Icelandic Met Office

Dispersion modeling and science into operations at the Icelandic Meteorological Office

Sara Barsotti, Elín B. Jónasdóttir, Melissa A. Pfeffer, Þórður Arason, Richard Yeo, Hermann Arngrímsson, Bolli Pálmason, Hrafn Guðmundsson, Björn S. Einarsson, Sigrún Karlsdóttir, Theodór F. Hervarsson, Guðrún N. Petersen, Halldór Björnsson

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Outline

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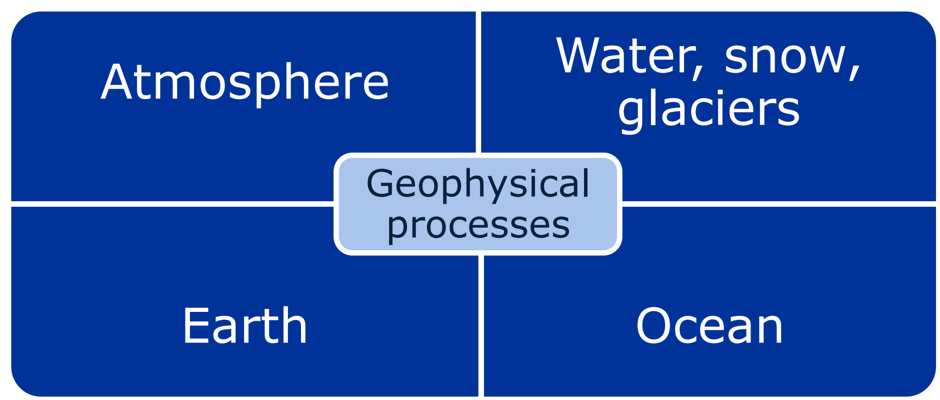
- Response to a volcanic crises at IMO/IVO
- from the acquisition of the plume height observation,
- to the dispersal modelling,
- to the forecast,
- to the final products disseminated to different end-users.
- A real example: the Holuhraun eruption in 2014-2015
- Conclusion

The role of the Icelandic Meteorological Office

The main purpose of IMO is to contribute towards increased security and efficiency in society by:

- **Monitoring**, analysing, interpreting, informing, giving advice and counsel, providing **warnings** and **forecasts** and where possible, predicting natural processes and natural hazards.
- Issuing public and aviation **alerts** about impending natural hazards, such as volcanic ash, extreme weather and flooding



IMO and IVO

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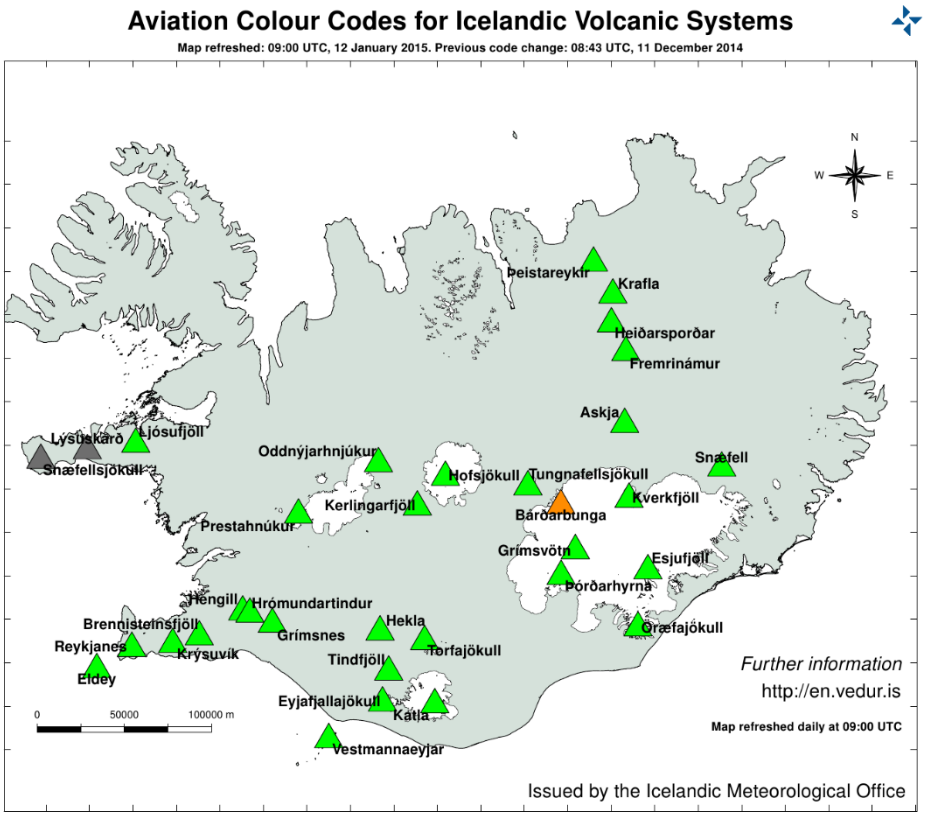
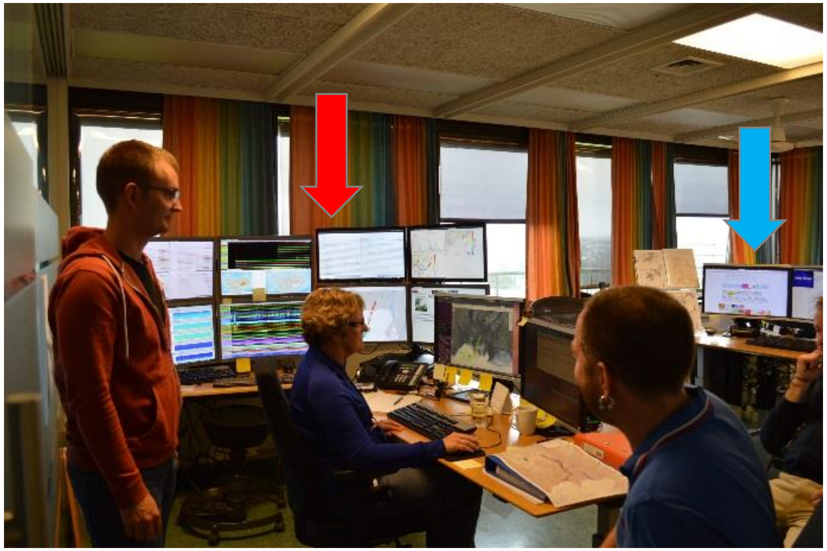
- IVO is the **Icelandic Volcano Observatory** and it coexists within IMO
- Integration of interpretations and multidisciplinary investigation
- Fast and effective communication



Aviation colour codes used by the Icelandic Meteorological Office



IMO‘s response in case of volcanic crises: the early-warning

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IMO monitors Iceland with a dense network of instrumentation and equipment deployed across the country:

- In the monitoring room the main **geo-physical real-time** data are received and processed
- Internal **automatic alert systems** are currently in place
- Change to the **Aviation color code**

IMO designed and follows **contingency plans** for all the natural hazards and for different field teams.

In case of a volcanic eruption our main stakeholders are:

1. AVIATION (L-VAAC, ISAVIA) (phone calls)
2. CIVIL PROTECTION (phone calls) and GENERAL PUBLIC (web-site)

Observation and estimation of plume height

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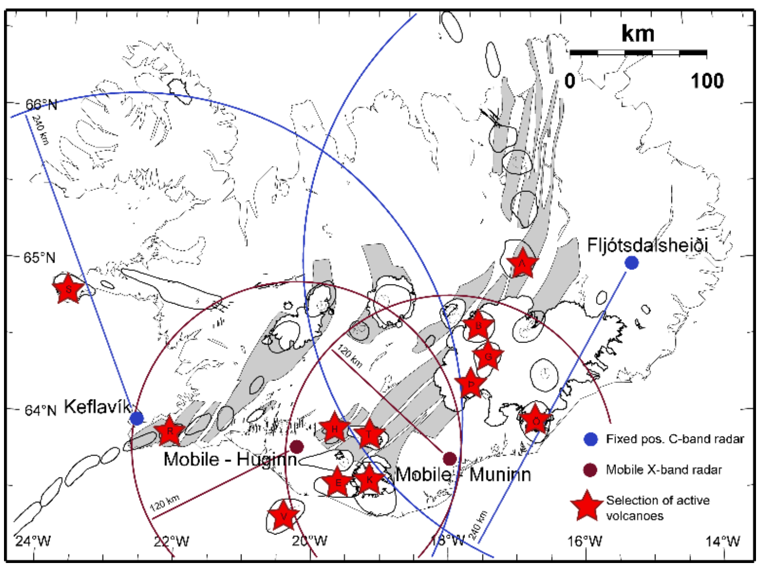
- The radar network allows to cover almost ***completely*** the entire country
- Most of the volcanoes have now been ***ranked*** on the basis of how well an eruption will be seen by the radar network



Volcano	Fixed C-band radars	Mobile X-band radars
Hekla		
Katla		
Grímsvötn		
Bárðarbunga		
Reykjanes - Svartsengi		
Öræfajökull		
Eyjafjallajökull		
Hengill		
Þórðarhyrna		
Askja		
Snæfellsjökull		
Vestmannaeyjar		
Torfajökull		

Observation and estimation of plume height

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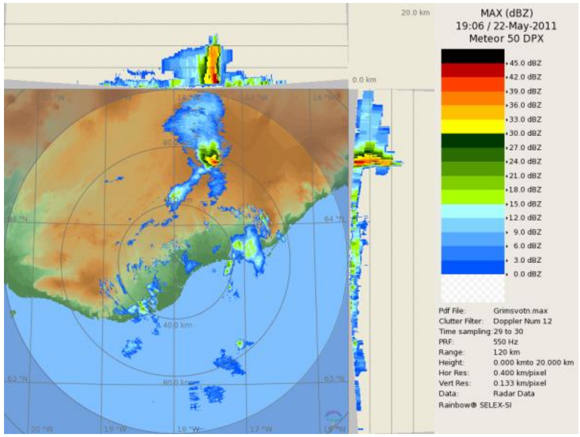
- The radars will see the ***top of the plume***
- A calculator has been created to compute the ***uncertainty*** in height estimation for any radar network configuration



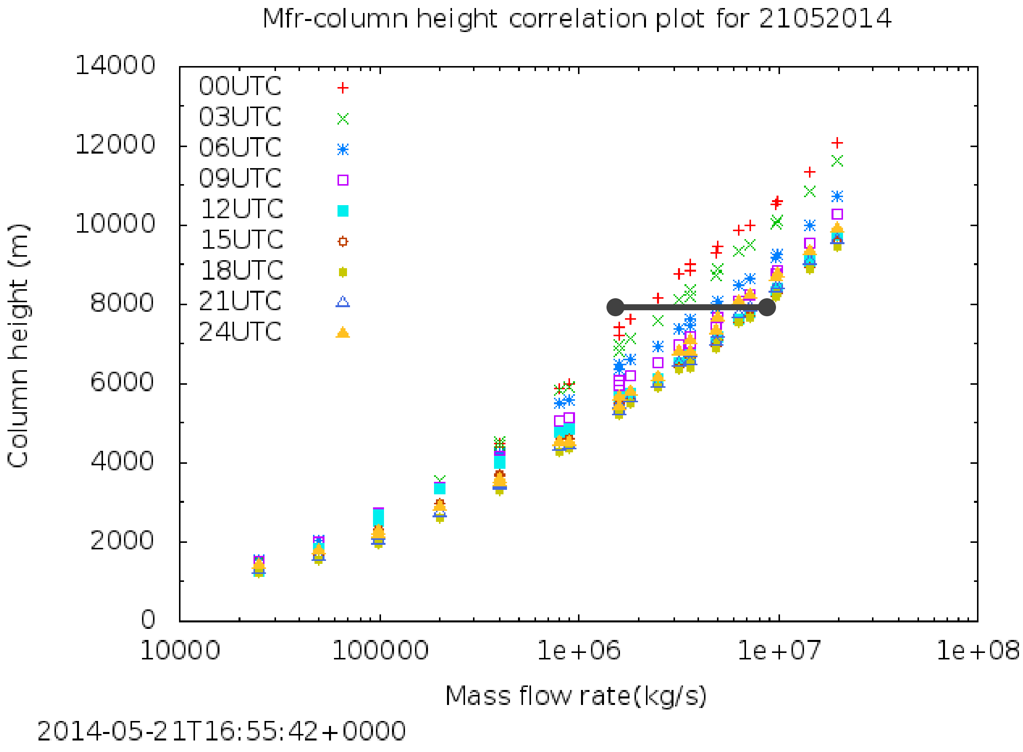
	Volcano	Lat (°N)	Lon (°W)	Elevation (m)
	Hekla	63,991900	19,667400	1491

Radar					Resolution at volcano				
Radar	Place name	Lat (°N)	Lon (°W)	Elevation (m)	Min height (km a.s.l.)	Min height (km a.g.l.)	Range resolution (km)	Azimutha resolutio (km)	Height resolution (km)
iskef	Keflavík	64,026383	22,635833	47	3,551	2,060	2,000	2,172	2,273
isegs	Fljótsdalsheiði	65,027944	15,038186	698	8,282	6,791	0,250	1,743	4,357
isx1	Gunnarsholt	63,860377	20,200538	90	1,810	0,319	0,250	0,522	0,652
isx2	Klaustur	63,774958	17,965092	40	3,207	1,716	0,250	1,514	1,893
Rvk	Veðurstofan - svalir	64,127494	21,904044	61	2,550	1,059			

Observation and estimation of plume height

The information of plume height (including uncertainty, top, buoyancy level, etc..) is received by both L-VAAC and ISAVIA (by phone calls).

IMO uses the information of observed plume height to provide a rough estimate of **mass flow rate** by inverting the plume model implemented in house (i.e. Bursik 2001 and de' Michieli Vitturi et al. 2015):



Numerical modelling and volcanic ash/gas dispersal

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Internally at IMO this information is used to initialize the numerical models for ash/gas dispersal and fallout.

Three different numerical models are in use:

- ***NAME* code** (currently used by London VAAC, Jones et al. 2007) – purely Lagrangian code for simulating volcanic particles transport and deposition
- ***VOL-CALPUFF* code** (Barsotti et al. 2008) – hybrid code for simulating volcanic plume rise and volcanic particles transport and deposition
- **CALPUFF code** (Scire et al. 1998) – air-quality model widely used for gas dispersal and ground concentration

Products currently available at IMO

- ✓ **NAME** is running at IMO, almost operationally, for 4 volcanoes (Hekla, Katla, Grímsvötn and Bárðarbunga) since February 2014. In case of real eruption a new runs will be initialized and executed, the results will be available to the forecasters
- ✓ **VOL-CALPUFF** is used for ad-hoc simulations and for Monte-Carlo simulations; in case of an eruption it will be used for tephra-fallout and ground concentration of ash
- ✓**CALPUFF** has been used to forecast the gas cloud from Holuhraun (2014-2015) and is ready to be used again (http://brunnur.vedur.is/kort/spakort/). It has been also used to produce hazard maps.

Operational tools at IMO: NAME

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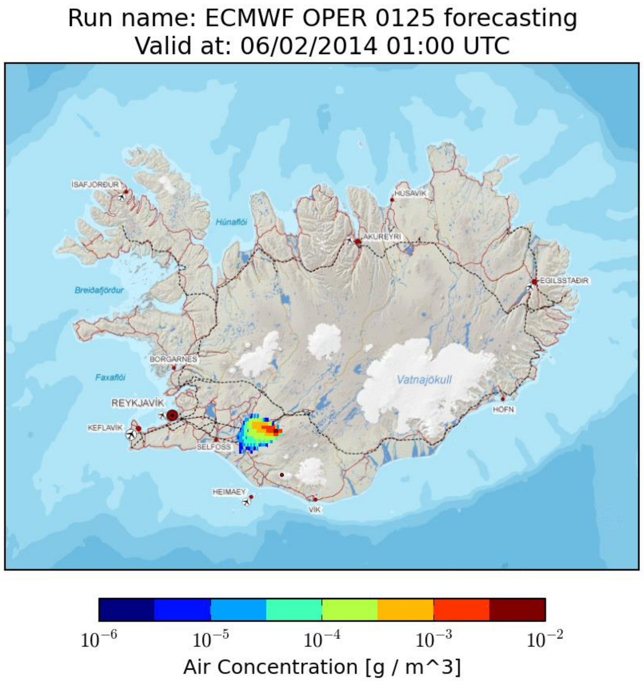

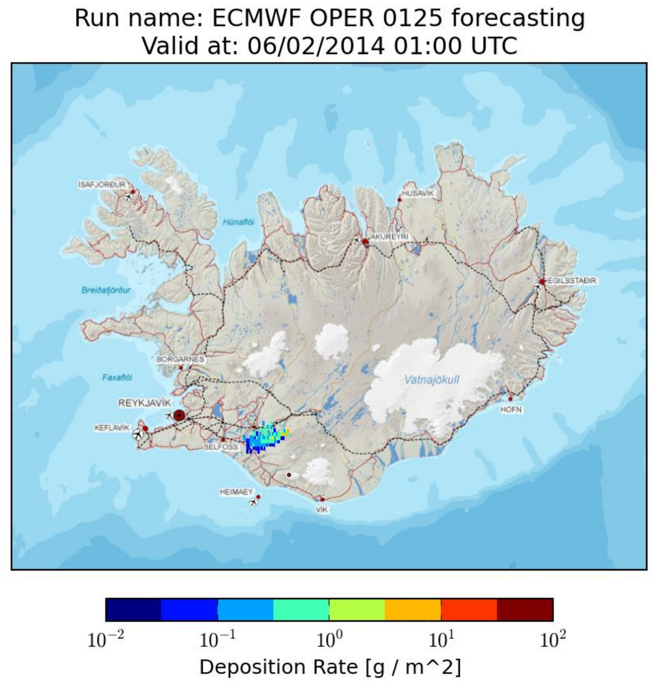

Ash concentration in the atmosphere (of concern for aviation)

Ash deposit on the ground (of concern for population, infrastructures, agriculture…)

VOL-CALPUFF for tephra loading computation: two examples (Hekla 2000 and Katla 1918)

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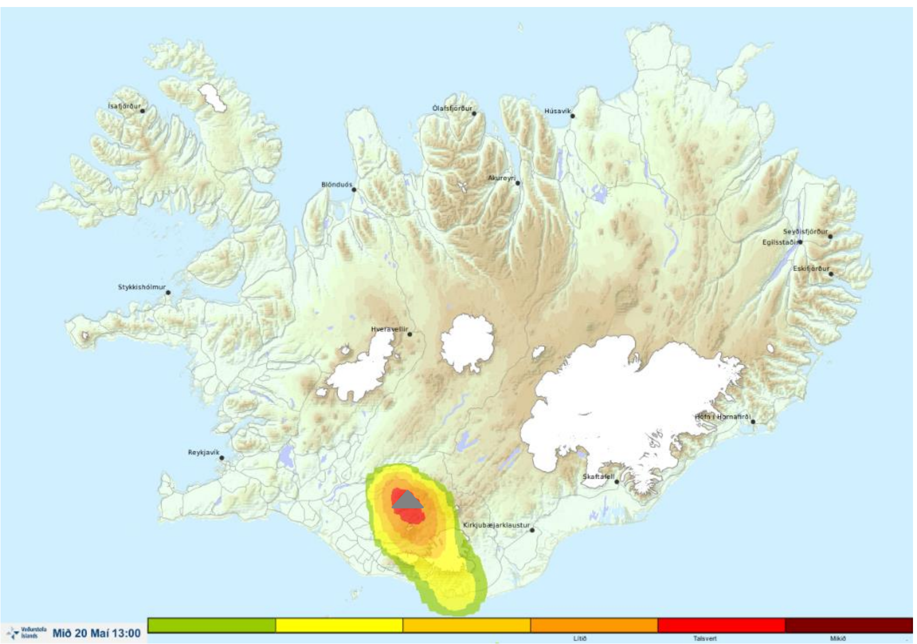
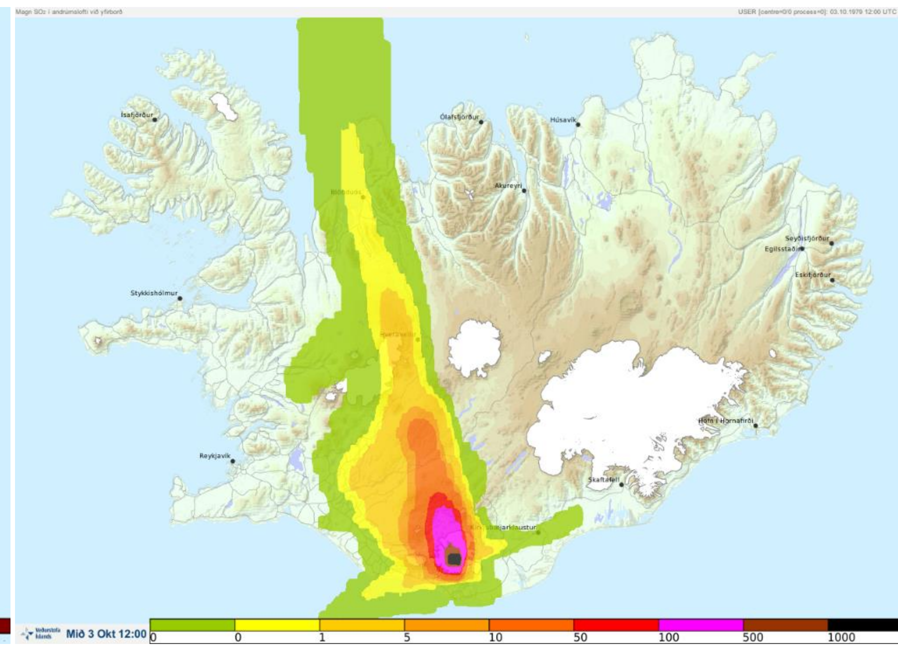
- The model has been used for scenario-based simulations
- Ground deposition in kg/m^2 at the end of the eruption (24 and 20 hours respectively)



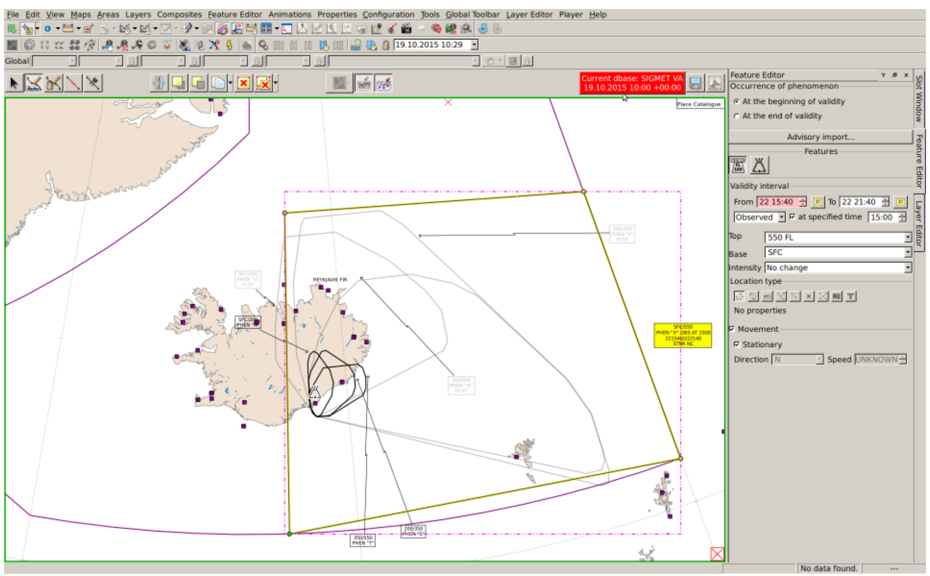


The issued products

AVIATION:

SIGMETs issued based on

1. Radar observation
2. NWP
3. In-house numerical modelling
4. Products from L-VAAC



CP and GENERAL PUBLIC:

- Daily **forecasts** of volcanic ash/gases dispersal (ground concentration and loading)
- **Hazard** assessment to identify critical localities that might be exposed to severe conditions (e.g. air quality issues, contamination of grass and water, exposure of critical infrastructures)
- Assessment of a **global impact** across the country at the end of the eruption (e.g. long-term health issues, enviromental impacts)

An example: Bárðarbunga unrest and Holuhraun eruption in 2014-2015

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At the onset of Bárðarbunga unrest phase the main concern was the potentiality for a *phreato-magmatic basaltic eruption* (ice-magma) and the production of ash.

When the lateral dike started to intrude the Scientific Advisory Board defined **three main scenarios**:

- Explosive eruption within the caldera (hundreds of meters of ice)
- Explosive eruption along the fissure (tenths of meters of ice)
- Explosive eruption at the margin of the glacier

For months, NAME has been run for all the three hypothetical scenarios twice a day, assuming three different plume heights (strong, moderate and small)

Volcanic cloud from the fissure

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- Rising up to 4.5 km
- Citizenship strongly affected by gas cloud
- SO_2 flux = 750 kg/s on average [from DOAS]
- Highest SO_2 concentration peak in Höfn has been 21,000 μg/m3

Photo courtesy G. Birkelsen

Photo courtesy R. Yeo

SO_2 cloud dispersal forecast over Iceland

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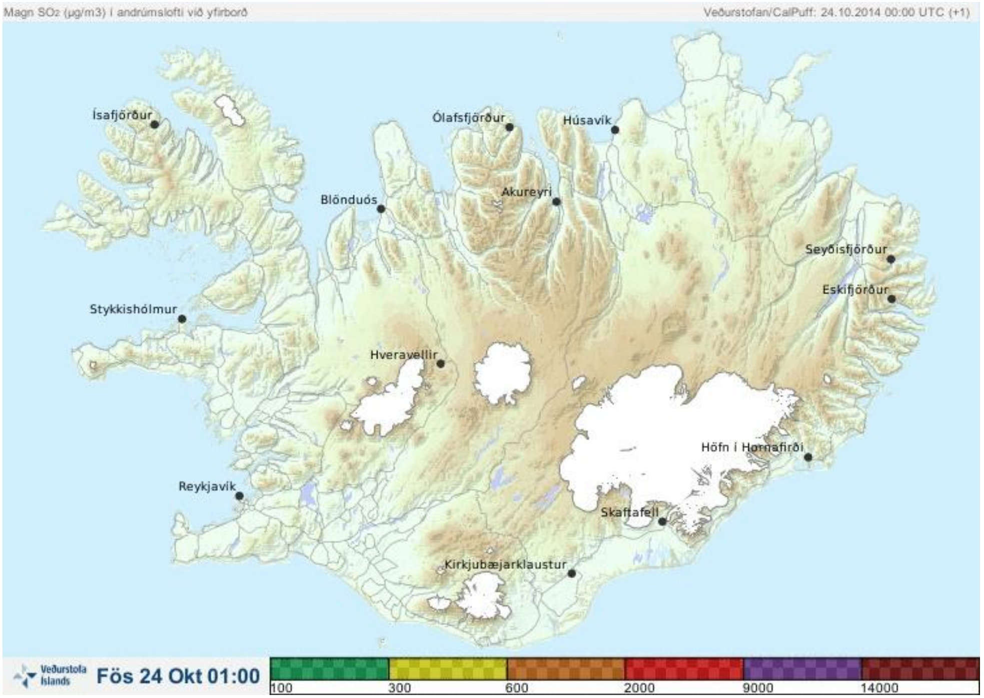
The CALPUFF code (Scire et al. 1998) has been used for producing forecast of SO_2 cloud dispersal, since few days after the starting of the eruption

It computes SO_2 concentration at ground level each hour

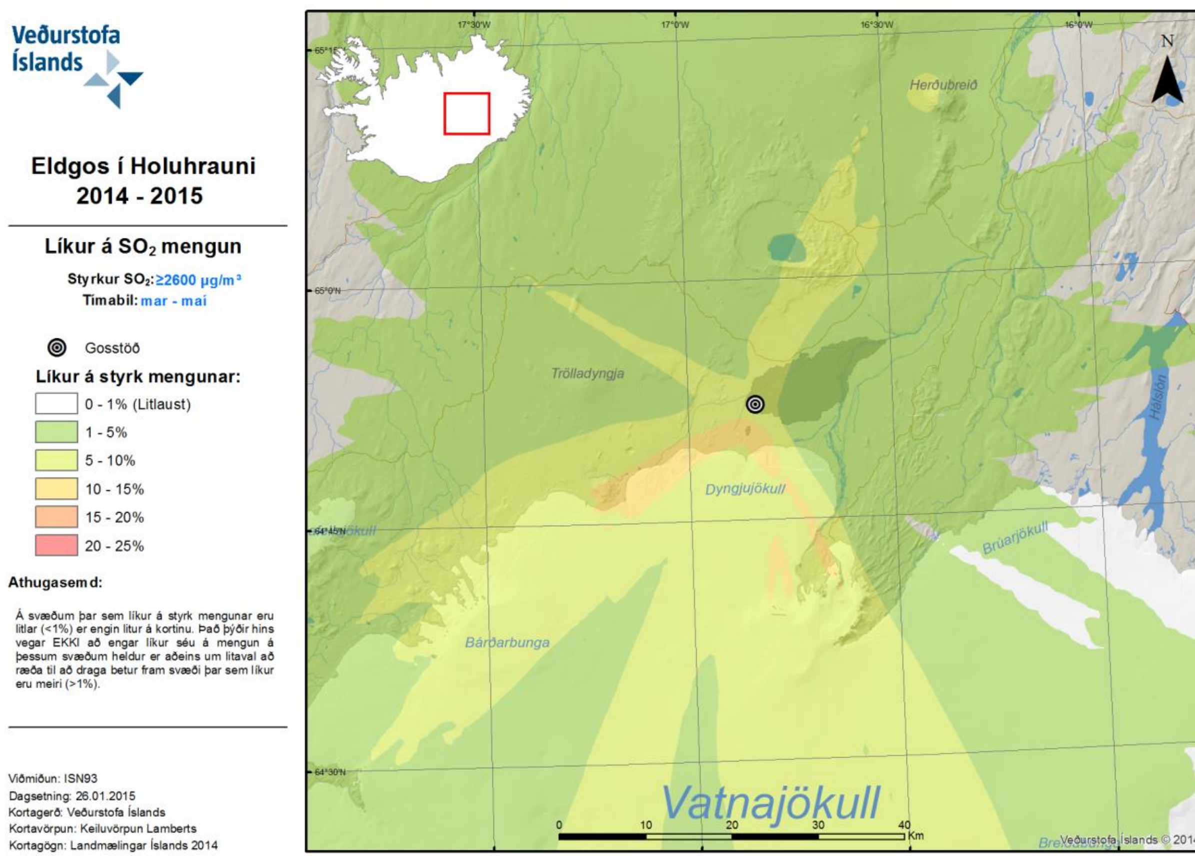
Plume height (m agl)	1000-4000
Flux (kg/s)	350
NWP data	ECMWF 0.125



Hazard maps for SO_2 ground concentration

- SO_2 ground concentration hazard maps based showing the likelihood of exceeding the threshold of 2,600 μg/m³
- This map has been used for the definition of the restricted area around the lava field

10 years of meteorological data



SO_2 could dispersal over Iceland: a reconstruction

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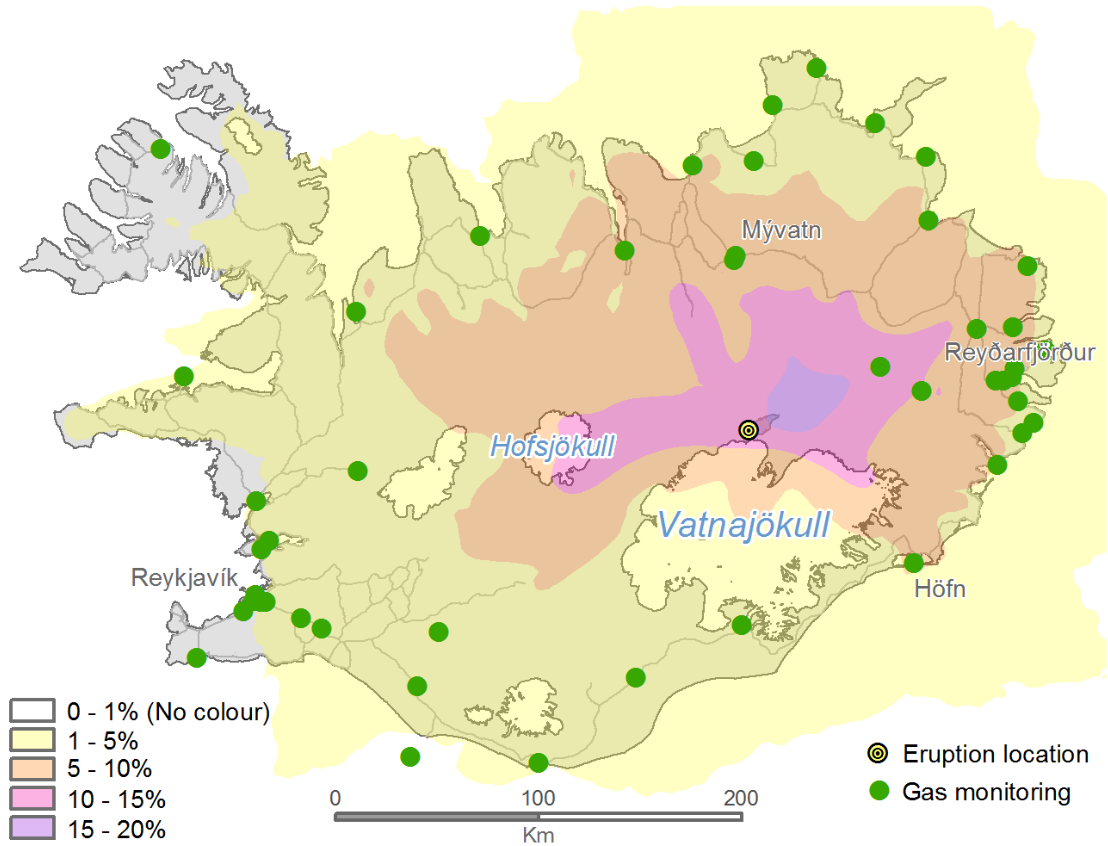
- The eruption released up to 11Mtons of SO2 in the atmosphere, more than the yearly anthropogenic emission in 2011
- Frequency in exceeding a concentration of 350 µg/m3 (modelled with CALPUFF code)
- Runs initialized with the best SO_2 flux values estimated with the DOASes



Conclusion

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- IMO‘s robust response capability is guaranteed by a **strong multidisciplinary collaboration** (volcanologists, meteorologists, seismologists, hydrologists, geo-physicists)
- IMO strongly relies on the **radar plume height detection** as the first best estimation of the „eruption size“
- Assessing (and communicating) the **uncertainty** affecting the plume height estimate is an important step toward a more comprehensive description of the ongoing event
- A **multi-model** runs approach guarantees IMO‘s capability to respond properly to the variety of services (aviation, public, infrastructures, etc)
- Holuhraun (Bárðarbunga) has been a **valid test-case** for checking IMO‘s response in case of gas rich eruption and raise important questions regarding sub-glacial events

Thank you...

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Photo courtesy: Á. Hoskuldsson

Criteria for radar volcano monitoring ranking

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Fixed C-band radars:		At least one fixed radar could observe initial phase of an eruption >2.5 km a.g.l., with beam width <2.5 km at volcano.
		At least one fixed radar could observe initial phase of an eruption >5 km a.g.l., with beam width <3 km at volcano.
		Worse resolution than 3 km or plume not visible below 5 km a.g.l.

Mobile X-band radars:		Mobile radars at Gunnarsholt or Klaustur could observe reasonably well the initial phase of an eruption.
		Site selection for mobile radars observing volcano ready. Electricity, communications and winter access optimal. A radar will deliver data to IMO within 12 hours of eruption start.
		Site selection for mobile radars observing volcano ready. Electricity, communications or winter access are not optimal.
		Site selection for mobile radars is not finished for this volcano.

SO_2 cloud dispersal over Iceland

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Quantity of SO_2*		Air quality description	Recommended actions	
µg/m³	ppm		Sensitive Groups **	Healthy individuals
		Good		
0-300	0-0,1	Poses little or no health risk.	Can experience mild respiratory symptoms.	No health effects expected.
		Moderate		
300-600	0,1-0,2	May cause respiratory symptoms in individuals with underlying diseases.	Caution advised. Follow SO_2 measurements closely.	Health effects unlikely.
		Unhealthy for sensitive individuals		
600-2.000	0,2-0,7	Individuals with underlying diseases likely to experience respiratory symptoms. Health effects unlikely in healthy individuals.	Avoid outdoor activities.	Health effects not expected. Heavy outdoor activities not advised.
		Unhealthy		
2.000-9.000	0,7-3,0	Everyone may experience respiratory symptoms especially individuals with underlying diseases.	Remain indoors and close the windows. Shut down air conditioning.	Avoid outdoor activities. Remaining indoors advised. Close the windows and shut down air conditioning.
		Very unhealthy		
9.000-14.000	3,0-5,0	Everyone may experience more severe respiratory symptoms.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.
		Hazardous		
> 14.000	>5,0	Serious respiratory symptoms expected.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.

Measurements and forecasts refer to the Hawaiian table for 15-min average exposure to SO_2