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Atmospheric Nitrogen Fixation by Volcanic Lightning during large Explosive Eruptions

MRS. DELPHINE CONTAMINE, PHD[1], ERWAN MARTIN[2], ADELINE AROSKAY[3], SLIMANE BEKKI[4], ILYA N. BINDEMAN[5], JOEL SAVARINO[6] AND SOPHIE SZOPA[7]

[1]Sorbonne Université - ISTeP
[2]Sorbonne Université, Institut des Sciences de la Terre de Paris, ISTeP UMR 7193
[3]OCE
[4]LATMOS/IPSL, Sorbonne Université, UVSQ, CNRS
[5]University of Oregon
[6]IGE, Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP
[7]Laboratoire des Sciences du Climat et de l'Environnement

Atmospheric dinitrogen, while abundant, is chemically inert and can only be assimilated directly by a few organisms. For nitrogen to become biologically available, specific processes are required to convert it into reactive nitrogen compounds, such as nitrates and ammonia. These processes can be abiotic and occur naturally, such as thunderstorm lightning or, in a modern atmosphere, anthropogenically, via industrial and engine emissions. During this transformation, often referred as fixation, ozone plays a critical role in the oxidation reactions leading to the formation of NOx (NO + NO_2) and then nitrate. This powerful oxidant exhibits the largest oxygen-17 isotopic anomaly ($\Delta^{17}O \approx 35‰$) in Earth's atmosphere, part of which is transferred to the nitrates produced ($\Delta^{17}O \approx 25‰$). In contrast, biological activity fixes atmospheric dinitrogen via interactions with surrounding H_2O and O_2, yielding nitrates with a mass-dependent signature ($\Delta^{17}O \approx 0‰$). This isotopic distinction permits the identification of nitrate sources and provides insight into nitrate observed in arid environments.

Recent discovery of high concentration of atmospheric nitrates in volcanic deposit has been attributed to fixation by volcanic lightning, a high-energy phenomenon characteristic of volcanic plume during large explosive eruptions.

Isotopic analysis of nitrates from volcanic deposits and sediment layers interbedded and preserved in an arid environment (Tecopa Basin, Ca, USA) has confirmed this hypothesis. The significantly higher proportion of atmospheric nitrates in volcanic deposits compared to sediments indicates a large and rapid production of atmospheric nitrates during eruption, driven by the breakdown of dinitrogen by volcanic lightning and subsequent ozone oxidation.

The isotopic signature of nitrates detected in deposits from the Minoan eruption of Santorini (Greece) will allow us to extend this analysis to non-arid environments, providing further insight into the impact of environmental conditions on nitrogen fixation. Moreover, as the dynamics evolved throughout the eruption, the study will reveal whether eruption dynamics have an impact on the lightning formation and therefore on the atmospheric dinitrogen fixation.