Volcanism and the Atmosphere

American Geophysical Union Chapman Conference

Selfoss, Iceland

10 - 15 June 2012

AGU Chapman Conference on Volcanism and the Atmosphere

Selfoss, Iceland
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Conveners

Michael R. Rampino, New York University
Alan Robock, Rutgers University
Thorvaldur Thordarson, University of Edinburgh

Program Committee

Claudia Timmreck, Max-Planck-Institute for Meteorology
Fred Prata, Norwegian Institute for Air Research
Hans-F. Graf, University of Cambridge
Stephen Self, The Open University
Tamsin A. Mather, University of Oxford

Financial Support

Cover photos

The lava fountain photo (red one) is from the Fimmvörðuháls flank eruption on Eyjafjallajökull volcano taken on 24 March 2010 at 18:30. [view is to NW]

The other one is from the summit eruption at Eyjafjallajökull volcano taken on 17 April taken at 11:30. [view is to the WNW].

Both photos are taken by Dr. Ármann Höskuldsson volcanologist at theEarth Science Institute, University of Iceland.

AGU Chapman Conference on Volcanism and the Atmosphere

Meeting At A Glance

Sunday, 10 June 2012

1800h – 1900h	Welcome Reception
1900h	Dinner on your own

Monday, 11 June 2012

0845h – 0900h	Introduction and Welcome Remarks
0900h – 1030h	Session 1 – Eyjafjallajökull
1030h – 1100h	Coffee Break
1100h – 1245h	Session 2 – Volcanic Eruptions and Aviation (cont.)
1245h – 1800h	Free Time
1800h – 1930h	Dinner on your own
1930h – 2030h	Keynote Talk – Katmai Centennial
2030h – 2200h	Poster Sessions (the following posters are presented on Monday and Tuesday) Tropospheric Aerosols and Chemistry Posters Remote Sensing Posters Volcanic Eruptions and Aviation Posters Eyjafjallajökull Posters Icelandic Volcanism Keynote Poster

Tuesday, 12 June 2012

0900h – 1035h	Session 3 – Tropospheric Aerosols and Chemistry
1035h – 1100h	Coffee Break
1100h – 1230h	Session 4 – Remote Sensing
1330h – 1800h	Trip #1: Trjáviðarlækur (tephra section)
1330h – 1800h	Trip #2: Western Volcanic Zone and the Hellisheiði Geothermal Power Plant
1330h – 1800h	Trip #3: Þingvellir
1800h – 1930h	Dinner on Your Own
1930h – 2030h	Keynote Talk – Icelandic Volcanism
2030h – 2200h	Poster Sessions

Wednesday, 13 June 2012

0900h – 1600h	Field trip to Eyjafjallajökull Volcano
1600h	Dinner on Your Own

Thursday, 14 June 2012

0900h – 1030h	Session 5 – Volcanism and the Last Millennium
1030h – 1100h	Coffee Break
1100h – 1225h	Session 5 – Volcanism and the Last Millennium (cont.)
1245h – 1800h	Free time
1300h – 1500h	News Media Workshop (optional)
1800h – 1930h	Group Dinner
1930h – 2030h	Keynote Talk – Geoengineering
2030h – 2200h	Poster Sessions
	(the following posters are presented on Thursday and Friday)
	Volcanism and the Last Millennium
	Geoengineering Proposals Using Stratospheric Aerosols
	Earth System Model Simulations of Large Volcanic Eruptions
	Dynamics of the Coupled Atmosphere Ocean Systems After Large Volcanic Eruptions
	Geoengineering Keynote Poster

Friday, 15 June 2012

0900h – 1030h	Session 6 – Dynamics of the Coupled Atmosphere Ocean Systems After Large Volcanic Eruptions
1030h – 1100h	Coffee Break
1100h – 1235h	Session 6 – Dynamics of the Coupled Atmosphere Ocean Systems After Large Volcanic Eruptions (cont.)
1245h – 1800h	Free time
1800h – 1930h	Dinner on your own
1930h – 2030h	Keynote Talk – Volcanic Eruptions and Aviation
2030h – 2200h	Poster Sessions

Saturday, 16 June 2012

0900h – 1800h	Post-conference Field Trip –Reykianes Peninsula

SCIENTIFIC PROGRAM

SUNDAY, 10 JUNE

1800h – 1900h **Welcome Reception**

1900h – 2100h **Dinner on Your Own (Sunday)**

MONDAY, 11 JUNE

0845h – 0900h **Introduction and Welcome**

Eyjafjallajökull
Presiding: Alan Robock, Tamsin A. Mather
Banquet Room 1: Aðalsalur

0900h – 0915h **Adriana Rocha Lima** | Optical, Microphysical and Compositional Properties of the Volcano Eyjafjallajökull (Iceland)

0915h – 0930h **Halldor Bjornsson** | Assessing Simple Models of Volcanic Plumes Using Observations From the Summit Eruption of Eyjafjallajökull in 2010

0930h – 0945h **Stephen Mobbs** | Overview of the VANAHEIM Project: Characterisation of the Near-Field Eyjafjallajökull Volcanic Plume and its Long-range Influence

0945h – 1000h **Christian Rolf** | Lidar Observation and Model Simulation of an Volcanic Ash Induced Cirrus Cloud During Eyjafjalla Eruption

1000h – 1015h **Adam J. Durant** | Passive Remote Sensing of Volcanic Clouds from Satellite, Aircraft and the Ground

1015h – 1030h **David C. Pieri** | Airborne Ash Hazards: In Situ Calibration and Validation of Remotely Sensed Data and Models

1030h – 1100h **Monday A.M.Coffee Break**

Volcanic Eruptions and Aviation (cont.)
Presiding: Alan Robock, Tamsin A. Mather
Banquet Room 1: Aðalsalur

1100h – 1115h **Eric J. Hughes** | Real-Time Estimation of Volcanic Ash/SO_2 Cloud Heights from UV Satellite Observations and Numerical Modeling

1115h – 1130h **John A. Stevenson** | Grímsvötn 2011 Tephra in the UK: Public Sampling, Air Quality and Comparison With Model Predictions

1130h – 1145h **Gerhard Wotawa** | Development and Operational Testing of New Volcanic Ash Prediction Services for International Aviation

1145h – 1200h **Mario Montopoli** | Microwave Remote Sensing of Volcanic Ash Clouds for Aviation Hazard and Civil Protection Applications: the 2011 Grímsvötn Eruption Case Study

1200h – 1215h **Pierre F. Coheur** | Global Multi-sensor Satellite Monitoring of Volcanic SO_2 and Ash Emissions in Support to Aviation Control

1215h – 1230h **Sibylle von Löwis** | Measurements of Suspended and Resuspended Volcanic Ash by Ground-based Depolarisation Lidar in Iceland

1230h – 1245h **Ulrich Platt** | Spectroscopic Observation of Volcanic Emissions – Results and Future Trends

1330h – 1800h **Free Time (Monday)**

1800h – 1930h **Dinner on Your Own (Monday)**

Katmai Centennial Keynote

Presiding: Alan Robock, Tamsin A. Mather

Banquet Room 1: Aðalsalur

1930h – 2000h **Judy Fierstein** | The 1912 eruption of Novarupta and collapse of Mount Katmai, Alaska—a centennial perspective (*Invited*)

2000h – 2030h **Bruce F. Houghton** | The 1912 Eruption of Novarupta and Collapse of Mount Katmai, Alaska - a Centennial Perspective (*Invited*)

2030h – 2200h **Tropospheric Aerosols and Chemistry Posters (Posters will be presented on Monday and Tuesday)**

Banquet Room 3: Norðursalur

TC-1 **Anja Schmidt** | Importance of Tropospheric Volcanic Aerosol in Assessments of the Aerosol Indirect Forcing of Climate

TC-2 **Auromeet Saha** | Properties of Sarychev sulphate aerosols over the Arctic

TC-3 **Bernard H. Grobety** | Volcanic sulfate aerosols

TC-4 **Dominik Schäuble** | First in situ measurements of Cl_2 in the plume of degassing volcano Mt. Etna

TC-5 **Evgenia Ilyinskaya** | On-Site Measurements of Gas Release from Grímsvötn Volcano

TC-6 **Herdis H. Schopka** | Atmospheric Carbon Consumption by Chemical Weathering of Basalt in the Tropics: The Hawaiian Example

TC-7 **Kirstin Krueger** | The Combined Bromine and Chlorine Release From Large Explosive Volcanic Eruptions: a Threat to Stratospheric Ozone

TC-8 **Lori Mandable** | **Source Detection of SO_2 Emissions with Unknown Origins Using Remote Sensing and Numerical Modeling**

TC-9 **Margaret A. Tolbert** | Volcanic Sulfur Chemistry in Reducing Atmospheres: Implications for Particles on the Early Earth

TC-10 **Narcisa Banda** | Quantifying the Processes that Contributed to the Anomalous Methane Growth Rate after the Eruption of Mt. Pinatubo

TC-11 **Nicole Bobrowski** | Bromine chemistry of volcanic plumes

TC-12 **Robert Martin** | The uptake of halogen (HF, HCl, HBr and HI) and nitric (HNO_3) acids into acidic sulphate particles in quiescent volcanic plumes

TC-13 **Robert Martin** | Bioindication of volcanic mercury deposition around Mt Etna

TC-14 **Roland von Glasow** | Reactive chemistry in tropospheric volcanic plumes

TC-15 **Sandra M. Andersson** | Volcanic Aerosol Composition and Its Development in the Lowermost Stratosphere

TC-16 **Tamsin A. Mather** | Halogen and Trace Metal Emissions From Volcanism: Insights From Hawai`i (*Invited*)

TC-17 **Deanna Donohoue** | 3-D modelling of the Atmospheric Chemistry of Quiescently Degassing Volcanoes

TC-18 **Arthur A. Few** | Lightning and Ice in Volcanic Clouds

2030h – 2200h **Remote Sensing Posters (Posters will be presented on Monday and Tuesday)**

Banquet Room 3: Norðursalur

RS-1 **Fred Prata** | Global, long-term volcanic SO_2 measurements from satellites and the significance to climate

RS-2 **Luca Merucci** | SO_2 flux time series reconstruction from MSG-SEVIRI measurements

RS-3 **Mhairi E. O'Hara** | An Integrated Near-Real-Time Lava Flow Tool: Incorporating Satellite Data

RS-4 **Silvio De Angelis** | The inaudible sound of volcanoes: infrasound applications to volcano monitoring

RS-5 **Simon A. Carn** | Satellite Measurements and Modeling of the 2011 Nabro (Eritrea) Volcanic Clouds

RS-6 **Stefano Corradini** | Volcanic SO_2 estimation from ash rich plumes using TIR satellite measurements: Comparison between MODIS, ASTER and IASI retrieval procedures

RS-7 **Christoph Hörmann** | Estimating the Lifetime of SO_2 From Space: A case Study of the Kilauea Volcano

RS-8 **Ulrich Foelsche** | Radio Occultation - A new Tool for the Observation of Changes in the Thermal Structure of the Atmosphere after Major Volcanic Eruptions

RS-9 **Aurometer Saha** | Properties of Sarychev sulphate aerosols over the Arctic

RS-10 **Auromeet Saha** | Multi-year investigation of stratospheric optical depths over the Arctic

RS-11 **Barbara Brooks** | LIDAR as a tool for the monitoring and forecast of re-suspended ash

RS-12 **Brendan T. McCormick** | Validating OMI measurements of tropospheric volcanic SO_2

RS-13 **Cathy Clerbaux** | Near Real-time Monitoring of SO_2 and Volcanic Ash with IASI/Metop

RS-14 **Christoph Hörmann** | Systematic investigation of bromine monoxide in volcanic plumes from space by using the GOME-2 instrument

RS-15 **Elisa Carboni** | A New Sulphur Dioxide Retrieval from IASI: Results for Recent Eruptions and Possible Volcanic Degassing

RS-16 **Adam E. Bourassa** | Volcanic Perturbations to the Stratospheric Aerosol Layer in the Last Decade: OSIRIS Measurements

RS-17 **Stephen R. McNutt** | Infrasound Observations of Explosive Volcanic Eruptions in Alaska, 2006-2011

2030h – 2200h **Volcanic Eruptions and Aviation Posters (Posters will be presented on Monday and Tuesday)**
Banquet Room 3: Norðursalur

VA-1 **Adam J. Durant** | Passive Remote Sensing of Volcanic Clouds from Satellite, Aircraft and the Ground

VA-2 **John A. Stevenson** | Grímsvötn 2011 Tephra in the UK: Public Sampling, Air Quality and Comparison With Model Predictions

VA-3 **Andreas Vogel** | Ground based stationary and mobile in situ measurements of volcanic ash particles during and after the 2011 Grímsvötn volcano eruption on Iceland

VA-4 **Anja Schmidt** | Future Icelandic flood lava eruptions: are our atmospheric models fit for purpose?

VA-5 **Daniel M. Peters** | Optical properties of volcanic ash

VA-6 **David C. Pieri** | Airborne Ash Hazards: In Situ Calibration and Validation of Remotely Sensed Data and Models

VA-7 **David A. Waddicor** | Characterisation of the Near-Field Eyjafjallajökull Volcanic Plume using Remote Sensing from UK Based Lidars

VA-8 **Deborah Lee** | Volcanic eruptions and the threat to air transport systems: a coordinated European Roadmap

VA-9 **Eric J. Hughes** | Some Perspectives on Uncertainty in Volcanic Emissions Forecasting

VA-10 **Eric J. Hughes** | Real-Time Estimation of Volcanic Ash/SO_2 Cloud Heights from UV Satellite Observations and Numerical Modeling

VA-12 **Gerhard Wotawa** | Development and Operational Testing of New Volcanic Ash Prediction Services for International Aviation

VA-12 **Kimberly Genareau** | Measuring Ash Properties That Help to Generate Lightning in Eruptive Plumes

VA-13 **Konradin Weber** | Airborne investigations of volcanic plumes with light aircrafts – examples of applications during the recent eruptions of the volcanoes Eyjafjallajökull, Grimsvötn and Etna

VA-14 **Konstantin Moeseyenko** | Inversion of eruption source parameters with use of numerical model for the transport and deposition of volcanic ash

VA-15 **Leif Vogel** | Preventing potential aircraft encounters with volcanic plumes: Early in-flight detection of volcanic SO_2 by 1-D Imaging Differential Optical Absorption Spectroscopy

VA-16 **Mario Montopoli** | Microwave Remote Sensing of Volcanic Ash Clouds for Aviation Hazard and Civil Protection Applications: the 2011 Grímsvötn Eruption Case Study

VA-17 **Mark J. Woodhouse** | Integral models of volcanic eruption columns in a wind field

VA-19 **Mauro Coltelli** | 2011 AND 2012 VOLCANIC PLUMES OF MT. ETNA AND THEIR IMPACT ON THE AVIATION

VA-19 **Pierre F. Coheur** | Global Multi-sensor Satellite Monitoring of Volcanic SO_2 and Ash Emissions in Support to Aviation Control

VA-20 **Sarah Millington** | Development of satellite volcanic ash products for the London VAAC

VA-21 **Sibylle von Löwis** | Measurements of Suspended and Resuspended Volcanic Ash by Ground-based Depolarisation Lidar in Iceland

VA-22 **Simona Scollo** | LIDAR SCANNING NEARBY ETNA SUMMIT

VA-23 **Ulrich Platt** | Spectroscopic Observation of Volcanic Emissions – Results and Future Trends

VA-24 **Judy Fierstein** | The 1912 eruption of Novarupta and collapse of Mount Katmai, Alaska—a centennial perspective (*Invited*)

VA-25 **Bruce F. Houghton** | The 1912 Eruption of Novarupta and Collapse of Mount Katmai, Alaska - a Centennial Perspective (*Invited*)

2030h – 2200h **Eyjafjallajökull Posters (Posters will be presented on Monday and Tuesday)**
Banquet Room 3: Norðursalur

E-1 **Andrey Skorokhod** | Influence of Eyjafjallajökull Eruption in April 2010 on the Atmospheric Air Composition in Moscow

E-2 **Halldor Bjornsson** | Assessing Simple Models of Volcanic Plumes Using Observations From the Summit Eruption of Eyjafjallajökull in 2010

E-3 **Manfred van Bergen** | Extreme compositional heterogeneity of particles in fallout from the 2010 Eyjafjallajökull ash cloud over England

E-4 **Stephan Nyeki** | Aerosol Optical Depth Measurements of the Eyjafjalla Volcanic Plume over Ireland

E-5 **Stephen Mobbs** | Overview of the VANAHEIM Project: Characterisation of the Near-Field Eyjafjallajökull Volcanic Plume and its Long-range Influence

E-6 **Adriana Rocha Lima** | Optical, Microphysical and Compositional Properties of the Volcano Eyjafjallajökull (Iceland)

E-7 **Anna María Ágústsdóttir** | Natural Hazard and Disaster Risk Reduction in Iceland Regarding Volcanic Ash, Vegetation and Soil Conservation

E-8 **Christian Rolf** | Lidar Observation and Model Simulation of an Volcanic Ash Induced Cirrus Cloud During Eyjafjalla Eruption

E-9 **Martin Stuefer** | A discussion of WRF-Chem volcanic ash particulate simulations of the 2010 Eyjafjallajökull eruption

2030h – 2200h **Icelandic Volcanism Keynote Poster (Poster will be presented on Monday and Tuesday)**
Banquet Room 3: Norðursalur

IC-1 **Jónas Gudnason** | Sulphur release from Phreatomagmatic Eruptions in Iceland

TUESDAY, 12 JUNE

Tropospheric Aerosols and Chemistry

Presiding: Michael R. Rampino, Fred Prata
Banquet Room 1: Aðalsalur

0900h – 0920h **Tamsin A. Mather** | Halogen and Trace Metal Emissions From Volcanism: Insights From Hawai`i (*Invited*)

0920h – 0935h **Sandra M. Andersson** | Volcanic Aerosol Composition and Its Development in the Lowermost Stratosphere

0935h – 0950h **Anja Schmidt** | Importance of Tropospheric Volcanic Aerosol in Assessments of the Aerosol Indirect Forcing of Climate

0950h – 1005h **Kirstin Krueger** | The Combined Bromine and Chlorine Release From Large Explosive Volcanic Eruptions: a Threat to Stratospheric Ozone

1005h – 1020h **Margaret A. Tolbert** | Volcanic Sulfur Chemistry in Reducing Atmospheres: Implications for Particles on the Early Earth

1020h – 1035h **Deanna Donohoue** | 3-D modelling of the Atmospheric Chemistry of Quiescently Degassing Volcanoes

1035h – 1100h **Tuesday A.M. Coffee Break**

Remote Sensing

Presiding: Michael R. Rampino, Fred Prata
Banquet Room 1: Aðalsalur

1100h – 1115h **Simon A. Carn** | Satellite Measurements and Modeling of the 2011 Nabro (Eritrea) Volcanic Clouds

1115h – 1130h **Adam E. Bourassa** | Volcanic Perturbations to the Stratospheric Aerosol Layer in the Last Decade: OSIRIS Measurements

1130h – 1145h **Christoph Hörmann** | Systematic investigation of bromine monoxide in volcanic plumes from space by using the GOME-2 instrument

1145h – 1200h **Ulrich Foelsche** | Radio Occultation - A new Tool for the Observation of Changes in the Thermal Structure of the Atmosphere after Major Volcanic Eruptions

1200h – 1215h **Cathy Clerbaux** | Near Real-time Monitoring of SO_2 and Volcanic Ash with IASI/Metop

1215h – 1230h **Elisa Carboni** | A New Sulphur Dioxide Retrieval from IASI: Results for Recent Eruptions and Possible Volcanic Degassing

1330h – 1800h **Trip #1: Trjáviðarlækur (tephra section)**

1330h – 1800h **Trip #2: Western Volcanic Zone and the Hellisheiði Geothermal Power Plant**

1330h – 1800h **Field Trip #3: Þingvellir**

1800h – 1930h **Dinner on Your Own (Tuesday)**

1930h – 2030h **Icelandic Volcanism - The 2010 Eyjafjallajokull and the 2011 Grimsvotn Eruptions, Thor Thordarson**

WEDNESDAY, 13 JUNE

0900h – 1600h **Field Trip to Eyjafjallajökull Volcano**

1800h – 1930h **Dinner on Your Own (Wednesday)**

THURSDAY, 14 JUNE

Volcanism and the Last Millennium
Presiding: Claudia Timmreck, Hans-Friedrich Graf
Banquet Room 1: Aðalsalur

0900h – 0920h **Stephen Self** | Deciphering the Climatic Effects of Volcanic Aerosols: What Lies Ahead and Why Should We Care? (*Invited*)

0920h – 0940h **Gifford H. Miller** | The Role of Volcanism as a Trigger for the Little Ice Age (*Invited*)

0940h – 0955h **Franck Lavigne** | The 1258 Mystery Eruption: Environmental Effects, Time of Occurrence and Volcanic Source

0955h – 1010h **Michael R. Rampino** | The 1963 Eruption of Mt. Agung, Bali, Indonesia: A Climatically Significant Eruption

1010h – 1030h **Philip D. Jones** | Cool North European Summers and Possible Links to Explosive Volcanic Eruptions (*Invited*)

1030h – 1100h **Thursday A.M. Coffee Break**

Volcanism and the Last Millennium(cont.)
Presiding: Claudia Timmreck, Hans-Friedrich Graf
Banquet Room 1: Aðalsalur

1100h – 1120h **Michael Mann** | Underestimation of Volcanic Cooling in Tree-Ring Based Reconstructions of Hemispheric Temperatures (*Invited*)

1120h – 1135h **Rosanne D'Arrigo** | Volcanic Signals in Tree-ring Records for the Past Millennium (*INVITED*)

1135h – 1150h **Kenneth L. Verosub** | New Perspectives on the Frequency and Importance of Tambora-like Events

1150h – 1205h **Matthew Toohey** | The Impact of Post-eruption Atmospheric Circulation Changes on Ice Core Records of Paleo-volcanism

1205h – 1225h **Aslaug Geirsdottir** | Holocene Climate Extremes: The Little Ice Age And The 8.2 Ka Event As Viewed From Iceland (*Invited*)

1300h – 1500h **News Media Workshop**

1330h – 1800h **Free Time (Thursday)**

1800h – 1930h **Group Dinner**

Geoengineering Keynote Session
Presiding: Claudia Timmreck, Hans-Friedrich Graf
Banquet Room 1: Aðalsalur

1930h – 2030h **Alan Robock** | Volcanic Eruptions as an Analog for Geoengineering (*Invited*)

2030h – 2200h **Keynote Poster (Poster will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

Fred Prata | The Ash Spring: How an Icelandic Volcanic Eruption Brought Europe to a Standstill

2030h – 2200h **Volcanism and the Last Millennium Poster (Posters will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

VM-1 **Florian Arfeuille** | Volcanic forcing for climate modeling (1600-2011)

VM-2 **Franck Lavigne** | The 1258 Mystery Eruption: Environmental Effects, Time of Occurrence and Volcanic Source

VM-3 **Gifford H. Miller** | The Role of Volcanism as a Trigger for the Little Ice Age (*Invited*)

VM-4 **Kenneth L. Verosub** | New Perspectives on the Frequency and Importance of Tambora-like Events

VM-5 **Maria Martinez-Cruz** | Unrest of Turrialba volcano (Costa Rica) after 145 years of quiescence:Research, Geo-monitoring and Socio-economic Vulnerability Assessments

VM-6 **Matthias Bittner** | Impacts of Strong Volcanic Eruptions on the Northern Hemisphere Winter in the CMIP5 MPI-ESM Simulations

VM-7 **Michael Mann** | Underestimation of Volcanic Cooling in Tree-Ring Based Reconstructions of Hemispheric Temperatures (*Invited*)

VM-8 **Michael R. Rampino** | The 1963 Eruption of Mt. Agung, Bali, Indonesia: A Climatically Significant Eruption

VM-9 **Petra D. Breitenmoser** | Solar and Volcanic Fingerprints in Tree-Ring Chronologies Over the Past 800 Years

VM-10 **Philip D. Jones** | Cool North European Summers and Possible Links to Explosive Volcanic Eruptions (*Invited*)

VM-11 **Renate Auchmann** | Extreme Climate, not Extreme Weather: The Summer of 1816 in Geneva, Switzerland

VM-12 **Sébastien Guillet** | Climatic and Environmental Impacts of the Unknown A.D. 1171 Eruption in Europe and the Middle East

VM-13 **Stephen Self** | Deciphering the Climatic Effects of Volcanic Aerosols: What Lies Ahead and Why Should We Care? (*Invited*)

VM-14 **Thor Thordarson** | 934AD Eldgjá flood lava eruption, Iceland: Variability in magma composition and its implication for timing of maximum discharge

VM-15 **Jónas Gudnason** | Sulphur release from Phreatomagmatic Eruptions in Iceland

VM-16 **Valerio Acocella** | Understanding volcano unrest to forecast the atmospheric impact of eruptions

VM-17 **Weiyan Gao** | Geological and geomorphological value of the monogenetic volcanoes in Wudalianchi National Park, NE China

VM-18 **Juan-Carlos Antuna** | Effects of El Chichón and Mt Pinatubo volcanic eruptions on SST and solar radiation in the Wider Caribbean

VM-19 **Giuseppe Solaro** | DINSAR ANALYSIS OF MT. ETNA VOLCANO RETRIEVED THROUGH FIRST AND SECOND GENERATION SENSORS

VM-20 **Giovanni Zeni** | YELLOWSTONE CALDERA DEFORMATION FIELD ANALYSIS BY USING THE ADVANCED SBAS DINSAR TECNIQUE

VM-21 **Mickael Mussard** | Investigation into the volcanic aerosol dispersal : a better way to constrain the climatic impact of past eruptions

VM-22 **Rosanne D'Arrigo** | The anomalous winter of 1783-4: Was the Laki eruption or an analog of the 2009-10 winter to blame?

2030h – 2200h **Geoengineering Proposals Using Stratospheric Aerosols Poster (Posters will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

GS-1 **Ben Kravitz** | Climate interactions between volcanic forcings and idealized solar forcings

GS-2 **Larry W. Thomason** | Toward a Long-term Stratospheric Aerosol Data Set from Multiple Spaced-based Sensors

GS-3 **Ulrike Niemeier** | Impact of Geoengineering on global Climate - Earth System Model Simulations within IMPLICC

2030h – 2200h **Earth System Model Simulations of Large Volcanic Eruptions Posters (Posters will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

ES-1 **Aideen Foley** | Carbon cycle responses to volcanic activity over 0-2000 AD: A model-data comparison using SIMEARTH

ES-2 **Benjamin A. Black** | Modeling the climate effects of S, Cl, and F degassing from the Siberian Traps

ES-3 **Claudia Timmreck** | Global and Regional Climate Impacts of the Young Toba Tuff Eruption

ES-4 **Doreen Metzner** | Southern Hemisphere climate response to an extremely large tropical volcanic eruption: Simulations with the MPI-ESM

ES-5 **Doreen Metzner** | Radiative Forcing and Climate Impact Resulting From SO_2 Injections Based on a 200,000 Year Record of Plinian Eruptions Along the Central American Volcanic Arc

ES-6 **Eric J. Hughes** | Evaluation of Baseline Volcanic Emissions in GEOS-5

ES-7 **Jessica Kandlbauer** | Climate response of the 1815 Tambora eruption: HadGEM2-ES model simulations vs. historical records

ES-8 **Jianxiong Sheng** | Parametric Modelling Study of the Mt. Pinabuto Eruption

ES-9 **Joachim Segschneider** | Impact of an extremely large magnitude volcanic eruption on the global climate and carbon cycle estimated from ensemble Earth System Model simulations

ES-10 **Linda T. Elkins-Tanton** | Environmental Effects of the Siberian Flood Basalts and Possible Links with the End-Permian Extinction (*Invited*)

ES-11 **Michael J. Mills** | Simulation of the June 2011 Nabro Eruption with SD-WACCM/CARMA

ES-12 **Mira Losic** | Impacts of Volcanic Eruptions on Baffin Island Climate Using a Regional Climate Model

ES-13 **Ralph Burton** | Volcanic plume simulations using the WRF model

ES-14 **Simon Driscoll** | Coupled Model Intercomparison Project 5 (CMIP5) Simulations of Climate Following Large Tropical Volcanic Eruptions and the Effect of the Quasi-Biennial Oscillation (QBO) on the Surface Climate Following Large Tropical Volcanic Eruptions

ES-15 **Valentina Aquila** | The Chemical and Dynamical Responses of Ozone and Nitrogen Dioxide to the Eruption of Mt. Pinatubo

ES-16 **Wyss W. Yim** | Volcanic eruptions as a cause of regional extreme weather events

2030h – 2200h **Dynamics of the Coupled Atmosphere Ocean Systems after Large Volcanic Eruptions Posters (Posters will be presented on Thursday and Friday)**

Banquet Room 3: Norðursalur

DA-1 **Matthew Toohey** | The Influence of Eruption Season on the Global Aerosol Evolution and Radiative Impact of Tropical Volcanic Eruptions

DA-2 **Carley E. Iles** | The Effect of Volcanic Eruptions on the Hydrological Cycle

DA-3 **Davide Zanchettin** | Strong Tropical Volcanic Eruptions as a Major Driver of Decadal European Winter Climate Variability During the Last Millennium

DA-4 **Georgiy Stenchikov** | Volcanic Test of Regional Climate in Middle East and North Africa

DA-5 **Hans-Friedrich Graf** | The Variable Climate Impact of Volcanic Eruptions (*Invited*)

DA-6 **Martin R. Palmer** | Impact of marine diagenesis of tephra on atmospheric CO2

DA-7 **Owen B. Toon** | The Microphysics of Stratospheric Volcanic Clouds, and Its Influence on Climate Forcing. (*Invited*)

DA-8 **Mark P. Baldwin** | How Do Changes to the Stratospheric Circulation Affect the Troposphere? (*Invited*)

2030h – 2200h **Geoengineering Keynote Poster (Poster will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

Alan Robock | Volcanic Eruptions as an Analog for Geoengineering (*Invited*)

2030h – 2200h **Climate Response to High Latitude Eruptions Posters (Posters will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

CR-1 **Alyson Lanciki** | Lack of stratospheric aerosols by the 1783 Laki volcanic eruption and implications on climatic impact

CR-2 **Aslaug Geirsdottir** | Holocene Climate Extremes: The Little Ice Age And The 8.2 Ka Event As Viewed From Iceland (*Invited*)

CR-3 **Cindy L. Young** | A satellite and ash transport model aided approach to assess the radiative impacts of volcanic aerosol in the Arctic

CR-4 **Hera Gudlaugsdottir** | The climatic signal in the stable isotope record of the NEEM SS0802 shallow firn/ice core from the NEEM deep drilling site in NW Greenland

CR-5 **Summer Praetorius** | Deglacial volcanism in the Gulf of Alaska: implications for timing and forcing of North Pacific climate transitions

2030h – 2200h **Improved Ice Core-Based Index of Volcanic Eruptions Poster (Posters will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

IV-1 **David Ferris** | A six thousand year volcanic record from the West Antarctic Ice Sheet Divide ice core

IV-2 **Matthew Toohey** | The Impact of Post-eruption Atmospheric Circulation Changes on Ice Core Records of Paleo-volcanism

2030h – 2200h **High Resolution Holocene Tephra Records of Explosive Eruptions Poster (Posters will be presented on Thursday and Friday)**
Banquet Room 3: Norðursalur

HR-1 **Tamsin A. Mather** | Late Quaternary tephrochronology of southern Chile: An ideal test site for constraining arc-scale volcanic response to deglaciation

FRIDAY, 15 JUNE

	Dynamics of the Coupled Atmosphere Ocean Systems after Large Volcanic Eruptions Presiding: Stephen Self, Thor Thordarson Banquet Room 1: Aðalsalur
0900h – 0920h	**Owen B. Toon** | The Microphysics of Stratospheric Volcanic Clouds, and Its Influence on Climate Forcing. (*Invited*)
0920h – 0940h	**Hans-Friedrich Graf** | The Variable Climate Impact of Volcanic Eruptions (*Invited*)
0940h – 1000h	**Mark P. Baldwin** | How Do Changes to the Stratospheric Circulation Affect the Troposphere? (*Invited*)
1000h – 1015h	**Davide Zanchettin** | Strong Tropical Volcanic Eruptions as a Major Driver of Decadal European Winter Climate Variability During the Last Millennium
1015h – 1030h	**Kirstin Krueger** | Do large tropical volcanic eruptions influence the Southern Annular Mode?
1030h – 1100h	**Friday A.M. Coffee Break**
	Dynamics of the Coupled Atmosphere Ocean Systems After Large Volcanic Eruptions (cont.) Presiding: Stephen Self, Thor Thordarson Banquet Room 1: Aðalsalur
1100h – 1115h	**Georgiy Stenchikov** | Volcanic Test of Regional Climate in Middle East and North Africa
1115h – 1135h	**Linda T. Elkins-Tanton** | Environmental Effects of the Siberian Flood Basalts and Possible Links with the End-Permian Extinction (*Invited*)
1135h – 1150h	**Claudia Timmreck** | Global and Regional Climate Impacts of the Young Toba Tuff Eruption
1150h – 1205h	**Doreen Metzner** | Radiative Forcing and Climate Impact Resulting From SO_2 Injections Based on a 200,000 Year Record of Plinian Eruptions Along the Central American Volcanic Arc
1205h – 1220h	**Simon Driscoll** | Coupled Model Intercomparison Project 5 (CMIP5) Simulations of Climate Following Large Tropical Volcanic Eruptions and the Effect of the Quasi-Biennial Oscillation (QBO) on the Surface Climate Following Large Tropical Volcanic Eruptions
1220h – 1235h	**Ulrike Niemeier** | Impact of Geoengineering on global Climate - Earth System Model Simulations within IMPLICC

1330h – 1800h **Free Time(Friday)**

1800h – 1930h **Dinner on Your Own (Friday)**

Volcanic Eruptions and Aviation Keynote
Presiding: Stephen Self, Thor Thordarson
Banquet Room 1: Aðalsalur

1930h – 2030h **Fred Prata** | The Ash Spring: How an Icelandic Volcanic Eruption Brought Europe to a Standstill

SATURDAY, 16 JUNE

0900h – 1600h **Post-Conference Field Trip - Reykjanes Peninsula**

ABSTRACTS

listed by name of presenter

Acocella, Valerio

Understanding volcano unrest to forecast the atmospheric impact of eruptions

Acocella, Valerio[1]

1. Dip Scienze Geologiche, Universita Roma Tre, Roma, Italy

Volcanoes are complex systems, experiencing unrest before erupting. Unrest is mainly due to the intrusion of magma, which may reach the surface and erupt. As most intrusions stall at depth, most unrest episodes do not culminate in eruptions. The limited physical understanding of magma intrusion, the dispersed and diverse information on unrest episodes and the difficulty in unambiguously interpreting any monitoring signal are behind our inadequate knowledge on pre-eruptive processes. This limitation affects a major challenge for studies on volcanoes, which is the short-term forecasting of eruptions and their atmospheric impact due to ash plumes, a primary aviation concern, and sulfur release, affecting climate. Also because of this limitation, such a forecast of the atmospheric impact of impending eruptions has yet to be attempted. This study describes an innovative approach to forecast 1) the atmospheric impact of eruptions due to ash plumes and 2) the related release of sulfur, which may affect climate on the short- to the medium-term. Such an approach considers an interdisciplinary method of understanding unrests (using databases, statistics and modeling) and of conveying this knowledge into a probabilistic forecast tool, which takes into account for the expected atmospheric impact of impending eruptions.

Ágústsdóttir, Anna María

Natural Hazard and Disaster Risk Reduction in Iceland Regarding Volcanic Ash, Vegetation and Soil Conservation

Ágústsdóttir, Anna María[1]

1. Soil Conservation Service of Iceland, Hella, Iceland

Recent Icelandic eruptions (2010-2011), proved beyond a doubt the value of pre-event planning for natural hazards. Here I focus on possible pre-disaster mitigation responses for ash-fall and vegetation. The United Nations International Strategy for Disaster Reduction defines “Disaster risk reduction”as “the concept and practice of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters. Reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment, and improving preparedness for adverse events are all examples of disaster risk reduction”[1]. Risk Identification Active volcanism is prevalent in Iceland with active regions covering 30% of the land with historical eruption frequency of 20-25 events per 100 years[2]. There is considerable risk for tephra deposition events to occur. Tephra can destroy/damage vegetation by the initial direct burial or with post-eruptive transport either by water or wind, extending the area of influence far away from the initial area. Tephra can also affect hydrology and air quality. Ecosystem resilience against deposition of aeolian material and volcanic ash fallout depends on various factors e.g.: depth of burial, species regeneration capability when buried, seasonality, water availability, toxicity etc. Vigorous ecosystems with tall vegetation generally have greater endurance capability; the sheltering effect minimizes the secondary wind transport of ash, and hastens the incorporation of ash into the soil. Whereas when ash falls onto areas with little or no vegetation, it is unstable and easily moved repeatedly by wind and water erosion possibly causing further abrasive damage. Risk reduction Build-up of healthy ecosystems increases resilience providing better capability of surviving ash fallout. The common range land in the highlands that are now degraded pose as Iceland’s most serious environmental problem. Existing vegetation in these range lands is generally sparse and low growing and therefore vulnerable to disruption. Ash-fall onto land in such condition can be catastrophic shown by recent events. Resilience to catastrophic events can be drastically improved by reclamation efforts. Effective governance through alignment of policies, e.g.: land use planning/zoning, natural resources management, agricultural policies, mitigation action against climate change through revegetation and carbon sequestration, restoration of natural birch forests[3], along with coherent legislation, multi-sectoral coordination with effective knowledge sharing, are important in successful risk management. Encouragement of sustainable use and appropriate management of fragile ecosystems through better land-use planning and development activities now has an additional aim to reduce risk and vulnerabilities to natural hazards.[4] 1. United Nations International Strategy for Disaster Reduction. “Disaster risk reduction” www.unisdr.org/ 2. Thordarson & Larsen 2007, Volcanism in Iceland in historical time. J. Geodynamics 43: 118 3. Ministry for the Environment. Plans for restoration of natural birch forests in Iceland. 4. The WMO Disaster Risk Reduction. A framework for Disaster Risk Management Derived from the Hyogo framework for Action 2005-2015.

www.land.is

Andersson, Sandra M.

Volcanic Aerosol Composition and Its Development in the Lowermost Stratosphere

Andersson, Sandra M.[1]; Martinsson, Bengt G.[1]; Friberg, Johan[1]; Brenninkmeijer, Carl A.[2]; Hermann, Markus[3]; van Velthoven, Peter P.[4]; Zahn, Andreas[5]

1. Division of Nuclear Physics, Lund University, Lund, Sweden
2. Max-Planck-Institut für Chemie, Mainz, Germany
3. Leibniz-Institut für Troposphärenforschung, Leipzig, Germany
4. Royal Netherlands Meteorological Institute, de Bilt, Netherlands
5. Institut für Meteorologie und Klimaforschung, Karlsruhe, Germany

Measurements of atmospheric aerosols by the CARIBIC (Civil Aircraft for Regular Investigation of the atmosphere Based on an Instrument Container) platform following the Kasatochi (Alaska), Sarychev (Russia) and Eyjafjallajökull (Iceland) eruptions in the period 2008-2010 are presented. The CARIBIC platform operates on a Lufthansa passenger aircraft usually on monthly inter-continental flights, measuring the atmospheric composition in the UT/LMS at 8-12 km altitude (Brenninkmeijer et al., 2007). Specific flights bringing the CARIBIC platform through the volcanic ash cloud from the Eyjafjallajökull eruption were carried out on April 20, May 16 and May 19, 2010. Aerosol particles of 0.08-2μm were collected by an impaction technique and analyzed by quantitative multi-elemental methods PIXE (Particle-Induced X-ray Emission) and PESA (Particle Elastic Scattering Analysis). Three of the samples taken during the special flights to study the Eyjafjallajökull eruption contained unusually high concentrations of elements pointing to crustal origin. The ratio of detected elements to iron in these samples showed good agreement with ash from a fall out sample for most of the elements (Fig. 1). Volcanically influenced aerosol following the eruptions of Sarychev and Kasatochi were identified by high concentrations of sulfur and by using air mass trajectories and CALIPSO lidar images. The ash component in these samples could be recognized by comparing to the composition of the aerosol form Eyjafjallajökull. By these methods volcanically influenced aerosol collected up to more than 100 days after the eruptions were identified. The residence time of SO2 in the stratosphere following the Sarychev eruption was estimated to be 52 days.
Brenninkmeijer C.A.M. et al. (2007). Atmos. Chem. Phys., 7, 4953-4976. Sigmundsson F. et al. (2010). Nature, 468, 426-430.

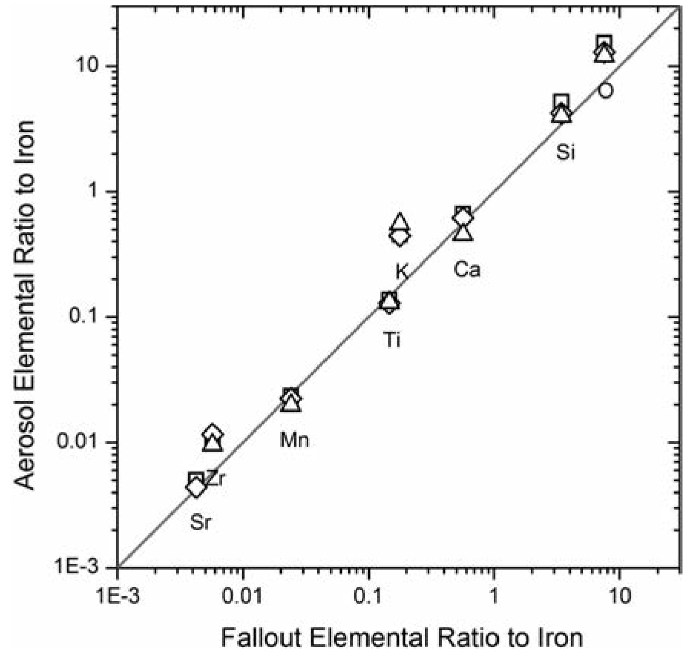

Figure 1. Elemental ratio to iron in aerosol samples (shown by different symbols) collected by the CARIBIC platform vs. fall out sample (SRG 5a, Sigmundsson et al., 2010). The solid line indicates equal ratio.

Antuna, Juan-Carlos

Effects of El Chichón and Mt Pinatubo volcanic eruptions on SST and solar radiation in the Wider Caribbean

Antuna, Juan-Carlos[1]; Estevan, Rene[1]; Barja, Boris[1]

1. Camaguey Meteorological Center, Camaguey, Cuba

Using the available global sea surface temperature data from meteorological stations, lower troposphere and stratosphere temperature measurements from a satellite instrument and several global solar radiation records in the Wider Caribbean the effects of the El Chichón and Mt. Pinatubo volcanic eruptions are studied. Global, tropical and regional SST anomalies means and its trends are compared showing the impact of both eruptions but with different magnitudes more evident in the tropics and at regional scale. Both lower troposphere and lower stratosphere temperature anomalies at global and regional scales are compared as well as its trends. In the lower stratosphere the warming produced by the presence of very high concentration of stratospheric aerosol from both eruptions is evident with almost no difference between the global and regional effect, in the general trends, the strength, extension and duration of the two peaks. The analysis of the few global radiation records available for the Wider Caribbean show in general the negative anomalies of the global radiation just after the eruption as well as the positive anomalies in the diffuse radiation for the same period. Using a column radiative transfer code, numerical simulations of the radiative effects of the Mt. Pinatubo eruption over the Wider Caribbean were conducted. Results are shown and discussed. The numerical simulations were also used to estimate in a first approximation the reduction of the solar radiation at the

surface in Cuba after the hypothetic eruptions of super-volcanoes of different magnitudes.

http://www.lidar.camaguey.cu/

Aquila, Valentina

The Chemical and Dynamical Responses of Ozone and Nitrogen Dioxide to the Eruption of Mt. Pinatubo

Aquila, Valentina[1]; Oman, Luke D.[1]; Stolarski, Richard S.[2]; Douglass, Anne R.[1]

1. Code 614, NASA GSFC, Greenbelt, MD, USA
2. Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, USA

Observations have shown that the concentration of nitrogen dioxide decreased in both hemispheres in the years following the eruption of Mt. Pinatubo. In contrast, the observed ozone response was largely asymmetrical with respect to the equator, with a decrease in the northern hemisphere and little or no change in the southern hemisphere. Simulations including enhanced heterogeneous chemistry due to the presence of the volcanic aerosol reproduce a decrease of ozone in the northern hemisphere, but also produce a comparable ozone decrease in the southern hemisphere contrary to observations. Our simulations show that the heating due to the volcanic aerosol enhanced both the tropical upwelling and the extratropical downwelling. The enhanced extratropical downwelling, combined with the time of the eruption relative to the seasonal phase of the Brewer-Dobson circulation, increased the ozone in the southern hemisphere and counteracted the ozone depletion due to heterogeneous chemistry on volcanic aerosol.

Arfeuille, Florian

Volcanic forcing for climate modeling (1600-2011)

Arfeuille, Florian[1, 2]; Weisenstein, Debra[3]; Heckendorn, Patricia[1]; Thomason, Larry[4]; Luo, Beiping[1]; Rozanov, Eugene[1, 5]; Sheng, JianXiong[1]; Schraner, Martin[6]; Peter, Thomas[1]; Brönnimann, Stefan[2]

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2. Oeschger Center and Institute of Geography, University of Bern, Bern, Switzerland
3. Harvard University, Cambridge, MA, USA
4. NASA Langley Research Center, Hampton, VA, USA
5. Physical-Meteorological Observatory / World Radiation Center, Davos, Switzerland
6. Federal office of Meteorology and Climatology, Meteoswiss, Zürich, Switzerland

As the understanding and representation of the volcanic eruption impacts on climate improved in the last years, uncertainties in the stratospheric aerosol forcing from large eruptions are now not only linked to the accuracy in the visible optical depths on a global scale but also to details on the size, latitude and altitude distributions of the stratospheric aerosols. We present a new model-based approach to generate a volcanic forcing for climate simulations. This volcanic forcing covering the 1600-2011 period uses an aerosol microphysical model (AER) to provide a realistic, physically consistent, treatment of the stratospheric sulfate aerosols. 26 eruptions were modeled individually using the latest available aerosol mass estimates from ice cores and historical data on the latitude and date of the eruptions. Aerosols spatial and size distribution evolutions after the sulfur dioxide discharges are hence characterized for each volcanic eruption. Large variations are seen in hemispheric partitioning and size distributions in relation to location and date of eruptions as well as SO2 masses, and results for recent eruptions are in good agreement with observations. By providing an alternative volcanic forcing with accurate amplitude and spatial distributions of shortwave and longwave radiative perturbations, this volcanic forcing may help refine the climate model responses to the large volcanic eruptions since 1600. The dataset consists in 3D values of aerosol concentrations and sizes which can in turn be used to calculate extinctions, single scattering albedos and asymmetry factors for different wavelength bands. General results from this forcing are shown and compared to previous reconstructions. Using this forcing, the climate response to the Tambora 1815 eruption (the largest eruption in the dataset) is analyzed using the CCM SOCOL. Finally, remaining issues in the representation of the stratospheric warming following large eruptions are highlighted by investigating the radiative response to the Pinatubo eruption using both the forcing from the AER simulation and a dataset derived from satellite observations. We suggest that the stratospheric warming overestimation often seen in climate models arises from model deficiencies rather than an insufficient data basis.

Auchmann, Renate

Extreme Climate, not Extreme Weather: The Summer of 1816 in Geneva, Switzerland

Auchmann, Renate[1]; Brönnimann, Stefan[1]; Breda, Leila[2]; Bühler, Marcel[1]; Spadin, Reto[2]; Wegmann, Martin[1]; Stickler, Alexander[1]

1. Oeschger Center for Climate Change Research and Institute of Geography, University of Bern, Bern, Switzerland
2. Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

1816 is known as the “Year without Summer” that followed the eruption of Tambora. The global scale surface cooling due to the Tambora eruption is estimated to approximately half a degree Celsius. In central Europe, where consequences were devastating both economically and socially, the cold anomalies were much larger calling for additional or amplifying mechanisms. We analyze weather and climate during the “Year without Summer” 1816 using recently digitized sub-daily data (DigiHom III) from Geneva, Switzerland, representing one of the climatically most severely affected regions. The record includes twice daily

measurements and observations of air temperature, pressure, cloud cover, wind speed, and wind direction as well as daily measurements of precipitation. Our aim is to answer the question to what extent the year without summer was characterized by extreme climate or by extreme weather (i.e., whether changes are largest in the central part of the frequency distribution or near the extremes). Furthermore, the analysis of sub-daily data might provide more insights into underlying mechanisms. Comparing 1816 to a contemporary reference period (1799-1821) reveals that the coldness of the summer of 1816 was most prominent in the afternoon, with a shift of the entire distribution function of temperature anomalies by 3-4 °C. Early morning temperature anomalies show a smaller change for the mean, a significant decrease in the variability, and no changes in negative extremes. Analyzing cloudy and cloud-free conditions separately suggests that an increase in the number of cloudy days was to a significant extent responsible for these features. In addition, differences of temperature anomalies on cloud-free days in the afternoon and early mornings are smaller in summer 1816, which for simplicity we address as decrease in the diurnal temperature range. A daily weather type classification based on pressure, pressure tendency, and wind direction shows extremely anomalous frequencies in summer 1816, with only one day classified as high-pressure situation but a tripling of low-pressure situations. The afternoon temperature anomalies expected from only a change in weather types was much stronger negative in summer 1816 than in any other year. For precipitation, our analysis shows that the 80% increase in summer precipitation compared to the reference period can be explained by 80% increase in the frequency of precipitation, while no change could be found neither in the average intensity of precipitation nor in the frequency distribution of extreme precipitation. The analysis shows that the regional circulation and local cloud cover played a dominant role. Although an attribution of the causes is not possible using only observational data, they still provide interesting insights which will be further used in model comparisons (e.g. decrease in diurnal temperature range). We show that the year without summer was not characterized by extreme weather (the tails of the distributions did not change much except for cold afternoons), but extreme climate (i.e., the statistics of weather types changed).

Baldwin, Mark P.

How Do Changes to the Stratospheric Circulation Affect the Troposphere? (*Invited*)

Baldwin, Mark P.[1]

1. NorthWest Research Associates, Redmond, WA, USA

Observations of atmospheric winds and temperatures indicate that changes to the strength of the wintertime circulation of the stratosphere (~10–50 km) often precede long-lasting changes to tropospheric weather. These changes to surface weather are often profound, affecting the surface pressure distribution, the positions of jet streams, storm tracks, and the likelihood of extreme weather events. This downward coupling is typically demonstrated in terms of 'annular modes,' which represent the strength of the polar vortex in the stratosphere, and correspond to the Northern Annular Mode or North Atlantic Oscillation near Earth's surface. Variations in the strength of the polar vortex can also be represented by anomalies in potential vorticity, which has a direct dynamical connection to both the height of the tropopause and surface pressure. Despite the clear evidence of downward coupling in observations and models, the primary mechanism by which stratospheric variability affects Earth's surface is not yet well understood. In this talk I will demonstrate observationally that the stratospheric residual circulation, which modulates the strength of vertical motion through the high-latitude tropopause, is tightly coupled to the height of the polar tropopause, as well as the movement of constant potential temperature surfaces. An elevated tropopause leads, through tropospheric stretching, to higher geostrophic vorticity in the underlying troposphere and lower surface pressure over the polar cap. This result is consistent with theoretical and observational studies of potential vorticity inversion. The temperature anomalies associated with the residual circulation correspond to the vertical structure of annular modes, and the long-lasting temperature anomalies just above the tropopause correspond to vertical displacements of the tropopause. To the extent that volcanic eruptions affect the strength of the vertical circulation over the polar cap, it follows that the troposphere will be affected by the same mechanism that during other major perturbations to the stratospheric circulation.

Banda, Narcisa

Quantifying the Processes that Contributed to the Anomalous Methane Growth Rate after the Eruption of Mt. Pinatubo

Banda, Narcisa[1, 2]; Krol, Maarten[3, 1]; van Weele, Michiel[2]; van Noije, Twan[2]; Röckmann, Thomas[1]

1. Institute of Marine and Atmospheric Science, Utrecht University, Utrecht, Netherlands
2. Royal Netherlands Meteorological Institute (KNMI), De Bilt, Netherlands
3. Meteorology and Air Quality Group, Wageningen University, Wageningen, Netherlands

Methane is an important greenhouse gas in the atmosphere. However, its evolution in the past two decades is not entirely understood. The growth rate of methane showed particularly large fluctuations after the eruption of Mount Pinatubo in June 1991. Being able to quantify the processes that determined these fluctuations can help us gain a better understanding of the methane budget. Methane concentrations are determined by methane emissions and methane lifetime. Its lifetime is determined by OH concentrations, which are affected by UV radiation levels and by non-linear tropospheric chemistry. OH is produced by ozone photolysis and photolysis frequencies are determined by the amount of UV radiation reaching the troposphere. OH reacts with other chemical species, such as

NO_X, CO and NMVOC, and thus its concentration is also driven by the concentrations of these species. The Pinatubo eruption injected about 18.5 Mt of SO_2 in the stratosphere, and triggered different photochemical effects, including feedback between climate and atmospheric photochemistry. Table 1 summarizes these processes which had both positive and negative impacts on the methane growth rate, affecting methane emissions and methane lifetime. SO_2 and sulfate aerosols formed from SO_2, as well as stratospheric ozone depletion observed after the eruption, determined changes in tropospheric UV levels, thus in OH and methane lifetime. The temperature decrease in the years after the eruption led to changes in chemical reaction rates, in water vapor, as well as in natural emissions of methane and NMVOCs. We represent the globally yearly averaged state of the troposphere in a column chemistry model, which accounts for non-linear CH_4-NO_X-CO-NMVOC-O_3 photochemistry. The effect of atmospheric perturbations on photolysis frequencies is calculated with the radiation transfer model TUV, and then used in the chemistry model. We model the transient response of methane and methane growth rate using the observed atmospheric changes after the eruption of Pinatubo. Using this setup, we try to quantify the different processes described above and find which of them contributed significantly to the observed methane growth rate in the following years.

Table 1. Mechanisms affecting methane concentrations after the Pinatubo eruption. Direction of the competing forcings

Process	Methane emissions	Tropospheric UV radiation	OH radical concentrations	Methane concentrations
UV absorption by SO 2		-	-	+
UV scattering by sulfate aerosols		-	-	+
Stratospheric ozone depletion		+	+	-
Slower reaction of methane with OH radicals				+
Reduced tropospheric water vapor			-	+
Reduced methane emissions from wetlands	-			-
Reduced isoprene emissions			+	-

Bittner, Matthias

Impacts of Strong Volcanic Eruptions on the Northern Hemisphere Winter in the CMIP5 MPI-ESM Simulations

Bittner, Matthias[1, 2]; Timmreck, Claudia[2]; Schmidt, Hauke[2]

1. Meteorological Insitute, KlimaCampus, University of Hamburg, Hamburg, Germany
2. The Atmosphere in the Earth System, Max Planck Institute for Meteorology, Hamburg, Germany

Strong tropical volcanic eruptions (SVE) inject huge amounts of sulfur-dioxide (SO2) into the stratosphere. Over chemical reactions and microphysical processes the SO2 converts to sulfate aerosols which scatter incoming short-wave radiation and absorb longwave and near infrared radiation therefore produce cooling of the surface as well as heating of the stratosphere. Because the bulk of the volcanic cloud is centered in the tropics and because of larger insolation, the tropical stratosphere warms more than the stratosphere in higher latitudes and therefore enhance the equator-to-pole temperature gradient. This leads to a strengthening of the polar vortex and via downward propagation to a positive phase of the North Atlantic Oscillation (NAO). In the CMIP5 simulations with the coupled atmosphere-ocean-biogeochemistry Max-Planck Earth System Model (MPI-ESM) we investigate the impacts of SVE on the northern hemispheric winter season. This applies to historical eruptions from 1850 onwards as well as more recent eruptions like El Chichon in 1982 or Mt. Pinatubo eruption in 1991 which can be compared to re-analysis data sets. Two model configurations with different vertical resolution are used to analyze anomalies in various variables, for example surface temperature, surface pressure and geopotential height. Influences of other atmospheric features like the El Nino Southern Oscillation (ENSO) or the Quasi-biennial Oscillation (QBO) are taken into account to investigate to which extent different states of the atmosphere have an impact on the volcanic signal. While a signal of volcanic aerosols is clearly visible in stratosphere, the effects on the surface remain small and in large parts non-significant in an average over all simulated historical eruptions. The expected change to a more positive phase of the NAO in the first winter after the SVE is not simulated and therefore the volcanic winter warming pattern is not visible on average. In this study we investigate the differences between the two model configurations (47 vertical layers vs. 95 vertical layers) to analyze the benefits of a higher vertical resolution.

Bjornsson, Halldor

Assessing Simple Models of Volcanic Plumes Using Observations From the Summit Eruption of Eyjafjallajökull in 2010

Bjornsson, Halldor[1]; Magnusson, Sindri[1]

1. Weather, Icelandic Meteorological Offic, Reykjavik, Iceland

A volcanic eruption plume enters into an atmosphere that has a pre-existing structure to it, in terms of temperature, moisture content, stratification, wind and wind shear. How high the plume rises depends predominantly on the strength of the eruption. However, through dynamic interactions with the rising plume, the ambient atmosphere also exerts an influence on how high into the atmosphere plume material can be lofted and how far afield it is distributed. Idealized models of volcanic plumes consider three dynamically distinct regions, the gas thrust region, where the dynamics is dominated by the exit velocity at the vent, the buoyancy driven convective region and the umbrella cloud where vertical motion is small. During the 2010 summit eruption at Eyjafjallajökull, several cameras where located with a view of the volcano. The time resolution of the images was 5 seconds and the vertical resolution was 7m. Based on this data, and on video recordings made by a TV crew we have analyzed variations in the speed of the updraft in the plume, the horizontal wind profile above the vent, and changes in the size of individual thermals as they rise in the atmosphere. We compare the results from the analysis with results obtained using simplified models of volcanic plumes. The results tend to agree with the simplified models, in that the boyancy driven phase seems to be well resolved by the data. However, resolving the shallow gas thrust region is more of a challenge. Furthermore, the profile of velocities in the plume shows various details not resolved by plume models.

Black, Benjamin A.

Modeling the climate effects of S, Cl, and F degassing from the Siberian Traps

Black, Benjamin A.[1]; Elkins-Tanton, Linda[2]; Shields, Christine[3]; Lamarque, Jean-Francois[3]; Kiehl, Jeffrey[3]

1. MIT—-EAPS, Cambridge, MA, USA
2. Department of Terrestrial Magnetism, Carnegie Institution for Science, Washington, DC, USA
3. NCAR, Boulder, CO, USA

The eruption of large igneous provinces such as the Siberian Traps marks an extreme end-member of the range of volcanic eruptions and potential environmental consequences. Degassing and atmospheric loading of volatiles is one of the critical mechanisms that links mafic volcanic eruptions with global environmental change. Quantitative petrologic estimates of degassing budgets, in particular for sulfur and chlorine, are now available for several large igneous provinces. We employ the comprehensive National Center for Atmospheric Research Community Earth System Model 1.0 with coupled ocean and atmosphere in order to assess the likely climatic effects from emissions of S, Cl, and F related to eruption of a large igneous province. We use the Siberian Traps as a test case in our modeling. The Siberian Traps large igneous province is one of the largest known continental flood basalts, and is a candidate for the trigger mechanism for the end-Permian mass extinction. For gases such as S and Cl, delivery to the stratosphere is a key step for determining the scale of climate response. Such delivery was probably sporadic during the eruption of the Siberian Traps. The eruptive activity itself may also have occurred in pulses. The full duration of Siberian Traps volcanism probably spanned <1 Myr. Due to the complexity and computational cost of the model, and the likelihood of sporadic introduction of volatiles to the stratosphere, we focus on potential consequences of a single and much shorter eruptive episode. Preliminary results suggest that cooling caused by sulfate aerosols could be significant and primarily restricted to the northern hemisphere due to the high latitude position of Siberia in the Permian and Triassic.

Bobrowski, Nicole

Bromine chemistry of volcanic plumes

Bobrowski, Nicole[1]; Vogel, Leif[1]; Jäkel, Evelyn[2]; von Glasow, Roland[3]; Munoz, Angelica[4]; Alverez, Julio[4]; Fickel, Matthias[5]; Delgado Granados, Hugo[5]; Calabrese, Sergio[6]; Giuffrida, Giovanni[7]; Liotta, Marcello[7]; Liuzzo, Marco[7]; Wittmer, Julian[1]; Platt, Ulrich[1]

1. IUP, University of Heidelberg, Heidelberg, Germany
2. LIM, University of Leipzig, Leipzig, Germany
3. University of East Anglia, Norwich, United Kingdom
4. INETER, Managua, Nicaragua
5. Instituto de Geofisica, Universidad Nacional Autónoma de México, Mexico, Mexico
6. Università di Palermo, Palermo, Italy
7. INGV, Palermo, Italy

Volcanic gas studies are an established tool for volcanic monitoring and enhance the understanding of volcanic manifestations. The central question of the project, which we will introduce here, is whether the ratio between bromine monoxide (BrO) to sulphur dioxide (SO2) can potentially serve as indicator for volcanic activity. Both species have the advantage that they can be remotely measured by Differential Optical Absorption Spectroscopy (DOAS) at safe distances from the emission source. To answer the question above, it is of great importance to link the measurements of halogen oxides to the total emission flux of individual halogen species and to understand the influences of meteorological conditions on the formation and measurements of halogen oxides. In a second step we can evaluate the feasibility whether halogen oxide measurements can be used as an indicator of certain volcanic processes. Additionally, the impact of volcanic halogen chemistry on the atmosphere is reinvestigated in light of the novel insights. To gain a quantitative understanding of volcanic plume chemistry, gas emissions and volcanic plume composition of Mt Etna, Italy, Popocateptl, Mexico and Masaya, Nicaragua are analysed. Continuous monitoring measurements are complemented by three intensive campaigns during which DOAS is employed to characterize the concentrations of halogen oxides, their ratios to SO2 and to quantify emission fluxes. In-situ gas sampling and measurements, meteorological parameter and incident solar radiation complete the data-set. Beside a description of the project first preliminary results will be presented.

Bourassa, Adam E.

Volcanic Perturbations to the Stratospheric Aerosol Layer in the Last Decade: OSIRIS Measurements

Bourassa, Adam E.[1]; Robock, Alan[2]; Randel, William[3]; Deshler, Terry[4]; Degenstein, Doug[1]; Llewellyn, E. J.[1]

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4. Department of Atmospheric Science, University of Wyoming, Laramie, WY, USA

The Canadian built OSIRIS instrument, currently in operation on the Swedish Odin satellite, has collected over a decade of atmospheric limb radiance spectra at UV, visible and near infrared wavelengths. These measurements are used to retrieve vertical profiles of stratospheric aerosol extinction. The relatively high horizontal sampling of the limb scatter technique, which provides nearly global coverage, combined with the decade long duration of the mission, makes this an increasingly useful and important data set. The OSIRIS stratospheric aerosol record shows the effect of several relatively small volcanic eruptions on the state of the stratospheric aerosol layer. The June 2011 eruption of the Nabro volcano caused the largest stratospheric aerosol load in the OSIRIS record.

Breitenmoser, Petra D.

Solar and Volcanic Fingerprints in Tree-Ring Chronologies Over the Past 800 Years

Breitenmoser, Petra D.[1, 2]; Beer, Jürg[3]; Brönnimann, Stefan[1, 2]; Frank, David[4, 2]; Steinhilber, Friedhelm[3]; Wanner, Heinz[2]; Wegmann, Martin[1, 2]

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The Sun is the main driver of Earth's climate, yet the contributions of the Sun and volcanic eruptions to climate variability – such as during the Little Ice Age – have remained controversial, especially in the context of understanding contributions of natural climate forcings to continuing global warming. To properly address forcing fingerprints on climate, long-term, very high-resolution, globally distributed climate proxy records are necessary. In this study we compile and evaluate a near global collection of annually-resolved tree-ring-based climate proxies spanning the past 800 years. We statistically assess these records in both the time and frequency domains for volcanic and solar forcing (i.e. Total Solar Irradiance; TSI) and climate variability. Analyses in the frequency domain indicate significant periodicities in the 208-year frequency band, corresponding to the DeVries cycle of solar activity. Additionally, results from superposed epoch analysis (SEA) point toward a possible solar contribution in the temperature and precipitation series. However, solar-climate associations remain weak, with for example no clear linkage distinguishable in the southwestern United States drought records at centennial time scales. Other forcing factors, namely volcanic activity, appear to mask the solar signal in space and time. To investigate this hypothesis, we attempt to extract volcanic signals from the temperature proxies using a statistical modelling approach. Wavelet analysis of the volcanic contribution reveals significant periodicities near the DeVries frequency during the Little Ice Age (LIA). This remarkable and coincidental superposition of the signals makes it very difficult to separate volcanic and solar forcing during the LIA. Nevertheless, the "volcano free" temperature records show significant periodicities near the DeVries periodicity during the entire past 800 years, further pointing to solar mechanisms and emphasising the need for solar related studies in the absence of strong multi-decadal volcanic forcing. Impacts of explosive volcanic eruptions on Northern Hemisphere summer temperatures over the past 400 years are further analyzed in a composite of 30 ensemble members of the ECHAM5.4 model simulations in the three years following volcanic eruptions and compared with information derived from the tree-ring chronologies.

Brooks, Barbara

LIDAR as a tool for the monitoring and forecast of re-suspended ash

Brooks, Barbara[1]; Groves, James[1]; von Löwis, Sibylle[2]; Petersen, Gudrún N.[2]; Mobbs, Stephen[1]

1. NCAS (National Centre for Atmospheric Science), Leeds, United Kingdom
2. Icelandic Meteorological Office, Reykjavík, Iceland

Ash and dust re-suspended into the atmosphere can be detrimental to the health of both animals and humans in addition to impacting on transport, communications, and agriculture. The ability to issue warnings and to forecast such events relies on an understanding of the mechanisms involved and also on the ability to monitor and to consistently and accurately distinguish such events from less critical situations; for example fog. As a consequence of the disruption to UK and European airspace resulting from the Eyjafjallajökull eruption of 2010 the National Centre for Atmospheric Science (NCAS) in the UK in cooperation with the Icelandic Meteorological Office deployed a Doppler LIDAR with de-polarisation capabilities at Önundarhorn in southern Iceland. The aim being to determine if ash forecast models could be improved by near field LIDAR measurements of the position of airborne ash. Within approximately three weeks of this, in May 2011, the Grímsvötn volcano erupted and a substantial quantity of particulate matter was deposited on the coastal plane, as well as in mountain regions, in the Önundarhorn area. Unless bound by vegetation or moisture this matter can be re-

suspended and transported over significant distances both vertically and horizontally with significant socio-economic impact. By making use of both the backscatter and de-pole capabilities of this LIDAR, re-suspended ash/dust clouds can be distinguished from the general aerosol background leading to the potential for near real time monitoring and the issuing of warnings and advisories. A series of case studies will be presented that show how a Doppler LIDAR with de-polarisation capacity can be used to identify ash and non ash events and to visualise turbulent structures in the atmosphere.

Burton, Ralph

Volcanic plume simulations using the WRF model

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The Weather Research and Forecasting (WRF) model is a state-of-the-art numerical weather prediction model, used for both operation weather forecasting and for detailed investigations of case studies. WRF includes very sophisticated representations of turbulence and microphysics. The WRF model has been modified to simulate the near field of a Plinian-type eruption. Using either a large temperature perturbation at the surface or a large vertical velocity, coupled with the release of a co-located atmospheric tracer, allows plume structures to be analysed. Results will be shown for a large-eddy type simulation of eruptions in an atmosphere at rest and for cases involving a background wind. The simulated plume structure will be compared with theoretical predictions for the rise height, the spread of the umbrella cloud, and other important parameters. This study suggests that the use of the WRF model could be a very useful tool when determining the characteristics of plume behaviour.

Carboni, Elisa

A New Sulphur Dioxide Retrieval from IASI: Results for Recent Eruptions and Possible Volcanic Degassing

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The results from a new algorithm for the retrieval of sulphur dioxide (SO2) from the Infrared Atmospheric Sounding Interferometer (IASI) data will be presented. This retrieval scheme determines the column amount and effective altitude of the SO2 plume with high precision (up to 0.3 DU error in SO2 amount if the plume is near the tropopause) and can retrieve informations in the lower troposphere. The scheme uses the IASI channels around the v1 and v3 SO2 absorption bands centered at about 7.3 and 8.7 microns (i.e. the spectra between 1000-1200 and 1300-1410 cm-1). The retrieval assumes a Gaussian distribution for the vertical SO2 profile and returns the SO2 column amount and the altitude of the plume. The scheme is based on the optimal estimation (OE) method (Rodgers, 2000). Within this scheme simulated spectra (constructed using a forward model) are compared with measured spectra. The simulations are based on RTTOV (Saunders et al.,1999) and ECMWF meteorological data. A comprehensive error budget for every pixel is included in the retrieval. This is derived from an error covariance matrix that is based on the SO2-free climatology of the differences between the IASI and forward modeled spectra. Within the simulation of the IASI spectra it is possible to include a cloud or ash layer. This feature is used to illustrate: (1) it is possible to discern if ash (or other atmospheric constituents not included in the climatological variability) affect the retrieval using quality control based on the fit of the measured spectrum to the forward modeled spectrum; (2) the SO2 retrieval is not affected by underlying cloud. In this work we present the results for recent volcanic eruptions (Monserrat, Eyjafjallajokull, Grimsvotn, Puyehue, Nabro, Etna) and compare the results against other satellite data. Finally we will demonstrate the potential to monitor quiescent degassing from some volcano.

Carn, Simon A.

Satellite Measurements and Modeling of the 2011 Nabro (Eritrea) Volcanic Clouds

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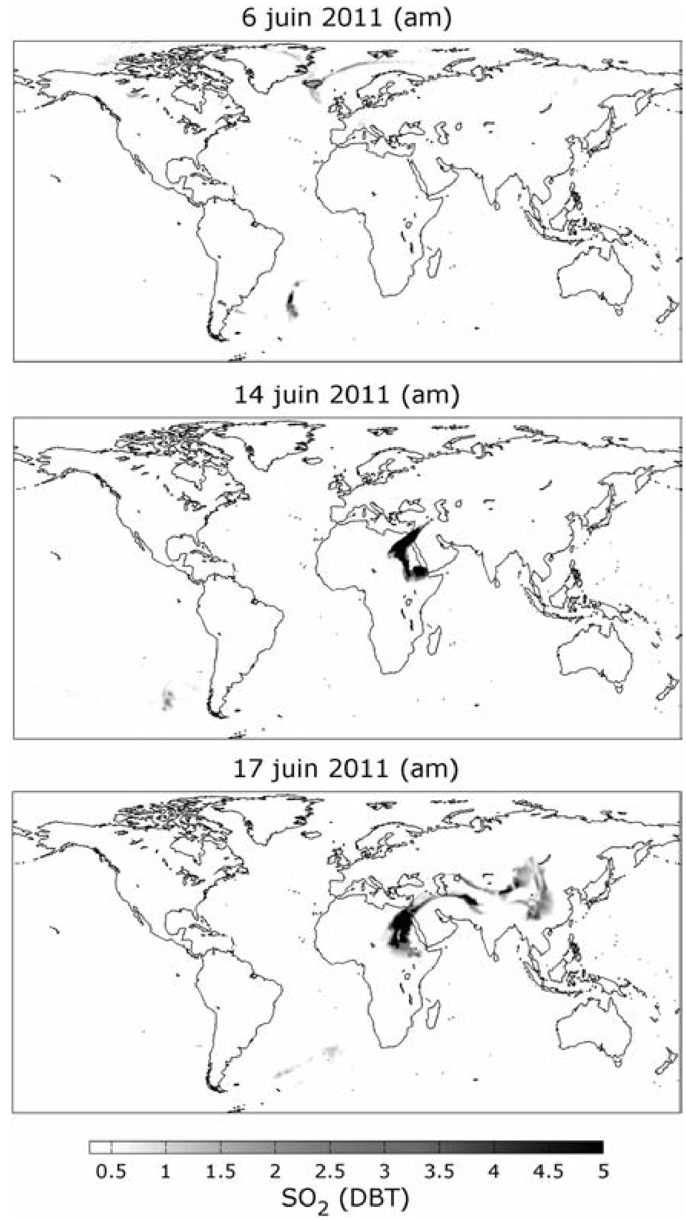
2. Dept of Atmospheric and Oceanic Science, University of Maryland, College Park, MD, USA
3. Dept. of Earth and Atmospheric Science, University of Nebraska Lincoln, Lincoln, NE, USA
4. Atmosphere and Climate Department, Norwegian Institute for Air Research, Kjeller, Norway

The period since the 1991 Pinatubo and Cerro Hudson eruptions has been devoid of major (VEI ≥ 5) sulfur-rich eruptions, but several lower magnitude (VEI ≤ 4) events have resulted in a systematic increase in stratospheric aerosol levels since 2002 [Vernier et al., GRL, 2011]. Detailed studies of the pathway by which sulfur dioxide (SO_2) emitted by moderate volcanic eruptions enters the stratosphere are therefore warranted. The June 2011 eruption of Nabro volcano (Eritrea), its first in recorded history, is among the most sulfur-rich eruptions measured since 1991, particularly in the subtropics, and resulted in a significant stratospheric impact in the northern hemisphere [Bourassa and Degenstein, Fall AGU, 2011] despite relatively modest reported plume altitudes (~9-14 km). We use satellite remote sensing data and a chemistry-transport model (CTM) to elucidate the emission and transport of SO_2 and its conversion to sulfate aerosol following the Nabro eruption. The initial, explosive phase of the eruption began on June 12, 2011 and was SO_2-rich, with a preliminary estimated SO_2 burden of ~1-2 Tg based on Ozone Monitoring Instrument

(OMI) and Atmospheric Infrared Sounder (AIRS) data from the Aura and Aqua satellites. Although the eruption disrupted aviation in the region, little volcanic ash was detected in the volcanic cloud, perhaps due to an abundance of ice. Based on satellite observations, most of the Nabro volcanic cloud was initially transported to the north-west and then eastwards by the subtropical jet, and then became confined in a region extending from the Middle East to East Asia. We ascribe this dispersion pattern to the Asian summer monsoon circulation, a strong anticyclonic vortex found in the upper troposphere and lower stratosphere (UTLS) during the boreal summer, linked to the elevated topography of the Tibetan Plateau. Significantly, recent work [Randel et al., Science, 2010] has highlighted the monsoon circulation as an effective route for anthropogenic pollution (and also water vapor) from Asia to enter the stratosphere, and we suggest that it may also have played a role in enhancing the stratospheric impact of the Nabro eruption. Continued emissions of SO_2 from Nabro were detected by OMI through mid-July, but were largely confined to the lower troposphere. To further investigate the transport and fate of the Nabro SO_2 emissions, we use the GEOS-Chem global CTM. The OMI and AIRS SO_2 observations, coupled with plume altitude constraints from advanced OMI retrieval algorithms and NASA A-Train data, will be used to initialize volcanic cloud simulations in GEOS-Chem. GEOS-Chem includes an advanced sulfate module including aerosol phase transitions, which permits accurate characterization of sulfate aerosol radiative forcing. The GEOS-Chem sulfate aerosol simulations will be compared to available satellite observations of aerosol (e.g., CALIPSO, Odin/OSIRIS) and to ground-based lidar measurements (e.g. EARLINET, MPLNET).



Clerbaux, Cathy

Near Real-time Monitoring of SO_2 and Volcanic Ash with IASI/Metop

Clerbaux, Cathy[1, 2]; Coheur, Pierre[2]; Clarisse, Lieven[2]; Hurtmans, Daniel[2]; Hadji-Lazaro, Juliette[1]; George, Maya[1]; Campion, Robin[2]

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2. Spectroscopie de l'atmosphère, ULB, Brussels, Belgium

The French IASI instrument launched onboard the European MetOp satellite series is providing essential inputs for weather forecasting and pollution/climate monitoring. This mission is recording high resolution atmospheric spectra, two times per day, with an excellent horizontal resolution and coverage, from which global, regional and local distributions of trace gases and aerosols can be performed. The talk will focus on the IASI contribution to measure SO2 and ash plumes associated with volcanic eruptions. A system has been set up to provide near real time information for alerts to civil aviation. Illustrations of the latest results will be provided and limitations will be discussed. The future of the IASI program will also be presented.

Coheur, Pierre F.

Global Multi-sensor Satellite Monitoring of Volcanic SO_2 and Ash Emissions in Support to Aviation Control

Coheur, Pierre F.[1]; Brénot, Hugues[2]; Theys, Nicolas[2]; Van Gent, Jeroen[2]; Van Roozendael, Michel[2]; Van der A, Ronald[3]; Clarisse, Lieven[1]; Hurtmans, Daniel[1]; Ngadi, Yasmine[1]; Clerbaux, Cathy[4, 1]

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4. LATMOS, CNRS, Université Pierre et Marie Curie, Paris, France

The "Support to Aviation Control Service" (SACS; http://sacs.aeronomie.be) is an ESA-funded project hosted by the Belgian Institute for Space Aeronomy. The service provides near real-time (NRT) global SO2 and volcanic ash data, as well as alerts 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 (SCIAMACHY, OMI, GOME-2) and infrared (AIRS, IASI) satellite instruments. When a volcanic eruption is detected, SACS issues an alert 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 visualized with user-friendly tools. The strength of a multi-sensor approach relies in the use of satellite data with different overpasses times, minimizing the time-lag for detection and enhancing the reliability of such alerts. This paper will give a general presentation of the SACS service, different techniques used to detect volcanic plumes. It will also highlight the strengths and limitations of the service and measurements.

http://sacs.aeronomie.be/

Coltelli, Mauro

2011 AND 2012 VOLCANIC PLUMES OF MT. ETNA AND THEIR IMPACT ON THE AVIATION

Coltelli, Mauro[1]; Ciancitto, Francesco[1]; Corradini, Stefano[2]; Merucci, Luca[2]; Prestifilippo, Michele[1]; Scollo, Simona[1]; Spata, Gaetano[1]

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2. CNT, INGV, Roma, Italy

Between 12 January 2011 and 9 February 2012 Mt. Etna, in Italy, produced twenty lava fountains from a volcanic vent opened on the eastern flank of the South-East Crater. The paroxysm phase, preceded by mild strombolian activity, has produced eruption columns ranging from a few up to ten kilometers of height. In order to give precise warnings to the Aviation and Civil Protection authorities, and to support the work of VAACs, a novel system for monitoring and forecasting Etna volcanic plumes was developed since 2006 at the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, in Catania. Monitoring is carried out using multispectral infrared measurements from satellites, and ground-based video-surveillance cameras and a Doppler radar able to detect important features of the eruption column dynamic and volcanic plume dispersal. 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 website dedicated to the Italian Civil Protection. We show data obtained from all these systems and integrate all these information in order to characterize the main features of the ash-rich plume dispersal during the 2011-2012 Etna eruptions. Observed eruption plumes show a quite large range of physical characters, from weak to strong plumes, with respect to the similar size of the eruptions. Risks and hazard assessment, in particular to the operations of the airports near the volcano, are hence evaluated considering the different dispersal produced from different plume types.

Corradini, Stefano

Volcanic SO_2 estimation from ash rich plumes using TIR satellite measurements: Comparison between MODIS, ASTER and IASI retrieval procedures

Corradini, Stefano[1]; Pugnaghi, Sergio[2]; Campion, Robin[3]; Carboni, Elisa[4]; Arvani, Barbara[2]; Guerrieri, Lorenzo[2]; Merucci, Luca[1]

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2. University of Modena and Reggio Emilia, Modena, Italy
3. Université Libre de Bruxelles, Bruxelles, Belgium
4. AOPP, University of Oxford, Oxford, United Kingdom

Observations of volcanic degassing yield insights into the magmatic processes which control volcanic activity during both quiescent and eruptive phases. SO2 also affect environment, health and when injected at high altitudes can be oxidized to form sulphates capable of reflecting solar radiation then causing surface cooling. Satellite observations have been used for a long time to monitor globally distributed volcanic activity because they offer a practical and safe source of valuable data. In the TIR spectral range SO2 has two absorption bands centered around 7.3 and 8.7 μm. The strongest 7.3 μm band lies in a region highly affected by atmospheric water vapour that makes the retrieval possible only over 3-4 km. The weaker 8.7 μm band can be used for a retrieval over all the atmospheric column because it lies in a transparent atmospheric region. During volcanic eruptions ash and gases are generally emitted simultaneously. The plume ash particles reduce the top of atmosphere radiance in the entire TIR spectral range causing a significant SO2 columnar abundance overestimation. In this work different procedures for the SO2 retrieval from ash rich volcanic plumes in the TIR spectral range using MODIS, ASTER and IASI measurements are compared. As test case some events of the 2010 Eyjafjallajokull (Iceland) eruption have been considered. Two retrievals procedures have been applied to MODIS data: the first (P1) [Corradini et al. 2009] is based on the simultaneous retrieval of both volcanic SO2 and ash in the same data set, exploiting the simulated atmospheric terms computed from a radiative transfer model. The second (P2) is a novel simplified procedure which determines, by the image itself, the plume transmittance knowing the plume temperature. A relationship, of the ash transmittance at 8.7 vs 11 μm, is used to retrieve the SO2 abundance. The ASTER retrieval procedure (P3) [Campion et al. 2010] consists of adjusting the SO2 column amount until the ratios of radiance simulated on several ASTER bands match the observations. The resulting retrievals depend much less on atmospheric humidity, sulfate aerosols, surface altitude and emissivity than the retrievals using the raw radiances. The IASI retrieval (P4) [Carboni et al. 2012] is an optimal estimation scheme that exploit the high resolution spectrometer measurements of the two SO2 absorption bands around 7.3 and 8.7 µm. The results show that the MODIS P1 and P2 retrievals, is strongly sensitive to ash type and plume altitude. The P2 procedure is, however, very fast and can be used for a volcanic early warning. The ASTER P3 procedure gives a very good spatial resolution but, because of that, the plume is generally not completely observed. The IASI retrieval is sensitive to low SO2 columnar abundance but with a poor spatial resolution. The P1 procedure seems overestimating the SO2 amounts with respect to the P2, P3 while P4 procedures seems underestimating it. A detailed comparison between the SO2 flux trends and total masses for all the different eruptive events is presented.

D'Arrigo, Rosanne

Volcanic Signals in Tree-ring Records for the Past Millennium (*INVITED*)

D'Arrigo, Rosanne[1]

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Tree rings are a valued proxy for past volcanic events as they are precisely dated to the year and, especially for higher latitude and alpine treeline regions of the world, can be very sensitive to past cold extremes as can result from climatically-significant volcanic episodes. Such volcanic signals have been detected in ring widths, yet are often most clearly represented in maximum latewood density time series (quantitatively), and in so-called frost and light ring chronologies (qualitatively). Over the past ~century of the science of dendrochronology, there is no real evidence that volcanic or other adverse events can cause such severely cold conditions that no rings might form at any of the trees at a given site, resulting in misdating of the final chronology. Rather, there is clear evidence of precise dating and laying down of rings in some trees even under adverse cold conditions, based on both tree-ring observations and modeling analyses. The relatively muted evidence for such events in large-scale temperature reconstructions in part reflects the predominance of ring widths in such records, as well as the varying spatial pattern of the response of the climate system to volcanic events, such that regional cooling can be masked in the large-scale reconstruction average.

D'Arrigo, Rosanne

The anomalous winter of 1783-4: Was the Laki eruption or an analog of the 2009-10 winter to blame?

D'Arrigo, Rosanne[1]; Seager, Richard[1]; Smerdon, Jason[1]; LeGrande, Allegra[2]; Cook, Edward R.[2]

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2. NASA GISS, New York, NY, USA

The multi-stage eruption of the Icelandic volcano Laki beginning in June, 1783 is speculated to have caused unusual dry fog and heat in western Europe and cold in North America during the 1783 summer, and record cold and snow the subsequent winter across the circum-North Atlantic. Despite the many indisputable impacts of the Laki eruption, however, its effect on climate, particularly during the 1783-4 winter, may be the most poorly constrained. Here we test an alternative explanation for the unusual conditions during this time: that they were caused primarily by a combined negative phase of the North Atlantic Oscillation (NAO) and an El Niño-Southern Oscillation (ENSO) warm event. A similar combination of NAO-ENSO phases was identified as the cause of record cold and snowy conditions during the 2009-10 winter in Europe and eastern North America. 600-year tree-ring reconstructions of NAO and ENSO indices reveal values in the 1783-4 winter second only to their combined severity in 2009-10. Data sources and model simulations support our hypothesis that a combined, negative NAO-ENSO warm phase was the dominant cause of the anomalous winter of 1783-4, and that these events likely resulted from natural variability unconnected to Laki.

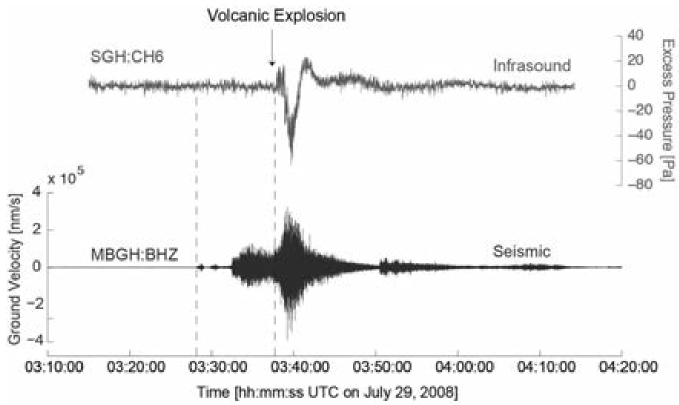
De Angelis, Silvio

The inaudible sound of volcanoes: infrasound applications to volcano monitoring

De Angelis, Silvio[1]

1. University of Alaska Fairbanks, Fairbanks, AK, USA

Acoustic measurements in the infrasonic band, popular in the late 1960s and throughout the "cold war" period, experienced a renaissance over the past two decades with several applications in the field of the Earth Sciences, including Volcanology. Visual, satellite remote sensing, and seismic monitoring can surprisingly fail to provide incontrovertible evidence of the onset of volcanic eruptions in a timely fashion. Volcanic eruptions inject columns of ash and debris into the atmosphere, which represent a considerable hazard to aviation. Fast moving avalanches of hot gas and rock rush down the flanks of volcanoes at speeds approaching 280 km/hour. These surges, called pyroclastic flows, can reach temperatures of 400°C. Fast density currents and hot temperatures can quickly overwhelm communities living in the shadow of volcanoes. Volcanoes are prolific sources of low frequency sounds, in the infrasonic acoustic band (0.01-20 Hz), inaudible to the human hearing but unmistakably detected by purpose-built sensors. Infrasound measurements have been increasingly used to confirm the onset of volcanic eruptions. Recent research efforts have been directed towards employing acoustic measurements to track the evolution of eruptive events and associated phenomena in real-time; consequently, the potential for infrasound-based volcanic alarm systems is rapidly emerging. This study presents acoustic data collected by sensors deployed on Soufriere Hills Volcano, Montserrat, WI and across the Aleutian Volcanic Arc, Alaska, USA. This unique dataset highlights the variety of volcanic phenomena and the diversity of associated acoustic signals, the challenges in collecting high-quality data in harsh environments, and unequivocably demonstrates the feasibility of detecting the onset of eruptions and tracking their evolution in real-time.



Infrasound (red, top panel) and seismic (blue, bottom panel) records of a volcanic explosion on July 29, 2008 at Soufriere Hils Volcano, Montserrat, WI. Note the utility of the infrasound trace to confirm the occurrence and timing of the explosive event.

Donohoue, Deanna

3-D modelling of the Atmospheric Chemistry of Quiescently Degassing Volcanoes

Donohoue, Deanna[1]; Surl, Luke[1]; von Glasow, Roland[1]

1. University of East Anglia, Norwich, United Kingdom

Recent field and modelling studies have suggested that the atmospheric plumes of quiescently degassing volcanoes are natural sources of trace gas species, such as halogen and mercury. These emissions are postulated to have significant impacts on the regional atmospheric chemistry resulting in O3 depletion, a reduction in the OH radical lifetime, and increased mercury oxidation. In previous studies a one-dimensional model was used to reproduce BrO/SO2 ratios from Mt. Etna. However, this 1-D model uses a parameterization to characterize the horizontal dilution of the plume and entrainment of background air. In an effort to better resolve the meteorology, we employed a 3-D regional chemical transport model (WRF-Chem). The WRF-Chem model is a fully coupled online Weather Research and Forecasting/Chemistry model which includes both a meteorology and chemistry components. This model was to further our understanding of the plume chemistry and evaluate the health and environmental trace gas emissions on regional and global scales.

Driscoll, Simon

Coupled Model Intercomparison Project 5 (CMIP5) Simulations of Climate Following Large Tropical Volcanic Eruptions and the Effect of the Quasi-Biennial Oscillation (QBO) on the Surface Climate Following Large Tropical Volcanic Eruptions

Driscoll, Simon[1]; Bozzo, Alessio[2]; Gray, Lesley J.[1]; Robock, Alan[3]; Stenchikov, Georgiy L.[4, 3]

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2. School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom
3. Department of Environmental Sciences, Rutgers University, New Brunswick, NJ, USA
4. Division of Physical Sciences and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

The ability of the climate models submitted to the Coupled Model Intercomparison Project (CMIP5) database to simulate the Northern Hemisphere winter climate following a large tropical volcanic eruption is assessed. When sulfate aerosols are produced by volcanic emissions into the tropical stratosphere and spread by the stratospheric circulation, it not only causes globally averaged tropospheric cooling but also a localized heating in the lower stratosphere which can cause major dynamical feedbacks. Observations show a lower stratospheric and surface response during the following Northern Hemisphere (NH) winter, that resembles the positive phase of the Northern Annular Mode for up to two years after the eruption. Simulations from 12 CMIP5 models that represent tropical eruptions in the 19th and 20th century are examined, focusing on the regional impacts during the NH winter season. The models generally fail to capture the NH dynamical response following eruptions and tend to overestimate the cooling in the tropical troposphere. The findings are confirmed by a superposed epoch analysis of the North Atlantic Oscillation index for each model. The study confirms previous similar evaluations and raises concern for the ability of current climate models to simulate the response of a major mode of global circulation variability to external forcings. This is also of concern for the accuracy of geoengineering modeling studies, that seek to emulate the large-scale response to stratosphere-injected particles. Possible suggestions as to why the models fail to achieve the response are discussed. Furthermore, previous studies have suggested significant interactions between the dynamic response to sulfate aerosol following volcanic eruptions and the Quasi-Biennial Oscillation (QBO). Observational and modelling evidence (from simulations of the volcanic response by a high-top coupled ocean-atmosphere model that includes an internally generated QBO) are examined. Diagnostics of MSLP and near surface temperature suggest that the QBO has a major influence on the surface climate following volcanic eruptions.

http://www2.physics.ox.ac.uk/contacts/people/driscoll

Durant, Adam J.

Passive Remote Sensing of Volcanic Clouds from Satellite, Aircraft and the Ground

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1. Atmosphere and Climate, Norsk institutt for luftforskning, Kjeller, Norway
2. Geological and Mining Engineering and Sciences, Michigan Technological University, Houghton, MI, USA

Passive remote sensing uses energy emitted by the sun or the surface of the Earth between the ultraviolet (UV) and thermal infrared (TIR) regions of the electromagnetic spectrum to infer the presence of gases and particles in the atmosphere. Using a radiative transfer model and information on the spectral refractive indices of target gases or particles (e.g., water, ice, silicate ash, and SO_2), ash mass loadings and effective particle size are routinely retrieved through exploitation of "reverse absorption" in the TIR between wavelengths of 8–12 μm. SO_2 mass loadings are quantified through exploitation of TIR and UV absorption bands. Volcanic clouds from the 2010 eruption of Eyjafjallajökull, Iceland, and 2011 eruption of Puyehue-Cordón Caulle (PCC), Chile, caused major disruption to aviation and were extensively tracked using satellites at temporal frequencies as high as 5 minutes. The PCC ash cloud circumnavigated the Earth, impacted aviation in Australia, and was observed by satellite for >4 weeks. The May 2008 eruption of Chaitén volcano, Chile, provided an opportunity to correlate observations of the long-range transport of ash emissions to the evolution of surface ash deposit using changes in surface reflectivity. The 2011 eruption of Nabro, Eritrea, released a large cloud of SO_2 that was observed from a suite of satellite sensors including OMI, AIRS, IASI, MODIS, GOME-2 and SEVIRI. Ice was first recognised as an important component of volcanic clouds based on satellite observations of the cloud generated by the 1994 eruption of Rabaul, Papau New Guinea, and has since been observed in varying proportions related to the style of eruption and latitude of the volcano. Data from hyperspectral imaging instruments (e.g., IASI) now supports the retrieval of other sulfur species such as H_2S, which should improve quantification of the volcanic sulfur budget. Advances in imaging technology have driven the recent development of ground-based passive remote sensing instrumentation based on the same fundamental principles. Measurements of ash and SO_2 emissions have been made at recent eruptions including the eruptions of Tavurvur, Papua New Guinea (2004), Grimsvotn, Iceland (2011), Lascar, Chile (2011), Karymsky, Russia (2011), and Turrialba, Costa Rica. High speed spectral imaging allows measurement of ash mass fluxes and column height at the point of emission and could provide value information to constrain eruption source parameters used to initiate volcanic cloud trajectory forecasts. Early airborne measurements of gases and particles in volcanic emissions were made from light aircraft in the late 1970s and early 1980s. Fast sampling spectral imaging technology has now been adapted for use on an aircraft platform. The Airborne Volcanic Object Infrared Detector (AVOID) is a forward-looking ash detection system that can provide several minutes warning of a volcanic ash encounter, during the day and night. Research flights were recently conducted in Sicily, at Mt Etna and Stromboli volcanoes, which identified vertical layering of volcanic aerosol at altitudes of up to 3.6 km MSL (12,000 ft MSL) from a detection range of >50 km.

Elkins-Tanton, Linda T.

Environmental Effects of the Siberian Flood Basalts and Possible Links with the End-Permian Extinction (*Invited*)

Elkins-Tanton, Linda T.[1]; Black, Benjamin[2]

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2. Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA, USA

For several decades researchers have proposed that large igneous provinces may provoke global extinction events. One of the largest continental igneous provinces, the Siberian flood basalts, appears to coincide temporally near 252 Ma with the devastating end-Permian extinction. Though our group is specifically studying this possible relationship, the mechanisms by which this large igneous province may have created global change can be considered for all large igneous provinces. There are only a limited number of processes that are known to create global extinctions. Among the options, large igneous provinces are most likely to create changes in atmospheric chemistry. Changing atmospheric chemistry requires production of an adequate mass of volatiles over a sufficiently brief period of time, and a mechanism for delivering them to the stratosphere where they can linger long enough to change global climate or chemistry. In Siberia there are two likely sources for volatiles: those that are carried by and released from the magmas themselves, and those that are sweated out of country rocks. To constrain the volatile load of the magmas we measured concentrations of sulfur, chlorine, fluorine, and carbon in melt inclusions inside crystals from Siberian Traps lavas, sills, and tuffs. New results from ion probe analysis of melt inclusions provide insight into the volatile budget of the earliest volcanism and the flow-dominated periods of flood volcanism. In particular, melt inclusions from four flows and tuffs belonging to the stratigraphically lowest extrusive suites provide the first estimates of dissolved volatiles within early-erupted Siberian Traps magmas. Comparison with studies of melt inclusions from the Deccan Traps and the Columbia River flood basalts suggests that volatile concentrations in some Siberian Traps magmas were anomalously high. We hypothesize that assimilation of evaporites and other sedimentary rocks from the Tunguska basin might have contributed to this budget. The chemical must then be delivered into the atmosphere. The size and temperature of flood basalt eruptions may produce local weather patterns with upwellings large enough to deliver chemicals to the tropopause. In addition there are tuff sequences tens to hundreds of meters thick near the base of the volcanic sequence in the Maymecha-Kotuy and Angara regions; these volcaniclastic deposits may reach 700 meters in thickness in the central Tunguska basin. Locally well-preserved accretionary lapilli provide evidence that many of these deposits are primary pyroclastic rocks. These explosive episodes may have enhanced the efficiency with which degassing volatiles were entrained into an ascending thermal plume. The high volatile contents we observe in many Siberian Traps rocks, if injected into the stratosphere, may have significantly contributed to ozone depletion and global temperature change at the Permian-Triassic boundary.

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Ferris, David

A six thousand year volcanic record from the West Antarctic Ice Sheet Divide ice core

Ferris, David[1]; Cole-Dai, Jihong[1]; McConnell, Joe[2]; Sigl, Michael[2]; Geng, Lei[1]

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2. Division of Hydrologic Sciences, Desert Research Institute, Reno, NV, USA

Explosive volcanic eruptions inject large quantities of solid and gaseous substances into the atmosphere. Volcanic aerosols are formed from the oxidation of sulfur dioxide, usually the most abundant gaseous component, and scatter incoming solar radiation. The resulting reduction in insolation can perturb the climate for brief time periods. These aerosols are transported globally, deposited onto Earth surface, and archived in the polar ice sheets. Ice core records based on chemical analysis can provide insight as to the date and magnitude of past eruptions and their impact on global climate. Previous ice core derived long volcanic records carry significant uncertainty in eruption dates from low dating precision due to low snow accumulation rates and analytical limitations. High snow accumulation at the West Antarctic Ice Sheet (WAIS) Divide site and improved analytical measurement on the WAIS Divide ice core offer an opportunity to reconstruct a well-dated and long volcanic record. A 6,000 year record has been obtained from the portion of the core analyzed to date, with a dating uncertainty of less than 1%. The record is consistent with other Antarctic volcanic records covering the last millennium providing evidence that the WAIS Divide site produces a highly accurate volcanic record. One of the largest volcanic signals, as measured by volcanic sulfate flux, during the past millennium is that of the 1815 Tambora eruption. The frequency of large eruptions is highest during the thirteenth century CE, when a number of large eruptions are thought to have possibly contributed to the onset of the Little Ice Age. In comparison to the last millennium, the previous five millennia can be characterized as a period of reduced volcanic eruption frequency and of generally lower intensity. Only three volcanic signals (ca. 2410, 3870, and 4900 BP) in this period have volcanic sulfate flux similar in magnitude to that of the 1815 Tambora eruption. Only one century (ca. 3850 to 3950 BP) displayed a volcanic frequency and volcanic sulfate flux similar to that of the 13th century. The WAIS Divide ice core is expected to yield a highly resolved 20,000 year volcanic record.

Few, Arthur A.

Lightning and Ice in Volcanic Clouds

Few, Arthur A.[1]

1. Rice University, Boulder, CO, USA

The recent Eyjafjallajökull volcano in Iceland (2010) and Alaska's Redoubt volcano (2009) have provided our best information on electrical activity in volcanos. There are two distinctively different electrical discharges: there are numerous, almost continuous, small discharges in the hot plume exiting the volcano vent; and later with the vertical development of the volcanic cloud there are discharges that are essentially identical to lightning from thunderstorms. The charging mechanism for the vent discharges has yet to be identified, but given the hot mixture of different materials colliding and fracturing there are a number of possibilities. In this paper I focus on the lightning-type discharges in/from the upper volcanic cloud, which I am confident are associated with ice just as in thunderstorm clouds. The magma of explosive volcanos contain ample quantities of water. Several models of the cooling of the plume are employed to show that the volcanic cloud will most certainly reach freezing temperatures at altitudes exceeding 10 km. There are important differences between thunderstorm ice and what we expect of the ice in volcanic clouds. Volcanic clouds are over seeded with silicate ice nuclei; therefore, we expect smaller crystals but much more numerous. As a consequence we expect more vigorous charging, greater adsorption of volcanic gases by ice, and enhanced lofting of ice into the stratosphere.

Fierstein, Judy

The 1912 eruption of Novarupta and collapse of Mount Katmai, Alaska—a centennial perspective (*Invited*)

Fierstein, Judy[1]; Hildreth, Wes[1]

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The 20^{th} century's most voluminous eruption, 6-8 June 1912 at Novarupta, spanned ~60 hours, including 3 explosive episodes that produced ~17 km^3 of fallout and 11±3 km^3 of ignimbrite, representing ~13.5 km^3 of zoned magma. Opening Episode I released ~70% of the total volume, including plinian fall Layers A-B and the Valley of Ten Thousand Smokes ignimbrite. Fallout and ash flows emplaced concurrently with identical compositional sequences extend from 100% crystal-poor rhyolite initially through increasing proportions of crystal-rich dacite and fluctuating fractions of andesite scoria. The ignimbrite was deposited during the first 16 hours as 9 compositionally distinct, sequentially emplaced ash-flow packages. After a lull of a few hours, Episode II released 4.8 km^3 (Layers C-D), then Episode III 3.4 km^3 (Layers F-G) of dacite-dominant

plinian fallout and minor pyroclastic density currents. Caldera collapse at Mount Katmai, 10 km east of Novarupta, began ~11 hours into the eruption, following release of ~6.9 km^3 of magma. Fitful subsidence was accompanied by >50 earthquakes (10 of Ms 6.0 to 7.0) and by phreatic ejections of hydrothermal mud and breccia, which deposited layers interbedded with contemporaneous plinian pumice-fall layers from Novarupta. No juvenile material was expelled from Mount Katmai during subsidence, but a small dacite dome extruded on the caldera floor sometime after the collapse. The 3-day sequence is one of the five largest in recorded history and one of the few historic eruptions to produce caldera collapse, voluminous high-silica rhyolite, wide zonation (51-78% SiO_2), banded pumice, welded tuff, an on-land ash-flow sheet that supported high-temperature metal-transporting fumaroles (for 15 years), and an aerosol/dust veil that depressed global temperature measurably. The ash cloud was driven eastward over Wisconsin on 8 June, Virginia 10 June, and Algeria 19 June. Abbot (1913) proposed that the haze affected the radiation budget by reflection, absorption, and scattering; the haze was assumed to be mainly silicate dust rather than sulfuric-acid aerosol. Application (by others) to 1912 ejecta of the "petrologic method" of calculating the mass of acid aerosol (by subtracting amounts of S, Cl, and F left in matrix glass from those contained by pristine melt inclusions sealed in phenocrysts) exaggerated the S yield and underestimated the halogens, because they analyzed only dacite Layers C-G. The 2.5 km^3 of Cl-rich rhyolite magma dispersed as fallout, with S contents of melt inclusions <65 ppm, was not sampled. Our recalculation, using compositional proportions and total fallout volume (6.5 km^3 DRE), yields 4.3 million metric tons (Mt) of HCl, 1.1 of HF, and 1.6 of H_2SO_4, for a total of 7 Mt of acid gases. If the ~7 km^3 of 1912 magma emplaced as ignimbrite are added, then total acid gases emitted would be >15 Mt; some fraction would have ascended with the concurrent plinian column, and some would have been evolved during outflow. If the 20-30 Mt of total 1912 acid aerosol estimated from Greenland ice cores (Hammer and others, 1980) and the 13-20 Mt of stratospheric aerosol (presumed largely H_2SO_4) estimated by optical density (Rampino and Self, 1984) are not exaggerated, then estimates by the petrologic method are too low.

Foelsche, Ulrich

Radio Occultation - A new Tool for the Observation of Changes in the Thermal Structure of the Atmosphere after Major Volcanic Eruptions

Foelsche, Ulrich[1]; Scherllin-Pirscher, Barbara[1]; Ladstädter, Florian[1]; Danzer, Julia[1]; Rieckh, Therese[1]; Steiner, Andrea K.[1]; Kirchengast, Gottfried[1]

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The Radio Occultation (RO) technique has originally been developed in the 1960s for the study of planetary atmospheres and ionospheres. Accurate RO measurements of the Earth's atmosphere became feasible in the 1990s, with the precise radio signals of the GPS satellite system (guaranteed by on-board atomic clocks). A few hundred times per day, a satellite in low Earth orbit (LEO) sees one of the GPS satellites setting or rising behind the Earth's horizon. In this "occultation" geometry, the GPS signals have to pass through the Earth's atmosphere and they are characteristically influenced (slowed and bent), depending on the density of the atmosphere. The respective motion of the satellites provides a scan through the atmosphere. Accurate measurements of the change in the GPS signal (onboard the LEO satellite) therefore allow to reconstruct the atmospheric density and, subsequently, profiles of pressure as well as temperature. RO measurements can be performed during day and night, over oceans and land, and even inside clouds. Highest accuracy is achieved ind the upper troposphere and lower stratosphere, with a high vertical resolution of about 1 km. During the last few years, RO measurements have been increasingly used by weather centers around the globe, and they show a surprisingly large positive impact on the quality of atmospheric analyses. RO data a very well suited for climate applications, since they do not require external calibration and only short-term measurement stability over the occultation event duration (1 – 2 min), which is provided by the atomic clocks onboard the GPS satellites. With this "self-calibration", it is possible to combine data from different sensors and different occultation missions (from 2001 onward) without need for inter-calibration and overlap (which is extremely hard to achieve for conventional satellite data). The comparison of RO climatologies from different receiving satellites of the COSMIC constellation shows a remarkable consistency of about 0.01 K, when RO data are globally averaged. Even though the RO record is still comparatively short, its high quality already allows to see statistically significant temperature trends in the lower stratosphere. The high vertical resolution allows to determine the tropopause height or the transition height between (anthropogenic) tropospheric warming and stratospheric cooling. Therefore we are convinced that the RO method is very well suited to determine atmospheric temperature changes after major volcanic eruptions. Due to a lack of such eruptions during the RO data era we could so far not prove this claim, but we are well prepared for the next one to come.

Foley, Aideen

Carbon cycle responses to volcanic activity over 0-2000 AD: A model-data comparison using SIMEARTH

Foley, Aideen[1]; Friend, Andrew[1]

1. Department of Geography, University of Cambridge, Cambridge, United Kingdom

Using a simple Earth system model (SIMEARTH), the coupled global climate-carbon cycle response to a range of climate forcings, including stratospheric aerosol forcing, was simulated over 0-2000AD with the aim of assessing the coupled model response to large temperature excursions, such as those resulting from volcanic eruptions. Model sensitivity to solar and volcanic forcing is assessed by forcing the model with different combinations of available forcing datasets. The modelled atmospheric CO_2 response was compared with reconstructions of atmospheric CO_2 derived from ice cores and stomatal index (SI), while the temperature response was compared with a selection of global and hemispheric temperature reconstructions. Mean temperature response to major volcanic events is greater in the model than in reconstructions, although this may be an artefact of growth effects in tree ring records used to generate some of the reconstructions. The model resembles the ice core reconstructions with respect to rising CO_2 concentrations during the industrial period, but not in terms of short term variability such as volcanic perturbations, as the climate-carbon cycle system effects of volcanic eruptions usually occur on a shorter timescale than is resolved by ice core records. While the SI reconstructions show short term variability, the amplitude of this variability is much greater than the variability of the model simulations. SI reconstructions have been shown to be comparable to ice core records when the effect of pore close-off is accounted for, suggesting that the fluctuations observed in these records reflect actual change in CO_2. However, the lack of stomatal response data for pre-industrial atmospheric CO_2 conditions may introduce some uncertainty, explaining some of the difference between modelled CO_2 concentrations and SI reconstructions. Results suggest that further research is required to better understand the short-term variability of SI reconstructions, before they can be considered a reliable dataset for model evaluation. This research highlights the uncertainties in our understanding of carbon cycle dynamics and of atmospheric CO_2 proxies over past millennia, especially with regards to short term variability such as volcanic perturbations of the climate-carbon cycle system.

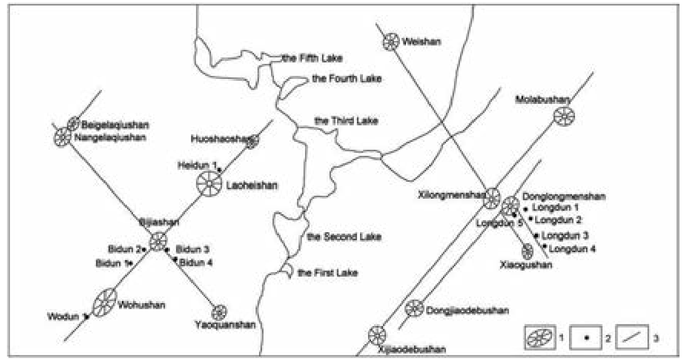
Gao, Weiyan

Geological and geomorphological value of the monogenetic volcanoes in Wudalianchi National Park, NE China

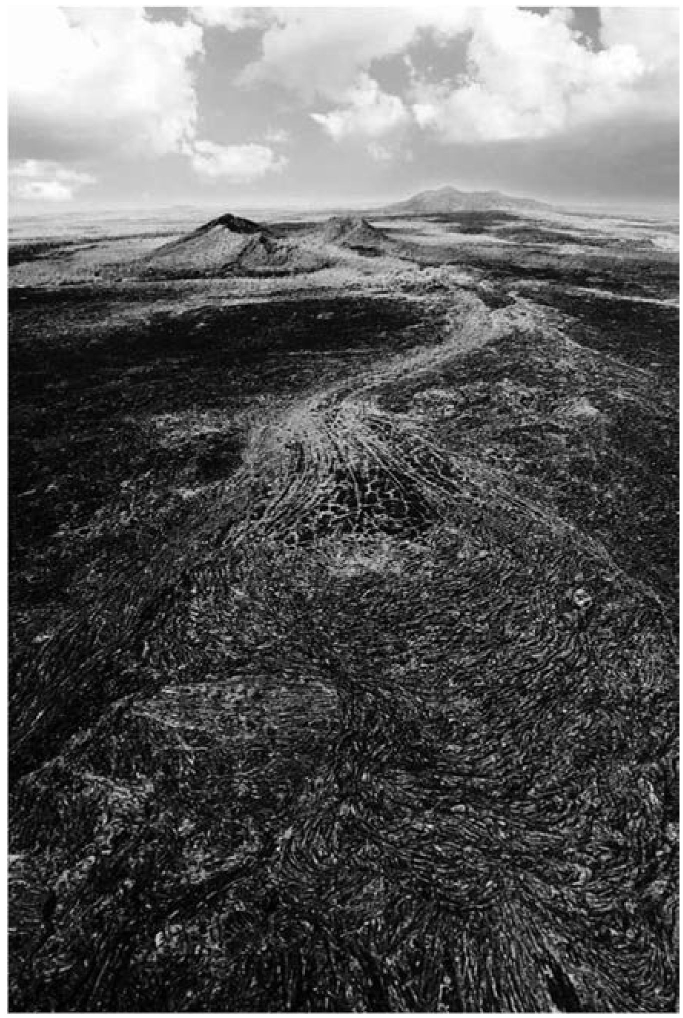
Gao, Weiyan[1]; Li, Jianghai[1]; Mao, Xiang[1]

1. Peking University, Beijing, China

In northeast China, the Cenozoic Wudalianchi volcanic field is located a marked distance (~1,800 km) away from the Pacific-Eurasia plate boundary and characterized by fourteen monogenetic basaltic volcanoes. The small-scale volcanoes were formed by discrete, relatively short-lived eruptive episodes, dispersedly distributed in region. The activity of the basaltic volcanic field occurred in seven eruption cycles spanning a period of 2.10 million years, and as the last major eruptions - Laoheishan and Huoshaoshan Volcanoes - took place in 1719-21 AD, Wudalianchi volcanic field contains an exceptionally well -preserved range of volcanic landforms. It developed the extensive lava flows, including all varieties of lava flow surfaces, subsidiary pyroclastic cones, driblet cones and dishes, and volcanic debris. As a member of the tentative list of World Natural Heritage in China, Wudalianchi National Park presents a high level of geological and geomorphological value with spectacular volcano and lava landform.



Compiled map of major faults, volcanic edifices and vents in the Wudalianchi volcanic field (modified after Tsutomu O 1936). Four distinct volcanic chains are recognized from the map


Photograph of new period lava plateau and lava flows around Laoheishan Volcano, taken by Guo Bolin

Geirsdottir, Aslaug

Holocene Climate Extremes: The Little Ice Age And The 8.2 Ka Event As Viewed From Iceland (*Invited*)

Geirsdottir, Aslaug[1]; Miller, Gifford H.[2, 1]; Larsen, Darren J.[1, 2]; Olafsdottir, Saedis[1]; Thordarson, Thorvaldur[3]

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2. Dept of Geological Sciences, INSTAAR, University of Colorado, Boulder, Boulder, CO, USA
3. School of GeoSciences, University of Edinburgh, Edinburgh, United Kingdom

The two most extreme cold-climate perturbations in the Northern Hemisphere during the Holocene, the 8.2 ka event and the Little Ice Age (LIA, 1250-1900) are well represented in high-resolution lacustrine records from Iceland. The 8.2 ka event as seen from the Icelandic lake sediment differs from its expression in ice cores, by beginning ca. 8.7 ka with an initial cooling on which the colder phase between 8.3 and 7.9 is superimposed. The 8.2 ka event and the LIA, as represented in Icelandic lake sediments, have a range of features in common, including a similar stepwise cooling trend and equally long duration of cooling of ~600 years. Pronounced increases in sedimentation rate, sediment density, and the influx of terrestrial organic matter, between 8.7 and 7.9 ka suggest early Holocene warmth was interrupted by two distinct 200 year-long cold pulses typified by cold summers that resulted in widespread landscape destabilization and possibly glacier expansion. Similarly, precisely dated records of ice-cap growth from Iceland show that the LIA began abruptly between 1275 and 1300 AD, followed by a substantial intensification of summer cold and ice growth 1435 – 1455 AD, with maximum ice dimensions reached ~1850 AD. The LIA is variably explained by solar irradiance and/or volcanic eruptions. Our records, however, of abrupt ice cap growth, coupled with climate modeling, suggest that the LIA can be explained by the known history of explosive volcanism and consequent sea-ice/ocean feedbacks during a hemispheric summer insolation minimum. The 8.2 ka event occurred during a summer insolation maximum in the Northern Hemisphere and has mainly been attributed to freshwater influx from the retreating Laurentide Ice Sheet. While there is a general consensus that the cooling at 8.2 ka as recorded in Greenland ice cores was likely associated with a freshwater forcing, we hypothesize that causes for the earlier onset of cooling and its longer duration may be linked to repeated episodes of volcanism on Iceland and possibly more distant sources. A possible candidate in Iceland would be the ~ 8.6 ka Thjorsarhraun lava (22km3), the largest Holocene basaltic flood lava in Iceland formed in an eruption that lasted for years and possibly decades. Minimum estimates of the atmospheric sulphate aerosol loading by this flood lava eruption, is ~240 Mt H2SO4. Greenland ice core records feature four sulphate peaks between 8.4-8.8 ka. Each of these peaks has amplitudes equal to or greater than those of the 13th and 15th Centuries. Thus it is highly probable that volcanic sulphur emissions in the 8.4-8.8 ka period led to significant atmospheric perturbations on regional to hemispheric scale. We suggest that a continued flux of icebergs and meltwater introduced into the North Atlantic from the decay of the remnant Laurentide Ice Sheet, coupled with local and possibly extra-regional volcanism, may explain the large cold-climate excursion of 8.7-8.3 ka,and that this was amplified by glacial lake drainage in the period 8.3-7.9 ka.

Genareau, Kimberly

Measuring Ash Properties That Help to Generate Lightning in Eruptive Plumes

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2. Geophysical Institute, University of Alaska, Fairbanks, AK, USA

Lightning within volcanic plumes has been observed and documented for several hundred eruptive events of various explosivities at volcanoes of various magma compositions. The presence of water substances (ice crystals, adsorbed water on grain surfaces) and ash grain concentration are thought to play key roles in the generation of volcanic lightning, but the influence of other ash characteristics has not been explicitly constrained in laboratory experiments on natural tephra samples. In particular, the electrical properties of volcanic ash are poorly known. Tephra samples from several ash-producing events of the ongoing eruption of the Soufrière Hills volcano, Montserrat, British West Indies were examined. Ash samples were packed into a 50 mL glass beaker, saturated with deionized water to create a conductive medium, and resistance measurements were taken using a standard multi-meter. Samples from an ash-venting episode in July 2005 were very fine grained and well sorted, providing an average resistance of 11.43 (± 1.46) kΩ. Samples from a pyroclastic flow erupted in August of 1997 were separated into coarser (-1ϕ to 2ϕ) and finer (>2ϕ) portions. The coarser ash fraction provided an average resistance measurement of 29.16 (± 5.25) kΩ. The finer ash fraction provided an average resistance of 187.2 (± 67.1) kΩ; roughly an order of magnitude increase in resistance. These results suggest that fragmentation efficiency, grain size distribution, and grain morphology of erupted ash may also play significant roles in the generation of electric charge and lightning in volcanic plumes. The Soufriere Hills ash-venting episode of July 2005 produced grains with blocky morphologies, while the pyroclastic flow samples contained grains with vesicular morphologies (and thus, comparatively higher surface area per grain) as a result of explosive fragmentation within the volcanic conduit. Thus, although the finer ash fraction of the pyroclastic flow deposit was similar in grain size to the ash-venting tephra, the ash-venting tephra was much more conductive, likely as a result of ash surface morphology and closer packing between the blocky grains. These findings may help to elucidate why volcanic lightning is typically observed in eruptions with explosivity indices of 2-3 and eruptive plumes

of 1-4 km and 7-12 km in height. Further investigations will determine the relationship between grain size and ash conductivity, in addition to the role of structurally bound water and mineralogy.

Graf, Hans-Friedrich

The Variable Climate Impact of Volcanic Eruptions (*Invited*)

Graf, Hans-Friedrich[1]

1. University of Cambridge, Cambridge, United Kingdom

The main effect of big volcanic eruptions in the climate system is due to their efficient transport of condensable gases and their precursors into the stratosphere. There the formation of aerosols leads to effects on atmospheric radiation transfer inducing a reduction of incoming solar radiation by reflection (i.e. cooling of the Earth surface) and absorption of near infrared radiation (i.e. heating) in the aerosol laden layers. In the talk processes determining the climate effect of an eruption will be illustrated by examples, mainly from numerical modelling. The amount of gases released from a magma during an eruption and the efficiency of their transport into very high altitudes depends on the geological setting (magma type) and eruption style. While mid-sized eruption plumes of Plinian style quickly can develop buoyancy by entrainment of ambient air, very large eruptions with high magma flux rates often tend to collapsing plumes and co-ignimbrite style. These cover much bigger areas and are less efficient in entraining ambient air. Vertical transport in these plumes is chaotic and less efficient, leading to lower neutral buoyancy height and less gas and particles reaching high stratospheric altitudes. Explosive energy and amount of released condensable gases are not the only determinants for the climatic effect of an eruption. The effect on shortwave radiation is not linear with the amount of aerosols formed since according to the Lambert-Beer Law atmospheric the radiative effect reaches a saturation limit with increased absorber concentration. In addition, if more condensable gas is available for aerosol growth, particles become larger and this affects their optical properties to less reflection and more absorption. Larger particles settle out faster, thus reducing the life time of the aerosol disturbance. Especially for big tropical eruptions the strong heating of the stratosphere in low latitudes leads to changes in atmospheric wave propagation by strengthened stratospheric zonal winds at polar latitudes in winter. This causes circulation anomalies in the troposphere resulting in advective warming of Northern Hemisphere continents, especially of Eurasia. While immediate, direct effects of volcanic aerosols normally vanish within few years with the removal of the aerosol, changes induced in slowly varying components of the climate system (ocean, sea ice) can be traced for decades especially in the high latitudes of the North Atlantic. For the strength and sometimes even the sign of the volcano related climate anomalies the background state of the climate system can be relevant.

http://www.geog.cam.ac.uk/people/graf/

Grobety, Bernard H.

Volcanic sulfate aerosols

Grobety, Bernard H.[1]; Botter, Cedric[1]; Meier, Mario[1]

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Volcanic eruptions contribute significantly to the sulfur content of the troposphere and the stratosphere (Oppenheimer, 2003). Satellite and ground-based remote sensing allow to measure the main gaseous species in an eruption plume e.g. SO2 and H2S. Electron microscopy of aerosols sampled at different volcanoes with mild eruptive and/or fumarolic activity (Stromboli, Vulcano, El Chichon, Oldonyo Lengai) have shown, that even close to the eruption vent, there is a considerable amount of sulfur in the plume, that is not present as gaseous compounds, but bound to either liquid sulfuric acid droplets or in solid sulfate minerals. The environmental effect of the condensed sulfate phases is different from the original gaseous compounds. It is, therefore, important to understand the underlying transformation processes. Aerosol formation in an eruption or a fumarole plume is very complex and occurs over a large temperature range (Symonds and Reed, 1993). Solid and liquid particles may be formed through magma disintegration, eruption conduit wall erosion, and through condensation or resublimation from the gas phase. Below 100°C volatile compounds will also partition into aqueous aerosol droplets. Cooling and/or evaporation of the droplets may lead to precipitation of solid phases. We used geochemical modelling to explore possible particle forming reaction in a model system Na-K-Ca-Mg-(Fe)-S-C-O-H and temperatures for the primary gaseous/liquid phase ranging from ambient to 800°C. Gas phase reactions were modelled with the software HSC (OUTOTEC), whereas aqueous geochemistry (precipitation) was explored using the Geochemist's Workbench code (RockWare). The modelling results were compared with aerosol samples collected along the crater rim and at the base of Stromboli (Italy) and El Chichon (Mexico) volcano. Up to 1000 particles were analyzed by automated single particle scanning electron microscopy imaging and chemical analysis by energy dispersive spectroscopy (EDS) as well as transmission electron microscopy (TEM). The sampled aerosols contained condensed sulfuric acid particles as well as a number of sulfate minerals, mainly aphthitalite, (K,Na)3Na(SO4)2, thernadite Na2SO4, and arcanite K2SO4 resp. their hydrated cousins. At the base of Stromboli, magnesium sulfates made their appearance. Compared with the thermodynamic modelling results, this sequence is much in favor of an initial condensation of sulfate rich alkaline brine droplets and subsequent precipitation of the sulfate phases when the droplets evaporate. The expected order of precipitation is arcanite, followed by aphthitalite, thenardite (mirabilite) and magnesium rich sulfates. For El Chichon a similar evolution was found. A preliminary estimation of the solid sulfate flux from the fumarolic vents of El Chichon gave around 0.1 kgs-1. Oppenheimer, C. (2003) Treatise in Geochemistry, 3, 123-166. Symonds, R.B. and Reed, M.H. (1993) Am. J. Sci., 293, 758-864.

Gudlaugsdottir, Hera

The climatic signal in the stable isotope record of the NEEM SS0802 shallow firn/ice core from the NEEM deep drilling site in NW Greenland

Gudlaugsdottir, Hera[1]; Sveinbjörnsdóttir, Árný E.[1]; Johnsen, Sigfús J.[2]

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2. Nils Bohrs center for Ice and Climate, University of Copenhagen, Copenhagen, Denmark

By studying paleoclimate one gets the opportunity to understand the interactions of complex processes that control long term climate, which complements the study of todays climate and its evolution. One of the best kept data on paleoclimate is found in polar ice cores where water isotopes have during many decades been used as proxies for past temperature and indicators for variations in the hydrological cycle. The chemistry of past atmosphere can be studied in the ice and in gas-bubbles that gets trapped in glacier ice through snow-ice transition. Ice core research in Greenland goes back to the 60s and since then several deep ice cores have been studied to detect and understand past climate variations. The latest deep ice core project "NEEM" in northwest Greenland aims at retrieving a complete ice core that includes the Emian interglacial period, around 140.000 years ago. The Eemian climate is thought to be about 5°C warmer than present climate and could therefore be used to predict future climate changes in a warmer world. The NEEM deep ice core project included drilling shallow cores with the aim to get a high resolution isotopic profile for the last ~300 years and its correlation with measured, available climate parameters. This will enhance our understanding of the climatic system and aid interpretation of the climate signal reflected in the isotopic record from the NEEM deep ice core. In the present study the 80 m shallow core, NeemSS0802, was analyzed for oxygen and hydrogen at the Institute of Earth Sciences, University of Iceland. Results on the annual isotopic cycle, correlation between temperature and volcanic events detected in the core and correlation between the isotopic record and available climatic parameters, like NAO, NATL ssT, sea ice cover and Greenland/Iceland temperature, will be presented.

Gudnason, Jónas

Sulphur release from Phreatomagmatic Eruptions in Iceland

Thordarson, Thor[2]; Gudnason, Jónas[1]

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2. Earth & Planetary Sciences, University of Edinburgh, "Edinburgh, Scotland", United Kingdom

Basaltic volcanism in Iceland often takes place in environments were the erupted magma interacts with external water to produce explosive eruptions and such events account for ~80% of the documented events and ~30% of erupted magma in historic times (i.e. last 1100 years). Most notable are the intra-glacial phreatomagmatic eruptions, where the principal contributors are Iceland's most active volcanoes; Grímsvötn, Bárdarbunga and Katla. Significant phreatomagmatic events have also occurred in subaerial settings, where the groundwater table within the volcanic zones is at or near the surfaces, and on the offshore extension of the active volcanic zones. This study examines magma degassing and atmospheric mass loading of sulphur from four historical phreatomagmatic eruptions in Iceland. These are the Katla 1755AD (~1 km3) and 1625 AD (~0.5 km3) event, representing the two the largest eruptions on the Katla volcanic system since the 934-40 Eldgjá flood lava eruption and two large volume phreatoplinian fissure eruptions on the Bárdarbunga-Veidivötn volcanic system; the 1477 AD Veidivötn (~7 km3) and ~870 AD Vatnaöldur (~3.5 km3) events. The pre eruption sulphur content of the magma is estimated by measurements of melt inclusions in phenocrysts. The results indicate that the pre-eruption sulphur content of these magmas is 2200±170 ppm for 1755 and 1625 Katla events and 1500±190 ppm for the Veidivötn and Vatnaöldur events. The mean post-eruptive sulphur as measured in the groundmass glass of the erupted tephra is 775±270 ppm (range 210-1470 ppm) for the Vatnaöldur event, 540±130 ppm (range 155-720 ppm) for the Veidivötn event, 980±230 ppm (range 540-1480 ppm) for the 1625 Katla event and 1060±250 ppm (range, 400-2000 ppm). These data indicate that 30 – 50% of the sulphur carried to the surface by the Veidivötn and Vatnaöldur events was released into the atmosphere; equal to 4 and 2 megaton SO2, respectively. In case of the Katla events, 47 – 55% of the sulphur mass was vented into the atmosphere, equal to 2 megaton for the 1625 and 3 megaton for the 1755 eruption. The residual sulphur values in the phreatomagmatic tephra is significantly higher and spans a wider compositional range than those obtained for tephra produced by magmatic explosive eruptions; typical value for magmatic tephra from the Katla system is 460±125 ppm S and for the Bárdarbunga-Veidivötn system it is 490±80 ppm S. This comparison implies that significantly smaller proportion (by factor ~0.5) of the sulphur cargo is released into the atmosphere upon eruption by phreatomagmatic versus magmatic events. This is attributed to premature arresting of magma degassing via quenching of magma by external water. The implications of these results for assessing atmospheric perturbations by phreatomagmatic eruptions will be discussed.

Guillet, Sébastien

Climatic and Environmental Impacts of the Unknown A.D. 1171 Eruption in Europe and the Middle East

Guillet, Sébastien[1]; Lavigne, Franck[1]

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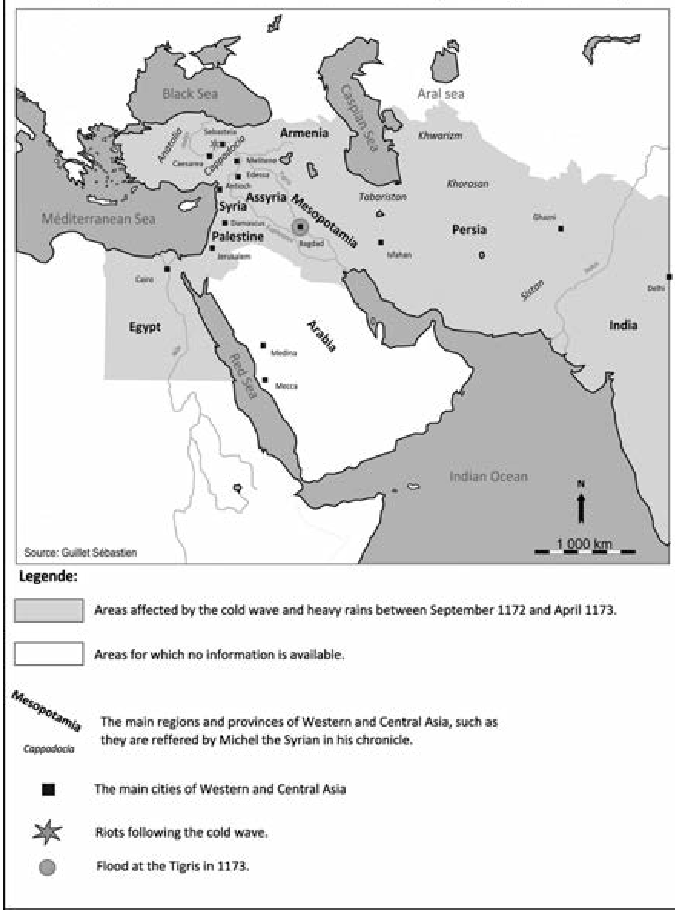
Although our current understanding of the impacts of volcanic eruptions on the atmosphere and climate has significantly improved these last years, the climatic and environmental impacts of volcanism in historical times still remain poorly known, especially for the medieval period. Ice cores from Greenland and Antarctica indicate that at least four large eruptions, potentially able to affect the climate system, occurred between the 12th and 13th centuries. Until now, none of these four events, except for the A.D. 1258 event, has been studied in detail. The aim of this study is to contribute to fill this gap. A multi-proxy approach based on glaciochemical records, dendrochronological records and on the investigation of more than 280 historical records has led us to conclude that an unidentified major volcanic eruptions, which occurred in A.D. 1171, may have had a noticeable impact on the climate system and may have been responsible for weather anomalies and unusual atmospheric phenomena reported by European and Syrian medieval chroniclers. We have found new historical evidence that attest the presence of a stratospheric dry fog over Europe and the Middle East in A.D. 1172. Several chronicles mention the occurrence of an abnormally dark lunar eclipse on 13 January 1172. In Syria, Michael the Great reports an unusual dimming of the sun. Written sources have also revealed that the winter of A.D. 1171-1172 was exceptionally warm in Europe. Our findings indicate the winter warming experienced over Europe could have been induced by a positive phase of the AO/NAO triggered by a low-latitude eruption. In addition, Syrian chroniclers have documented an outstanding episode of cold weather and heavy snowfall that spread over the entire Middle East in A.D. 1172. This weather pattern is not inconsistent with the climatic response generally expected after large tropical eruptions (Robock, 2003). Our hypothesis is supported by ice core records but also by dendrochronological evidence. Frost rings, lights rings, and narrow rings have respectively been identified in tree rings records from Western USA, Quebec and Siberia for the years A.D. 1171 and 1172. This study highlights the valuable contribution of historical accounts in order to reconstruct with more accuracy the history of explosive volcanism.

The Cold Wave of 1172.
An attempt of reconstruction based on historical accounts provided by Michael the Syrian.



Hörmann, Christoph

Estimating the Lifetime of SO_2 From Space: A case Study of the Kilauea Volcano

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S. Beirle, M. Penning de Vries, C. Hörmann, T. Wagner MPI Mainz, Germany Satellite observations of atmospheric trace gases have revolutionized our insights regarding the location and amount of various pollutants. In addition, it has been demonstrated recently that atmospheric lifetimes can be derived by analyzing the downwind decay of point sources. Here we present an analysis of the downwind evolution of the SO2 plume from the Kilauea volcano (Hawaii) in 2008. Both the SO2-patterns observed from space (GOME-2) and the wind fields according to ECMWF stay rather stable over several months, making this an ideal case for lifetime determination. Using a relatively simple mathematical analysis, an e-folding lifetime of SO2 and the total release of SO2 can be estimated simultaneously on the basis of monthly mean SO2 maps and wind fields. We estimate the lifetime of volcanic SO2 to be about 2-3 days. The potential and the limitations of our approach are discussed, and the consequences for the OH concentrations and the chemistry occurring within the volcanic plume are investigated.

Hörmann, Christoph

Systematic investigation of bromine monoxide in volcanic plumes from space by using the GOME-2 instrument

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Bromine monoxide (BrO) plays a key role as a catalyst in the depletion of both tropospheric and stratospheric ozone (O_3), e.g. during springtime in polar regions. In addition to sources like salt lakes or the surface of sea ice in polar regions, it turned out that volcanic emissions are a further natural source of BrO. The injection of bromine compounds from persistent degassing volcanoes as well as during major eruptions, might therefore have an important impact on atmospheric chemistry. Since the first observation of BrO in the volcanic plume of Soufrière Hills in 2002 by ground-based Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) measurements, similar observations have been made at several volcanoes worldwide. While a first systematic investigation with the GOME and SCIAMACHY satellite instruments failed to detect volcanic BrO also from space for selected volcanic events, large amounts of BrO were detected for the first time in the plume of the Kasatochi eruption in August 2008 by GOME-2. This showed the capability of GOME-2 to monitor such events and that satellite instruments offer in principle the unique opportunity to investigate the behavior of BrO inside volcanic plumes for large scales, what is usually not possible with ground-based measurements. In order to detect further events of volcanic unrest, where BrO might be present in the vicinity of the plume, we systematically investigated the whole dataset of the GOME-2 satellite instrument from the beginning of the measurements in January 2007 until June 2011. Almost 800 volcanic plumes were automatically extracted from the data by using sulfur dioxide (SO_2) as a proxy and the slant column densities (SCDs) for BrO were additionally retrieved. While the majority of the captured volcanic plumes showed no signs for enhanced BrO, several other plumes were found with clear evidence for the coincidentally presence of volcanic BrO next to SO_2, even for minor eruptions. In the latter case, the resulting SCDs for both species were analyzed for a possible correlation and the BrO/SO_2 ratios are discussed. The results show, that a close correlation between SO_2 and BrO only occurs for some of the observed eruptions or only for certain parts of the examined volcanic plumes. For some other cases, only a rough spatial correlation can be found. We discuss possible explanations for the occurrence of different spatial SO_2 and BrO distributions in aged volcanic plumes.

Houghton, Bruce F.

The 1912 Eruption of Novarupta and Collapse of Mount Katmai, Alaska - a Centennial Perspective (*Invited*)

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Despite extensive study the 1912 eruption, the largest eruption recorded in the 20th century, poses some intriguing questions. Why were peak eruption rates, and the most voluminous production of pdc's and magmatic volatiles, recorded early in the eruption? Why did discharge rates of dacitic and rhyolitic magmas, which show similar conditions of pre-eruptive storage, show such a strong degree of inverse correlation throughout 5 eruption phases? What modulated the significant pauses in the eruption? We answer some of these questions here and also explore the history of shallow ascent and vesiculation of the Novarupta magmas. We have modeled the isothermal growth of CO2 - H2O bubbles at Novarupta starting from the time of bubble nucleation to the final size preserved as vesicles in pumice. Assuming classical nucleation theory, bubbles nucleate with a diameter of the order of 10 nm and grow to sizes ranging from 1 μm to greater than 1 mm, the typical range of vesicle sizes found in pumice. The smallest bubbles are typically also the most abundant in number e.g. episode 3 pumice contains of the order of 10E+6 bubbles with sizes less than 10 μm in diameter per mm3 of melt, or almost 90% of the entire bubble population. These bubbles must have nucleated within a time interval of about 100 ms, at a supersaturation equivalent to several 10s to ≤100 MPa of H2O pressure. This implies that bubble nucleation culminated during decompression rates in the range of 10 to 100 MPa/s over a depth interval of 1 to 10 m.

Hughes, Eric J.

Real-Time Estimation of Volcanic Ash/SO_2 Cloud Heights from UV Satellite Observations and Numerical Modeling

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An efficient iterative method has been developed to estimate the vertical profile of SO2 and ash clouds from volcanic eruptions by comparing near real-time satellite

observations with numerical modeling outputs. The approach uses UV based SO2 concentrations, Aerosol Index (AI) measurements, and dispersion model simulations from the PUFF model (driven by the GFS meteorological model) to estimate the simulation injection altitudes that lead to the best observation/simulation correlation. The method is computationally fast and was recently implemented for operational use at the NOAA Volcanic Ash Advisory Centers (VAACs) in Washington, DC, USA, to support the Federal Aviation Administration (FAA) effort to detect, track and measure volcanic ash cloud heights for air traffic safety and management. We show the methodology, statistical analysis and SO2 and AI input products derived from the Ozone Monitoring Instrument (OMI) onboard the NASA EOS/Aura research satellite. We also show how a VAAC analyst interacts with the system by providing the initial inputs, such as location and time of the volcanic eruption. The application of this system to recent volcanic eruptions will be shown and compared to altitude estimates from other sources.

Hughes, Eric J.

Some Perspectives on Uncertainty in Volcanic Emissions Forecasting

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The work presented here addresses some of the difficulties in forecasting the advection of volcanic emissions using a trajectory model. Even in idealized cases where the altitude of the emissions is known, different meteorological analyses can advect volcanic clouds in different directions. For example, the advection is sensitive to the location of hyperbolic points in wind fields, and small differences among different models can drive neighboring air parcels in vastly different directions. Other uncertainties arise from the model itself, for example the vertical dispersion when using an isentropic model is usually much smaller than when using the omega field for vertical motion. In this presentation, the ability of meteorological analyses to accurately advect volcanic SO2 is evaluated. Several volcanic eruptions are considered under different meteorological conditions in order to gain a better understanding about the nature of uncertainties in volcanic emissions forecasting.

Hughes, Eric J.

Evaluation of Baseline Volcanic Emissions in GEOS-5

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Understanding and modeling the contribution of volcanic SO2 into the overall sulfur of the atmosphere requires accurate estimates of the SO2 mass loading and injection height from volcanic eruptions. A database of such estimates is used for the baseline sulfate cycle in the NASA GEOS-5 model. Using the initial conditions from this inventory, the GOES-5 model produces simulations of the dispersal and removal of SO2 from volcanic eruptions. The major paths for loss of SO2 are attack by OH and reactions with dissolved H2O2 in clouds; in the stratosphere where clouds are few, OH reactions dominate and lifetimes are longer (about a month compared to a day in the troposphere). To evaluate the accuracy of the volcanic SO2 mass and injection height database, simulations of volcanic eruptions from the GOES-5 model are compared to successive satellite observations. The injection height is evaluated by comparison with trajectory analyses. These comparisons will also help evaluate the accuracy of the SO2 loss/mixing rate in the GEOS-5 model.

Iles, Carley E.

The Effect of Volcanic Eruptions on the Hydrological Cycle

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Large, explosive volcanic eruptions emit sulphate aerosols to the stratosphere, which reflect solar radiation, causing a short-term reduction in global temperature and precipitation. Whilst this cooling effect is well established, the precipitation response has only recently been investigated. These precipitation changes have important implications for society and highlight the potentially serious side effects of geo-engineering schemes that aim to replicate the volcanic cooling effect. However, current general circulation models (GCMs) appear to underestimate this precipitation response, and there is a need for more thorough quantitative comparisons with observations. We examine the average precipitation response to 18 large, mostly low-latitude eruptions in an ensemble of 11 runs of the Hadley Centre general circulation model (HadCM3) over the period 1400-2000. We then compare the modelled precipitation response for 20th century eruptions with gridded gauge data, applying an observational mask to the model and using various eruption strength criteria. For the 600 year runs we find a significant reduction in global mean precipitation of 0.036 mm per day, peaking 2 years after the eruption date and remaining significant until year 5. The response is more rapid and of greater magnitude over land, peaking one year after the eruptions at 0.05mm per day and remaining significant for 3 years. There is a good degree of agreement between ensemble members. Spatially, precipitation decreases in the extratropics, whilst in tropical regions the areas with the wettest climatology coincide well with the areas that experience drying, whilst the drier regions have a more spatially inhomogeneous response, but on average get wetter. A global reduction can also be seen for the 20th century eruptions in observations of global-scale land precipitation. This reduction is significant for the year following the eruptions in the boreal cold season, regardless of the eruption strength criterion used. However, whether the boreal warm season response is significant and in which year is variable. The warm season response lies within the model ensemble envelope, but the cold season decrease is greater than any individual ensemble member. There is, however, a large degree of variability between ensemble members.

Ilyinskaya, Evgenia

On-Site Measurements of Gas Release from Grímsvötn Volcano

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2. Geography, University of Cambridge, Cambridge, United Kingdom
3. University of Palermo, Palermo, Italy

The subglacial Grímsvötn volcano erupts more frequently than any other volcanic system in Iceland with the most recent explosive episode in May 2011. Gaseous emissions (SO_2, H_2S, CO_2, H_2 and H_2O) were measured using a system of electrochemical sensors (MultiGAS) soon after the 2011 eruption, and repeated in May 2012. Measurement locations include both the 2011 eruptive vent, and the long-lived fumaroles on a caldera rim nunatak. This is the first time that such data have been collected at Grímsvötn. Here we discuss variations in the gas composition between sites, with particular emphasis on the concentration of glacier-sourced H_2O relative to CO_2 and sulfur-species.

Jones, Philip D.

Cool North European Summers and Possible Links to Explosive Volcanic Eruptions (*Invited*)

Jones, Philip D.[1]

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Tree-ring-width reconstructions of summer temperatures in northern Fennoscandia reveal a number of extremely cool summers over the last 6000 years. Long observational temperature records, which extend back to about 1780 for this region, reveal none of the markedly cool summers that are reconstructed. Slightly longer instrumental records for northwestern Europe reveal some well-known dates such as the year-without-a-summer in 1816. The two coolest summers in the CE part of the long reconstruction occurred in 536 and 1601, well before instrumental records began. The pre-CE part of the reconstruction reveals a similar number, 6 similar magnitude events during the previous 4000 years. There appears to be a clear link for 1601 event to the eruption of Huaynaputina eruption in Peru the year before and a volcanic cause has been postulated for the event in 536. Presumably the earlier 6 events have similar causes, but the link to volcanic layers in the Greenland Ice Cores is tenuous as the earliest known exactly datable layer is that from Vesuvius in 79 CE. Recent studies by Miller et al (2012) and Mann et al (2012) have respectively suggested (a) that large volcanic eruptions in the 1200-1500 CE period were likely responsible for possibly initiating the Little Ice Age or (b) that volcanic effects are underestimated in tree-ring based reconstructions. Both publications have raised the profile of volcanic forcing as a possible cause of past climatic variability over the Holocene, as have a number of earlier studies. The difficulty with the hypothesis is squaring the information from the Greenland Ice Sheet (exact dating and the possible size of the volcano from the content of the ash layer) and the effects on trees in the study area. This paper will discuss several issues relating to the tree-ring evidence, suggesting that we need more of the multimillennial reconstructions in other high-latitude regions of Northern Eurasia and Northern North America to ensure that what is being seen in Fennoscandia is not just a local response and whether the tree-ring effects are simply due to cool summer temperatures, or whether more climatic variables or direct deposition are involved. Mann, M.E., Fuentes, J.D., Rutherford, S., 2012: Underestimation of Volcanic Cooling in Tree-Ring Based Reconstructions of Hemispheric Temperatures, Nature Geoscience, doi:10.1038/NGEO1394 Miller, G. H., et al., 2012: Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks, Geophys. Res. Lett., 39, L02708, doi:10.1029/2011GL050168.

Kandlbauer, Jessica

Climate response of the 1815 Tambora eruption: HadGEM2-ES model simulations vs. historical records

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The 1815 Tambora eruption released about 51-58 MT SO2 in the atmosphere, leading to a global temperature decrease of 1-1.5°C. The effects of the 1815 Tambora eruption were extensively documented in historical records, indicating that the weather in Europe and New England was abnormally cold and rainy in summer 1816. The year 1816 became famous as ‘the year without summer’ with serious famine due to crop failures and high food prices. Simulations have been performed with the UK Met Office coupled Earth system model HadGEM2-ES. The model has

an atmospheric resolution of 1.875° x 1.25° with 38 vertical levels. It also includes terrestrial and ocean carbon cycle components and an interactive atmospheric chemistry scheme, allowing for assessment of some potentially important climatic feedback mechanisms. The 1815 Tambora eruption was implemented in a pre-industrial climate simulation using an aerosol forcing scenario consistent with PMIP3/CMIP5. A second simulation included the preceding 1809 eruption which may be important in conditioning the climate system response to the larger 1815 event. The comparison of the two simulations will help to understand whether the Tambora volcanic forcing alone could have caused the documented climate response or if the unknown 1809 eruption was partly responsible for 'the year without summer'. Initial model results give an estimated global temperature decrease of 0.8-0.9°C for the 1815 volcanic forcing only, whereas the combined 1809/1815 volcanic forcing indicates a temperature reduction of 1-1.1°C. Very cold summer temperature anomalies are generally found over land areas in the northern midlatitudes, however, the cooling pattern for the 1815 volcanic forcing only simulation seems to develop in a lesser degree and cooler temperatures over western Europe are not as well captured. A positive NAO phase with a consequent warming over northern Europe and Asia and cooler temperatures over NE America in the winter season after the eruption was identified.

Kravitz, Ben

Climate interactions between volcanic forcings and idealized solar forcings

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Both volcanic and solar forcings are known to have radiative and climate impacts, particularly surface cooling effects, which has prompted their use as geoengineering methods and analogues. However, these two forcings are not interchangeable, particularly in terms of their stratospheric chemical and circulatory effects. We use GISS ModelE2, a general circulation model of Earth's climate, to simulate large volcanic eruptions occurring during the G3 solar experiment of the Geoengineering Model Intercomparison Project to investigate the effects of these two types of forcing superimposed on each other. We perform simulations of both tropical (on the equator) and high latitude (50°N) eruptions. We highlight the interactions between these forcings, their compounding and mitigating effects on each other, and the transient climate responses to these forcings, as well as the time scales of the responses. Our simulations specifically include stratospheric chemistry to account for effects on ozone. Although the radiative forcings combine approximately linearly, effects on stratospheric temperature and circulation from the two forcings oppose each other. Chemical effects, particularly on ozone, from the two forcings are quite different, and the combination exhibits highly nonlinear behavior. Reductions in solar forcing mitigate increases in diffuse light from the aerosol layer, dampening growth of the land carbon sink. We also investigate potential strategies for dealing with the possibility of a large volcanic eruption during solar geoengineering, including the timing of the return of solar forcing to its normal levels. We also illustrate the potential for multiple simultaneous approaches to geoengineering.

Krueger, Kirstin

The Combined Bromine and Chlorine Release From Large Explosive Volcanic Eruptions: a Threat to Stratospheric Ozone

Krueger, Kirstin[1]; Kutterolf, Steffen[1]; Hansteen, Thor H.[1]; Appel, Karen[2]; Freundt, Armin[1]; Perez, Wendy[1]; Wehrmann, Heidi[1]

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Large explosive volcanic eruptions inject gases, aerosols and fine ash into the stratosphere, potentially influencing climate. Emissions of chlorine (Cl) and bromine (Br) from large eruptions play an important role for catalytic destruction of ozone in the stratosphere, but hitherto the effects of volcanic Br release with respect to an extended pre-historic time series is not known on a regional or global scale. The bromine release from 14 large explosive eruptions in Nicaragua covering the last 70 ka and a whole subduction zone segment was determined with the petrologic method. Melt inclusions in minerals from felsic and mafic tephras were analyzed using a new optimized synchrotron radiation X-ray fluorescence microprobe set-up. The eruptions produced Br outputs of 4 to 600 kt per event, resulting in an average Br emission of 27 kt per eruption. Based on our estimated Nicaraguan Br and Cl loading to the stratosphere, we conclude that, in contrast to the general opinion until now, many large tropical volcanic eruptions had and have the potential to substantially deplete ozone on a global scale, eventually forming (pre-industrial) ozone holes.

Krueger, Kirstin

Do large tropical volcanic eruptions influence the Southern Annular Mode?

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Large tropical volcanic eruptions have been observed to have a significant influence on the large-scale circulation patterns of the Northern Hemisphere, through mechanisms related to the radiative effects of the sulfate aerosols resulting from the volcanic injection of SO2 into the stratosphere. While no such (confirmed) volcanically induced anomalies in the Southern Hemisphere (SH) circulation have yet been observed, we find that general circulation model simulations of eruptions with SO2 injections larger than that of the 1991 Mt. Pinatubo eruption do result in significant circulation changes in the SH, specifically an enhanced positive phase of the Southern Annular Mode (SAM). We explore the mechanisms for such a volcanically induced SAM response, as well as the corresponding changes in SH temperature, sea ice and precipitation. The anomalous strong zonal winds characterizing the positive SAM phase have potential impacts on the Southern Ocean and the sulfate deposition to the Antarctic ice-sheet hence ice-core based reconstructions of past volcanic activity. This study has relevance for better understanding SAM forcing mechanisms, interpreting observed SAM time series, and predicting future SAM changes after large explosive volcanic eruptions.

Lanciki, Alyson

Lack of stratospheric aerosols by the 1783 Laki volcanic eruption and implications on climatic impact

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Historic records and research have suggested that the 1783-1784 eruption of the Laki fissure volcano in Iceland impacted Northern Hemisphere climate significantly. The eruption produced a dry fog which spread from the Arctic to continental Europe and to the Far East, causing numerous deaths due to famine. Examination of climate records showed that Northern Hemisphere climate was unusually cold in the winter of 1783-1784 and throughout 1784, consistent with the direct injection of Laki materials into the stratosphere where the volcanic aerosols would persist for years to cause surface cooling. However, there has been no direct evidence that Laki eruption plume reached the stratosphere. Recent modeling work by D'Arrigo and colleagues (2011) indicates the Laki climatic impact was limited to parts of the Northern Hemisphere and only in the second half of 1783. The abnormally cold conditions in 1784 may have been a result of unusual combination of NAO and ENSO. We measured sulfur-33 isotope excess ($\Delta^{33}S$) in volcanic sulfate of historical eruptions including Laki, Tambora, and the 1259 Unknown Event found in Summit, Greenland ice cores. No $\Delta^{33}S$ excess is found in sulfate of apparently tropospheric eruptions, while sulfate of stratospheric eruptions is characterized by significant $\Delta^{33}S$ excess and a positive-to-negative change in $\Delta^{33}S$ during its gradual removal from the atmosphere. The isotopic composition of Laki sulfate is essentially normal and shows no characteristics of sulfate produced by stratospheric photochemical reactions. This clearly indicates that the Laki plume did not reach altitudes of the stratospheric ozone layer. Further, the short aerosol residence time (less than 6 months) suggests that the bulk of the Laki plume and subsequent aerosols were probably confined to the middle and upper troposphere. These conclusions support the hypothesis of D'Arrigo and colleagues that the unusually cold winter of 1783-1784 was not caused by Laki.

Lavigne, Franck

The 1258 Mystery Eruption: Environmental Effects, Time of Occurrence and Volcanic Source

Lavigne, Franck[1]; Guillet, Sébastien[1]; Khodri, Myriam[2]; Degeai, Jean-Philippe[1]; Robert, Vincent[1]; Komorowski, Jean-Christophe[3]; Vidal, Céline[1]; Robin, Anne-Kyria[1]; Kuzucuoglu, Catherine[1]; Wassmer, Patrick[1]; Sri Hadmoko, Danang[4, 1]; Lahitte, Pierre[5]; Virmoux, Clément[1]; Brunstein, Daniel[1]; Grancher, Delphine[1]

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4. Research Center on Disasters, Gadjah Mada University, Yogyakarta, France
5. Département des Sciences de la Terre, Paris Sud University, Orsay, France

In recent years a sequence of papers has discussed the potential impact of volcanic eruptions on global weather patterns. Many researchers have linked ecological, environmental and historical phenomena to recent large-scale eruptions like the 1258 AD major event. The goal of this presentation is fourfold: (1) to evaluate the climatic, environmental, and socio-economic responses to this large volcanic eruption based on new data; (2) to discuss the year and season of occurrence of the eruption in order to improve climate modelling; (3) to propose a new and credible source candidate for this major tropical volcanic eruption; and (4) to model the climate impacts of this eruption based on this new volcanic source. Our study on the environmental effects of this eruption is based on a combination of written sources, selected proxies and the use of climate simulations with the IPSL model. The identification of the volcanic source is based on a pluri-disciplinary study based on: written records, remote sensing analysis, field analysis (sedimentatology, stratigraphy, physical volcanology) and sampling of volcanic products, radiocarbon dating of charcoal from the primary volcanic deposits, and geochemical laboratory analysis on whole rock and matrix juvenile glass. Following Oppenheimer (2003), we argue that climatic and environmental effects of this eruption may be identified since the end of 1257 AD. Indeed a dry fog was identified in England a few months before the 1258 AD fog recognized by Stothers (2000). This is confirmed by two additional sources in Germany and Italy. We also noticed a total eclipse of the Moon on November 12th, 1258, in

addition to the one reported by Stothers on May 23rd, 1258. A mild winter of 1257-58 in Europe may have been triggered by a positive phase of the NAO induced by this tropical eruption. We compared the observed effects based on written sources and proxies with climate simulations based on our new suggested location for the volcanic source. The identification of a new credible volcanic source after over 30 years of fruitless investigations constitutes the key finding of this research. It will contribute to improve our knowledge of both near-source and far-field environmental impacts of the strongest eruption in human history. Keywords: Volcanic eruption, environmental effects, climate variability, climate modeling, history, proxies.

Lee, Deborah

Volcanic eruptions and the threat to air transport systems: a coordinated European Roadmap

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The ash clouds from the eruption of the Icelandic volcano Eyjafjallajökull, in April and May 2010, caused widespread disruption to European air traffic routes. Thousands of flights were grounded, affecting millions of travellers, with an enormous financial impact. This event revealed the vulnerability of the air transport system when faced with widespread hazards such as volcanic ash, in conjunction with complex atmospheric conditions. As part of an EC (European Commission) framework programme, WEZARD (weather hazards for aeronautics) was set up in July 2011 for a 2-year period to focus on hazards which can be spread over very large areas, in particular volcanic ash. The WEZARD consortium consists of airframers, engine manufacturers, research organizations, regulatory authorities and a grouping of 29 European National Meteorological Services (EUMETNET). The key deliverable will be a comprehensive R&D roadmap, setting out the types of activity needed to develop a safer air transport system and limit the effects of disrupting events. Work package 3 of WEZARD, led by EUMETNET, investigates meteorological aspects, including improving: volcanic ash observation capabilities, data storage and access, data assimilation and outputs, and coordination and user focus. The first phase of the review work identified a high priority need for an "operational integrated observation system", recognising the need for (a) improvement of observations of the eruptive column at source, (b) additional measurements in the downwind eruptive plume, and (c) enhanced capabilities for the monitoring of distal volcanic ash. Because all observation techniques have their limitations, it is critical to integrate a range of techniques, both in-situ and remote sensing, to provide the most accurate spatial data and characterisation of the ash cloud. It is recognised that both operational European observing networks and ongoing R&D initiatives can be exploited more fully to help achieve a coordinated and integrated approach to volcanic ash monitoring. In the first half of 2012, the project focuses on the compilation and validation of a preliminary European R&D roadmap, comprising reviews, gap analysis and recommendations. Additional input is provided by way of a "European Aviation Volcanic Ash Questionnaire" distributed by EUMETNET to members, requesting details of capabilities, requirements and plans for volcanic ash related activities in each country. This encompasses aspects such as volcanic ash forecasting tools, observational capabilities, geophysical monitoring, institute collaborations, and user consultation and education strategies. The work also takes into account ongoing reviews of requirements and regulations at an international level, and key recommendations following the Icelandic eruptions of Eyjafjallajökull in 2010 and Grímsvötn in 2011. Here we present highlights of this work to date and future challenges.

Losic, Mira

Impacts of Volcanic Eruptions on Baffin Island Climate Using a Regional Climate Model

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The effects of volcanic aerosol loading into the stratosphere are transient, with radiative forcing lasting only a few years after a single large eruption. However, Miller et al. [2012], using climate modeling and glacier observations over Baffin Island, Canada suggest that the Little Ice Age onset could be explained by a series of four large decadally-paced volcanic eruptions.. At this time, glaciers on Baffin Island advanced and did not retreat until the past century, due to Arctic Ocean sea ice feedbacks. We use this premise as motivation to ask the following question: What temperature change is necessary to increase the summer minimum snow extent and lower the snow line altitude across Baffin? We use the high-resolution regional-scale Weather Research and Forecasting (WRF) model to allow improved representation of atmospheric and snow processes given the steep and complex terrain of Baffin Island. Results from four 6-month long (April-September), 10-km resolution simulations are presented. The control simulation is forced with 2005 Global Forecasting System Final Analysis boundary conditions. Two simulations are run with imposed ±3°C temperature perturbations to the control boundary conditions and the fourth run applies a 5% reduction to the solar constant. Results suggest that WRF simulated snow-line altitude evolution on Baffin Island in the control case is different than satellite-derived snow cover observations, but the observations may have issues. We find that the imposed temperature perturbation and solar constant experiments affect the rate of bare ground exposure throughout the melt season but minimally change the date of melt onset. We repeat these experiments, but with 13th Century greenhouse gas concentrations to see if this longwave radiation change promotes a larger minimum snow extent compared to the 2005 runs. We also perform experiments with sea-ice-free and ice-covered conditions to examine the impact of sea ice presence on the snow line elevation. The results from these

and further sensitivity tests provide insight into the relative influence of radiation and advection on the behavior of ice caps on Northern Baffin Island long after the 13th Century eruptions. Reference: Miller, Gifford H., et al. (2012), Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks, Geophys. Res. Lett., in press.

Mandable, Lori

Source Detection of SO_2 Emissions with Unknown Origins Using Remote Sensing and Numerical Modeling

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The detection and modeling of Sulfur dioxide, SO2, is a very important problem due to its effects on flight operations, health and the environment. The AURA/OMI satellite can measure atmospheric trace gases, such as SO2, at a spectral resolution of 0.5nm from wavelengths of 270-500nm covering Earth daily. This information provides near-real time information on the location of SO2 emissions throughout the atmosphere. The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) system can model the transport and dispersion of the observed SO2 in two capacities: a) in a forward direction to forecast the size and trajectory of the observed cloud, or b) in a backward direction to discover the source characteristics. This poster presentation discusses a new source detection methodology that uses a combination of AURA/OMI observations and HYSPLIT running both forward and backward simulations. It is assumed that volcanoes are the source of these unknown releases, but this methodology can be applied to a far wider array of sources such as smelting operations and chemical/power plants. Initially, backwards simulations are run from the location of each observed SO2 cloud to identify the general characteristics of the source. Backwards simulations carry a very high uncertainty and cannot provide exact source characteristics, but can be used to identify a general search area where the source is likely to exist. Forward numerical simulations are then run from candidate sources identified within this general search area. Each simulation is evaluated by computing the error between the simulated concentrations and the OMI/AURA data. A stochastic search is used to generate candidate sources, and minimize the error between the observations and the simulations.

Mann, Michael

Underestimation of Volcanic Cooling in Tree-Ring Based Reconstructions of Hemispheric Temperatures (*Invited*)

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The largest tropical eruption of the past millennium occurred during AD 1258/1259, with an estimated radiative forcing several times larger than the 1991 Pinatubo eruption. The prominent (~2 oC) predicted cooling is largely absent, however, in tree-ring reconstructions of temperature (and muted in reconstructions that employ a mix of tree-rings and other proxy data), seemingly calling into question the climate impact of the eruption. Using a biological growth model driven by simulated temperature variations, we show that the discrepancy likely arises as an artifact of the reduced sensitivity to cooling in trees lying near treeline, combined with secondary effects of chronological errors due to missing growth rings, and volcanically-induced alterations of diffuse light. Our findings support a substantial climate impact of volcanic eruptions in past centuries. They also hold implications for previous estimates of climate sensitivity based on proxy temperature reconstructions.

Martin, Robert

The uptake of halogen (HF, HCl, HBr and HI) and nitric (HNO_3) acids into acidic sulphate particles in quiescent volcanic plumes

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The uptake of halogen and nitric acids into acidic sulphate particles has important implications for volcano monitoring and the environmental geochemistry of volcanic emissions. Using the Extended Aerosol Inorganics Model (E-AIM) for HCl, HBr and HNO_3, combined with a simple three-parameter model for HF and HI, we show that equilibrium partitioning of halogen and nitric acids into sulphate particles is maximised at high relative humidity (RH), low temperature, low plume dilution (i.e., near-source) and high SO_4^{2-}/SO_2. We predict that acidic gas partitioning is quantitatively significant (> 1%) only in cool humid conditions (e.g., > 80% RH at 298 K), adding confidence to spectroscopic and/or electrochemical determinations of gas ratios (e.g., SO_2/HCl, HCl/HF) for volcano monitoring. However, acidic gas partitioning remains environmentally important over a wide range of conditions because of the significant variability in the amounts of acidic gases in

particle form ($Cl^-_{(aq)}$, $Br^-_{(aq)}$, $I^-_{(aq)}$, $NO_3{}^-_{(aq)}$, $HF_{(aq)}$). This may result in diurnal and seasonal changes in acidic gas deposition downwind of the volcano.

Martin, Robert

Bioindication of volcanic mercury deposition around Mt Etna

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Mt Etna is a major natural source of Hg to the Mediterranean region. Total mercury concentrations, $[Hg]_{tot}$, in *Castanea sativa* (sweet chestnut) leaves sampled 7-13 km from Etna's vents (during six campaigns in 2005-2011) were determined using atomic absorption spectroscopy. $[Hg]_{tot}$ in *C. sativa* was greatest on Etna's SE flank reflecting Hg deposition from the typically overhead volcanic plume. $[Hg]_{tot}$ also showed Hg accumulation over the growing season, increasing with leaf age and recent eruptive activity. $[Hg]_{tot}$ in *C. sativa* was not controlled by $[Hg]_{tot}$ in soils, which instead was greatest on Etna's NW flank, and was apparently controlled by the proportion of organic matter in the soil (% Org). An elevated $[Hg]_{tot}$/% Org ratio in soils on Etna's SE flank is therefore indicative of increased Hg deposition. This ratio was also found to decrease with local soil pH, suggesting that Hg deposited to the low pH and organic-poor soils on Etna's SE flank may not be retained but will instead be released to groundwater or re-emitted to the atmosphere. These results show that the deposition of volcanic Hg has clear impacts and confirm that Etna is an important source of Hg to the local environment.

Martinez-Cruz, Maria

Unrest of Turrialba volcano (Costa Rica) after 145 years of quiescence:Research, Geo-monitoring and Socio-economic Vulnerability Assessments

Martinez-Cruz, Maria[1]; Fernandez-Soto, Erick[1]; Avard, Geoffroy[1]; Pacheco-Alvarado, Javier[1]; Hernandez-Rodriguez, Enrique[1]; Saenz-Vargas, Wendy[1]; Brenes-Marin, Jorge[1]; Menjivar-Perez, Efrain[1]

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Turrialba, the easternmost of Costa Rica's Holocene volcanoes, is a basaltic-to-dacitic stratovolcano. Five major explosive eruptions have occurred at Turrialba during the past 3500 years. A series of explosive eruptions occurred during its last eruptive period in 1864-1866 triggering some pyroclastic flows. Since then, weak fumarolic activity has manifested at the central and SW summit craters. More recently, in 1995, Turrialba has shown unrest signals, which have become more conspicuous from 2007, pointing to the beginning of a new eruptive phase that has been characterized by strong fumarolic outgassing and the sporadic but sudden opening of vents accompanied by the emission of small volumes of non-juvenile ashes. Currently, research and monitoring is been done in order to extensively document the activity of the volcano for a better understanding of the processes and hence, of the volcanic hazards and risks (eg. Eyre et al., 2011; Martini et al., 2010; Ruiz et al., submitted; Vaselli et al., 2010). These efforts would provide great improvement of the geophysical and geochemical monitoring systems that are currently being used, and would allow to generate crucial information for national protection authorities and the population living in Turrialba volcano`s hazard-prone areas. Through this work, we will show how the unrest of Turrialba volcano represents an outstanding experience since it is the first time in the geological history of Costa Rica that local people have the opportunity to witness, document, and study the unrest processes of a dormant volcano. Also the awakening of Turrialba is giving managers, authorities, and our society the opportunity to learn about the dramatic consequences of volcanic hazards on human society, natural environment, and economy, and how to develop social-economic vulnerability assessments and improve in risk prevention and preparedness in this context. References: Eyre, T., O'Brien, G.S., Martini, F., Bean, C.J., Mora, M.M., Pacheco, J.F., Soto., G.J. (2011). Investigating seismic source mechanism at Turrialba volcano, Costa Rica. Geophysical Research Abstracts, 13, EGU2011-8859, 2011. EGU General Assembly 2011. Martini, F., Tassi, F., Vaselli, O., Del Potro, R., Martínez, M., Van Der Laat, R. y Fernández, E. (2010) Geophysical, Geochemical and Geodetical signals of reawakening at Turrialba volcano (Costa Rica) after almost 145 years of quiescence. Journal of Volcanology and Geothermal Research, 198 (3-4), 416-432. doi: 10.1016/j.jvolgeores.2010.09.021. Ruiz, p., Turrin, B., del Potro, R., Gagnevin, D., Gazel, E., Soto, G.J., Carr, J., M., Mora, M., Swisher, C.C. submitted: 40Ar/39Ar ages of Late Pleistocene-Holocene lavas from Turrialba volcano Costa Rica, some 2 of the youngest lavas reported in Central America by this method. G-Cubed: Geochemistry, Geophysics, Geosystems. Vaselli, O., Tassi, F., Duarte, E., Fernández, E., Poreda, R.J. y Delgado, A. (2010). Evolution of fluid geochemistry at the Turrialba volcano (Costa Rica) from 1998 to 2008. Bulletin of Volcanology, 72(4), 397-410.

Mather, Tamsin A.

Halogen and Trace Metal Emissions From Volcanism: Insights From Hawai`i (*Invited*)

Mather, Tamsin A.[1]; Witt, Melanie L.[1]; Pyle, David M.[1]; Aiuppa, Alessandro[2, 3]; Bagnato, Emanuela[2]; Martin, Rob S.[4]; Sims, Ken W.[5]; Edmonds, Marie[6]; Sutton, Jeff[7]; Ilyinskaya, Evgenia[8]

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Volcanoes are important sources of halogen gases and metallic elements to the Earth's atmosphere and environment. Volcanic plume samples taken in 2008 and 2009 from the Halema`uma`u eruption at Kilauea provide new insights into its degassing and can be compared with other volcanic systems to give insights into global volcanic degassing budgets and impacts. Compared to most other global volcanoes, Kilauea's gases are depleted in Cl with respect to S. Similarly, our Br/S and I/S ratio measurements in Halema`uma`u's plume are lower than those measured at arc volcanoes, consistent with contributions from the subducting slab accounting for a significant proportion of the heavier halogens in arc emissions. Plume concentrations of many metallic elements (Rb, Cs, Be, B, Cr, Ni, Cu, Mo, Cd, W, Re, Ge, As, In, Sn, Sb, Te, Tl, Pb, Mg, Sr, Sc, Ti, V, Mn, Fe, Co, Y, Zr, Hf, Ta, Al, P, Ga, Th, U, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Er, Tm) are elevated above background air. There is considerable variability in metal to SO_2 ratios but our ratios (generally at the lower end of the range previously measured at Kilauea) support assertions that Kilauea's emissions are metal-poor compared to other volcanic settings. Our aerosol Re and Cd measurements are complementary to degassing trends observed in Hawaiian rock suites although measured aerosol metal/S ratios are about an order of magnitude lower than those calculated from degassing trends determined from glass chemistry. Plume enrichment factors with respect to Hawaiian lavas are in broad agreement with those from previous studies allowing similar element classification schemes to be followed (i.e., lithophile elements having lower volatility and chalcophile elements having higher volatility). The proportion of metal associated with the largest particle size mode collected (>2.5 μm) and that bound to silicate is significantly higher for lithophiles than chalcophiles. Many metals show higher solubility in pH 7 buffer solution than deionised water suggesting that acidity is not the sole driver in terms of solubility. Nonetheless, many metals are largely water soluble when compared with the other sequential leachates suggesting that they are delivered to the environment in a bioavailable form. Preliminary analyses of environmental samples show that concentrations of metals are elevated in rainwater affected by the volcanic plume and even more so in fog. However, metal levels in grass samples showed no clear enrichment downwind of the active vents.

Mather, Tamsin A.

Late Quaternary tephrochronology of southern Chile: An ideal test site for constraining arc-scale volcanic response to deglaciation

Mather, Tamsin A.[1]; Watt, Sebastian F.[2]; Pyle, David M.[1]; Naranjo, Jose A.[3]; Lachowycz, Stefan[1]; Rawson, Harriet[1]; Fontijn, Karen[1]

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Late Quaternary terrestrial, lacustrine and marine sediments in southern Chile contain an important record of explosive volcanic activity over the past 15-18,000 years. They offer considerable potential for the development of a regional tephrochronological framework, with the possibility of linking marine records from the Pacific, offshore from southern Chile, and the south Atlantic, offshore from southern Argentina. In recent years, we have established a tephrochronology for the Hualaihue region (~41 - 42° S) of southern Chile (Watt et al., 2011), which we can now integrate with the well established stratigraphy for southern Patagonia (Naranjo and Stern, 2004; Stern, 2008), and the much less-well developed records from Chiloe island (~42 - 43° S) and the Chilean Lake District (~38 - 40° S). Prominent among the tephra units which we have documented are the widely dispersed rhyolitic tephra from a major eruption of Chaitén volcano (Cha1; dated at ~9.75 cal kyr BP). This eruptive unit had a minimum erupted volume of 3.5 km^3, and a regionally-unusual dispersal pattern which extends north from Chaiten (42° S): most eruptive products are dispersed to the East, across Argentina. The deposits of this substantial eruption may correlate with the '9.6 kyr' tephra units recognised on Chiloe island, at ODP site 1233 and in the Chilean Lake District (Lamy et al., 2004). Our new eruptive stratigraphy covers a region whose volcanic history was previously very little known, and contributes to a

regional record of large explosive eruptions that now spans an 800 km segment of the southern Andean arc, between Laima and Hudson volcanoes. This record will underpin continuing work evaluating the links between deglaciation and eruption rate, and will lead to an improved understanding of the volcanic hazards of the region.
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McCormick, Brendan T.

Validating OMI measurements of tropospheric volcanic SO_2

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The Ozone Monitoring Instrument (OMI) is a satellite-based UV spectrometer with unprecedented sensitivity to atmospheric sulphur dioxide (SO2). Recent studies have demonstrated that OMI can detect, and characterise patterns in, passive volcanic degassing of SO2 into the troposphere. Understanding rates and variations in passive degassing are crucial to fully understanding its importance to global volcanic volatile budgets, to investigating the impact of volcanism on Earth's climate and environment, and for monitoring of volcanic activity for hazard mitigation purposes. Satellite-based studies are especially useful in remote or inaccessible regions where ground-based measurements are sparse or absent. However, OMI retrievals of tropospheric SO2 remain unvalidated, hampered by a limited understanding of the impact of particular atmospheric and meteorological conditions on SO2 detection (e.g. clouds masking volcanic plumes; humidity and temperature promoting rapid loss of SO2 via oxidation to sulphate or by various wet/dry deposition processes; wind dispersal of plumes), in addition to various difficulties inherent to direct comparison of satellite- and ground-based measurements (e.g. differing spatial resolution, non-simultaneous measurements, column concentrations versus fluxes). We present a novel numerical modelling-based validation study of OMI's sensitivity to volcanic SO2 emissions from Tungurahua volcano, Ecuador, using the atmospheric chemistry/transport model REMOTE. REMOTE has already been successfully used to model post-emission SO2 dispersion from volcanoes in Nicaragua and Indonesia. Model input is high time resolution SO2 flux data derived from Differential Optical Absorption Spectroscopy using ground-based UV spectrometer instruments at Tungurahua. The model output is spatial maps of SO2 column concentration for comparison with those produced from OMI data. We calculate total daily atmospheric SO2 burdens for the REMOTE and OMI datasets, and use REMOTE's treatment of atmospheric chemical reactions, wind dispersal, and cloud cover, as well as additional OMI data products (effective reflectivity and aerosol index) to interpret the variation in agreement between the two datasets. The use of high time resolution flux data enables REMOTE to distinguish sudden changes in degassing behaviour (e.g. minor explosive eruptions); such changes may be evident in OMI data if they occur shortly before the satellite overpass. In addition to the availability of quality ground-based data, Tungurahua is an ideal target volcano since its strong SO2 emissions are frequently detected by OMI and its high altitude and Equatorial location are optimal for satellite measurements. This study offers great potential in assessing the use of OMI as a volcano monitoring tool, in addition to providing new insights into the behaviour of volcanic SO2 post-emission.

McNutt, Stephen R.

Infrasound Observations of Explosive Volcanic Eruptions in Alaska, 2006-2011

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Infrasound studies of Alaskan volcanic eruptions have increased dramatically in the last decade. There are presently 30 infrasound sensors operating in the state; the I53US array (8 sensors) in Fairbanks; an array in Dillingham (6); small arrays at Okmok and Akutan volcanoes (4 each); a pair of sensors at Fourpeaked; and individual sensors at Pavlof, Shishaldin, Augustine and Redoubt volcanoes. In addition to infrasound sensors, seismometers have recorded several explosive eruptions via ground coupled air waves. The periods observed range from 0.1 to 540 sec (0.002 to 10 Hz), with the short periods from small eruptions at close distances and the longest from acoustic gravity waves. In general, for short duration explosive eruptions, the strongest waves occur early in the event (first few 10s of sec) so analysis of signals has potential to provide rapid information on the occurrence and size of events. The UAF team is presently developing alarm systems using combined infrasound and seismic data. These are expected to verify eruptions at monitored volcanoes and provide new capabilities to detect explosive eruptions at unmonitored volcanoes. Eruptions at Pavlof (2007) and Shishaldin (1999 and later) volcanoes have produced thousands of small explosions recorded on local seismometers and infrasound sensors. Larger explosive eruptions at Augustine (2006) and Redoubt (2009) produced large signals on local sensors that fixed the source term, and also distant recordings at arrays ~600 km away. Very large eruptions at Okmok (2008) and Kasatochi (2008) were recorded on distant arrays (~2000 km). For Okmok, local seismometers (but no infrasound sensors at the time) provided source constraints. For Kasatochi there were no local data. Thus the distant array data were used to characterize the time histories of the eruptions. The infrasound data provided information on the location, timing (onset and cessation), and changes in intensity of the eruptions. Recently, explosive eruptions at the unmonitored Cleveland volcano have been analyzed. Here a variety of signals have been recorded with very different acoustic and seismic parameters, reflecting the varying atmospheric conditions as well as differences at the source. Because of this, development of automated alarm systems will remain a challenge. Infrasound data are useful because they help quantify the flux of ash and gas to the atmosphere.

Merucci, Luca

SO_2 flux time series reconstruction from MSG-SEVIRI measurements

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Volcanic plumes images collected by thermal infrared satellite sensors are routinely processed to extract quantitative information such as SO2 and ash columnar abundance maps. If the wind field is known the SO2 and/or ash flux time series can be derived from these maps. Here we show how the flux time series can be calculated from SEVIRI data by exploiting the high acquisition frequency offered by the geostationary MSG platform. The flux time series back-calculation procedure has been recently described for the SO2 maps based on images collected by the MODIS instrument (on board on the A-train polar platforms) and on the wind field knowledge given by the LAMI model. In a pilot study focused on the TIR MODIS dataset of the December, 2006 Mt. Etna (Sicily, Italy) eruption we successfully compared the retrieved MODIS SO2 flux time series with those measured by FLAME, a ground-based network of DOAS instruments which constantly monitors the volcano SO2 emissions since its deployment. We highlight that a single image framing a volcanic cloud can be regarded as the evolution in time of physical and volcanologic parameters, and effectively records many hours of volcanic activity. A collection of images of the same eruptive events offers further advantages that can be used for the chronological reconstruction of the flux time series. This approach provides information that can be extremely valuable in case of remote and poorly monitored volcanoes and opens new perspectives to investigate the processes driving the volcanic activity.

Metzner, Doreen

Southern Hemisphere climate response to an extremely large tropical volcanic eruption: Simulations with the MPI-ESM

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In this study we investigate the climate response in the Southern Hemisphere (SH) to an extremely large volcanic eruption. For this purpose we use a two-step approach: first, we calculate with the MAECHAM5-HAM general circulation model including detailed aerosol microphysics an aerosol optical depth (AOD) distribution resulting from a stratospheric injection of 700 Mt SO_2; secondly, an ensemble of simulations (5 x 200 years) is performed forcing the complex Max-Planck-Institute Earth System Model (ESM) with this obtained AOD distribution. The SO_2 emission strength exemplary used corresponds to that estimated from tephra analysis from the Los Chocoyos eruption (VEI > 7) in Guatemala (84 ka BP) of the Central American Volcanic Arc (CAVA) [Metzner et al., 2012 submitted]. This work focuses on coupled atmospheric-oceanic responses in the SH, whose complexity arises from the dynamical interactions between the radiative forcing and the ongoing broadband internal variability of the climate system. Due to the extremely large volcanic radiative forcing the surface cools over almost the entire SH. Negative temperature anomalies propagate down to the deep SH ocean ~2000 m in the first ~50 years, being significant negative for the whole simulated 200 years. Consequently, the ocean heat content in the SH is significantly reduced. Atmospheric circulation changes in the model can be described as a significant positive Southern Annual Mode (SAM), which persists for at least 12 months after the eruption and is associated with significant surface changes of temperature, precipitation and wind fields. In particular, the anomalies resemble a dipole pattern resulting from a distinct increase in magnitude and poleward movement in position of the strong SH westerlies. The upper ocean is significantly affected by the forced poleward shift of the zonal winds, and the upper ocean circulation in the Antarctic Circumpolar Current region is significantly modified, at least for the time of the anomalous wind forcing in the first two years after the eruption. Due to the propagation of the forced anomalies into the deep ocean layers, the anomalous oceanic state persists well beyond the atmospheric response timescale. Hence, in our simulations of the Los Chocoyos eruption, a detectable volcanically-forced climate signal persists over several decades (even more) being a sort of an upper-limit for the timescale of responses to volcanic eruptions.

Metzner, Doreen

Radiative Forcing and Climate Impact Resulting From SO_2 Injections Based on a 200,000 Year Record of Plinian Eruptions Along the Central American Volcanic Arc

Metzner, Doreen[1]; Kutterolf, Steffen[1]; Toohey, Matthew[1]; Timmreck, Claudia[2]; Niemeier, Ulrike[2]; Freundt, Armin[1]; Krüger, Kirstin[1]

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We petrologically estimated SO_2 emissions from 36 detected Plinian volcanic eruptions occurring at the Central American Volcanic Arc (CAVA) during the past 200,000 years. Using this record and simple parameterized relationships collected from past studies we derive estimates of maximum volcanic aerosol optical depth (AOD) and radiative forcing (RF) for each eruption. For selected CAVA eruptions comprising different SO_2 emission strengths, AOD and RF time series are derived in parallel from simulations with the global aerosol model MAECHAM5-HAM. The model shows a relationship between stratospheric SO_2 injection and maximum global mean AOD that is linear for smaller volcanic eruptions (<4 Mt SO_2), and non-linear for larger ones (≥4 Mt SO_2), which is qualitatively and quantitatively consistent with the relationship used in the simple parameterized method. Potential climate impacts of the selected CAVA eruptions are estimated using an earth system model of intermediate complexity by RF time series derived (1) directly from the global aerosol model, and (2) from the simple parameterized method assuming a 12-month exponential decay of global AOD. We find that while the maximum AOD and RF values are consistent between the two methods, their temporal evolutions are significantly different. As a result, simulated maximum temperature anomalies and the duration of the temperature response depend on which RF time series is used, varying between 2.1 K and 3.1 K and ~ 60 and 90 years for the largest eruption of the CAVA data set. The presented results can be used to estimate the volcanic forcing and potential climate impacts from sulfur emissions, sulfate aerosol or AOD data for any tropical eruption that reached the stratosphere in the past but also in the future.

Miller, Gifford H.

The Role of Volcanism as a Trigger for the Little Ice Age (*Invited*)

Miller, Gifford H.[1, 2]; Geirsdottir, Aslaug[2]; Zhong, Yfang[1]; Larsen, Darren[2, 1]; Otto-Bliesner, Bette[4]; Holland, Marika[4]; Anderson, Chance[1]; Bjornsson, Helgi[2]; Thordarson, Thorvaldur[3]

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Northern Hemisphere summer temperatures over the past 8000 years have been largely paced by the slow decrease in summer insolation resulting from the precession of the equinoxes. However, the causes of superposed century-scale cold summer anomalies, of which the Little Ice Age (LIA) is the most extreme, remain debated, largely because the natural forcings are either weak or, in the case of volcanism, short lived. Precisely dated records of ice-cap growth from Arctic Canada and Iceland show that the LIA began abruptly between 1275 and 1300 AD, followed by a substantial intensification of summer cold and ice growth 1435 – 1455 AD, with maximum ice dimensions reached ~1850 AD. These intervals of sudden and sustained ice growth coincide with the three most volcanically perturbed half-centuries of the past millennium. Explosive volcanism can explain the abrupt coolings but on their own cannot explain the century-scale persistence of summer cold. We explore how feedbacks in the climate system might engage a self-sustaining positive feedback following decadally paced explosive volcanism as recorded in the late 13th Century. Climate modeling shows that decadally paced volcanism can produce a greater North Atlantic cumulative cooling than even a very large single eruption, and that a multi-decadal expanded sea ice state may engage a sea-ice/ocean feedbacks that allows sea ice to remain in an expanded state long after volcanic aerosols are removed. Our records of abrupt ice cap growth, coupled with climate modeling, suggest that the LIA can be explained by the known history of explosive volcanism and consequent sea-ice/ocean feedbacks during a hemispheric summer insolation minimum, and that large changes in solar irradiance are not required.

Millington, Sarah

Development of satellite volcanic ash products for the London VAAC

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During volcanic eruptions that eject ash into the atmosphere Volcanic Ash Advisory Centres (VAACs) issue statements on the forecast dispersion of the ash so that the

aviation industry can manage airspace to avoid aircraft encountering volcanic ash. Satellite-derived products have been developed to provide forecasters operating the VAAC service with qualitative and quantitative information on the dispersing volcanic ash cloud. These, along with other observations, are used together with ash forecasts from an atmospheric dispersion model to provide guidance for the aviation industry. A robust method to detect volcanic ash, using data from the infrared channels of the SEVIRI instrument mounted on-board the Meteosat Second Generation satellite, has been developed. The simultaneous retrieval of quantitative volcanic ash physical properties is achieved using a one-dimensional variational analysis. From this, images are generated showing detected ash, total column mass loading, particle effective radius and ash cloud top height. These retrieved properties have been validated against lidar data for the Eyjafjallajökull eruption in 2010, which demonstrated that the retrievals are realistic. Ash forecasts from an atmospheric dispersion model are compared with observations to assess the quality of the forecasts. A method has been developed to enable like-with-like comparison between satellite imagery of volcanic ash and simulated imagery using the forecast ash concentration data from an atmospheric dispersion model. The ash concentration and numerical weather prediction data are used as inputs to a radiative transfer model to simulate radiances. Simulated satellite images are created from these simulated radiances. In addition to providing a useful tool for forecasters in a VAAC, the simulated images can be used to aid the understanding of how the ash affects the satellite imagery and also the physical properties of the ash. Other satellite data utilised in the London VAAC include infrared and visible imagery from SEVIRI and instruments on polar orbiting satellites (AVHRR and MODIS), sulphur dioxide retrievals from SEVIRI and IASI data, and aerosol and sulphur dioxide products from instruments such as OMI. An overview of the detection of volcanic ash, retrieval of the physical properties and simulation of volcanic ash imagery will be presented and some examples will be shown for recent eruptions.

Mills, Michael J.

Simulation of the June 2011 Nabro Eruption with SD-WACCM/CARMA

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The June 2011 eruption of the Nabro stratovolcano (13°22'N, 41°42'E) in Eritrea is estimated to have put 1.3 Tg of SO2 into the upper troposphere between 9.1 and 13.7 km. Observations indicate that winds carried this cloud into the Asian summer monsoon, where deep convection lofted it into the lower stratosphere. Thus, with the aid of strong tropical upwelling, an eruption that did not directly inject sulfur into the stratosphere produced the largest perturbation to stratospheric aerosol loading since the 1992 eruption of Mt. Pinatubo. We study this eruption with the Whole Atmosphere Community Climate Model (WACCM4), a capability of the Community Earth System Model (CESM1) that extends from the Earth's surface to the lower thermosphere. We have added sulfur chemistry to WACCM4, and coupled it to a bin microphysics code, the Community Aerosol and Radiation Model for Atmospheres (CARMA), which we have adapted to study stratospheric sulfate aerosol. We specify WACCM4 dynamics by nudging to GEOS-5 analyzed meteorological fields representing observed conditions before, during, and after the eruption. We compare our calculations to observations, and discuss the implications for stratosphere-troposphere exchange, aerosol microphysics, stratospheric chemistry and model parameterizations.

Mobbs, Stephen

Overview of the VANAHEIM Project: Characterisation of the Near-Field Eyjafjallajökull Volcanic Plume and its Long-range Influence

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The volcanic plume from the Eyjafjallajökull eruption caused major disruption to air transport across Europe. The regulatory response, ensuring aviation safety, depends on dispersion models. The accuracy of the dispersion predictions depend on the intensity of the eruption, on the model representation of 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. It integrates new modelling and insights into the dynamics of the volcanic plume and its gravitational equilibration in the stratified atmosphere, effects of meteorological conditions, physical and chemical behaviour of ash particles and gases, physical and chemical in situ measurements, ground-based remote sensing and satellite remote sensing of the plume with very high resolution numerical computational modelling. When integrated with characterisations of the emissions themselves, the research will lead to enhanced predictive capability. This project aims to ensure that the science and organisational lessons learned from the April/May 2010 emergency response to Eyjafjallajökull are translated fully into preparedness for subsequent eruptions of other volcano over the coming years. Overall, the project will (a) complete the analysis of atmospheric data from the April/May eruption, (b) prepare for future observations and forecasting and (c) make additional observations if there is another eruption during within the four years of the project. 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.

Moeseyenko, Konstantin

Inversion of eruption source parameters with use of numerical model for the transport and deposition of volcanic ash

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In explosive eruptions, the total amount of fragmental material and its grain size characteristics are the key parameters commonly used to quantify numerous environmental effects produced by volcanic debris. As the significant amount of pyroclasts in such eruptions are airborne fragments of pyroclasts fall (tephra), knowing its component abundance is a necessary prerequisite for correct assessment of net geological and climatic effects of the eruptions on the Earth. In this study, we use state of the art RAMS6.0/HYPACT atmospheric modeling system for direct simulation of ash dispersal and fallout for eruption events on andesitic volcanoes Bezymianny 25 Dec 2006 and 17 Dec 2009, Karumsky on 21 April 2007, and Kizimen on 12 Jan 2011 (Kamchyatka Peninsular). The calculated ground loads are compared against field data obtained immediately after eruptions to inverse TEMs and bulk granulometries through linear regression approach. Estimates for fine ash content were conducted under the general assumption of a power-low cumulative mass distribution such that m, the mass of fragments of size > d, is $\propto d^{-D+3}$. D values are found in a range from 3.1 to 4.1, and are about 4.0 in three episodes of four, showing an important role of secondary fragmentation processes in a conduit and eruption column. The value of D tends to increase with height of eruption column, as higher rate of fragmentation provides more efficient mechanism for buoyancy production within the column. Consistency of the proposed methodic is verified through comparison with TEM values calculated by (i) straight-lines approximation of logarithm of thickness versus area$^{1/2}$ and (ii) inversion of eruption column terminal height – source heat power dependence stated by the theory of convective plumes. We conclude, that the proposed numerical approach, although being not completely free of some subjective elements, seems to produce better constrains on the plausible range for derived TEM values compared to (i, ii) and can be used as a rational basis for estimation of eruption source parameters.

Montopoli, Mario

Microwave Remote Sensing of Volcanic Ash Clouds for Aviation Hazard and Civil Protection Applications: the 2011 Grímsvötn Eruption Case Study

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The prompt detection of explosive volcanic eruptions and accurate determination of eruption-column altitude and ash-cloud movement are critical factors in the mitigation of volcanic risks to aviation and in the forecasting of ash fall on nearby communities. Ground based and satellite observations have been recently used to identify and track the ash dispersal path in the atmosphere at different spatial and temporal scales. These remote sensing tools are promising but there is an increasing need to better investigate their potential for operational use. Satellite remote sensing techniques can be exploited for this purpose, using thermal infrared channels available on both low-Earth orbit (LEO) and geosynchronous Earth orbit (GEO) satellites. Due to the strong extinction of ash cloud top layers, optical and infrared spaceborne imagery can provide a good estimate of the fine ash cloud coverage but a less accurate estimate of its concentration and columnar content. Microwave weather scanning radars have been successfully used to provide basic eruption observations in the last three decades, even though initially only qualitative description of eruption features have been provided through the analysis of radar reflectivity measured fields. More recently, by exploiting the well established techniques used for physically-based radar remote sensing of rainfall, the weather radar backscattered power has been used to derive quantitative estimates of volcanic eruptive mass, ash fall out and ash size category. The presented work is devoted to the description and discussion of new results of the VARR methodology, for the first time applied to the recent sub-glacial Plinian explosive eruptions of Icelandic Grímsvötn volcano, whose maximum activities occurred on May 2011. The 2011 Grímsvötn eruption has been monitored and measured by the Keflavík C-band weather radar at a distance of about 260 km from the volcano vent in a way similar to the eruption of 2004. The prevailing southerly winds stretched the plume toward the Arctic, thus preventing the ash plume to move towards continental Europe and threatening the airline traffic. The sub-Plinian ash cloud in Eyjafjallajökull was persistent and fine-grained, while the ash in Grímsvötn was coarser and not as dangerous as for Eyjafjallajökull since it fell to the ground faster. Radar-based ash retrieval results have been qualitatively and quantitatively compared with available satellite microwave radiometric imagery. Results from the radar analysis of the Grímsvötn 2011 eruption evidence a plume height up to 18 km, a maximum eruption discharge rate of about 10000 m^3/s, a total mass of 4.5 10^11 kg and a total ash cloud volume of 3.6 10^8 m^3. On the other hand, the satellite microwave radiometric imagery shows a negative correlation with radar estimates of ash columnar content up to -0.63 depending from the microwave channel used. This is encouraging for a potential use of satellite microwave sensors for detecting and quantify the ash content along vertical columns.

Mussard, Mickael

Investigation into the volcanic aerosol dispersal : a better way to constrain the climatic impact of past eruptions

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Among the gas and solid particles during Plinian volcanic eruptions, large amount of sulphur (tens of teragrams) injected into the stratosphere has been observed. Over a few weeks in the stratosphere, sulphur gas is chemically converted into sulphate aerosols. It has been shown that these aerosols may act on the Earth ?s radiative balance by scattering and backscattering the incoming solar flux leading to a surface cooling and by absorbing the infrared emission leading to a stratospheric warming. The global cooling, which occurs immediately after the volcanic eruption, represents the most significant and direct effect. In case of the 1991 Pinatubo volcanic eruption (30 Tg of sulphate aerosols), a global cooling of 0.3°C was detected one year following the eruption. Historical eruptions may also help to better understand the impact on climate. The presence of acidity peaks in ice cores from the Greenland and Antarctica ice sheets have enabled the reconstruction of successive eruptions (including the amounts of released sulphur into the stratosphere and the produced sulphate aerosols). To investigate the impact of volcanism on climate, the IPSLCM4 atmosphere-ocean coupled model has been forced with the optical thickness reconstructed by Amman et al (2003) and Gao et al (2008), which mimics the amount of sulfate aerosols in the stratosphere (Khodri and Fluteau, in prep). Comparisons between simulated climate models and various sets of observations have shown some disagreements, suggesting that the optical depth prescribed in the experiment may be biased. We have investigated the effects of the location, timing and height of the gas injection on the dispersal of sulphate aerosols using the LMDzINCA climate model. It will provide more robust simulations of the climate changes caused by volcanic eruptions during the last millenium, Quaternary period (Toba, 73 ka) and the emplacement of large igneous provinces.

Niemeier, Ulrike

Impact of Geoengineering on global Climate - Earth System Model Simulations within IMPLICC

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In recent years, several methods have been suggested for “geoengineering” the climate to limit global temperature increase. One of these assumed geoengineering techniques tries to reduce the incoming solar radiation through space-born reflectors at the Lagrangian point, a second tries to reduce global warming via the emission of SO2 into the stratosphere. Using an earth system model (MPI-ESM), that consists of the GCM ECHAM6 coupled to the ocean model MPIOM, simulations have been performed to balance an increase of CO2 and other greenhouse gases assumed in different CMIP5 scenarios. The simulations were performed within the EU project IMPLICC and follow the suggestions of the GeoMIP initiative. We will present results of different geoengineering assumptions to balancing a GHG increase: SO2 injections, reduction of solar constant, sea salt emissions into stratocumulus clouds and compare the impact on the climate. First results show a slight global decrease of precipitation compared to year 2020 conditions. Regional differences vary between the different geoengineering techniques. SO2 concentrations, necessary to balance a CO2 increase, have been estimated using results of injection studies with a detailed aerosol micro-physical model. Results depend strongly on the emission strategy Niemeier et al, ASL, 2011). A short overview will be given.

Nyeki, Stephan

Aerosol Optical Depth Measurements of the Eyjafjalla Volcanic Plume over Ireland

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Aerosol Optical Depth Measurements of the Eyjafjallajökull Volcanic Plume over Ireland Long-term measurements of ground-based aerosol optical depth (AOD) serve as an important validation of satellite-based and modeling studies of AOD. On the other hand, short-term measurements can help to characterize transient events such as the recent Eyjafjallajökull volcanic eruption during April to May 2010 on Iceland. AOD has been routinely measured at Mace Head (MHD; 53.33°N, 9.89°W, 20 m) and Valentia Observatory (VTO; 51.93°N, 10.24°W, 24 m asl) using PFRs (Precision Filter Radiometers) since 2000 and 2007, respectively. Both sites belong to the WMO GAW-PFR (Global Atmosphere Watch) network (www.pmodwrc.ch/worcc) which currently numbers 27 baseline or regional stations around the world. In this study we examine several particularly strong volcanic plume events in April and May 2010 over Ireland, and compare short-term with long-term AOD values at MHD and VTO. O'Dowd et al. [2012] identified three main events at MHD using a suite of ground-based instruments and a ceilometer. The main events detected at ground-level were from 19 – 21 April, 3 – 5 May and 16 – 17 May. As PFR measurements are only available during sunny periods, only the first two events were observed. The daily AOD average (λ = 500 nm) was 0.531 (MHD) and 0.605 (VTO) on 21 April, and 0.264 (MHD) on 4 May. The Ångström exponent (α; λlog(AOD)/Δlogλ) is a measure of the relative size of atmospheric aerosols. Low values were observed at MHD (α = 0.50) and VTO (α = 0.28) on 21 April with a higher value at MHD (α = 1.19) on 4 May. This therefore implies that a higher fraction of coarse mode aerosols was present in the plume on 21 April. In addition to these events, elevated AOD was also observed from 8 – 10 and 22 – 25 May at both MHD and VTO, and suggests that volcanic plume layers did not mix into the boundary layer at either station. However, this would need to be further investigated as air-masses were not exclusively from the clean, western sector on 22 – 25 May, and may therefore have been influenced by anthropogenic pollution. A comparison of the long-term AOD data-set at MHD (2000 – 2010) with volcanic plume events on 21 April and 4 May was conducted. Average long-term April and May AOD values are 0.164 and 0.161, and are substantially lower than daily values of 0.531 and 0.264 reported above. Similar results were obtained for VTO. Further analysis is presently underway to examine how the volcanic plume compared to long-term AOD measurements at other GAW-PFR Scandinavian and central Europe stations. O'Dowd, C., et al. (2012), The Eyjafjallajökull ash plume - Part I: Physical, chemical and optical characteristics, Atmos. Environ. 48, 129 - 142, doi:10.1016/j.atmosenv.2011.07.004.

O'Hara, Mhairi E.

An Integrated Near-Real-Time Lava Flow Tool: Incorporating Satellite Data

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The ability to accurately forecast future events would be like finding the holy grail of volcanology. This would greatly aid the development of response efforts, and ultimately minimize lives lost and damage caused. In recent years, technological advances have revolutionized the way we monitor and model hazards. Remote sensing, GIS and the internet enables us to gather, process, and share data globally at unprecedented speeds. This research aims to utilise these resources to create a tool that can predict the path and maximum distance of a newly erupted terrestrial lava flow in near-real-time. With the use of the Hawaii Institute of Geophysics and Planetology (HIGP) online MODVOLC algorithm, which detects hotspots as they appear, the coordinates of a newly occurring lava flow eruption point can be automatically inserted into the model, initiating it to run. It will then calculate the route of lava flow, based on the path of steepest descent derived from a DEM. This stage of the model is fairly straight forward, as the lava flow path is a stochastic calculation controlled solely by its surrounding topography. This has been shown to be highly beneficial in lava flow modelling, as demonstrated by the DOWNFLOW model, as it requires minimal inputs and very short computational time (Favalli, 2005). The second stage of the model will calculate the maximum distance that the lava will flow, which is adapted from the kinematic thermo-rheological model FLOWGO. It takes into account the interactions between heat loss, core cooling, crystallization, rheology and the flow dynamics for lava flowing in a channel (Harris and Rowland, 2001). This part of the model runs more calculations, requiring many input parameters and as a result, has a much longer computational time. Fortunately many of the parameters can be entered as constant values for a given volcano based on field measurements. The effusion rate, however will be extracted through the analysis of thermal satellite data, as it is a major consideration in evaluating flow dynamics, making the accuracy and constant update of its measurement, vital to the estimation of maximum lava flow distance (Andrew et al, 2007; Pinkerton and Wilson, 1994). The aim of this research is not only to create a viable lava flow model, which has been achieved previously through the success of multiple models such as FLOWFRONT (Young and Wadge, 1990), SCIARA (Crisci, 2004), LavaSIM (Hidaka, 2005), and MAGFLOW (Negro et al., 2007). Rather the emphasis is placed on the integration of the underlying mechanisms demonstrated by the DOWNFLOW and FLOWGO model, coupled with satellite data. This model will predict the path and maximum distance of a lava flow,

as it extracts and inserts the eruption point and effusion rate, derived from thermal satellite imagery, which greatly contributes to the time considerations and accuracy of a hazard prediction tool. The precision of the model will be quantified against previous lava flow episodes at Eyjafjallajokull, Hekla and Krafla in Iceland.

Palmer, Martin R.

Impact of marine diagenesis of tephra on atmospheric CO2

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Studies of tephra diagenesis in the oceans derived from the 1991 Pinatubo eruption(1) and our work on the 2006 Montserrat eruptions(2) have shown that dissolved O2 in sediment pore waters is depleted to zero within a few mm of the sediment-water interface. Although the global significance of this process is small relative to the flux of dissolved O2 consumed by organic carbon oxidation today, there are periods in Earth history, however, when it may have led lowered atmospheric CO2 sufficiently to impact global climate. Oxidation of organic carbon in marine sediments is an important means by which CO2 sequestered by biological activity is returned to the ocean-atmosphere. The efficiency of organic carbon oxidation is highly dependent on its exposure time to dissolved O2. Hence, most organic carbon initially buried in sediments lying beneath well-oxygenated bottom water is oxidised(3). The intensity of O2 uptake by tephra is such, however, that a 5 cm layer of tephra on the sea floor permanently isolates organic carbon in the underlying sediments from dissolved O2, leading to increased burial efficiency of organic carbon and reducing the flux of CO2 back to the atmosphere. While the area of ocean floor covered by thick tephra is small in the modern ocean, even for Pinatubo-sized eruption, it is estimated that some super eruptions covered ~10% of the Earth's surface in a tephra layer of this thickness. Deposition of such a large area of tephra is not, however, sufficient to impact organic carbon preservation on its own. For example, despite suggestions that the Toba super eruption played a role in triggering descent into an ice age ~80 ka, it is now apparent that it had only a small impact on climate. It may be significant, however, that much of the Toba tephra was deposited in the deep, well-oxygenated waters of the Indian Ocean. Hence, enhanced preservation of the low concentrations of organic carbon in these sediments would have minimal impact on atmospheric CO2 levels. In contrast, tephra from the Late Ordovician super eruptions was largely deposited in shallow equatorial seas, at a time when the oceans had lower dissolved O2 concentrations than today. Under these conditions the potential for enhanced organic carbon preservation, and lowering of atmospheric CO2 was much greater. It may be significant, therefore, that the Late Ordovician is marked by several positive carbon isotope excursions, marking enhanced organic carbon burial, and culminated in the intense Hirnantian glaciation(4). We will discuss our studies of diagenesis of Montserrat tephra in the Caribbean and how these results can be extrapolated to examine the impact of large explosive eruptions in the past. 1. Haeckel M et al. 2001. The impact of the 1991 Mount Pinatubo tephra fallout on the geochemical environment of the deep sea sediments in the South China Sea. Earth Planet. Sci. Lett. 193, 151-166. 2. Hembury DJ et al. 2012. Uptake of dissolved oxygen during marine diagenesis of fresh volcanic material. Geochim. Cosmochim. Acta doi: 10.1016/j.gca.2012.01.017. 3. Hartnett HE et al. 1998. Influence of oxygen exposure time on organic carbon preservation in continental margin sediments. Nature 391, 572-574. 4. Sheehan PM 2001. The Late Ordovician extinction. Annu. Rev. Earth Planet. Sci. 29, 331-364.

Peters, Daniel M.

Optical properties of volcanic ash

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The recent eruption of Eyjafjallajökull volcano has emphasized the importance measuring volcanic ash clouds remotely. Current methods of detection use wavelengths from the UV to infra-red both actively (lidar) and passively (radiometers and spectrometers) on both ground and satellite platforms. Underpinning these remote measurements is the requirement to know the optical properties of the ash. As ash composition varies from eruption to eruption the refractive index also differs; our aim is to derive the refractive index of a range of ashes including Eyjafjallajökull. The refractive index data are required and will underpin remote measurements and further work. This poster shows our latest findings.

Pieri, David C.

Airborne Ash Hazards: In Situ Calibration and Validation of Remotely Sensed Data and Models

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Current remote sensing retrieval and transport modeling efforts to detect, characterize, and track airborne volcanic emissions suffer from very sparse in situ validation data. This has been a chronic and pervasive problem, long identified in scientific forums, and highlighted by the need for operational estimates of airborne ash concentrations throughout Europe as a consequence of the 2010 eruption at Ejyafjallajokull. In response to that urgent need, heroic ad hoc attempts were mounted in Europe to conduct airborne in situ observations with manned aircraft to validate ash concentration estimates based on remote sensing data and transport models, and to provide crucial accuracy and precision estimates for predictions of locations, trajectories, and concentrations of the drifting ash, which caused significant negative economic and air safety impacts throughout Europe and worldwide. Nevertheless, in the aftermath of the Icelandic crisis, ash and gas concentrations from analysis of satellite remote sensing data remain systematically unvalidated by in situ data. Of special concern with respect to aircraft operations are the validity of estimates of the lateral and vertical extent, concentrations, and spatio-temporal variability of drifting volcanic ash clouds provided by aerosol transport models and remote sensing techniques. In the past, such insufficiencies have centrally contributed to inadvertent aircraft encounters with ash plumes (e.g., the 1989 eruption of Redoubt Volcano, Alaska—near-fatal Boeing 747 ash encounter; the 2000 eruption of Hekla Volcano, Iceland—NASA McDonnell-Douglas DC8, encounter, severe damage to all four turbine engines). The current paucity of syn-eruption in situ data persists because of the obvious extreme difficulty of deploying and recovering samples and physical/chemical data over remote regions and at altitudes where such clouds occur, especially given the demonstrated danger to manned aircraft that such ash concentrations generally present. The issue is compounded by the comparable lack of publicly available, peer-reviewed and validated data on acceptable ash exposure thresholds within aircraft engines, although there are attempts afoot to ameliorate that situation. On the bright side, if and when resources can be brought to bear, there exist a variety of novel technological approaches for conducting in situ validation experiments, particularly the use of specially designed unmanned aircraft to range through ash clouds, and the deployment of instrumented tethered aerostats up into such clouds, in coordination with multispectral satellite, airborne, and ground-based observations. Shared access to comprehensive aircraft engine information should be encouraged, as well. A brief review of related scientific issues and state-of-the-practices will be presented, as well as the prospects for future improvement. This work was carried out in part at the Jet Propulsion Laboratory of the California Institute of Technology under contract to NASA.

Platt, Ulrich

Spectroscopic Observation of Volcanic Emissions – Results and Future Trends

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In recent years spectroscopic quantification of gas emissions from volcanoes made considerable progress. In particular spectroscopic approaches observing volcanic gases in the ultra-violet spectral range evolved from an art to mature techniques, which are routinely applicable on a campaign basis as well as in fully automated installations. Using spatio-temporal correlation techniques also absolute amouts of trace gas fluxes can be determined. This is e.g. demonstrated by the NOVAC network. At the same time systems operating in the infra-red (IR) spectral range also made enormous progress. Here two varieties are in use: Absorption spectroscopy using direct sunlight and emission spectroscopy using thermal emission from the trace constituents to be studied. Although neither of the two IR varieties is yet applicable in automated routine observation these techniques have considerable potential as well. For instance thermal emission spectroscopy would also allow observations at night. Moreover, novel techniques for remote sensing of volcanic emissions, the SO2-Camera and imaging-DOAS (I-DOAS), where the I-DOAS technique trace gas distributions using the DOAS principle, came into widespread use recently. In particular the SO2 camera allows real time observation of the 2-dimensional evolution of volcanic plumes. Here we present a brief technical description, as well as a critical assessment of the above techniques and discuss the relative merits of the different approaches for quantifying volcanic emissions by giving examples of successful applications for SO2-flux measurements and BrO/SO2 ratios at Etna, Colima, and other volcanoes. Also expected future developments and requirements for volcanic monitoring and surveillance, in particular with respect to CO2-flux measurements are discussed.

http://www.iup.uni-heidelberg.de/en/

Praetorius, Summer

Deglacial volcanism in the Gulf of Alaska: implications for timing and forcing of North Pacific climate transitions

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Deglaciation may promote volcanic activity through decompression-melting related to glacial unloading. Ice core records and global compilations of volcanic data have revealed enhanced frequency of volcanic eruptions (2-6x modern levels) during the last deglacial transition in mid-to-high latitudes, providing support for this hypothesis. The regional and global response to this volcanic forcing is poorly constrained. This is in part due to the short-term nature of these events, the fairly localized fallout of macrotephras and the difficulty in obtaining high-resolution records that can capture short-term climate variability. Marine sediment records from the Gulf of Alaska (GOA) have exceptionally high resolution (~0.2 – 1 cm/yr) and span the last deglacial transition (18 – 10 ka), allowing for detailed climatic reconstructions in addition to a number of well-defined ash layers. Volcanic ash layers are absent in the marine sequence during the Late Glacial period, but become abundant within the Bolling-Allerod (BA) warm period, consistent with the hypothesis that regional deglaciation can lead to enhanced volcanic activity. The largest fluctuations in the foramaniferal oxygen isotope record within the BA interval occur just after the deposition of ash layers, which suggests local cooling and/or shifts in oceanic conditions as a response to volcanic eruptions. Ash layers are also associated with shifts in faunal assemblages and abundance, indicating that volcanic fallout could have potential effects on marine productivity, especially given that the GOA is an iron-limited HNLC region. Microprobe analysis of select ash layers is currently underway to allow correlation to land-based tephra sequences. This will ideally allow for more precise constraints on the timing of major climatic transitions in the North Pacific relative to other regions, and provide independent estimates of the marine radiocarbon reservoir effect.

Prata, Fred

Global, long-term volcanic SO_2 measurements from satellites and the significance to climate

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There is increasing interest in the gaseous composition of the atmosphere, especially with the recognition that changes are occurring more rapidly than expected and through both anthropogenic and natural causes. Sulphur dioxide (SO2) has both natural and man-made sources, has a significant effect on the radiative forcing of the atmosphere and significant vertical structure. In recent years several satellite instruments have demonstrated that the total column of SO2 can be measured well and it has been shown that some limited vertical information can be obtained due to the sensitivity of the kernel functions. Retrievals of total or partial column SO2 can be made using infrared (IR), ultra-violet (UV) and microwave satellite instruments and here we concentrate on the IR and UV measurements. In the UV, TOMS, SCIAMACHY, GOME, OMI, GOME-2 and OMPS provide global information on SO2 at differing spatial and time-scales dating back to 1979. In the IR, HIRS, MODIS, AIRS, SEVIRI, GOES and IASI provide similar information, also going back to 1979. Many of these sensors can only detect SO2 above a certain threshold and the IR sensors mostly detect SO2 in the upper-troposphere/lower stratosphere. The UV sensors have better sensitivity to emissions closer to the surface and are able to measure passively degassing volcanic emissions as well as emissions from anthropogenic sources. Thus they are well-suited to assessing the contributions of SO2 from both strong and weak volcanic eruptions. Combing the IR with the UV measurements offers the possibility to explore the vertical structure of SO2 emissions and potentially separate out natural form anthropogenic emissions in the upper troposphere. By utilizing the more accurate modern satellite instruments, such as IASI, AIRS, GOME-2 and OMI to post-calibrate older measurements (e.g. from TOMS and HIRS) a long time series of volcanic SO2 emissions, dating from 1979 is being developed. The data-set has the potential to offer an improved climatology of volcanic SO2 emissions to the UTLS and will allow models to better constrain the effects of SO2 on the radiative balance and hence on climate. The data set will be described, along with the processing chain, assumptions, limitations and error characteristics and possible applications of the data. These data may be considered as a global climatology of volcanic SO2 emissions and they data could be used as an SO2 inventory for climate models or as validation data for hindcast and model sensitivity experiments.

http://web.me.com/fredprata/FredPrata/Homepage.html

Prata, Fred

The Ash Spring: How an Icelandic Volcanic Eruption Brought Europe to a Standstill

Prata, Fred[1]

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In the spring of 2010 a little known volcano in southern Iceland alerted the world to the aviation hazard of volcanic ash. This was not some impending climate catastrophe nor an immediate threat to human health, but a clash of one of the most powerful and ancient forces of nature with one of mankind's greatest technological achievements, the jet aircraft transport system. The chaos, reaction and effects related to the spread of the Eyjafjallajökull ash clouds over continental Europe have been widely discussed in the media and in learned journals. Ironically, the International Civil Aviation Organisation (ICAO) had been making great progress on the problem of ash and aviation for many years by convening regular meetings between the science community, aviation stakeholders and regulators. Major agencies, including the UK Civil Aviation Authority (CAA), the European Aviation Safety Agency (EASA), ICAO and the World Meteorological Organisation (WMO) have been galvanised into setting new policies and procedures for jet aircraft flights into ash affected airspace, while science has been challenged to improve both quantitative forecasting of volcanic ash concentrations and enhance observation networks. The Norwegian Institute for Air Research (NILU) is leading a major European Space Agency (ESA) project– "Support to Aviation for Ash Avoidance" (SAVAA) and its successor, the Volcanic Ash Strategic-initiative Team (VAST) project, involving European volcanologists, satellite remote sensing and dispersion modelling experts. The SAVAA team developed the world's first inversion scheme for improving the forecasting of volcanic ash. Here I will describe the background and progress in forecasting the atmospheric dispersion of volcanic ash, by utilising space-based assets and I will show how improvements in forecasting accuracy can be enhanced through improved quantification of the time-dependent eruption source term. The inversion scheme was not available at operational centres at the time of the Eyjafjallajökull eruption and the lack of reliable observational data led to a very cautious response to the event, and a complete shutdown of air transport systems across Europe for several days. The Eyjafjallajökull, Grímsvötn, and to a certain extent, the long-lived and ash-rich Puyehue Cordón-Caulle eruptions during the past two years have now provided researchers with a wealth of new data on the behaviour and fate of volcanic ash in the atmosphere. For the first time it has been possible to independently validate satellite retrievals of volcanic ash. Examples will be given from past eruptions including Galunggung, Eyjafjallajökull, Grímsvötn and Puyehue Cordón-Caulle . These new results suggest that dispersed ash plumes can be highly inhomogeneous, exist in thin layers of ~500–2000 m thickness and undergo transport over 1000's km, staying aloft for days to weeks. The infrared sensors on operational, geosynchronous and polar orbiting satellites can measure ash mass loadings as low as 0.2 g m-2 with rms accuries of ±0.15 g m-2 and hence when combined with inversion schemes give dispersion models the opportunity to meet regulatory requirements and the demands of the aviation industry.

Rampino, Michael R.

The 1963 Eruption of Mt. Agung, Bali, Indonesia: A Climatically Significant Eruption

Rampino, Michael R.[1]; Self, Stephen[1]

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The February 1963 to January 1964 eruption of Gunung Agung, Indonesia's largest and most devastating eruption of the 20th Century, was a multi-phase explosive and effusive event that produced both basaltic andesite tephra and andesite lava. . The eruption is notable as it had a considerable affect on atmospheric opacity, especially in the Southern Hemisphere, and was followed by a brief global cooling of a few tenths of a degree C . A rather unusual eruption sequence with an early lava flow followed by two explosive phases, and the presence of two related but distinctly different magma types, is best explained by successive magma injections and mixing in the conduit or high-level magma chamber. The 7.5-km-long blocky-surfaced andesite lava flow of ~ 0.1 km3 volume was emplaced in the first 26 days of activity beginning on 19 February. On 17 March 1963 a major moderate-intensity (~ 5 x 107 kg/s) explosive phase occurred with a ~ 3.5—hour-long explosive climax producing an eruption column that reached heights of 19-23 km above sea level and deposited a fall unit with Plinian dispersal characteristics. This phase created a scoria-lapilli to fine-ash-fall deposit up to ~ 0.2 km3 (DRE) in volume, and small but devastating scoria and ash-flow deposits. On 16 May a second intense explosive phase occurred, with a 4-hour-long event producing an ~ 25-km high eruption column and depositing up to ~ 0.1 km3 (DRE) volume of similar ash-fall and flow deposits, the latter of which were more widespread than in the March phase. Two magma types were erupted, porphyritic basaltic andesite and andesite, which are found as distinct juvenile scoria populations. This indicates magma mixing prior to the onset of the 1963 eruption, and successive pulses of the more mafic magma may have modulated the pulsating style of the eruption sequence and added S-rich volatiles. Even though a total of only ~ 0.4 km3 (DRE volume) of lava, ash fall, and scoria-and-ash pyroclastic flow deposits were produced by the 1963 eruption, the eruption column reached the stratosphere, and much local damage was caused, mainly by a combination of pyroclastic flows and lahars that formed from the flow deposits in the saturated drainages around Agung. Minor explosive activity and lahar generation by rainfall persisted into early 1964

Robock, Alan

Volcanic Eruptions as an Analog for Geoengineering (*Invited*)

Robock, Alan[1]

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In response to the global warming problem, there has been a recent renewed interest in geoengineering "solutions" involving "solar radiation management" by injecting particles into the stratosphere, brightening clouds or the surface, or blocking sunlight with satellites between the Sun and Earth. This talk addresses stratospheric geoengineering, the topic that has produced the most discussion. While volcanic eruptions have been suggested as innocuous examples of stratospheric aerosols cooling the planet, the volcano analog also argues against geoengineering because of ozone depletion, regional hydrologic responses, and other negative consequences. I will show climate model calculations that evaluate stratospheric geoengineering, and then give volcanic examples that can inform us about their validity. Volcanic eruptions are an imperfect analog, since solar radiation management proposals involve the production of a permanent stratospheric aerosol layer, while volcanic layers are episodic. Nonetheless, we can learn much from the volcanic example about the microphysics of stratospheric sulfate aerosol particles; changes in atmospheric circulation, producing regional climate responses, such as changes to the summer monsoon; atmospheric chemistry; changes of the partitioning of direct and diffuse insolation; effects on satellite remote sensing and terrestrial-based astronomy; and impacts on the carbon cycle. By the way, I now have 26 reasons why geoengineering may be a bad idea, and nine reasons why it might be a good idea. Much more research is needed before we can quantify each of these, so that policymakers in the future can make informed decisions about whether to ever implement stratospheric geoengineering. Given what we know today, global efforts to reduce anthropogenic emissions and to adapt to climate change are a much better way to address anthropogenic global warming.

Rocha Lima, Adriana

Optical, Microphysical and Compositional Properties of the Volcano Eyjafjallajökull (Iceland)

Rocha Lima, Adriana[1]; Martins, J. Vanderlei[1, 2]; Krotkov, Nickolay[2]; Schumann, Ulrich[4]; Tabacniks, Manfredo[3]; Artaxo, Paulo[3]

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Volcanoes are one of the most important sources of aerosols in the atmosphere and the chemical and physical properties of these particles are of fundamental importance for better understanding of Earth's climate and weather patterns. One of the main parameters missing in current aerosol models is the complex refractive index of aerosol particles from the UV to the short wave infrared (SWIR) wavelengths. The main objective of this research was to perform a detailed characterization of important optical, microphysical and compositional properties of aerosol particles from the Eyjafjallajökull volcano. Ash from this volcano was collected in the vicinity of the eruption and brought to our laboratory. Particles from the ash were initially sieved to retain particles smaller than 45 um, and were de-agglomerated, re-suspended and carried out by a flow of air through the use of a Fluidized Bed Aerosol Generator (FBAG). This experimental setup allows us to separate particles into PM10, PM2.5, or PM1.0. Particles were collected on Nuclepore filters and analyzed by different techniques, such as Scanning Electron Microscopy (SEM) for determination of size distribution and shape, spectral reflectance for determination of the optical absorption properties as a function of the wavelength, mass concentration, material density, Proton Induced X-ray Emission (PIXE), and X-Ray fluorescence for the elemental composition. The spectral imaginary part of refractive index (from 300 to 2500nm) was derived empirically from the measurements of the mass absorption coefficient, size distribution and density of the material. A new method to measure aerosol density has also been implemented and was applied to our samples. The SEM images show very asymmetrical PM10 particles requiring the combination of multiple viewing angles for the determination of the geometrical volume, cross-section and consequently the material density. The volcano Eyjafjallajökull shows strong absorption and consequently high imaginary refractive index for UV and visible wavelengths. The observed density of the material is lower than what is expected from compositional predictions.

Rolf, Christian

Lidar Observation and Model Simulation of an Volcanic Ash Induced Cirrus Cloud During Eyjafjalla Eruption

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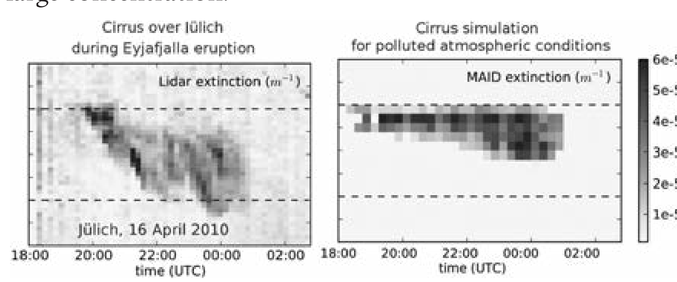
The Eyjafjalla volcano in Iceland eject a large ash cloud during its eruptions in April 2010. The cloud spread out over central Europe in a period of 6 days and disrupt air traffic. A two days after the first large eruption on April 16, we detect the ash cloud with a backscatter lidar system over western Germany, Juelich (50° 54' north, 6° 24' east).The lidar (short for light detection and ranging) measures optical properties (i.e. backscatter and extinction coefficient) and depolarization of particles at a wavelength of 355 nm in a high vertical resolution of around 30 m. In the depolarization channel it is possible to distinguish various shapes of observed particles. Cirrus clouds or ash particles mostly create a large signal in the depolarization because of their non spherical shape. While spherical particles creates a depolarization close to zero. The ability of heterogeneous deposition ice formation induced by volcanic ash from the Eyjafjalla volcano eruption in April 2010 is investigated. In particular these impact on cloud formation is not completely understood and atmospheric measurements are very rarely. We investigate one of the observed cirrus cloud embedded in a volcanic ash layer in detailed. First the origin of the observed airmass is assigned by calculating ECMWF (European Center for Medium rangeWeather Forecast) backward trajectories. With our detailed microphysical box model MAID (Bunz et al., 2008), we simulate the ice formation along these trajectories. Thus it is possible to discriminate observation from pure volcanic ash, natural cirrus, and induced cirrus cloud. By using a cirrus cloud observation with a backscatter lidar over Juelich western Germany and a backward trajectory based ice formation model, it is possible to reproduce the observation of an ash induced cirrus cloud (see figure 1). The microphysical properties and optical properties of this cirrus cloud could investigated through this combination of lidar observation and model simulation. A strong influence of ash particles on ice formation by acting as very efficient ice nuclei is found. Ice formation could occur in an environment only view percent supersaturated wrt ice with small ice particles in a large concentration.



Saha, Auromeet

Properties of Sarychev sulphate aerosols over the Arctic

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Aerosols from the Sarychev Peak volcano entered the Arctic region less than a week after the strongest SO2 eruption on June 15 and 16, 2009 and had, by the first week in July, spread out over the entire Arctic region. These predominantly stratospheric aerosols were determined to be sub-micron in size and inferred to be composed of sulphates produced from the condensation of SO2 gases emitted during the eruption. Average (500 nm) Sarychev-induced stratospheric optical depths over the Polar Environmental Atmospheric Research Laboratory (PEARL) at Eureka (Nunavut, Canada) were found to be between 0.03 and 0.05 during the months of July and August, 2009. This estimate, derived from sunphotometry and integrated lidar backscatter profiles was consistent with averages derived from lidar estimates over Ny-Ålesund (Spitsbergen). The Sarychev SOD e-folding time at Eureka, deduced from lidar profiles, was found to be approximately 4 months relative to a regression start date of July 27. These profiles initially revealed the presence of multiple Sarychev plumes between the tropopause and about 17 km altitude. After about two months, the complex vertical plume structures had collapsed into fewer, more homogeneous plumes located near the tropopause. It was found that the noisy character of daytime backscatter returns induced an artifactual minimum in the temporal, pan-Arctic, CALIOP SOD response to Sarychev sulphates. A depolarization ratio discrimination criterion was used to separate the CALIOP stratospheric layer class into a low depolarization subclass which was more representative of Sarychev sulphates. Post-SAT (post Sarychev Arrival Time) retrievals of the fine mode effective radius (reff,f) and the logarithmic standard deviation for two Eureka sites and Thule, Greenland were all close to 0.25 um and 1.6 respectively. The stratospheric analogue to the columnar reff,f average was estimated to be reff,f(+) = 0.29 um for Eureka data. Stratospheric, Raman lidar retrievals at Ny-Ålesund, yielded a post-SAT average of reff,f(+) = 0.27 um. These results are ~ 50% larger than the background stratospheric-aerosol value. They are also about a factor of two larger than modeling values used in recent publications or about a factor of five larger in terms of (per particle) backscatter cross section.

Saha, Auromeet

Multi-year investigation of stratospheric optical depths over the Arctic

Saha, Auromeet[1]; O'Neill, Norman T.[1]; Lesins, Glen[2]; Duck, Thomas J.[2]

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2. Dalhousie University, Halifax, NS, Canada

An investigation of stratospheric optical depths over a multi-year year period was carried out with the objective of investigating volcanic intrusions and Polar stratospheric clouds (PSCs) in the Arctic. Pan-Arctic "stratospheric-layer" events in CALIOP data were classified into low and high depolarization optical depth and these results were analyzed within the context of known volcanic and PSC events (specifically the Kasatochi, Alaska and Sarychev, Russia volcanos in 2008 and 2009 respectively and all years for PSCs with a focus on the ozone depletion winter of 2010/2011). Preliminary results showing significant stratospheric optical depth increases in the summer and winter of 2009/2010 and the winter of 2010/2011 will be presented.

Schäuble, Dominik

First in situ measurements of Cl_2 in the plume of degassing volcano Mt. Etna

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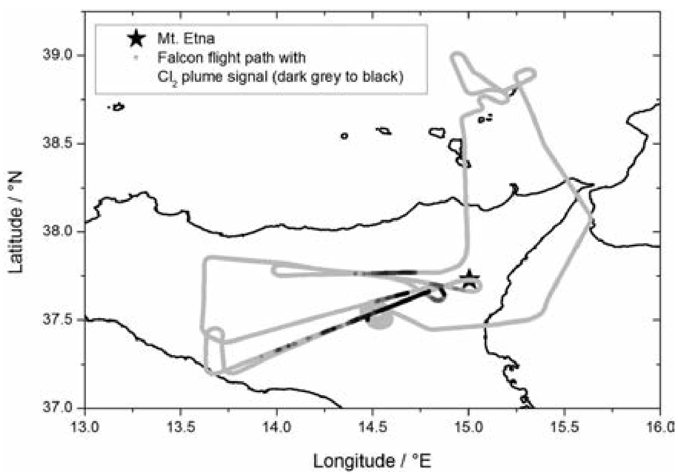
Degassing volcanoes are strong local sources of tropospheric halogens including chlorine species. Besides large amounts of relatively stable HCl, photochemically active compounds like Cl_2 and HOCl may be directly emitted by volcanoes or produced by homogeneous and heterogeneous reactions inside volcanic plumes. These species are rapidly photolyzed generating chlorine atoms which participate in tropospheric ozone chemistry: Cl may oxidize volatile organic compounds (VOCs) like methane leading to ozone production. At the same time Cl may catalytically destroy ozone depending on the concentrations of active nitrogen (NO_x) and hydrogen oxides (HO_x). Here we present first measurements of gaseous Cl_2 inside a plume of a degassing volcano. On 29 and 30 September 2011 during the CONCERT2011 campaign, we sampled the plume of degassing volcano Mt. Etna (Sicily) with the research aircraft DLR-Falcon equipped with a variety of in situ instruments for detection of trace gases and aerosol particles. The plume was probed at plume ages up to 8 hours at altitudes of 3000 to 3700 m in the free troposphere. Measurements of gaseous Cl_2 were performed with the chemical ionization mass spectrometer AIMS using I^- reagent ions. HCl, HNO_3, and SO_2 were detected with a second identical mass spectrometer using SF_5^- reagent ions. In addition, meteorological

parameters, NO, NO_y, CO, and particle size distributions were observed onboard the Falcon. Inside the volcanic plume the Cl_2 signal was enhanced by factors of up to 200 compared to the atmospheric background. Potential sources and sinks of photochemically active chlorine are investigated in terms of the evolution of Cl_2 to HCl and Cl_2 to SO_2 ratios as a function of plume age and aerosol particle density. Our measurements provide a base for the validation of volcanic plume chemistry models and input for photochemical models simulating tropospheric ozone chemistry. Open questions that might be addressed are: Can Cl from photolysis of active chlorine species compensate for the OH depletion in volcanic plumes (mainly caused by reaction with SO_2) with respect to the oxidation of methane? Might methane oxidation even be enhanced in regions influenced by emissions of degassing volcanoes? Our observations may stimulate laboratory studies of heterogeneous reaction rates of chlorine species on sulfuric acid-water-droplets and coated volcanic ash particles at lower tropospheric conditions.



Schmidt, Anja

Importance of Tropospheric Volcanic Aerosol in Assessments of the Aerosol Indirect Forcing of Climate

Schmidt, Anja[1]; Carslaw, Kenneth S.[1]; Rap, Alexandru[1]; Mann, Graham W.[1, 2]; Spracklen, Dominick V.[1]; Pringle, Kirsty J.[1]

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2. National Centre of Atmospheric Science, University of Leeds, Leeds, United Kingdom

Volcanic eruptions have a significant potential to impact the Earth's radiation budget, the environment and human health [e.g., 1, 2, 3]. The atmospheric and climatic effects of volcanic aerosol released into the troposphere by continuously degassing and sporadically erupting volcanoes has only recently become of greater interest. Oppenheimer et al. [4] stress that "changes in time and space in this 'background' emission could represent an important forcing factor that has yet to be characterized." We used the volcanic emission inventory by Andres & Kasgnoc [5] in a global aerosol microphysics model (GLOMAP-mode) to investigate the role of tropospheric volcanic aerosol in assessments of the aerosol indirect forcing of climate. We found that under pre-industrial (PI) atmospheric conditions, volcanic degassing induces a global annual mean cloud albedo effect of -1.06 Wm-2 (uncertainty range between -0.78 Wm-2 and -1.56 Wm-2 based on a plausible halving and doubling of the inventory), and of -0.56 Wm-2 (uncertainty range between -0.36 Wm-2 and -0.84 Wm-2) under present-day (PD) conditions. Using the inventory as-is and assuming no change in the volcanic sulphur flux between PI and PD, we calculate a global annual mean cloud albedo forcing due to anthropogenic aerosol of -1.08 Wm-2 which is well within the range of the equivalent IPCC estimate [6]. By doubling and halving the inventory, we calculate an uncertainty range of -0.86 Wm-2 to -1.16 Wm-2 with the uncertainty solely arising from our incomplete knowledge of the magnitude of the volcanic sulphur flux. We note that the magnitude of the total cloud albedo forcing (i.e. volcanic plus anthropogenic) could lie between -0.38 Wm-2 and -1.64 Wm-2 if we assume the volcanic sulphur source strength between PI and PD changed within its plausible upper and lower limits. Therefore, the uncertainties in the strength of volcanic degassing over time play an important role in assessments of the present-day cloud albedo forcing, and are likely to have played an important role in other periods of Earth's history.

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Schmidt, Anja

Future Icelandic flood lava eruptions: are our atmospheric models fit for purpose?

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The 1783–1784 AD Icelandic Laki eruption is the prime and best documented example of a long-lasting flood lava event which, over the course of eight months, injected around 122 Tg of sulphur dioxide into the upper troposphere and lower stratosphere (Thordarson and Self, 2003). In our previous work we used a global aerosol microphysics model (GLOMAP) together with concentration-response functions to predict the impact of a modern-day equivalent of Laki on European air quality and the health of the population (Schmidt et al., 2011) . Since the eruptions of Eyjafjallajökull in 2010 and Grimsvötn in 2011, the United Kingdom has debated whether to include Icelandic volcanic eruptions such as Laki in its National Risk Register - in the same manner as is done for floods and heatwaves. Hence, there is now an increasing interest in assessing not only the volcanically-induced pollutant levels in the form of sulphur dioxide and sulphate aerosol at the ground but also at commercial flight altitude. We will show results from our probabilistic assessment of Icelandic flood lava events using both a Lagrangian dispersion model (NAME) that is used operationally by the UK Met Office and a more complex Eulerian model (GLOMAP) that is used mainly for research purposes. We investigate and compare what sulphur dioxide and sulphate aerosol concentrations these models predict at the ground and at commerical flight altitudes. We will also assess whether these models are fit for purpose in being able to predict the evolution of the volcanic pollutants under the extreme conditions following a large flood lava eruption. We also suggest ways in which operational forecasting tools could be improved to be able to predict the impact of a long-lasting, sulphur-dominated Icelandic eruption on aviation. References: SCHMIDT, A., OSTRO, B., CARSLAW, K. S., WILSON, M., THORDARSON, T., MANN, G. W. & SIMMONS, A. J. 2011. Excess mortality in Europe following a future Laki-style Icelandic eruption. Proceedings of the National Academy of Sciences, 108, 38, 15710-15715. THORDARSON, T. & SELF, S. 2003. Atmospheric and environmental effects of the 1783-1784 Laki eruption: A review and reassessment. J. Geophys. Res.-Atmospheres, 108(D1), 4011.

Schopka, Herdis H.

Atmospheric Carbon Consumption by Chemical Weathering of Basalt in the Tropics: The Hawaiian Example

Schopka, Herdis H.[1, 2]

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Volcanic provinces are key components of the global carbon cycle. Chemical weathering of Ca- and Mg-rich volcanic rocks sequesters atmospheric CO2 into long-term geologic storage. Chemical weathering rates and carbon consumption fluxes from volcanic regions are among the highest yet recorded from any environment on Earth (Dessert et al. 2003. In this study I quantify fluxes of atmospheric CO2 by chemical weathering on the tropical volcanic islands of Hawai'i. The island of Hawai'i is the youngest island in the archipelago (0-350 kyr). It is little eroded and largely retains the constructive morphology of its constituent shield volcanoes. Kaua'i is the oldest of the Hawaiian islands (4.5 Myr). Its original shield surface topography has been heavily modified by landsliding, fluvial erosion and tectonics. These two islands were chosen as study sites for representing the extremes in age and landscape development in the Hawaiian archipelago. The results show no statistically significant differences in area normalized chemical weathering fluxes from streams in different regions on the island of Hawai'i as compared to each other and to Kaua'i. The only exceptions are fluxes of Ca+Mg, which are significantly elevated in the Hamakua-Hilo region on the island of Hawai'I compared to the Kohala peninsula on the island of Hawai'i, and to Kaua'i. These results imply that bedrock age is not a primary control on surface chemical weathering fluxes. Carbon consumption by surface chemical weathering in Hawai'i is low to average compared to the global average in basaltic settings and identical to or slightly higher than the values reported by Dessert et al. (2003). Upon inclusion of chemical weathering fluxes delivered by submarine groundwater discharge, this picture changes substantially. Considering the island of Hawai'i as a whole, I find that chemical weathering fluxes via submarine groundwater discharge are at least an order of magnitude larger than those from chemical weathering occurring on the Earth's surface. The ratio of groundwater chemical fluxes to surface chemical fluxes decreases as landscapes age: minimal incision is sufficient to lower the ratio of subsurface to surface weathering fluxes down to ~1-1.5, and in the heavily incised landscapes of Kaua'i the ratio has decreased to ~0.5. These results highlight the importance of groundwater as a pathway for chemical fluxes from volcanic islands to the ocean. This work has implications for, e.g., studies of the short- and long-term climatic impact of large igneous provinces such as the Siberian and the Deccan Traps. Dessert, C., B. Dupre, J. Gaillardet, L. M. Francois, and C. J. Allegre (2003), Basalt weathering laws and the impact of basalt weathering on the global carbon cycle, Chem. Geol., 202, 257-273.

Scollo, Simona

LIDAR SCANNING NEARBY ETNA SUMMIT

Scollo, Simona[1]; Boselli, Antonella[3]; Coltelli, Mauro[1]; Leto, Giuseppe[4]; Pica, Giulia[6]; Pisani, Gianluca[2]; Spinelli, Nicola[2]; Wang, Xuan[5]

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On 15 November 2010, a first test using a small-portable LIDAR system was performed at Mt. Etna, Italy, with the aim to retrieve volcanic plumes erupted during an ash emission event. The LIDAR system is mounted on a bi-axial motorized fork and may be moved in azimuth and elevation with the possibility to scan the volcanic plume either horizontally and/or vertically at a maximum speed of 0.1 rad/sec. The laser beam was directed toward the Etna summit craters in order to evaluate the spatial distribution of volcanic ash above the eruptive vents. During the measurements, ash emission from the North East Crater and high degassing from the Bocca Nuova Crater were well visible. Through the LIDAR measurements we were able to evaluate: i) volcanological features of the eruptive event, and ii) the region affected by the volcanic plume presence. Backscattering and depolarization measurements showed that the Bocca Nuova Crater ejected non depolarizing particles while depolarization values up to 45% were retrieved in the volcanic plume from the North East Crater. We also calculated the volcanic ash concentration in atmosphere and, using the ash thresholds defined by ICAO, evaluated the region which should be avoided by air traffic operations. The advantage of having a permanent LIDAR near an active volcano is hence shown.

Segschneider, Joachim

Impact of an extremely large magnitude volcanic eruption on the global climate and carbon cycle estimated from ensemble Earth System Model simulations

Segschneider, Joachim[1]; Beitsch, Alexander[1]; Timmreck, Claudia[1]

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The response of the global climate-carbon cycle system to an extremely large northern hemisphere mid latitude volcanic eruption is investigated using a comprehensive Earth System Model (MPI-ESM). The model includes dynamical compartments of the atmosphere and ocean and an interactive carbon cycle with modules of the terrestrial vegetation and soil as well as ocean biogeochemistry. This model was forced with anomalies of aerosol optical depth and effective radius of aerosol particles corresponding to a super eruption of the Yellowstone volcanic system. The forcing is obtained from a global stratospheric aerosol model including sulfur chemistry. An ensemble of fifteen model integrations is constructed by starting model runs from different ENSO states of a 2000 year control experiment and integrate them for a time span of 200 years after the eruption. The ensemble's range of maximum global monthly mean surface air temperature cooling is from 3 to 4 K. This cooling occurs during the first two years after the eruption. The maximum cooling over land is more than twice as strong as over the ocean. In response, atmospheric pCO2 decreases. This is a result of uptake and release processes in the ocean and on land. The ocean shows a pronounced uptake of carbon shortly after the eruption due to an increase in solubility. This uptake is weakly counteracted by a reduction of the biological export production mainly in the tropical Pacific. In addition, the spring phytoplankton bloom at high latitudes in both hemispheres, and in particular the Southern Ocean, is delayed by one month. This may have an impact on higher trophic levels. The long term behavior of the ocean is dictated by the land system, as the ocean compensates tends to compensates for anomalies in the atmosphere caused by fluxes between land and atmosphere. The land vegetation shows a distinct loss of carbon in the initial years after the eruption which is not present in smaller scale eruptions. The soil compartment determines the long term behavior of the overall system: an initial gain is followed by a very slow return towards pre-eruption levels, lasting for more than 150 years. In response, atmospheric pCO2 decreases by 5 to 6 ppm for individual ensemble members approximately 5 years after the eruption and only very slowly returns to near pre-eruption level at year 200 after the eruption.

Self, Stephen

Deciphering the Climatic Effects of Volcanic Aerosols: What Lies Ahead and Why Should We Care? (*Invited*)

Self, Stephen[2, 1]

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The twentieth century was perhaps unusually free of explosive eruptions that affected highly populated Northern Hemisphere regions, where ~ 90 % of global residents live, thus our informed historic perspective on aspects of widespread volcanic-aerosol-induced climatic changes is limited. Because future eruptions will occur that will generate dense aerosol clouds, it will serve society well if we understand the climatic impact of past eruptions. Which eruption type and size should be considered in this regard? What is the most severe climatic impact that we can expect from an eruption? Highly explosive eruptions up to VEI 6 [Krakatau-size (bigger than Pinatubo), with a mean frequency over the past millennium of ~ 2 per century, cause ash and aerosol clouds that affect global climate, weather, and possibly communications; aerosol-induced cooling is small (< 1 degree C). Perhaps VEI 7 explosive eruptions (bigger than Tambora 1815) should concern us more? They are under-reported in the record of past eruptions, with a > 10 % chance of one occurring in the next century. However, the radiative effects of aerosols derived from Tambora's ~ 60 Mt release of sulphur dioxide may have been limited by rapid aerosol droplet growth and sedimentation from the stratosphere; estimates of the hemispheric or global aerosol-induced cooling are quite small (1-2 degrees C). Basaltic fissure eruptions such as Laki 1783 can also cause long-lasting aerosol clouds (although this aspect has been recently challenged), with well-documented severe local, and possibly widespread, health effects. Some far-field health impacts ascribed to Laki's gas or aerosols may have other explanations, but recent models have suggested a high chance of severe respiratory effects in 1783-4. The > 100 Mt of sulphur dioxide released from Laki over several months may have caused an aggregate mass of ~ 200 Mt of aerosols, and climate model results support cooling due to aerosols, but the cold 1783-4 winter has been claimed to be within the range of climatic variability. In order to assess what lies in our future, further modelling is required to attempt to isolate the effects of volcanic stratospheric aerosols from the influences of other forcings that lead to climatic variability. This is especially important for the types and sizes of eruptions mentioned above, that have a high likelihood of happening in the next century. Our society should not be overly concerned about newsworthy but rare super-eruptions (> VEI 8); the probability of one occurring in the foreseeable future is negligible and expected climatic impacts may not be as severe or as past studies suggested. The magmas typically causing super-eruptions probably have low S contents. Positive effects of future eruptions include possible offset of global warming via radiatively effective stratospheric aerosols, and ash-fall onto oceans, which may help decrease atmospheric carbon dioxide.

Sheng, Jianxiong

Parametric Modelling Study of the Mt. Pinabuto Eruption

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The eruption of Mt. Pinatubo is the largest well documented volcanic eruption on record. However, the uncertainties in determining the initial total mass and altitude distribution of its emissions remain high. In this study, we perform atmospheric simulations of the Mt Pinatubo eruption using the AER 2-D sulfate aerosol model, which is among the stratospheric aerosol models with best performance in a recent international aerosol assessment (SPARC, 2006). The eruption is modelled assuming various magnitudes of SO2 injections, as well as different initial vertical and meriodional distributions. Our results suggest that an injection region extending vertically from the tropical tropopause to 25-27 km with a skewed distribution, largely corrects the previously found overestimation in modeled extinctions at high altitudes when comparing to satellite measurements, e.g. from SAGE II. This approach paves the way to define an optimal set of the emission parameters such that the resultant extinctions match satellite and lidar measurements also in the most heavily perturbed regions in which occultation measurements are unavailable due to instrument saturation.

Skorokhod, Andrey

Influence of Eyjafjallajökull Eruption in April 2010 on the Atmospheric Air Composition in Moscow

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The effect of eruption of volcano Eyjafjallajökull in April 2010 on the composition of the atmosphere in Moscow has been studied. Plume from the Eyjafjallajökull eruption on April 14-15 reached Moscow for a few days. According to satellite measurements (OMI) increased aerosol indexes as well SO2 total content were observed over northern Europe on April 16. This cloud spread to the northern regions of European Russia. In Moscow on April 17 there was a continuous cloud cover and precipitation associated with the passage of the Atlantic cyclone. According to the OMI data the total content of sulfur dioxide in the troposphere over European part of Russia increased on April 18 and 19. Surface concentrations of main trace gases measured at the Moscow State University meteorological observatory on south-western part of Moscow have been investigated. The ash cloud passed Moscow at altitude of 6.7 kilometers, but due to the establishment of anticyclonic weather type, on April 17 and 18 there was a dynamic subsidence of air from the upper layers. As a result, sulfur dioxide revealed significant increase on 18 and 19 April exceeding the average concentrations for the period 2004-2010 by about 6 times. The concentration maxima were observed during the daytime, when most developed convection had occurred. Changes of other gases as well as of aerosol optical thickness (AOT) measured at the MSU observatory within AERONET program were less evident. In addition to the atmospheric gas composition, the effect of the volcano was manifested in the precipitation, sampled and analyzed at the MSU Meteorological Observatory. In the samples of rainwater taken on 16-18 April unusual black solid particles of very large size were found. Chemical analysis of rainwater samples showed unusually high concentrations of magnesium and sodium ions. Such concentrations are extremely rare, even in polluted rain samples collected after a long dry period. Forward and backward trajectory analysis on base of the NOAA hysplit trajectory model confirmed that the analyzed air could pass Iceland and contain products of Eyjafjallajökull eruption. It was shown that the presence of dynamic subsidence under anticyclonic activity is a prerequisite for stable registration of volcanic impurities by ground stations. Analysis of altitude distribution showed that pollution of the atmosphere in Moscow was caused by all tiers of volcanic emissions, at the same time on April 18 and 19 ground observatories could register only impurities, thrown from the heights up to 1500 meters of volcanic column in the beginning of the active phase of the eruption. Assessment of SO2 emission under Eyjafjallajokull active eruption in the period from 14th to 16th April was made using NOAA hysplit dispersion model. It amounted to around 0.43 million tons/day, or ~ 5 Mg/s. This work was supported by Russian Academy of Sciences and by the Ministry of Education and Science of Russia (State Contract N 02.740.11.0676).

Solaro, Giuseppe

DINSAR ANALYSIS OF MT. ETNA VOLCANO RETRIEVED THROUGH FIRST AND SECOND GENERATION SENSORS

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Mt. Etna is a large basaltic stratovolcano located on the eastern coast of Sicily (southern Italy). It arose from a succession of central vents and flank eruptions in the last 200 ka and is currently characterized by a continuous seaward motion of the eastern and southern flanks that produces extension on its upper part and a pronounced bulge along its south-eastern and south-western base sectors. This volcano has been the object of several conventional and advanced Differential SAR Interferometry (DInSAR) studies, aimed to detect and analyze its deformation dynamics. In this work we apply the advanced DInSAR approach referred to as the Small BAseline Subset (SBAS) technique in order to investigate the surface deformation occurring between 1992 and 2010. In particular, we take advantage of the multi-sensor data processing capability of the SBAS algorithm which allows us to generate mean deformation velocity maps and the corresponding time series by jointly exploiting two different set of SAR images collected by the ERS and the ENVISAT radar sensors. We also benefit from the use of multi-orbit (ascending and descending) data which permit us to discriminate the vertical and east-west components of the volcano edifice displacements. The retrieved ERS-ENVISAT deformation patterns are rather complex and may be summarized as follows: from 1994 to 2000, the volcano inflates with a linear behavior accompanied by the eastward and westward slip on the E and W flanks, respectively. The portions proximal to the summit show higher deformation rates, whereas the distal portions show several sectors bounded by faults, in some cases behaving as rigid blocks. From 2000 to 2003, the deformation becomes non-linear, especially on the proximal E and W flanks, showing marked eastward and westward displacements, respectively. This behavior results from the deformation induced by the emplacement of feeder dikes during the 2001 and 2002-2003 eruptions. From 2003 to 2008, the deformation approaches linearity again, even though the overall pattern continues to be influenced by the emplacement of the dikes from 2001 to 2002. The eastward velocity on the E flank shows a marked asymmetry between the faster sectors to the N and those, largely inactive, to the S. In addition, from 1992 to 2010 part of the volcano base (S, W and N lower slopes) has undergone a constant trend of uplift, in the order of ~0.5 cm/yr; In order to better follow the more recent deformative pattern of the volcano, we also analyze the new sensor COSMO-SkyMed data acquired in the 2009 – 2010 time interval. Accordingly, we present the results achieved by applying the SBAS approach to a set of 78 COSMO-SkyMed SAR data on descending orbit acquired from July 2009 to December 2010; such analysis shows the strong impact that the new generation sensor data may have in volcano deformation studies, particularly in terms of spatial coverage and temporal sampling of the retrieved measurements. Finally, we show first preliminary results on 2-3 April 2010 seismic swarm at Etna retrieved by inverting COSMO-SkyMed and ALOS data with a high-resolution modeling.

Stenchikov, Georgiy

Volcanic Test of Regional Climate in Middle East and North Africa

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We have tested the regional climate sensitivity in the Middle East and North Africa (MENA) to radiation perturbations caused by the large explosive equatorial volcanic eruptions of the second part of 20th century, El Chichón and Pinatubo occurred, respectively, in 1982 and 1991. The observations and reanalysis data show that the surface volcanic cooling in the MENA region is two-three times larger than the global mean response to volcanic forcing. The Red Sea surface temperature appears to be also very sensitive to the external radiative impact. E.g., the sea surface cooling, associated with the 1991 Pinatubo eruption, caused deep water mixing and coral bleaching for a few years. To better quantify the regional impacts of volcanic eruptions we use the Geophysical Fluid Dynamics Laboratory global High Resolution Atmospheric Model (HIRAM) to conduct simulations of both the El Chichón and Pinatubo impacts with the effectively 25-km grid spacing. We find that the circulation changes associated with the positive phase of the arctic oscillation amplified the winter temperature anomalies in 1982-1984 and 1991-1993. The dynamic response to volcanic cooling also is characterized by the southward shift of the inter-tropical convergence zone in summer and associated impact on the precipitation patterns. Thus, these results suggest that the climate regime in the MENA region is highly sensitive to external forcing. This is important for better understanding of the climate variability and change in this region.

http://www.kaust.edu.sa/academics/faculty/stenchikov.html

Stevenson, John A.

Grímsvötn 2011 Tephra in the UK: Public Sampling, Air Quality and Comparison With Model Predictions

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The May 2011 eruption of Grímsvötn, Iceland, was short-lived but powerful. Tephra was transported to the UK, where it could be identified in rainwater, sticky-tape samples and air quality data. We present analysis of timings and extent of tephra transport and compare them to predictions from the NAME dispersion model. Daily rainwater samples collected during the eruption were analysed. Tephra grains were identified in a number of samples and the most common diameter was 20–40 μm. A nationwide public sampling effort, coordinated by the British Geological Survey, returned over 100 sticky-tape samples. Confident identification of tephra is only possible where mass loadings are high. Samples were labelled with start time, end time and location, which allowed both the timing and location of deposition to be resolved. The results show that most deposition took place during rainfall, 48–70 hours after the onset of eruption, and was restricted to Scotland and further north. Air quality monitoring data show an increase in surface PM10 concentration as the plume passed over the UK. The highest hourly concentration, ~ 250 μgm−3, was measured in Aberdeen on 24 May 2011. Smaller peaks are found at other locations further south. Predictions by the NAME dispersion model show good agreement with the timing and extent of tephra distribution, however validation of concentration/mass-loading estimates is currently much more difficult.

Stuefer, Martin

A discussion of WRF-Chem volcanic ash particulate simulations of the 2010 Eyjafjallajökull eruption

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An algorithm describing the dispersion of ash particles from explosive volcanic eruptions was included in WRF-Chem, and applied to study the 2010 eruption of Eyjafjallajökull. Here we evaluate our results using the WRF-Chem model initialized with volcanic ash from the Eyjafjallajökull event with available ash detection data from satellite and airborne sensors, and from ground based Lidar measurements. The volcanic ash was distributed into 10 different bins according to the particle size ranging from 2 mm to less than 3.9 μm; 40 % of the particles were assumed to be 62.5 μm or smaller in diameter. An umbrella shaped initial ash cloud and an empirical relationship between mass eruption rates and eruption heights were used to initialize the WRF-Chem host models with ash particulates. From the initial plume heights (5 – 9 km above sea level, ASL) and mass eruption rates (70 m^3/s; 1 x 10^5 kg/s), the volcanic ash concentrations crossing mainland Europe were 0.5 – 2 mg/m^3, centered around 5 km ASL, +/- 1 km. Comparisons with satellite remote sensing volcanic ash retrievals showed good agreement, also ground-based LIDAR compared well to the model simulations. The model sensitivity analysis of the Eyjafjallajökull event showed a considerable bias of ass mass concentrations afar from the volcano depending on initial ash size and eruption rate assumptions. However the WRF-Chem model initialized with reliable eruption source parameters has strong potential to produce good quality forecasts for future extreme volcanic aerosol events.

Thomason, Larry W.

Toward a Long-term Stratospheric Aerosol Data Set from Multiple Spaced-based Sensors

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Stratospheric aerosol play a key role in ozone chemistry and climate forcing. Space-based observations of stratospheric aerosol date back to the mid-1970s and have been continuously made since 1978 with the start of the Stratospheric Aerosol Measurement (SAM II; 1978-1994). Through the past 3 decades, a number of instruments have provided valuable aerosol measurements that have shown

the effects of a few large volcanic injections of aerosol and its precursors (e.g., El Chichon in 1982 and Pinatubo in 1991) as well as a number of moderate (Ruiz/Nyamuragira 1984/1985) and smaller events (e.g., Ruang in 2002, Manam in 2005, Soufriere Hills in 2006, etc.). For much of this period, space-based measurements have been primarily based on solar occultation measurements (e.g., The SAGE and POAM series, HALOE) though some limb emission measurements are also available (e.g., CLAES). While these measurements provide valuable information about the stratospheric aerosol, they do not contain sufficient information to provide a robust depiction of aerosol composition and size distribution or climate relevant parameters like surface area density or radiative properties. Attempts to produce these derived data sets are generally based on a single or set of similar instrument data sets. Since instruments may employ different measurement strategies, the information contained in the measurements varies from measurement strategy to measurement strategy. As a result, it should be possible to make better inferences of aerosol properties by using data from these diverse sources. Herein, we will discuss recent advances we have made in the use of multiple sensors to produce a more robust depiction of the Pinatubo eruption aftermath focusing on the combined use of SAGE II and HALOE (visible and infrared wavelength aerosol extinction coefficient measurements) in a period that spans from late 1991 through 2005. This period also covers a period of low aerosol loading in which the effects of several small eruptions can be clearly seen and evaluated. This will entail a significant evaluation of the consistency of these observations and an effort to produce realistic uncertainties and consideration of limitations on the information that can reasonable be extracted from the composite measurement ensemble. In addition, we will discuss the prospects for completing the climatology from 2005 to the present; a period in which no member of the solar occultation ensemble is functioning. In this period, the long-term data set becomes dependent measurements that are fundamentally different than solar occultation and include stellar occultation (GOMOS), lidar backscatter (CALIPSO) and limb-scatter (OSIRIS/SCIAMACHY) observations. Fortunately there is substantial overlap between the older and newer observation techniques which allow a more complete understanding of the challenges involved in transitioning between the two periods.

Thordarson, Thor

934AD Eldgjá flood lava eruption, Iceland: Variability in magma composition and its implication for timing of maximum discharge

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Manifesting one of the two most voluminous and potentially climate impacting basaltic flood lava eruptions in the last 1100 years, the 934-40 AD Eldgjá eruption on the Katla volcanic system produced 18.3 km3 of lava and >5 km3 of tephra. It also released more than 200 Mt of SO2 into the atmosphere. The eruption took place on a 75-km-long volcanic fissure trending northeast from the glacier-capped Katla volcano. Sulphate deposition onto the Greenland glacier indicates the eruption lasted >3 and possibly 8 years starting around 934 AD. Geologic mapping recognizes distinct fissure segments; the south, central, and north Eldgjá fissures and Eldgjá proper wich separates the latter two. About one-half of the south Eldgjá fissure was subglacial and typified by explosive hydromagmatic activity that produced >4 km3 of tephra. The reminder of the tephra was produced by magmatic explosive activity of sub-Plinian intensities on the ice-free parts of the vent system. The tephra was dispersed along two major sectors, covering an area of ~20,000 km2; one trending to the southeast and another to the northwest. The tephra deposit comprises 24 phreatomagmatic and 10 magmatic fall units, with accumulated thickness of 2.5 m at a distance of 15 km from the source vents. The fall units define six eruption phases in accordance with the position of their source vents, underpining our reconstruction of the course of events. The eruption began with an explosive eruption (Phase 1) on the subglacial part of South Eldgjá. This was followed by explosive magmatic activity and lava emission from the subaerial part of South Eldgjá (Phase 2). Thereafter, the eruption shifted to the subglacial Katla caldera (Phase 3) and subglacial explosive activity was resumed. Subsequently, activity returned to the subaerial part of South Eldgjá, forming the magmatic tephra fall units of Phase 4. The remaining fissure segments became active in a stepwise fashion during Phases 5 and 6; first central Eldgjá and then Eldgjá proper and finally North Eldgjá, all featuring tephra producing magmatic explosive activity and lava production. Measurements of major and trace element composition of Eldgjá tephra shows that the early formed tephra on south and central Eldgjá and Eldgjá proper exhibits more evolved major and trace element composition than the tephra formed during the later stages of activity. Furthermore, the tephra from the North Eldgjá fissure has composition compatible to that produced by the late stage activity on the other fissure segments, while the lava flows consistently exhibit composition comparable to that of the more evolved

tephra. These evidences suggest that the bulk of the Eldgjá magma was erupted during the early stages of the eruption and from the fissure segments extending from Katla to Eldgjá proper in a rapid succession. If this is correct, then the bulk of the sulfur mass carried towards the surface by the magma was released into the atmosphere during the early stages of the eruption, carrying implication of significant atmospheric perturbations.

Timmreck, Claudia

Global and Regional Climate Impacts of the Young Toba Tuff Eruption

Timmreck, Claudia[1]; Graf, Hans[2]; Zanchettin, Davide[1]; Lorenz, Stephan[1]; Niemeier, Ulrike[1]; Hagemann, Stefan[1]; Kleinen, Thomas[1]; Krüger, Kirstin[3]; Matei, Daniela[1]; Jungclaus, Johann[1]; Crowley, Thomas[4]

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Super eruptions have been linked to global climate change, biotic turnover, and, for the Younger Toba Tuff (YTT) eruption 74,000 years ago, near-extinction of modern humans. Very large volcanic eruptions produce extremely strong radiative forcing, which can affect the Earth system for longer times than the pure atmospheric residence time of the volcanic aerosol. This leads to large negative temperature anomalies at the surface and significant warming of the aerosol containing layers altering substantially the atmospheric and oceanic circulation and composition. Here we present and discuss Earth system model simulations of the YTT eruption taking into account also the temporal evolution of the volcanic aerosol size distribution, which was one of the largest uncertainties in prior calculations. We demonstrate that there is a large negative feedback that has heretofore not been considered and which greatly reduces the climate impact of the aerosol cloud. The temperature response of the YTT is shorter and weaker than previously suggested. As the climatic consequences of the YTT eruption are a crucial argument in the current discussion about the fate of modern humans especially in Africa and Asia, we are focusing in particular on areas relevant to human evolutionary issues during that time. Information about transient changes in vegetation types after the eruption are obtained by forcing an offline dynamical global vegetation model with the climate anomalies simulated by the ESM under both glacial and interglacial background climate conditions. The simulated temperature changes in those areas that were inhabited by humans at the time of the eruption suggest thermal discomfort, but not a real challenge. Precipitation is reduced in all regions during the first two years, but recovers quickly thereafter. Some catchments (Ganges/Brahmaputra, Nile) experienced an over-compensation in precipitation during the third to fifth post-eruption years, which is also reflected in anomalously strong river runoffs. Change in vegetation composition may have created the biggest pressure on humans, who had to adapt to more open space with fewer trees and more grasses for some decades, especially in the African regions. The strongest environmental impacts of the YTT eruption are simulated under interglacial conditions suggesting that the climate effects of this eruption did not impact humans on a major scale and for a period long enough to have dramatic consequences for their survival.

Tolbert, Margaret A.

Volcanic Sulfur Chemistry in Reducing Atmospheres: Implications for Particles on the Early Earth

Tolbert, Margaret A.[2, 3]; DeWitt, Helen L.[2, 3]; Hasenkopf, Christa[2, 3]; Toon, Owen B.[1]; Jimenez, Jose[2, 3]

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On the present day Earth, volcanic emissions of sulfur lead to the stratospheric sulfate aerosol layer composed of particles containing concentrated mixtures of sulfuric acid in water. However, on the early Earth during the Archean, a time period approximately 4-2.45 billion years ago, the lack of oxygen (O2) could prevent sulfur oxidation to sulfate. Instead, reduced sulfur aerosols may form, impacting atmospheric chemistry and climate on the early Earth. Here we use real-time aerosol mass spectrometry to directly detect the sulfur-containing aerosols formed when SO2 either photolyzes at wavelengths from 115 to 400 nm, to simulate the UV solar spectrum, or interacts with high-energy electrons, to simulate lighting. We find sulfur containing aerosols form under all laboratory conditions. Further the addition of a reducing gas, in our experiments hydrogen (H2) or methane (CH4), increases the formation of elemental sulfur (S8). The partitioning between sulfate and S8 also varies with the initial SO2 concentration. Finally, we observe formation of organosulfur compounds from the photolysis of CH4 in the presence of SO2. The implications of these laboratory studies for sulfur aerosols on the early Earth are discussed.

Toohey, Matthew

The Impact of Post-eruption Atmospheric Circulation Changes on Ice Core Records of Paleo-volcanism

Toohey, Matthew[1]; Krüger, Kirstin[1]; Timmreck, Claudia[2]

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Reconstructions of radiative forcing due to volcanic aerosols are essential for properly modeling the past climate, and for estimating the impact of the largest volcanic eruptions of the past, such as the Young Toba Tuff (YTT) super-eruption. Prior studies have reconstructed volcanic

aerosol loadings (and their associated radiative impact) based on chemical analysis of Greenland and Antarctic ice cores, and the assumption that aerosol deposition to ice sheets varies linearly with atmospheric loading. Here we describe results from volcanic eruption simulations of a range of eruption magnitudes using a coupled aerosol-general circulation model which simulates the full microphysical lifecycle of volcanic aerosols and feedbacks between the aerosols and atmospheric dynamics. We find that sulfate deposition to the Greenland and Antarctic ice sheets is a nonlinear function of eruption magnitude and that variability in ice sheet deposition may be related to volcanically induced perturbations to large-scale atmospheric circulation. Suppression of sulfate transport to Antarctica for large eruptions due to changes in atmospheric circulation may be responsible for the lack of a strong volcanic sulfate signal in Antarctic ice cores for the YTT super-eruption.

Toohey, Matthew

The Influence of Eruption Season on the Global Aerosol Evolution and Radiative Impact of Tropical Volcanic Eruptions

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Simulations of tropical volcanic eruptions using a general circulation model with coupled aerosol microphysics are used to assess the influence of season of eruption on the aerosol evolution and radiative impacts at the Earth's surface. This analysis is presented for eruptions with SO2 injection magnitudes of 17 and 700 Tg, the former consistent with estimates of the 1991 Mt. Pinatubo eruption, the later a near-"super eruption". For each eruption magnitude, simulations are performed with eruptions at 15° N, at four equally spaced times of year. Sensitivity to eruption season of aerosol optical depth (AOD), clear-sky and all-sky shortwave (SW) radiative flux is quantified by first integrating each field for four years after the eruption, then calculating for each cumulative field the absolute or percent difference between the maximum and minimum response from the four eruption seasons. Eruption season has a significant influence on AOD and clear-sky SW radiative flux anomalies for both eruption magnitudes, with sensitivity reaching maximum values of ~75 %. Global mean AOD and clear-sky SW anomalies show sensitivity to eruption season on the order of 15–20 %, which results from differences in aerosol effective radius for the different eruption seasons. Smallest aerosol size and largest cumulative impact result from a January eruption for Pinatubo-magnitude eruption, and from a July eruption for the near-super eruption. In contrast to AOD and clear-sky SW anomalies, all-sky SW anomalies are found to be insensitive to season of eruption for the Pinatubo-magnitude eruption experiment, due to the reflection of solar radiation by clouds in the mid- to high latitudes. However, differences in all-sky SW anomalies between eruptions in different seasons are significant for the larger eruption magnitude, and the ~15 % sensitivity to eruption season of the global mean all-sky SW anomalies is comparable to the sensitivity of global mean AOD and clear-sky SW anomalies. Our estimates of sensitivity to eruption season are larger than previously reported estimates: implications regarding volcanic AOD timeseries reconstructions and their use in climate models are discussed.

Toon, Owen B.

The Microphysics of Stratospheric Volcanic Clouds, and Its Influence on Climate Forcing. (*Invited*)

Toon, Owen B.[1, 4]; English, Jason[2]; Neely, Ryan[4, 5]; Mills, Michael[3]

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Owen B. Toon Campus Box 600 Laboratory for Atmospheric and Space Physics, Department of Atmospheric and Oceanic Sciences University of Colorado, Boulder 80303 Jason English NCAR Climate and Global Dynamics Division National Center for Atmospheric Research 1850 Table Mesa Drive, Boulder, CO 80305 Ryan Neely NOAA's Earth System Research Laboratory Department of Atmospheric and Oceanic Sciences Cooperative Institue in Environmental Studies CB 216 University of Colorado Boulder, CO 80309-0216 Mike Mills Earth System Research Laboratories National Center for Atmospheric Research P.O. Box 3000, Boulder, Colorado 80307-3000 Volcanic eruptions hurl dust and sulfur dioxide gases, as well as other materials, into the stratosphere. There the sulfur dioxide is photochemically converted into sulfuric acid, which nucleates new particles, and condenses on dust and pre-existing aerosols. Climate models have often assumed that the resulting stratospheric volcanic particles are uniform in size. However, both models and observations show this is not the case, and that the particle properties evolve in both time and space. It has also been known for more than two decades, but largely ignored in the climate modeling literature, that the particles can become quite large for massive sulfur dioxide injections. The particle size growth limits the possible climate perturbations both because the particle optical depth is inversely proportional to size, and because the particle fall velocity increase with approximately the square of the particle size. Here we use a three dimensional microphysical/climate model called WACCM/CARMA to evaluate the microphysical evolution of several categories of stratospheric

particles. We find both micrometeorites and organic aerosols to significantly impact ambient stratospheric aerosol. We explore whether the increase in ambient stratospheric aerosol over the past decade is perturbed by tropospheric pollution or small volcanic eruptions. Finally, we investigate the evolution of the particles in the stratosphere after the eruption of Mt. Pinatubo.

van Bergen, Manfred

Extreme compositional heterogeneity of particles in fallout from the 2010 Eyjafjallajökull ash cloud over England

van Bergen, Manfred[1]; Nikogosian, Igor[1]

1. Earth Sciences, Utrecht University, Utrecht, Netherlands

The composition of particles from the 2010 summit eruption of Eyjafjallajökull that reached western England provides insight into the potential diversity within remotely dispersed clouds or within distal deposits of ash originating from Icelandic volcanoes. We used EPMA and SEM techniques to investigate mineral and glass phases in up to ~50 μm-sized particles deposited on the ground during a single brief event. Lithics dominated strongly over juvenile grains, in agreement with the phreatomagmatic character of the explosive eruption during its initial stages. Taking admixture of atmospheric particles from local sources into account, the volcanic particles were marked by an extreme heterogeneity and mineralogical diversity. Apart from grains with typical volcanic minerals and textures, many of the single crystals and compound grains consisted of non-magmatic silicate assemblages, including quartz, various micas, chlorite, epidote, albite, K-feldspar, in addition to carbonate, sulphates, sulphides, oxides, REE-fluoride and other secondary phases. Particles containing volcanic glass were uncommon and showed compositionally different populations. Siliceous glass shards (60-70 wt.% SiO2) were relatively abundant, whereas basaltic glass (~46% SiO2, ~10% MgO) was extremely rare. The latter approximates the composition of the Fimmvörduháls lavas erupted on the flank during the preceding effusive stage of the 2010 activity. The observed compositions point to bimodality of melt compositions and fit into the overall variation trend of lavas produced earlier in Eyjafjallajökull's history. A third group of glassy particles (47-54% SiO2) is marked by a highly vesicular texture. The extreme mineralogical diversity, combined with the diverse chemical signatures of the glasses, is consistent with a scenario for the opening stages of the violent central eruption whereby the ice-capped summit part of the volcano was fragmented and cleared before juvenile magma could be emitted in larger volumes. The observed association of secondary minerals represents altered volcanic lithologies, comparable to those of active hydrothermal systems in Iceland, which suggests the (former) presence of such a system in the summit region of the edifice below the glacier. The siliceous glass represents melts that presumably originated in the altered rocks from the heat of the rising basaltic(-andesitic) magma. The observed heterogeneity of Eyjafjallajökull's distal ash may be more common to violently erupting Icelandic volcanoes, and should be taken into account in tephrochronological applications as well as in studies focusing on the potential dangers during aircraft encounters.

Verosub, Kenneth L.

New Perspectives on the Frequency and Importance of Tambora-like Events

Verosub, Kenneth L.[1]

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The 1815 Tambora eruption is generally accepted as having had a significant impact on global climate. What is not clear is whether any earlier volcanic eruptions of about the same Volcanic Explosivity Index had similar impacts. The tree-ring record suggests that the 1600 eruption of Huaynaputina volcano in Peru may have been one such event. Although the instrumental record for this eruption is minimal, historical sources provide a wealth of data about the climatic impacts of this eruption, Famines in Russia and Estonia, late harvests in central Europe, and the early onset of winter conditions for lakes in Japan and harbors on the Baltic Sea document that 1601 was indeed a particularly cold and fairly wet year. Extensive Spanish and Jesuit archives covering the Americas and parts of Asia, plus records of the imperial court in China and the shogunate in Japan should make it possible to obtain a global record of the human and social impacts of the 1600 eruption. The historical record can also be used to determine whether volcanic eruptions produced anomalously cold conditions in 1258 and 1453. Taken together, these four events imply that the return period for Tambora-like events is actually on the order of 200 years, a figure that is in agreement with estimates from ice core records. Since it has been 196 years since the last such event, it is worth considering what the impacts would be if another event were to occur within the next ten years. In particular, the current global agricultural economy may be less resilient to a very cold year than more regionally-based agriculture was in 1816.

Vogel, Andreas

Ground based stationary and mobile in situ measurements of volcanic ash particles during and after the 2011 Grímsvötn volcano eruption on Iceland

Vogel, Andreas[1]; Weber, Konradin[1]; Fischer, Christian[1]; Pohl, Tobias[1]; von Löwis, Sibylle[2]; Moser, Hans M.[1]

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2. Forecast and observation, Icelandic Meteorological Office, Reykjavik, Iceland

Volcanic eruptions emitted a large amount of gas and particles to the atmosphere, which have a strong influence to the environment and the economic. The past eruptions of Icelandic volcanoes, Eyjafjallajökull and Grímsvötn, particularly strong affected the air traffic with flight cancellations or shifts as well as the environment for several

weeks. During the eruption phase of the Grímsvötn volcano, a series of particle measurements where performed in the direct near field of the eruption event. Two fixed monitoring stations in the south of Iceland (south westerly of the eruption event) are established to discriminate continuously the plume dispersion. The both stations in Skogar and Hvollsvollur are approximately 150km linear away from the eruption event at two significant positions. In additional to these measurements mobile measurements around the Vatnajökull glacier were performed. In situ particle characteristics were measured using a Grimm 107 optical particle counter (OPC). The OPCs were able to detect particles in a size range between 0.25- 32 micron in 31 classes. The number concentrations, delivered by the OPCs, were converted to mass concentrations for TSP (Total Suspended Particles), PM10, PM2.5 and PM1 which are important for limit values. To characterize the measured particles, they were collected to filters for study the optical and chemical properties. The results show the propagation of the particles and their changes of the size distribution during the eruption event. The chemical property of the particles from this eruption event varies to the particles of the Eyjafjallajökull. After the eruption enormous quantities of ash had been deposited on the ground, which were re-suspended frequently into the atmosphere depending on wind and other meteorological conditions. The particle emissions contained in great distance still large amounts of bigger particles.

Vogel, Leif

Preventing potential aircraft encounters with volcanic plumes: Early in-flight detection of volcanic SO_2 by 1-D Imaging Differential Optical Absorption Spectroscopy

Vogel, Leif[1]; General, Stephan[1]; Poehler, Denis[1]; Bobrowski, Nicole[1]; Platt, Ulrich[1]

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Volcanic ash is a threat to aviation, mainly due to its effect on jet engines with the risk of total engine failure. Other risks include abrasion of windshields and damage to avionic systems. These threats have been widely recognized since the early 1980s, when volcanic ashes provoked several near fatal incidents of jet aircraft engine failure (e.g. Mt. St. Helens, USA, 1980; Mt. Galunggung, Indonesia, 1982 and Redoubt volcano, USA, 1989). One of the most recent and most famous examples of volcanic ash in aviation is the eruption of Eyjafjallajökull, Iceland, between March and May 2010, which led to temporal closure of the European air space. Although no severe incidents were reported, it affected an unprecedented number of people and economic losses are estimated to amount up to U.S. $1.7 billion. In addition to volcanic ash, also volcanic gases pose a threat. Prolonged and/or cumulative exposure of sulfur dioxide (SO_2) or sulfuric acid (H_2SO_4) aerosols potentially affects e.g. windows and airframes, also damage to engines has been recorded. SO_2 receives most attention because its presence above the lower atmosphere is a clear proxy for a volcanic plume and indicates that fine ash could also be present. Up to now, remote sensing of SO_2 via Differential Optical Absorption Spectroscopy (DOAS) in the ultraviolet spectral region (300 – 330nm) has primarily been used to measure volcanic clouds from satellites and ground-based platforms. It was recently shown (Vogel et al. Atmos. Meas. Tech. 4, 1785–1804, 2011) that the DOAS technique can be used as an early detection technique for volcanic SO_2 clouds onboard aircrafts. A set of ground-based and airborne measurements were conducted at Popocatépetl volcano, Mexico, in April 2010. With a summit height of 5426m above sea level, Popocatépetl is especially suited for such an experiment since the volcanic plume is released in the free troposphere at high altitudes. This allowed to draw conclusions on the performance of the technique at typical altitudes of air space traffic. The measurements suggested that an extended volcanic cloud at 10km altitude and SO_2 concentration of 10^{12}molec/cm^2 can be detected at distances up to 80km away. These first test flights were carried out with an instrument not originally designed for the task. A novel forward looking DOAS instrument was designed, capable of spatially resolved measurements of SO_2 and other gases in the spectral range of 300-400nm at 0.6nm resolution, a total field of view of 7° x 0.18° (vertical x horizontal forward from the airplane) and a vertical sampling of 31 heights. At a distance of 80km from an aircraft, this corresponds to a vertical observation range extending 4.9km above and below a horizontally flying aircraft. This is sufficient to capture an extended volcanic cloud in the flight path and to determine whether it is actually located at flight altitude. Thus the system will provide early warning to pilots allowing them to avoid potentially dangerous encounters of aircraft-threatening volcanic plumes. Further test flights with the novel instrument and theoretical studies show that our system is complementary to other early in-flight detection schemes in the infra-red spectral region.

von Glasow, Roland

Reactive chemistry in tropospheric volcanic plumes

von Glasow, Roland[1]; Bobrowski, Nicole[2]; Vogel, Leif[2]; Fickel, Markus[2]; Hoermann, Christpoh[2]; Kern, Christoph[2, 3]; Platt, Ulrich[2]

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2. Insitute of Environemental Physics, University Heidelberg, Heidelberg, Germany
3. U.S. Geological Survey, Vancouver, WA, USA

In the last few years reactive gases, especially halogens, have been measured in surprisingly high concentrations in the atmospheric plumes of active volcanos. These measurements were made in quiescent degassing as well as explosive plumes. Numerical models have been used to reproduce the evolution of the chemistry in these plumes. We will present an updated version of the model used in Bobrowski et al (2007) and von Glasow (2010) and highlight the factors that are important for the plume evolution such as initial composition of the plume, dilution ratio with ambient air and meteorological conditions. We will compare the model results with data from Mt Etna, Sicily for field campaigns conducted in 2005, 2008 and 2009. We will furthermore present model results that discuss quantitatively the long-range effects of volcanic plumes on tropospheric chemistry and will address a number of important open questions such as the speciation of chlorine, sulphur - halogen interactions and the interaction of halogens with mercury.

von Löwis, Sibylle

Measurements of Suspended and Resuspended Volcanic Ash by Ground-based Depolarisation Lidar in Iceland

von Löwis, Sibylle[1]; Brooks, Barbara[2]; Petersen, Gudrún Nína[1]; Groves, James[2]; Mobbs, Stephen[2]

1. Icelandic Meteorological Office, Reykjavik, Iceland
2. National Centre for Atmospheric Science, Leeds, United Kingdom

During the eruption in Grímsvötn volcano in May 2011 a Doppler depolarisation lidar was installed at Keflavík International Airport, in south-west Iceland, for monitoring the atmosphere above the airport. The volcano is located beneath the Vatnajökull glacier in south-east Iceland about 260 km away from the airport. The eruption started on the evening of 21 May and only lasted for a few days. During that time the volcanic ash plume was advected over the airport area and was detected by the lidar. The depolarisation ratio helped to distinguish between cloud droplets and ash and dust particles in the lower troposphere. With these observations the local aviation authority were assisted by the Icelandic Meteorological Office (IMO) and the UK National Centre of Atmospheric Science (NCAS) in decision making regarding closings and openings of the airport. Two cases were studied in particular: 1. In the evening of 21 May a plume of dry volcanic ash arrived over Keflavík airport. An ash cloud layer was observed below 1500 m. 2. A mixed cloud of water droplets and non-spherical particles, probably volcanic ash, was observed on 24 May. The cloud base height of the 1000m thick cloud was at about 3000 m. After the eruption the lidar was moved to a farm in south Iceland for the purpose of measuring resuspended volcanic ash and dust. In this area most of the ash fall on land was observed during the Eyjafjallajökull eruption in 2010 and the Grímsvötn eruption in 2011. In September 2011, during a period of several days, heavy dust and sand storms were observed in the south part of Iceland. Clouds of resuspended volcanic ash and dust were detected and observed by the depolarisation lidar. Due to favourable meteorological conditions MODIS satellite images can be used to determine the sources of these dust clouds. The ongoing project aims to answer the question if lidar instruments have the potential for near-field monitoring of explosive eruptions. Promising results were found from the Grímsvötn eruption.

Waddicor, David A.

Characterisation of the Near-Field Eyjafjallajökull Volcanic Plume using Remote Sensing from UK Based Lidars

Waddicor, David A.[1]; Vaughan, Geraint[1]; Ricketts, Hugo[1]; Wareing, David[1]

1. Centre for Atmospheric Science, The University of Manchester, Manchester, United Kingdom

The eruption of the Icelandic volcano, Eyjafjallajökull, on the 20th March 2010 foreshadowed a period of unprecedented travel disruption across European airspace. The volcano entered a new explosive phase on the 14th April 2010, producing large quantities of ash and tephra. This episode instigated the widespread closure of European airspace, from approximately 14th April till 23rd May – the largest closure of European airspace since World War II, with losses estimated between € 1.5 and 2.5 billion. Fine ash particles were very resistant to sedimentation and were thus transported extensively across European skies. The explosive phase also saw significant local ash fall which affected local population and livestock health – and continues to do so. The European scientific community responded with swift action in order to detect and track the approaching ash cloud. Great scientific work was done in a limited time frame which helped to yield answers to many safety and airworthiness questions. Many of the guidelines at that time were unhelpfully rigid; up till that point, any ash in the air was considered enough to shut down a whole air sector. With airlines and governments becoming increasingly worried, the scientific community began to characterize the ash cloud and find more definite mass loading limits for safe flying. Flights were made into some of the ash cloud layers to make direct measurements and take impact samples. Complementing this, ground-based remote sensing devices such as lidar were used to track the ash cloud and find its features and composition. The work by the University of Manchester (UK) focused on 3 UK-based lidars: two in Aberystwyth (west Wales) and the other in Cardingdon (south-east England). The Aberystwyth lidars are referred to as the Raman lidar and the Elight lidar; the Cardington based lidar is referred to as the leosphere. The majority of our work is focused on the Raman and Elight lidars. Both as these lidars have their advantages and disadvantages. The Raman lidar is so named because it has a raman channel. This channel can be used to define an aerosol backscatter ration and was therefore able to detect ash particles from the volcano. On the downside, the Raman signal is very weak and can therefore only really be used at night. The Elight signal however can be used in the daytime and returns the pure backscatter power signal. On the other hand, this lidar does not have Raman detection and therefore cannot yield a quantitative aerosol backscatter. It is the aim of this work to combine the two datasets so that the two lidars complement each other and their relative disadvantages are removed. In other words, the Raman data and the Elight will be used to give a true aerosol backscatter signal for both day and night. Another advantage of this method is the production of a

depolarisation factor. Both lidars are singularly polarised (one polarisation plane) but backscattered light, particularly from irregularly shaped particles such as ash, is often strongly depolarised. This final factor will be an important result for our work because if we can distinguish from other particles, such as ice cloud particles, then we can use the parameterisation for future detection events.

Weber, Konradin

Airborne investigations of volcanic plumes with light aircrafts – examples of applications during the recent eruptions of the volcanoes Eyjafjallajökull, Grimsvötn and Etna

Weber, Konradin[1]; Eliasson, Jonas[2]; Vogel, Andreas[1]; Fischer, Christian[1]; Moser, Hans Martin[1]

1. Laboratory of Environmental Measurement Techniques, Duesseldorf University of Applied Sciences, Duesseldorf, Germany
2. Earthquake Engineering Research Institute, University of Iceland, Reykjavik, Iceland

Volcanic eruptions can pose a considerable threat to aviation. This became evident in Europe by the airspace closures during the eruption of Eyjafjallajökull 2010 and Grimsvön 2011 and interim closures of the airport Catania after paroxysmal eruptions of Etna 2011. In these situations the Laboratory of Environmental Measurement Techniques (LEMT) of the Duesseldorf University of Applied Sciences and the Earthquake Engineering Research Institute (EERI) of the University of Iceland used light aircrafts, equipped with optical particle counters (OPCs) and partly with volcanic gas measurement systems, for exploring the volcanic plumes. During the eruption of the Eyjafjallajökul 2010 LEMT performed 14 research flights over North Germany in situations with and without ash plume over Germany. The results of these flights were compared with the model calculations of the London VAAC. In parallel EERI performed measurement flights over western Iceland. During two of these flights the outskirts of the ash plume were entered directly by the aircraft delivering concentrations of about 2000 μg/m3. However, airborne ash concentrations over western Iceland outside the plume proved to be low. In Germany, several thousand kilometers away from the eruption vent, the Eyjafjallajökull ash plume appeared to be strongly structured in horizontal and vertical direction during the flights. Peak concentrations of up to 330 μg/m3 could be found in altitudes between 2500 m and 4500 m . During the Grimsvötn eruption 2011 LEMT and EERI performed several cooperative measurement flights over Iceland and northern Germany. A part of the flights on Iceland was performed for the Icelandic flight operator ISAVIA. Whereas ground-based OPCs in the south of Iceland showed high ash concentrations, the aircraft measurements in the region over Keflavik and Reykjavik revealed mostly small ash concentrations. Therefore these aircraft measurements helped to re-open the international airport of Keflavik by ISAVIA. In a similar way aircraft measurements over northern Germany on 25 May 2011, which were performed by LEMT for the German Weather Service DWD, showed comparatively low ash concentrations over northern Germany, despite of high predicted VAAC model calculations. Therefore the re-opening of the German airports Hamburg, Bremen and Berlin was in accordance with the low measured ash concentrations by the LEMT aircraft. Moreover this light aircraft was used by LEMT for studies of aerosols and gases of the volcanic plumes of Etna after paroxysmal eruptions in 2011 and enabled the determination of SO2-fluxes. In general light piston-motor driven aircraft proved to be robust and reliable enough to operate even at elevated ash concentrations. Because these aircraft are able to fly at low cruising velocities during measurements they can deliver spatial high resolution results. Moreover, the OPCs of these aircraft were calibrated in a special dust/wind tunnel with volcanic ash, thus delivering ash concentration results with high accuracy.

http://mv.fh-duesseldorf.de/d_pers/Weber_Konradin

Woodhouse, Mark J.

Integral models of volcanic eruption columns in a wind field

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2. School of Earth Sciences, University of Bristol, Bristol, United Kingdom

The eruption of Eyjafjallajökull in April 2010 resulted in several weeks of disruption to aviation in Europe. Forecasting ash dispersion in the atmosphere require, as input, estimates of source parameters, in particular the mass discharge rate. Typically the discharge rate has been determined from empirical relations 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 eruptions such as Eyjafjallajökull, atmospheric conditions can strongly effect the rise height of the plume and lead to inaccurate estimates of the mass flux of volcanic ash injected into the atmosphere. We formulate an integral model of a volcanic eruption column in a wind field in order to assess the influence of local atmospheric conditions. We show that atmospheric winds strongly influence the rise of the plume, such that empirical relations which do not consider the strength of the wind may underestimate the mass discharge rate by an order of magnitude. By employing observations of the local meteorology during the first explosive phase of Eyjafjallajökull (14th to 18th April 2010) in the integral model, we demonstrate that varying atmospheric conditions can account for observed variations in the rise height of the plume while the mass discharge rate is held constant. The integral plume model is used to provide a new relationship between mass discharge rate and the height of rise of the plume in which the strength of the wind is explicitly included.

Wotawa, Gerhard

Development and Operational Testing of New Volcanic Ash Prediction Services for International Aviation

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2. Norwegian Institute for Air Research (NILU), Kjeller, Norway

In April and May 2010, large parts of the European airspace were shut down for several days as a consequence of the eruption of the volcano Eyjafjallajökull in Iceland. The significant economic impact and public awareness of these air traffic restrictions raised the need to promote initiatives aimed at improving the management of volcanic eruptions in the context of civil aviation. All new services heavily rely on the modelling of the transport of volcanic ash from the eruption location. Besides the possible improvement of models, the real key to improve predictions lies is the rapid assessment of ash emissions, and their variations in time. The variability involves not only the release strength, but also the release height. As part of the ESA project VAST, it is not only planned to develop improved methods of ash prediction based on automated source estimates, but also to integrate these methods into an operational environment. For a period of one year, the operational testing will show the potential of the system, which will be one of the prerequisites for the introduction of volcanic ash concentration limits. The methods tested will be open for subsequent use at Volcanic Ash Advisory Centres (VAACs).

Yim, Wyss W.

Volcanic eruptions as a cause of regional extreme weather events

Yim, Wyss W.[1]

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Satellite tracking of volcanic clouds arising from selected eruptions since 1980 has led to the recognition of a connection between volcanic eruptions and regional extreme weather events. Although every eruption differs in terms of climatic impact, the difference seen may be explained mainly by their geological characteristics, timing and geographic location. Atmospheric changes may take place in a number of ways including: (1) Air circulation changes including a possible role in atmospheric rivers. (2) Input of particulates. (3) Input of gases including sulfur dioxide and water vapor. A selection of regional extreme weather events identified to be associated with volcanic eruptions since 1980 is shown in Table 1. Multiple volcanic eruptions and/or a big eruption may have a possible role in changing the 'normal' atmospheric circulation pattern to exert influences on climatic variability including the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation and the Indian Ocean Dipole.

Table 1 Selection of regional extreme weather events identified to be associated with volcanic eruptions since 1980

Volcanic eruption	Main eruption date	Extreme weather events
El Chichón, Mexico	28/3/1982	Heavy rainfall in southern China during late April/early May including the second wettest year in Hong Kong since record began in 1884
Pinatubo, Philippines	15/6/1991	Post-eruption drought conditions in southern China; heavy winter snowfall in eastern Mediterranean
Chaitén, Chile	2/5/2008	Wet May in South Africa; wet June over much of the Australian continent; wettest June in Hong Kong since record began in 1884 including a severe rainstorm on 7/6/2008 causing ~2400 landslides on Lantau Island
Soufrière Hills, Montserrat	11/2/2010	East Atlantic frontal activity storms affecting Madeira (20/2/2010) and western Europe (Xynthia 26-28/2/2010)
Eyjafjallajökull, Iceland	14/4/2010	Frontal activity storms affecting central Europe in May including the wettest year in Slovakia since record began in 1881

Young, Cindy L.

A satellite and ash transport model aided approach to assess the radiative impacts of volcanic aerosol in the Arctic

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Volcanic aerosols may be expected to have a particularly strong influence on the regional Arctic climate because of the sensitivity of the Arctic environment to radiative perturbations, as indicated by numerous studies focusing on other aerosol types, both natural and anthropogenic. Volcanic aerosol is primarily composed of ash and sulfate particles, which scatter and absorb radiation differently. Very few studies actually consider ash along with sulfate aerosol in making assessments of regional radiative effects. This is because sulfate aerosol can reside in the stratosphere for a much longer time than ash. However, at the timescales involved in regional transport, ash becomes important, especially in the troposphere where the lifetimes of ash and sulfate are very similar. Additionally, ash deposits can lower the reflectivity of ice and snow covered surfaces, which would also be expected to perturb the Arctic's radiation balance. Considering the 2009 eruption of Mt. Redoubt, this study presents an analysis of the properties, evolution and regional radiative impact of volcanic aerosols through integration of modeling and multi-satellite, multi-sensor data. The Ozone Monitoring Instrument (OMI), the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging SpectroRadiometer (MISR), and the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model for volcanic ash were used to characterize the spatiotemporal resolution of aerosol across the region and aerosol optical depth. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) was used to determine the altitude and thickness of the plumes. The optical properties of volcanic aerosol were calculated using a compositionally resolved microphysical model developed for both ash and sulfates. Two compositions of volcanic aerosol were considered in order to examine a fresh, ash rich plume and an older, ash poor plume. Optical models were incorporated into a modified version of the Santa Barbara Disort Atmospheric Radiative Transfer (SBDART) model, which was used to quantify the aerosol TOA and surface forcings. In addition, we used an Eulerian Eulerian Langrangian (EEL) multiphase flow model to investigate the evolution of ash particle size distributions and plume vertical stratification. This model is designed to predict vertical and horizontal motion of gaseous and particulate species of varying sizes, given initial conditions

of the eruption and the ambient atmosphere. We use the EEL model to compute the relative motion between different particle sizes and the gas phase, enabling a transient calculation of the evolving concentration and grain size distribution in the proximal plume. We present, for the first time, both shortwave and longwave components of the radiative forcing due to volcanic aerosol. Our results demonstrate that the longwave component makes an important contribution to the total radiative forcing and cannot be ignored, especially in the Arctic. Our results also reveal that volcanic aerosol compositions rich in ash can produce the dominant radiative forcing signal when compared to other aerosols common to the Arctic region.

Zanchettin, Davide

Strong Tropical Volcanic Eruptions as a Major Driver of Decadal European Winter Climate Variability During the Last Millennium

Zanchettin, Davide[1]; Bothe, Oliver[1, 2]; Timmreck, Claudia[1]; Lorenz, Stephan[1]; Jungclaus, Johann H.[1]

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Numerical climate simulations suggest that strong tropical volcanic eruptions (SVEs) have the potential to induce decadal and even longer timescales dynamical responses in the coupled ocean-atmosphere system. Here, we illustrate the post-eruption decadal-to-multidecadal climate evolution in the Max-Planck-Institute-Earth system model (MPI-ESM) simulation ensemble of the last millennium, focusing on (i) the emergence of winter warm anomalies over continental Europe about one decade after a major eruption (delayed winter warming) and on (ii) the distinctive traits characterizing the multidecadal response to the SVE clusters during the late Medieval Warm Anomaly and during the late Little Ice Age. Additional MPI-ESM simulations conducted in a sensitivity study about the climate response to the 1815 Tambora eruption allows to individuate the key processes involved in the climate response to SVEs and to sketch out the physical mechanism(s) likely governing the occurrence of delayed winter warming events. In particular, we illustrate how background climate conditions affect especially the simulated oceanic response to the 1815 Tambora eruption. Cross-validation of our numerical results with reconstructed temperatures for the European region substantiate the hypothesis that delayed warming events are likely true feature of past climate forced variability. It also paves the way to our discussion on the necessity to interpret simulations as a probabilistic ensemble in order to extract relevant features of simulated decadal past regional temperature variability, hence to properly relate numerical simulations and reconstructions.

Zeni, Giovanni

YELLOWSTONE CALDERA DEFORMATION FIELD ANALYSIS BY USING THE ADVANCED SBAS DINSAR TECNIQUE

Zeni, Giovanni[1]; Tizzani, Pietro[1]; Pepe, Antonio[1]; Lanari, Riccardo[1]

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The Yellowstone volcanic field located at the Yellowstone National Park, Wyoming, represent the largest and most active volcanic systems in the world (Smith and Siegel, 2000; Christiansen, 2001) comparable to other volcanic fields such as Long Valley, California, and Phlegrean Fields, Italy. In the past two million years, three catastrophic caldera-forming eruptions characterize the Yellowstone volcanic history (Christiansen, 2001). The last eruption, 0.64 million-years-old, formed the 40-km-wide by 60-km-long Yellowstone caldera. Since the last cataclysmic eruption at least 30 dominantly ryholitic and basaltic lava flows, as young as 70 000 years old, have been erupted, covering much of Yellowstone. Geodetic measurements of Yellowstone from 1923 to 2004 using precise levelling, GPS (Global Positioning System), and InSAR (interferometric synthetic aperture radar) have revealed multiple episodes of caldera uplift and subsidence, with maximum average rates of ~1 to 2 cm/year generally centered at its two resurgent domes, Sour Creek and Mallard Lake. In addition, an area northwest of the caldera near Norris Geyser Basin experienced periods of substantial ground deformation . These spatial and temporal variations of the Yellowstone unrest also correlated with pronounced changes in seismic and hydrothermal activity. In this work, we analyse the temporal variations of ground deformation of the Yellowstone volcanic features applying the SBAS-DInSAR technique (Berardino el al 2002) on the 1992-2010 time interval. The achieved analysis related to the 1995-2010 DInSAR time series present a complex scenario of detected deformation field. In particular, the dynamic of caldera region and surrounding area is characterized by four main deformation trend. The first one, from 1992 to 1995, a broad subsidence pattern involve the entire caldera region along its major axis, with maximum displacement in WSW – ENE direction (Mallard lake dome and Sour Creek dome). The second one, between 1995 -1998, reveals an new uplift phenomenon focused in the area at west of Sour Creek dome (Mud volcano). In the 1995 -2003 time interval the previous uplift event grows significantly involving the area of Norris Geyser Basin located outside caldera rim. Finally the 2003 -2009 time interval is characterized by a spectacular inversion of caldera floor deformation. More specifically, the area affected by subsidence during the 1992 – 1995 time interval are involved in a new uplift event, jointly the area Norris Geyser Basin is also characterized by the inversion of ground deformation. According to previous studies, the performed analysis shows a spatial and temporal migration of deformation field whose oscillations can be seen as the breath of volcano.