:00-18:15		**Closing of second day of conference**	
18:15-19:45		**Poster session (ground floor bar area)**	
20:30		**Meeting dinner at** Restaurant Vieux-Bois 12 Avenue de la Paix 1202 Geneve http://goo.gl/maps/z5s13	

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Wednesday, 20 November 2013 (Room C1, WMO)

		Session 3A. Ash and gas dispersal modelling (Conveners: P. Webley, A. Folch)	
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09:00-09:15	O3.1-01	S. Galmarini (EC/DG -JRC/IES) TANSTAAFL: issues to keep in mind when using multi-model ensembles	pg. 53
09:15-09:30	O3.1-02	A. Stohl (NILU, Norway) Inverse modelling of source term and data assimilation	pg. 54
09:30-09:45	O3.1-03	R. Denlinger (USGS - CVO, USA) Improving ash cloud forecasts via Bayesian learning algorithms	pg. 55
09:45-10:00	O3.1-04	M. Herzog (Cambridge University, UK) Assessing the potential to observe volcanic ash clouds from space by combining volcanic plume simulations with microwave radiometric remote sensing	pg. 56
10:00-10:15	O3.1-05	A. Schmidt (University of Leeds, UK) Sulfur pollution from Icelandic volcanic eruptions	pg. 57
10:15-10:30	O3.1-06	A. Costa (INGV Bologna, Italy) Modelling strategies for particle aggregation in volcanic plumes	pg. 58
10:30-11:00		**Coffee Break**	
		Session 3B. Ash and gas dispersal modelling	
11:00-13:30		**Break-out sessions** List of groups for break-out sessions will be provided at the meeting	
13:30-14:30		**Lunch (WMO cafeteria)**	
14:45-16:15		**Plenary discussion** Mediators: Organizing committee	
16:15-16:45		**Coffee Break**	
16:45-17:15		Presentation of main points to include in consensual document Mediators: Organizing Committee	
17:15		**Closing of Conference**	

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Oral Contributions Abstracts

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O1.1-01

Outcomes from the first IUGG-WMO workshop on Ash Dispersal Forecast and Civil Aviation (November 18-20, 2010)

Costanza Bonadonna[(1)], Arnau Folch[(2)], Susan Loughlin[(3)], Herbert Puempel[(4)]

[(1)] *Department of Earth Sciences, University of Geneva, Switzerland*
[(2)] *Barcelona Supercomputing Center, Spain*
[(3)] *British Geological Survey, U.K.*
[(4)] *World Meteorological Organization, Switzerland*

As a result of the serious consequences of the 2010 Eyjafjallajökull eruption (Iceland) on civil aviation, 52 volcanologists, meteorologists, atmospheric dispersion modellers and space and ground-based monitoring specialists from 12 different countries (including representatives from 6 Volcanic Ash Advisory Centres and related institutions) gathered to i) discuss the needs of the ash dispersal modelling community, ii) investigate new data acquisition strategies (i.e. observations, including quantitative measurements) and iii) discuss how to improve communication between the research community and institutions with an operational mandate. Based on a dedicated benchmark exercise and on 3 days of in-depth discussion, recommendations were made for future model improvements, new strategies of ash cloud forecasting, multidisciplinary data acquisition and more efficient communication between different communities. Issues addressed in the workshop include i) ash dispersal modelling, ii) uncertainty, iii) ensemble forecasting, iv) combining dispersal models and observations, v) sensitivity analysis, vi) model variability, vii) data acquisition, viii) pre-eruption forecasting, ix) first simulation and data assimilation, x) research priorities and xi) new communication strategies to improve information flow and operational routines. Our main conclusion was that model developers, meteorologists, volcanologists and stakeholders needed to work closely together in order to develop new and improved strategies for ash dispersal forecasting and, in particular, to: (1) improve the definition of the source term, (2) design models and forecasting strategies that can better characterize uncertainties, (3) explore and identify the best ensemble strategies that can be adapted to ash dispersal forecasting, (4) identify optimized strategies for the combination of models and observations and (5) implement new critical operational strategies. All workshop documents can be found at: http://www.unige.ch/hazards/Workshop.html (including the consensual document, the model summary document, the data-acquisition summary document and the benchmark results).

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O1.1-02

Scientific Progress and Recommendations from the International Volcanic ash Task Force

Marianne Guffanti(1)

(1) *U.S. Geological Survey, USA*

In response to severe disruptions to air travel resulting from Eyjafjallajökull's 2010 eruption, the International Civil Aviation Organization (ICAO) quickly formed the International Volcanic Ash Task Force (IVATF) to accelerate development of the global risk-management framework for volcanic-ash hazards to aviation. The IVATF held four meetings in Montreal, Canada, finishing its work in June 2012 with results and recommendations documented at
http://www.icao.int/safety/meteorology/ivatf/Pages/default.aspx. From the start, the IVATF recognized the need for scientific guidance on best methods to detect and forecast ash clouds. An important source of such guidance was the Volcanic Ash Scientific Advisory Group, established in May 2010 by the WMO and IUGG in their support of on-going ICAO work on the topic. The IVATF also benefited from the work of many scientists around the world who adjusted their research to focus more directly on ash-cloud characterization, detection, and forecasting. Substantial scientific progress was made, notably in: airborne in-situ sampling of volcanic clouds; use of lidar (ground-based, airborne, space-based) to detect and characterize volcanic clouds; quantitative retrieval of ash-cloud microphysical properties from satellite data; and development of inversion methods that use satellite data to improve dispersion model forecasts. A specific science-based recommendation of the IVATF is that ash concentration charts –such as were introduced in Europe in 2010– should not be used as an official ICAO advisory product at this time because their model-based forecasts of concentrations have at least an order of magnitude in uncertainty and do not delineate hazardous airspace with the level of confidence needed by the aviation sector (nor is there a global user requirement for those charts). The need remains for tangible improvements in detection and measurement of volcanic plumes and ash clouds during eruptions and in accuracy of dispersion-model forecasts of cloud transport –improvements that can only be attained by a broad range of continued scientific investigations such as those discussed at this workshop.

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O1.1-03

Summary of volcanology projects since 2010

Sue Loughlin[(1)]

[(1)] *British Geological Survey, U.K.*

The small but prolonged 2010 eruption of the Eyjafjallajökull volcano was unprecedented in terms of its global economic impact and drew attention to the scientific challenges of forecasting volcanic ash dispersal and the difficulties of managing air traffic under conditions of uncertainty. It provided a unique opportunity for scientists across Europe to collect diverse datasets and to cooperate, collaborate and demonstrate the socio-economic value of their work. It also brought together different disciplines and communities worldwide: earth science, atmospheric science, satellite remote sensing and modelling who clearly need to work together to advance the state-of-the-art. The availability of funding from different sources including national and regional research funds, international agencies and the private sector together with rapid analysis of the situation by the international scientific community through expert committees, conferences and workshops has led to significant and coordinated progress in science. There has been thorough post-event analysis. The focus of science ranges from magmatic processes, eruption triggers, volcano monitoring and early warning, short-term forecasting and magma fragmentation mechanisms to modelling of plume dynamics, the interaction of plumes with the atmosphere, new instrumentation and technology, new EO retrieval algorithms, novel application of models and observations to derive eruption source term parameters and large-scale experiments. There are consortia explicitly working across disciplines to address many of these topics and going further to ensure effective and timely dissemination of processed data, analysis and research results. Researchers are noticeably making greater efforts to ensure the latest knowledge can be used operationally and close links to real-time responders are important if the science is to be relevant and useful. As an integrated community we must build on this progress, maintain momentum in terms of research outputs, interact more effectively with our stakeholders and ensure that responses to future eruptions are effective, coordinated and co-productive.

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O1.1-04

Volcanoes and Aviation - Detection, Prediction and Expectation

Ian Lisk[(1)], Deborah Lee[(1)], Matthew Hort[(1)], Claire Witham[(1)]

[(1)] *Met Office, U.K.*

The 39-day long eruption of the Icelandic volcano, Eyjafjallajökull (Eyja), during April and May 2010 is probably the best researched and documented volcanic eruption in history. The duration of the event coupled with the prevailing north-westerly winds required an emergency revision of the ICAO (International Civil Aviation Organisation) EUR/NAT (European/North Atlantic) volcanic ash contingency plan, exposed gaps in European volcanic ash observational capabilities and the lack of guidance from aircraft and engine manufacturers relating to what level of ash contamination poses a threat to flight safety. The large eruptions of Merapi (Indonesia 2010), Grimsvötn (Iceland, 2011) and the long-lasting eruption of Cordón Caulle (Chile, 2011-12) have similarly resulted in varying degrees of impact on international airspace. At the global level, ICAO established the cross-discipline International Volcanic Ash Task Force (IVATF) to accelerate the harmonisation of volcanic ash service delivery mechanisms and processes to include agreed definitions of what "hazardous" ash actually is. The IVATF, heavily supported by the IUGG/WMO Volcanic Ash Scientific Advisory Group (VASAG) concluded its work in June 2012 with business as usual governance again maintained by the International Airways Volcanic Watch Operations Group (IAVWOPSG). In Europe, the 2011-13 European Commission Coordination and Support Action funded WEZARD (WEather hazARDs for Aviation) project has conducted a cross-industry volcanic ash capability and gap analysis with the EUMETNET (network of 29 European national meteorological services) led Work Package 3 of the project focussing on geophysical monitoring, observations, dispersion modelling and data exchange. Based primarily on the outcomes of the activities described above, this talk summarises the progress that has been made in the "end to end" volcanic ash service delivery process and looks to some of the priorities for future work.

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O1.1-05

The Impact Volcanic Ash has on Jet Engines - Latest Understanding

Rory Clarkson[(1)]

(1) *Rolls-Royce plc, U.K.*

The talk covers the latest interpretation of existing data on the quantitative impact volcanic ash has on aircraft jet engines, from the threat of engine shutdown during flight to sustaining damage that leads to premature removal and repair of engines. Uncertainties in the understanding are discussed along with the existing and proposed activities to address the uncertainties, and how these activities fit into the current approach for managing aviation in the vicinity of volcanic ash clouds.

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The Support to Aviation Control Service, an overview and recent developments

L. Clarisse[1], N. Theys[1], H. Brenot[1], J. Van Gent[1], R. van der A[1], M. Van Roozendael[1], P.-F. Coheur[1], P.D. Hurtmans[1], C. Clerbaux[1]

[1] *Université Libre de Bruxelles, Belgium*

The Support to Aviation Control Service (SACS; http://sacs.aeronomie.be) is an on-line service displaying in near real-time satellite observations of volcanic ash and SO2. Relying both on UV-visible (OMI, GOME-2) and thermal infrared (IASI, AIRS) satellite sounders, it is aimed at aviation authorities, atmospheric scientists and volcanologists. In addition to the near real-time data, the service issues warnings by email and accommodates a large archive of over 10 years of satellite data. After having reviewed SACS' main features, we focus on more recent developments, in particular the introduction of an algorithm capable of discriminating volcanic ash and airborne sand using the hyper spectral infrared sounders. We also present first results of a new retrieval algorithm for determining size, mass and altitude of volcanic ash. This algorithm was designed and is able to run in an operational context.

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O1.1-07

A European network for ground based profiling of wind and aerosols E-PROFILE

Alexander Haefele[(1)]

[(1)] *MeteoSwiss, Switzerland*

The eruptions of the Icelandic volcanoes in 2010 and 2011, respectively, had a strong impact on aviation over Europe and revealed that the capabilities for operational real-time monitoring of the vertical and horizontal distribution as well as of the density of volcanic ash was not sufficient. At the same time it has been shown that state-of-the-art profiling ceilometers are capable of detecting aerosol layers including volcanic ash in the free troposphere. As a consequence, EUMETNET, the network of European meteorological services, initiated a new operational service called E-PROFILE for ground-based profiling of wind and aerosols by means of radar windprofilers and profiling ceilometers. E-PROFILE is the continuation of the E-WINPROF programme, which was focused on the operation of radar windprofilers, only. The integration of profiling ceilometers in E-PROFILE will take place in two phases: The concept phase will last from 2013 – 2014 and will be terminated by the production of a business case. The implementation phase will last from 2015 – 2017. In this presentation the potential of the E-PROFILE network for volcanic ash monitoring will be shown and we will report on progress in the concept phase discussing the most challenging questions like instrument calibration and quality control.

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O1.1-08

The Volcanic Ash Strategic initiative Team –VAST: Advanced satellite retrievals of volcanic ash and SO_2

Fred Prata[(1)]

[(1)] *NILU, Norway*

A new ESA project has been established involving teams from four European countries to improve the quality and use of EO based observations in numerical atmospheric dispersion models for the purpose of assisting global aviation. Large amounts of EO data are being utilised for this activity and new retrieval schemes are being developed to better quantify ash in the atmosphere and to characterise the sources of error. The satellite retrievals are made available in real-time for use in volcanic ash transport models (VATMs). Here we describe some of the advances being made in the retrieval schemes with an emphasis on better detection of ash through the use of physically and statistically based methods applied to multi-channel broadband satellite instruments. The new schemes are based on the results of 30 years of R&D on cloud detection schemes, adapted for volcanic ash and build on the techniques outlined by Clarisse et al. (2013). We also consider improvements in ash detection from high spectral resolution data and describe methods for retrieving ash and SO_2 simultaneously. Finally, we outline a new ash eruption database being developed in VAST and suggest some new aviation-specific satellite data products.

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O1.1-09

Real-time global volcano monitoring by geostationary and polar orbiting payloads

Fabrizio Ferrucci[(1)], Stephen Tait[(2)], Nicolas Theys[(3)], Sue Loughlin[(4)], Barbara Hirn[(5)], Marco Vimercati[(6)]

[(1)] *The Open University, Milton Keynes, U.K.*
[(2)] *Institut de Physique du Globe de Paris, France*
[(3)] *Institut d'Aéronomie Spatiale de Belgique, Brussels, Belgium*
[(4)] *NERC – British Geological Survey, Edinburgh, U.K.*
[(5)] *Intelligence for Environment and Security s.r.l., Rome, Italy*
[(6)] *Compagnia Generale per lo Spazio S.p.A., Milan, Italy*

Within the Global Monitoring for Environment and Security (GMES) framework of the European Commission, EVOSS – a consortium of thirteen academic and industrial partners – has created a satellite-based, real-time observation system to support volcano crisis management worldwide. Data from seven different satellite payloads (SEVIRI, MODIS, GOME-2, IASI, OMI, Cosmo-SkyMED and, until April 8th 2012, SCHIAMACHY) acquired at five different down-link stations, are on-line processed at six locations in Italy, Netherlands, Belgium and Germany and transferred to a dynamic repository and real-time, web-based GIS, for display and supervised post-processing. Physical modelling of eruptive phenomena, with an emphasis on rapid numerical calculations, underpins the system. This allows interpretation of acquired data in terms of eruptive activity on ground, and hence assessment of hazard on the ground and in the atmosphere. The results are split in three geographic data streams: one at very-high temporal resolution (thermal and volcanic ash products: typical refresh rates between 5 and 15 minutes), one at high temporal resolution (SO_2 and thermal products: between daily and four-times daily) and one at very-high spatial resolution and delayed-time (precise volume changes on ground: 3-meter horizontal and 0.5-meter vertical target resolutions). Such "Virtual Volcano Observatory" operates 24H/24-7D/7 since September 2011 on all volcanoes in Europe, Africa, the Lesser Antilles, and the oceans around them: during this interval EVOSS has detected and monitored all subaerial eruptions that occurred in this region, delivering its results to a group of 14 qualified end users, bearing the direct or indirect responsibility of monitoring and managing volcano emergencies. Aimed to extend the geographic cover and/or to improve the quality of results, the system is ready to include data streams from other payloads and products from new algorithms, as for instance thermal ground products from MTSAT–JAMI or NPP–VIIRS, and straightforward modelled constraints on eruptive columns for ash retrieval improvement.

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O1.1-10

SMASH overview and ash related projects at University of Oxford

Elisa Carboni[1]

[1] *University of Oxford, UK*

Here it will be presented an overview of the SMASH ESA project that involve several European groups in the team and is carried out together with the similar project SACS-2. SMASH include new and improved algorithms for volcanic ash and SO2 using satellite sensors in polar orbit as:

(1) radiometers with channel in visible-infrared spectral range (MODIS);
(2) ultraviolet spectrometer (GOME-2 and OMI);
(3) infrared spectrometer (IASI).

The main retrieved quantity are column amount and altitude (for SO2), and optical depth, effective radius and altitude (for ash). These quantities are then extrapolated into total masses, flux quantities and used for sources characterization. Others ongoing works at university of Oxford that will be presented include:

- SHIVA: a NERC funded project to study the properties of volcanic ash using ground and space-based high resolution infrared spectrometer measurements.
- Laboratory measurements of volcanic ash refractive index.
- Aerosol extinction from MIPAS using singular vector decomposition.
- ORAC: Oxford and RAL Aerosol and Cloud optimal estimation retrieval.

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Observing and Modelling Near- to Far-Field Plume Processes: Update on the VANAHEIM Project

Stephen Mobbs [(1)], Susan Loughlin [(2)]

[(1)] *National Centre for Atmospheric Science, UK*
[(2)] *British Geological Survey, UK*

The VANAHEIM project was an immediate UK response to the major disruption to air transport across Europe. The regulatory response, ensuring aviation safety, depends on dispersion models. The accuracy of the dispersion predictions depends on the model representations of the intensity of the eruption, the plume dynamics and the physical properties of the ash and gases in the plume. Better characterisation of these processes and properties will require improved understanding of the near-source plume region. The VANAHEIM (Volcanic and Atmospheric Near- to far-field Analysis of plumes Helping Interpretation and Modelling) consortium is a group of nine UK institutes working with 24 international partners (including research centres, forecasting agencies, regulatory authorities and airlines). The consortium has been formed to advance interpretation and modelling of volcanic plumes with the aim of enabling improved dispersion prediction. This project started in April 2011 and brings to bear observations and modelling in order to achieve more accurate and validated dispersion predictions. The investigation seeks to integrate volcanological and atmospheric science methods in order to initiate a complete system model of the near-field atmospheric processes. When integrated with characterisations of the emissions themselves, the research will lead to enhanced predictive capability. This project aims to contribute to the translating the science and organisational lessons learned from the April/May 2010 response to Eyjafjallajökull into preparedness for subsequent eruptions of other volcano over the coming years. In this presentation we will give an overview of the aims of the VANAHEIM project and will describe the latest emerging results from large eddy modelling of plumes, mathematical modelling of plumes, new remote sensing retrieval methods and analysis of samples collected from the Eyjafjallajökull eruption. We will also discuss the prospects for new atmospheric observational technologies.

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The contributions of the EU–funded MEDiterranean SUpersite Volcanoes (MED–SUV) project to the assessment of volcanic ash hazard

S. Barsotti(1), F. Buongiorno(1), M. Coltelli(1), A. Costa(1), E. Del Bello(1), M. de Michieli Vitturi(1), T. Esposti Ongaro(1), G. Macedonio(1), L. Nannipieri(1), A. Neri(1), M. Prestifilippo(1), G. Puglisi(1), P. Scarlato(1), S. Scollo(1), G. Spata(1), C. Spinetti(1), J. Taddeucci(1)

(1) *Istituto Nazionale di Geofisica e Vulcanologia, Italy*

More than 3 million people are threatened by volcanic hazards in a large region of the Mediterranean Sea where two among the largest European volcanic regions are located: Mt. Etna and the Campi Flegrei/Vesuvio area. The MED–SUV project aims to improve our capacity to assess volcanic hazards of supersite volcanoes of Southern Italy by optimising and integrating existing and new observation/monitoring systems, by a breakthrough in the understanding of relevant volcanic processes and by increasing the effectiveness of coordination between scientific and end-user communities. In particular the project aims to fully exploit the unique in-situ monitoring datasets available at these volcanoes and integrate them with Earth Observation (EO) data and numerical models, thus producing the basic tools for a significant step ahead in the analysis of pre-, syn- and post-eruptive processes and the quantification of their hazards. With specific reference to volcanic ash a variety of multidisciplinary activities are planned in the project. These include: 1) physical and analogue laboratory experiments on ash dispersal and aggregation, 2) integration of satellite data (e.g. METEOSAT, MODIS) and ground-based measurements (e.g., RADAR, LIDAR) of Etna′s volcanic plumes to quantify key eruptive variables, such as mass eruption rate, grain-size distribution at source, and ash cloud concentration, with a greater accuracy, 3) development of long-term probabilistic ash fallout maps at the supersite volcanoes, 4) development of modelling tools and automatic procedures for the short-term hazard assessment of volcanic ash by adopting multi-model and multi-scenario approaches, 5) development of short-term probabilistic hazard assessment modelling tools able to use direct measurements and observations of the plume and ash cloud in almost real time (i.e. now-casting).

FUTUREVOLC: A European supersite project on an integrated monitoring network for Icelandic eruptions

Magnus T. Gudmundsson[(1)], the FUTUREVOLC Team

[(1)] *Institute of Earth Sciences, University of Iceland*

FUTUREVOLC is a funded through the FP7 Environment call and has 26 partners in 10 countries. The main objectives of FUTUREVOLC are to establish an integrated volcanological monitoring procedure, develop new methods to evaluate volcanic crises, increase scientific understanding of magmatic processes and 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. For early warning, FUTUREVOLC will track subsurface magma movements with satellite interferometry, continuous GPS, earthquakes, and precursory gas and thermal signals. From the onset of eruption, mass eruption rate and atmospheric ash loading will be continuously evaluated. This will be achieved through the use of real-time to near-real-time data from two C-band weather radars, two mobile X-band radars, radiosondes for ambient atmosphere monitoring, infrasound arrays, arrays of time lapse cameras, electric field sensors, automated tephra samplers and analysers, gas monitoring systems and lightning detection systems. The signals from these systems will be supplemented by aircraft observations and the deployment of a mobile field lab for rapid characterization of tephra. The data from all these sources will be fed into an integrated near-real-time system that will evaluate the eruption rate. New algorithms for analysis of radar backscatter and both physics-based and empirical plume models will be implemented as a part of the system. Various data from previous eruptions, especially those of Eyjafjallajökull in 2010 and the Grímsvötn in 2011, will be used to calibrate the system. It is expected that the system will be operational in 2016, resulting in signifiant improvement in ash dispersal forcasting in Iceland, the North Atlantic region and Europe.

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Dispersion Modelling and the Provision of Warnings for Volcanic Ash in the Australian Region

Rodney Potts[(1)], Andrew Tupper[(2)], Richard Dare[(1)], Emile Jansons[(2)], Chris Lucas[(1)], Meelis Zidikheri[(1)]

[(1)] *Centre for Australian Weather and Climate Research, Bureau of Meteorology, Melbourne, Australia*
[(2)] *Bureau of Meteorology, Darwin, Australia*

Over the years there has been much work to improve warnings for volcanic ash for the aviation industry and this includes more effective use of satellite data and dispersion models and the development of tools to streamline generation of the volcanic ash advisory. Despite these improvements there are still considerable uncertainties in the provision of warnings for volcanic ash. In the Australian region this was highlighted with the eruption of the Indonesian volcano Merapi in Oct-Nov 2010 and Chilean Payehue-Cordon Caulle volcano complex in June 2011 with both events causing major disruption to airline operations. During these events many airlines sought more detailed information on the spatial distribution of ash concentration which could not be provided. . Work is now underway to improve the guidance that can be made available noting that the ICAO IVATF has since recommended work on concentration charts be discontinued due to the considerable uncertainties. The Bureau currently uses the HYSPLIT dispersion model to provide guidance on the dispersion of volcanic ash plumes with uncertainties arising from the underlying meteorological fields, the simplified source term used to initialise the model and uncertainties in the dispersion model including the ash microphysics. The underlying meteorological fields now come from the Bureau?s coupled climate and earth system simulator, the Australian Community and Climate Earth System Simulator (ACCESS) which became operational in 2010. This provided a substantial improvement in the meteorological fields used by HYSPLIT but there are still issues with reliability in tropical regions. The source term is also assumed to be a column source with a uniform mass distribution and no account of deposition. The presentation will outline work underway to improve the source term parameters and to better quantify the uncertainties in the dispersion model guidance.

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The eruption of Mt. Tongariro on August 6th 2012: Operational response and dispersion modelling challenges

Cory Davis[1], John Crouch[1], Nick Zachar[1], Brooke Oakley[1], Paul Shucksmith[1]

[1] *Metservice New Zealand Ltd., New Zealand*

On 6th August and 21st November 2012, there were eruptions at the Te Maari craters of Mt. Tongariro. The first eruption resulted in several VAAs from the Wellington VAAC, and although the impact of the event was limited by its timing (near midnight NZDT), flights were cancelled in and out of several surrounding airports.

This talk will describe the model guidance available to Wellington VAAC forecasters, and its usefulness and limitations in this particular event. A major challenge is providing reasonable eruption parameters to the dispersion model (in this case PUFF-UAF) with limited observational information. The talk describes what information was available and how early dispersion model runs were initialised. The eruption was detected by three MetService weather radars, New Plymouth, Bay of Plenty (Mamaku) and Mahia. Imagery from these C-band radars illustrated the potential usefulness of this data in estimating initial plume height.

The 2012 VAAC "Inputs and Outputs" Modelling Workshop highlighted several areas in which our dispersion modelling could be improved, including the quality and usage of driving NWP data, the lack of quantitative output, and the physical completeness of the dispersion model. This talk will describe work underway to address these limitations.

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The Puyehue-Cordón Caulle re-suspended volcanic ash event

Gabriel Damiani(1), Ximena Calle(1), Arnau Folch(2), Leonardo Mingari(1,3,5,6) Soledad Osores(1,3,4) Estela Collini(5)

(1) *Servicio Meteorológico Nacional (SMN), Argentina*
(2) *Barcelona Supercomputing Center (BSC–CNS), Spain*
(3) *CONICET, Argentina*
(4) *CONAE, Argentina*
(5) *Servicio de Hidrograía Naval (SHN), Argentina*
(6) *Departamento de Física, FCEyN, UBA, Argentina*

In the last five years, the eruptions of Chaitén (2008) and Puyehue-Cordón Caulle (2011) volcanoes have introduced new challenges to the VAAC Buenos Aires Operators. Since the eruption of the Chaitén volcano, two Lidars were installed in the Argentinian Patagonia region, the FALL3D model coupled to regional forecasting models was implemented and communications with stakeholders were improved. The eruption of the Chilean volcanic complex Puyehue-Cordón Caulle from June 2011 throughout April 2012, resulted in many events where the ash cloud simultaneously affected Argentina, Uruguay, Paraguay and Brazil and, in fact, the whole Southern Hemisphere due to its continuous movement to the East, disrupting the aviation activity as well as having an enormous impact on the tourism industry and on the lives of the inhabitants of the nearby Argentinean cities. Thus, large regions of ash deposits covered the Argentinian side of the Andes range. These regions are mainly characterized by strong winds with a katabatic component over the eastern lee of the Andes. This condition increases the upward transport of the ash, producing a mixed layer that reaches heights of 1500 to 2000 meters. In addition to the difficulties associated with forecasting this event was the added complexity of the management of re-suspended ash. In October 2011, the huge amounts of accumulated volcanic ash mentioned above were unusually re-suspended after a cold front passage associated to a typical winter meteorological situation, affecting again Argentina and Uruguay, and causing the closure of domestic and international airports along its North-Eastbound trajectory. An event of re-suspended ash from fallout deposits is the result of a complex combination of weather conditions, soil moisture and physical properties of particles. Currently, there are neither studied nor developed specialized emissions schemes for re-suspended volcanic ash. The research group adapted and implemented several schemes originally developed for emission of mineral dust, on the WRF-ARW/FALL3D modelling system, in order to investigate its behavior for the transport of volcanic ash clouds, applied to the October 2011 episode as a test case.

A Case Study of Atmospheric Transport and Dispersion Sensitivity: Implications for Volcanic Ash Modelling

Alain Malo[(1)], René Servranckx[(1)], Nils Ek[(1)]

[(1)] *Meteorological Service of Canada, VAAC Montreal*

For several years, the Canadian Lagrangian Particle Dispersion Model (LPDM) MLDP0 has been in use operationally at the Canadian Meteorological Centre (CMC) to support national and international mandates. The model is used by VAAC Montreal operational staff to track and forecast volcanic ash/gas clouds. MLDP0 is also regularly used in various environmental emergencies such as smoke from forest fires, dust storms, toxic spills in the atmosphere and industrial chemical fires. Numerous forest fires burn in North America each summer. In July 2012, VAAC Montreal monitored and modelled the transport of smoke from two distinct, but in close proximity, pyroCbs that originated in northern Alberta, Canada. A pyrocumulonimbus (pyroCb) is a fire-aided or caused convective cloud with considerable vertical development. This phenomenon can inject significant amounts of smoke and biomass into the upper troposphere and sometimes into the lower stratosphere, reaching altitudes in the range of 10-15 km. Similar to volcanic ash emitted by explosive eruptions, smoke from pyroCbs can be transported downwind over great distances in the atmosphere. With the availability of remote sensing data, these events represent a unique case study to explore the impact of varying modelling parameters on the total column mass loadings and airborne concentrations for two sources in close proximity. Sensitivity tests are performed for the following input parameters: computational grid mesh (horizontal resolution), initial eruption column geometry (radius, height), mass vertical distribution, horizontal wind velocity variance (mesoscale fluctuations) and numerical weather prediction (NWP) meteorological data (global, regional). The results are compared qualitatively against AVHRR and MODIS satellite data and the implications for the modelling or airborne pollutants, including volcanic ash, are discussed.

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MOCAGE Accident description and operational use

M. Martet[(1)], M. Deslandes[(1)], N. Asencio[(1)]

[(1)] *Météo-France, Toulouse VAAC, France*

MOCAGE (MOdéle de Chimie Atmosphérique a Grande Echelle) is the multi-scale 3D Chemistry and Transport Model developped by Météo-France. From air quality forecasting to the study of interactions between climate and chemistry, MOCAGE is a flexible tool that is currently used for both research on atmospheric composition and operations in Météo-France.
In particular, the specific configuration “MOCAGE Accident” is currently used in operations by Météo-France forecasters, in support of the international responsibilities as a VAAC (Volcanic Ash Advisory Centre).
Regarding the current operations, the horizontal resolution of MOCAGE Accident is 0.5deg all over the globe, with 47 levels from surface to 5 hPa. This model is thus able to represent accidental emissions from any place of the world, in the troposphere and/or lower stratosphere, as long as provided meteorological forcings are appropriate.
MOCAGE Accident runs in off-line mode, using Météo-France ARPEGE or ECMWF/IFS operational NWP products as dynamical forcings. Meteorological forcings (hydrostatic winds, temperature, humidity and pressure) feed the advection scheme, as well as the physical parameterizations. Within MOCAGE Accident, the choice of the NWP trajectory is left to the forecaster, who has several options for global forecasts depending upon his appreciation of the best NWP model in the area and in the period concerned with the accidental or volcanic release.
MOCAGE Accident is a eulerian large scale model, and thus is well suited for eruptions that have at least a regional impact. However near the source, its results are more mitigated and present a too wide plume of ash (resolution of 0.5deg, dispersive transport scheme, eulerian model...). Increasing model resolution may improve this behavior but a compromise has to be done between accuracy and time response (In operational uses, the goal is to have available results in less than 20 minutes).

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Volcanic Ash Fall Forecasts of Japan Meteorological Agency

Yoshihiko HASEGAWA[(1)], Akira SUGAI[(1)], Yosuke HAYASHI[(1)], Shota IMAMURA[(1)], Toshiki SHIMBORI[(2)], Toshiyuki MATSUMORI[(1)]

[(1)] *Japan Meteorological Agency, Japan*
[(2)] *Meteorological Research Institute, Japan*

The Japan Meteorological Agency (JMA) has issued Volcanic Ash Fall Forecasts (VAFFs) domestically since March 2008. When an eruption with potential to cause ash-fall on wide area occurs, JMA issues VAFF accompanying a graphical format and provides an hourly ash-fall area prediction for up to 6 hours after. VAFFs were issued for Asamayama in 2009, Kirishimayama Shinmoe-dake in 2011 and Sakurajima in recent years. The impact of ash-fall depends on its quantity and the demand for quantitative VAFF has been increasing. So far, however, insufficient accuracy of JMA Regional Atmospheric Transport Model (JMA-RATM) has been an obstacle to provision of the quantitative prediction. Meanwhile, the recent improvement made by Meteorological Research Institute (MRI) (Shimbori, et al.), especially in the measurement of volcanic plume height using weather radar, is expected to allow for the quantitative forecast with accuracy of practical use. In this context, JMA plans to improve VAFF based on this new monitoring technique. In addition, JMA is developing new VAFF also taking into account needs of residents around active volcanoes identified by questionnaire surveys, as well as advice of experts on wide-ranged fields concerning volcanic ash-fall such as volcanology, disaster prevention, broadcasting and medical service. Following are the characteristics of new VAFF:

- to provide quantitative ash-fall prediction and forecast of centimeter-sized lapilli-fall area.
- to provide information on impacts of ash-fall on residents and countermeasures to be implemented, by classifying the predicted quantity of ash-fall according to the impacts and countermeasures.
- to consist of 3 types of information: pre-eruption information; quick and brief information immediately after the eruption; and subsequent, detailed information.
- to be issued when the amount of ash-fall is forecasted to reach prescribed levels based on the impacts on people or community. JMA plans to start to issue new VAFF in a few years.

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VAAC London operational response and developments following the recent Icelandic eruptions

Claire Witham(1), Anton Muscat(1), Matthew Hort(1), Susan Leadbetter(1), Peter Francis(1), Michael Cooke(1), Sarah Millington(1)

(1) *Met Office, UK*

The eruption of Eyjafjallajökull in 2010 led to the rapid introduction of new products, and hence procedures, at VAAC London and the UK Met Office. New products included those requested by end-users, such as ash concentration maps, and new data sources such as observations from the UK Laser Cloud Base Recorder network. All of these subsequently needed to be fully consolidated into the VAAC operational framework. The eruption of Grimsvötn in 2011 provided a good test of these new procedures and also revealed remaining areas for improvement in both processes and systems. Over the last three years new science and functionality have been introduced to VAAC London in the areas of: quantitative satellite retrievals of volcanic ash, eruption source parameters for initialising the NAME dispersion model, simulated satellite imagery, satellite retrievals of SO_2, WebEx communication tools and the development on an improved "intervention tool" for producing the forecast products. Outcomes and recommendations from the IVATF and other meetings have helped steer these and future developments. The UK Met Office is now also involved in a number of research projects with an aim to enhance the data and the science available to the VAAC. Given the recent rapid progress, major challenges include ensuring that VAAC forecasters are not only familiar and comfortable with using these new tools and understand their limitations, but that they are also able to communicate the "message" to end-users. The developments, current practice and challenges will be reviewed in this talk.

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Data integration, analysis/forecast process, and collaboration: Path toward a global harmonization of volcanic ash products and services

J. Osiensky[(1)], D. Moore[(1)], N. Eckstein[(1)], G. Swanson[(1)], J. Kibler[(1)], C. Miner[(1)]

[(1)] *NOAA/National Weather Service Alaska Region, USA*

The global network of nine volcanic ash advisory centers (VAACs) provides a suite of text and graphical volcanic ash products to various customers including the airline industry. Although the original intent of these products was to provide guidance to the world's meteorological watch offices (MWOs), the VAACs now provide products and services to a wide range of customers mainly through their web pages. Airline dispatchers and other organizations use these products in both tactical and strategic decision making when volcanic ash impacts the world's airspace. The need for a fully collaborated process between the VAACs is integral to ensure a globally harmonized set of products. This set of products includes, but is not limited to, ash dispersion models, remote sensing data, observational data and other datasets used to produce a graphical and text product. A collaboration tool could also be used in post event analysis, research, and training applications. Dispersion model comparisons can easily be produced in addition to ensemble and probabilistic forecast products. Shared situational awareness amongst the VAACs to produce an accurate analysis and suite of forecast graphics is necessary to fulfill the requirement set forth by the International Air Transport Authority (IATA). This requirement is for the VAACs to produce a seamless, globally harmonized suite of forecast products. In order to achieve this goal, a tool is needed for all VAACs to share data and have a Common Operating Picture (COP). The U.S. VAACs are leading an effort to demonstrate this capability.

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Building relationships for better ash products: Overcoming language barriers, limited observational data, technology limitations and inaccurate weather models by enhancing communication in equatorial locations

J. Kibler[1], G. Swanson[1], J. Osiensky[1]

[1] *NOAA/NESDIS/Satellite Analysis Branch, USA*

The overall goal for each VAAC is to provide quality text and graphical ash products in a timely and efficient manner for aviation purposes. One of the challenges the Washington VAAC has to deal with is the availability of observational data throughout Central and South America. During the last ten years the Washington VAAC has worked actively with WMO contacts and numerous MWO and geological institutes throughout the region to gain access to volcanic ash information and to encourage the flow of data. Each forecast and scientific group from the equatorial region must deal with limitations imposed by technology. An even larger problem is the language barrier between the Washington VAAC and the many groups. It can be a challenge to relay vital information on volcanic ash activity. Several solutions have been created and are currently being used. One final challenge and likely the most difficult to solve for the Washington VAAC is the use of forecast and trajectory model data for +06, +12, +18 hour forecast in equatorial locations. The lack of routine surface and radiosonde observations, and complex terrain, results in forecast model output that can often be at odds with the observed direction of motion of ash plumes. This is a challenge we continue to work on. The recent relocation of the Air Resources Laboratory (ARL) and the Washington VAAC to the National Center for Weather and Climate Prediction (NCWCP) has led to improved collaboration on modelling issues. Increased communication with MWOs and geological institutes across Central and South America through phone and e-mail have improved the flow of vital information necessary to ensure that the Washington VAAC can issue high quality ash products for aviation purposes.

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A view from the volcano observatory

Chris Newhall(1)

(1) *Earth Observatory of Singapore*

The primary concern of most volcano observatories is risk to those living and working around the volcano. That's what they are funded for. Though most observatories now commit to sending information to VAACs and/or local ATM offices, the delivery sometimes falls short. Only a few observatories consider warnings to aviation as their top priority.
Volcano observatory capabilities vary greatly. At the high end, a full set of instruments and a large, highly trained staff allow for the best possible forecasts, tracking, and notification of eruptions. Even here, some language barriers may complicate communication with VAACs. At the other end of the spectrum, a single observer with a high school education is watching a lone seismograph and communicating to a duty officer or supervisor in national headquarters. If the duty office is staffed 24/7, if the duty officer speaks the language of the pertinent VAAC, and if he/she is empowered to contact the VAAC, information about the eruption may be relayed quickly. If not, it might be held until the next time that an authorized person is available to contact the VAAC. In some cases, messages in the local language will be sent to local ATM before they are sent to VAACs.
Consider the following scenario. The volcano has just erupted explosively, at night, with only minor warning signs a week earlier. Pyroclastic flows are indicated on seismometers, ash is blowing toward the nearby city, and the mayor of that city wants to know if an evacuation is required. The director and other staff are rushing back from their homes. As soon as the director arrives, he responds to the mayor, to the agency headquarters, and to local media who arrived even before he did because they monitor Twitter. An hour later, someone calls headquarters to ask if they have called the VAAC.

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Lessons learned from North Pacific Volcanoes: AVO, KVERT and SVERT

P.W. Webley[(1)], J. Freymueller[(1)], P. Izbekov[(1)]

[(1)] *Geophysical Institute/Alaska Volcano Observatory, University of Alaska Fairbanks, Fairbanks, Alaska*

Volcanoes across the North Pacific (NOPAC) can produce large explosive events, and the ash clouds can drift across international boundaries as well as Volcanic Ash Advisory Center (VAAC) designed regions. For volcanoes in the Kurile Islands in the North Western Pacific, through the Kamchatkan Peninsula, Aleutian Islands into mainland Alaska in the North Eastern Pacific, real-time monitoring is a critical tool for alerting on any precursors, detecting the volcanic events and assesses the associated hazard. Three volcano organizations provide this monitoring capability: Sakhalin Volcanic Eruption Response Team (SVERT), Kamchatka Volcanic Eruption Response Team (KVERT) and the Alaska Volcano Observatory (AVO). AVO is a joint program of the United States Geological Survey, the Geophysical Institute of the University Of Alaska Fairbanks, and the State of Alaska Division of Geological and Geophysical Surveys. These groups are assisted by the VAAC′s and their host meteorological organizations. It′s a shared duty, especially once an eruption occurs. Here, we present on the real-time data collected, how the difference sources are analyzed together, examples of alert systems developed in these regions, an overview of the common information statement formats and color codes used, provide a discussion on how collaborations and communications occur during volcanic events, give examples of novel near real time techniques that have been applied specifically in these remote regions, and illustrate how the strong links between the three volcano observatories and the VAAC′s in the NOPAC region assist in the hazard assessment and provide an improved knowledge of the eruptive event.

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The 2011 – 2013 lava fountains of Mt. Etna forming volcanic ash clouds have represented a test case for observatory operations in support to aviation safety management

M. Coltelli[(1)], M. Prestifilippo[(1)], S. Scollo[(1)], G. Spata[(1)], D. Patane[(1)]

[(1)] *Istituto Nazionale di Geofisica e Vulcanologia, Catania, Italy*

Between 12 January 2011 and 27 April 2013 Etna produced thirty-eight basaltic lava fountains from a new volcanic vent opened on the volcano summit. The eruptive episodes were characterized by similar successions in which a paroxysmal phase, lasted on average about one hour, was preceded by mild strombolian activity and lava flow. Every paroxysm produced an eruption column ranging from a few up to eleven kilometers of height above sea level. The ash cloud contaminated the controlled airspace (CTR) of Catania and Reggio Calabria airports and caused tephra fallout on eastern Sicily sometime disrupting the operations of these airports.
In order to give prompt and precise warnings to the Aviation and Civil Protection authorities a novel system for monitoring and forecasting Etna volcanic plumes was put in operation since late 2008 at the Osservatorio Etneo (OE) of INGV, in Catania. Monitoring is carried out using multispectral (from visible to infrared) images of Meteosat satellite and ground-based video-surveillance cameras; signals of seismic and infrasound stations that are processed in real-time and finally a Doppler radar (Voldorad IIB) able to detect important features of the eruption column dynamic in all weather conditions. Forecasting is performed using automatic procedures that download weather forecast data from meteorological mesoscale models, run tephra dispersal models, plot hazard maps and publish them on a dedicated website. 24/7 OE-Control Room operators were able to timely inform Aviation and Civil Protection operators for an effective aviation safety management. Observed eruption plumes show a quite large range of physical characters, from weak to strong plumes, with respect to the comparable size of the eruptions. Achieved data are used to enhance the dispersal models also for a next, quasi real-time, forecasting system of the ongoing eruption (nowcasting) that will improve the management of air traffic and airport operations during future contingencies.

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Monitoring volcanoes in Iceland; an update

Sigrún Karlsdóttir [1], Melissa Anne Pfeffer [1], Þórður Arason [1], Hermann Arngrímsson [1], Sara Barsotti [1], Baldur Bergsson [1], Bergur H. Bergsson [1], Halldór Björnsson [1], Evgenia Ilyinskaya [1], Kristín Jónsdóttir [1], Ingvar Kristinsson [1], Sibylle von Löwis [1], Guðrún Nína Petersen [1], Matthew J. Roberts [1], Gunnar S. Sigurðsson [1], Kristín Vogfjörð [1], Richard Yeo [1], Hróbjartur Þorsteinsson [1]

[1] *Icelandic Meteorological Office, Iceland*

The Icelandic Meteorological Office is responsible for monitoring pre- and syn-eruptive volcanic activity, monitoring volcanic emissions in the atmosphere, and disseminating information. There are ∼32 active volcanic systems in Iceland. Pre-eruptive monitoring has emphasized seismic-, GPS-, strain-, tilt- and hydrological measurements. The network is being expanded and gas and infrasound measurements are now included. Air-borne eruption product monitoring is also being improved. The atmospheric monitoring system includes ∼210 weather stations, a mobile sounding station, and lightening detectors to provide meteorological properties inside and outside of an eruption cloud. Two fixed C-band weather radars and two mobile dual-polarization X-band radars are operated. Radars provide information on the maximum height and location of the eruption cloud, indicate emission rate, and may provide experimental products such as columnar ash concentration. Two scanning Lidars will arrive in November 2013. One will be fixed at Keflavík airport and one mobile. These may provide information on the location of air-borne ash, sphericity of particles, and cloud thickness. Seven ceilometers will retrieve cloud base height. Two particle counters will measure the concentration and ash size distribution at the ground. Fixed and mobile DOAS and MultiGas instruments may provide information on the emission rate of SO_2 and the ratios of other species. UV, visible and IR cameras will provide information on maximum cloud height and particle velocities within a cloud. Satellite products based on SEVIRI, AVHRR, MODIS and GOME-2 instruments will be used for determining the location of an eruption cloud and deposited products and to provide information about the ash and SO2 mass loading, cloud height, and ash effective radius. The EU FP7 project "Futurevolc- European volcanological supersite in Iceland: a monitoring system and network for the future"will lead to further improvements in IMO' s monitoring systems and will help IMO integrate the many streams of information.

FUTUREVOLC real-time tephra sampling: a state-of-the-art mobile laboratory to characterize eruptive dynamics and enhance ash-dispersal forecasting

Ármann Höskuldsson(1)

(1) *Institute of Earth Sciences, University of Iceland*

Tephra is a collective term typically used to indicate all particles that are ejected through the atmosphere during a volcanic explosive eruption, while volcanic ash refers to a specific grainsize (particles with diameter <2mm). Tephra deposits have been traditionally studied after emplacement in order to constrain physical parameters (i.e., erupted mass, plume height, mass eruption rate and eruption duration) and eruptive/fragmentation conditions (i.e., initial grainsize distribution, chemistry and particle morphology, textural features, density and vesicularity). This information is crucial to the characterization and the long-term hazard assessment of active volcanoes. However, ash-dispersal forecasting requires a real-time determination of eruptive parameters and conditions that is more complex to derive. FUTUREVOLC mobile laboratory is aimed at resolving this task. The laboratory is composed of: i) field based sampling beakers, ii) automated analogue balances and iii) light-weight transportable analytical equipment. The size and direction of the sector to be monitored is mainly controlled by plume height and wind advection, and, therefore, needs to be decided based on specific eruption and atmospheric conditions. Sampling beakers and automated balances are to place both downwind and crosswind with respect to the dispersal axis. The beakers serve as tephra samplers, while the balances provide information on mass loading with time. Light weight analytical instruments are also planned to be set up in the field in order to shorten the processing time. Currently they consist of: i) a particle-shape analyser that can accurately analyse more than 15.000 clasts in the size range between 350 and 5 μm within 10 minutes; ii) a scanning electron microscope that can perform chemical and particle shape analyses within 10-30 minutes from sample collection; iii) a hand held x-ray chemical analyser that can provide indications on magma compositional changes during the eruption. In this talk the concept of mobile laboratory shall be introduced.

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Ground-based imaging of volcanic plumes for mass flux

Sébastien Valade[(1)], Andrew J.L Harris[(2)]

[(1)] *University of Florence, Italy*
[(2)] *Laboratoire Magmas et Volcans, Université Blaise Pascal, Clermont Ferrand, France*

Although remote sensing techniques dedicated to the monitoring of volcanic emissions have continuously improved in recent years, quantitative assessment of source eruptive parameters (i.e., mass flux, exit velocity, particle size distribution and ash concentration) remains a major challenge. To this day, it is clear that no unique sensor is able to provide all of this information simultaneously. In turn, there is a priority need to integrate multiple observational techniques, in order to fully parameterize volcanic plumes and thus feed VATD models with appropriate inputs during times of crisis. With this in mind, an experiment was deployed on Stromboli in 2012, involving a wide range of ground-based remote sensing capabilities spanning microwave to ultraviolet wavelengths. Here we focus on the use of thermal infrared cameras and Doppler radar to extract particle mass flux. The Doppler radar (VOLDORAD) provides insitu measurements of both particle velocities and backscattered powered (proportional to particle size/number) in the region directly above the vent. Reconstruction of synthetic data sets allows us to unravel the internal dynamics of the eruptive jet, and combined with inversion algorithms, gives constraints on particle mass flux and exits velocities. On the other hand, thermal cameras provide a synoptic view of the plume rise. PlumeTracker, a user-friendly Matlab-based software, was designed to analyse this imagery data, and characterize the plume through time and space, yielding data on plume ascent velocity, spreading rate, and air entrainment. Using analytical 1D plume models in which electromagnetic radiation equations were introduced, synthetic radiometric images were simulated. These were then compared to the recorded video data (which was processed to obtain a mean image of the plume) to recover plume mass flux and particle size distribution.

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Remote Sensing of Volcanic Ash Plumes Using Microwave Scanning Weather Radars

Frank S. Marzano[1,2], Errico Picciotti[2,3], Mario Montopoli[2,4], Luigi Mereu[1], Gianfranco Vulpiani[5]

[1] *Dept. of Information Engineering, Sapienza University of Rome, Rome, Italy*
[2] *Center of Excellence CETEMPS, University of L′Aquila, L′Aquila, Italy*
[3] *HIMET, L′Aquila, Italy*
[4] *Dept. of Geography, University of Cambridge, Cambridge, UK*
[5] *Presidency of the Council of Ministers, Dept. of Civil Protection, Rome, Italy*

Microphysical and dynamical features of volcanic tephra due to Plinian and sub-Plinian eruptions, can be quantitatively monitored by using ground-based microwave weather radars. The methodological rationale and unique potential of this remote sensing technique is illustrated and discussed. Volume data, acquired by ground-based weather radars, are processed to automatically classify and estimate ash particle concentration and fallout. The physical-statistical retrieval algorithm is based on a backscattering microphysical model of fine, coarse, and lapilli ash particles, used within a Bayesian classification and optimal estimation methodology. The experimental evidence of the usefulness and limitations of radar acquisitions for volcanic ash monitoring is supported describing several case studies of volcanic eruptions all over the world. The radar sensitivity due to the distance, the system noise as well as the various radar bands and configurations (i.e., Doppler and dual-polarized) are taken into account. The discussed examples of radar-derived ash concentrations refer to the case studies of the Augustine volcano eruption in 2002, observed in Alaska by a S-band radar, the Grimsvötn volcano eruption in 2004 and 2011 and the Eyjaffjallajökull volcano eruption in 2010, observed in Iceland by a C and X band weather radar and compared with in situ samples and the Mt. Etna volcano eruption in 2011, observed by an X-band polarimetric radar. These applications demonstrate the variety of radar-based products, which can be derived and exploited for the study of explosive volcanism.

Four-dimensional distribution of the 2010 Eyjafjallajökull volcanic cloud over Europe observed by EARLINET

Lucia Mona[(1)], the EARLINET team

(1) *CNR-IMAA Consiglio Nazionale delle Ricerche, Istituto di Metodologie per l'Analisi Ambientale, Potenza, Italy*

EARLINET (European Aerosol Research Lidar NETwork) performed almost continuous lidar measurements during the Eyjafjallajökull eruption event in April–May 2010. The coordinated observations by EARLINET and a methodology that was specifically designed ad hoc for this event provided a detailed description of the 4D distribution of the volcanic cloud over Europe for the whole event. Geometrical properties of the volcanic cloud over Europe were provided with high vertical resolution (typically 60–180 m) in terms of base, top, and center of mass of the volcanic layer. A first volcanic layer was observed over Hamburg in the early morning of 16 April. In the following days the ash plume was observed over Central Europe and Belarus. Volcanic particles were observed over Italy on 20 April and over Greece on 21 April. The volcanic cloud was persistent over Central Europe for the whole period (15 – 26 April), with varying aerosol loads. Apparent descending aerosol layers were typically observed in all of Europe and intrusion into the PBL was commonly detected at almost each site. In May volcanic particles were detected over Spain and Portugal and then over the Mediterranean and the Balkans. Volcanic particles were observed over Central Europe until 25 May. Mixing of volcanic particles with other kind of aerosol (dust, continental and local) was identified. Mixing with Saharan dust was observed mainly during May for all Southern stations. The results about the 4D distribution of the volcanic cloud are reported in a specific relational database available on request through the EARLINET web site. Quantitative optical data collected by EARLINET for this event, including the specific relational database related to the geometrical properties of the volcanic cloud, represent a unique database for model evaluation, data validation, and integration.

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Characterization of eruption source parameters through infrasound

M. Ripepe[(1)], E. Marchetti[(1)], G. Lacanna[(1)]

[(1)] *Department of Earth Sciences, University of Florence, Italy*

Ash cloud forecasting strongly depends on eruptive source parameters (ESP) such as onset, locations, duration of the eruption and mass eruption rate (MER), which is typically inferred from plume height. Plume height estimates are affected by a certain degree of uncertainty, especially when the ascend dynamics is affected by the wind field with consequence on downwind ash concentration and total erupted mass. Infrasonic monitoring can help to reduce uncertainties on eruptive source parameters and providing this information in near-real-time. Volcanic gases rapidly expanding in the atmosphere produce pressure perturbations (infrasonic waves) which propagates for thousands of kilometers from the vent. Our ability to detect these pressure waves allows to define onset, location and duration of the eruption in near-real-time also at regional scale distance (>500 km). Using linear theory of sound we can explain acoustic pressure in terms of exit velocity of the eruptive cloud which can be converted into mass eruption rate using additional information on vent diameter and mixture density. At local scale (<100 km) acoustic amplitude is sensitive both to ground topography and to the wind field which should be considered when MER is acoustically derived and eventually converted into plume heights. The use of infrasonic monitoring is nowadays expanding and may lead to important understanding of the plume dynamics and allows for real-time determination of ESP. Infrasound could improve substantially the forecasting of volcano-related hazards, with important implications for civil aviation safety.

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Development of a System for Quantitatively Analysing Volcanic Clouds

Michael Pavolonis[1], Justin Sieglaff[2], John Cintineo[2]

[1] *National Oceanic and Atmospheric Administration (NOAA), NESDIS/STAR, Madison, WI, USA*
[2] *University of Wisconsin, Cooperative Institute for Meteorological Satellite Studies, Madison, WI, USA*

Previously developed methods for extracting quantitative information on volcanic clouds from satellite measurements have several important limitations that greatly reduce their significance for research and operational applications. No published method is capable of utilizing the entire volcanic cloud relevant space-based observing system to detect and characterize all major types of volcanic clouds (ash plumes/dispersed ash clouds, ice rich/opaque ash clouds, and SO2 clouds) with the exceptional skill needed for automated alerting, model validation, and real-time data assimilation applications. In an effort to contribute to the development of a comprehensive system for quantitatively analysing volcanic clouds in near real-time, the National Oceanic and Atmospheric Administration (NOAA), in collaboration with the University of Wisconsin, has developed new, globally applicable, techniques for automatically identifying volcanic clouds in satellite imagery with much greater skill than ever demonstrated in the literature. The NOAA algorithm suite also contains procedures for automatically retrieving important volcanic cloud properties relevant to modelling applications and alerting forecasters when a volcanic cloud is detected. The NOAA methods are applicable to any volcanic cloud relevant satellite sensor and can actually utilize combinations of satellite sensors to produce consistent, high quality, results. An overview of the NOAA volcanic cloud remote sensing methods will be given.

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Detection and quantification of volcanogenic sulphur dioxide using orbital, sub-orbital and ground-based instrumentation

I. Matthew Watson[(1)]

[(1)] *University of Bristol, U.K.*

Sulphur dioxide has been a species of interest to volcanologists for many decades. Those whose research focuses on physical volcanology, climate and aircraft hazard mitigation have used measurements of SO_2 -although in the latter case, most as a proxy for ash. The idea that SO_2 can act as a passive tracer for drifting ash clouds has been regularly challenged as, although SO_2 is arguably easier to detect and quantify, the two species do not necessarily spatially co-exist. It is interesting to note that the UK government are concerned enough about SO_2 in its own right to conduct pieces of work, currently ongoing, into infiltration into aircraft cabins (Department for Transport) and, specific to an eruption of a scale similar to Laki 1783, to both include it in the national risk register (Cabinet Office) as an extreme scenario and fund research into health and environmental effects (Department for Environment, Food and Rural Affairs). In this talk I will present a historical overview of SO_2 detection, discuss the state-of-the-art and look forward into the near future to see what technologies are currently being proposed and tested, within the current political context, as well as highlight the potential pitfalls of relying too heavily on SO_2 when considering ash clouds.

Models and experimental investigations of volcanic ash aggregation

S.J. Lane[(1)], J.S. Gilbert[(1)], M.R. James[(1)]

[(1)] *Lancaster University, U.K.*

Volcanic ash is generated during the fragmentation of magma. Primary magma fragmentation occurs as the continuous rock phase becomes discontinuous in response to large pressure gradients. Secondary fragmentation processes (for example, comminution during flow in the conduit, jet, column or gravity current) then act to further reduce particle size. The fracturing processes involved generate ions and charged silicate fragments. Once outside the eruption vent, radiation and air entrainment act to cool the flow and condense a complex soup of chemicals that act to stabilize aqueous liquids on the surface of ash particles. The erupting flow is, therefore, an environment highly conducive to the aggregation of ash particles both during and soon after the fragmentation process. The aggregation of ash particles leads almost exclusively to an increase in the sedimentation rate of fine-grained ash from the atmosphere. Neglecting aggregation within volcanic ash transport and deposition models (VAT-DMs) will: (1) overestimate the atmospheric mass loading of fine-grained ash subject to long-range transport, and (2) underestimate deposition of fine-grained ash close to the volcano. These systematic uncertainties are particularly acute where ash concentration and electrostatic effects are high and the volcanic environment dominates over the atmospheric. It is the ash particles and aggregates that escape proximal deposition that become available for long-range transport and deposition dominated by atmospheric processes. Here we briefly review the current conceptual and experimental understanding of ash aggregation in the presence of electrostatic forces and liquid films and discuss the consequences for ash transport and deposition.

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Ash particle aggregation governed by hydrometeor formation in volcanic clouds

Adam Durant[(1)]

[(1)] *Norwegian Institute for Air Research, Norway*

Aggregation (or coagulation) occurs in volcanic ash clouds during dispersion and transport in the atmosphere, and reduces the atmospheric lifetime of fine volcanic ash (particles <63 μm diameter). The aggregation process is typically inferred from observations of ash aggregates falling from ash clouds, or through analysis of tephra deposits at the surface. This observational-based evidence indicates cloud microphysical processes such as hydrometeor formation should be considered as a fundamental process that governs the rate of ash particle aggregation. Model simulations used to generate volcanic ash cloud dispersion forecasts include a description of the atmospheric emission source (fluxes and vertical distribution of products emitted by the volcano) and the "sink" (processes which drive particle removal through deposition). Since the eruption of Eyjafjallajökull in 2010, a notable advance in forecasting capability has included an approach to optimise the source term through model inversion constrained by satellite (and other) observations. However, if aggregation is not included in the description of the sink term, ash cloud dispersion forecasts will continue to under-predict rates of fine ash sedimentation and, consequently, will over-predict airborne ash concentrations, with the greatest discrepancies impacting far-field (1000s km from source) predictions. A two-step approach is required to address the current situation surrounding the ash sink. First, process-based understanding must be increased through field observation and laboratory experimentation to refine and validate theoretical models, which should also include cloud microphysical processes. The second step will involve parameterisation of process-based models of ash aggregation in order to be integrated into operational models used to generate "real-time" ash cloud forecasts. This talk aims to review field observation-based knowledge of ash aggregates and will present conceptual models for proximal and distal aggregate formation with an emphasis on the role of water and hydrometeor formation.

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Airborne in-situ measurements in volcanic plumes with light aircraft - examples of research flights during eruptions of Eyjfjallajökull, Grimsvötn, Etna, Stromboli and Sakurajima volcanoes

K. Weber[(1)], A. Vogel[(1)], C. Fischer[(1)], J. Eliasson[(1)], T. Palsson[(1)], N. Yasuda[(1)]

[(1)] *Duesseldorf University of Applied Sciences, Laboratory of Environmental Measurement Techniques, Germany*

A new approach of the Duesseldorf University of Applied Sciences (DUAS) for the measurement of volcanic plumes using light and microlight aircraft, equipped with optical particle counters, UV-DOAS instrumentation and FTIR sensors is presented in this paper. The small aircraft used in this study are equipped with durable and sturdy piston-motors in contrast to big jet-engine powered research aircraft. It could be proven, that these aircraft are an excellent means for exploring volcanic ash plumes as they can fly even at elevated ash plume concentrations, in cases when jet-engine powered aircrafts cannot fly because of possible failure or damage of the engines. Moreover, these aircraft are very cost effective and can be equipped with instrumentation in a short certification process. This became of high importance during the recent eruptions of the Icelandic volcanoes Eyjafjallajökull and Grimsvötn, when aircraft measurements became necessary at very short notice. Moreover, during the Grimsvötn eruption 2011 the aircraft measurement results of DUAS contributed significantly to the decision of the air navigation service provider ISAVIA in Iceland of re-opening of the international airport of Keflavik. This international airport had been closed before because of high ash concentrations predicted by the London VAAC model. As these light aircraft have proven to be very suitable for the investigation of volcanic plumes, they have been used by DUAS for studies of the emissions of aerosols and SO_2 at the volcanoes Etna and Stromboli during several research flights in the year 2011. Moreover, in 2013 ash plume flights have been performed directly in the plume of Sakurajima (Japan) volcano. By this means visibility within the plume could be related to the measured aerosol concentration. Additionally, SO_2-fluxes of the plume could be determined. Moreover, new aerosol measurement techniques and quality assurance issues will be addressed within this presentation.

VolcATS – Volcanic ash impact on the Air Transport System

Ralf Meerkötter[(1)], Stephan Kox[(1)], Hans Schlager[(1)], Daniel Sauer[(1)], Bernadett Weinzierl[(1)], Marius Schmidl[(1)], Josef Gasteiger[(1)], Ulrich Schumann[(1)], Florin Linke[(1)], Angela Schmitt[(1)]

[(1)] *DLR–Institute of Atmospheric Physics, Oberpfaffenhofen, Germany*

The volcanic eruptions of the Eyjafjallajökull in 2010 and the Grimsvötn in 2011 had large impact on aviation resulting in the most extensive restriction of the airspace over Europe since the end of World War II. More than 100.000 flights all over Europe were cancelled affecting more than 10 million passengers. The German Aerospace Center, DLR, with its research aircraft Falcon has performed 17 measurement flights during the Eyjafjallajökull providing different in-situ and lidar measurements of the volcanic ash plume during its drift from Iceland to the European continent. Based on these eruptive events and related activities the DLR project VolcATS - Volcanic ash impact on the Air Transport System- was initialized. The DLR-Institute of Atmospheric Physics is responsible for three main working packages in VolcATS: 1. The detection of volcanic ash, i.e. the development of a satellite-product identifying ash-contaminated as well as ash free regions with a related activity contributing to the ICAO working groups who deal with a solid definition of “visible ash”, 2. the evaluation of the satellite retrieval algorithm by utilizing already existing aircraft measurements (Falcon, e.g. Eyjafjallajökull) considering interfering effects of clouds (cirrus) and accessorily an investigation to which extent measurements during events of mineral dust breakouts can similarly be used for validation (Saharan Aerosol Long-range Transport and Aerosol-Cloud-Interaction Expertiment, SALTRACE), and 3. the development and test of small sensors measuring SO_2 and particles planned to be installed aboard airliners for warning the crew against unexpected intrusion into volcanic ash. The VolcATS project will be introduced on the basis of first and new results which have been achieved within the first year of the project. Finally ATM aspects will be mentioned and an outlook to project milestones for the next future will be given.

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Characterization of Eruption Source Parameters and Propagation of Errors in Transport and Dispersal Models

Marcus Bursik[(1)]

[(1)] *University at Buffalo, USA*

Uncertain initial volcanic conditions can be estimated from ground based observations of plume or clast speed and crater diameter, or from satellite observations of umbrella cloud and downwind plume spreading rates. Source parameters can been assigned probability distributions based on data characterizing our current knowledge. For windfields, ensemble methods allow the estimation of the probability density function of future states of the atmosphere by addressing uncertainties present in initial meteorological conditions and in model approximations. NCEP GEFS ensembles consist of 21 members and are run 4 times daily. The underlying model for the GEFS is the Global Forecasting System (GFS), a high-resolution spectral atmospheric model run 4 times daily. The probability distributions for input variables are sampled to yield the polynomial chaos quadrature weighted estimate (PCQWE) of output plume position and concentration. At each of the sample points for the input variables, 21 windfield model runs are performed. Output moments and probabilities are then computed by properly summing the weighted values of the output parameters of interest. For Eyjafjallajökull, careful source parameter estimation suggests that initial mass eruption rate on 14 April 2010 was almost certainly above 107 kg/s, which is consistent with the probabilistic envelope computed by PCQWE for the downwind plume. Our results show that statistical moments and probabilities can be accurately computed with as few as 161 Conjugate Unscented Transform (CUT) PCQWE model runs times 21 GEFS forecast members. Probabilistic ash cloud maps compare well with four-dimensional ash cloud position as retrieved from Meteosat-9 SEVIRI data for 16 April 2010 as the ash cloud drifted over north-central Europe.

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3D numerical simulation of volcanic plume dynamics and ash dispersal

Yujiro J. Suzuki[(1)]

[(1)] *Earthquake Research Institute, The University of Tokyo, Japan*

We are developing a 3-D numerical model which reproduces the dynamics of volcanic plume, the ash transport, and fallout deposits near the vent. Recently, particle-tracking models such as PUFF and advection-diffusion models such as TEPHRA2 and FALL3D try to forecast both particle concentration in the atmosphere and particle loading at ground level far from the vent. In these models, the source conditions (the plume height, and mass release level) should be given on the basis of 1D simplified models of bent-over plume (e.g., Bursik [2001]) which contains an empirical constant (entrainment coefficient related to the wind-caused entrainment). We try to determine the value of this entrainment coefficient and the other source conditions for tephra dispersion. We carried out a series of simulations of a small-scale eruption in various wind fields. The simulation results show that as the wind speed increases the mass of the entrained air increases and the plume height decreases. Through comparisons between the present results and the 1-D model predictions, we found that the preferable value of the entrainment coefficient related to the wind-caused entrainment is 0.2-0.3, which is substantially smaller than those suggested in previous works (0.3-1.0). The simulation results also indicate that the main mass release level of particles is lower than the total height of plume, and that it depends on the particle size. We confirmed that the present model correctly reproduces the plume height and ash fall area during the 2011 eruptions in Shinmoe-dake, Japan.

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Eruption Frequency and ESP uncertainty

Chuck Connor[1], Laura Connor[1], Koji Kiyosugi [2]

[1] *University of South Florida, USA*
[2] *Tokyo University, Japan*

Worldwide, tremendous progress has been made in recent decades in forecasting volcanic events, such as episodes of volcanic unrest, eruptions, and the potential impacts of eruptions. Generally these forecasts are divided into two categories. Short-term forecasts are prepared in response to unrest at volcanoes, rely on geophysical monitoring and related observations, and have the goal of forecasting events on timescales of hours to weeks to provide time for evacuation of people, shutdown of facilities, and implementation of related safety measures. Long-term forecasts are prepared to better understand the potential impacts of volcanism in the future and to plan for potential volcanic activity. Long-term forecasts are particularly useful to better understand and communicate the potential consequences of volcanic events for populated areas around volcanoes and for potential impacts on critical infrastructure, such as aviation. One any time scale, all volcanic hazard assessments rely on a geologically reasonable conceptual model of volcanism. Conceptual models are used to bound potential rates of volcanic activity, potential magnitudes of eruptions, and to understand temporal and spatial trends in volcanic activity. It is these conceptual models that provide essential justification for assumptions made in statistical model development and the application of numerical models to generate quantitative forecasts. It is a tremendous challenge in quantitative volcanic hazard assessments to encompass alternative conceptual models, and to create models that are robust to evolving understanding of specific volcanic systems by the scientific community. Especially for long-dormant volcanic systems, data from the geologic record may be sparse, individual events may be missing or unrecognized in the geologic record, patterns of activity may be episodic or otherwise nonstationary. This leads to uncertainty in forecasting long-term rates of activity. Examples of integration of geological models and statistical models for eruption frequency and eruption parameters will be provided.

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Compilation of a global eruption dataset with source parameters and observations for model validation

Larry G. Mastin(1), Costanza Bonadonna(2), Barbara A. Stunder(3), Arnau Folch(4), Peter Webley(5)

(1) *U.S. Geological Survey, Cascades Volcano Observatory, USA*
(2) *Section des sciences de la Terre et de l'environnement, University of Geneva, Switzerland*
(3) *National Oceanic and Atmospheric Administration, College Park Maryland, USA*
(4) *Barcelona Supercomputing Centre, Barcelona, Spain*
(5) *Geophysical Institute, University of Alaska, Fairbanks, Alaska, USA*

Since 2010 there has been an increased focus on improving the accuracy of dispersion models to forecast movement and concentration of volcanic ash clouds during eruptions. Accuracy can best be quantified by comparing model output with measurements of ash-cloud properties during eruptions, yet there is currently no database of observations, satellite retrievals, and source parameters from well-documented eruptions that can be used to validate dispersion models. In a joint effort between the IAVCEI Tephra Commission and the World Meteorological Organization's Volcanic Ash Scientific Advisory Group, we are developing a high-quality database of well-documented eruptions, with links to source parameters and data from satellite retrievals, lidar, and airborne measurements for validation studies of both atmospheric dispersal and ground sedimentation. Uncertainties of eruption source parameters will also be assessed and characterized. Starting from previous compilations of source parameters (e.g. Mastin, 2009, JVGR, 186:10-32, Table 1), we have selected events with good satellite and other observations of the downwind cloud, and added recent eruptions: Kasatochi 2008, Redoubt 2009, Eyjafjallajökull 2010, Grímsvötn 2011, Chaitén 2008, and Cordón Caulle 2011, among others. We are working with several institutions (and express gratitude to them) who are supplying observational data and high-quality numerical wind fields. Results will be posted at vhub.org and a web address for the location of these data will be provided at the time of this meeting.

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TANSTAAFL: issues to keep in mind when using multi-model ensembles

Stefano Galmarini(1)

(1) *European Commission/DG joint research center/ Institute for environment and sustainability*

In any other application field, multi-models ensembles are apparently providing better results than an individual deterministic model approaches. This is in general the case however it has been demonstrated, contrary to all expectations, that an increasing number of ensemble members produces and evident deterioration of the ensemble performance. The reasons for this have been investigated over the years and can to be found in the lack of model independence which is normally confused with model difference. The presentation will demonstrate the above mentioned concept in a number of application fields of atmospheric dispersion. Methodologies to inspect the ensemble and to retain only the relevant information will be presented. The paper will clearly demonstrate than in many cases ensembles are abused and that care has to be taken in the selection of the information and the models relevant for the case study. The JRC has been involved in ensemble dispersion analysis since 1999 and has a variety of case studies form short range point dispersion to hemispheric scale diffused dispersion, of passive to decaying to chemically active species. The analyses of these different cases has allowed us to collect elements common to all cases thus producing a general theoretical framework applicable to any other field.

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Inverse modelling of source term and data assimilation

Andreas Stohl[(1)] and the VAST team

[(1)] *NILU - Norwegian Institute for Air Research, Norway*

Inaccurate knowledge of the source term of a volcanic eruption is the major cause of uncertainty in the prediction of volcanic ash transport and the associated hazards for aviation. While a priori information about the eruption (e.g., eruption type, radar measurements of the eruption plume height, etc.) is useful, the remaining uncertainties in the total mass of fine ash emitted and its vertical distribution in the eruption column as a function of time are so large that quantitative prediction of mass concentrations is almost impossible without incorporation additional information. Satellite measurements of atmospheric ash mass loadings provide such information and this information can be used to derive information on the source term. This is a typical problem of inverse modelling, where unknown variables are retrieved indirectly from known variables by using a model to relate the known and unknown variables. This concept has proven valuable also for volcanic ash modelling. Data assimilation can further improve the situation by not only retrieving information about the source term, but by also correcting errors in the model. We will demonstrate the capacities of these methods at the example of the eruptions of Eyjafjallajökull and Grimsvötn.

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Improving ash cloud forecasts via Bayesian learning algorithms

Roger P Denlinger[(1)]

[(1)] *US Geological Survey, USA*

Clouds of volcanic ash resulting from volcanic eruptions may drift downwind for thousands of kilometers, depositing ash as they drift and creating lingering hazards for air travel and airports. As satellites can measure these clouds as they flow downwind, satellite data are used here to update and improve forecasts of future cloud locations. In previous work, Stohl et al. (2011) and Kristiansen et al. (2011) showed that during the eruptions of Eyjafjallajökull in 2010, satellite measurements of each ash cloud constrained a narrow range in the elevations at which ash from the plume fed the cloud (though this range varied between eruptions). Denlinger et al (2012) exploited this aspect to develop an approximate forecast method. As in the latter paper, I use Bayesian inference here to forecast volcanic ash clouds. Once a plume begins to feed an ash cloud, each subsequent satellite measurement of cloud load is used in a neural network learning algorithm to improve the posterior distribution from which a forecast is made. Beginning with a prior distribution of model input parameters, I incorporate each new satellite data set to include uncertainty and improve the posterior distribution. I compare two different methods for such Bayesian learning: the approximate forecast method of Denlinger et al (2012) and a method using Langevin Monte Carlo sampling. Using satellite data from the 2010 Eyjafjallajökull eruption, I show that both methods converge to very similar posterior distributions for data collected within hours after an ash cloud begins to form. Once near real-time satellite data of cloud loads become available, the approximate method (which assumes a dominant posterior peak exists) can rapidly forecast volcanic ash clouds and help mitigate their potential damage.

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Assessing the potential to observe volcanic ash clouds from space by combining volcanic plume simulations with microwave radiometric remote sensing data

Michael Herzog[1], Mario Montopoli[2], Domenico Cimini[2], Frank S. Marzano[2]

[1] *Cambridge Centre for Climate Science, Department of Geography, University of Cambridge, U.K.*
[1] *Centre of Excellence CETEMPS, University of L'Aquila, L'Aquila, Italy*

The potential of satellite passive microwaves sensors to provide quantitative information about near-source volcanic ash cloud parameters is assessed. To this aim ground-based microwave weather radar and spaceborne microwave radiometer observations are used together with forward model simulations. The latter are based on two-dimensional simulations with the numerical plume model Active Tracer High-Resolution Atmospheric Model (ATHAM), in conjunction with the radiative transfer model Satellite Data Simulator Unit (SDSU) that is based on the delta-Eddington approximation and includes Mie scattering assuming spherical particles. Quantitative correlation analysis between ATHAM/SDSU forward model columnar content simulations and available microwave radiometric brightness temperature measurements, derived from the Special Sensor Microwave Imager/Sounder (SSMIS), are encouraging in terms of both dynamic range and correlation coefficient. The potential to develop, evaluate and improve retrieval algorithms through numerical modelling is highlighted.

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Sulfur pollution from Icelandic volcanic eruptions

Anja Schmidt[(1)], Claire Witham[(2)], Kenneth S. Carslaw[(1)]

[(1)] *School of Earth and Environment, University of Leeds, LS2 9JT, Leeds, UK*
[(1)] *Met Office, FitzRoy Road, Exeter, EX1 3PB, UK*

The eruptions of Eyjafjallajökull in 2010 and Grímsvötn in 2011 in Iceland not only alerted European governments and the aviation industry to the risks posed by volcanic ash but also to those that could arise from "low-probability, high-impact" sulfur-dominated volcanic events such as the 1783–1784 CE Laki eruption (Iceland). It is widely recognized that volcanic gases such as sulfur dioxide can have detrimental effects on air quality and human health. Using a global aerosol model developed at Leeds (GLOMAP) together with volcanological datasets, we will show that volcanic gases and airborne particles could be a significant health hazard to the European population if a much longer-lasting, gas-rich eruption occurred in Iceland. In January 2012, these "Laki-type" eruptions were added to the UK National Risk Register of Civil Emergencies as a high priority risk with potentially widespread impacts on health, agriculture and transport. To date, it is virtually unknown whether and to what degree the aviation industry might be affected by volcanic sulfur dioxide or high sulfate aerosol concentrations at flight level following longer-lasting eruptions in Iceland. Using the NAME dispersion model, we will discuss and quantify sulfur dioxide and sulfate aerosol concentrations that might occur in the transatlantic flight corridors from eruptions of Eyjafjallajökull-magnitude and from equivalents scaled by a factor of 10 and 30 in terms of sulfur dioxide released into the atmosphere.

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Modelling strategies for particle aggregation in volcanic plumes

Antonio Costa[(1)]

[(1)] *Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Bologna, Italy*

Laboratory experiments, theoretical models, and field observations all indicate that aggregation of volcanic ash plays a fundamental role in the atmospheric transport of volcanic particles. Aggregates form from the combination of ash particle collision and sticking. Collision occurs where particles contact each other because of several processes such as differential sedimentation, Brownian motion, ambient fluid shear, turbulence. Electrostatic forces, especially in the proximal region before atmospheric processes have acted to reduce charge separation back to the molecular scale, significantly influence collision. Following collision, sticking is strongly enhanced by the presence of a liquid layer on the particle surface as well as electrostatic attraction under conditions of high surface resistivity. The combined collision and sticking probabilities give the aggregation probability, which varies with the sizes of the interacting particles and their local environment. It is known that ash particles have an increasing probability of being transported in aggregated form in both wet and dry environments as particle collision energies decline. The effect of aggregation can enhance sedimentation by an order of magnitude. Recent studies showed that fine ash particles can comprise up to half, or even more of, the erupted mass of explosively volcanism. For this reason the change in aerodynamic behavior caused by aggregation with respect to that of single component particles, can have a pivotal impact on the subsequent atmospheric transport and ground dispersal of ash ejected during explosive eruptions. Modelling particle aggregation in volcanic plumes in a quantitative way is extremely challenging. Several approaches, ranging from purely empirical parameterizations to the full solution of the Smoluchowsky equation, have been proposed. Here they will be discussed and reviewed.

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"VERTIGO" (FP7-PEOPLE-2013-ITN) volcanic ash: field, experimental and numerical investigations of processes during its lifecycle

Ulrich Kueppers(1)

(1) *Ludwig-Maximilians-University Munich (LMU), Germany*

Explosive volcanic eruptions are an unavoidable natural hazard: Volcanic ash, the ejected lethal mixture of crystals, lava, glass and older rocks, is the most far-reaching threat. In April 2010, the ash cloud from Eyjafjall volcano in Iceland, a comparatively small event, paralysed large parts of Europe for up to one week in a manner unique in history. The impact was dramatic: several million passengers were grounded due to closed air pace and decelerated or halted industrial production caused several billion Euros of estimated economic loss. This scenario was largely amplified by the quasi-Babylonian lack of understanding and interaction amongst volcanologists, meteorologists, atmospheric researchers, engineers, private sector and politics. This eruption was not a singular "accident": Europe has active volcanoes and is surrounded by others and must be prepared for similar future events. This requires a comprehensive and supradisciplinary approach to allow for an encompassing mechanistic and quantitative understanding of the physico-chemical processes during the lifecycle of volcanic ash: from formation in a volcano, through changes during the dispersal in the atmosphere to the impacts on life and society. VERTIGO will address this challenging issue with a unique and innovative portfolio of partners from academia, research institutes and the private sector from eight European countries. We will offer an outstanding platform for research and training for highly-skilled students with a background in geology/volcanology, petrology/chemistry, informatics, biology, toxicology, fluid dynamics and/or engineering. The research-through-training projects for 13 students accomplish the EUROPE–2020 strategy for a modern system of education. They will be educated in scientific and transferable skills, spiced with experience in private sector applications, to qualify for career opportunities in academia, research institutes, civil protection and private sector.

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The national Norwegian ash project

Birthe Marie Steensen[(1)], Michael Schulz[(1)], Agnes Nyiri[(1)], Nina Iren Kristiansen[(2)], Alvaro Valdebenito[(1)], Viel Ødegaard[(1)], Arve Kylling[(2)], Lisbeth Bergholt[(1)], Øystein Hov[(1)], Kjetil Tørseth[(2)]

[(1)] *The Norwegian Meteorological Institute, Norway*
[(2)] *NILU, Norway*

A three year Norwegian ash project is funded since October 2012 by the Norwegian ministry of transport and communications and Avinor, the operator of most of the civil airports in Norway. The project will be conducted by the Norwegian Meteorological Institute and NILU and aims to improve observations and modelling of volcanic ash in the Norwegian airspace. NILU has developed algorithms to determine the amount of ash in an observed satellite pixel. These algorithms are planned used for better ash cloud detection, and a better estimate of the ash cloud top temperature and surface temperature. In addition the possible use of satellite observations by IASI will be explored. A ceilometer funded by the project is also installed at the Norwegian Meteorological Institute in Oslo. One of the main goals of the project is to develop an operational ash transport model with improved rapidly adjusted emission calculations. The result of the project will have a forecast time up to 48 hours and have a high time and grid resolution for the Norwegian airspace. An operational version of the EMEP model called emergency EMEP (eEMEP) is already running twice a day at the Norwegian meteorological institute. This model will be improved by increasing the vertical resolution as well as an increase of the top height of the model to 30 km. Advanced ash parametrization will also be explored. By the end of the project the inversion technique developed at NILU will be operational at the Norwegian meteorological institute based on the EMEP model.

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UK MOD Volcanic Ash Research Programme

Varunjay Ahluwalia [(1)], Rory Clarkson [(2)]

[(1)] *UK Ministry of Defence, U.K.*
[(2)] *Rolls Royce Plc, U.K.*

The poster will give a summary of current UK MoD position regarding flights through VA. It will outline the ongoing and future research activities under Sense, Protect and Co-ordinate work streams. It will briefly describe the “way forward” with regards to identifying/quantifying the VA Hazard, defining operating limits and providing the data to inform management/technical procedures. Finally it will summarise the key challenges faced by the UK defence community.

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Operational demonstration services for volcanic ash prediction - activities of the Austrian Meteorological Service (ZAMG) as part of the ESA project VAST

G. Wotawa(1), D. Arnold(1), C. Maurer(1), N. Kristiansen(2), F. Prata(2), E. Sollum(1), K. Stebel(1), A. Stohl(2), C. Zehner(1)

(1) *Central Institute for Meteorology and Geodynamics, Vienna, Austria*
(2) *NILU, Norway*

The main objective of the ESA-funded project VAST is to enhance the use of Earth Observation (EO) data in volcanic ash monitoring and forecasting for civil aviation. The project aims at further exploring the suitability of EO data to identify ash in the upper airspace, and to improve volcanic ash forecasts based on atmospheric models by a seamless integration of inverse modelling and ensemble prediction approaches. While some of the methods applied are already well-established and considered as state-of-the-art in the scientific domain, it still remains to be proven whether they can be applied in an operational environment within the characteristic time/resources constraints. The demonstration system consists of a tool to start operational model simulations connected with a volcano database, a module to take into account the meteorological forecast spread (ensemble prediction system), a module to consider the spread between different prediction systems (atmospheric transport models from different institutions), and last but not least a volcanic ash emission estimator based on inverse modelling fed with EO data. After the end of the VAST project, the validated demonstration system will be available to VAACs and other users, and is also considered for operational implementation at ZAMG for national purposes.

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A University-Based Startup Company to Enable Near Real-Time Decision Making of Volcanic Hazards

Jonathan Dehn(1), Peter Webley(1)

(1) *V-ADAPT, Geophysical Institute, University of Alaska Fairbanks, USA*

As federal support for operational volcano remote sensing has waned, researchers have been forced to pursue other avenues of funding to support research and students. This research is critical at times of decreased support for monitoring, because satellite remote sensing offers the best synoptic coverage of volcanic activity for the least expense by utilizing existing satellite systems. Many universities have marketable intellectual property, these logically include tools to evaluate emergent volcanic activity, detect eruptions and hazards, track eruptive products, and perform post-eruption assessments. Many of these functions are well beyond the mandate of observatories and the Volcanic Ash Advisory Centers. With university backing, work like this can be successfully marketed in the private sector, supporting research and development. Given that most of the air travel industry is ultimately responsible to the safety of the passengers, equipment and cargo, these tools are designed to be integrated into their decision making process. V-ADAPT, Volcanic-Ash Detection, Avoidance and Preparedness for Transportation provides these tools, but does not perform monitoring of the world′s volcanoes. It allows the customers to evaluate the events for themselves. Four key areas have been identified, (1) forecasting, so a pre-made plan can be implemented when a volcano erupts, not first conceived; (2) detection of eruptive activity as soon as possible to trigger plan implementation; (3) tracking of the ash cloud using integrated satellite data and model feedback, and (4) the end of the eruption and detailed assessment of the response. V-ADAPT builds on the intellectual property developed over 15 years of federal support as part of the Alaska Volcano Observatory. These are marketed as individual modules, and customers can choose those that best fit their needs. Hopefully this approach will create a stable base for this research improving the response to volcanic events.

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NASA Volcanic Cloud Products for Aviation Hazard Mitigation

Simon Carn[(1)]

[(1)] *Michigan Technological University, USA*

Effective mitigation of volcanic hazards to aviation requires both robust detection of volcanic eruption clouds and accurate forecasting of ash dispersal. We report the status of several current NASA-funded efforts focused on these themes. Ingestion of near real time (NRT) satellite volcanic cloud data is vital for improving reliability of volcanic ash forecasts and minimizing risks of volcanic eruptions to aviation safety. NASA′s NRT volcanic products from the polar orbiting UV Aura/OMI (Ozone Monitoring Instrument) sensor are currently disseminated through the NOAA operational volcanic SO2/ash web site. Direct-broadcast (DB) OMI data received at the Sodankyla ground station are processed in real time at the Finnish Meteorological Institute (FMI) and disseminated at: http://omivfd.fmi.fivolcanic.html. The primary goal of NASA′s new volcanic hazards project is to expand collaboration with NOAA, USGS/Alaska Volcano Observatory (AVO) and FMI to ensure timely dissemination of satellite SO2 and volcanic ash data to decision support systems. Additionally, it will demonstrate the value of reduced data latency by utilizing DB volcanic cloud data downloads from the Suomi-NPP/Ozone Mapping and Profiler Suite (OMPS) sensor at ground stations in Finland and Alaska. The project is in an initial feasibility study phase to explore several improvements to the existing volcanic ash decision support systems in Alaska and Finland. Accurate forecasting of volcanic cloud dispersal is dependent on specification of the eruption source term, particularly the eruption duration, mass eruption rate and injection altitude or vertical profile. By combining information from satellite observations and numerical weather prediction (NWP) model simulations, crucial forecasting parameters can be better constrained to produce more accurate forecasts. NASA′s Goddard Earth Observing System model, version 5 (GEOS-5) is being used to forecast dispersion of volcanic emissions and observations from several satellites, including Suomi-NPP/OMPS, are being used to improve the accuracy of the GEOS-5 forecasts.

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Space-borne Operational Products for Volcanic Ash Cloud Monitoring in Argentina

Gloria C. Pujol [1,2], Guillermo Toyos [1], Monica Rabolli [1,2], Marisa Kalemkarian [1,2]

[1] *Servicio Meteorológico Nacional (SMN), Argentina*
[2] *Comisión Nacional de Actividades Espaciales (CONAE), Argentina*

Starting from the operational implementation at CONAE's Ground Segment of the concept of reverse absorption, an extensive review of the ash detection algorithms available has been carried out, which use features of the spectral behavior of both ash and SO_2 such as those present at 11.0 and 12.0, 8.5, 4.0 and 0.65 μm. We present here example applications of such algorithms on the eruptions of Puyehue Cordón Caulle Volcanic Complex and Volcán Chaitén in June 2011 and May 2008, respectively, and the results of a comprehensive statistical analysis of brightness temperatures, radiances and spectral indices using data captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the satellites TERRA and AQUA on the eruption of Puyehue Cordón Caulle Volcanic Complex in June 2011. The results of this analysis will facilitate the adjustment of the ash detection algorithms as well as the design of a classification scheme for the delineation of volcanic ash clouds. We also show examples of quantitative retrievals (i.e. mass loadings and concentration) by using the brightness temperature differences measured at 11 and 12 μm and a radiative transfer model that solves for the infrared absorption/scattering processes of the volcanic ash cloud. We look forward to completing these exercises for the eruption of Cordón Caulle and to extending it to other eruptions, to consider other space-borne sensors and in the middle/long term we aim at combining volcanic ash satellite retrievals with the application of volcanic ash transport and dispersion models. The ultimate aim is to make this kind of products operational at the Argentinean′s National Space Agency′s (CONAE) Ground Segment for further use by end users such as the Buenos Aires VAAC.

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The application of satellite data to support the London VAAC

Sarah Millington [1], Michael Cooke [1], Peter Francis [1], Roger Saunders [1]

[1] *Met office, U.K.*

Satellite data are widely used in the operational service of the London Volcanic Ash Advisory Centre, and applications are under continual development. Our main source of data is from SEVIRI on Meteosat giving 15-minute imagery covering much of our area of interest. From these data ash clouds are detected and tracked. Physical Properties including ash column loading, particle effective radii and ash cloud height are retrieved using a 1D-Var method. These data are presented to forecasters every 15 minutes as images and animations. The method employed in the retrievals is being extended to enable the information on mass loading and ash height to be incorporated into the ash dispersion forecasts using an inversion method. This enables the information contained in the satellite data to influence the source term in the dispersion model, thus improving the forecasting of ash dispersion. This method is currently being developed and is it hoped that it will soon be operational. A further tool has been developed to assist in the assessment of the quality of the ash dispersion forecasts; this is the development of simulated SEVIRI volcanic ash imagery. Ash concentration data from the ash dispersion model and NWP data are used to simulate radiances using the RTTOV radiative transfer model. The resulting output are displayed and compared to the measured values to identify model errors (e.g. location errors, source strength errors). Further developments in this area are looking at the large impact of the assumed particle size distribution and refractive indices on the simulated imagery. Data from polar orbiting satellites are also important, particularly to cover the arctic region. Ash clouds are detected and tracked using AVHRR and MODIS data in addition to the use of external UV-based products, and work is underway to make greater use of IASI data.

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A new approach on the detection of volcanic ash clouds

Stephan Kox [(1)], Marius Schmidl [(1)], Robert Buras [(1)], Josef Gasteiger [(1)], Hermann Mannstein [(1)], Ralf Meerkötter [(1)]

[(1)] *DLR-Institute of Atmospheric Physics, Oberpfaffenhofen, Germany*

The volcanic eruptions of the Eyjafjallajökull in 2010 and the Grimsvöttn in 2011 had large impact on aviation resulting in the most extensive restriction of the airspace over Europe since the end of World War II. More than 100 000 flights all over Europe were cancelled affecting more than 10 million passengers. In order to minimize the impact of such events with closed airspace and cancelled flights and to prevent hazards of volcanic ash to aircrafts a reliable detection of such eruptive volcanic ash clouds is necessary. In this work we present a new approach on the spaceborne detection of volcanic ash. Our algorithm detects ash-contaminated regions as well as ash-free regions utilizing the infrared brightness temperatures measured by SEVIRI with its high spatial and high temporal resolution. The algorithm, based on a Backpropagation Neural Network, is trained by simulated brightness temperatures for the SEVIRI channels which have been obtained from radiative transfer calculations (libradtran) [Mayer et al. 2009, Emde et al. 2011, Buras and Mayer 2011], representing a comprehensive range of different atmospheric conditions usually occuring as a function of latitude and season. In addition, and to account for volcanic eruptions and their manifold distributions of ash load, a broad range of particle concentrations for different ash types has been included in various layers of the model atmospheres. Beside the detection of ash-contaminated and ash-free airspace, the algorithm gives additional information on e.g. the accuracy of the classified regions and a mask of high clouds derived by the COCS algorithm [Kox 2012, 2011], which may cover the eruptive ash cloud, so that no clear classification can be processed. First examples and comparisons of detected volcanic ash and classified airspace are shown for the eruptions of the Eyjafjallajökull 2010, the Grimsvöttn 2011, and the Puyehue 2011.

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The APhoRISM project: MACE integrated approach for volcanic products

Luca Merucci [(1)], Stefano Corradini [(1)], Christian Bignami [(1)], Salvatore Stramondo [(1)], and the APhoRISM partners

[(1)] *INGV, Rome, Italy*

APHORISM project addresses the development of innovative products based on space and ground sensors and ground data to support the management and mitigation of the volcanic and the seismic risk. The objective of the project is to demonstrate that satellite remote sensing data and ground data, appropriately managed by means of novel methods, can provide new and improved products able to be used by the stakeholders for managing volcanic and seismic crisis and, stemming from a wider exploitation of available instruments, to achieve new performances in terms of accuracy and quality of information. APHORISM project proposes the development and testing of two new methods to combine in a fruitful way Earth Observation satellite data from different sensors and ground data. The first method involves the development of remote sensing methods related to monitoring volcanic crisis. The second one concerns the generation of products dealing with seismic crises events. Concerning volcanic crisis, the outcome is the Multi-platform volcanic Ash Cloud Estimation (MACE). The MACE method will exploit the complementarity between GEO (Geosynchronous Earth Orbit) sensor's platform, LEO (Low Earth Orbit) satellite sensors and ground measurements to improve the ash detection and retrieval and to fully characterize the volcanic ash clouds from source to the atmosphere. The basic idea behind the proposed method consists to meaningfully improve (calibrate and integrate), in a novel manner, the volcanic ash retrievals at the space–time scale of typical geostationary observations using both the LEO satellite estimations and in-situ data. The typical ash thermal infrared (TIR) retrieval will be integrated by using a wider spectral range from visible (VIS) to microwave (MW) and the ash detection will be extended also in case of cloudy atmosphere or steam plumes. APHORISM methods have been defined in order to provide products oriented toward the next ESA Sentinels satellite missions.

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Inverting for hourly volcanic SO_2 flux using plume satellite imagery and chemistry-transport modelling: application to the 2010 Eyjafjallajökull eruption

M. Boichu [1], L. Menut [1], D. Khvorostyanov [1], L. Clarisse [2], C. Clerbaux [2,3], S. Turquety [1], P-F. Coheur [2]

[1] *Institut Pierre Simon Laplace (IPSL), Laboratoire de Météorologie Dynamique, Ecole Polytechnique, Paris, France*
[2] *Spectroscopie de l'Atmosphere, Service de Chimie Quantique et Photophysique, Université Libre de Bruxelles, Brussels, Belgium*
[3] *Université Pierre et Marie Curie (Univ. Paris 06), Université Versailles St-Quentin, CNRS/INSU, LATMOS-IPSL, UMR8190, Paris, France*

Depending on the magnitude of their eruptions, volcanoes impact the atmosphere at various temporal and spatial scales. The volcanic source remains the major unknown to rigorously assess these impacts. At the scale of an eruption, the limited knowledge of source parameters, including time-variations of erupted mass flux and emission profile, currently represents the greatest issue that limits the reliability of volcanic cloud forecasts. However, various satellite and remote sensing observations of distant plumes are available today and indirectly bring information on these source terms. Here, we develop an inverse modeling approach combining satellite observations of the volcanic plume with an Eulerian regional chemistry-transport model (CHIMERE) to better characterise the volcanic SO_2 emissions during an eruptive crisis. The 2010 Eyjafjallajökull eruption is a perfect case-study to apply this method as the volcano emitted substantial amounts of SO_2 during more than a month. We take advantage of the SO_2 column amounts retrieved from a vast set of observations by the IASI (Infrared Atmospheric Sounding Interferometer) instrument on board the METOP-A satellite to reconstruct retrospectively the time-series of the SO_2 flux emitted by the volcano with a temporal resolution of about 2 hours, spanning the period from 1 to 12 May 2010. The initialisation of chemistry-transport modelling with this reconstructed source allows a reliable simulation of the evolution of the long-lived tropospheric SO_2 cloud over thousands of kilometres. Heterogeneities within the plume, which result from the temporal variability of the emissions, are also correctly tracked over a time scale of a few days. The robustness of our approach is also demonstrated by the broad similarities between the SO_2 flux history determined by this study and the ash discharge behaviour estimated by other means during the phases of high explosive activity at Eyjafjallajökull in May 2010. Finally, we show how a sequential IASI data assimilation allows for a substantial improvement in the forecasts of the location and concentration of the plume compared to an approach assuming constant flux at the source. As the SO_2 flux is a good indicator of the volcanic activity, this approach is also of interest for volcanologists to monitor from space poorly instrumented volcanoes.

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Volcanic ash and SO_2 retrievals using multispectral satellite sensors in the thermal infrared spectral range: error assessment and perspectives

S. Corradini (1), L. Merucci (1), W. Di Nicolantonio (2), A. Cacciari (2)

(1) *INGV-Roma, Italy*
(2) *CGS-OHB, Bologna, Italy*

The 2010 Eyjafjallajökull (Iceland) eruption established the changing from the "zero tolerance" approach (no flight permitted in the areas of volcanic ash presence) to the "ash threshold" approach (flights not permitted in the areas where the volcanic ash concentration is higher than 2 mg/m^3). In this new perspective an accurate and reliable quantitative determination of the ash present in a volcanic cloud become of primary importance. Together with ash, SO_2 is another important volcanic species to be monitored because it is supposed to have long term effects on aircraft engines and because It is used as proxy for volcanic ash when this latter is undetectable. In this work the procedure for the simultaneous retrievals of ash (mass, aerosol optical thickness and effective radius) and SO_2 retrievals in the volcanic clouds using multispectral satellite measurements in the thermal infrared (TIR) spectral range are presented. A retrievals error assessment, due to the different input parameters uncertainties, will be shown with particular emphasis on ash optical properties. The retrievals are realized by using the measurements collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Spin Enhanced Visible and Infrared Imager (SEVIRI), aboard the NASA polar satellites Terra and Aqua and the EUMETSAT geostationary satellite MSG respectively. As test case some events of the 2010 Eyjafjallajökull (Iceland) eruption and Etna (Italy) 2011–2012 activity are considered. Finally, the future perspectives of the satellite multispectral measurements with particular emphasis on the way towards the further improvements of the volcanic ash and SO_2 estimations will be discussed.

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Estimating the ash and SO_2 source terms for the 2011-Grimsvötn eruption – for improved volcanic cloud forecasting

E. Moxnes [(1)], N.I. Kristiansen [(1)], A. Stohl [(1)], L. Clarisse [(2)], A.Kylling [(1)]

[(1)] *NILU-Norwegian Institute for Air Research, Norway*
[(2)] *Spectroscopie de l'Atmosphére, Service de Chimie Quantique et Photophysique, Université Libre de Bruxelles, Brussels, Belgium*

The eruption of the Grimsvötn volcano in May 2011 released large amounts of both ash and sulphur dioxide (SO_2) into the atmosphere. The source terms for the emissions play a significant role in the model predictions for the transport of the eruption clouds, particularly for the aviation hazard and for assessing the potential climate impact. An inversion technique has been applied to estimate the source term for both SO_2 and ash from the Grimsvötn eruption using modelled a priori emission scenarios and satellite observations from the SEVIRI and IASI instruments to constrain the emissions. The Grimsvötn eruption is a particularly interesting case because it was evident from satellite observations that the SO_2 was transported mostly northwards from the volcano while the ash was transported southwards. This point to the fact that the source terms likely are quite different and the inversion technique is tested for whether it can re-produce the differences in the source term and transport characteristics. The results are then validated by using independent observation data from other satellite instruments and ground-based observation data.

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Towards real-time measurements of tephra fallout grain-size distribution

Emanuele Marchetti [(1)], Pasquale Poggi [(1)], Costanza Bonadonna [(2)], Armann Hoskuldsson [(3)]

[(1)] *University of Firenze, Italy*
[(2)] *University of Geneva, Switzerland*
[(3)] *University of Iceland, Iceland*

Particle size controls the particle residence time in the atmosphere. As a result, an accurate estimation of ash concentration in the atmosphere based on numerical modelling requires an accurate description of grainsize. The grain size distribution of the material injected into the atmosphere can be inferred from the grain size distribution of fallout material deposited at various distance from the eruptive vent, which is typically derived after the explosive event. Here we show how total grainsize distribution can be derived in real time in order to better describe the source term and improve the accuracy of real-time ash dispersal forecasting. In the framework of the FP7 EU project (FUTUR-EVOLC), a field instrument for real-time automatic measurement of grain-size distribution of fallout material is currently being developed, by a SME based in Italy (Item s.r.l.) under the supervision of three other project partners (University of Geneva, University of Iceland, University of Firenze). The instrument is currently calibrated in the laboratory and will be delivered as a prototype by April 2014. The instrument design consists of a laser unit for grain-size distribution and a collector where the weight and the height of material fallout are measured automatically. The laser (wavelength 635 nm / red) emits a linear beam and is detected by a linear array of photo detectors (2048 sensors 14μm x 14μm) 5 KHz. Grain size and terminal velocity are obtained from the shadows of single particles crossing the beam, assuming particle spherical shape. Cumulative distributions are provided every 15 minutes as the mean of 15 measurements of 10 second duration. Detectable grain size is as low as 50 μm diameter. Simultaneously, weigh (with a resolution of $\approx$0.1 g) and thickness (resolution of $\approx$1 mm) of fallout material accumulated in the collector is provided. Data are GPS time stamped and made available for remote data transmission for real-time monitoring.

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Incorporating field measurements of ash aggregation into high-resolution eruption column models: insights for faster-running treatments

Alexa R. Van Eaton [1,2], Larry G. Mastin [1], Kristi L. Wallace [3], Hans F. Schwaiger [3], David P. Schneider [3], Michael Herzog [4], Amanda B. Clarke [2]

[1] *U.S. Geological Survey (CVO, Vancouver USA)*
[2] *School of Earth and Space Exploration, Arizona State University, USA*
[3] *U.S. Geological Survey (AVO, Anchorage USA)*
[4] *Centre for Atmospheric Science, University of Cambridge, U.K.*

We present an integrated dataset combining information from field deposits, remote sensing and eruption column modeling of the 2009 eruptions from Redoubt volcano, Alaska. The nineteen major ash-generating explosions between 15 March and 4 April, 2009, deposited a bulk ash volume of approximately 0.05 km3. Events 5 and 19, in particular, were imaged with high-resolution satellite, airborne thermal infrared and Doppler radar data, and linked with field deposits to establish the spatial distribution and structure of the volcanic plumes. Owing to the short duration and relative simplicity of the eruption style (compared to the complex, long-lived eruptions of EyJafjallajökull in 2010), and the detailed deposit grain size measurements (including distributions of whole-aggregate diameters at varying distances from source), this case study represents a superb scenario for calibration and intercomparison of aggregation models that are being actively developed globally. A key focus of this study is to establish the impact of magma-water interaction, followed by abundant proximal ash aggregation, on the overall ascent of the volcanic clouds and corresponding ash transport. Additional near-vent processes, such as partial column collapse and interaction between buoyant and non-buoyant cloud components are also assessed. Simulations using the Active Tracer High-resolution Atmospheric Model (ATHAM) provide insights into the microphysical structure of the Redoubt clouds, highlighting links between the volcanic and meteorological feedbacks (e.g., surface water versus atmospheric moisture and volcanic exit velocities versus ambient wind fields) involved in ash cloud injection, transport and fallout.

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PlumeRise - a web-tool for modelling volcanic plumes rising in a wind field

Mark Woodhouse [1], Chris Johnson [1], Andrew Hogg [1], Jeremy Phillips [1], Steve Sparks [1]

[1] *University of Bristol, U.K.*

Integral models of volcanic plumes can be used to estimate the source conditions during eruptions by comparing model predictions with observations. The simple mathematical structure of integral models allows solutions to be readily obtained, allowing an assessment of source and atmospheric controls to be made. We have formulated an integral model of volcanic eruption columns that utilizes meteorological observations to determine the trajectory of the plume motion. We demonstrate, for weakly-explosive eruptions, atmospheric conditions have a strong effect on the rise of the plume. In particular, atmospheric winds strongly influence the rise of volcanic plumes, with the wind restricting the rise height such that obtaining equivalent rise heights for a plume in a windy environment would require an order of magnitude increase in the source mass flux over a plume in a quiescent environment. In order to facilitate these calculations, we have developed a web-tool, PlumeRise. PlumeRise allows detailed meteorological profiles to be employed, and incorporates an inversion procedure to allow the source mass flux to be estimated from the plume rise height. We compare solutions of the plume model to observations of the plume from the 2010 eruption of Eyjafjallajokull, Iceland, provided webcameras and a lightning mapping array. The plume model can describe the trajectory and spreading of the plume and the comparisons can be used to infer values for the entrainment coefficients in the plume model. Furthermore, the comparison to direct observations allow estimates of the eruption source mass flux to be made.

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Do one-dimensional plume models improve estimates of mass eruption rate?

Larry G. Mastin [(1)]

[(1)] *U.S. Geological Survey, Cascades Volcano Observatory, USA*

Empirical relationships are commonly used to estimate mass eruption rate from plume height but can underestimate rates for small eruptions in windy conditions. 1-D plume models can incorporate atmospheric conditions, and are thought to give potentially more accurate estimates. To test this idea, I modified the 1-D plume model Plumeria (Mastin, 2007, G^3, v. 8, no. 3, (Q03014)) for cross winds by incorporating a term in the mass conservation equation for crossflow entrainment, and added equations for momentum conservation in x and y based on momentum of the entrained air. I then modelled 33 historical eruptions where plume height H was well observed, and where mass eruption rate (Mobs) could be calculated from mapped deposit mass and observed duration. The simulations considered wind, temperature, and phase changes of water. Input atmospheric conditions for the time and location of these eruptions were obtained from the NCEP/NCAR 50-Year Reanalysis 2.5 degree model. Simulations were run over a series of eruption rates to find the value (M_{wind}) that fit the plume height. Eruption rates also were estimated from simulations that ignored wind (M_{nowind}), and from the empirical relationship $M_{empir} = 140H^{4.14}$, rearranged from Mastin et al. (2009, JVGR v. 186, pp. 10-21, eq. 1). For these 33 eruptions, the standard error of the residual in log space (i.e. of $log(M_{xxx}/M_{obs})$) is about 0.53 for M_{wind}, 0.50 for M_{empir}, and 0.62 for M_{nowind}. The mean residual is 0.06 for M_{wind}, -0.07 for M_{empir}, and -0.25 for M_{nowind}. Thus for this dataset, the model that incorporates wind is slightly less accurate at predicting Mobs than the empirical curve, but does not systematically over-or underestimate it. The model that ignores wind is least accurate at predicting Mobs and systematically underestimates it by about 0.25 log units.

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Effect of wind on mass flow rate estimates and the column collapse condition of volcanic plumes

Wim Degruyter [(1)]

[(1)] *Georgia Institute of Technology, USA*

Understanding the style and magnitude of volcanic eruptions is necessary for optimal hazard assessment at volcanoes. We examine under what conditions explosive volcanic eruptions produce a buoyant plume and if so, how their rise height is related to the source mass flow rate. We particularly focus on the impact of the wind on eruption dynamics as it can (i) reduce the final height of the plume, (ii) be the dominant entrainment mechanism, and (iii) prevent a plume from collapsing. Here we investigate these three mechanisms using a one-dimensional plume model. We introduce dimensionless parameters to quantify each of these effects and propose a novel analytical expression that allows for fast assessment of mass flow rate of both vertically-rising and bent-over volcanic plumes as a function of their height, while first order physical insight is maintained. This new expression has important implications for current strategies of real-time forecasting of ash transport in the atmosphere. Currently, ash concentration in the atmosphere forecasted by VATDMs can only be constrained within a factor of ten. This is mainly due to the large uncertainty associated with the operationally used relations between plume height and mass flow rate, which are not adaptable to the variability of the eruption source and the atmosphere. We apply these findings to the 2010 Eyjafjallajökull eruption and find that (i) the wind determined the rise height of the plume (ii) the mass flow rate calculated based on the operationally used relations is underestimated by as much as one order of magnitude, and (iii) the wind enhanced the buoyancy of the plume, suppressing episodes of collapse that could have occurred in a still environment.

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Interactive numerical modeling of the atmospheric water cycle and volcanic ash aggregation

Baerbel Langmann (1)

(1) *Institute of Geophysics, University of Hamburg, KlimaCampus, Germany*

For improving the numerical modelling of volcanic ash atmospheric concentration by addressing volcanic ash aggregation processes and removal by wet deposition during long-range transport, an interdisciplinary approach by combining volcanic, meteorological, atmospheric and climate research is wishful. The application of the coupled on-line atmosphere-ash model REMOTE (Langmann et al., 2008; Langmann et al., 2010) is well beyond the current modelling strategy for volcanic ash dispersion and deposition as it offers the possibility to study feedback mechanisms between trace species and climate (Langmann, 2007). REMOTE explicitly determines cloud processes at every model time step so that e.g. ice formation on volcanic ash can directly alter precipitation formation. It is planned to use REMOTE to develop suitable algorithms for volcanic ash aggregation and wet deposition during long-range transport to be used in standard off-line volcanic ash forecast models. Neglecting volcanic ash aggregation mechanisms may lead to model results, which underestimate fine volcanic ash fallout and overestimate airborne ash concentrations during long-range transport.

Langmann, B., K. Zaksek and M. Hort, Atmospheric distribution and removal of volcanic ash after the eruption of Kasatochi volcano: A regional model study, J. Geophys. Res., 115, D00L06, doi:10.1029/2009JD013298, 2010.

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Langmann, B., A model study of the smoke-haze influence on clouds and warm precipitation formation in Indonesia 1997/1998, Atmos. Environ. 41, 6838–6852, doi:10.1016/j.atmosenv.2007.04.050, 2007.

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Comparison of volcanic ash cloud observations and model predictions

Helen Dacre [(1)]

[(1)] *University of Reading, U.K.*

During the crisis caused by the Eyjafjallajökull eruption a lot of data on the volcanic ash cloud became available, mainly from ground based Lidar and aircraft measurements. While the data was useful to the emergency response effort, to achieve maximum benefit the data needed to be analysed, compared with the model predictions, and appropriate lessons learnt regarding how much material was actually being emitted from the volcano and how much material survived the near source fall out processes (sedimentation of large particles, aggregation and sedimentation of fine ash, wash out etc.) to reach the far field. The poster will present examples of such analysis and show its role in the development of the ash modelling approach. The revised approach was deployed to good effect during the eruption of Grimsvötn in 2011.

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On-line coupling of volcanic ash and sulfate aerosols with global and regional meteorological models

Alex Martí [1], Arnau Folch [1], Oriol Jorba [1]

[1] *Barcelona Supercomputing Center - Centro Nacional de Supercomutación, Spain*

Large explosive volcanic eruptions can inject significant amounts of tephra and gaseous materials into the atmosphere inducing a multi-scale array of physical, chemical and biological feedbacks within the environment. The assessment of the tephra dispersion hazards is critical when determining local and regional environmental and socio- economic disruptions. Additionally, stratospheric sulfate aerosols generated from volcanic sulfur gases and fine ash particles might result in disturbance of the energy balance and chemistry of the atmosphere at a global scale. Effective models for forecasting the spatial and temporal distribution of volcanic ash and sulfate aerosols are necessary to assess the magnitude of these feedback effects, and they have become critical tools in addressing the scientific, economic and political issues associated with large volcanic eruptions. However, the magnitude of these feedback effects within the climate system still remains poorly documented.
In the frame of the NEMOH Network, we aim at validating the off-line hypothesis currently assumed by most tephra transport models, by analyzing the extent to which the near-source and regional meteorology is affected by dense ash clouds altering the radiative budget and the climate system in general. The first step of this 3-year project, is to compare the spatial and temporal distribution-sedimentation of volcanic ash outputs from the off-line FALL3D-TTDM with those on-line from the new non-hydrostatic Multiscale Meteorological model on a B grid (NMMB). For this purpose, the transport and sedimentation module for volcanic ash existing in the FALL3D model is coupled to a new version of the NMMB model. This poster summarizes the capabilities, limitations, and sources of uncertainty from modelling ash dispersal for large volcanic eruptions, both off and on-line with meteorological models.
The NMMB model is the evolution of the WRF-NMME meteorological model. The BSC is also implementing an on-line gas-aerosol chemical module to model sulfate aerosols generated during large explosive volcanic eruptions and evaluate their impact within the climate system.

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A new web site for running HYSPLIT for volcanic ash

Barbara Stunder [(1)], Steven Albersheim [(2)]

[(1)] *National Oceanic and Atmospheric Administration, Office of Oceanic and Atmospheric Research, Air Resources Laboratory, USA*
[(2)] *Federal Aviation Administration, Washington, DC, USA*

The HYSPLIT transport and dispersion model is used operationally by the NOAA National Weather Service to support the U.S. VAACs. In addition, NOAA Air Resources Laboratory has provided the opportunity for users to run HYSPLIT on the web in a non-operational setting, and produce ”VAFTAD-format” output (8 panels per page, 4 layers by 2 valid times). A new web interface to run HYSPLIT for volcanic ash has been developed that produces "HYSPLIT-format“ graphics (1 panel per page). This allows improved graphical depiction of ash at individual output layers / times. In addition, there is more flexibility in terms of eruption source parameters, the output fields, and output layers than the VAFTAD-format web-based run capability. The initial mass of ash in the eruption column defaults to 1 unit, however users can enter the appropriate value or use the Mastin et al. (2009) relationship between height and mass eruption rate. A linear (uniform) distribution in the vertical is the default, but a Suzuki distribution is available. The four particle size bin GSD may be user-specified. Up to six user-defined output layers are possible. Output may be concentration, deposition, or ashfall, which may be output as time-average or instantaneous values. A three dimensional depiction of the model particles with time is also produced. Available output graphics formats are GIF, PDF and Google Earth/Maps. An example is shown in the poster.
Planned R&D includes promoting global harmonization to minimize differences in the provision of volcanic ash information to the aviation community, improving quantitative ash forecasts, both in terms of eruption source parameters (ESP) and inverse modeling, and participating in the development of a volcanic ash dispersion model evaluation database (see Mastin et al, this workshop) to enhance confidence levels in the model output. This research is in response to requirements and funding by the Federal Aviation Administration (FAA).

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Did the 2008 eruption of Kasatochi cause the 2008 North Pacific phytoplankton bloom?: Insights from fallout modelling

Hans F. Schwaiger [(1)], Christopher F. Waythomas [(1)], Gary Drew [(1)], Christian E. Zimmerman [(1)]

[(1)] *Alaska Volcano Observatory / U.S.G.S, USA*

Much of the North Pacific is a high-nutrient, low-chlorophyll (HNLC) region where biological activity is limited by the amount of iron available. Volcanic ash has been identified as a potentially significant source of bioavailable iron for these HNLC regions. The August 2008 eruption of Kasatochi volcano in the Aleutian Islands of Alaska was followed by a widespread phytoplankton bloom across the NE Pacific. This eruption has been implicated as the likely cause of the bloom and potentially the cause of subsequent increases in salmon returns. Simulations of ash fall using Ash3d indicate that this eruption produced only limited fallout over the North Pacific Ocean. Our analysis of the ash fall associated with the eruption shows that it is unlikely that a sufficient amount of ash fall occurred over a large enough area to instigate a phytoplankton bloom as extensive as the one observed in late August, 2008. Our results suggest that only very large (and rare) eruptions are capable of producing the ash volumes needed for widespread dispersal and impacts to the surface ocean.

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A new model for the predication of drag of non-spherical volcanic particles

Gholamhossein Bagheri[(1)]

[(1)] *Department of Earth Sciences, University of Geneva, Switzerland*

We present a new model for the prediction of the drag of non-spherical solid particles of regular and irregular shape that travel in air. Reynolds numbers investigated are between 10 and 105 (i.e. laminar to turbulent regimes). The results are obtained from experiments performed on micron size particles in a falling column and on millimetric size particles suspended in a vertical wind tunnel. Both apparatus were designed and built at University of Geneva for the study of sedimentation and aggregation of volcanic particles. Particle shape factors are measured based on various methods existing in the literature and benchmarked against our experimental results. Shape factors are calculated with different instruments depending on the size of particles such as 3D-scanning and image analysis. New easy to measure shape factors are introduced which have the highest correlation with the measured drag coefficient of particles. Performance of the models is benchmarked against well-known spherical and non-spherical models. As an example, we have found that both existing spherical and non-spherical models can estimate settling velocity of volcanic particles with an average error of about 30%. We have also found that the effect of surface roughness on terminal velocity of non-spherical particles of millimetric size is almost negligible. Finally, we observed that secondary motions of particles are considerably higher at high Reynolds numbers. This implies that particles falling in the turbulent regime are better characterized by a range of terminal velocities instead of a single value especially in case of particles with high variation in their projected area. Our experimental benchmarks show that our new model is a reliable and easy to apply model for estimating drag coefficient of non-spherical particles of various shapes in a wide range of Reynolds number.

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Breaking magma: Controls on magma fragmentation and ash formation

K.V. Cashman [(1)], E.J. Nicholson [(1)]

[(1)] *University of Bristol, U.K.*

The 2010 eruption of Eyjafjallajökull highlighted many deficiencies in our understanding of explosive volcanic eruptions, not the least of which is the absence of a theoretical basis for estimating the amount of fine ash a given eruption might produce. To address this problem, we are working to link the dynamics of eruptions to the grain size of the deposits they produce. Our work to date suggests that simple models of bubble-bubble interaction can explain both the low ash content of Hawaiian-style eruptions and the high ash content and related fragmentation mechanisms in viscous low crystallinity magmas. More puzzling is the origin of fine ash particles in mafic eruptions that involve interactions between magma and surface water. I will present textural and morphological data from the recent eruptions of Eyjafjallajökull (2010) and Grimsvötn (2011), and on ash remobilised during a blizzard in March 2013 that contains both ash components. Grimsvötn ash is particularly interesting as it contains both dense (blocky and platy) and vesicular components that vary systematically in abundance as a function of grain size and transport distance. Not surprisingly, the fraction of vesicular particles drops dramatically when the grain size is less than the mean bubble size; of more interest is the increase in the fraction of vesicular particles with transport distance, and the corresponding increase in mean particle size with distance. This latter observation underscores the importance of particle density in determining its fall velocity. Our work on the Grimsvötn ash has led us to explore the role of thermal stresses in rapidly quenched glass using Prince Rupert′s drops (quenched glass beads that fail by self-sustaining fractures).

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A case analysis of volcanic ash dispersion when Mt. Baegdu is erupted

Eun-Suk Jang [(1)]

[(1)] *Hanzhong University, Republic of Korea*

Though Mt. Baegdu which located in the northern part of the Korean peninsula has known as an inactive volcano, now precursor phenomena of various eruptions are appearing. The eruption of Mt. Baegdu expected about 1000 years ago is approximately 50 times more than that of Vesuvius which swallowed Pompeii, and it′s estimated as the largest scale since A.D. In 35km away off the pond at the top Mt. Baegdu, more than 10m volcanic ejecta has been piled, In Hokkaido of 1,500km away off Mt. Baegdu, Mt. Baegdu′s volcanic ash layers have been found. If Mt. Baegdu is erupted, it′s expected to have great damage to South Korea and Japan as well as China and North Korea bounded by Mt. Baegdu, the spread of the ejected ash due to the volcanic eruption is expected to have an indirect effect on the air quality of the Korean peninsula. In this study, numerical experiments were performed using numerical models Weather Research and Forecast(WRF) and FLEXPART to analyze the impact on moving path of volcanic ash and the air quality of South Korea when Mt. Baegdu is erupted. Various eruption strength and weather conditions were considered since it was not possible to measure the strength of volcanic eruption of real Mt. Baegdu. The ash incoming from East Coast in the volcanic ash′s spread experiment according to eruption strength is concentrated along East coastline due to Taebaek Mountains′ shielding effect. In the analysis of the deposition by city within the Korean peninsula, the deposition of Gangneung, Daegu and Busan usually appeared high in the early according to the ash′s influx to the East Coast, and that of Seoul, Daejeon, Gwangju showed to increase after a certain period of time.

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Monitoring volcanoes in Iceland; an update

Sigrún Karlsdóttir [1], Melissa Anne Pfeffer [1], Þórður Arason [1], Hermann Arngrímsson [1], Sara Barsotti [1], Baldur Bergsson [1], Bergur H. Bergsson [1], Halldór Björnsson [1], Evgenia Ilyinskaya [1], Kristín Jónsdóttir [1], Ingvar Kristinsson [1], Sibylle von Löwis [1], Guðrún Nína Petersen [1], Matthew J. Roberts [1], Gunnar S. Sigurðsson [1], Kristín Vogfjörð [1], Richard Yeo [1], Hróbjartur Þorsteinsson [1]

[1] *Icelandic Meteorological Office, Iceland*

See Oral Abstract O1.2-13.

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GIS-based tool to support civil aviation management during explosive volcanic eruptions

C. Scaini [(1)], T. Bolic [(2)], L. Castelli [(2)], A. Folch [(1)]

[(1)] *Barcelona Supercomputing Center - centro Nacional de Supercomputación, Spain*
[(1)] *Università degli Studi di Trieste, Italy*

We present a software tool (yet under development) for short and long-term civil aviation management in case of explosive volcanic eruptions. The tool covers the needs of stakeholders involved in civil aviation management and interested in taking decisions based on a range of possible tephra dispersal scenarios and/or ash dispersal forecasts. The GIS-based tool allows to display hazard and vulnerability information, overlap maps to and estimate expected impacts (airports disrupted, routes cancelled, etc.). We present the structure of the tool underlining the scientific background and technical aspects of each element.
Hazard and vulnerability data are stored in a spatial database specifically designed to store deterministic and probabilistic data sources. The database has a central role for the risk management process, acting as a repository of maps to be used by the stakeholders for different purposes. To our knowledge, this is the first "ad hoc" database proposed to store information about tephra dispersal hazard and vulnerability.
The tool allows to overlap hazard and vulnerability data and estimate expected impacts through spatially-based rules. Vulnerability and impact assessments are implemented by means of plug-ins embedded in the GIS friendly interface. The analysis has been automated for the European air traffic management during explosive eruptions. Results are relevant for the long-term risk assessment in the European area. Regarding short-term, we present an example of application during an explosive eruption at an active Icelandic volcano.
This GIS-based tool improves civil aviation management by automating short and long-term analyses and making them faster and repeatable. Although this is only a prototype and still needs further development, the up-to-date work can be a relevant contribution to the scientific community.

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Integrated risk assessment of volcanoes in Iceland

Sigrún Karlsdóttir [1], Emmanuel P. Pagneux [1], Evgenia Ilyinskaya [2], Melissa Pfeffer [1], Sara Barsotti [1]

[1] *Icelandic Meteorological Office, Iceland*
[2] *British Geological Survey, U.K.*

An integrated risk assessment for volcanoes in Iceland started in the autumn of 2011. The main purpose of the assessment is to increase the resilience of the society and decrease its vulnerability. The work is organized in accordance with the risk assessment framework of the UN and WMO (www.unisdr.org). In the first phase (2012-2014) four projects are conducted; a) An appraisal of the current knowledge of the eruptive activity and potential hazards, b) Initial risk assessment of floods triggered by volcanic eruptions, c) Initial risk assessment of explosive eruptions in Iceland, d) Initial risk assessment of volcanic eruptions that may cause extensive damage to property, i.e. eruption in the vicinity of urban areas and international airports in Iceland. The first two projects have started and the last two will start in the summer and autumn 2013. In project a. the main outcome will be a catalogue with detailed information on each active volcano in Iceland freely available on the internet. In addition eruption precursors will be defined, and likely eruption scenarios will be described. The aim is to provide operational institutions with a support for decision making and to decrease their response time during a crisis. The overall objectives of task b. are to provide the Icelandic authorities with a comprehensive assessment of flood risk in areas prone to floods triggered by volcanic eruptions. Two test areas have been selected, Öreafajökull and Mýrdalsjökull, for which a set of flood hazard maps and flood risk maps will be developed in compliance with the guidelines formulated in the European Directive on the Assessment and Management of Flood Risks (2007/60/EC). The risk assessment will benefit from domestic and international research projects, e.g. FUTUREVOLC.

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Risk assessment for tephra dispersal and sedimentation: the example of four Icelandic volcanoes

S. Biass [(1)], C. Scaini [(2)], C. Bonadonna [(1)], K. Smith [(3)], A. Folch [(2)], A. Höskuldsson [(4)], A. Galderisi [(5)]

[(1)] *Section of Earth and Environmental Sciences, University of Geneva, Switzerland*
[(2)] *CASE Department, Barcelona Supercomputing Center, Spain*
[(3)] *University of Exeter, U.K.*
[(4)] *Nordic Volcanological Center, University of Iceland, Iceland*
[(5)] *Universitá Federico II di Napoli, Italy*

In order to assist the elaboration of proactive measures for the management of future Icelandic volcanic eruptions, we developed a new approach to assess the impact associated with tephra dispersal and sedimentation at various scales and for multiple sources. Target volcanoes are Hekla, Katla, Eyjafjallajökull and Askja, selected for their high probabilities of eruption and/or their high potential impact. We combined stratigraphic studies, probabilistic strategies and numerical modelling to develop comprehensive eruption scenarios and compile hazard maps for local ground deposition and regional atmospheric concentration using both TEPHRA2 and FALL3D models. New algorithms for the identification of comprehensive probability density functions of eruptive source parameters were developed for both short and long-lasting activity scenarios. A vulnerability assessment of socio-economic and territorial aspects was also performed at both national and continental scales. The identification of relevant vulnerability indicators allowed for the identification of the most critical areas and territorial nodes. At a national scale, the vulnerability of economic activities and the accessibility to critical infrastructures was assessed. At a continental scale, we assessed the vulnerability of the main airline routes and airports. Resulting impact and risk were finally assessed by combining hazard and vulnerability analysis.

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A multi-model approach to forecast volcanic ash dispersal at Mt. Etna: statistical analysis and evaluation of model outcomes

S. Barsotti [(1)], A. Neri [(1)], L. Nannipieri [(1)], S. Scollo [(2)], M. Coltelli [(2)], M. Prestifilippo [(2)], G. Spata [(2)], A. Costa [(3)], G. Macedonio [(4)]

[(1)] *Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Italy* now at *IMO, Iceland*
[(2)] *Osservatorio Etneo (INGV-CT), Italy*
[(3)] *Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Italy*
[(4)] *Osservatorio Vesuviano (INGV-NA), Italy*

Since 2008 a prototype system for the forecast of volcanic ash dispersal and deposition at Mt. Etna is running at INGV-Osservatorio Etneo. The system provides, on a daily basis, forecasting maps for three hypothetical pre-defined eruptive scenarios and displays them on a dedicated web-site. The maps are produced by three different dispersal codes and represent aerial ash concentration at specific altitudes, columnar content of ash and cumulative deposit on the ground. Model outcomes are then integrated to produce synthetic maps that could be used as early-warning information for aviation and airport operations.
Here we present a test of this multi-model system through a statistical analysis aimed at the evaluation of the precision and accuracy of the forecasting procedure. The analysis has been carried out in two steps: firstly, a statistical investigation of the model-dependent uncertainty characterizing the modelling capability is performed, then model outcomes are compared against the reconstruction of well-known eruptive events observed in the recent past. The three running numerical codes, named FALL3D, PUFF and VOL-CALPUFF, are based on different modelling approaches, different physical formulations of the dispersal process, as well as different numerical algorithms, and can offer independent representations of the phenomenon. Quantitative comparisons between different model results have been performed estimating key features of ash dispersal in the atmosphere. Some of the most important are the plume height, the main dispersal axis of the cloud, the ash cloud aerial extension and the concentration at specific distance from the source. A statistical analyses have been carried out on these parameters to discriminate between casual random and systematic differences between the models. Then, in order to validate the simulation outcomes, the models have been used to reconstruct specific dispersal events,for which an extended description of the eruption exists. The numerical results have been compared with measurements and observations thus allowing to evaluate the capabilities and limitations of each model. Furthermore, the efficacy of synthetic maps obtained considering the contributions of all models and integrated with different techniques is discussed.

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Improvement of Etna Volcanic Ash Monitoring and Forecasting

S. Scollo [(1)], F. Azzopardi [(2)], A. Boselli [(3)], M. Coltelli [(1)], R. Ellul [(2)], G. Leto [(4)], G. Pisani [(5)], M. Prestifilippo [(1)], G. Spata [(1)], N. Spinelli [(5)], X. Wang [(6)], R. Zanmar Sanchez [(4)]

(1) *Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Italy*
(2) *Physics Department, University of Malta, Malta*
(3) *CNISM and IMAA-CNR, Potenza, Italy*
(4) *INAF, Osservatorio Astrofisico di Catania,Catania, Italy*
(5) *CNISM and Dipartimento di Scienze Fisiche, Universitá di Napoli Federico II, Napoli, Italy*
(6) *SPIN-CNR and Dipartimento di Scienze Fisiche, Universitá di Napoli Federico II, Napoli, Italy*

Mount Etna, in Sicily, is the largest volcano in Europe and one of the most active in the world. Since 2011 Etna produced 33 lava fountains that formed eruption columns rising up to ten kilometres above the vent and dispersed volcanic ash toward the neighboring countries. Malta is collocated at the center of the Mediterranean, 100 km south of Sicily and is sometimes affected from the tephra fallout. Thanks to the support of a new project named VAMOS SEGURO (Volcanic Ash Monitoring and FOrecaSting between Sicilia and Malta arEa and sharinG of the resUlts foR aviatiOn safety), funded by PO Italia-Malta 2007-2013, the monitoring and forecasting of volcanic ash plumes at Etna was recently improved through: 1)The increase of monitoring locations where the volcanic plume features may be observed. They are the INAF astronomical observatories of Serra La Nave, the observatory of Comune of Montedoro (CL) and the Giordan lighthouse and Xewkija (Gozo) of University of Malta. The new sites are 7, 100 and 200 km far from the Etna summit craters.
2)The installation of new instruments in Gozo (an aerosol optical depth analyzer, microbalance, laser cascade instrument, meteorological stations, aethelometer) and the realization of an innovative Lidar system able to identify the area affected by volcanic ash and quantify the ash concentration in atmosphere.
3) An automatic forecasting system that produces dispersal maps for the region between Sicily and Malta. This system is an extension of the previously forecasting system at the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo.
New data taken at a considerable distance from the volcanic vent together with the forecasting of volcanic ash plumes will help to improve INGV observations and give ready answers to aviation authorities in Catania and Malta during Etna eruptions.

List of Participants

	Organizing Committee	Institution	Contact
1	Costanza Bonadonna	University of Geneva, Switzerland	Costanza.Bonadonna@unige.ch
2	Arnau Folch	BSC-CNS, Spain	arnau.folch@bsc.es
3	Sue Loughlin	BGS, UK	sclou@bgs.ac.uk
4	Matt Hort	VAAC London, UK	matthew.hort@metoffice.gov.uk
5	Peter Webley	University of Alaska Fairbanks, USA; AVO; WOVO	pwebley@gi.alaska.edu
6	Herbert Puempel	Aeronautical Meteorology Division, WMO	HPuempel@wmo.int

	Participant	Institution	Contact
7	Varunjay Ahluwalia	Ministry of Defence, UK	vahluwalia@mail.dstl.gov.uk
8	Nicole Asencio	VAAC Toulouse, France	Nicole.Asencio@meteo.fr
9	Gholamhossein Bagheri	University of Geneva, Switzerland	Gholamhossein.Bagheri@unige.ch
10	Sara Barsotti	Icelandic Meteorological Office, Iceland	sara@vedur.is
11	Sebastien Biasse	University of Geneva, Switzerland	Sebastien.Biasse@unige.ch
12	Marie Boichu	IPSL, France	mboichu@lmd.polytechnique.fr
13	Greg Brock	Meteorology netCDF Air Navigation Bureau, ICAO	gbrock@icao.int
14	Federico Brogi	University of Geneva, Switzerland	Federico.Brogi@unige.ch
15	Marcus Bursik	University at Buffalo, USA	mib@buffalo.edu
16	Elisa Carboni	University of Oxford, UK	elisa@atm.ox.ac.uk
17	Simon Carn	Michigan Technological University, USA	scarn@mtu.edu
18	Katharine Cashman	University of Bristol, UK	glkvc@bristol.ac.uk
19	Lieven Clarisse	Université Libre de Bruxelles, Belgium	Lieven.Clarisse@ulb.ac.be
20	Rory Clarkson	Rolls-Royce Civil Aerospace, UK	Rory.Clarkson@rolls-royce.com

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List of Participants

	Participant	Institution	Contact
21	Mauro Coltelli	INGV, Sezione di Catania, Italy	Coltelli@ct.ingv.it
22	Chuck Connor	University of South Florida, USA	chuck.connor@gmail.com
23	Stefano Corradini	INGV Roma, Italy	corradini@ingv.it
24	Antonio Costa	INGV, Sezione di Bologna, Italy	antonio.costa@bo.ingv.it
25	Julia Crummy	BGS, Edinburgh, UK	juli@bgs.ac.uk
26	Helen Dacre	University of Reading, UK	h.f.dacre@reading.ac.uk
27	Gabriel Damiani	VAAC Buenos Aires, Argentina	sovaacbue@smn.gov.ar
28	Cory Davis	VAAC Wellington, New Zealand	Cory.davis@metservice.com
29	Wim Degruyter	Georgia Institute of Technology, USA	wim_degruyter@msn.com
30	Jonathan Den	University of Alaska Fairbanks, USA	jdehnavo@gmail.com
31	Roger Denlinger	USGS - CVO, USA	roger@usgs.gov
32	Adam Durant	NILU, Norway	Adam.Durant@nilu.no
33	Nils Ek	VAAC Montreal, Canada	Nils.Ek@ec.gc.ca
34	Fabrizio Ferrucci	Open University, Milton Keynes, UK	Fabrizio.Ferrucci@open.ac.uk
35	Stefano Galmarini	EC/DG-JRC/IES	stefano.galmarini@jrc.ec.europa.eu
36	Magnús Gudmundsson	University of Iceland, Iceland	mtg@raunvis.hi.is
37	Marianne Guffanti	USGS, USA	guffanti@usgs.gov
38	Alexander Haefele	Office fédéral de météorologie et de climatologie MétéoSuisse, Switzerland	Alexander.Haefele@meteoswiss.ch
39	Michael Herzog	University of Cambridge, UK	mh526@cam.ac.uk
40	Charles Holliday	Air Force Weather Agency, USA	hollidac@offutt.af.mil
41	Armann Höskuldsson	University of Iceland, Iceland	armh@hi.is
42	Eun-Suk Jang	Hanzhong University, South Korea	breeze@empas.com
43	Sigrún Karlsdóttir	Icelandic Meteorological Office, Iceland	sigk@vedur.is
44	Jamie Kibler	VAAC Washington, USA	jamie.kibler@noaa.gov
45	Stephan Kox	DLR-Institut für Physik der Atmosphäre, Germany	Stephan.Kox@dlr.de
46	Nina Kristiansen	NILU, Norway	Nina.Iren.Kristiansen@nilu.no

	Participant	Institution	Contact
47	Ulrich Kueppers	Ludwig-Maximilians-University Munich, Germany	u.kueppers@lmu.de
48	Steve Lane	Lancaster University, UK	s.lane@lancaster.ac.uk
49	Baerbel Langmann	University of Hamburg, Germany	baerbel.langmann@zmaw.de
50	Peter Lechner	CMO of CCA New Zealand and Chairman of the ICAO International Airways Volcano Watch SG	Peter.Lechner@caa.govt.nz
51	Ian Lisk	WMO, WEZARD	ian.lisk@metoffice.gov.uk
52	Giovanni Macedonio	Osservatorio Vesuviano, Italy	macedon@ov.ingv.it
53	Emanuele Marchetti	University of Firenze, Italy	emanuele.marchetti@unifi.it
54	Alex Martí	Barcelona Supercomputing Center, Spain	alejandro.marti@bsc.es
55	Frank Marzano	University of Rome, Italy	marzano@diet.uniroma1.it
56	Larry Mastin	USGS - CVO, USA	lgmastin@usgs.gov
57	Ralf Meerkötter	DLR-Institut für Physik der Atmosphäre, Germany	Ralf.Meerkoetter@dlr.de
58	Luca Merucci	INGV, Sezione Roma, Italy	luca.merucci@ingv.it
59	Sarah Millington	Met Office, UK	sarah.millington@metoffice.gov.uk
60	Stephen Mobbs	University of Leeds and NCAS, UK	s.d.mobbs@ncas.ac.uk
61	Lucia Mona	CNR, Potenza, Italy	mona@imaa.cnr.it
62	Augusto Neri	INGV, Sezione di Pisa, Italy	neri@pi.ingv.it
63	Chris Newhall	Earth Observatory, Singapore	cnewhall@ntu.edu.sg
64	Jeff Osiensky	VAAC Anchorage, USA	jeffrey.osiensky@noaa.gov
65	Soledad Osores	Servicio Meteorologico Nacional, Buenos Aires, Argentina	soledad_osores@hotmail.com
66	Thorgeir Palsson	Reykjavik University, Island	tpalsson@hr.is
67	Mike Pavolonis	NOAA/NESDIS, USA	mpav@ssec.wisc.edu
68	Melissa Pfeffer	Icelandic Meteorological Office, Iceland	melissa@vedur.is
69	Rodney Potts	Darwin VAAC, Australia	r.potts@bom.gov.au
70	Daniel Ponzini	Federal Office of Civil Aviation, Switzerland	daniel.ponzini@bazl.admin.ch

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List of Participants

	Participant	Institution	Contact
71	Fred Prata	NILU, Norway	Fred.Prata@nilu.no
72	Gloria Pujol	Servicio Meteorológico Nacional,Buenos Aires, Argentina	gpujol@smn.gov.ar
73	Theo Rindlisbacher	Federal Office of Civil Aviation, Switzerland	Theo.Rindlisbacher@bazl.admin.ch
74	Maurizio Ripepe	Universitá di Firenze, Italy	maurizio.ripepe@unifi.it
75	Eduardo Rossi	University of Geneva, Switzerland	Eduardo.Rossi@unige.ch
76	Chiara Scaini	Barcelona Supercomputing Center, Spain	chiara.scaini@bsc.es
77	Hans Schlager	DLR, Germany	Hans.Schlager@dlr.de
78	Anja Schmidt	University of Leeds, UK	A.Schmidt@Leeds.ac.uk
79	Hans Schwaiger	USGS - CVO, USA	hschwaiger@usgs.gov
80	Simona Scollo	INGV, Sezione di Catania, Italy	scollo@ct.ingv.it
81	Birthe Steensen	Norwegian Meteorological Institute, Norway	birthems@met.no
82	Andreas Stohl	NILU, Norway	ast@nilu.no
83	Martin Stuefer	University of Alaska Fairbanks, USA	stuefer@gi.alaska.edu
84	Barbara Stunder	NOAA Air Resources Laboratory, USA	Barbara.Stunder@noaa.gov
85	Yujiro Suzuki	ERI, University of Tokyo, Japan	yujiro@eri.u-tokyo.ac.jp
86	Joerg Thurnheer	Federal Office of C. Aviation, Switzerland	Joerg.Thurnheer@bazl.admin.ch
87	Andrew Tupper	VAAC Darwin, Australia	A.Tupper@bom.gov.au
88	Tetsuyuki Ueyama	VAAC Tokyo, Japan	tetsu.ueyama@met.kishou.go.jp
89	Sebastien Valade	Universita di Firenze, Italy	valade.sebastien@gmail.com
90	Alexa Van Eaton	Arizona State University, USA	alexa.vaneaton@gmail.com
91	Matt Watson	University of Bristol, UK	Matt.Watson@bristol.ac.uk
92	Konradin Weber	Fachhochschule Düsseldorf, Germany	konradin.weber@fh-duesseldorf.de
93	Claire Witham	VAAC London, UK	Claire.witham@metoffice.gov.uk
94	Mark Woodhouse	University of Bristol, UK	mark.woodhouse@bristol.ac.uk
95	Gerhard Wotawa	National Meteorological Centre, Austria	gerhard.wotawa@zamg.ac.at

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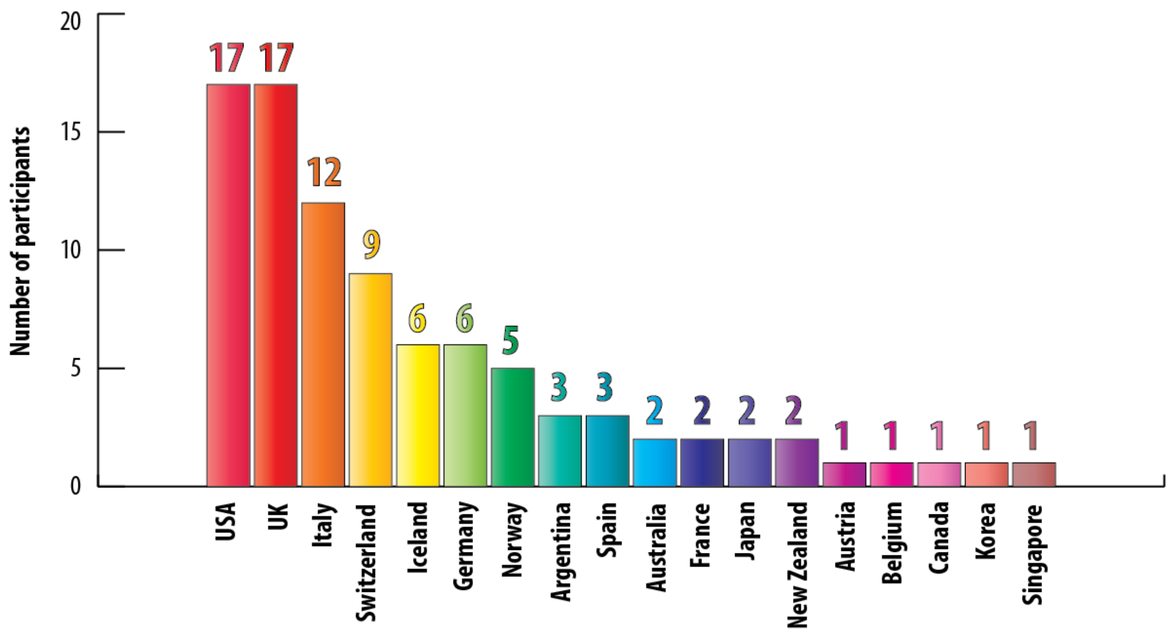
Statistics

The Workshop in numbers

- Number of oral contributions: 47
- Number of poster contributions: 32
- Number of participants: 95
- Number of represented countries: 18



Distribution of participants per country