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Determining the mass fraction of external water in the plume of the 2011 eruption of Grímsvötn, Iceland

Magnus T. Gudmundsson (1), Finnur Pálsson (1), Thor Thordarson (1), Ármann Höskuldsson (1), Gudrún Larsen (1), Thórdís Högnadóttir (1), Björn Oddsson (2), Bergrún Óladóttir (1), and Jónas Gudnason (1)

(1) University of Iceland, Nordvulk, Institute of Earth Sciences, Reykjavik, Iceland (mtg@hi.is, 354 525 4800), (2) National Commissioner of the Icelandic Police, Civil Protection Department, Reykjavik, Iceland

The VEI4 eruption of Grímsvötn in May 2011 produced an up to 20-km high eruption plume with on over 100 km wide umbrella cloud. The plume was sustained at or above 15 km height for the first 24 hours of this 7-day long eruption. It alternated between wet, phreatomagmatic phases and dry magmatic phases, with over half of the erupted material formed during dry conditions. The eruption fissure was about 1.5 km long, located in the southwest part Grímsvötn, outside the boundaries of the subglacial Grímsvötn lake but within the topographic boundaries of the Grímsvötn caldera. Before the eruption this locality was mostly covered by 50-150 m thick ice. During the eruption the ice was melted, and a 700 m wide and up to 150 m deep ice cauldron with meltwater was formed. This meltwater lake within the cauldron surrounded and saturated the craters during the later and less energetic part of the eruption. The melting of this ice did at first not affect the surrounding glacier and the water level in the cauldron near the end of and shortly after the eruption was lower than in the subglacial Grímsvötn lake, about 1 km further to the northeast in the central part of the caldera. Apparently, no hydrological connection existed between the main subglacial lake and the eruption site during the eruption and it seems that no meltwater from the eruption was lost subglacially from the eruption site to the subglacial lake. The ice cauldron was therefore a system with only one open pathway for loss of meltwater – as steam added to the volcanic plume. Thus, the mass of ice melted, heated and evaporated could be determined. The eruption therefore provided a unique opportunity to quantify the mass of external water added to a volcanic plume. The results indicate that external water was 5-10% of the total mass of tephra erupted. Of the order of one fifth of the total thermal energy was used to generate the steam. This large external mass of steam modified the behaviour of the plume and may have been an important factor in sustaining the very large, but ash-poor umbrella cloud for up to 24 hours. These results should provide useful constraints on the role of external water in models of eruption plume behaviour.