Met Office

Veðurstofa Íslands
Icelandic Meteorological Office

Charge mechanism of volcanic lightning revealed during the Eyjafjallajökull 2010 eruption

Þórður Arason Icelandic Meteorological Office (arason@vedur.is)
Alec J. Bennett Met Office (alec.bennett@metoffice.gov.uk)

1 Introduction

The subglacial Eyjafjallajökull volcanic eruption in Iceland, 14 April - 23 May 2010, may have revealed its charge mechanism of volcanic lightning.

During these almost 40 days, the eruption went through a few phases while the conditions of the surrounding atmosphere also changed, but at different times. Measured lightning activity during previous eruptions in Iceland only lasted for a few days. Therefore, this new data gives a better opportunity to distinguish between internal and external causes of the charge generation.

We compare the plume height and atmospheric conditions to lightning occurrences as measured by the UK Met Office's ATDnet lightning location network. It should be noted that minor vent-sparks were probably poorly detected by the long-range ATDnet network during the eruption.

2 Possible charge generation processes

Scientists have speculated on possible charge generation processes for centuries, and several processes have been proposed to explain the electrification of volcanic plumes, e.g.:

Magma-water interactions. Submarine and subglacial eruptions lead to magma-water interactions and explosive volcanism. Laboratory experiments show that such processes lead to charge generation with water droplets positively charged and the ash negatively.

Magma pulveration. The break up or internal friction and collisions of fine grained dry material may lead to charge generation.

Dirty thunderstorm. The physical conditions, especially vertical temperature profiles of the atmosphere, control at what height the water droplets in the volcanic plume will freeze. Processes related to the freezing of cloud droplets are thought to be responsible for charge generation in meteorological thunderclouds. Such conditions in a volcanic plume may lead to charge generation, and ash in the plume may facilitate such meteorological processes.

Various processes. Photographs of lightning during the Eyjafjallajökull eruption indicate two types: many show numerous small sparks at the vent and a few photographs show large thunderbolts through the entire plume. The small sparks must be due to charge generation within the volcanic crater, such as magma-water interaction or ash friction/break up processes.

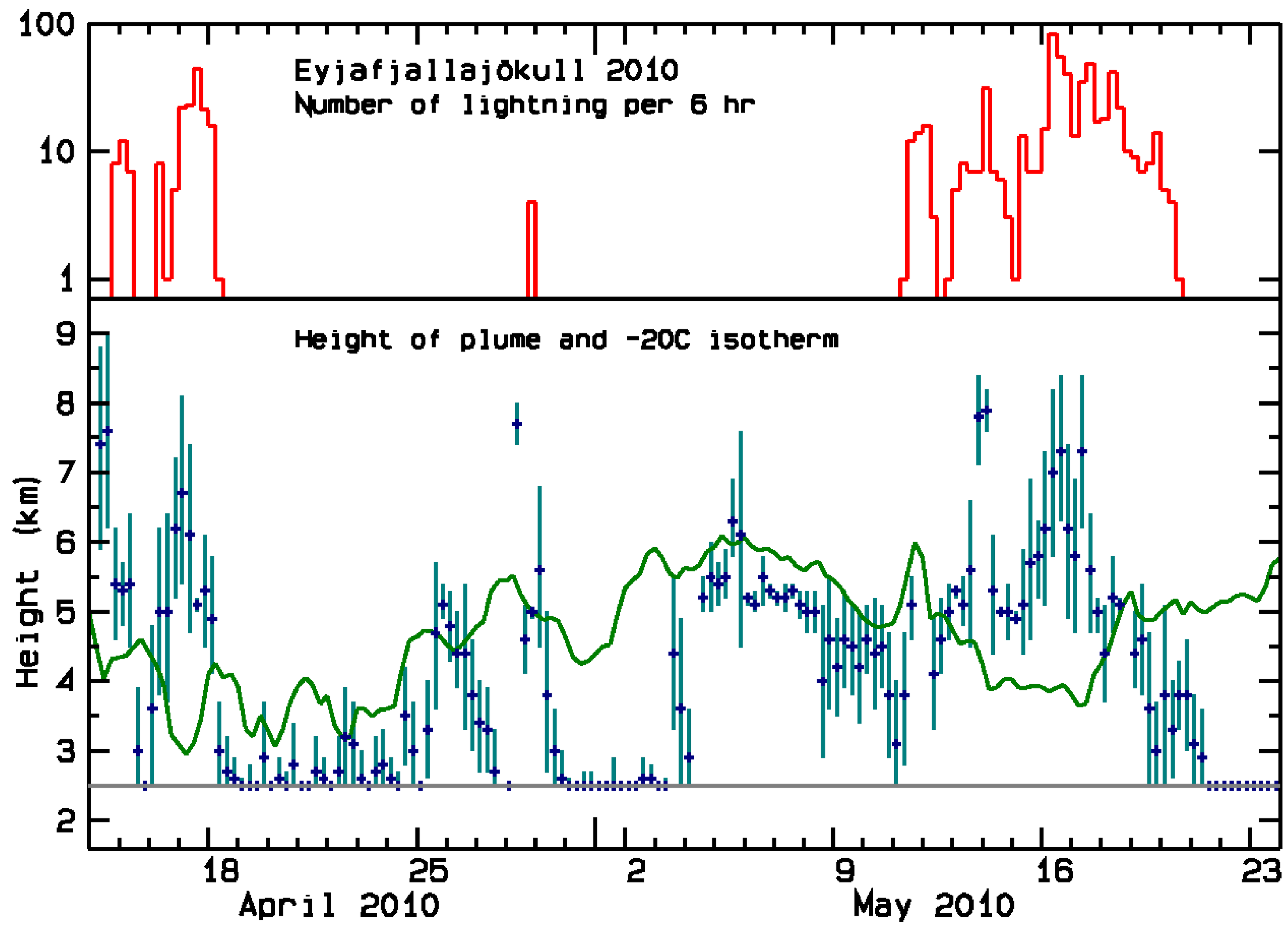

Fig. 1. Plume height (cyan bars), height of atmospheric -20°C isotherm (green) and lightning occurrences in the plume (red) during the eruption 14 April – 23 May 2010. Lightning activity was observed when the plume penetrated significantly up into atmospheric droplet freezing conditions. The upper air was relatively warm during the lightning-free period 3-10 May, and although the eruption plume was fairly strong, it did not reach the green droplet freezing zone.

3 The May 11th surprise

The most surprising change in the lightning activity during the Eyjafjallajökull eruption occurred on 11 May when there was no obvious change in the physical eruption character or strength. During 3-10 May there was no lightning recorded by long-range networks, but 11-20 May the lightning activity in the plume was intense, with the highest activity of the entire eruption on 16 May.

The change in lightning activity on 11 May coincides with a change in the conditions of the surrounding atmosphere. At this time the isotherms for droplet freezing (about -20°C) dropped drastically and the plume top reached the lowest temperatures on 16 May. Therefore, it seems likely that the atmospheric conditions around the plume are influencing the lightning activity.

4 Conclusions

The synchroneity of the main lightning activity with the atmospheric freezing conditions supports that the charge generation of the larger long-range volcanic lightning is analogous to meteorological lightning.

Veðurstofa Íslands – Icelandic Meteorological Office
Bústaðavegi 9, IS–150 Reykjavík, Iceland
Ph. +354 522 6000, www.vedur.is

Met Office
FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom
Ph. +44 1392 885680, www.metoffice.gov.uk

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A Lightning data

The lightning were detected by the UK Met Office long-range lightning location network, ATDnet, operating in the VLF radio spectrum. The network probably did not detect lightning with peak currents of less than 3 kA, and detection efficiency in Iceland is estimated at 60% for strokes generating 15 kA.

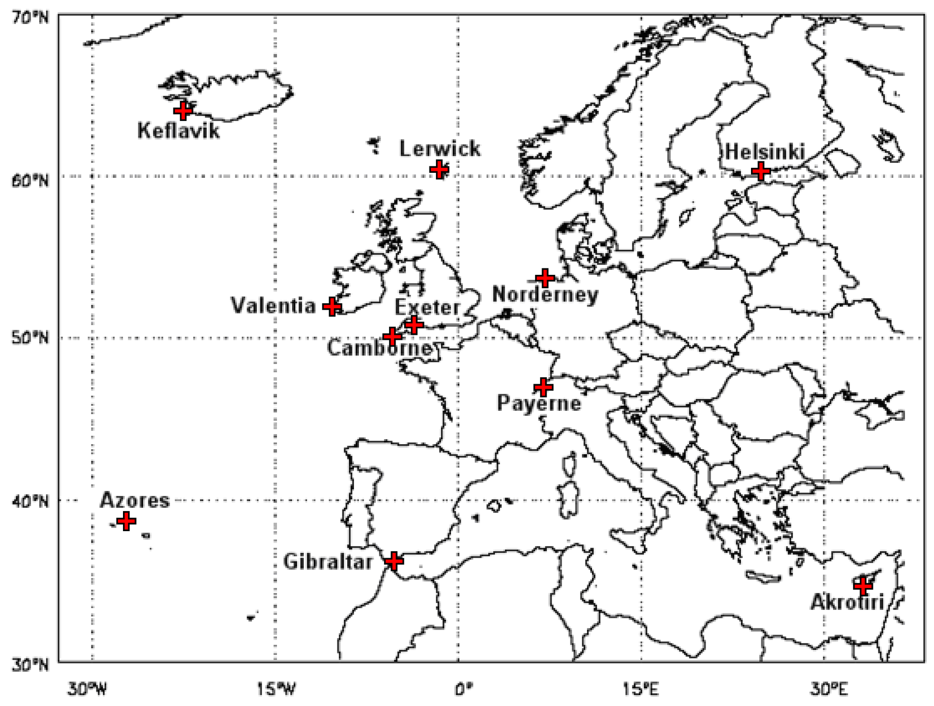

Fig. 2. ATDnet lightning out-stations in Europe. The long-range VLF network uses arrival time differences of a 10-14 kHz vertical electric field signal to locate lightning.

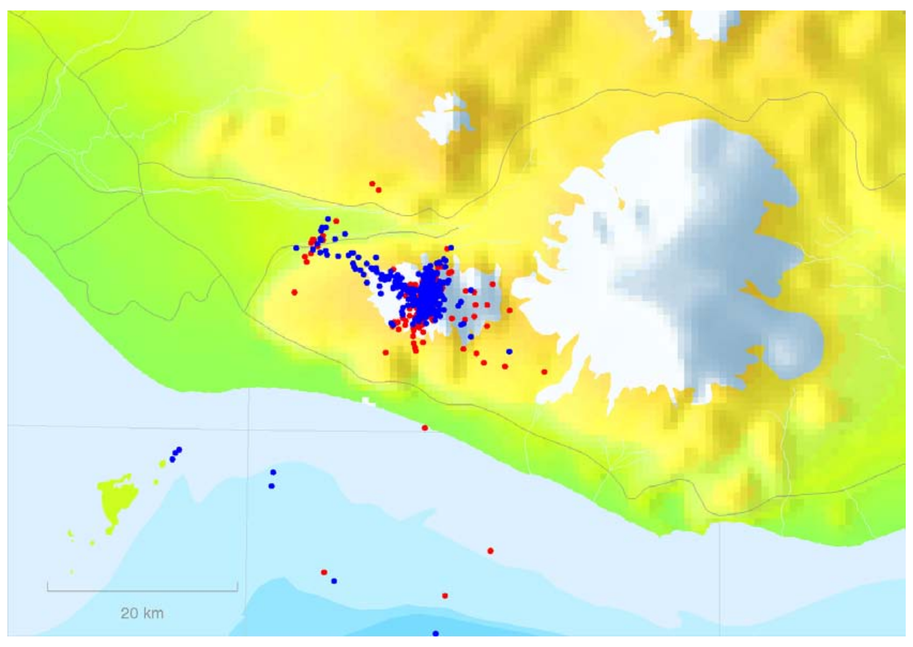

Fig. 3. Located lightning around Eyjafjallajökull in April (red) and May (blue). Some of the outliers may be mislocated due to poor configuration of stations detecting the event.

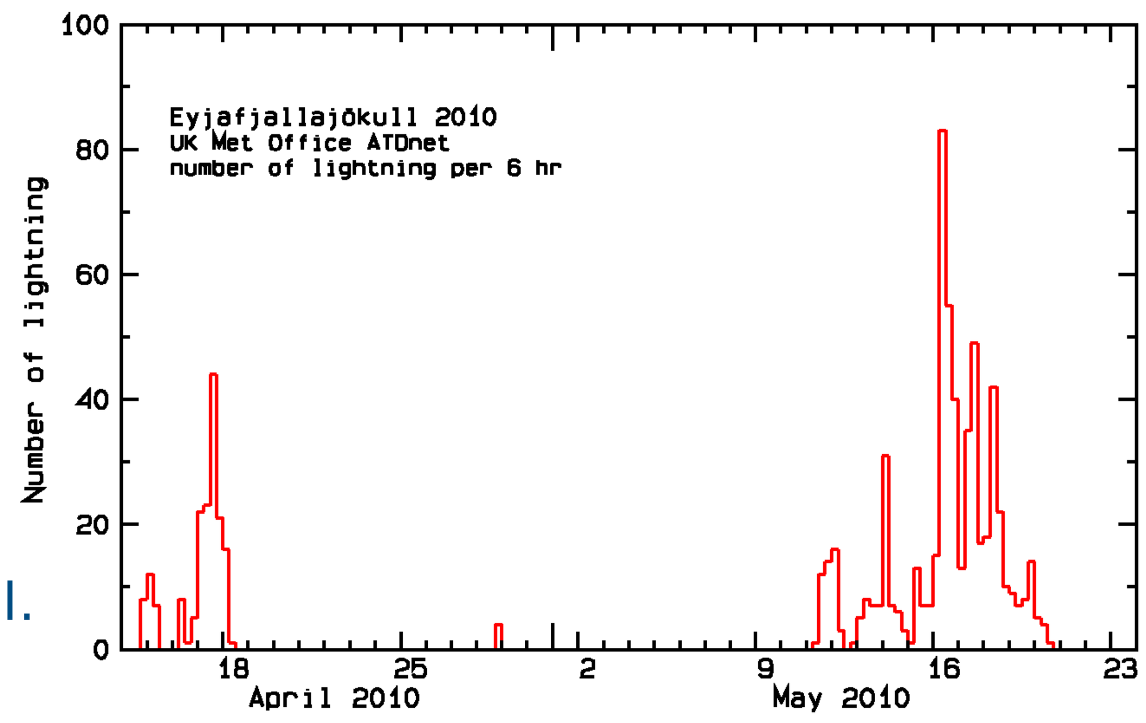

Fig. 4. Number of lightning per 6 hours around Eyjafjallajökull.

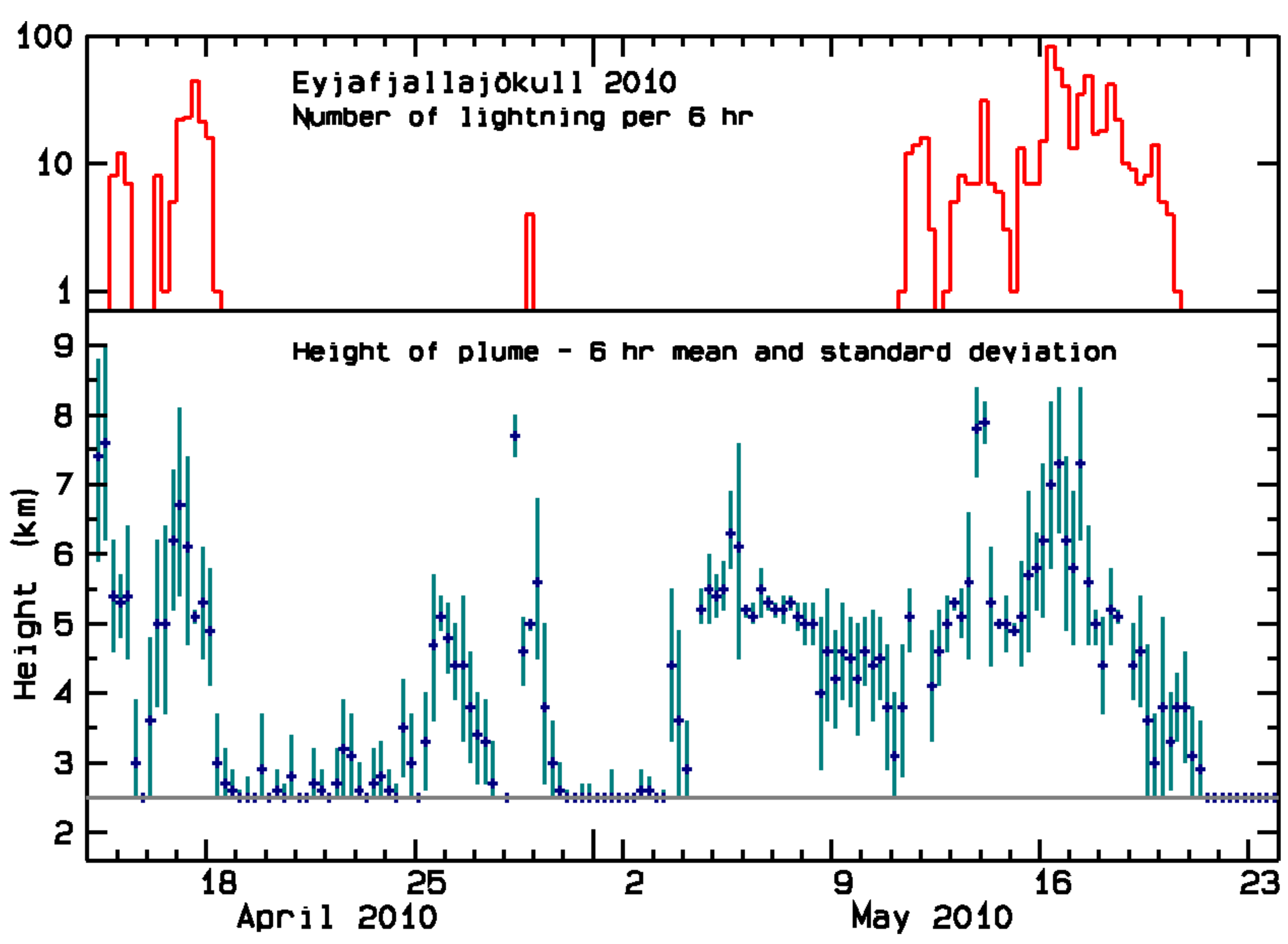

Fig. 9. The plume altitude as observed by weather radar and the frequency of lightning as measured by the long-range ATDnet system of the Met Office. A vigourous plume is needed for lightning occurrences. The absence of lightning during 3-10 May was puzzling.

B Plume height data

The volcanic plume height was measured by a weather radar every 5 minutes during the eruption. The radar estimates were validated by comparison to web-photos of the plume.

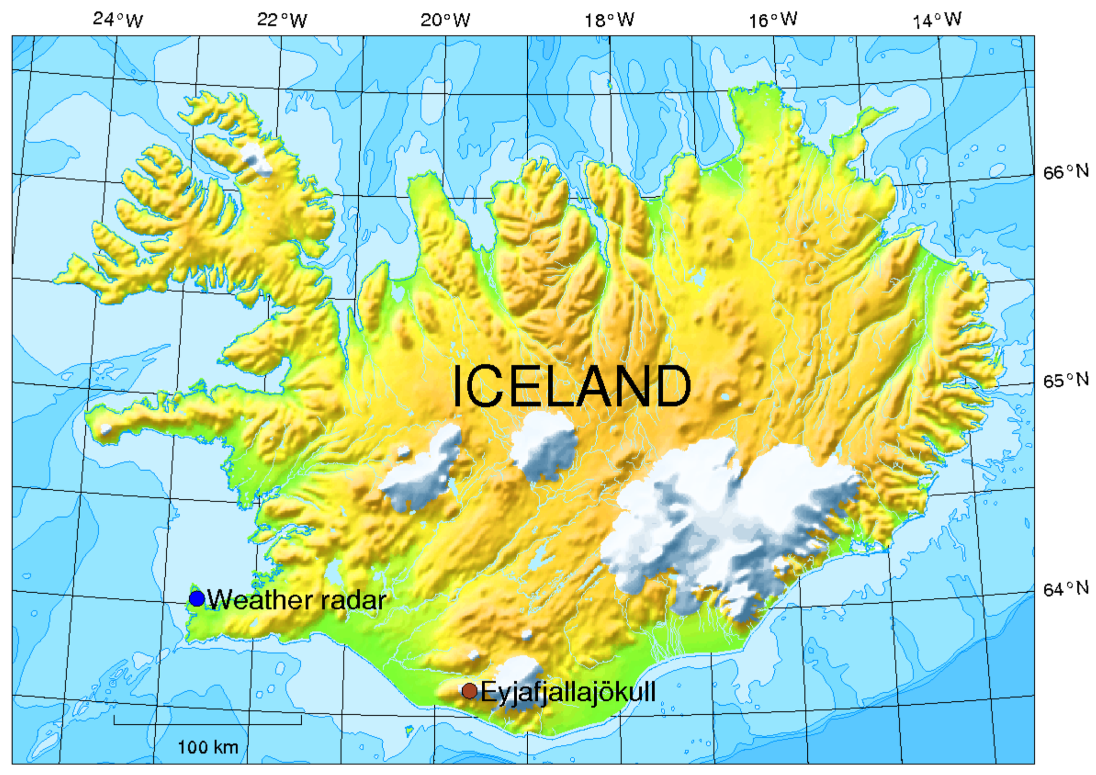

Fig. 5. The weather radar located at Keflavík international airport is about 150 km from the Eyjafjallajökull volcano in S-Iceland.

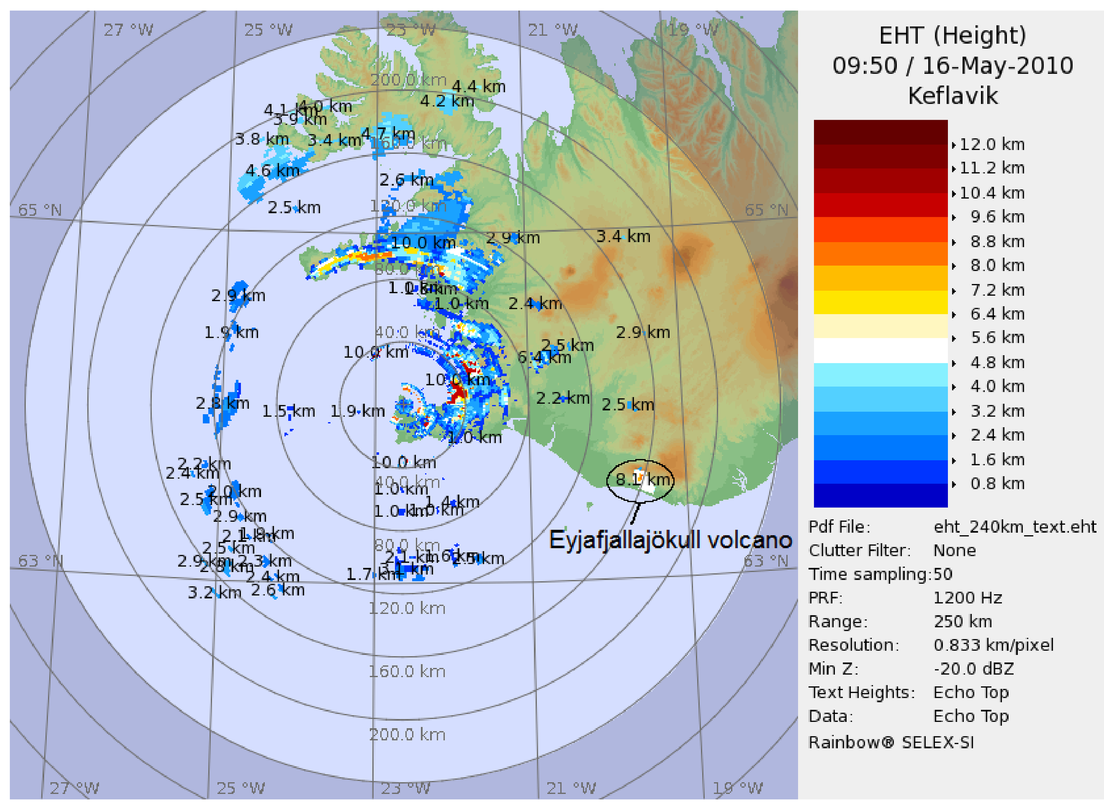

Fig. 6. Echo top image of the weather radar scan on 16 May 2010 at 09:50 UTC.

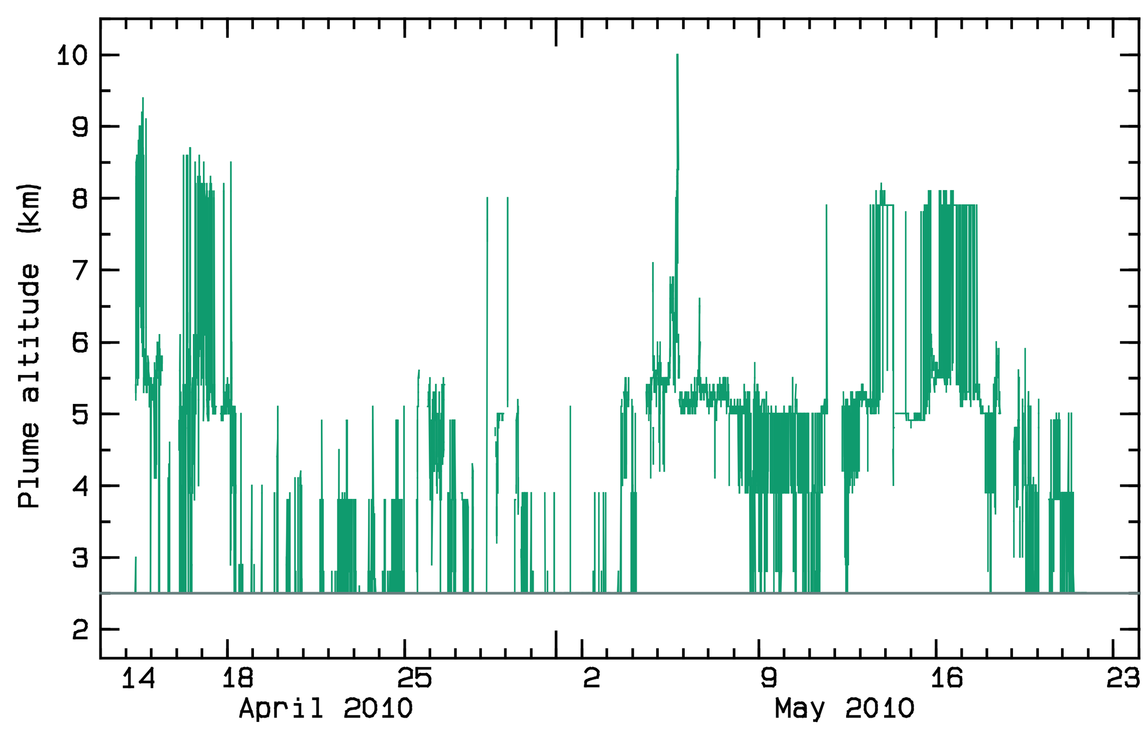

Fig. 7. The 5-min time series of the plume altitude (km a.s.l.) as measured by weather radar.

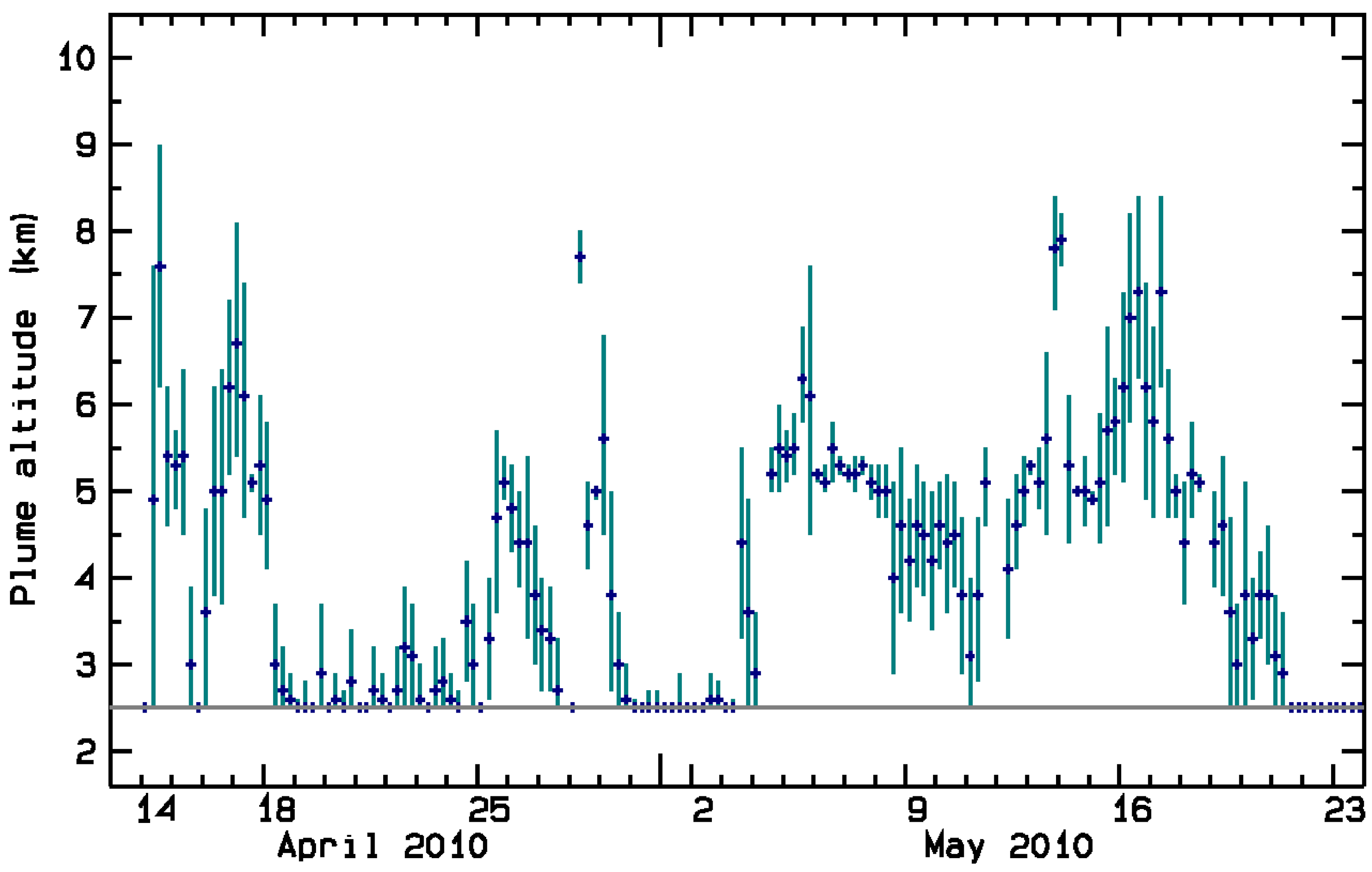

Fig. 8. A 6-hour average of the echo top height of the eruption plume (km a.s.l.). The bars represent one standard deviation.

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C Atmospheric conditions

Conditions of the surrounding atmosphere during the volcanic eruption were estimated from radiosonde measurements and numerical weather prediction (NWP) models. The atmospheric conditions influence the volcanic plume and appear to control lightning activity.

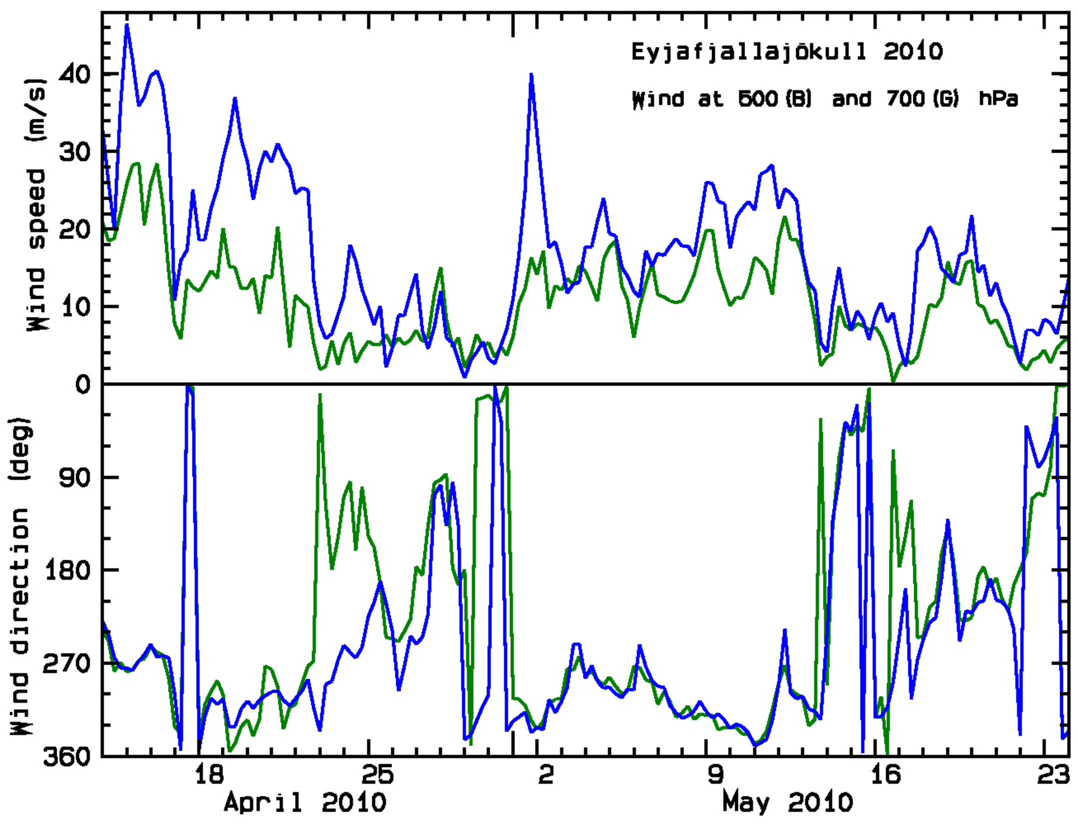
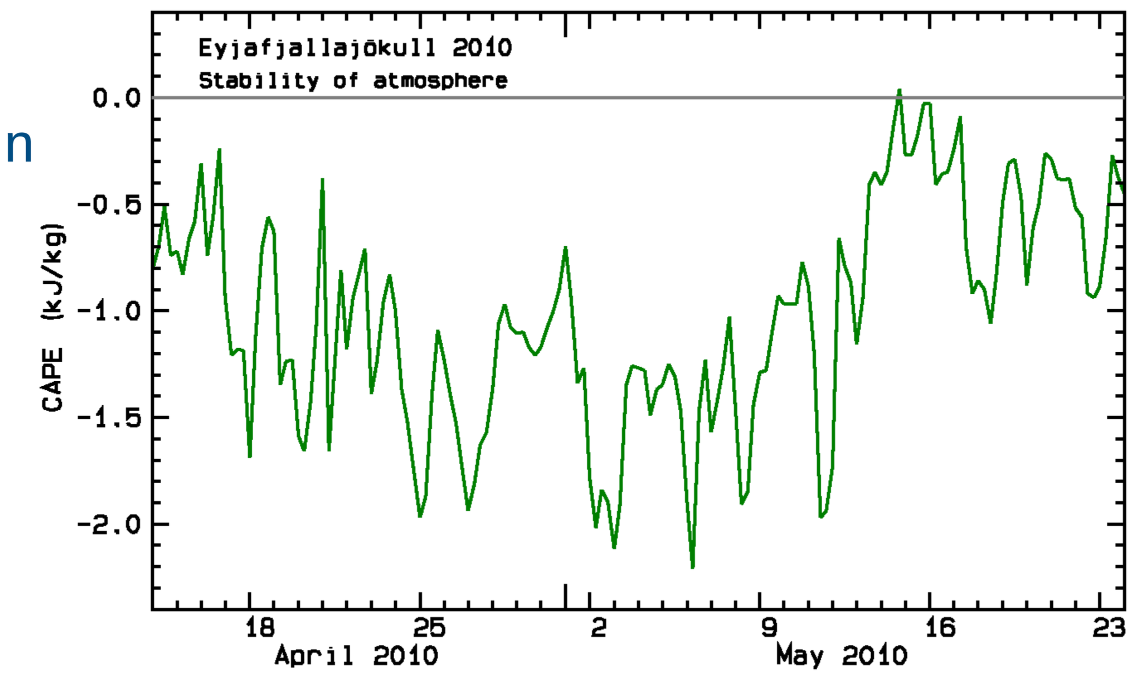


Fig. 10. Wind speed and wind direction above Eyjafjallajökull during the eruption at two pressure levels, 700 hPa (~2.9 km, green) and 500 hPa (~5.4 km, blue).

Fig. 14. The volcanic eruption in Eyjafjallajökull in S-Iceland. Photo Þ. Arason 17 April 2010 at 16:35 UTC.

Fig. 11. Stability of the atmospheric column above Eyjafjallajökull, measured by CAPE (Convective Available Potential Energy), where negative values indicate stable conditions.



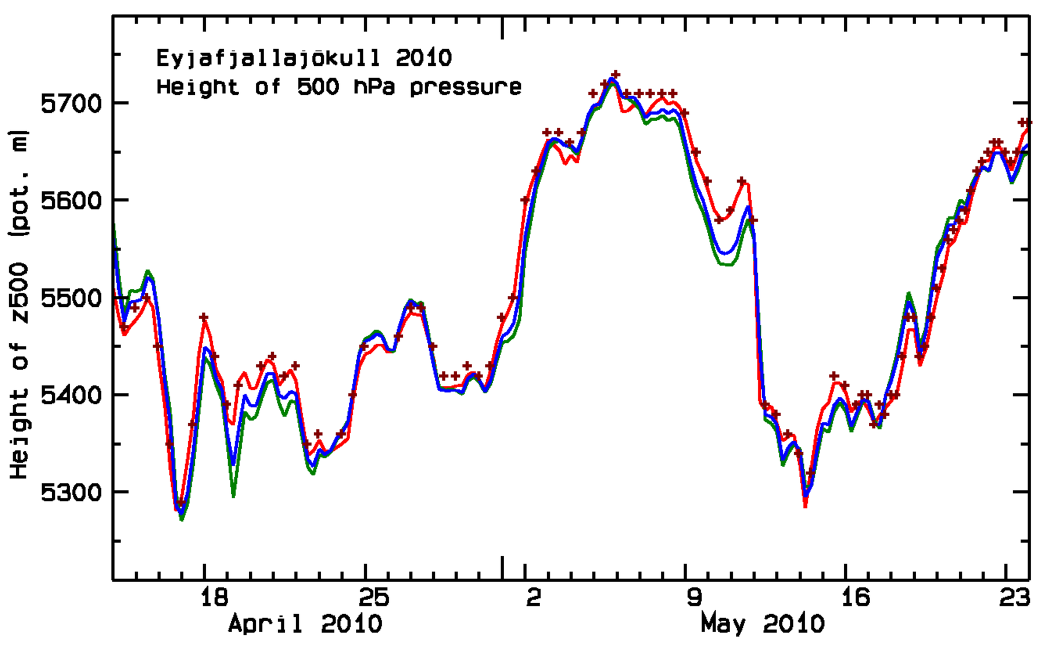


Fig. 12. The height of the 500 hPa pressure level. The blue and green curves are NWP values for the atmosphere above the volcano. The red curve and dots show NWP and radiosonde data for Keflavík 150 km from the volcano.

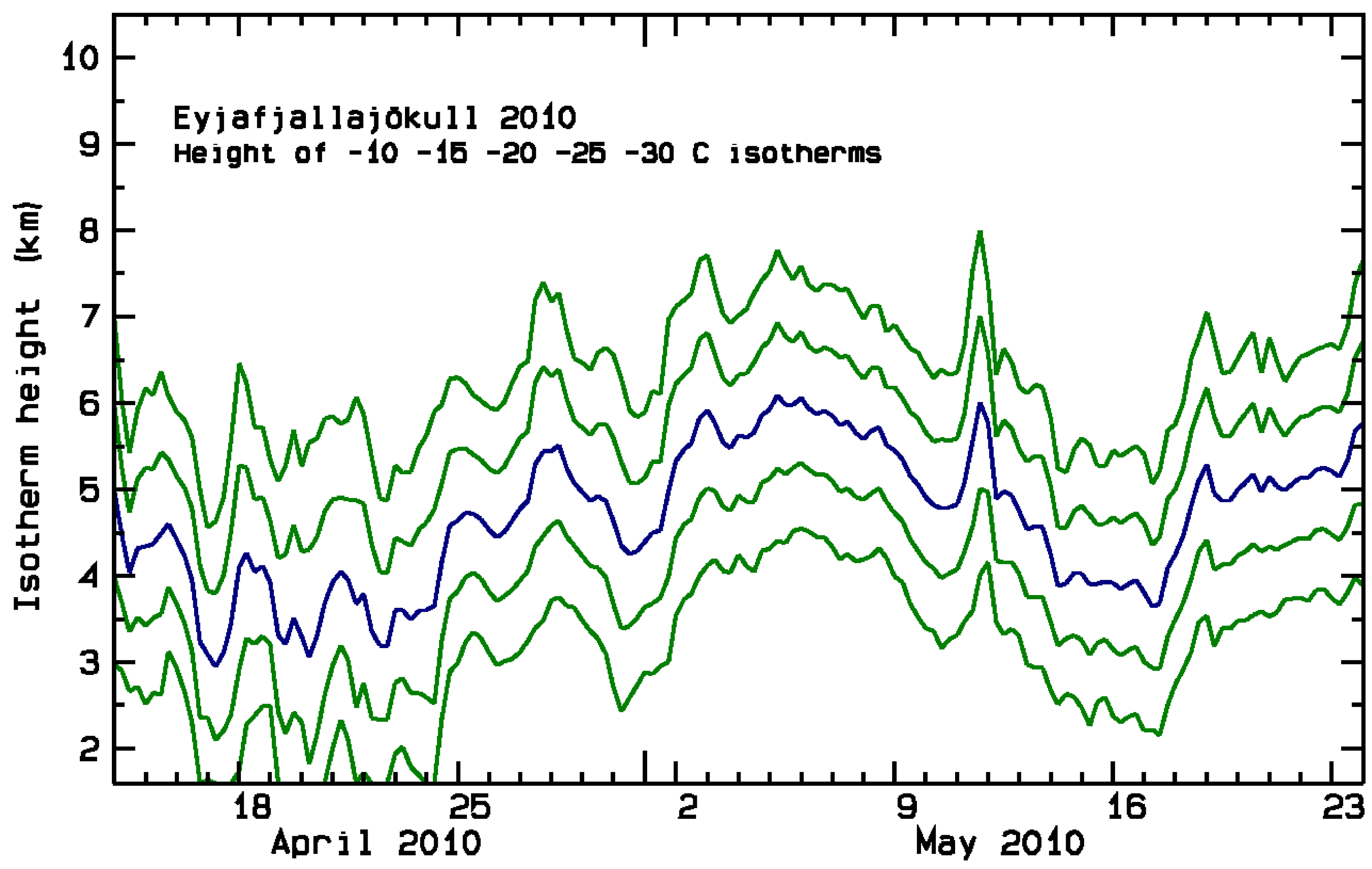


Fig. 13. The variations of the height of the isotherms -10°C to -30°C over Eyjafjallajökull in a NWP-model.

Main Conclusions

The synchroneity of the main lightning activity with the atmospheric freezing conditions supports that the charge generation of the larger long-range volcanic lightning is analogous to meteorological lightning.

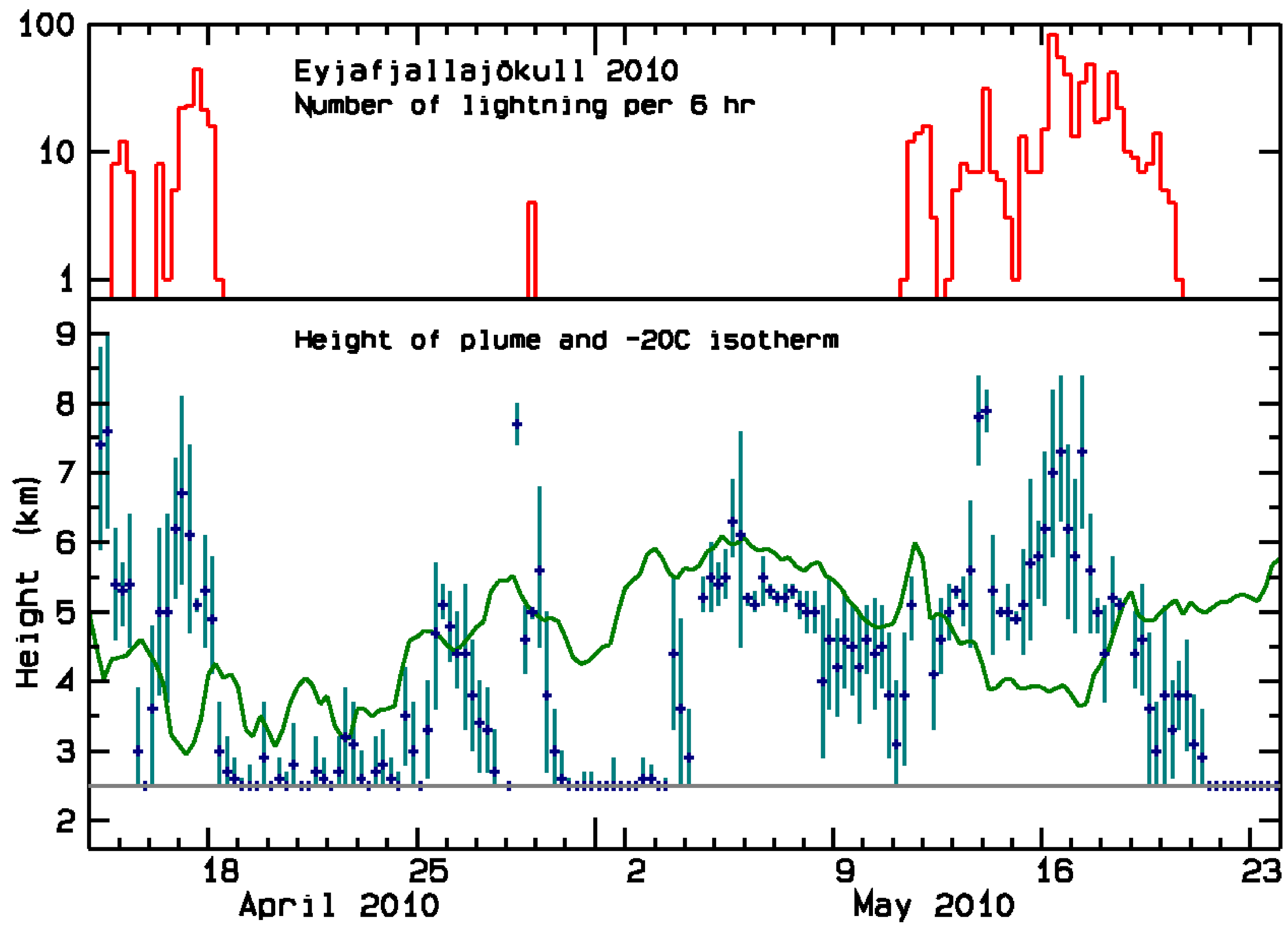


Fig. 15. Plume height (cyan bars), height of atmospheric -20°C isotherm (green) and lightning occurrences in the plume (red) during the eruption 14 April – 23 May 2010. Lightning activity was observed when the plume penetrated significantly up into atmospheric droplet freezing conditions. The upper air was relatively warm during the lightning-free period 3-10 May, and although the eruption plume was fairly strong, it did not reach the green droplet freezing zone. (Same as Fig. 1)