RISK ASSESSMENT FOR TEPHRA DISPERSAL AND SEDIMENTATION

THE EXAMPLE OF FOUR ICELANDIC VOLCANOES

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30

AIMS

- Identification of most critical volcanoes in Iceland
- Definition of eruption scenarios
- Identification of eruption source parameters
- Hazard assessment for multiple sources
- Hazard assessment at multiple scales

- Definition of vulnerability indicators at multiple scales
- Identification of critical threshold of tephra
- Impact /risk assessment at multiple scales

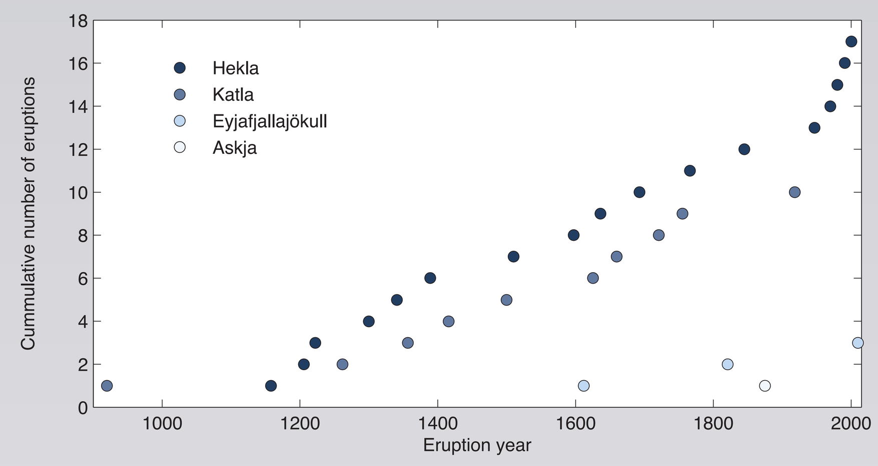
METHODS

- Understanding of eruptive history from field and litterature studies
- Use of stochastic sampling to infer missing parts of the geological record
- Probabilistic hazard assessment
- Combined use of the TEPHRA2 and FALL3D models for assessment at national and continental scales (Fig.1)

- Buiding up GIS databases at multiple scales
- Risk assessment overlaying hazard and vulnerability layers

Figure 1 ◀ Overview of the computational domains at (a) continental and (b) national scales used with FALL3D and TEPHRA2, respectively.

Figure 2 ▶ Eruptive history for the selected volcanoes since the settlement in Iceland (Thordarson and Larsen 2007). Only eruptions from central vents are considered here.



Volcano	Eruption	Strategy	Plume height	Duration	Mass	Md Φ	σ Φ	Max Φ	Min Φ	Aggregation
Hekla	2000–type	ERS	6–16 a	0.5–1 h b	$6.9x10^9$–$6.9x10^{10}$	–	–	-6	11	0.2–0.8 c
	1947–type	ERS	16–30 a	0.5–1 h b	$6.9x10^{10}$–$3.5x10^{11}$	-1–1 b	1–2 b	-5	8	0.2–0.8 c
Katla	VEI 4	LLERS	10–25 a	1-4 days b	10^{11}–10^{12}	-1–1 b	1–2 b	-7	8	0.2–0.8 b
Eyja	2010	LLOES	2.5–7.8 d	40 days	–	–	–	-2	11	–
Askja	Askja C	OES	23	1 h	$4.8x10^{11}$	–	–	-6	6	0.2–0.8
	Askja D	OES	26	1.5 h	$5.0x10^{11}$	–	–	-10	6	0.2–0.8

▲ Table 2 Ranges of ESP for all eruption scenarios based on litterature studies. Sampling are constrained on the following distributions: (a) logarithmic; (b) uniform; (c) gaussian; (d) data from Arason et al. (2011).

ERUPTION SCENARIOS

Eruption scenarios are identified to reflect typicial eruption styles at a given volcano and must rely on a geological reality. Here, the main eruption characteristics of the target volcanoes during historical times in Iceland are:

Hekla	18 eruptions since settlement Repose interval: 10-102 years Mixed eruptions
Katla	18 eruptions in historical times Mean repose interval: 47 years Eruptions lasting between 2 weeks and 5 months 80-90% of tephra generated during the first days
Eyjafjallajökull	Poor knowledge of the pre-17th century history Historical eruptions in 1612, 1821-23, 2010 Similar in composition and magnitudes
Askja	Last central eruption: 1875 Shifts from phreatomagmatic to dry styles

Figure 2 shows the eruptive history since the settlement in Iceland. Table 1 summarizes the probabilistic eruption scenarios. Table 2 shows the identified eruption scenarios and their eruption source parameters (ESP).

Table 2 ▶ Probabilistic eruption scenarios as described in Bonadonna (2006) and Biass et al. (in prep)

Eruption scenario	ESP	Wind	Duration
One Eruption Scenario (OES)	Fixed	Variable	Short
Eruption Range Scenario (ERS)	Variable	Variable	Short
Long-lasting OES (LLOES)	Fixed	Variable	Long
Long-lasting ERS (LLERS)	Variable	Variable	Long

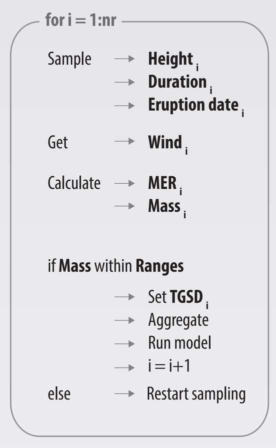
GENERATION OF PROBABILITY DENSITY FUNCTIONS FOR ERUPTION SOURCE PARAMETERS

Eruption scenarios are typically expressed as a range of ESP and a probability function (PDF), where the shape of the PDF reflects the knowledge of the system. When several ESP are stochastically sampled simultaneously (e.g. ERS and LLERS), constrains must be apply in order to obtain realistic sets or input conditions only. Here,we apply a hard constrain on the mass range for such eruption scenario as following:

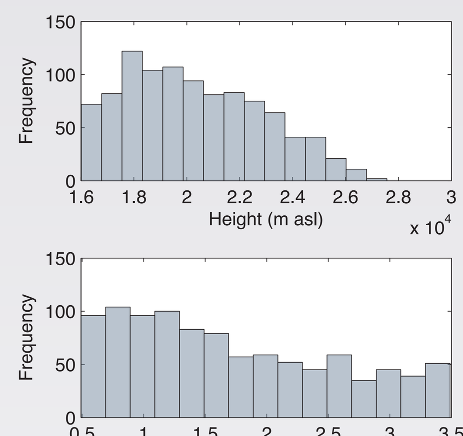
- Set mass range
- Sample plume height, eruption date and duration
- From the wind condition at the eruption date and plume height, the mass eruption rate (MER) is calculated with the method of Degruyter and Bonadonna (2012)
- From duration and MER, mass is calculated
- Check if mass within initial range, else resample

Total grainsize distribution (TGSD) were used when available, else available information were used to reconstruct TGSD assuming a gaussian distribution. Aggregation was accounted for using empirical models of Bonadonna et al. (2002) and Bonadonna et al. (2011). Aggregation coefficients are sampled and used to remove an equal amount of particles of phi classes >4, equally redistributed into phi classes -1 to 4.

ERS ALGORITHM

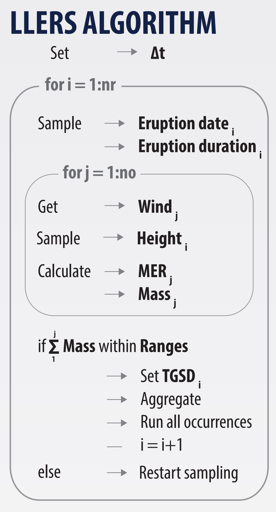


HEKLA 1947 ERS

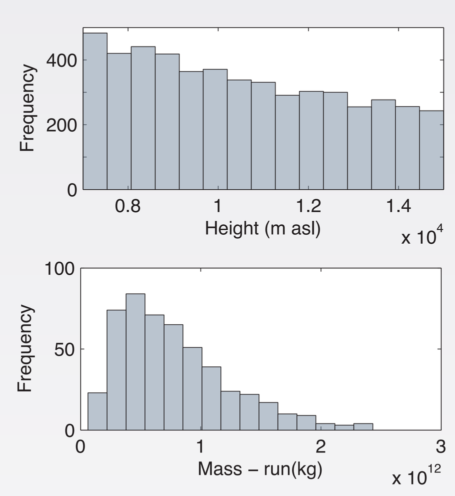


◀ Algorithm for the stochastic sampling of EPS for Eruption Range Scenarios and resulting PDF for Hekla 1947 using ranges defined in Table 2. The ERS is the result of 1000 runs of the model.

LLERS ALGORITHM

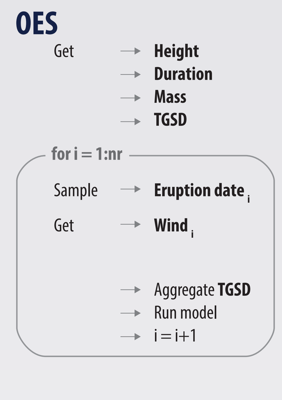


KATLA LLERS



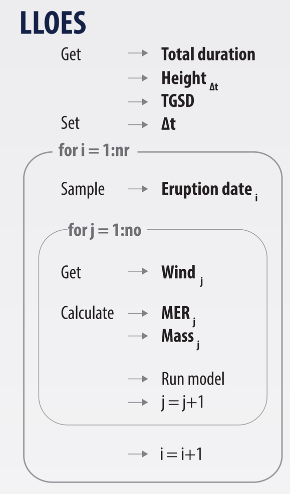
◀ Algorithm for the stochastic sampling of EPS for Long-lasting Eruption Range Scenarios and resulting PDF for Katla using ranges defined in Table 2. The ERS is the result of 1000 runs, where each run consists in consecutive updates of the models every 6 hours. Eruptions conditions are assumed constant between updates.

OES



◀ Algorithm for running One Eruption Scenarios. All eruption source parameters are chosen deterministically. The hazard assessment for Askja 1875 consists in two consecutive, starting with the phreatomagmatic phase Askja C followed by the dry Plinian phase Askja D.

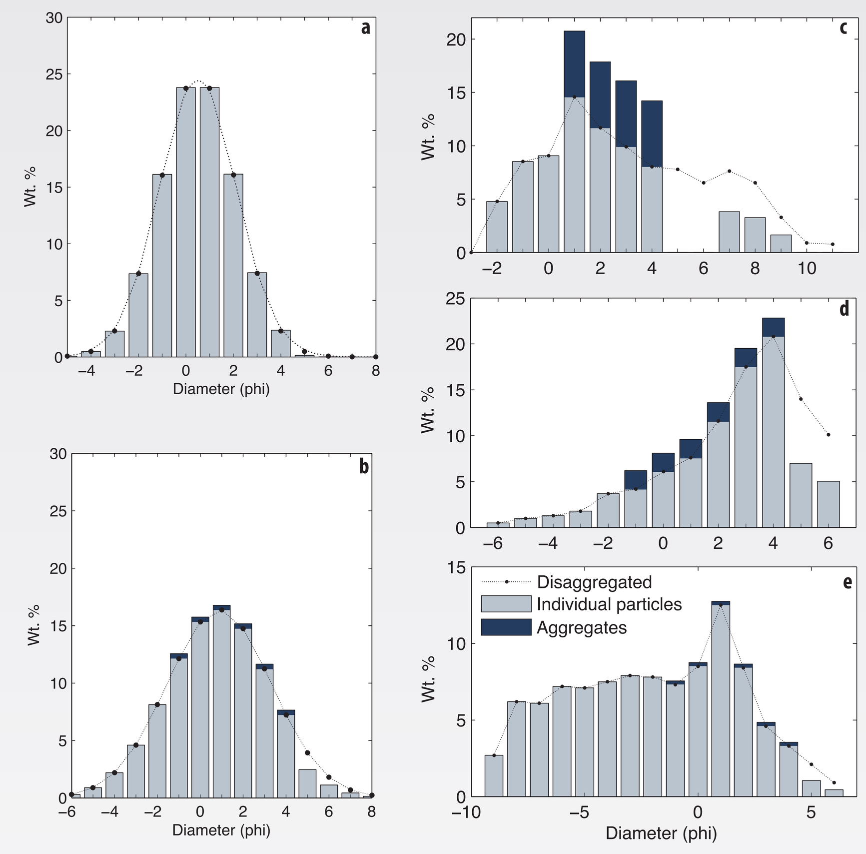
LLOES



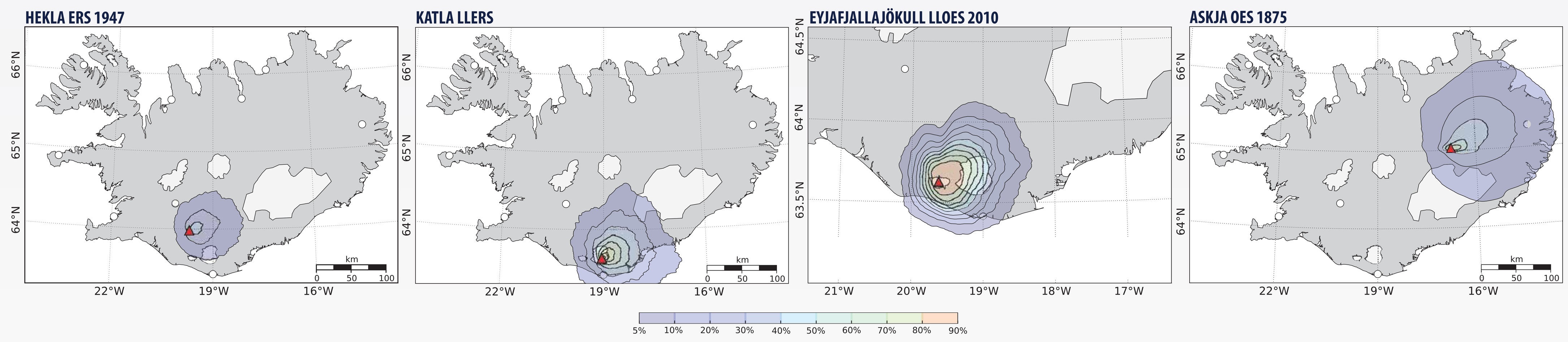
◀ Algorithms for running Long-Lasting One Eruption Scenarios. Eruption source parameters are chosen deterministically and are expressed as time series. For Eyjafjallajökull 2010, we used measurements of plume heights from Arason et al. (2011).

TOTAL GRAINSIZE DISTRIBUTION

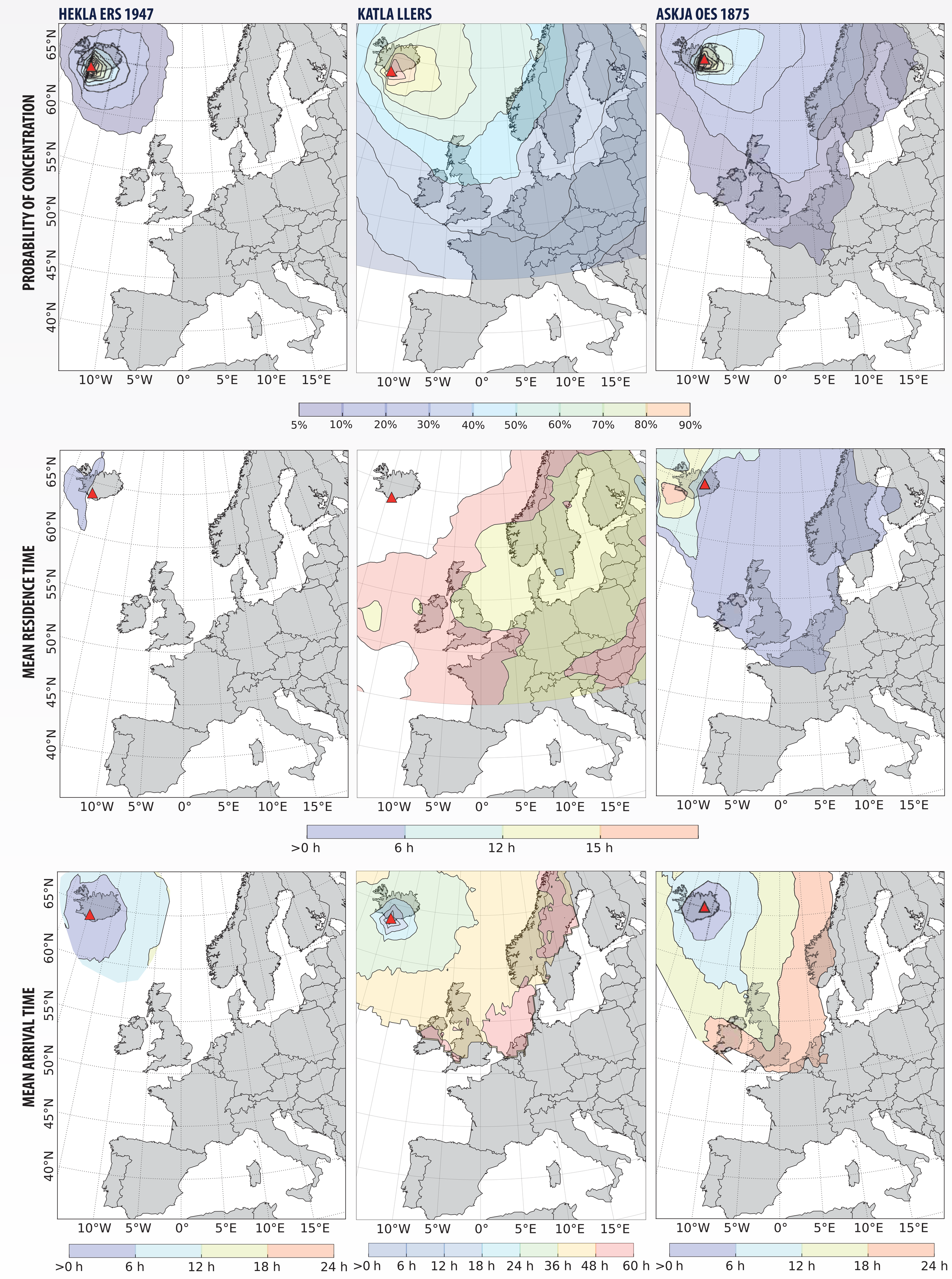
Total grainsize distributions after aggregation for **a** Hekla 1947, **b** Katla, **c** Eyjafjallajökull 2010 (Bonadonna et al. 2011), **d** and **e** the phreatoplinian and Plinian phases of Askja 1875 C and D, respectively (Sparks et al. 1981). For ERS and LLERS, a variability of both the median and the standard deviation of the gaussian distributions was allowed at each run (Table 2).



PROBABILITY MAPS - GROUND ACCUMULATION > 10 KG/M²



PROBABILITY MAPS - ATMOSPHERIC CONCENTRATION AT FL 150 > 2 MG/M³



WORST-CASE SCENARIOS

Worst-case eruptions based on historical eruptions were accounted for and modeled with worst wind conditions (i.e. conditions that occurred during Eyjafjallajökull 2010). Considered scenarios are:

- Hekla 1947
- Katla 1918
- Eyjafjallajökull 2010
- Askja 1875

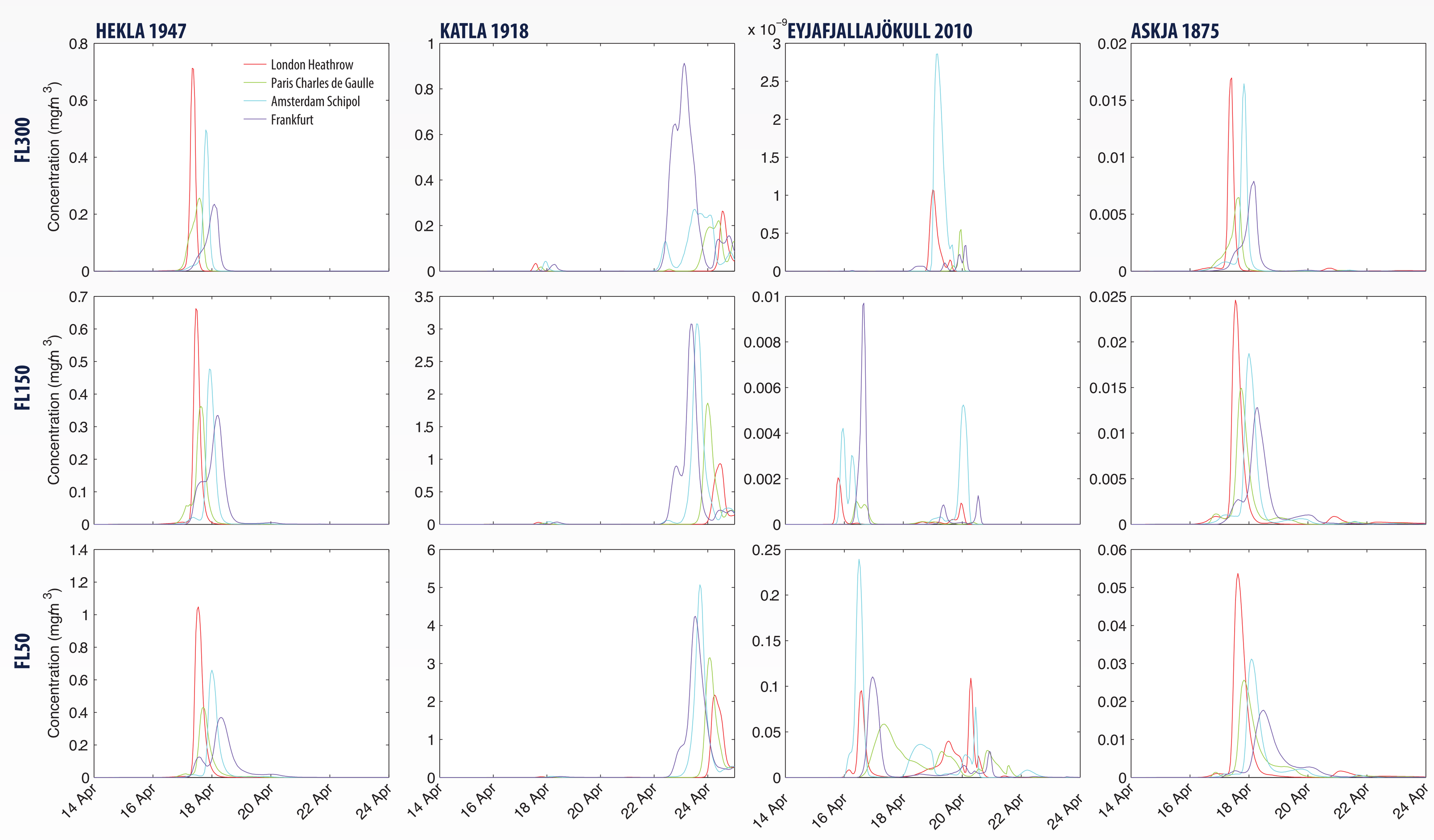


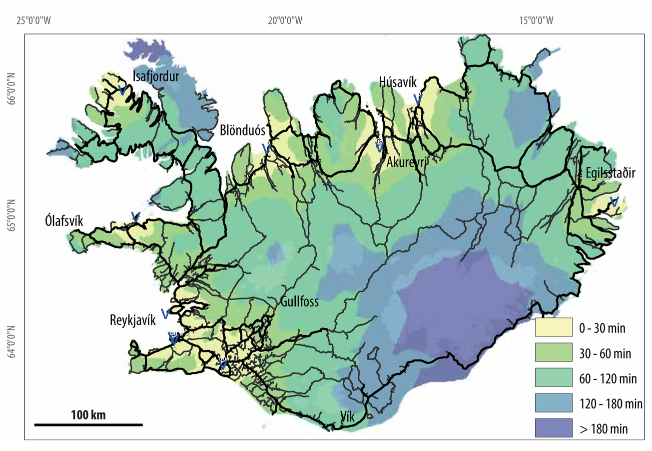
Figure 3 ▶ Comparison of the atmospheric concentration from worst-case eruptions over the four most important airports of Northern Europe. Data for Eyjafjallajökull from Folch et al. (2011).

VULNERABILITY ASSESSMENT

NATIONAL SCALE

Category	Theme	Indicator
Functional	Critical facilities	Hospitals
		Aluminum smelters
		Energy plants
	Road network	Primary roads
		Redundancy
		Accessibility
Socio-Economic	Agricultural activities	Agricultural area
		Milk production
		Wool production

▲ Vulnerability indicators defined for ground tephra accumulation for functional and socio-economic aspects at the national scale.

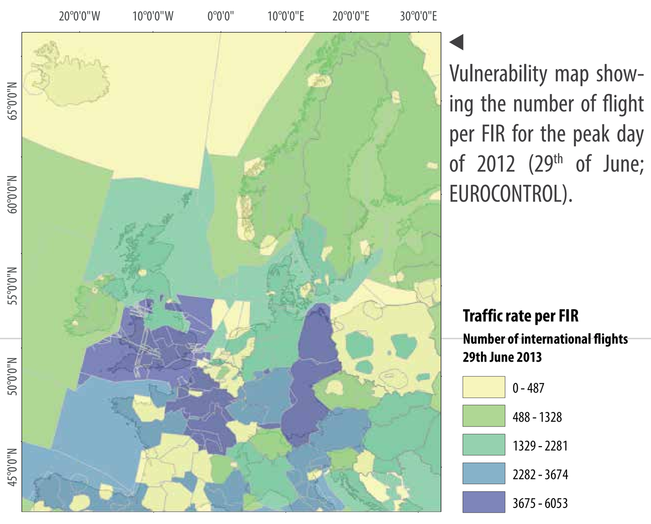


▲ Anisotropic accessibility map showing the time to access the closest hospital. Are accounted for topography, land use and the hierarchy of the road network.

CONTINENTAL SCALE

Category	Theme	Indicator
Functional	Relevance	Airports
		Routes
		Airspace sector
Socio-Economic	Aerial traffic and regional development	Population
		Accessibility

▲ Vulnerability indicators defined for atmospheric concentration for functional and socio-economic aspects at the eurppean scale.



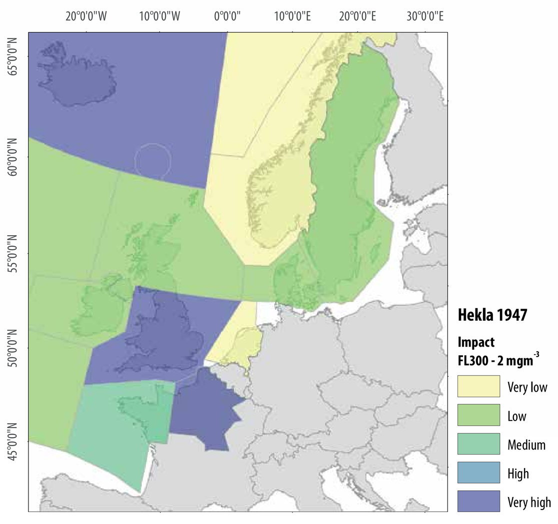
◀ Vulnerability map showing the number of flight per FIR for the peak day of 2012 (29th of June; EUROCONTROL).

QUALITATIVE RISK ASSESSMENT

IMPACTS ON FIR

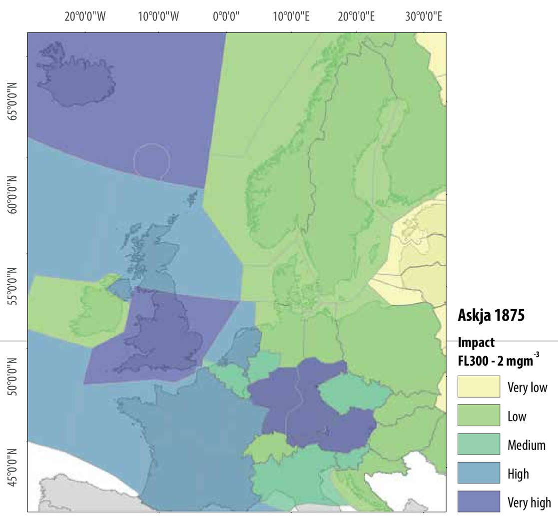
HEKLA 1947 ▶

Qualitative impact assessment per FIR related to the Hekla 1947 scenario, accounting for the presence of a critical concentration of ash (i.e. 2 mg/m³ at FL300) and the relevance of the FIR.



ASKJA 1875

Qualitative impact assessment per FIR related to the Askja 1875 scenario, accounting for the presence of a critical concentration of ash (i.e. 2 mg/m³ at FL300) and the relevance of the FIR.



QUANTITATIVE IMPACT ASSESSMENT

▶ First level estimation of the impacts from the selected probabilistic eruption scenarios on the airports of Keflavìk and Heathrow.

Eruptive scenario	Average disruption duration (h)	Average arrival time (h)	Expected passengers stranded	Expected movements disrupted
Hekla-2000	4 / 0	3 / 0	~350 / 0	~6 / 0
Hekla-1947	7 / 0	3 / 0	~600 / 0	~12 / 0
Katla	0 / 0	0 / 0	0 / 0	0 / 0
Askja-1875	20 / 0	11 / 23	~1.740 / ~55.500	~60 / ~380

CONCLUSIONS

- Eruption scenarios and ESP must be defined using probabilistic strategies based on strong field evidences
- Moderate long-lasting and intense short-lasting eruptions produce different hazard and risk patterns, due namely to the TOTGS they produce
- At Icelandic scale, main issues related to ground accumulation of tephra concern electrical power lines and agricultural activities (i.e. accumulations of 10 kg/m²)
- Using the probabilistic approach, Askja is the most critical volcano amongst all eruption scenarios
- Using the worst-case scenario approach, Katla is by far the most critical volcano, reaching critical concentrations over most of the main european hubs
- Qualitative risk assessments allow for rapid identification and comparison of critical zones; quantitative impacts assessments allow for costs estimation

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