# Icelandic volcanic emissions and climate

**To the Editor** — On 31 August 2014, a large non-explosive fissure eruption of more than 1 $km^3$ of lava began in Iceland, about 45 km from the Bárðarbunga volcano[1,2]. For more than 100 days the 'Nornahraun' eruption emitted an average of about 35 kilotons of sulphur dioxide ($SO_2$) per day into the atmosphere[1]; almost three times the daily anthropogenic emissions of $SO_2$ by the 28 European Union member states in 2010[3]. Our global climate model simulations of the eruption (Supplementary Information) suggest that if the eruption were to continue into the spring and summer of 2015, its radiative forcing over the North Atlantic and Western Europe would exceed, in absolute value, that of all current human aerosol emissions in the same region.

During September 2014, peak $SO_2$ emissions reached 120 kilotons per day, although there is substantial uncertainty associated with the $SO_2$ emission fluxes. So far, the eruption has not emitted any significant amounts of volcanic ash. Even though $SO_2$ emissions from the Nornahraun eruption do not reach the stratosphere, this type of eruption can have significant effects on regional climate by increasing the albedo of low-level liquid clouds[4–6], thereby reflecting more solar radiation back to space (Fig. 1).

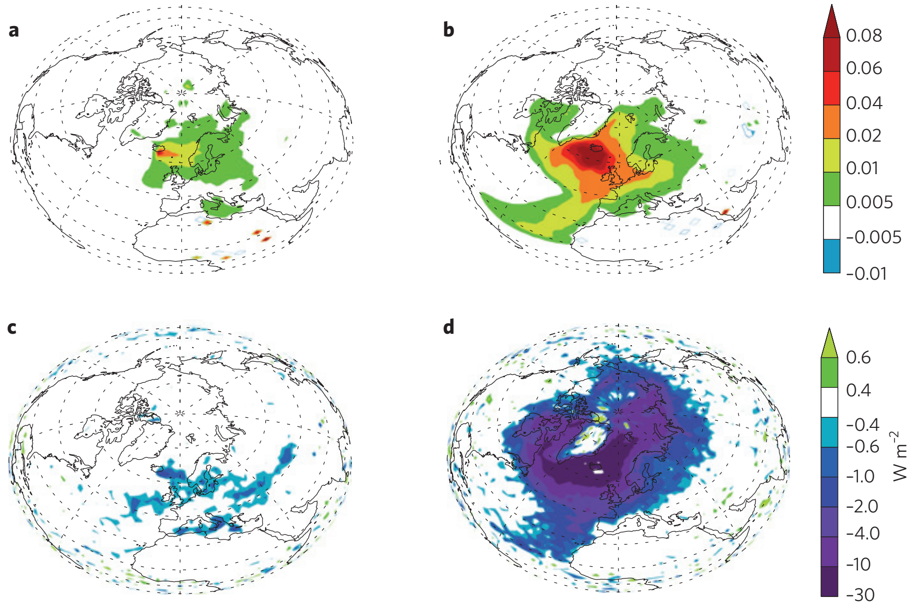


**Figure 1 |** Simulated changes due to the Nornahraun eruption in Iceland. **a**,**b**, Differences in aerosol optical depth (ΔAOD, unitless) at visible wavelengths (550 nm) between simulations with and without volcanic sulfur dioxide emissions during September–November (**a**) and June–August (**b**). **c**,**d**, Differences in radiative flux at the top of the atmosphere (ΔTOA) for the same simulations, for September–November (**c**) and June–August (**d**).

Our model simulations assume emissions of 40 kilotons per day into an altitude range of 1,500 m to 3,000 m, and account for different meteorological conditions (Supplementary Information). Our simulations predict significant regional radiative forcing over Europe and the North Atlantic (45–70° N, 50° W–15° E), estimated from differences with control simulations (without the eruption). In the autumn months (September–November), radiative forcing amounts to −0.21 W $m^{-2}$ ($\sigma = 0.05$) (Fig. 1), of which a striking 80% ($\sigma = 5\%$) is attributable to albedo effects of sulphur on liquid clouds in solar wavelengths. Simulations indicate that should this level of emissions occur in summer (June–August), −7.4 W $m^{-2}$ ($\sigma = 1.0$) of radiative forcing would result, with 94% attributable to indirect effects ($\sigma = 2\%$).

By comparison, based on similar simulations, we estimate −1.5 W $m^{-2}$ and −5.8 W $m^{-2}$ of radiative forcing from all anthropogenic aerosol emissions in autumn and summer, respectively, in this same region. During summer the radiative effects are larger due to a greater solar flux and a higher burden of sulphates from gas-phase oxidation. The simulated change in regional aerosol optical depth (ΔAOD, Fig. 1) due to the eruption would be hard to detect in autumn (mean ΔAOD = 0.005, $\sigma = 0.001$), but may be detectable in satellite data during boreal summer for similarly large eruptions (mean ΔAOD = 0.03, $\sigma = 0.006$, but local ΔAOD up to 0.1). At present, there are limited ground-based aerosol data in this region.

The Nornahraun eruption provides an unprecedented opportunity to observe aerosol–cloud interactions induced by continuous volcanic degassing into a region of high cloud susceptibility[7]. This magnitude of indirect forcing by aerosols may significantly alter regional modes of climate variability, even without reaching the stratosphere. Sensitivity tests (Supplementary Information) indicate that the radiative forcing is sensitive to different atmospheric flow conditions in the region during the eruption. The radiative perturbation of the Northern Hemisphere (Fig. 1) may result in atmospheric circulation anomalies. Similar climate impacts may have occurred during historic Icelandic volcanic eruptions (for example, Laki in AD 1783–1784)[8,9].

Local $SO_2$ and particle emissions are currently being analysed, but more detailed regional measurements are needed of the various gaseous and particulate species from both ground-based and satellite platforms[4,5,10]. Permanent ground-based instrumentation in Iceland would be valuable to augment existing global networks. This would enable detailed evaluation of climate simulations of the impacts of this and similar eruptions. ❐


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Additional information

Supplementary information is available in the online version of the paper.


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