



Towards a transfer function for tropospheric volcanic sulfur emissions: The Holuhraun 2014/15 eruption

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Holuhraun 2014/15: Non-explosive but impactful

🔥 An effusive eruption took place at the Holuhraun lava field in Iceland between 31 August 2014 and 27 February 2015.

💧 The eruption released an estimated **8.3 Tg of SO₂** into the **troposphere** (Thordarson & Hartley, 2015).

❄️ Elevated sulfate concentrations (Du et al., 2019; Nakazawa et al., 2021) and conductivity values (Kjær et al., 2022) have been **observed in snow pits** in Central Greenland (EGRIP site) summer 2015.

Tropospheric sulfate is missing from reconstructions of volcanic forcing

⚠️ **Sulfate aerosols** in the atmosphere impact radiative forcing and are climate-relevant.

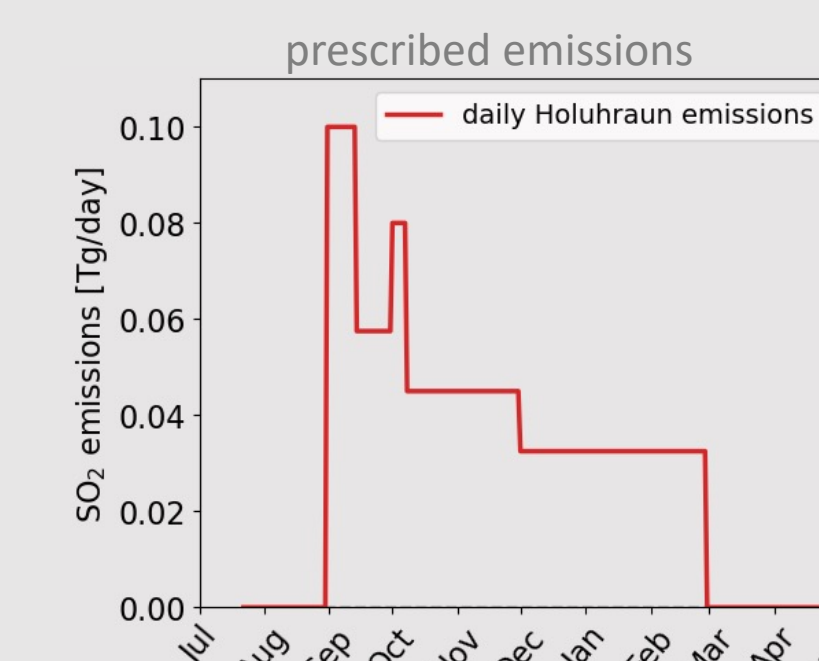
☁️ Explosive volcanic eruptions contribute large amounts of sulfate to the stratosphere, whereas effusive eruptions and anthropogenic sources emit into the troposphere.

❓ There is a research gap in historical volcanic sulfur fluxes to the **troposphere**.

📄 This work aims to fill this gap by calculating a **transfer function** for the **Holuhraun eruption** 2014-2015 in Iceland using observations, modelling, and ice core data.

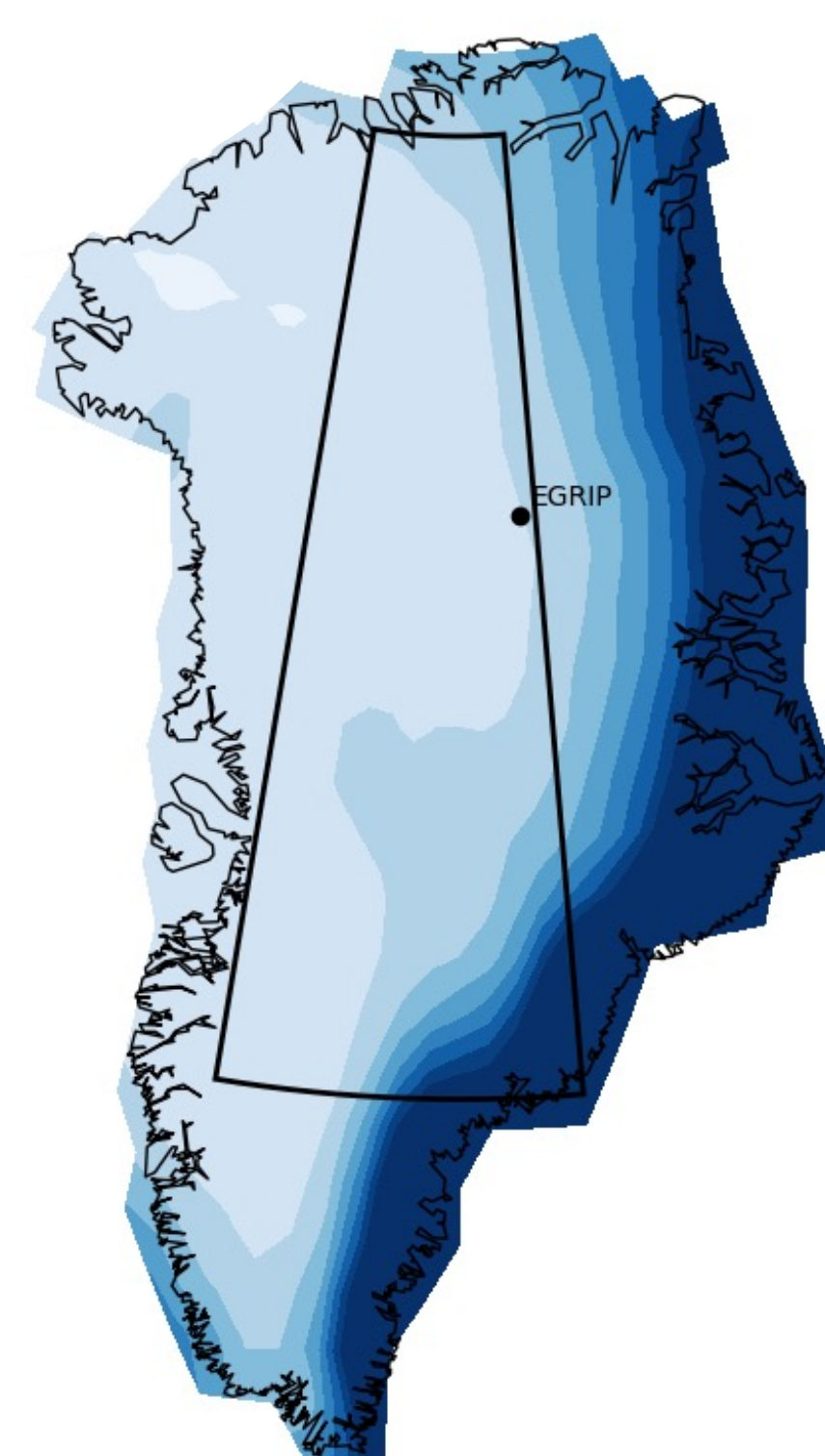
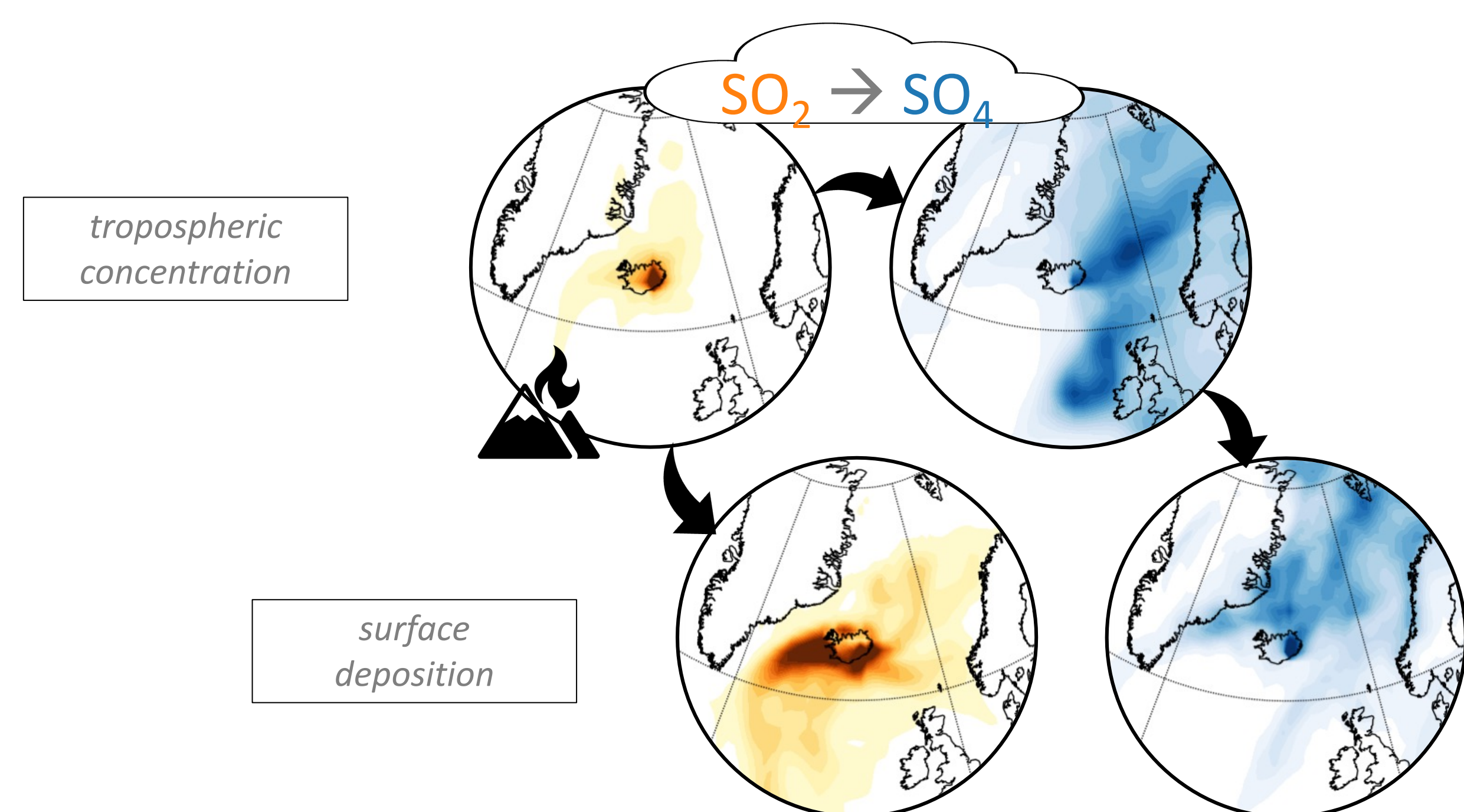
Modeling the eruption with CESM2

- Community Earth System Model version 2 (Danabasoglu et al., 2020)
 - 1 simulation with nudged horizontal winds using MERRA-2 reanalysis (GMAO, 2015)
 - 10 free-running simulations with different meteorologies
 - Paired anomalies are calculated for each experiment
 - Prescribed 8.3 Tg SO₂ emissions (see plot) at altitude 0.95-3 km
- The simulations were carried out and published by Zoëga et al. (2025).



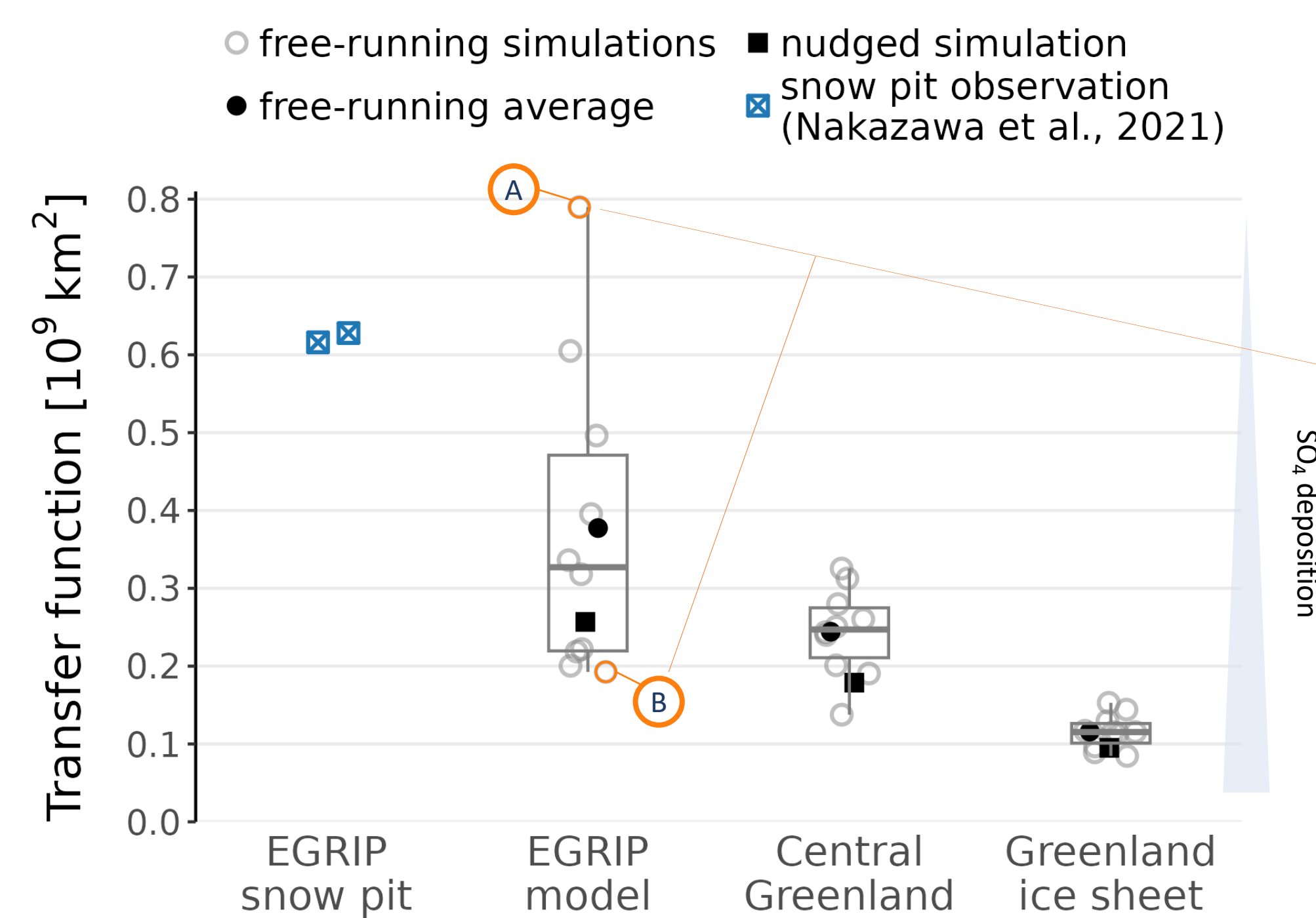
Deposition in equal parts as SO₂ and SO₄

For stratospheric eruptions, it is generally assumed that all emitted sulfur is converted into and deposited as SO₄. For the modelled Holuhraun eruption, an **average of 48.8%** (range: 42.3-56.7%) of emitted sulfur is deposited in the form of SO₄ in the free-running simulations, with the rest deposited as SO₂. In the nudged simulation, SO₂:SO₄ partition is 51.4%:48.6%. Other sulfur pathways are negligibly small in all experiments.



SO₄ deposition (nudged simulation). Darker shades mean higher deposition.

Results



High local/regional sulfate deposition yields low transfer function values.

EGRIP snow pit	CESM2 experiment	EGRIP model	Central Greenland domain	Greenland ice sheet
0.62, 0.63	nudged	0.26	0.18	0.10
	free-running average (range)	0.38 (0.19-0.79)	0.24 (0.14-0.33)	0.12 (0.08-0.15)

(calculated from data by Nakazawa et al., 2021)

Comparison with high-latitude stratospheric eruptions

Gao et al. (2007) found $L_G \approx 0.57 \times 10^9 \text{ km}^2$ for modeled 1783-84 Laki and 1912 Katmai eruptions. Fuglestad et al. (2024) report $L_G \approx 0.44 \times 10^9 \text{ km}^2$ for a range of modeled explosive eruptions in Iceland.

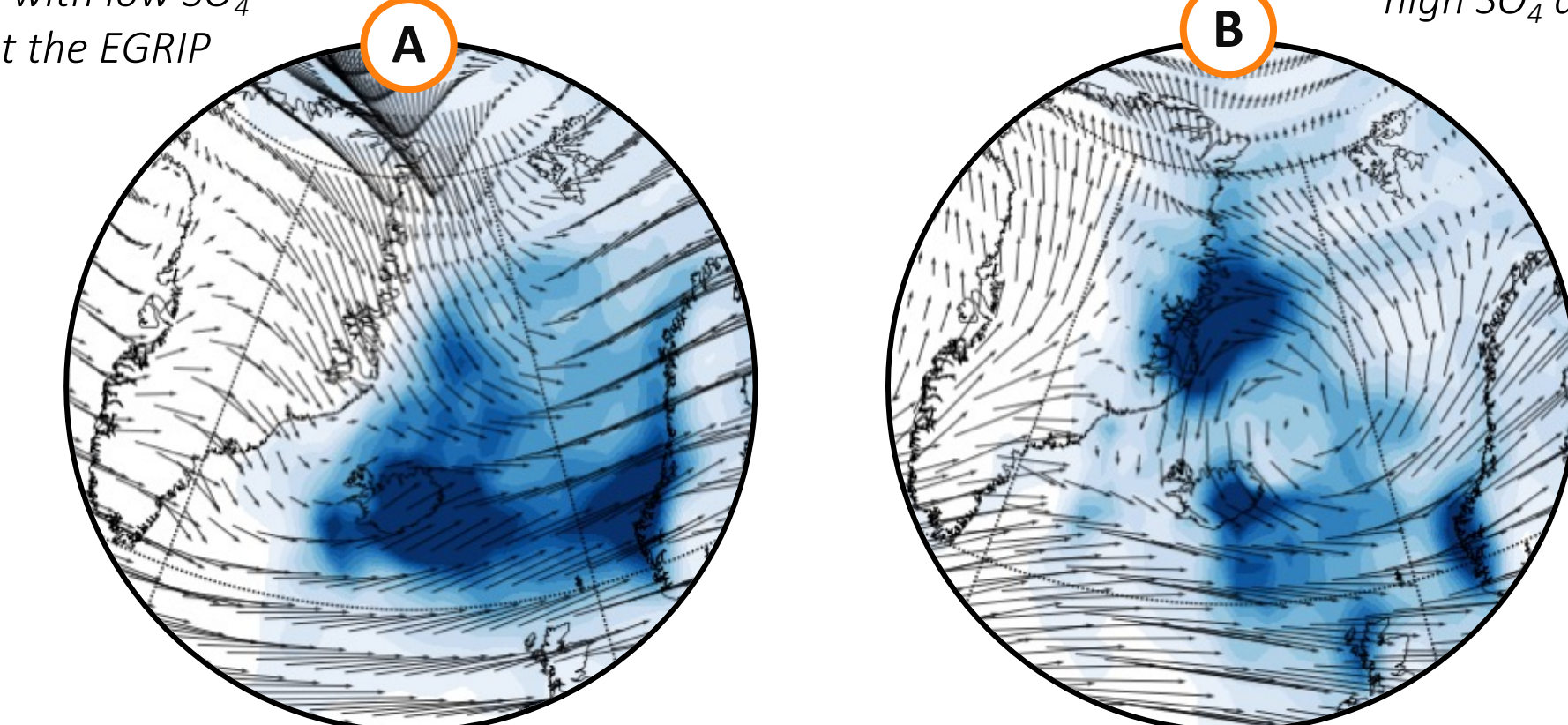
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Different atmospheric conditions

There is a large inter-simulation spread of transfer function values especially at the EastGRIP location, which we attribute to different meteorological conditions in the experiments. Sulfate transport to Greenland depends on synoptic weather conditions.

September winds in free-running simulation 1 with low SO₄ deposition at the EGRIP site vs. ...



Translating between local SO₄ deposition and total SO₂ emissions

Stratospheric eruptions

A **transfer function** is defined as the ratio between the total sulfate flux (D_{SO_4}), which reflects the total stratospheric sulfur loading, and the ice core sulfate flux (f_{SO_4}):

$$L_G = \frac{D_{SO_4}}{f_{SO_4}}$$

Tropospheric eruptions

We base our calculation on the total emitted sulfur (E_S) instead, because...

- Holuhraun S emissions are well constrained.
- the assumption that all emitted sulfur is deposited as SO₄ does not hold.

$$L_G = \frac{E_S}{f_{SO_4} \cdot m_{SO_4}}$$

Summary and discussion

On average, the **transfer functions** in the Holuhraun case are **lower** than those reported by Gao et al. (2007) and Fuglestad et al. (2024) for stratospheric eruptions at high latitudes.

SO₄ deposition in Greenland was therefore **higher relative to the total SO₄ deposition**, facilitated by the **proximity** to the emission source, and a **limited deposition region**.

The **large spread between simulations** may result from a strong dependence on **meteorological conditions**.

The presented transfer function links local deposition and total sulfur emissions for eruptions similar to the Holuhraun eruption in magnitude, emission rate, season, and SO₂-SO₄ partition.

❓ **Dependence on these parameters remains to be investigated.**