

SOLar and Volcanic Fingerprints in Past and Future Climates (SOLVe)

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In Short

- Miyake events
- Grand Solar Minima
- Volcanic eruptions



Figure 1: SOLar and Volcanic Fingerprints in Past and Future Climates

Human activity significantly impacts the climate system, affecting its mean state, variability, and extreme meteorological/hydrological events. While the effects of human actions on climate are well-understood, the influence of anthropogenic climate change on extreme solar/volcanic events and their climate signatures remains unclear. Understanding how human activities modulate these solar/volcanic fingerprints in atmospheric dynamics and the coupling of climate subsystems is crucial. Paleorecords indicate the substantial impact of extreme solar/volcanic events over the past 42,000 years, including volcanic eruptions preceding the Little Ice Age and increased flooding during Grand Solar Minima in Europe. Additionally, cosmogenic nuclide excursions, produced by extreme solar particle events (SPEs), are influenced by event magnitude, meteorology, and Earth's magnetic field. As part of the SOLVe project, we will study how standardized extreme solar (Grand Solar Minima and Miyake events) and volcanic events unfold under varying climatic conditions.

Miyake events are rare but powerful solar storms that cause dramatic spikes in cosmogenic nuclides like ^{10}Be and ^{14}C , which are recorded in natural archives such as ice cores and tree rings. Once considered highly unlikely, these events are now known to occur more frequently and can be hundreds of times stronger than the most intense solar storms observed. If such an event occurred today, it could pose significant health risks, increase UV exposure, and disrupt communication systems. Miyake

events also generate nitrogen oxides (NO_x) in the atmosphere, leading to ozone depletion and altering temperature gradients, which in turn affect atmospheric circulation. Interpreting the signatures of these events is difficult due to the influence of factors such as event timing, local weather conditions, and deposition processes.

In the SOLVe project, we will explore how long-term climate trends and changes in Earth's magnetic field influence the signatures of these events. By using advanced modeling with ECHAM/MESSy (EMAC), we aim to improve our understanding of their effects on atmospheric composition, radiation exposure, and climate dynamics. This will enhance our knowledge of past Miyake events and help assess the potential risks they may pose to modern society.

A Grand Solar Minimum (GSM) is a period of reduced solar activity, marked by fewer sunspots and lower solar radiation, lasting for decades and linked to cooler regional temperatures. The Maunder Minimum (1645–1715) coincided with colder winters in Europe and an increase in rainfall and floods in Central Europe. Recent studies suggest that a future GSM could partially offset anthropogenic climate change. GSMs influence climate through radiative processes, atmospheric dynamics, and ocean-ice interactions. Understanding how they unfold in both past and future climates is critical.

In the SOLVe project, we will explore how GSMs have impacted climate subsystems over the past 42,000 years. We will focus on their effects on meteorological extremes, such as heatwaves, cold waves, and precipitation patterns, and use the UFZ's mesoscale Hydrological Model (mHM) to examine whether the increase in hydrological extremes is linked to reduced solar energy.

Volcanic eruptions have significantly shaped the climate over the past 42,000 years. Major eruptions like Samalas (1257 CE), Kuwae (1452/1453 CE), Huaynaputina (1600 CE), and Tambora (1815 CE) are linked to periods of cooling, such as the Little Ice Age, or short-term effects like the "Year Without a Summer" (1816 CE). More recently, the Hunga Tonga-Hunga Ha'apai eruption injected 50,000 tons of water vapor into the stratosphere, causing temporary warming rather than cooling. This also led to the production of hydroxyl radicals, resulting in short-term ozone depletion.

In the SOLVe project, we will study the effects of extreme volcanic eruptions, both historical and mod-

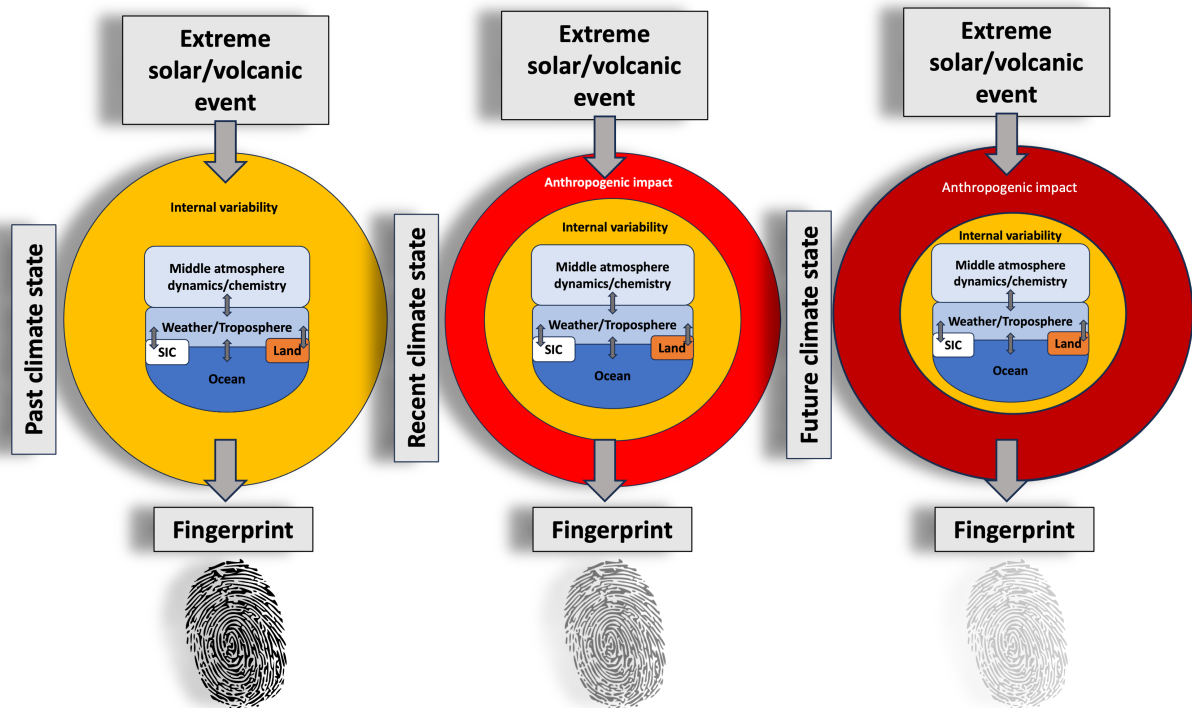


Figure 2: Extreme solar/volcanic events across different climate stages

ern, under past and future climate conditions. We will focus on how these eruptions influence the transport between the lower stratosphere, upper troposphere, and surface climate, using machine learning techniques.

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<https://earthenvironment.helmholtz.de/changing-earth/innopool-projects/>

More Information

[1] <https://www.awi.de/en/science/climate-sciences/paleoclimate-dynamics.html>

Project Partners

GEOMAR, GFZ, FZJ, Hereon, KIT, UFZ

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