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ProScience 1 (2014) 348-352

ProScience

Conference Proceedings

1st International Conference on Atmospheric Dust - DUST2014

Does volcanic ash re-mobilization from its deposits contribute to ocean fertilization?

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Abstract

Recent studies on the iron fertilization of the surface ocean with volcanic ash are all focused on the immediate time after a volcanic eruption. Here we investigate a post-eruptive effect: volcanic ash may be re-mobilized into the atmosphere from ash deposits on land by wind. Therefore it may fertilize the surface ocean during periods of months to years and not only during a volcanic eruption. Observations confirm such re-mobilization events, e.g. after the volcanic eruptions of Katmai, Alaska (1912), Mt. Hudson, Chile (1991) and Eyjafjallajökull, Iceland (2010). Even though the Katmai eruption is more than 100 years ago, volcanic ash re-mobilization events occur until today. Here we report first model simulation results after the volcanic eruption of Mt. Hudson, Chile (1991) focusing on the deposition of volcanic ash into the Atlantic sector of the Antarctic Ocean and its potential to iron-fertilize surface ocean waters.

Keywords: Volcanic ash; re-mobilization; ocean iron fertilization.

1. Introduction

Volcanic ash is known to be mobilized by wind from its deposits (Hobbs et al., 1983; Hadley et al., 2004; Wilson et al., 2011; Leadbetter et al., 2012; Thorsteinsson et al., 2011; 2012; Folch et al., 2014), which have accumulated after volcanic eruptions on land. Such deposits are located along the main transport directions of the volcanic eruption cloud, which spreads out over hundreds to thousands of kilometres, dependent on wind speed, ash size, ash density and eruption magnitude. Volcanic ash re-mobilization contradicts the general assumption that volcanic ash environmental and climate effects are restricted only to the duration of a volcanic eruption with time scales of days to weeks (Langmann, 2013). Wilson et al. (2011) for example report such post-eruptive volcanic ash clouds being

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ISSN: 2283-5954
Selection and peer-review under responsibility of DUST2014 Scientific Committee
DOI:10.14644/dust.2014.057

transported over the Patagonian desert for several months to years after the 1991 eruption of Mt. Hudson in Chile (Fig. 1). Following the recent eruption of Eyjafjallajökull in Iceland during April/May 2010, volcanic ash re-mobilization created poor air quality and health concerns for the local population for several months (Leadbetter et al., 2012; Thorsteinsson et al., 2011, 2012). Hadley et al. (2004) and Wilson et al. (2011) also report volcanic ash from re-suspensions events from the Katmai/Novarupta eruption in 1912 in Alaska, which typically occur in the fall before snowfall. The June 6-8, 1912 Katmai/Novarupta eruption was the largest volcanic eruption in the 20th century and produced volcanic ash deposits of 1-10 meters thickness around the volcano. A lack of snow combined with strong northerly winds is able to mobilize the hundred years old volcanic ash into the atmosphere even nowadays (Fig. 1).

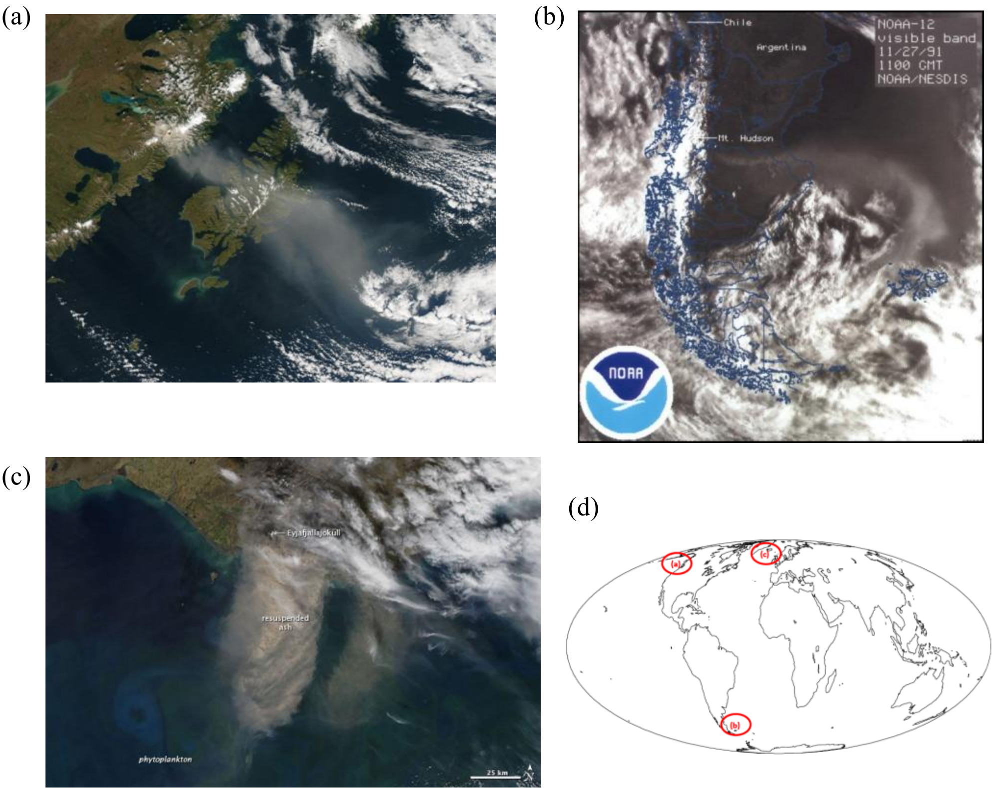

Fig. 1: Volcanic ash re-suspension event as seen from satellite: (a) September 21, 2003: Katmai/Novarupta, Alaska; (b) November 27, 1991: Cerro Hudson, Chile; (c) May 27, 2010: Eyafjallajökull, Iceland; (d) approximate location of (a) – (c). Courtesy of NASA.

In contrast to atmospheric mineral dust, the importance of volcanic ash for climate has long been considered negligible (Robock, 2000). Reduced atmospheric CO_2 concentrations were observed in the years following the 1991 Pinatubo eruption (Sarmiento, 1993; Watson, 1997). Mercado et al. (2009) argued that this was the consequence of increased vegetation photosynthesis induced by the presence of a volcanic sulfate aerosol layer in the atmosphere. Notably, Sarmiento (1993) suggested that the atmospheric CO_2 drawdown was the result of ocean fertilization by Pinatubo ash. While the 1991 Pinatubo eruption released

5–6 km^3 of ash, a percentage limited amount fell into the iron-limited Southern Ocean. However, the eruption of Mt. Hudson around the same time deposited approximately 1.1 km^3 of ash into the iron-limited Atlantic sector of the Southern Ocean (Scasso et al., 1994). Surprisingly, this ash deposition event has never been evoked to explain the decrease in atmospheric CO_2 concentration. Furthermore, the fertilization potential of the Mt. Hudson ash deposited in Patagonia (~1.6 km^3), which was easily re-mobilized by the roaring forties during several months to years after the eruption has never been considered.

2. Model set-up

Model parameterizations of volcanic ash re-mobilization from its deposits on land build on mineral dust mobilization schemes (Leadbetter et al., 2012). Here we present preliminary model results of volcanic ash re-mobilization, dispersion and deposition simulated with the three-dimensional on-line meteorological-ash model REMOTE (Langmann et al., 2008, 2010) for the first year after the Hudson eruption in August 1991. The re-mobilization parameterization is based on Marticorena & Bergametti (1995), but with a constant threshold of 0.3 m/s for the friction velocity, because of the unknown properties of the volcanic ash deposit. The spatial distribution of the ash deposit from the Hudson eruption in 1991 is based on Scasso et al. (1994). Volcanic ash is modelled with a log-normal size distribution with a median radius of 2 micrometres. The model resolution is 1° in latitude and longitude. ECMWF analysis data serve as initial and lateral boundary information.

3. Preliminary model results and conclusions

Preliminary results for a one-year simulation period look promising. Maximum atmospheric near surface ash concentrations (Fig. 2a) of about 5 mg/m^3 are reached in March 1992 and are associated with an intense re-mobilization event. Similar maximum atmospheric ash concentrations have been measured following the Eyjafjallajökull eruption on Iceland in 2010 (Thorsteinsson et al., 2012). According to the model results, major re-mobilization events of volcanic ash occurred in 1991 during September, November and December and in 1992 during March and September (Fig. 2b) pointing to a reasonable reproduction of observed re-mobilization events (see Fig. 1b and http://www.volcano.si.edu/volcano. cfm? vn=358057). Total deposition closely follows the temporal evolution of emissions due to ash mobilization. The accumulated ocean deposition in September 1992 makes up nearly half of the total deposition (Fig. 2b) with considerable ash deposition into the Atlantic sector of the Southern Ocean (Fig. 3a). Ash deposition nearby the Falkland Islands of 1–5 g ash/m^2/y is comparable to estimated mineral dust deposition fluxes over the Falkland Islands (Mahowald et al., 2005). Assuming an iron content of 200 nmol Fe/(g ash), the iron deposition fluxes associated with volcanic ash re-mobilization into the Southern Ocean (Fig. 3b) slightly exceed estimated iron deposition fluxes associated with mineral dust (Fung et al., 2000). However, the iron content of aged volcanic ash is rather uncertain, so that this statement should be taken as very preliminary. Nevertheless, volcanic ash may carry additional nutrients (but also toxic substances) to be supplied to the ocean as discussed in Browning et al. (2014) for the Southern Ocean. Therefore, the fertilization potential of volcanic ash can be even higher (or lower) than pure iron sulfate, in particular in the case of co-limitations.

(a) (b)

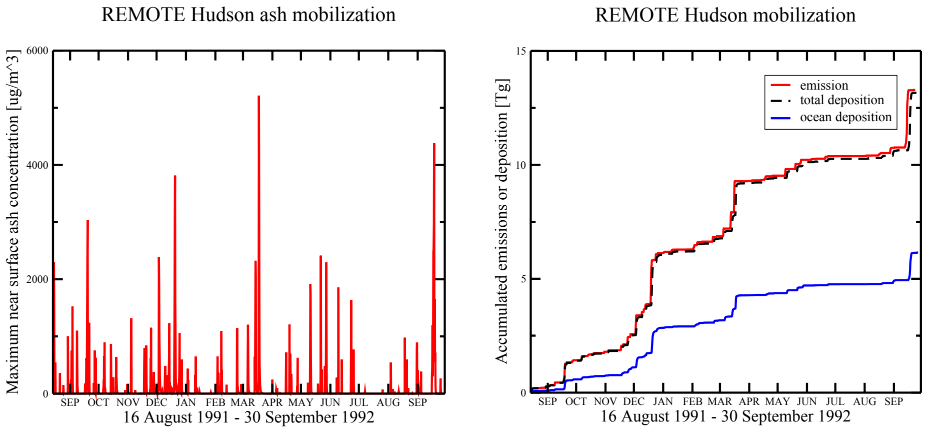

Fig. 2. REMOTE model results for the period August 1991 – September 1992 for (a) maximum near surface ash concentration [µg/m^3] and (b) accumulated ash emissions due to re-mobilization [Tg] (red line), accumulated total deposition [Tg] (broken black line) and ocean deposition [Tg] (blue line).

(a) (b)

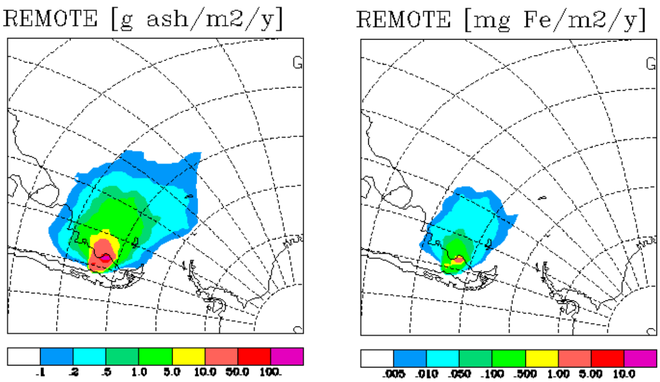

Fig. 3. REMOTE model results for the period August 1991 – September 1992 for (a) total ash deposition fluxes [g ash/m^2/y] and (b) estimated iron fluxes [mg Fe/m^2/y].

4. Outlook

Further sensitivity studies will be necessary to illuminate the effect of e.g. grain size distributions, horizontal model resolution, precipitation, soil moisture, deposit area and friction velocity.

5. Acknowledgements

The authors acknowledge the financial support through the Cluster of Excellence 'CliSAP' (EXC177), University of Hamburg funded through the German Science Foundation (DFG).

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