Operational Reliability of a System Based on Lightning Data for Early Estimation of Eruption Site Location

Þórður Arason (arason@vedur.is),
Guðrún Nína Petersen, Halldór Björnsson

Veðurstofa Íslands — Icelandic Meteorological Office, Bústaðavegur 9, IS-108 Reykjavík, Iceland

Cities on Volcanoes 10, Naples, Italy, 2-7 September 2018

S02.13 - Strategies for eruption forecasting and early-warning to support operational hazard evaluation during volcanic crises (539)

Early Location of Eruption Sites

Icelandic Met Office

- **Visual** – depending on daylight, weather and visibility: Vent site seen by inhabitants, hikers, column seen from a distance, airplane-pilots, reconnaisance flights
- **Satellite images**
- **Earthquake activity**
- **Weather radars**

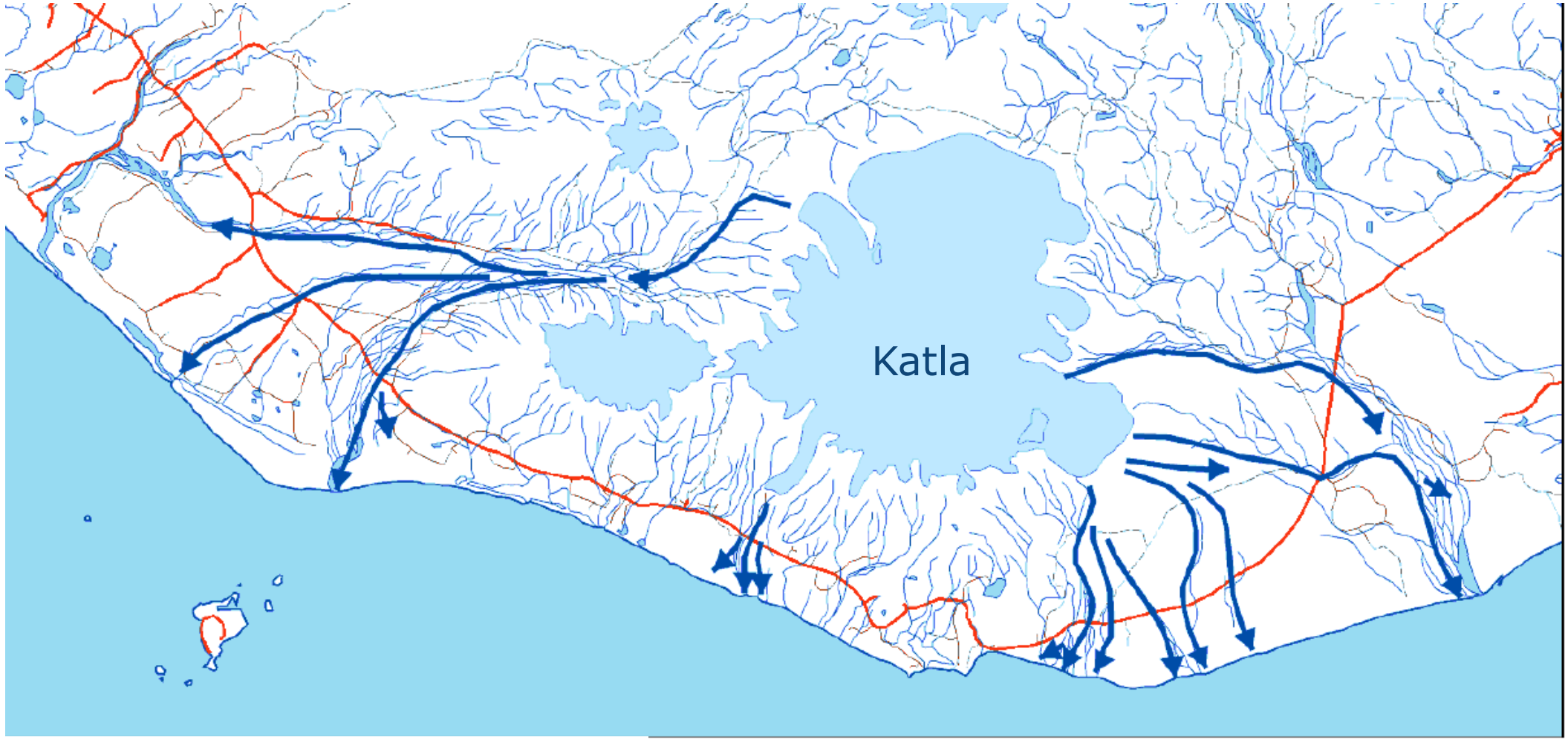
- **Volcanic lightning** – Operational real-time automatic system at IMO Since April 2013 using lightning locations. PDF-report available on www.vedur.is:

  Þórður Arason, Guðrún Nína Petersen & Halldór Björnsson (2013), *Estimation of eruption site location using volcanic lightning*, Report VÍ 2013-006, Icelandic Meteorological Office, Reykjavík, Iceland, 15 p.

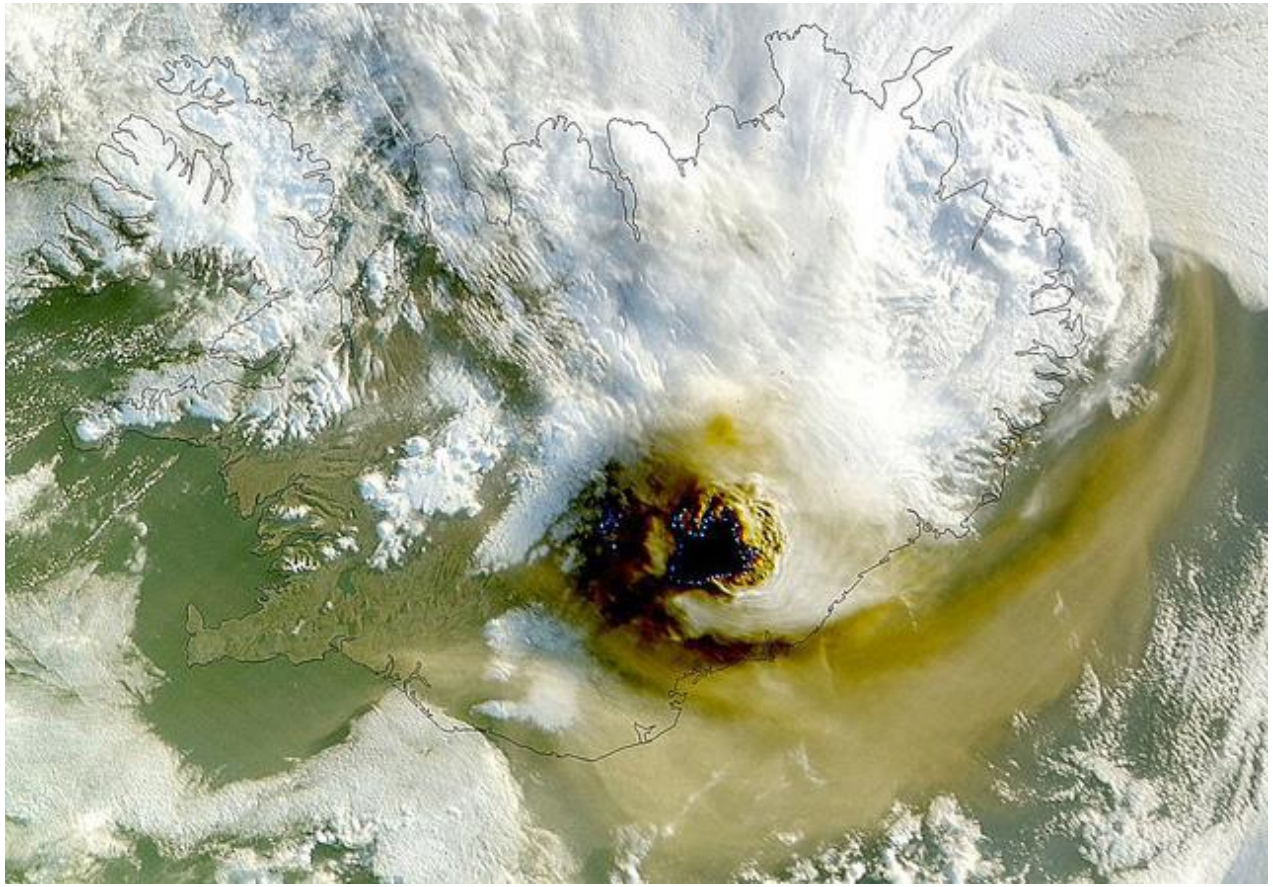
Why is Early Knowledge of Exact Eruption Site Location Important?

- Subglacial volcanism may lead to catastrophic floods
- Early knowledge may be critical to activate civil protection evacuation plans

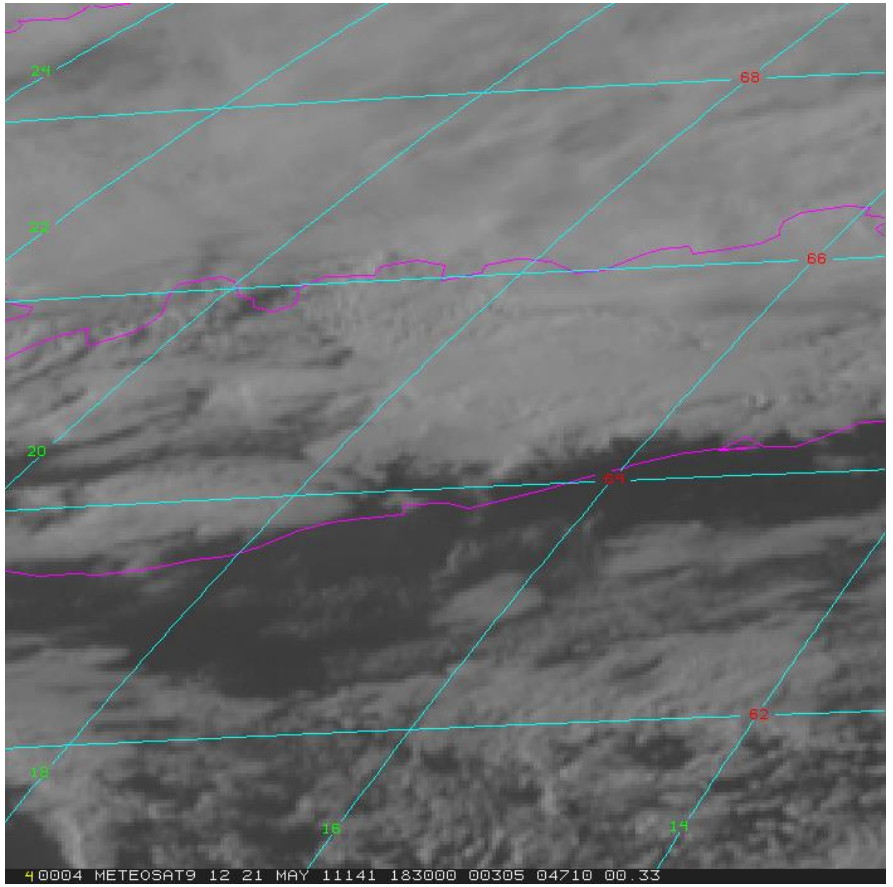
Catastrophic Floods from Katla



Satellite Images



Modis 2011-05-22 05:10

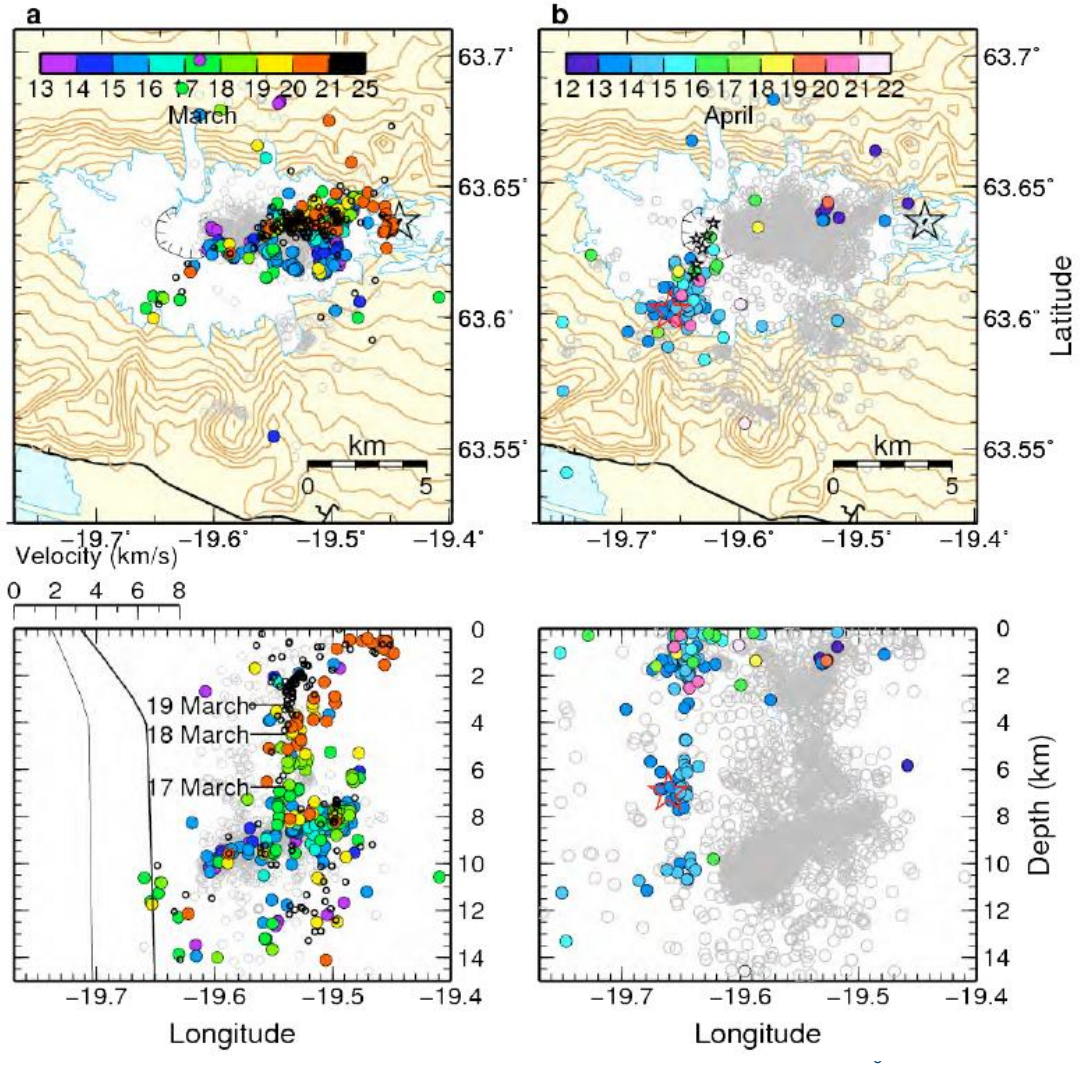


Meteosat9 every 15 min

Earthquake Locations

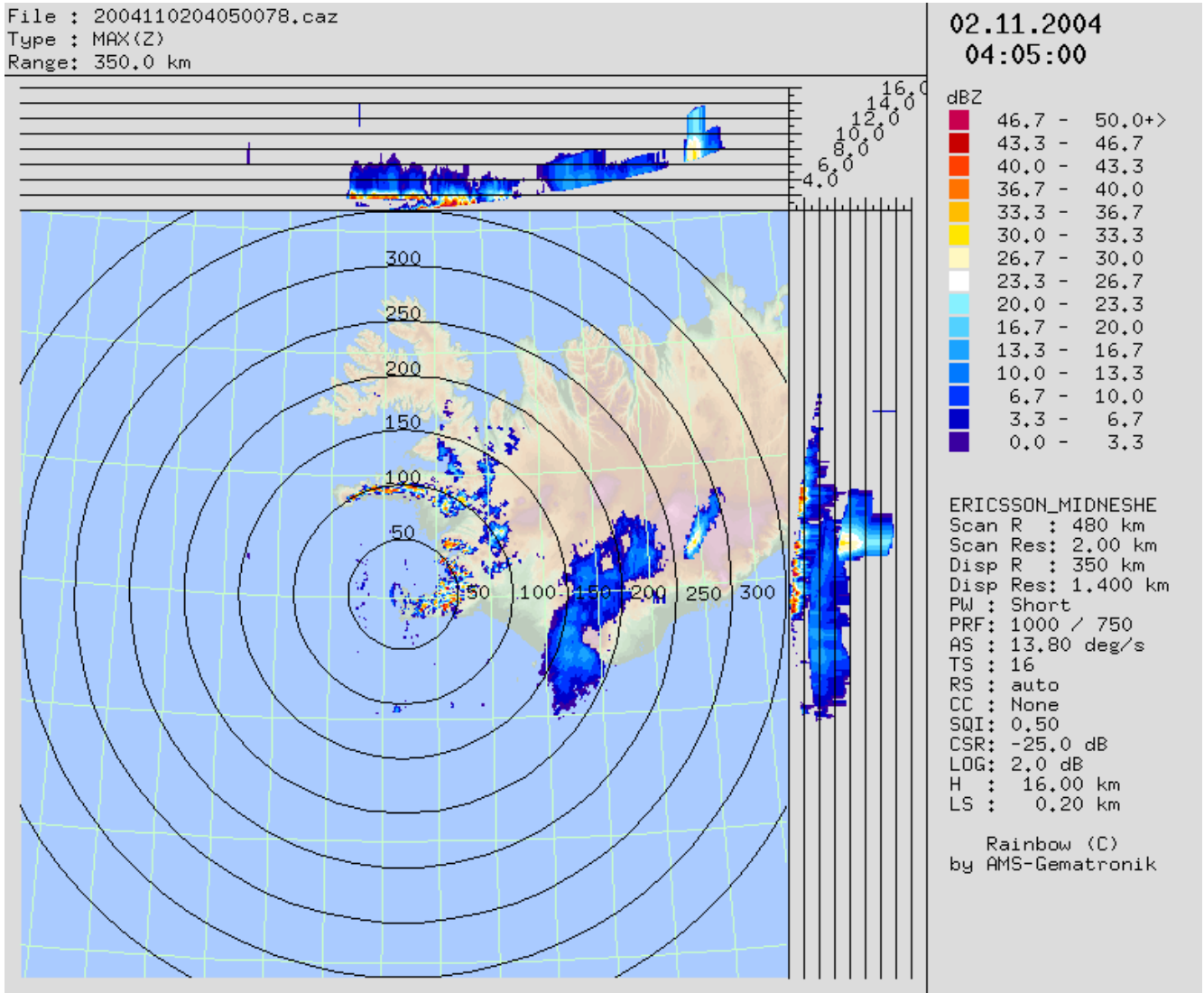
Earthquake locations under Eyjafjallajökull during March and April 2010, colored by dates

The caldera eruption of Eyjafjallajökull started on 14 April 2010



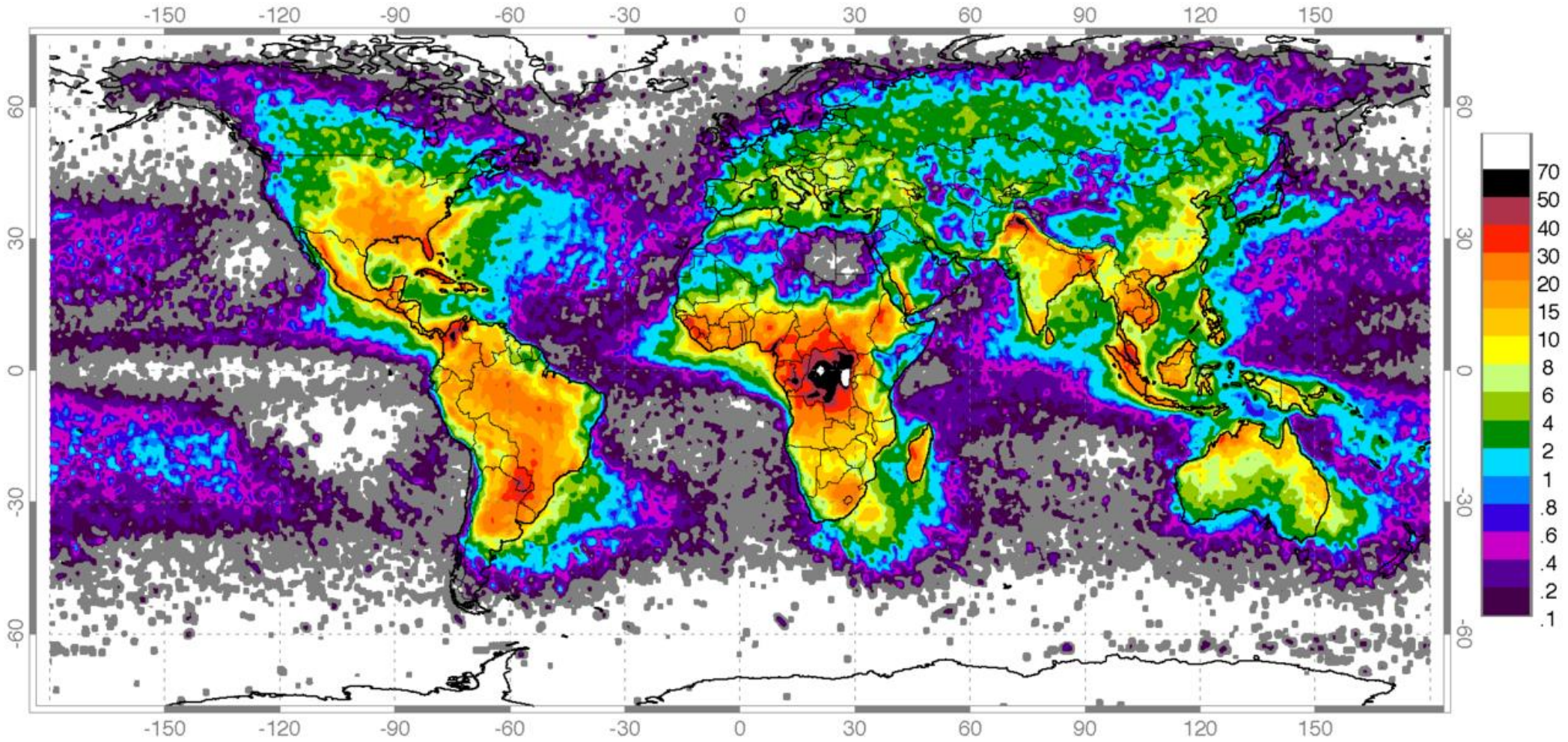
Weather Radars

Icelandic Met Office



Meteorological Lightning Frequency

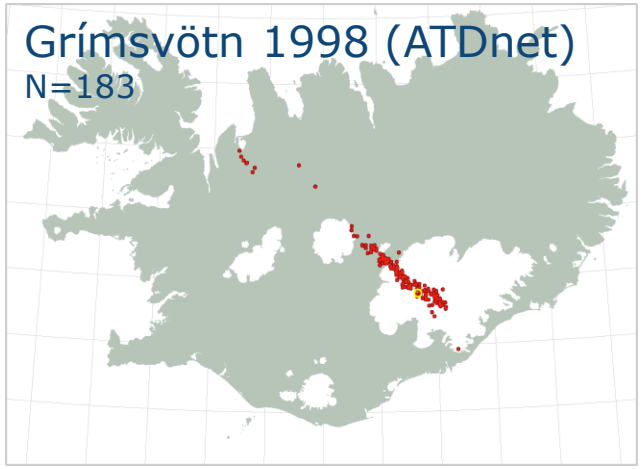
Icelandic Met Office



NASA: World distribution of lightning frequency (strikes/km^2/yr)

Grímsvötn 1998 & Hekla 2000

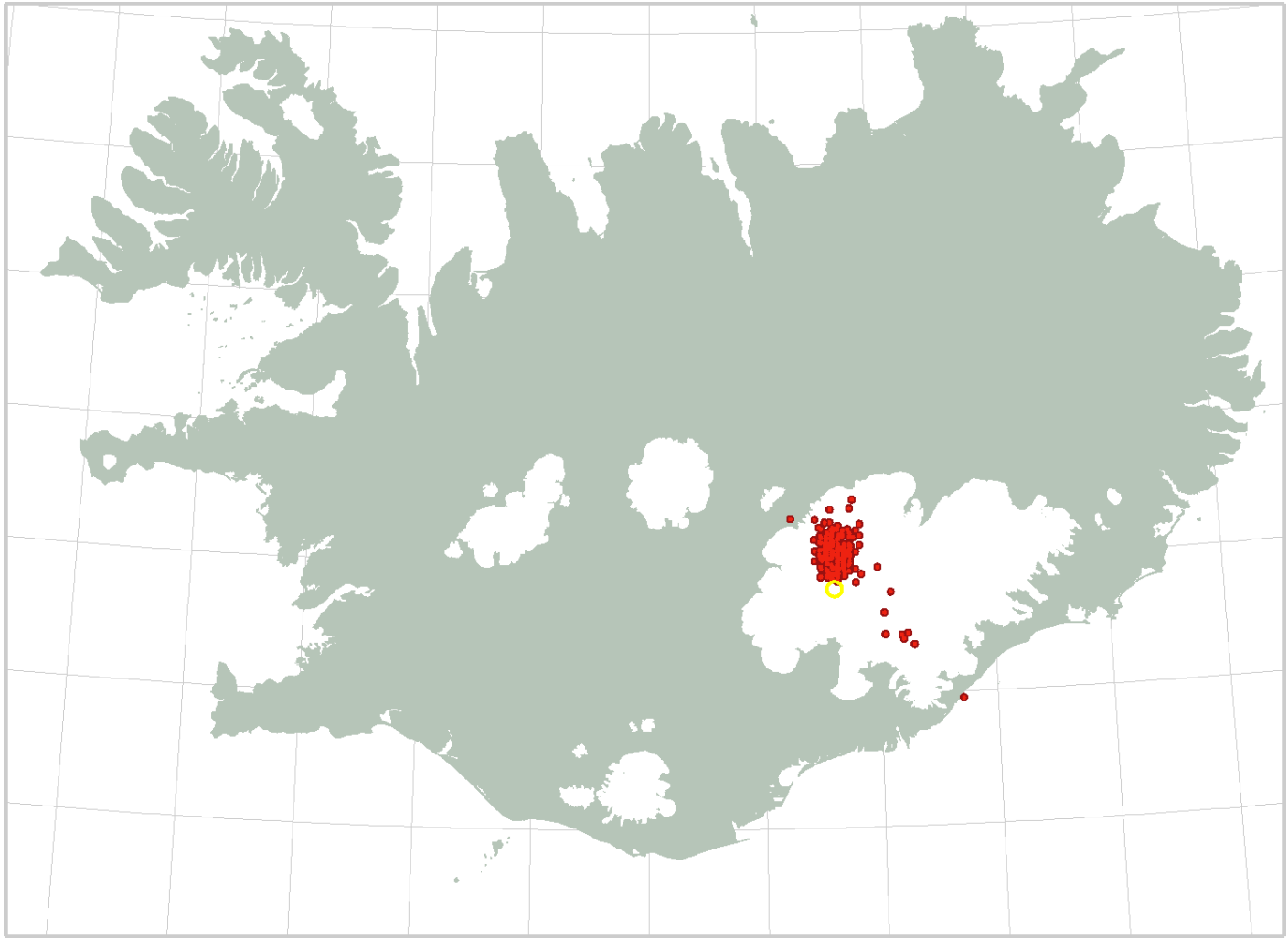
Icelandic Met Office



Grímsvötn 2004

251 Lightning (15 during first 6 h)

Icelandic Met Office



Eyjafjallajökull 2010

790 Lightning (0 during first 12 h)

Icelandic Met Office

Grímsvötn 2011

16195 Lightning (888 during first 1 h)

Icelandic Met Office

Observed Lightning During Initial Phase of Eruptions

Icelandic Met Office

Volcano	Start	First	Number of lightning <1h	<3h	<6h	<12h	<24h	Total
Grímsvötn	1998-12-18 09:20	2 h	0	1	20	121	167	183
Hekla	2000-02-26 18:17	41 min	1	4	6	6	6	6
Grímsvötn	2004-11-01 21:50	4 h	0	0	15	59	142	251
Fimmvörðuháls	2010-03-20 23:34	-	0	0	0	0	0	0
Eyjafjallajökull	2010-04-14 01:15	17 h	0	0	0	0	10	790
Grímsvötn	2011-05-21 19:00	15 min	888	3340	6484	11729	16041	16195
Holuhraun	2014-08-29 00:02	-	0	0	0	0	0	0

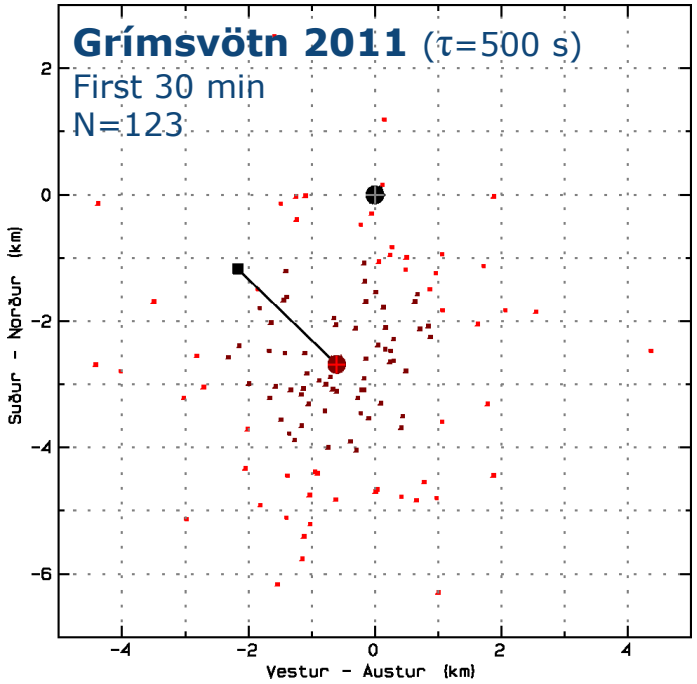
Eyjafjallajökull 2010 – plume and lightning blown downwind
Photo Þórður Arason, 17 April 2010 04:47

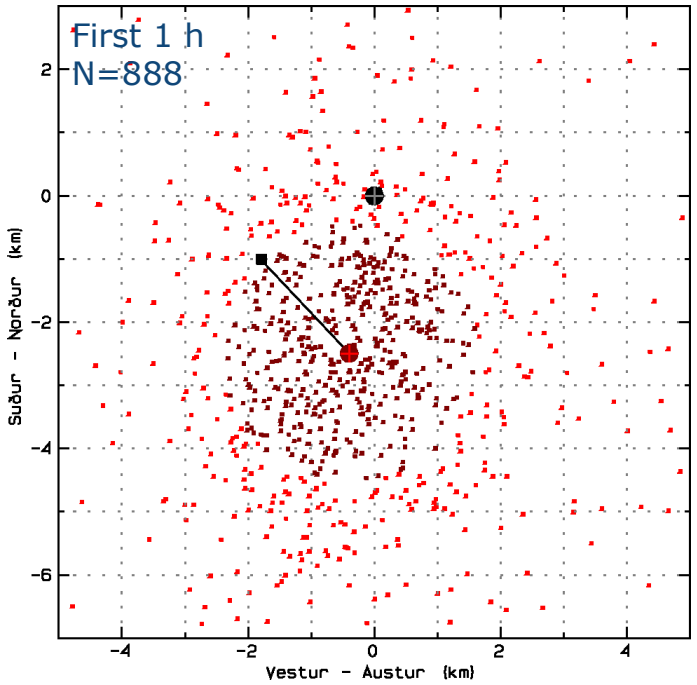
Wind Correction

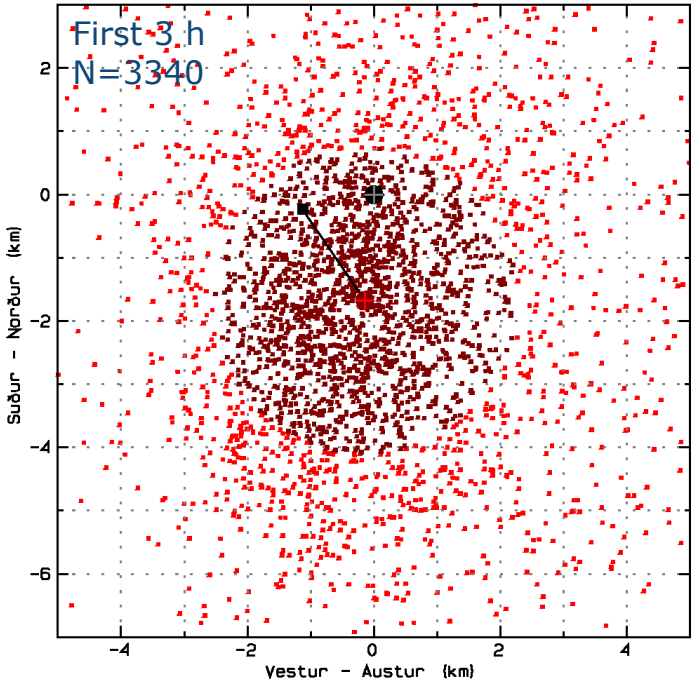
Icelandic Met Office

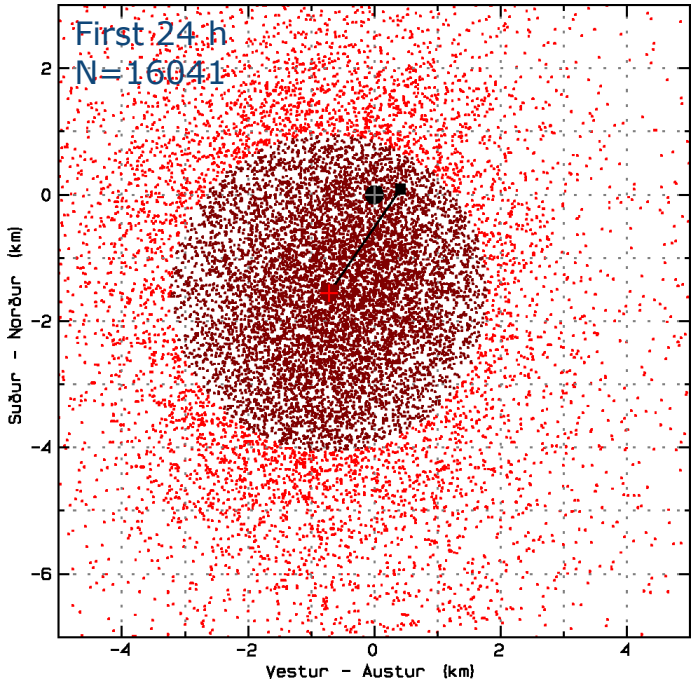
- Automatic wind correction is not implemented in the system
- A weak plume may be blown by atmospheric winds and average location of lightning may be downwind of the eruption site
- The eruptions of 2004, 2010 and 2011 indicate that the wind at 500 hPa pressure level (about 5 km altitude) over a time period of $\boldsymbol{\tau}$**=500 s** may provide a resonable wind correction – A 2 m/s wind for 500 s travels 1 km – If a plume rises at 10-20 m/s, then it will rise 5-10 km in 500 s


15 km
10 km
Tr
5 km
Gr
Grímsvötn 2011
Photo Bolli Valgarðsson 21 May 2011 19:20


Grímsvötn 2011 (τ=500 s)
First 30 min
N=123
Suður - Norður (km)
Vestur - Austur (km)


First 1 h
N=888
Suður - Norður (km)
Vestur - Austur (km)


First 3 h
N=3340
Suður - Norður (km)
Vestur - Austur (km)


First 24 h
N=16041
Suður - Norður (km)
Vestur - Austur (km)

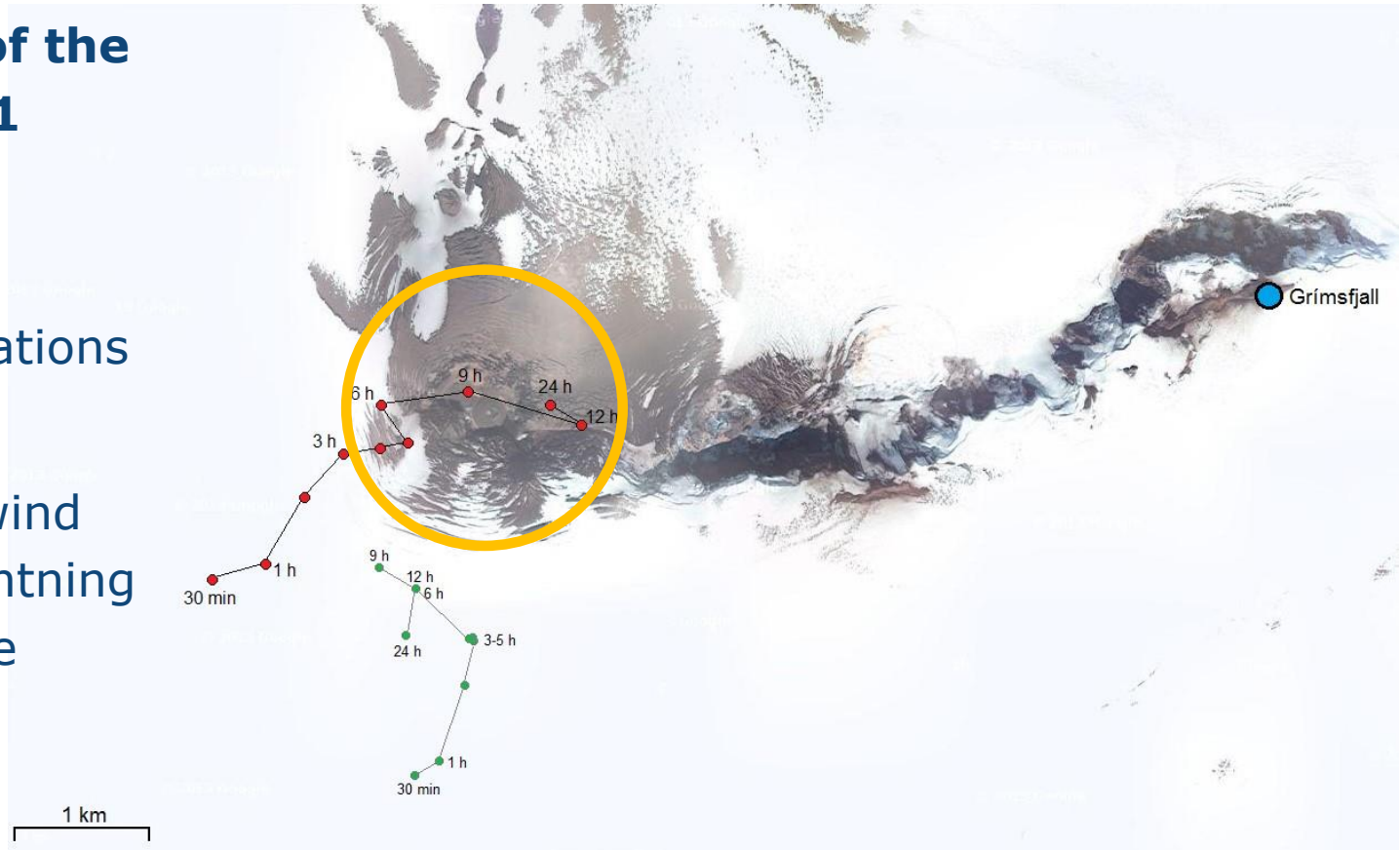
Median Lightning Location

Time Evolution, 30 min — 24 h After Eruption Onset

Icelandic Met Office

Aerial view of the southern rim of the Grímsvötn Caldera after the 2011 eruption

- Green - Raw median lightning locations
- Red - With simple wind correction
- Four hours into the eruption the wind corrected median estimates of lightning locations are all within 1 km of the actual vent



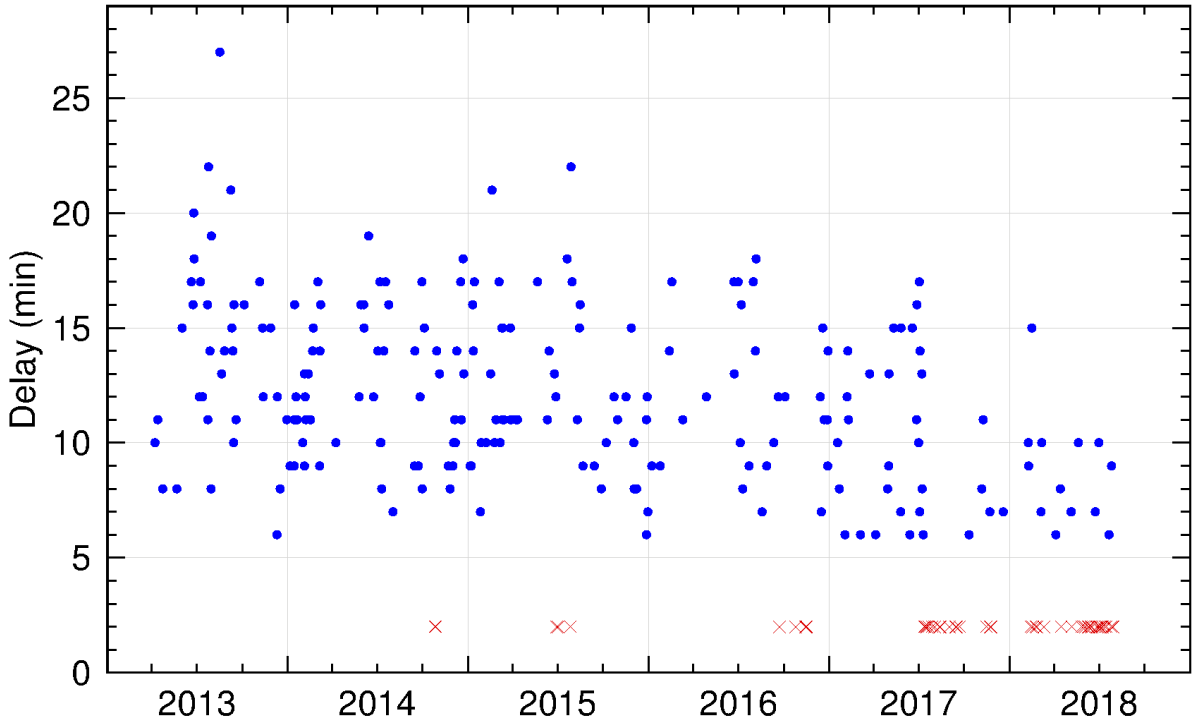
Operation of the System

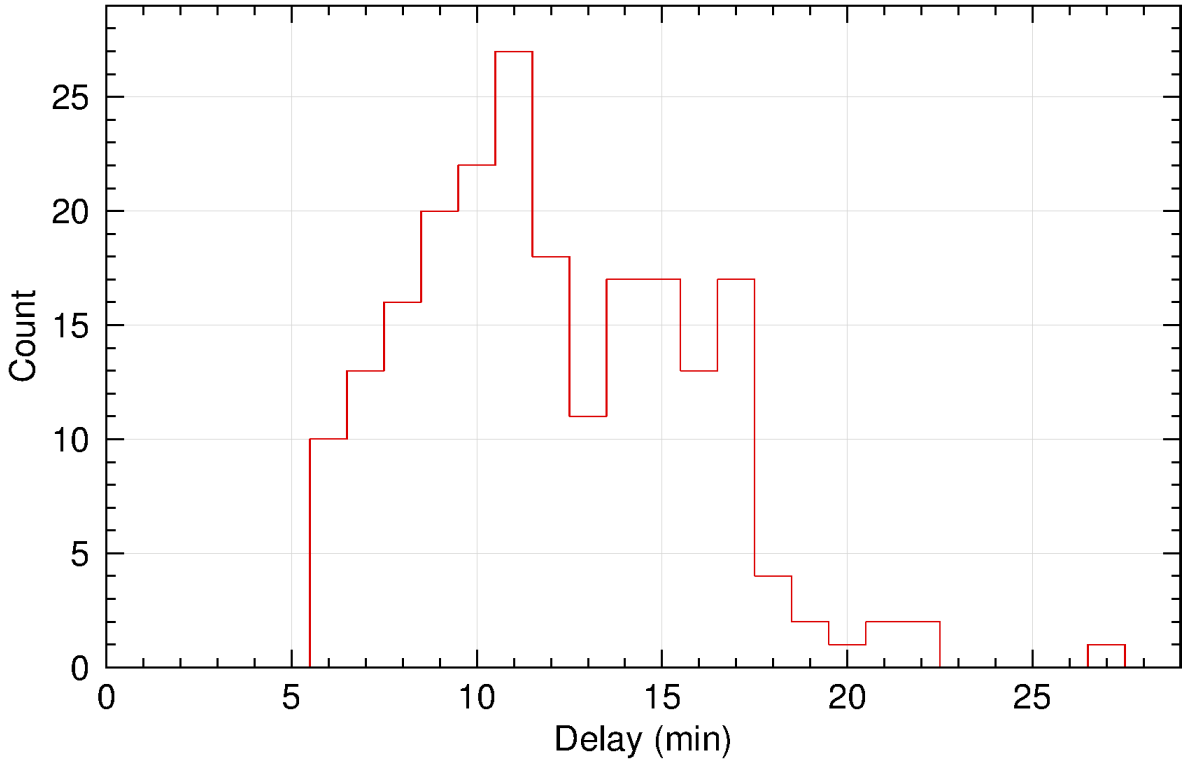
- The system retrieves lightning location data, and checks for new lightning over Iceland every 10 minutes
- All data for the past week are analyzed in 1, 6 and 24 hour bins for tables and maps, and published on a web-page
- If new lightning is observed, E-mail warnings are issued to the 24/7 monitoring room of the IMO (conditional)

Delay of Warnings

Delay from the first lightning occurrence to E-mail warnings

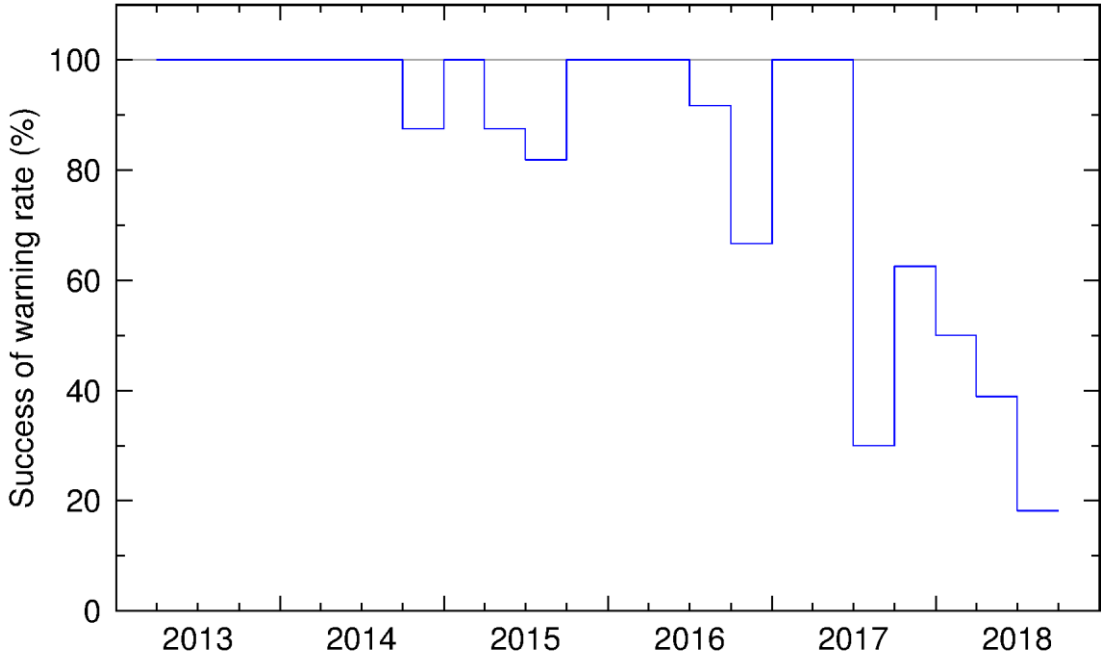
Icelandic Met Office





Operational Reliability of the System

- The system appeared reliable for the first four years
- In 2017 the system went through a major IT-systems upgrade, where programs needed to be recompiled and moved to a new computer system
- Furthermore, the responsibility for the operation of the system was changed
- The changes in 2017 had noticable effect on the reliability of the system



Conclusions

- An automatic real-time system analyzes observed lightning in Iceland, calculates mean and median locations and delivers E-mail warnings
- The system has been operational since April 2013, but with no real test yet — No explosive volcanic eruption was in Iceland during this time
- Most of the time the system is quiet
- Analysis of E-mail warnings due to meteorological thunderstorms indicate that the system may have degraded after a major change in its operation in mid 2017 — This needs to be addressed !

Abstract

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arason@vedur.is, gnp@vedur.is, halldor@vedur.is

At the onset of an explosive eruption, the early determination of the exact eruption site may be critical to activate civil protection evacuation plans. Powerful subglacial volcanism is expected to produce volcanic lightning during its early hours. In April 2013, an automatic real-time system was installed at the Icelandic Meteorological Office, that monitors and analyses lightning to locate the eruption site. This system is based on lightning data from the ATDnet long range system of the UK Met Office. During these first five years of operation, the system has never been tested by an explosive eruption, as none has occurred. A dormant automatic monitoring system waiting for a rare event is quite susceptible to degeneration during the waiting period, and IT-system upgrades pose a serious threat. However, ordinary weather thunderstorms in Iceland are used to monitor the status of the system. At high latitudes, thunderstorms are rare and during these first years of operation, the system was automatically activated on average once per week. The time from the first observed lightning strike of a thunderstorm until the system had finished analysing the data and sent an E-mail warning was usually 7-18 minutes (90% of warnings). In late 2017 this system went through a major IT-systems upgrade, where programs needed to be recompiled and moved to a new computer. Furthermore, the responsibility for the operation of the system was changed. As expected this change had noticable effect on its reliability. This study reviews the use of the lightning detection system as an important monitoring tool for an early detection of eruption source location, and its long term sensitivity to computer upgrades.