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# Impact of tropospheric sulphate aerosols on the terrestrial carbon cycle

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ABSTRACT

Tropospheric sulphate aerosols (TSAs) may oxidise the photosynthesising tissues if they are taken up by plants. A parameterisation of this impact of tropospheric sulphate aerosols (TSAs) on the terrestrial gross primary production is suggested. This parameterisation is implemented into the global Earth system model developed at the A.M. Obukhov Institute of the Atmospheric Physics, Russian Academy of Sciences (IAP RAS CM). With this coupled model, the simulations are performed which are forced by common anthropogenic and natural climate forcings based on historical reconstructions followed by the RCP 8.5 scenario. The model response to sulphate aerosol loading is subdivided into the climatic (related to the influence of TSA on the radiative transport in the atmosphere) and ecological (related to the toxic influence of sulphate aerosol on terrestrial plants) impacts. We found that the former basically dominates over the latter on a global scale and modifies the responses of the global vegetation and soil carbon stocks to external forcings by 10%. At a regional scale, however, ecological impact may be as much important as the climatic one.



## 1. Introduction

It is broadly accepted now that the atmospheric composition greatly affects the state of the Earth's climate. In turn, the former depends on both natural processes and human activities. In particular, atmospheric aerosols are important for the Earth's climate. Their direct (e.g., related to scattering and absorption of radiation in the solar and near-infrared bands, and change of snow albedo due to deposition of black carbon on snow) and indirect radiative effects (arising because of impact of hygroscopic aerosols on cloud albedo (Twomey, 1974) and cloud lifetime (Albrecht, 1989)) are known to modify climate state both at global and regional scales. Until recently, it was commonly adopted that scattering aerosols dominate in the total aerosol burden, aerosol radiative forcing counteracts the ongoing climate warming and leads to a reduction of precipitation (e.g., Charlson et al., 1992; Mitchell et al., 1995; Taylor and Penner, 1994; Meehl et al., 1996; Lohmann and Feichter, 1997; Boer et al., 2000; Bertrand et al., 2002; Jones et al., 2003a; Volodin and Diansky, 2006; Stendel et al., 2006; Knutson et al., 2006; Meehl et al., 2006; Eliseev et al., 2007). Recent estimates, however, concluded that, despite the central estimate for aerosol direct radiative forcing is negative, its uncertainty range is large and contains both positive and negative values (Myhre et al., 2013).

Nonetheless, one may speculate on other impacts of aerosols on the Earth's climate. First, change in climate state may modify the state of the biogeochemical cycles, hence activating a respective feedback loop. In particular, Jones et al. (2003a) have shown that accounting for the tropospheric sulphate aerosol in the simulations with the HadCM3L model leads to significant changes in the terrestrial and oceanic carbon uptakes and in the vegetation and soil carbon stocks.

In addition, there is an ecological impact of tropospheric sulphate aerosols (TSAs) which are toxic for terrestrial plants. When these aerosols are taken up by plants, they could oxidise the photosynthetic tissues of these plants. Hence, these aerosols might suppress terrestrial photosynthesis and, therefore, are able to impact the Earth's carbon cycle as well (Semenov et al., 1998; Kuylenstierna et al., 2001). In this respect, the sulphates are similar to the ozone which hurts plant stomata (Sitch et al., 2007). Such an ecological impact of sulphate aerosols was never implemented in global climate models, and its climatic consequences are unknown. Semenov et al. (1998), based on the empirical relations, assessed this impact for Europe and found that it is not significant. However, the TSA ecological impact might be important in other principal aerosol-polluted regions, e.g., China and south-eastern North America. The latter regions also exhibit a relatively high biological productivity. Moreover, plant functional types (PFTs), typical for these regions, exhibit strong sensitivity to toxic impact of sulphate aerosols (Semenov et al., 1998; Kuylenstierna et al., 2001).

We note that sulphate ions enter a number of commonly used agricultural fertilisers (e.g., Huang et al., 2011). Upon entering the soil, sulphate anions may react with soil alkalis and make the soil more fertile. However, if these anions are taken up by plants, they, depending on other conditions, may serve as a nutrient or may still be toxic for these plants (e.g., Rubin, 1985).

In the present paper, a simple representation of the toxic impact of sulphate aerosol on terrestrial gross primary production is suggested. This representation is implemented in the carbon cycle module of the

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