ESA/EUMETSAT volcanic ash and aviation User Workshop, Dublin, 4-6 March 2013

Day 1 (4 March): Operational priorities

08:30–09:30 Registration, coffee

Session 1A: Operational priorities and user requirements
Claus Zehner (chair) / Fred Prata (co-chair)

09:30–09:45 Welcome and introduction

Mark Doherty [1]

1. European Space Agency, ESRIN, Frascati, ITALY

09:45–10:00 1A-1. The Volcanic Ash Strategic-initiative Team (VAST) – Advances in remote sensing of volcanic clouds

Fred Prata [1] and members of VAST [1,2,3,4,5]

1. Norwegian Institute for Air Research, Climate & Atmosphere Department, Kjeller, NORWAY
2. Finnish Meteorological Institute, Helsinki, FINLAND
3. Zentralanstalt für Meteorologie und Geodynamik, Vienna, AUSTRIA
4. National University of Ireland, Galway, IRELAND
5. Science & Technology Corporation, Oslo, NORWAY

A new ESA project has been established involving teams from four European countries to improve the quality and use of EO-based retrievals of volcanic ash in numerical atmospheric dispersion models for the purpose of assisting global aviation. All available 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 (VATM). An overview of the project is provided with an emphasis on the developments and improvements in our understanding of the radiative transfer for volcanic clouds applied to EO-based ash and SO_2 retrievals.

10:00–10:15 1A-2. Support to Aviation Control Service: overview

N. Theys [1], H. Brenot [1], L. Clarisse [2], J. Van Gent[1], R. van der A [3], P. Wang [3], R. Siddans [4], C. Poulsen [4], D. Balis [5], M. Koukouli [5], C. Zehner [6], M. Van Roozendael[1], P.-F. Coheur [2], D. Hurtmans [2], C. Clerbaux [7,2]

1. Belgian Institute of Spatial Aeronomy (BIRA-IASB), Atmospheric Composition Department, Brussels, BELGIUM
2. Université Libre de Bruxelles (ULB), Spectroscopie de l'Atmosphère, Service de Chimie Quantique et Photophysique, Brussels, BELGIUM
3. Royal Netherlands Meteorological Institute (KNMI), Climate Observations division, De Bilt, NETHERLANDS
4. Rutherford Appleton Laboratory (RAL), Earth Observation and Atmospheric Science Division, Chilton, UK
5. Aristotle University of Thessaloniki (AUTH), Laboratory of Atmospheric Physics, Thessaloniki, GREECE
6. European Space Agency (ESA-ESRIN), Frascati, ITALY
7. UPMC Univ. Paris 6; Université Versailles St.-Quentin ; CNRS/INSU, LATMOS-IPSL, Paris, FRANCE

The Support to Aviation Control Service (SACS; http://sacs.aeronomie.be) provides global near real-time data of volcanic ash and SO_2, as well as warnings in the form of e-mail notifications in case of volcanic eruptions. SACS is based on the combined use of UV-visible (OMI, GOME-2) and thermal infrared (IASI, AIRS) satellite instruments. In

this presentation we give an overview of SACS with a focus on recent developments of the system as for the detection and monitoring of volcanic plumes. The second part of the talk is dedicated to the SACS2 project. The main objective of SACS2 is to improve the existing Support to Aviation Control Service by developing algorithms to retrieve concentrations and heights of volcanic ash and SO_2 using polar-orbiting instruments.

10:15–10:30 1A-3. Study on an end-to system for volcanic ash plume monitoring and prediction – SMASH project overview

Lucia Tampellini [1], F. Ferrucci [2], **S. Tait** [2], S. Corradini [3],F. Buongiorno [3], E. Carboni [4], M. Sofiev [5], P. Valks [6]

1. CGS S.p.A. Compagnia Generale per lo Spazio (CGS), Via Gallarate, 150 20151 Milano, ITALY
2. Institut de Physique du Globe de Paris (IPGP), Paris, FRANCE
3. Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, ITALY
4. University of Oxford, Clarendon Laboratory, Oxford, UK
5. Finnish Meteorological Institute, Helsinki, FINLAND
6. German Aerospace Center, Remote Sensing Technology Institute, Wessling, GERMANY

The SMASH project has started its activity recently, in September 2012, as part of the General Studies Programme of the European Space Agency. SMASH is led by CGS SpA, and relies on the partnership of two Volcano Observatories (the “Institut de Physique du Globe de Paris” -IPGP – and the “Istituto Nazionale di Geologia e Vulcanologia” of Rome –INGV) and three scientific institutions: the University of Oxford, the Finnish Meteorological Institute and the German Aerospace Center. The broad scope of SMASH is the exploitation of current polar-orbiting satellite instruments for retrieval of quantitative measurement of volcanic SO2 and ash clouds parameters, such as: concentration, height, particle size distribution. In particular, main objectives of SMASH, to be achieved in a time frame of 18 months, are the following: 1) development of innovative satellite information products characterizing significant geophysical parameters at the eruption source; 2) development of innovative satellite information products for quantitative retrieval of volcanic ash and SO2 plumes; 3) definition of an optimal end-to-end system for volcanic ash monitoring and prediction for Europe, based on the existing remote sensing infrastructure.

10:30–10:45 1A-4. EUMETSAT volcanic ash products

M. Doutriaux-Boucher [1], M. Koenig [1], H.L. Lutz [1], and M. Grzegorski [1]

1. EUMETSAT, Remote Sensing and Product division, Darmstadt, GERMANY

EUMETSAT operates four geostationary (Meteosat) and two polar orbiting (Metop) satellites. A real-time operational volcanic ash product is currently produced at EUMETSAT based on an algorithm developed by F. Prata. The first part of the presentation will present the current EUMETSAT operational product emphasing on its main strengths and weaknesses using few examples of recent volcanic activities. The second part of the talk will detail some of the future enhancements foreseen for the existing volcanic ash product as well as new volcanic ash products based on the third generation of geostationary satellites and on polar observing satellites.

10:45–11:10 Coffee break

Session 1B: Operational priorities and user requirements

Adam Durant (chair) / Colin O'Dowd (co-chair)

11:10–11:30 1B-1. A Civil Aviation Safety Regulator’s perspective (IAA)

Eamonn Brennan [1]

1. Irish Aviation Authority, Dublin, IRELAND

This presentation will centre on the key regulatory risks associated with volcanic ash incidents. Issues including: the risk to airline operations; engine ingestion issues; long-term maintenance costs / risk; disruption to airports and the legal basis for airspace closures and varying stances taken by European / North American authorities in previous incidents, will be discussed.

11:30–11:50 1B-2. Volcanic Ash – Engine Manufacturer's Perspective

Rory Clarkson [1],

1. Rolls-Royce, Engine Environmental Protection, Derby, UK

This presentation gives a brief overview of how volcanic ash damages gas turbine engines, from a qualitative perspective, and points out the limitations in the quantitative understanding. It also covers the activities that the engine manufactures are engaged in to support airline operations in volcanic ash contaminated airspace, from understanding the global risk, supporting airline safety risk assessments, engaging with research institutions to working with regulators and national aviation authorities to minimise flight disruption whilst keeping flight safe. An outline will be given of the VIPR-III engine test programme, the volcanic ash elements of the WEZARD project and an outline of the research studies Rolls-Royce has been undertaking on behalf of its military customers.

11:50–12:10 1B-3. How to fly safely in ash-contaminated airspace

Ian Davies [1]

1. easyJet Airline Company Limited Hangar 89, London Luton Airport, Luton, UK

This presentation will demonstrate the importance of a systematic approach to navigational control of aircraft flying in contaminated airspace. It will examine the various tools available the aviation industry to enable Operators to quantify levels of volcanic ash in the atmosphere during an eruptive event. It will also allow Operators to accurately locate the position, distribution, calculated estimate of concentrations of ash and forecast its movement up to 48 hour ahead. Additionally some Operators, including easyJet, British Airways and Flybe, are developing various detection devices that will further enhance our ability to detect the location, altitude and density of contaminated airspace. Making this information available in near real-time to National Air Traffic Systems and Eurocontrol would enable the development of a 3 dimensional model in which air traffic can be managed in the same way as weather is currently managed.

12:10–12:30 1B-4. Airline Responsibilities and decision making

Eamon Kierans [1], Dr Fred Prata [2], Colin Pollard [3],

1. Aer Lingus Limited, Head Office Building, Dublin Airport, IRELAND
2. Norwegian Institute for Air Research, Climate and Atmosphere Department, Kjeller, NORWAY
3. Weather Services International, Aviation Weather Section, Birmingham, UK

In this presentation we will review the responsibilities of the Airline with regard to decision making in relation to operations proximate to Volcanic Ash. The relevance of information sources with regard to risk will be considered along with the revised regulatory situation. How safe operation in the Medium and High contamination areas is now possible and can be approved by the National Regulator. We will also consider the benefits of a combined European information source with recognized standards and consistent output methodology with regard to Airline decision making and possible variations in outcome.

12:30–12:50 1B-5. Flight operations during volcanic eruptions

Klaus Sievers [1]

1. German Airline Pilots' Association (German APA), Vereinigung Cockpit e.V., Main Airport Center (MAC), Frankfurt, GERMANY

Flight operations can be under the influence of volcanic activity right from the time the crew familiarizes itself with the route and flight details. The briefing-time is usually short; therefore easy to use ash and SO_2 advisories and charts are required. Near real - time satellite measured ash and SO_2 distribution, height and concentration should be part of all briefings. These points are demonstrated using real-world examples. Pilots are tasked to "avoid visible ash". The real-world difficulties to fulfill this requirement start with identifying ash. As neither training nor other guidance exists as to what is to be considered visible ash, examples of how ?????? looks from the cockpit will be shown. At the end of the presentation, aspects of volcanic ash in relation to an unplanned landing will be highlighted.

12:50–14:00 Lunch break

Session 1C: Operational priorities and user requirements

Andreas Stohl (chair) / Gerrit de Leeuw (co-chair)

14:00–14:20 1C-1. FUTUREVOLC: A European volcanological supersite in Iceland, a monitoring system and network for the future

Freysteinn Sigmundsson [1], Andy Hooper [2], Fred Prata [3], Magnus T. Gudmundsson [1], Arve Kylling [4], Sigrun Hreinsdottir [1], Benedikt G. Ofeigsson [5], Karsten Spaans [2], Vincent Drouin [1], Colm J. Jordan [6], Kristin Vogfjord [5], Ingvar Kristinsson [5], Sue Loughlin [6], Evgenia Ilyinskaya [6], Claire Witham [7], Chris Bean [8], Maurizio Ripepe [9], Christian Minet [10] and other members of the FUTUREVOLC team [11]

1. Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, ICELAND
2. University of Leeds, UK
3. Nicarnica Aviation, NORWAY
4. NILU-Norwegian Institute for Air Research, NORWAY
5. Icelandic Meteorological Office, ICELAND
6. British Geological Survey, UK
7. UK Met Office, UK
8. University College Dublin, IRELAND
9. University of Florence, ITALY
10. DLR - Deutsches Zentrum für Luft- und Raumfahrt, GERMANY
11. FUTUREVOLC Consortium, EC FP7 project

FUTUREVOLC is a collaborative project funded through the FP7 Environment call, encompassing 26 partners in 10 countries. The main objectives of FUTUREVOLC are to establish an integrated volcanological monitoring procedure through European collaboration, develop new methods to evaluate volcanic crises, increase scientific understanding of magmatic processes and improve early-warning of eruptions and delivery of relevant information to civil protection and authorities. To reach these objectives the project combines broad European expertise in seismology, volcano deformation, volcanic gas and geochemistry, infrasound, eruption monitoring, physical volcanology, satellite studies of plumes, meteorology, ash dispersal forecasting, and civil protection. This requires combination of space and ground based observations, both for (i) studies of volcano unrest and magma movements prior to eruptions and (ii) the monitoring of eruptive activity, volcanic plumes and ash dispersal during eruptions. Volcano deformation mapped with InSAR will be combined with continuous GPS tracking of displacements, in order to constrain models for of active deformation sources at volcanoes. The results will be combined with relocated earthquakes, for better understanding of physical processes taking place inside volcanoes prior to eruptions. During eruptions, satellite constraints on plume dispersal will be combined with ground-based observations to estimate the mass eruption rate and the amount of ash distributed to far distances. The outlook for future combined space and ground based monitoring and observations of Icelandic volcanoes will be evaluated with respect to experience gained in relation to the Eyjafjallajökull 2010 and Grímsvötn 2011 eruptions.

14:20–14:40 **1C-2. Volcanic Ash Activities in Argentina: Satellite Retrievals at the Argentinean National Commission of Space Activities**

G. Toyos [1,2], G. Pujol [2,3], M. Rabolli [3], M. Kalemkarian [3]

1. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, ARGENTINA

2. Comisión Nacional de Actividades Espaciales (CONAE), Buenos Aires, ARGENTINA
3. Servicio Meteorológico Nacional (SMN), Buenos Aires, ARGENTINA

This talk will start with an overview of volcanic ash-related activities in Argentina and the involvement of the National Space Commission of Space Activities (CONAE) in the support of emergencies caused by volcanic eruptions. It will then follow with the guidelines of a project that aims at using remote sensing for operational volcanic ash retrievals suitable for the local/regional context. Starting from the operational implementation at CONAE's Ground Segment of the concept of reverse absorption and an extensive review of the ash detection algorithms available, a classification scheme for the delineation of volcanic ash clouds is under design, involving a comprehensive statistical analysis of the spectral characteristics of volcanic ash 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. We have also started working on retrievals of mass loadings and concentration by using the brightness temperature differences measured at 11 and 12 μm by MODIS and a radiative transfer model that solves for the infrared absorption/scattering processes of the volcanic ash cloud. The plan is to extend this exercise to other eruptions, to facilitate retrievals of remobilized ash, to consider other space-borne sensors and to combine satellite retrievals with models such as FALL-3D. 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.

14:40–15:00 1C-3. NASA near Real-time Volcanic Cloud Products for Aviation Alerts

N. Krotkov [1], S. Habib[1], G. Vicente [2], Kai Yang [3], A. da Silva[1], J. Joiner[1], Eric Hughes[3], S. Carn[4], K. Evans [5], Jay Cable [6], C. Seftor[7], K. Brentzel[8], P. Coronado[8], J. Murray[9], G. Swanson[10], F. Prata[11], M. Guffanti[12], Johanna Tamminen[13], Seppo Hassinen[13], Robert Hoffman[14], A. Krueger[15]

1. NASA, Goddard Space Flight Center (GSFC), Greenbelt, Maryland, USA
2. NOAA, NESDIS/OSPO, Satellite Products and Service Division, College Park, Maryland, USA
3. University of Maryland, Atmospheric and Oceanic Science, College Park, Maryland, USA
4. Michigan Technological University, Geological/mining Engineering and Sciences, Michigan, USA
5. University of Maryland Baltimore County, JCET, Baltimore, USA
6. University of Alaska, Geophysical Institute, Fairbanks, Alaska, USA
7. Science Systems and Applications, Inc, Lanham, Maryland, USA
8. NASA, GSFC, Direct Readout Laboratory, Greenbelt, Maryland, USA
9. NASA, Langley Research Center, Hampton, Virginia, USA
10. NOAA, NESDIS-SAB, W-VAAC, College Park, Maryland, USA
11. Norwegian Institute for Air Research, Climate and Atmosphere, Norway
12. U.S. Geological Survey, Reston, Virginia, USA
13. Finnish Meteorological Institute, Helsinki, Finland
14. Metron Aviation, Dulles, Virginia, USA
15. NASA and UMBC (retired), USA

NASA research in volcanic cloud remote sensing includes development of infrastructure for operational applications and improved forecasts of affected areas and altitudes. Ingesting near-real time (NRT) satellite volcanic cloud data is vital for improving reliability of volcanic ash forecasts; and minimizing risks of volcanic eruptions for aviation safety. NASA's volcanic products from the polar orbiting Aura/OMI (Ozone Mapping Instrument) UV sensor are currently disseminated through the NOAA operational volcanic SO_2/ash web site (http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html). The primary goal of NASA's new volcanic hazards project is to expand collaboration with NOAA, USGS and other industrial partner organizations to fully utilize and disseminate NASA SO_2 and ash volcanic NRT data. This will further improve their existing Decision Support Systems (DSS) for aviation warning. Additionally, it is to demonstrate the value of reducing data latency times by utilizing multiple satellites orbital observations by merging with direct readout (DR) volcanic cloud data downloads at both Finland and Alaska ground stations. Given a new emphasis on quantitative ash mass forecasts for air traffic management (ATM), the project will deploy satellite data assimilation techniques into a NASA's global GEOS-5 model to demonstrate improved experimental forecasts of volcanic cloud location, density and vertical extent. The project is in initial feasibility study phase to explore several improvements to the existing DSSs and ensuring all user communities are engaged and planning to use NASA products in their decision process.

15:00–15:20 1C-4. Volcanic Ash Perspectives from the North Pacific Region

Peter. W. Webley [1,§] and Jeffrey Osiensky [2]

1. Geophysical Institute/Alaska Volcano Observatory, University of Alaska Fairbanks, Fairbanks, Alaska, USA
2. NOAA/National Weather Service, Alaska Region Headquarters, Anchorage, Alaska, USA

§ Webley presenting to represent AVO and the Anchorage VAAC

Volcanic eruptions in the North Pacific (NOPAC) happen on a regular basis, either from a >20 km lava flow starting in late 2012 from Tolbachik Volcano in Kamchatka to 19 separate explosive events from Mount Redoubt Volcanic in Alaska during March – June 2009. At any one time, there can be up to 6–7 volcanoes at elevated alert (yellow, orange or red) and as such there exists a group of agencies across the NOPAC who work closely together in terms of volcanic event detection and alerting, provide ash advisories to the airline industry and ash fall information releases to the public. Here, we will highlight how the Alaska Volcano Observatory (AVO) and National Weather Service work together both during periods of quiescence and during periods of volcanic unrest and how multiple data sets from seismic instruments, satellite remote sensing, ground based radar, infrasound and pilot reports are used together for event confirmation and as the basis for volcanic activity notices (VAN) from AVO and volcanic ash advisories (VAA) from the Anchorage Volcanic Ash Advisory Centre (VAAC). We also provide details on experience from volcanic events that cross VAAC boundaries and also within different countries to the location of the drifting volcanic ash cloud. We focus on the Kamchatka Peninsula for these cross-VAAC events. We highlight the need for international communication with collaboration on research and operational methods and access to the mutually beneficial datasets. We show how situational awareness and preparedness are critical tools to mitigate the risk that a large volcanic event in the North Pacific can have on the global air routes and population centers.

15:20–15:40 Coffee break

Session 1D: Operational priorities and user requirements

Christina Aas / Aasmund Vik (moderators)

15:40–16:00 1D-1. VAST User Requirements Survey

C. Aas [1], F. Prata [2], A. Durant [2], A. Vik [2], C. Zehner [5]

1. Science [&] Technology AS, Oslo, Norway
2. Norwegian Institute for Air Research, Kjeller, Norway
3. European Space Agency, Frascati, Italy

During the User Workshop in Dublin, Ireland, March 4th – 6th, 2013, results from a user requirements analysis for satellite-based data products for volcanic ash monitoring and forecasting will be reported on. The analysis of user requirements was supported by a user survey activity, conducted in December 2012. The input from the potential future users of the operational volcanic ash cloud and SO2 monitoring and forecasting services developed as part of VAST, will be used to formulate a set of recommendations for planning, development and strategic purposes. During the User Survey we have invited representatives from the most relevant user groups to participate with their input and feedback on user requirements for the three ESA-projects VAST, SACS2 and SMASH. Particularly input from the VAACs are of high importance to the project, as they will act as a first user for the project output developed. On January 16th, 2012, the User Survey had 74 respondents, 29 operational and 45 from research. The operational respondents covered seven out of the nine VAACs (Toulouse, Darwin, London, Montreal, Wellington, Washington and Tokyo), several airlines (KLM, Icelandair, Qantas airways), regulative authorities (EASA, Irish Aviation Authority, CAA – ICAO), air traffic services operators, pilots and meteorologists.

16:00–17:00 Plenary/discussion

19:30–22:00 Workshop dinner, Morrison Hotel

Day 2 (5 March): Research priorities

Aer Lingus Operations Tour

08:30–09:00 Transport to Dublin airport
09:00–12:00 Tour of Aer Lingus operations room and volcanic ash exercise
12:00–12:30 Transport back to The Morrison Hotel

12:30–14:00 Lunch Break

Session 2A: Observational research priorities

Fred Prata (Chair) / Nicolas Theys (co-Chair)

13:40–14:00 2A-1. A unified method for detection of volcanic aerosols using hyperspectral infrared sounders and analysis of 5 years IASI and AIRS data

L. Clarisse [1], P.-F. Coheur [1], F. Prata [2], N. Theys [3], H. Brenot [3], J. Hadji-Lazaro [4], D. Hurtmans [1], C. Clerbaux [1,4]

1. Université Libre de Bruxelles (ULB), Spectroscopie de l'Atmosphère, Brussels, BELGIUM
2. Norwegian Institute for Air Research (NILU), Climate and Atmosphere Department, Kjeller, NORWAY
3. Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, BELGIUM
4. Université Pierre et Marie Curie (UPMC) Univ. Paris 6; Université Versailles St.-Quentin; CNRS/INSU; LATMOS-IPSL; Paris, FRANCE

We present a unified method for measuring aerosol distributions and their composition using high resolution infrared measurements. The algorithm is based on results from classical discrimination analysis, optimal estimation, distance measures and in addition uses spatio-temporal context to enhance sensitivity. We demonstrate the method on global IASI measurements and show that it allows detecting and differentiate six different types of aerosols, namely volcanic ash, mineral dust, ice particles, sulphuric acid aerosol, ammonium sulphate and smoke. We detect sulphuric acid droplets in the lower troposphere following minor volcanic eruptions and up to 6 months after injection for larger eruptions in the upper troposphere/lower stratosphere. In the near future the volcanic ash detection system will operate in near-real time as part of the SACS service. Archive data has already been processed and we analyze and evaluate detection of over 5 years of IASI and AIRS data, which combined offer 4 times a day global coverage. If time allows we will also present first results of a new fast quantitative ash retrieval algorithm for hyperspectral sounders.

14:00–14:20 2A-2. UV-VIS satellite remote sensing of ash

R. van der A [1] and Nicolas Theys [2]

1. Royal Netherlands Meteorological Institute (KNMI), Climate Observations, AE De Bilt, NETHERLANDS
2. Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, BELGIUM

Existing UV-Visible ash products are the Absorbing Aerosol Index (AAI), and Sulphur Dioxide (SO_2), which are currently used for volcanic plume detection in the SACS system. The new UV-VIS products planned in the SMASH/SACS-2 project are the Volcanic Ash Layer Height (ALH), Aerosol Optical Thickness (AOT) and the Volcanic Ash Mass Loading (AML). Using information from the O2A band, these products can be made from the reflectances of the three operational UV-Visible instruments: OMI on AURA and the GOME-2 instruments on METOP-A and METOP-B. The products will be validated using satellite data during the episodes of recent volcanic eruptions (Eyjafjallajökull, Kasatochi, Grimsvötn).

14:20–14:40 2A-3. CALIPSO characterisation of volcanic aerosol properties and developed tools

J. Pelon [1], D. Winker [2], A. Garnier [3], D. Josset [3], J.-P. Vernier [3], M. Vaughan [2], P. Dubuisson [4], N. Pascal [5], J. Descloitres [5], J. Jumelet [1], Y. Hu [2], P. Lucker [3] and C. Trepte [2]

1. LATMOS-IPSL, Université Pierre et Marie Curie-UVSQ-CNRS, Paris, FRANCE
2. LaRC, NASA, Hampton VA, USA
3. SSAI, Hampton, VA, USA
4. LOA, Université de Lille 1-CNRS, Lille, FRANCE
5. ICARE, Lille, FRANCE

CALIPSO spaceborne observations have been used to characterize particles emitted over Europe after Eyjafjallajökull eruption in spring 2010, as well as for other important events observed over the globe. The vertical information from CALIOP is a critical input in the analysis as previously emphasized. We show here that the combination with IR information leads to very accurate retrievals of the absorption optical depth in the thermal window at a 1 km scale and on the ash particle size. In the case of Eyjafjallajökull, the effective diameter De of the particles was estimated to be in the range of 3-6 µm. This direct determination of De combined to the profile of the extinction coefficient allows to reduce uncertainties in the estimation of the mass concentration and to identify several periods and regions where the load in mineral material could be reliably estimated to be exceeding the mass concentration value of 2 mg/m^3 at aircraft flight altitudes.

14:40–15:00 2A-4. Ash retrievals using multispectral satellite measurements: improvement of the quantitative estimation

S. Corradini [1]

1. Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, ITALY

After the Eyjafjallajokull 2010 eruption the quantitative ash determination in a volcanic cloud has become more important because of the policy change from the previous 'zero tolerance' to the new 'ash threshold based approach' in aviation hazard management. Due to the sporadic nature of volcanic eruptions and of their large geographic extent, satellite remote sensing provides the most suitable technique to detect and retrieve volcanic emissions. The detection and retrieval of volcanic ash clouds have been performed by using different multispectral polar and geostationary satellite instruments as MODIS, AVHRR and SEVIRI. The most broadly used algorithms for the detection and characterisation of volcanic ash clouds are based on the brightness temperature difference (BTD) algorithm in the TIR spectral range. The use of radiative transfer models (RTM) allows estimation of volcanic ash cloud total mass, mean effective radius and aerosol optical depth. RTM require many different inputs including plume altitude and thickness, atmospheric profiles, surface temperature and emissivity, and ash optical properties. All terms are affected by uncertainties that lead to meaningful retrieval errors. Here the ash retrieval errors from multispectral satellite data are discussed with particular emphasis on ash optical properties uncertainties. A novel, simple and fast, ash retrieval procedure is also presented.

15:00–15:20 Coffee break

Session 2B: Observational research priorities

Gerhard Wotawa (chair) / Adam Durant (co-chair)

15:20–15:40 2B-1. Ground-based characterisation of volcanic ash clouds

Colin O'Dowd [1], Darius Ceburnis [1], Jurgita Ovadnevaite [1], Jakub Bialek [1], Giovanni Martucci [1], Aditya Vaishya [1], Tomas Grigas [1], Damien Martin [1] and Peter Nolan [2]

1. School of Physics & Centre for Climate and Air Pollution Studies, Ryan Institute, National University of Ireland Galway, University Road, Galway, IRELAND
2. Irish Aviation Authority, Dublin 2, IRELAND

Ground-based measurements, both *in situ* and remotely sensed, of volcanic ash clouds compliment space-borne remote sensing and airborne measurements in that they can provide for a more sophisticated and more diverse range of characterisation measurements once the plume enters the boundary layer. *In situ* measurements can be extremely useful for the evaluation of forecast model performance, while ground based remote sensing is useful for plume height, layer thickness, and ash density quantification. We illustrate the advantage of such measurements from the Eyjafjallajökull ash cloud detected at the Mace Head supersite and outline the development of a national 4 node operational LIDAR network being developed by the IAA and NUIG, with ESA promoting the development of real-time ash plume detection algorithms.

15:40–16:00 2B-2. Airborne aerosol *in situ* measurements and the visual appearance of volcanic ash

Daniel Sauer [1], Bernadett Weinzierl [1], Andreas Minikin [1], Hans Schlager [1], Kaspar Graf [1] and Stephan Kox [1]

1. Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, GERMANY

The volcanic ash cloud from the Eyjafjallajökull volcano in Iceland strongly impacted aviation in Europe in April and May 2010: more than 100,000 flights were cancelled affecting more than 10 million passengers. To avoid such scenarios in the future, major research efforts are focused on the detection and forecasting of airborne volcanic ash plumes. A key aspect of remote sensing methods from space-based, airborne and ground-based platforms is the reliable identification of volcanic ash through unique signatures rooted in the aerosol microphysical and optical properties. Airborne *in situ* measurements of the microphysical and optical properties of volcanic ash are important for understanding the impact of this particular atmospheric aerosol type on atmospheric radiation and therefore the signatures for remote sensing applications. Developing retrieval algorithms for remote sensing of volcanic ash and the validation of remote sensing volcanic ash products crucially requires *in situ* observations of particle properties. Based on the research flights performed with the DLR Falcon aircraft during the Eyjafjallajökull eruption period in April/May 2010 we present an overview of airborne *in situ* measurement methods, data analysis techniques and the aerosol parameters that can be deduced from such measurements. Using the *in situ* measurements, photos taken during the flight campaigns and idealised radiative transfer calculations, we assess the feasibility of visual detection of volcanic ash and other aerosol layers in flight by aircraft operators. Our findings show that it is difficult to determine a lower threshold for the mass concentration of "visible ash". While under ideal observing conditions volcanic ash might indeed be visible at very low concentrations, the visibility strongly depends on many parameters such as the geometry of the layer and observing angles, illumination by the sun, background contrast and cloud coverage, and the aerosol microphysical and optical properties. Using these results we critically discuss the concept of "avoiding visible ash" as a safety measure recommended by national and international aviation organizations.

16:00–16:20 2B-3. Airborne Measurements of Volcanic Plumes with Light Aircraft - Examples of Research Flights during Eruptions of the Volcanoes Eyjafjallajökull, Grimsvötn, Etna and Sakurajima and Quality Assurance Aspects

Konradin Weber [1], Jonas Eliasson [2], Thorgeir Palsson [3], Andreas Vogel [1], Christian Fischer [1], Tobias Pohl [1], Nario Yasuda [4]

1. Duesseldorf University of Applied Sciences, Laboratory for Environmental Measurement Techniques (LEMT), Duesseldorf, GERMANY
2. University of Iceland, Earthquake Engineering Research Institute (EERI), Selfoss, ICELAND
3. Reykjavik University, Reykjavik, ICELAND
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During recent eruptions of the volcanoes Eyjafjallajökull, Grimsvötn, Etna and Sakurajima the Duesseldorf University of Applied Sciences in cooperation with the two Universities on Iceland performed a large number of research flights in order to investigate the volcanic plumes using light and microlight aircraft, equipped with optical particle counters and Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS) instrumentation. The light aircraft used in these studies are equipped with durable and sturdy piston-motors. 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. During the eruptions of the Eyjafjallajökull 2010 and Grimsvötn 2011 numerous research flights were performed by LEMT and EERI on Iceland and over Northern Germany for mapping the plume and evaluating the predicted ash concentration by the VAAC model. During the eruption of the Grimsvötn volcano 2011 the results of the aircraft measurements contributed significantly to the decision of the Icelandic air navigation service provider ISAVIA of re-opening of the international airport Keflavik, which was closed before because of high ash concentrations predicted by the London VAAC model. Moreover, it could be demonstrated during active phases of the volcanoes Etna and Sakurajima that the zenith-view UV DOAS system is a very useful tool in order to track the SO2-plume, give estimates of volcanic SO2-fluxes and to give visualization of the SO2-plumes, which can be compared to satellite images. Quality assurance issues of the in-situ measurements and examples of visibility within the plume have been addressed within these studies as well.

16:20–16:40 2B-4. Fluid mechanical models of explosive eruption jets and the resultant characteristics of ash injection into the atmosphere

Steve Tait [1], Guillaume Carazzo [1], Frédéric Girault [1], Edouard Kaminski [1] and Fabrizio Ferrucci [1]

1. Institut de Physique du Globe de Paris, Paris, FRANCE

We introduce a set of fluid mechanical models of explosive volcanic jets that mix turbulently with the atmosphere and rise above the vent as plumes to a height (depending mainly on the eruptive mass flux and the atmospheric stratification) before spreading horizontally. An important goal of these models, regarding the injection of ash into the atmosphere, is to achieve a compromise between the need for calculations to be rapid and efficient, but nevertheless to include an appropriate level of complexity inherent in natural volcanologic systems. The key novel features are: 1) the description of turbulent mixing by an entrainment formalism in which the “entrainment coefficient” depends on the amount of buoyancy-induced turbulence, via local Richardson number, and 2) the evolution of the particle size distribution of the ash and pumice in the plume due mainly to sedimentation. These 1-D models, valid for the flow above the source where vertical convection dominates, predict average plume characteristics as a function of height above the eruptive vent. We present and discuss a suite of results, including ash loading and particle-size distribution at the height of neutral buoyancy for different cases that cover a range of possible explosive volcanic events.

16:40–17:00 2B-5. The effect of wind on the rise of volcanic plumes: determining the ‘source term’

Mark Woodhouse [1], Andrew Hogg [1], Jeremy Phillips [2] and Steve Sparks [2]

1. University of Bristol, School of Mathematics, Bristol, UK
2. University of Bristol, School of Earth Sciences, Bristol, UK

Forecasting ash dispersion in the atmosphere requires, as input, estimates of source parameters, in particular the mass flux of material from the volcano and the height at which ash is injected into the atmosphere. Typically in operational settings a rapid estimate of the mass flux has been made using simple formulae relating the source mass flux to the height of the plume. These empirical relations are derived from a small dataset of historical eruptions where independent estimates of the height of the eruption column and of the mass flux of material released from the volcano are available. For small explosive eruptions such as the 2010 eruption of Eyjafjallajökull, atmospheric conditions can strongly effect the rise height of the plume. The empirical scaling relationships are then unreliable and systematically under-predict the mass flux of volcanic ash injected into the atmosphere. We formulate an integral model of volcanic eruption columns that includes a description of the thermodynamics of heat transfer between erupted solid pyroclasts, magmatic gases and the atmospheric air entrained by turbulent eddies, and describes the bending over of the plume trajectory in a cross- wind. We show that 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. The model predictions are in accord with a dataset of historic eruptions if the profile of atmospheric wind shear is described and our calculations are used to calibrate a semi- empirical relationship between the plume height and the source mass flux which explicitly includes the atmospheric wind speed. By employing observations of the local meteorology during the first explosive phase of the Eyjafjallajökull eruption (14th to 18th April 2010) in our integral model, we demonstrate that varying atmospheric conditions can account for observed variations in the rise height of the plume while the source mass flux is held constant. The source mass flux estimate we obtain is up to two orders of magnitude larger than the estimate obtained from a relationship which does not account for the effect of the wind.

17:00–17:20 2B-6. Inverse modeling of volcanic ash

Andreas Stohl [1], Nina I. Kristiansen [1], Sabine Eckhardt [1], G. Wotawa [2], D. Arnold [2]

1. Norwegian Institute for Air Research (NILU), Kjeller, NORWAY
2. Central Institute for Meteorology and Geodynamics (ZAMG), Vienna, AUSTRIA

The so-called source term (i.e., the ash and sulfur dioxide emissions as a function of altitude and time, as well as other emission characteristics such as the aerosol composition and size distribution) is the largest uncertainty for modeling the dispersion of volcanic eruption debris. We present our method to determine the source term based on inverse modeling using dispersion model calculations as well as satellite retrievals, as well as several applications. We will also outline limitations of the method, needs for improvement and we will discuss constraints for an operational application.

Session 3A: General contributions: volcanic ash and aviation (posters)

Fred Prata (chair) / Adam Durant (co-chair)

17:20–19:00 Drinks reception, poster presentations

3A-1. Support to Aviation Control Service: monitoring of volcanic SO_2 and ash emissions by a multi-sensor satellite system

H. Brenot [1], N. Theys [1], J. van Gent [1], M. Van Roozendael [1], R. van der A [2], L. Clarisse [3], D. Hurtmans [3], P.-F. Coheur [3], C. Clerbaux [3,4], C. Zehner [5]

1. Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, BELGIUM
2. Royal Netherlands Meteorological Institute (KNMI), Climate Observations, AE De Bilt, NETHERLANDS
3. Université Libre de Bruxelles (ULB), Spectroscopie de l'Atmosphère, Brussels, BELGIUM
4. Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS-IPSL), Paris, FRANCE
5. ESA Centre for Earth Observation (ESA-ESRIN), Frascati, ITALY

The “Support to Aviation Control Service” (SACS; http://sacs.aeronomie.be) is a ESA-funded project hosted by the Belgian Institute for Space Aeronomy. The service provides near real-time (NRT) global SO_2 and volcanic as data, as well as warnings in case of volcanic eruptions. The SACS service is primarily designed to support the Volcanic Ash Advisory Centers (VAACs) in their mandate to gather information on volcanic clouds and give advice to airline and air traffic control organisations. SACS also serves other users that subscribe to the service, in particular local volcano observatories and research scientists. SACS is based on the combined use of UV-visible (OMI, GOME-2) and thermal infrared (AIRS, IASI) satellite instruments. When a volcanic eruption is detected, SACS issues a warning that takes the form of a notification sent by e-mail to users. This notification points to a dedicated web page where all relevant information is available and can be visualised with user-friendly tools. The strength of a multi-sensor approach relies in the use of satellite data with different overpasses times, minimising the time-lag for detection and enhancing the reliability of such warnings.

3A-2. The VAST demonstration services – testing and activities

G. Wotawa [1], D. Arnold [1], C. Maurer [1], R. Klonner[1], N. Kristiansen [2], A. Stohl [2], F. Prata [2]

1. Central Institute for Meteorology and Geodynamics, Vienna, AUSTRIA
2. Norwegian Institute of Air Research, Kjeller, NORWAY

The VAST project aims at making a step forward in using EO data for volcanic ash monitoring/forecasting and at helping improve the volcanic ash atmospheric transport forecasting services. The latter is addressed through exercises and demonstration activities in operational environments considering the end-user needs. The in-house deployment of such a demonstration service requires several previous steps that will be presented here. These include local technical improvements and conceptual planning of the operations with procedure development,

volcanic eruptions drills that trigger the acquiring of data and dispersion/forecasting calculations and preliminary source term estimate systems by means of inverse modeling all into a coordinated in-house 24/7 test-bed. This is supplemented by the planning of an international exercise based on a hypothetical volcanic event to evaluate response times and the usefulness of the different products obtained. In addition, one important line of development is the use of ensemble dispersion forecasts, on one hand multi-input ensembles utilizing the ECMWF EPS system, and on the other hand multi-model ensembles based on different dispersion models driven with different input data. This is currently being evaluated regarding resources demands and trade-offs needed to produce ensemble runs in reasonable times with the existing resources.

3A-3. Implementation of a global volcano remote sensing observation system

Jonathan Dehn [1], Peter Webley [1]

1. V-ADAPT, Fairbanks, Alaska, USA

For over 25 years the volcano remote sensing group has built a system of tools and techniques to effectively mitigate hazards from volcanoes in the North Pacific. The start-up company, V-ADAPT (Volcanic-Ash Detection Avoidance and Preparedness for Transportation) was founded in 2013 to apply these tools and techniques globally and provide these to customers world-wide. Building on the base set of tools, a near-real time image browser with thermal and ash alerts as well as the Puff volcanic ash transport and dispersion model, a series of modules designed to meet the needs of the transportation industry is designed (and in many cases already implemented). The development pathway will be determined by the customers as the company grows. Further modules range from near real-time ash mass determination and restarting of ash tracking models based on this data to long term probabilistic modeling for planning where volcanic ash is least likely to be present. Feedback from the volcanic monitoring community is needed to best design tools to meet the needs of a financially-strained transportation system.

3A-4. Monitoring volcanic activity with satellite remote sensing to reduce aviation hazard and mitigate the risk: application to the North Pacific

Peter W. Webley [1] and J. Dehn [1]

1. Geophysical Institute, University of Alaska Fairbanks, 903 Koyukuk Drive, Fairbanks. Alaska. 99775. USA

Volcanic activity across the North Pacific (NOPAC) occurs on a daily basis and as such monitoring needs to occur on a 24 hour, 365 days a year basis. The risk to the local population and aviation traffic is too high for this not to happen. Given the size and remoteness of the NOPAC region, satellite remote sensing has become an invaluable tool to monitor the ground activity from the regions volcanoes as well as observe, detect and analyze the volcanic ash clouds that transverse across the Pacific. Here, we describe the satellite data collection, data analysis, real-time alert/alarm systems, observational database and nearly 20-year archive of both automated and manual observations of volcanic activity. We provide examples of where satellite remote sensing has detected precursory activity at volcanoes, prior to the volcanic eruption, as well as different types of eruptive behavior that can be inferred from the time series data. Additionally, we illustrate how the remote sensing data be used to detect volcanic ash in the atmosphere, with some of the pro's and con's to the method as applied to the NOPAC, and how the data can be used with other volcano monitoring techniques, such as seismic monitoring and infrasound, to provide a more complete understanding of a volcanoes behavior. We focus on several large volcanic events across the region, since our archive started in 1993, and show how the system can detect both these large scale events as well as the smaller in size but higher in frequency type events. It's all about how to reduce the risk, improve scenario planning and situational awareness and at the same time providing the best and most reliable hazard assessment from any volcanic activity.

3A-5. Time series of North Pacific volcanic eruptions

Jonathan Dehn [1], Anna K. Worden [1], Peter Webley [1]

1. Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska, USA

The record of volcanic eruptions was gathered from the 1986 eruption of Augustine Volcano to present for Alaska, Kamchatka and the Kurile Islands. In this time over 400 ash producing eruptions were noted, and many more events that produced some other activity, e.g. lava, lahar, small explosion, seismic crisis. This represents a minimum for the volcanic activity in this region. The records for Alaska are likely complete for this time period, but it is possible that activity in the Kuriles and Kamchatka could have been overlooked, particularly smaller events. For the Alaska region, 19 different volcanoes have been active in this time. Mt. Cleveland shows the most activity over the time period (22 % likely to have activity in a 3 month period), followed by Pavlof volcano (12% likely). In Kamchatka only 7 volcanoes have been active, Shiveluch is the most active (30% likely) followed by Bezymianny and Kliuchevskoi volcanoes (tied at 20%). The Kuriles only have had 5 active volcanoes, and only 8 known eruptions. Overall this region is one of the most active in the world, in any 3 month period there is a 81% likelihood of volcanic activity. For half of the events, explosive activity is preceded by thermal signals in infrared satellite data. Rarely (about 5% of the time) is a stand-alone thermal signal not followed within 3 months by an explosive eruption. For remaining events where an ash plume begins the activity, over 90% of the cases show a thermal signal during eruption. The volcanoes with the most activity are the least likely to produce large ash plumes. Conversely the volcanoes that erupt rarely often begin with larger ash producing events.

3A-6. MIPAS observations of Sarychev Peak: Plume detection and sulphate aerosol formation

Harjinder Sembhi [1], David P. Moore [1], Tim Trent [1], John Remedios [1], Reinhold Spang [2]

1. University of Leicester, Earth Observation Science – Dept Physics & Astronomy, Leicester, UK
2. Forschungszentrum Jülich, Institute for Energy and Climate Research - Stratosphere (IEK-7), Juelich, GERMANY

In recent years, investigations of volcanic eruptions and their influence on the upper troposphere and lower stratosphere has shown large uncertainties in the determination of vertical injection heights, “young” plume constituents, tracing plume transport and the evolving plume composition. Not only does this highlight the need for improved detection/retrievals of such aerosols and their related trace gases but also to improve knowledge on the vertical distribution of these pollution sources and the separation of aerosol, cloud and pollutants within the plumes. We use thermal infrared limb emission spectra (4.6 µm to 14.5 µm) measured by ESA’s Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) to investigate the formation of sulphate aerosols from the Sarychev Peak eruptions of June 2009. We will show that several days after the eruptions, a stratospheric plume filament was observed moving away from the main tropospheric plume component and use plume height information from CALIOP to verify this. We will describe a method to distinguish between ice clouds and volcanic plumes and finally show the evolving spectral structures of sulphur dioxide (SO_2) and sulphate aerosols. These results will exemplify a) what MIPAS has revealed about stratospheric injections in particle and gas composition effects from Sarychev Peak and b) what can be achieved with space-borne limb sounding FTIR instruments.

3A-7. Remote sensing and inverse transport modeling of the Kasatochi eruption sulfur dioxide cloud

Nina Iren Kristiansen [1], Andreas Stohl [1], Fred Prata [1], Andreas Richter [2], Sabine Eckhardt [1], Petra Seibert [3], Anne Hoffmann [4], Christoph Ritter [4], Lubna Bitar [5], Thomas J Duck [5] and **Kerstin Stebel** [1]

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2. Institute of Environmental Physics, University of Bremen, Bremen, GERMANY
3. Institute of Meteorology, University of Natural Resources and Applied Life Sciences, Vienna, AUSTRIA
4. Alfred Wegener Institute, Potsdam, GERMANY
5. Department of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, CANADA

An analytical inversion method is used to estimate the vertical profile of sulfur dioxide (SO_2) emissions from the major 2008 eruption of Kasatochi Volcano, located on the Aleutian Arc, Alaska. The method uses satellite-observed total SO_2 columns from the Global Ozone Monitoring Experiment-2 (GOME-2), Ozone Monitoring Instrument (OMI), and Atmospheric InfraRed Sounder (AIRS) during the first 2 days after the eruption, and an atmospheric transport model, FLEXPART, to calculate the vertical emission profile. The inversion yields an emission profile with two large emission maxima near 7 km above sea level (asl) and around 12 km asl, with smaller emissions up to 20 km. The total mass of SO_2 injected into the atmosphere by the eruption is estimated to 1.7 Tg, with ~1 Tg reaching the stratosphere (above 10 km asl). The estimated vertical emission profile is robust against changes of the assumed eruption time, meteorological input data, and satellite data used. Using the vertical emission profile, a simulation of

the transport extending for 1 month after the eruption is performed. The simulated cloud agrees very well with SO2 columns observed byGOME-2, OMI, and AIRS until 6 days after the eruption, and the altitudes agree with both Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation measurements and ground-based lidar observations to within 1 km. The method is computationally very fast. It is therefore suitable for implementation within an operational environment, such as the Volcanic Ash Advisory Centers, to predict the threat posed by volcanic emissions for air traffic.

3A-8. OMI Very Fast Delivery (VFD) service - real time view of the Arctic atmosphere

Seppo Hassinen [1], Johanna Tamminen [1], Simo Tukiainen [1], Janne Hakkarainen [1], Osmo Aulamo [2], Timo Pirttijärvi [2], Jyri Heilimo [2], Nickolay Krotkov [3], Pepijn Veefkind [4]

1. Finnish Meteorological Institute, Earth Observation, Helsinki, FINLAND
2. Finnish Meteorological Institute, Arctic Research Center, Sodankylä, FINLAND
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4. The Royal Netherlands Meteorological Institute, De Bilt, NETHERLANDS

The modern society is more and more dependent on real-time information about the atmospheric composition affecting the air quality and air traffic. The need and usefulness of real-time satellite data products of volcanic ash was clearly recognised during the last major Icelandic volcanic eruptions, which disturbed the European air traffic. While geostationary satellites provide information continuously at lower latitudes the high latitudes are best covered with polar- orbiting satellites whose data is downlinked typically only once per orbit. The NASA's EOS-Aura satellite has so called Direct Broadcast (DB) capability, i.e. the ability to broadcast data at the same time as it is measured. This possibility is utilized in the OMI Very Fast Delivery (VFD) Service (http://omivfd.fmi.fi) for monitoring atmospheric composition and UV-radiation in almost real time, within 20 minutes after the overpass. The service started in 2006 with UV and ozone. After the eruption of the Eyjafjallajökull the system was updated in 2010-11 with volcanic products: ash and SO_2. The OMI VFD covers presently Northern Europe and Arctic Ocean, but the coverage is restricted by the fact that the satellite has to be visible from the Sodankylä ground station in northern Finland. Work is on-going to extend the coverage by using a ground station in Alaska. In this presentation we demonstrate the operational OMI VFD system, available products and plans for future.

3A-9. The 2010 Eyjafjallajökull eruption: Estimations of volcanic ash release and transport modelling using different models

Nina Iren Kristiansen [1], **Andreas Stohl** [1], Fred Prata [1], Lieven Clarisse [2], Stephan Henne [3]

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2. Spectroscopie de l'Atmosphere, Service de Chimie Quantique et Photophysique, Universite Libre de Bruxelles, Brussels, BELGIUM
3. EMPA, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, SWITZERLAND

To accurately simulate the transport and concentrations of volcanic ash, an estimate of the ash release rate is needed. The ash release rate is here defined as the emitted mass of volcanic ash and the altitude at which it is effectively released into the atmosphere. With two different dispersion models (FLEXPART and NAME), run on different meteorological input data, we simulate the ash transport from the 2010 Eyjafjallajökull eruption. Furthermore, with an inversion method and satellite observations (SEVIRI) of the ash cloud we optimise the ash release estimate as a function of height and time for the 40 days eruption period in April-May 2010. Using the estimated ash emission rate, we can simulate with increased accuracy, the ash transport and ash concentrations over Europe in the weeks of the eruption. The results are validated against independent observations (e.g. aircraft-, lidar-, and ground-based measurements) to assess the degree of improvement. This method can provide information to more accurately predict the fate of hazardous volcanic emissions and determine the air space which the air traffic has to avoid.

3A-10. Volcanic ash monitoring using AATSR dual view

Timo H. Virtanen [1], Pekka Kolmonen [1], Gerrit de Leeuw [1,2]

1. Finnish Meteorological Institute, Climate Change Unit, Helsinki, FINLAND
2. University of Helsinki, Department of Physics, Helsinki, FINLAND

We describe an algorithm for retrieving information on volcanic ash spatial distribution, plume height and aerosol concentration using radiances measured at the top of the atmosphere (TOA) by the Advanced Along Track Scanning Radiometer (AATSR) aboard the ENVISAT satellite. The AATSR instrument has two views, a nadir view and a 55° forward view. The center wavelengths of the AATSR visible (VIS) and near-infrared (NIR) channels are 0.555, 0.659, 0.865, 1.61 µm. The AATSR thermal infrared channels are centered at 3.7, 11, and 12 µm and provide brightness temperature data. The visible channels can be used for aerosol optical depth (AOD) retrievals, while the thermal channels are useful in ash detection. Volcanic ash can be detected using the brightness temperature difference between the 11 and 12 µm channels, which is negative for ash and positive elsewhere, to first approximation (Prata, 1989). The other channels can also be used for ash detection by employing a number of reflectance thresholds. The stereo view is used to estimate the plume height. An area based spatial correlation algorithm can be used to collocate the views at the ash plume top, and the resulting parallax gives a height estimate with nominal accuracy of 1 km. The AOD is retrieved using AATSR dual view (ADV) algorithm (Veefkind *et al.* 1998, Kolmonen *et al.* 2013). The algorithm utilizes stereo view, and does not require prior knowledge of the surface reflectance. Using the aerosol model, the AOD can be converted to an estimate of the ash mass column load.

3A-11. Observing volcanic signatures from space, and in the lab

A.J.A. Smith [1], E. Carboni [1], D.M. Peters [1], G.E. Thomas [1], T.M. Sears [1], A. Dudhia [1] and R.G. Grainger [1]

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The Earth Observation Data Group at the University of Oxford has a wide range of tools that can be applied to the observation of volcanic ash. Lab measurements of volcanic ash from the Aso, Eyjafjallajökull, and Tongariro eruptions provide size distribution, extinction, and refractive index data which are then used to create forward models of volcanic ash plumes for satellite aerosol retrievals. Using visible and near infra-red measurements from SEVIRI and AATSR, the ORAC optimal estimation retrieval can provide optical depth, effective radius, aerosol speciation, and (using stereoscopic techniques available from AATSR's dual view, or the thermal channels for thick plumes) plume height. In the infra-red, IASI and MIPAS fast flagging methods, relying on unique features of the IR volcanic ash spectrum, can be used to spot potential danger areas for aircraft in real time. An IASI SO_2 retrieval providing plume height and column concentration is also available, and is used along with the above ash flags and retrievals to discuss the merits of using SO_2 flagging as a proxy for areas likely to contain volcanic ash.

3A-12. Monitoring of volcanic events: GOME-2 SO_2 column observations

P. Hedelt [1], P. Valks [1], D. Loyola [1], J. van Gent [2], M. van Roozendael [2], N. Theys [2], N. Hao [1], W. Zimmer [1]

1. Deutsches Zentrum für Luft- und Raumfahrt (DLR), Remote Sensing Institute, Wessling, GERMANY
2. Belgian Institute for Space Aeronomy (IASB-BIRA), UV-Visible DOAS Research, Brussels, BELGIUM

This contribution focuses on the GOME-2 SO_2 column products from the METOP-A and B satellites. The GOME-2 SO_2 column product has been developed in the framework of EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF). Satellite-based remote sensing measurements of volcanic SO_2 provide critical information for reducing volcanic hazards. Volcanic eruptions may bring ash and gases (e.g. SO_2) high up into the atmosphere, where a long-range transport can occur. SO_2 is an important indicator for volcanic activity, an excellent tracer for volcanic eruption clouds, especially if ash detection techniques fail. SO_2 can affect aviation safety: In the cabin it can cause disease and respiratory symptoms, whereas in its hydrogenated form H_2SO_4 it is highly corrosive and can cause damage to jet engines as well as pitting of windscreens. We will present results for volcanic events retrieved from GOME-2 solar backscattered measurements in the UV wavelength region around 320nm using the Differential Optical Absorption Spectroscopy (DOAS) method. The SO_2 product is available in near-real-time, i.e. within two hours after sensing. SO_2 is mainly produced by volcanic eruptions and anthropogenic activities. It is thus an excellent marker for pollution events and volcanic activity.

3A-13. Potential impact of erroneous VAG

Rory O'Loughlin [1]

1. Delta Airlines, Meteorology, Atlanta, GA, USA

Volcanic Ash Graphics, Satellite photos and dispersion model output associated with an eruption from Sakura Jima and the potential impact on Airline operations.

3A-14. Comparison of volcanic ash cloud observations and model predictions

Helen Dacre [1] and Alan Grant [1]

1. University of Reading, Reading, UK

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. We 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.

3A-15. Variational inversion of SO_2 emission flux in the 2011 Grimsvötn eruption

Julius Vira [1]

1. Finnish Meteorological Institute, Air Quality Research, Helsinki, FINLAND

The poster discusses adaptation of the 4D-Var data assimilation method for obtaining time and height resolving estimates of pollutant emissions in volcanic eruptions. The optimal source term with regard to the observations is found iteratively, which makes the approach computationally efficient. The current study employs the SILAM chemistry transport model and the SO_2 observations by the OMI satellite instrument. The algorithm is applied to the eruption of Grimsvötn in 2011, where significant amounts of SO_2 were observed over arctic areas by OMI and other instruments. The estimated source term is localized realistically in time and vertical dimension. In particular, the inversion localises the emission above approximately 5 km, below which the air masses were transported towards Northern Europe. While the inversion does not include direct regularization, the estimate can be constrained to follow the observed evolution of the eruption height. The choice of the plume height constraint is shown to have strong influence on the results.

Day 3 (6 March): Discussion and wrap-up

Session 4A: Plenary discussion

Claus Zehner / Fred Prata (moderators)

09:30–09:50	Claus Zehner (ESA) **Progress since the ESRIN workshop**
09:50–10:30	All WP leaders **Panel discussion**
10:30–10:50	Fred Prata (NILU) **Meeting wrap-up**

10:50–11:10 Coffee break

11:10–14:00	SAVAA and VAST team members **Closed project meeting (SAVAA and VAST)**