Istituto Nazionale di Geofisica e Vulcanologia

Icelandic Met Office

The Vespa-system: Real-time estimation of eruption source parameters

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Cities on Volcanoes 10, Naples, Italy, 2-7 September 2018
S01.26 - Volcanic ash: From monitoring to impacts (540)

Why Provide Eruptive Source Parameters?

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During explosive volcanic eruptions it is important to have access to timely and reliable time series of plume height and mass eruption rate to assess the intensity and potential impact of the event

The primary users in our case are

- The Icelandic Civil Protection and Emergency Management
- The Icelandic Aviation Service Provider (Isavia)
- London VAAC (Volcanic Ash Advisory Center)
- The scientific community using our time series as input data for various simulations of the impact on ground, atmosphere, local population and air traffic

C-band radar
Fljótsdalsheiði
C-band radar
Mobile X-band radar
Keflavík
Gunnarsholt
Klaustur
100 km
SELEX-SI
Gematronik

Plume Height Time Series
Manually estimated from radar images

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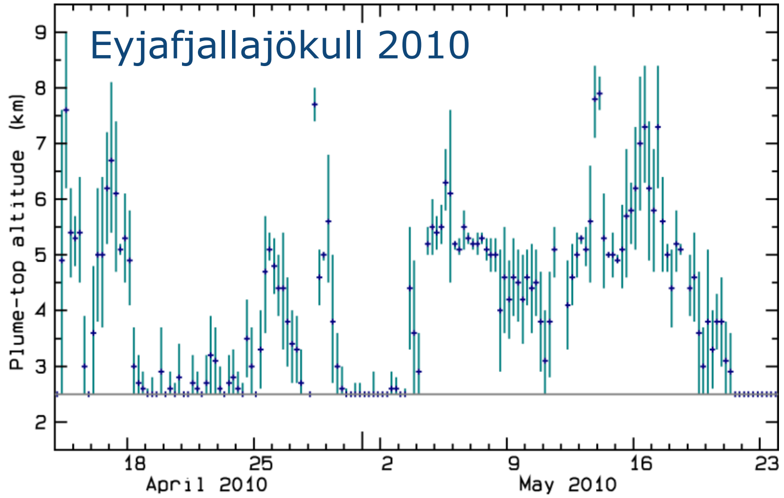
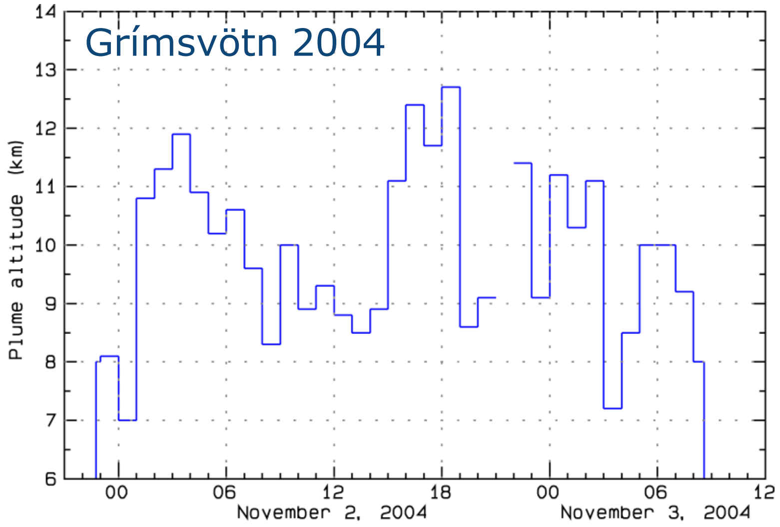
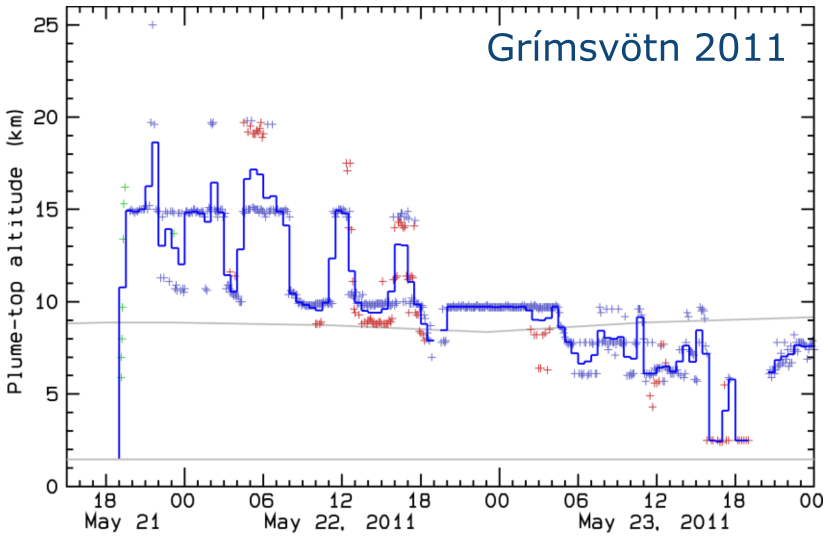


Arason et al. (2011)

Vogfjörd et al. (2005)



Petersen et al. (2012)



The VESPA System
Volcanic Eruptive Source Parameter Assessment

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Integrated automatic real-time system

1. **Eruption Onset:** Manually estimated
2. **Plume Height:** Weather radar data are used to estimate plume height over volcano every hour
3. **Source Parameters:** Inversion for source parameters in the 1D DAKOTA PlumeMoM model using the radar plume height and vertical atmospheric profile from the ECMWF numerical weather prediction model
4. **Ash Dispersal:** Initialization of the dispersal models VOL-CALPUFF and NAME with the estimated source parameters and weather data

Vespa web
http://brunnur.vedur.is/radar/vespa/

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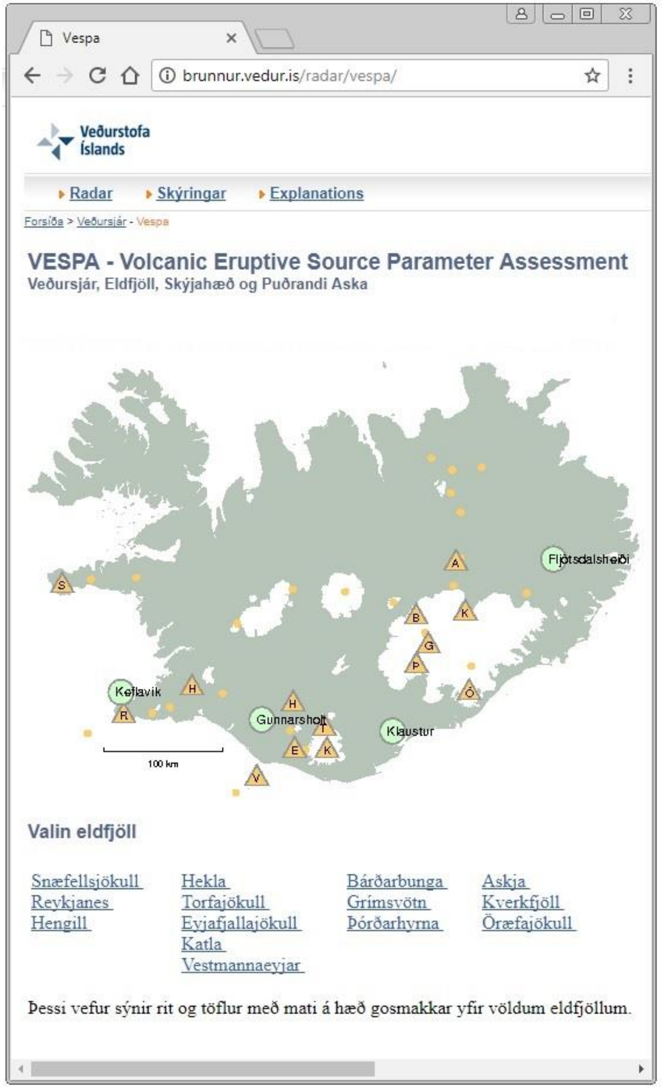
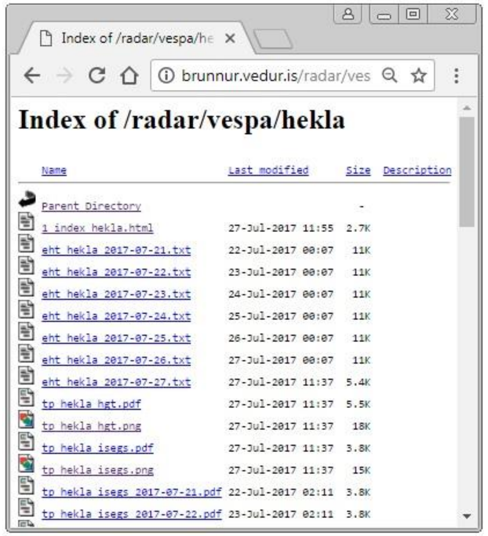
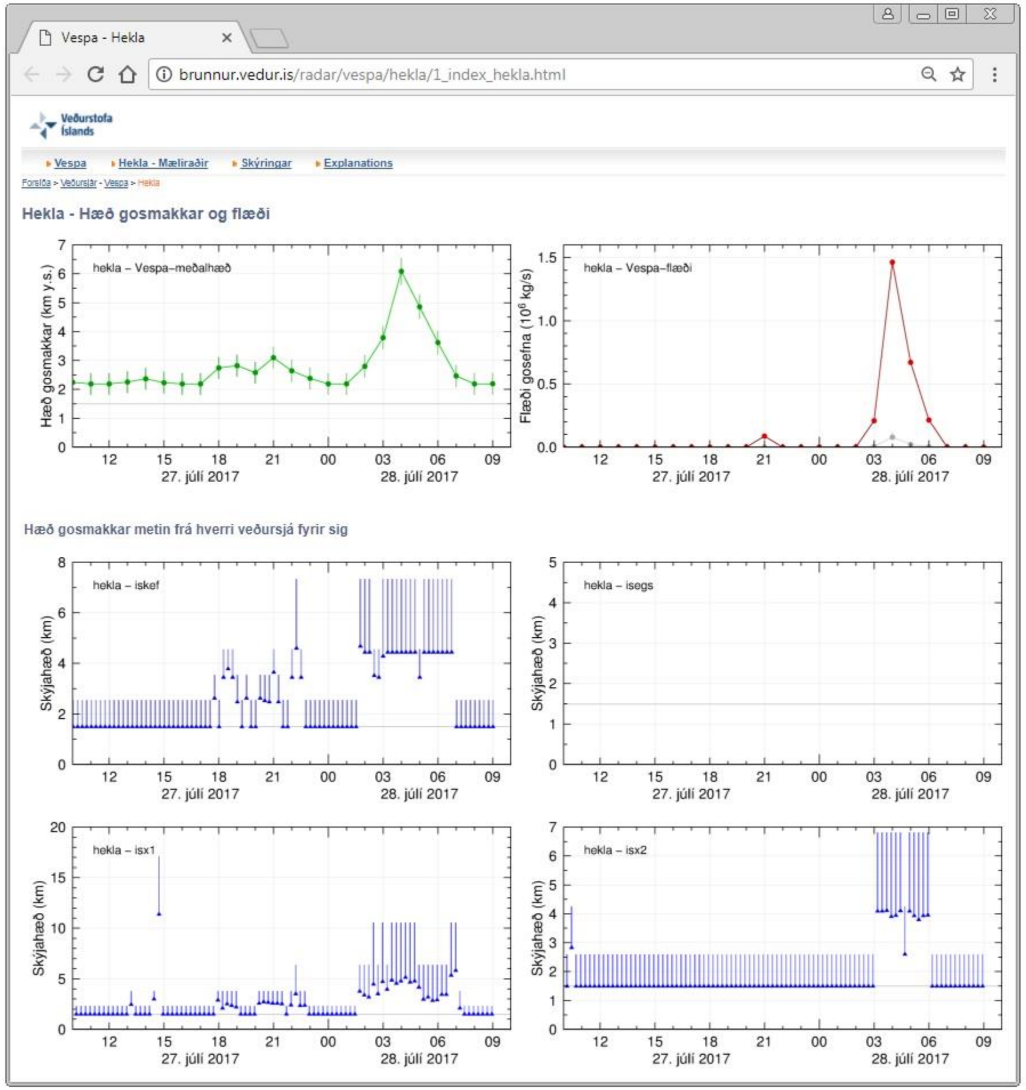
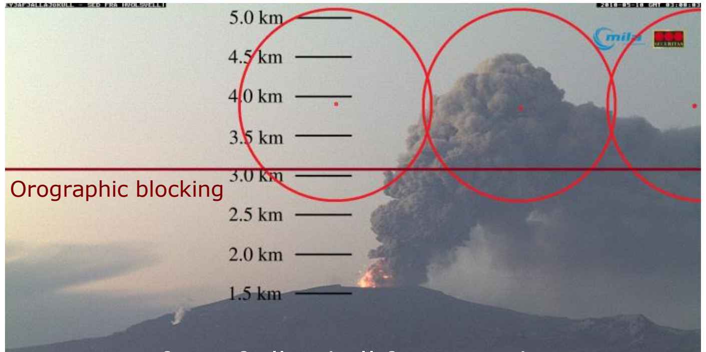




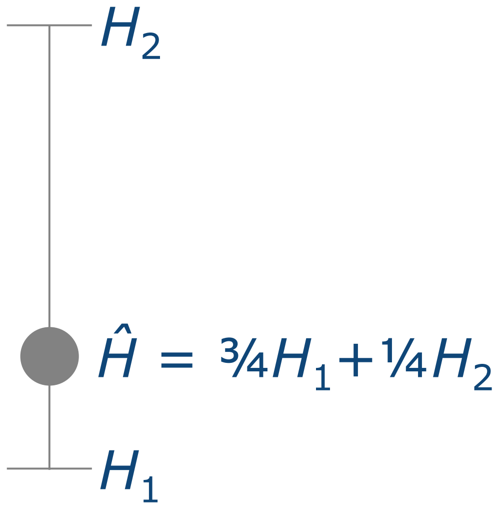


Plume Height Estimation
Hourly mean plume height and uncertainty

- For each radar scan two heights are determined, $\boldsymbol{H_1}$ the highest point where a significant radar reflection was detected within 10 km distance of the volcano, and $\boldsymbol{H_2}$ the height of the next radar elevation angle above volcano, where plume was not detected
- Comparison of the $\boldsymbol{H_1}$ and $\boldsymbol{H_2}$ radar heights to plume height determined from wind corrected web camera images during Eyjafjallajökull 2010 indicate that mean height is closer to the lower level: $\boldsymbol{\hat{H} = \tfrac{3}{4}H_1 + \tfrac{1}{4}H_2}$
- Uncertainty was chosen to be asymmetric from $\boldsymbol{H_1}$ to $\boldsymbol{H_2}$
- Plume height on the hour is estimated as the mean, weighted by uncertainties, for all scans between 30 min before the hour and 30 min after the hour (4-48 scans)



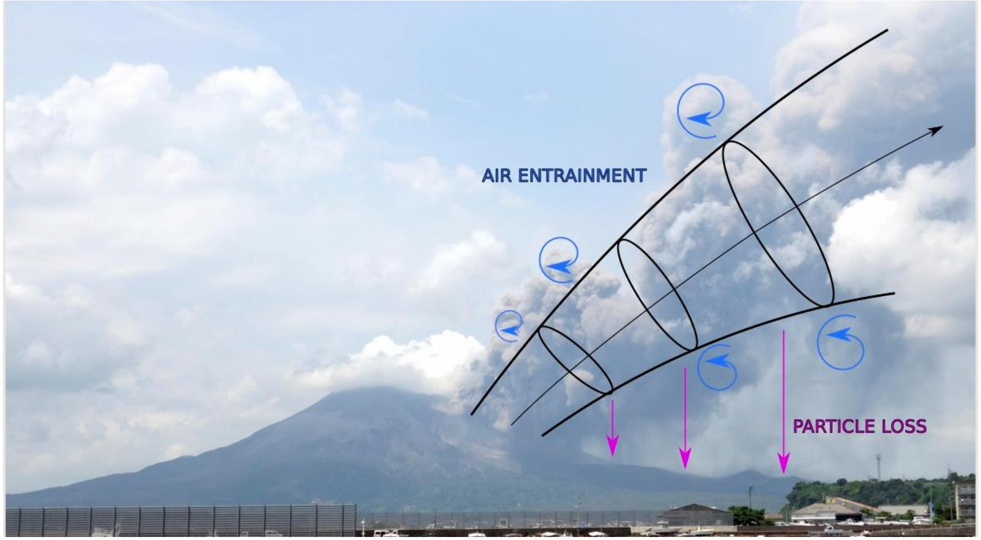
View of Eyjafjallajökull from a web camera at Hvolsvöllur, 10 May 2010 at 03:00

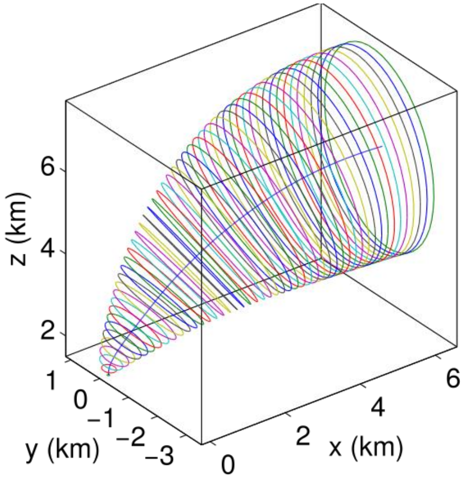


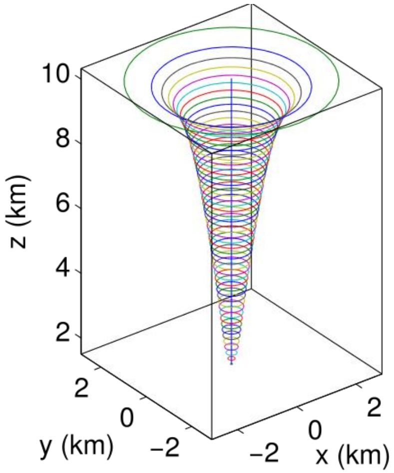
Plume Model – PlumeMoM[1]

Accounts for effects of wind on plume

- Accounts for the effect of wind, which bends the plume trajectory and increases entrainment of ambient air
- Accounts for particle fallout. Radial and crosswind air entrainment are parameterized using two entrainment coefficients
- Solves equations for the conservation of mass, momentum, energy, and the variation of heat capacity and mixture gas constant
- Possible to describe a continuous size distribution of particles through the method of moments
- Vertical profile of wind above volcano is retreived from the latest ECMWF[2] numerical weather prediction model





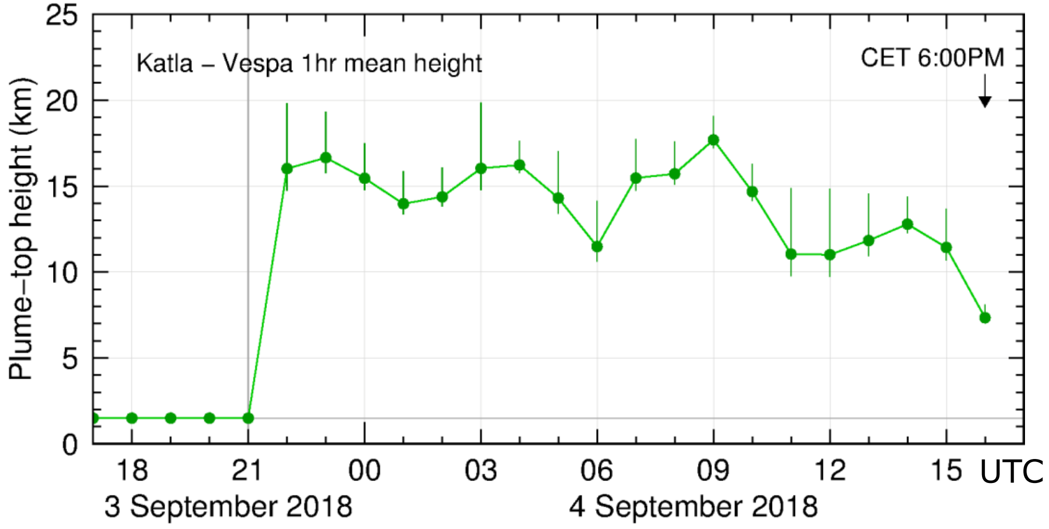


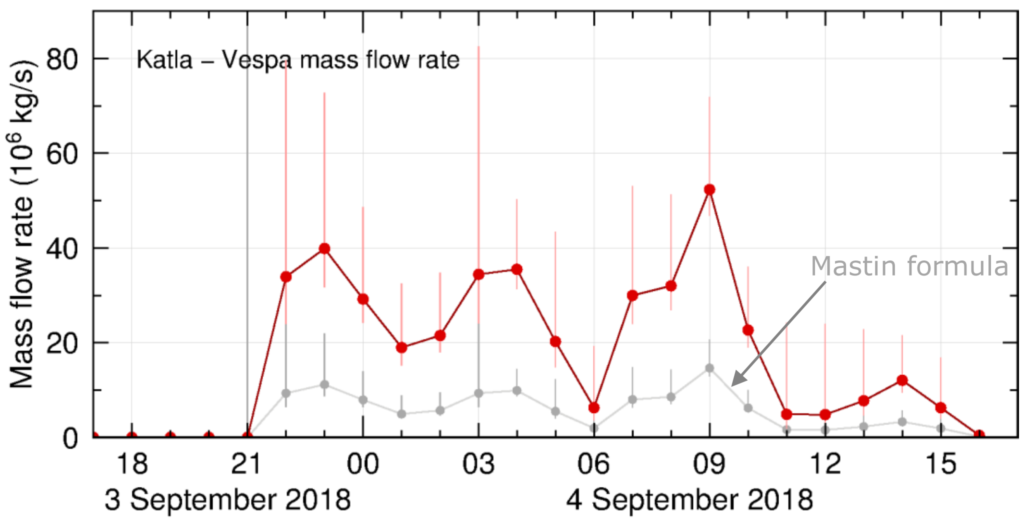
1 de' Michieli Vitturi et al. (2015; 2016)

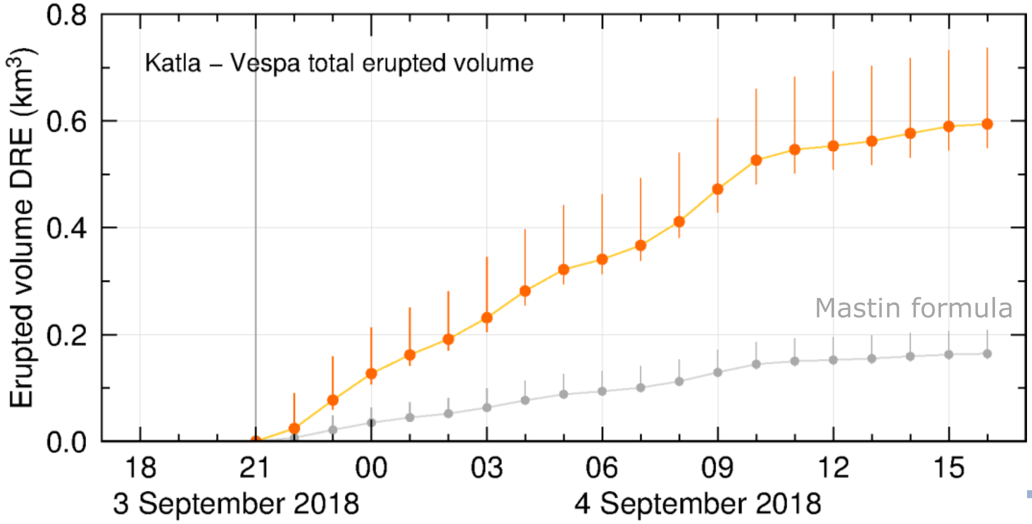
2 ECMWF: European Centre for Medium-Range Weather Forecasts is an independent intergovernmental organisation supported by 34 European states. ECMWF is based in Reading UK.

EXERCISE: Eruption of Katla

Started 19 hours ago: 3 September at 21:00 UTC







Validation — Total Erupted Material
Three explosive eruptions in Iceland

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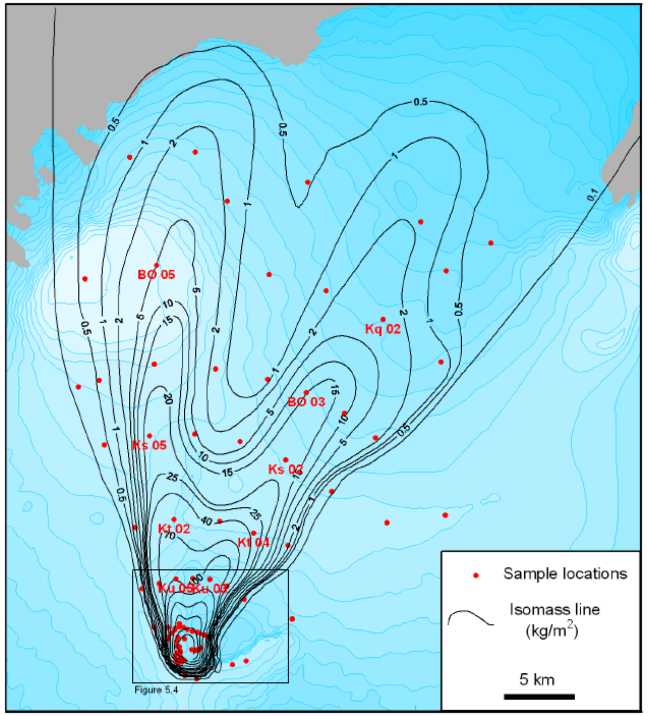
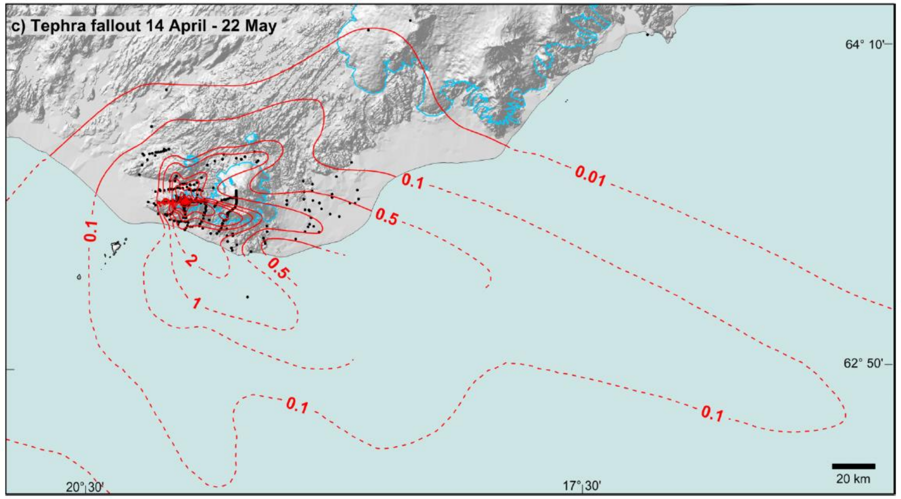
Grímsvötn 2004
$21 \pm 2 \times 10^6$ m^3 DRE



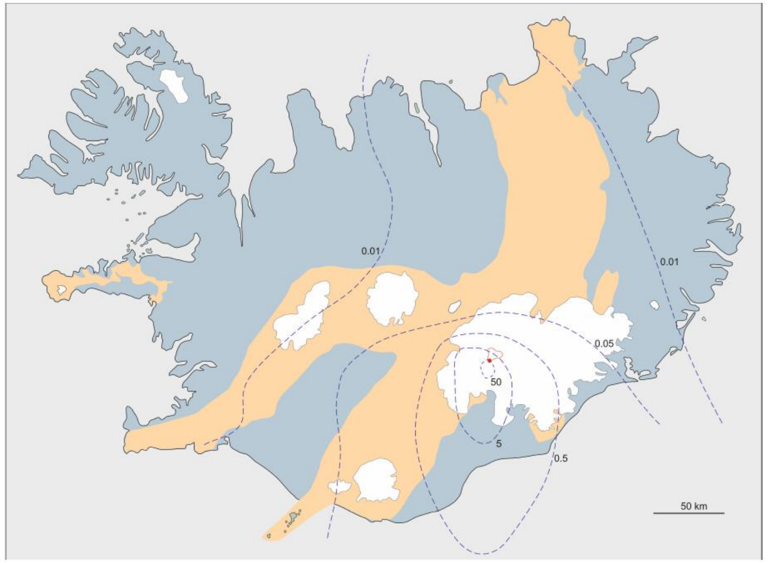
Oddsson (2007)

Eyjafjallajökull 2010
$180 \pm 50 \times 10^6$ m^3 DRE



Gudmundsson et al. (2012)

Grímsvötn 2011
$270 \pm 70 \times 10^6$ m^3 DRE



Hreinsdóttir et al. (2014)
Lynch (2015)

Validation I — Grímsvötn 2004
Weak plume — Strong winds

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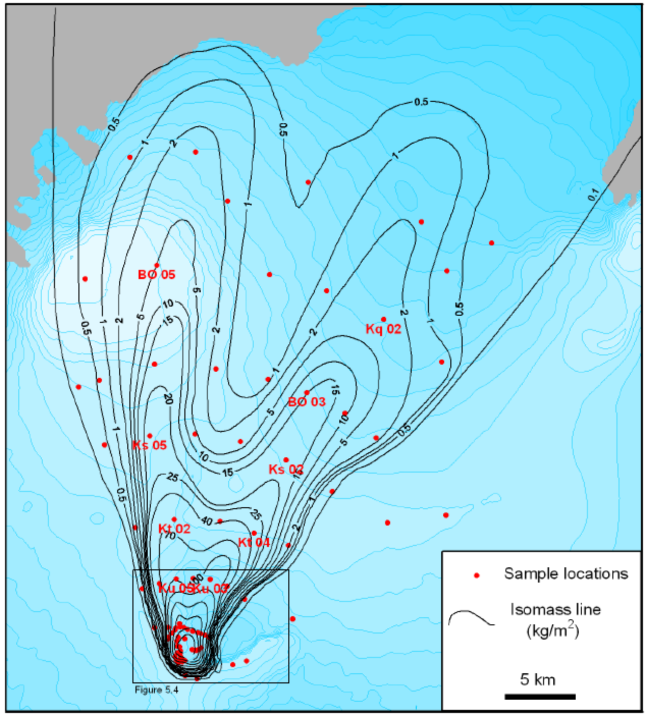
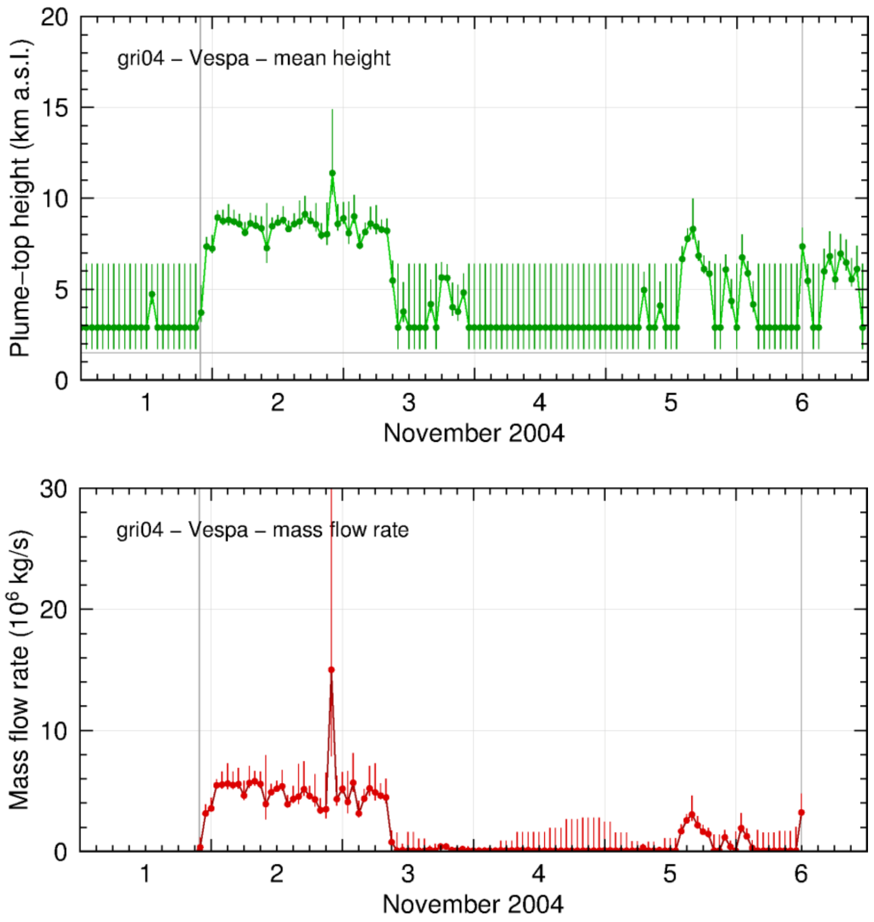
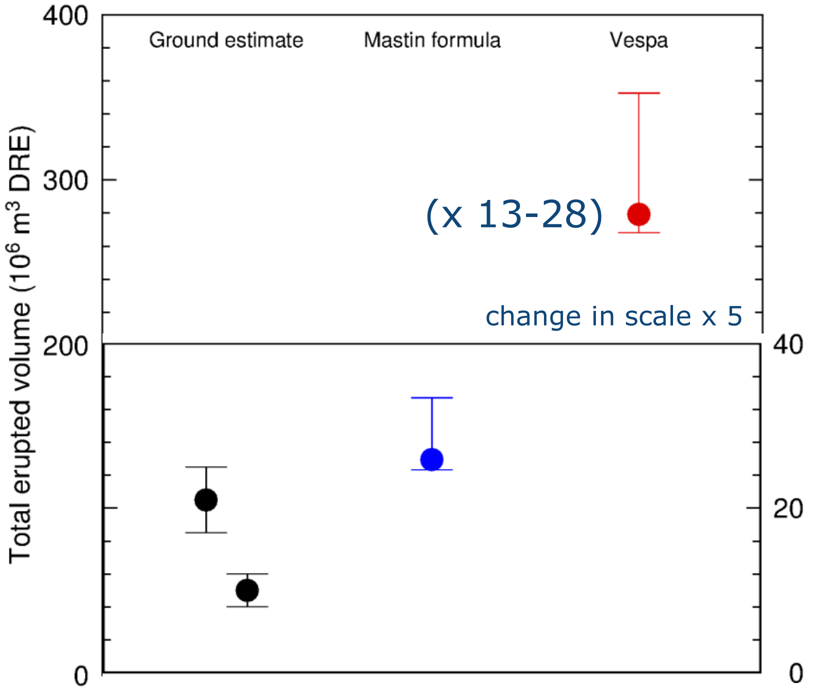


21 ± 4 x 10^6 m^3 DRE
10 ± 2 x 10^6 m^3 DRE
Oddsson (2007)





Validation II — Eyjafjallajökull 2010
Weak plume — Strongly variable winds

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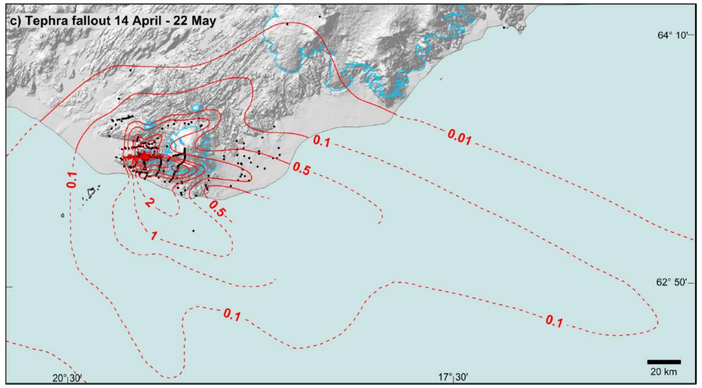
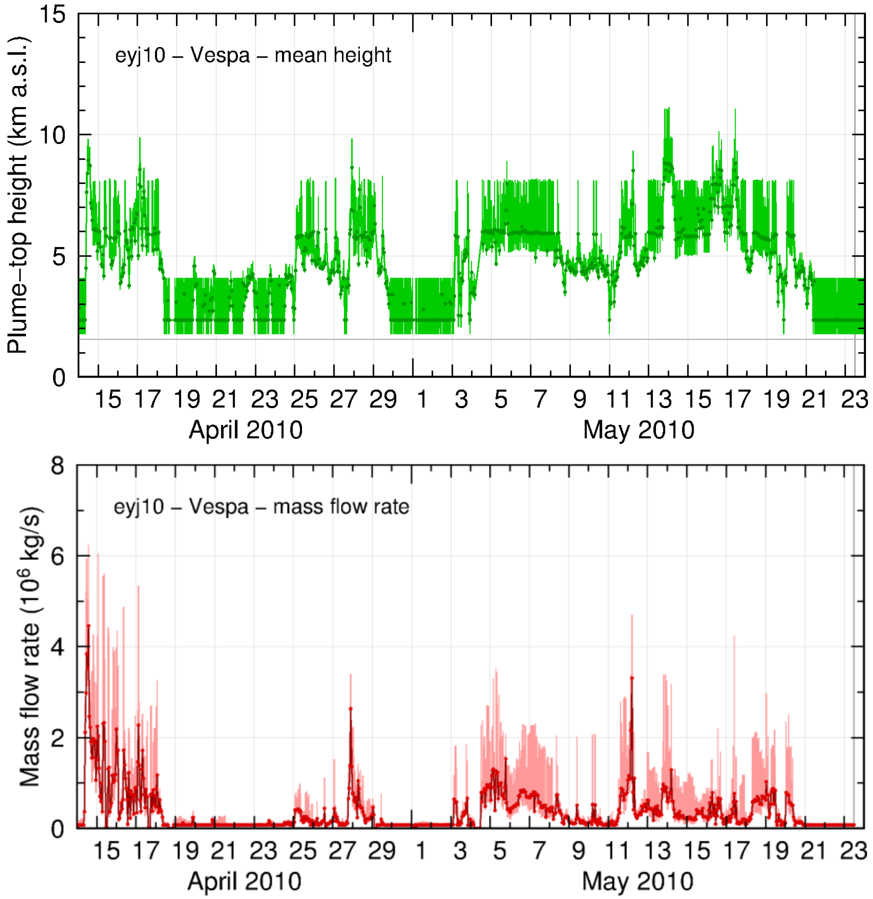
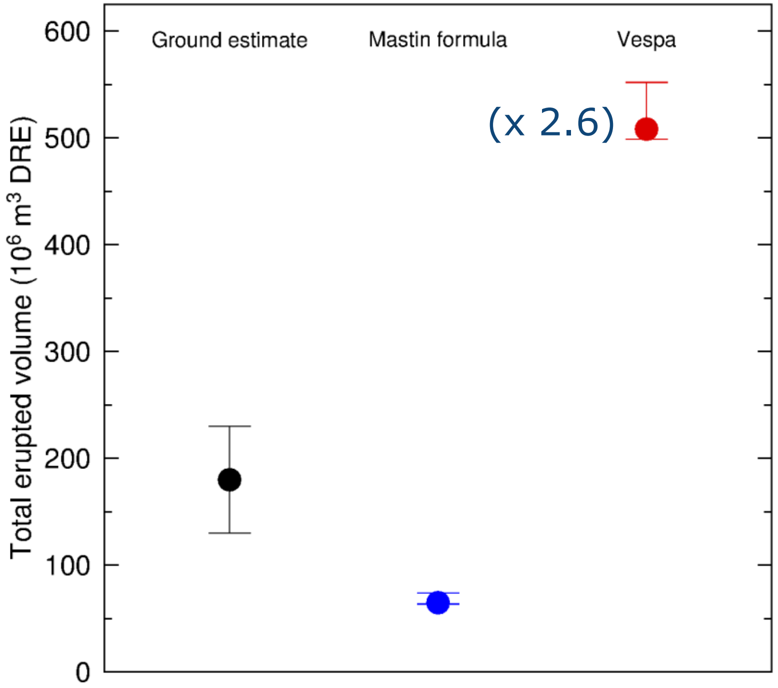
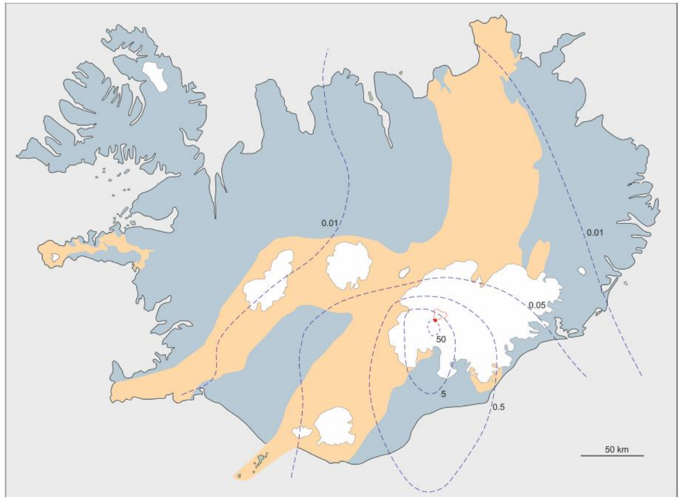


180 ± 50 x 10^6 m^3 DRE
Gudmundsson et al. (2012)

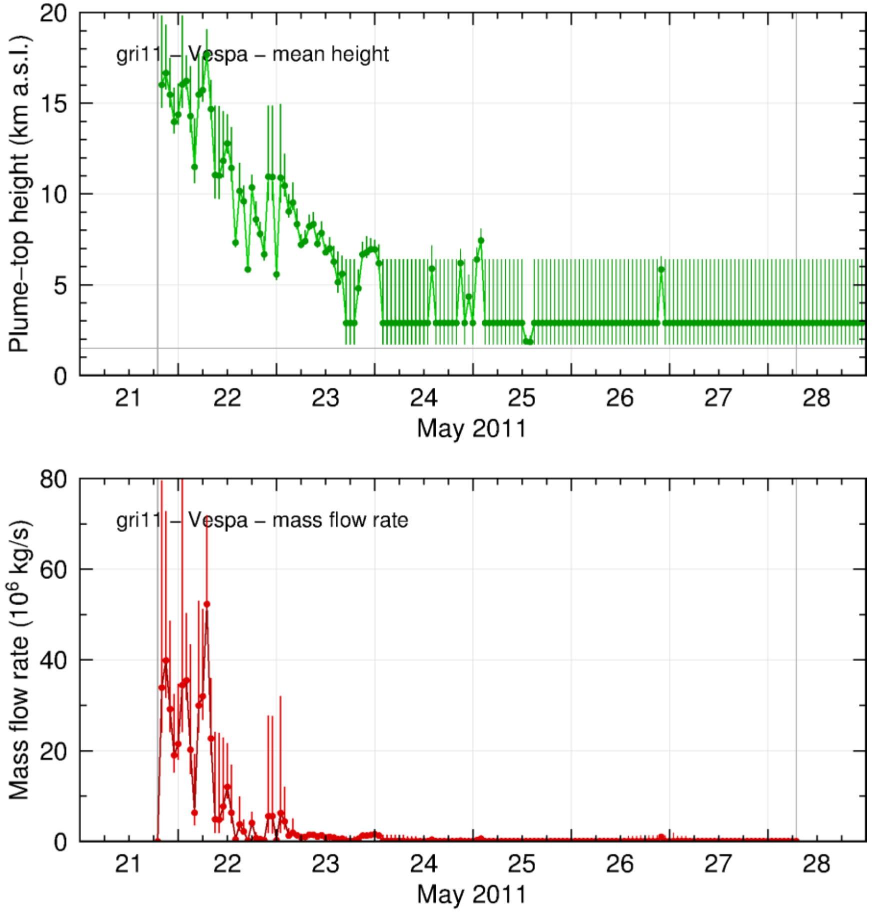


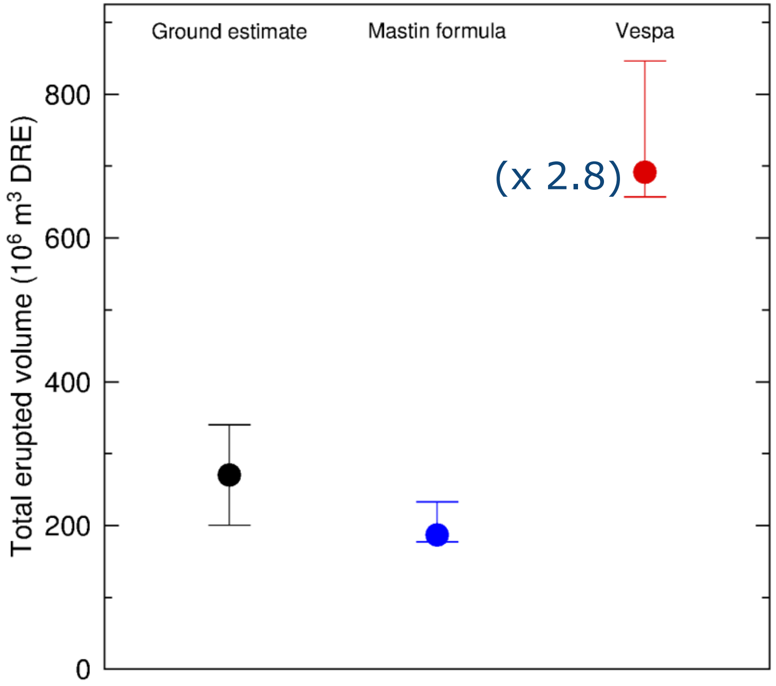


Validation III — Grímsvötn 2011
Strong plume — Low winds



270 ± 70 x 10^6 m^3 DRE
Hreinsdóttir et al. (2014)
Lynch (2015)





Bent-Over Plumes by Wind

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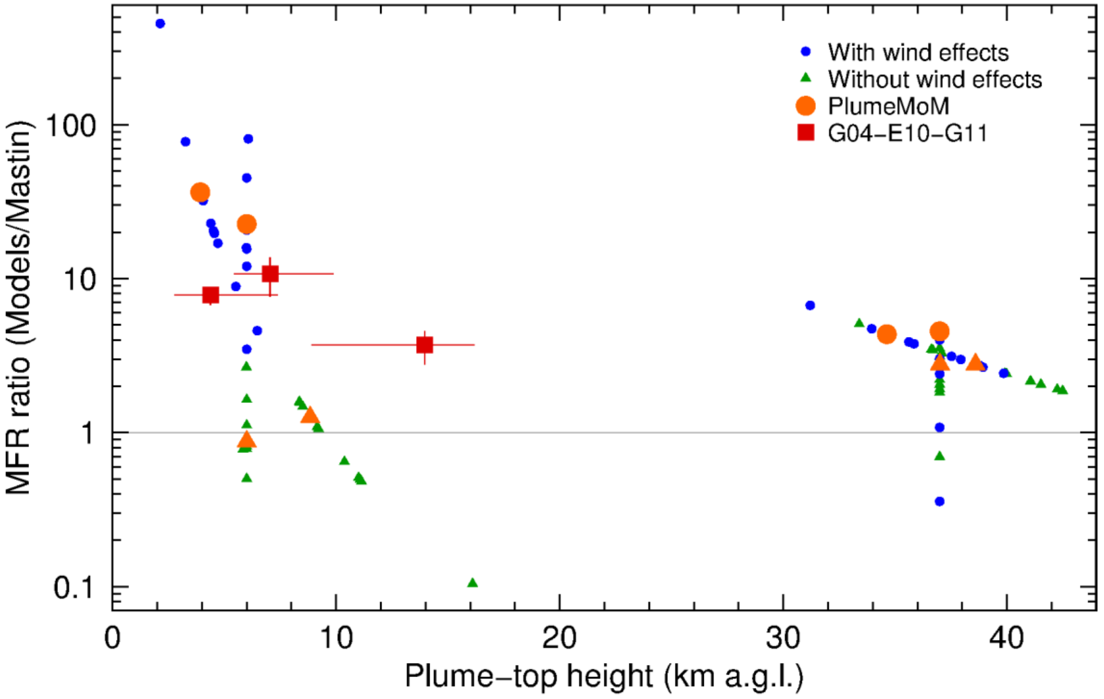
- Inter-comparison study of numerical plume models indicates that results for weak plumes, bent-over by wind, often provide an order of magnitude higher mass flow rate than calculated by the Mastin formula
- The graph shows ratio of calculated mass flow rate from 13 models vs. the Mastin formula, both with and without wind effects. The results for the PlumeMoM model are highlighted
- Values for Grímsvötn 2004, 2011 and Eyjafjallajökull 2010 were added



Data from Costa et al. (2016)

Conclusions

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- The Vespa system is currently in a semi-operational mode, while various aspects of the system are still under developement, including the link to the dispersal model VOL-CALPUFF
- Real-time output of the Vespa system is available for selected volcanoes, and can be turned on in case of unrest or sudden eruption at a new volcano: **http://brunnur.vedur.is/radar/vespa/**
- Discrepancies between plume rise models and "ground truth" (e.g. for the Grímsvötn 2004 case) are unconfortably high — and need to be resolved or understood

References

Arason, Þ., G. N. Petersen & H. Bjornsson (2011), Observations of the altitude of the volcanic plume during the eruption of Eyjafjallajökull, April-May 2010, *Earth System Science Data*, **3**, 9-17, doi:10.5194/essd-3-9-2011

Barsotti, S., A. Neri & J. S. Scire (2008), The VOL-CALPUFF model for atmospheric ash dispersal: 1. Approach and physical formulation, *Journal of Geophysical Research*, **113**, B03208, doi:10.1029/2006JB004623

Barsotti, S. & A. Neri (2008), The VOL-CALPUFF model for atmospheric ash dispersal: 2. Application to the weak Mount Etna plume of July 2001, *Journal of Geophysical Research*, **113**, B03209, doi:10.1029/2006JB004624

Costa A., Y. J. Suzuki, M. Cerminara, B. J. Devenish, T. Esposti Ongaro, M. Herzog, A. R. Van Eaton, L. C. Denby, M. Bursik, M. de' Michieli Vitturi, S. Engwell, A. Neri, S. Barsotti, A. Folch, G. Macedonio, F. Girault, G. Carazzo, S. Tait, E. Kaminski, L. G. Mastin, M. J. Woodhouse, J. C. Phillips, A. J. Hogg, W. Degruyter & C. Bonadonna (2016), Results of the eruptive column model inter-comparison study, *Journal of Volcanology and Geothermal Research*, **326**, 2–25, doi:10.1016/j.jvolgeores.2016.01.017

de' Michieli Vitturi, M., A. Neri & S. Barsotti (2015), PLUME-MoM 1.0: A new integral model of volcanic plumes based on the method of moments, *Geoscientific Model Development*, **8**, 2447-2463, doi:10.5194/gmd-8-2447-2015

de' Michieli Vitturi, M., S. L. Engwell, A. Neri & S. Barsotti (2016), Uncertainty quantification and sensitivity analysis of volcanic columns models: Results from the integral model PLUME-MoM**,** *Journal of Volcanology and Geothermal Research*, **326**, 77-91, doi:10.1016/j.jvolgeores.2016.03.014

Gudmundsson, M. T., T. Thordarson, Á. Höskuldsson, G. Larsen, H. Björnsson, F. J. Prata, B. Oddsson, E. Magnússon, T. Högnadóttir, G. N. Petersen, C. L. Hayward, J. A. Stevenson & I. Jónsdóttir (2012a), Ash generation and distribution from the April-May 2010 eruption of Eyjafjallajökull, Iceland, *Scientific Reports*, **2**, 572, doi:10.1038/srep00572

Hreinsdóttir, S., F. Sigmundsson, M. J. Roberts, H. Bjornsson, R. Grapenthin, Þ. Arason, T. Arnadottir, J. Holmjarn, H. Geirsson, R. A. Bennett, M. T. Gudmundsson, B. Oddsson, B. G. Ofeigsson, T. Villemin, T. Jonsson, E. Sturkell, A. Hoskuldsson, G. Larsen, T. Thordarson & B. A. Oladottir (2014), Volcanic plume height correlated with magma pressure change at Grímsvötn volcano, Iceland, *Nature Geoscience*, **7(3)**, 214-218, doi:10.1038/ngeo2044.

Lynch, R. A. (2015), *Magma vesiculation and nature of the explosive activity in the 2011 Grímsvötn eruption*, M.Sc. thesis, Faculty of Earth Sciences, University of Iceland.

Mastin, L. G., M. Guffanti, R. Servranckx, P. Webley, S. Barsotti, K. Dean, A. Durant, J. W. Ewert, A. Neri, W. I. Rose, D. Schneider, L. Siebert, B. Stunder, G. Swanson, A. Tupper, A. Volentik & C. F. Waythomas (2009), A multidisciplinary effort to assign realistic source parameters to models of volcanic ash-cloud transport and dispersion during eruptions, *Journal of Volcanogy loand Geothermal Research*, **186**, 10-21, doi:10.1016/j.jvolgeores.2009.01.008

Oddsson, B. (2007), *The Grímsvötn eruption in 2004: Dispersal and total mass of tephra and comparison with plume transport models*, M.Sc. thesis, Faculty of Earth Sciences, University of Iceland

Petersen, G. N., H. Bjornsson, Þ. Arason & S. von Löwis (2012), Two weather radar time series of the altitude of the volcanic plume during the May 2011 eruption of Grímsvötn, Iceland, *Earth System Science Data*, **4**, 121-127, doi:10.5194/essd-4-121-2012

Vogfjörd, K. S., S. S. Jakobsdóttir, G. B. Guðmundsson, M. J. Roberts, K. Ágústsson, Þ. Arason, H. Geirsson, S. Karlsdóttir, S. Hjaltadóttir, U. Ólafsdóttir, B. Thorbjarnardóttir, T. Skaftadóttir, E. Sturkell, E. B. Jónasdóttir, G. Hafsteinsson, H. Sveinbjörnsson, R. Stefánsson & T. V. Jónsson (2005), Forecasting and monitoring a subglacial eruption in Iceland, *Eos Transactions, American Geophysical Union*, **86**(26), 28 June 2005, 245-248, doi:10.1029/2005EO260001

Abstract

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The Vespa-system: Real-time estimation of eruption source parameters

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We describe attempts to automatically estimate time series of plume height and mass eruption rate during explosive eruptions in Iceland. The Icelandic Meteorological Office (IMO) is responsible for monitoring over 30 active volcanic systems, and operates two fixed position C-band weather radars and two mobile X-band radars, which are crucial in monitoring plume height, due to their independence of daylight, weather and visibility. These data are available in real-time to the natural hazards specialists and meteorologists on duty in the IMO's 24/7 monitoring room. In case of an eruption the data are also communicated to London VAAC to support their ash transport simulations for aviation safety purposes. The newly developed VESPA software uses automatically derived plume height estimates from the radar data to calculate the eruptive source parameters (mass flow rate, vertical velocity and vent radius) through an inversion algorithm using PlumeMoM, which solves the 1D plume model equations, and atmospheric profiles from the ECMWF numerical weather prediction model. Furthermore, the estimate of mass eruption rate calculated by VESPA are used to initialize the VOL-CALPUFF dispersion model to forecast the local impact on the ground due to tephra fallout. In this study we describe the VESPA-system and discuss estimated eruption source parameters for the eruptions of Grímsvötn 2004, Eyjafjallajökull 2010 and Grímsvötn 2011.