Climate and society impacts in Scandinavia following the 536/540 CE volcanic double event

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Can we link volcanic climate impast to changes in society?

Introduction

One of the coldest decades in Europe and the NH of the last 2000 years occurred during the mid-6th century, which was initiated by the volcanic double event in 536/540 CE. This cold period was discovered in tree-ring and ice core records (Larsen et al., 2008; Sigl et al., 2015), and coincided with historical documents reporting a dimming of the sun in 536 CE (Stothers, 1984). The 536 CE eruption has been linked to the 'Fimbulwinter myth' (Fig. 1, Gräslund, 2008), in which no summer occurred for three years in a row. A prolonged summer cooling could have potentially led to widespread crop failure. This is especially true for areas that are already at the temperature limit for growing certain crops, where the effect could be substantial.

In Norway, the transition from the Migration Period (400-550 CE) to the Merovingian Period (550-800 CE) occurred right after the volcanic double event in 536/540 CE (Iversen, 2016; Gundersen, 2019). Bajard et al. (2022) reconstructed the agricultural practices from lake sediments in southeastern Norway (lake Ljøgottjern) and identified a correlation between temperature change and agricultural practices in this area during the Late Antiquity.

Here, we continue the study of van Dijk et al., (2021, in discussion) and analyse the temperature change in Norway after the 536/540 CE eruptions, and the effect it would have had on the agricultural practices in three different areas (Fig.2). We discuss the likely volcanic climate- and society response over Scandinavia based on the climate model data, a growing-degree-day model, and the local archaeology and pollen records next to other available records.

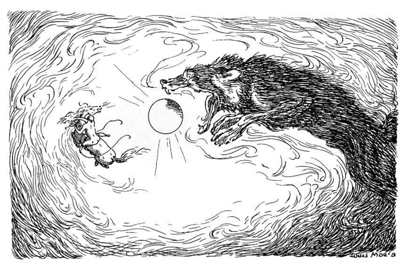

Figure 1. The Fenrys wolf swallows the sun in the Fimbul winter myth.

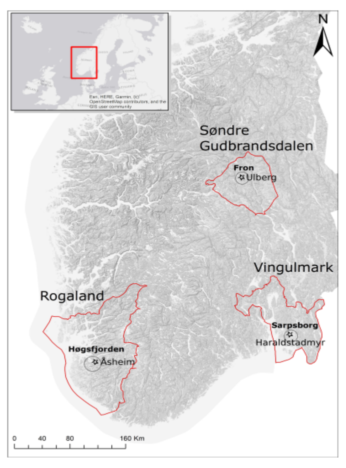

Figure 2. Map of southern Norway and the three study areas.

Background

Large volcanic eruptions spit out ash and sulfur (SO_2) into the atmosphere. Sulfur in the stratosphere reacts with water to form sulfuric acid. This aerosol reflects incoming solar radiation, which leads to a surface cooling (Fig. 3). **Here we want to find out how cold it got and what the effect on society was in Norway after the 536/540 CE eruptions.** For this we use:

- The **MPI-ESM** version for CMIP6 on a 2x2° grid (47 vertical levels) 12 ensembles x 160 years (520-680 CE)
- **Growing-degree-day (GDD) model** using a DEM and metereological data from 1961-1990
- **Pollen diagrams** from local bogs
- **Archaeological data (^{14}C) from southern Norway**

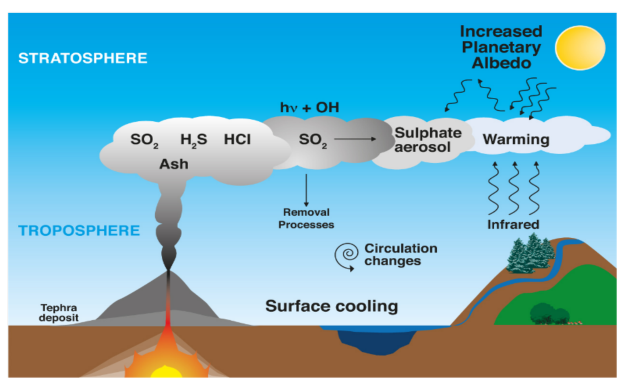

Figure 3. Volcanic impact on the climate system (after Timmreck 2012).

Simulated temperature

2 m air temperature from the model simulations show (Fig. 4):

- **The 5°C line shifts southward**
- **More than 2K cooling** after the 540 CE eruption

With the volcanic cooling after 536/540 CE the mean temperature for the growing season falls below 5°C in some areas.

5°C is taken as the threshold temperature for defining the growing season, so having the mean below 5°C is not good for crops. But this is the mean, so let's investigate further by using a GDD model.

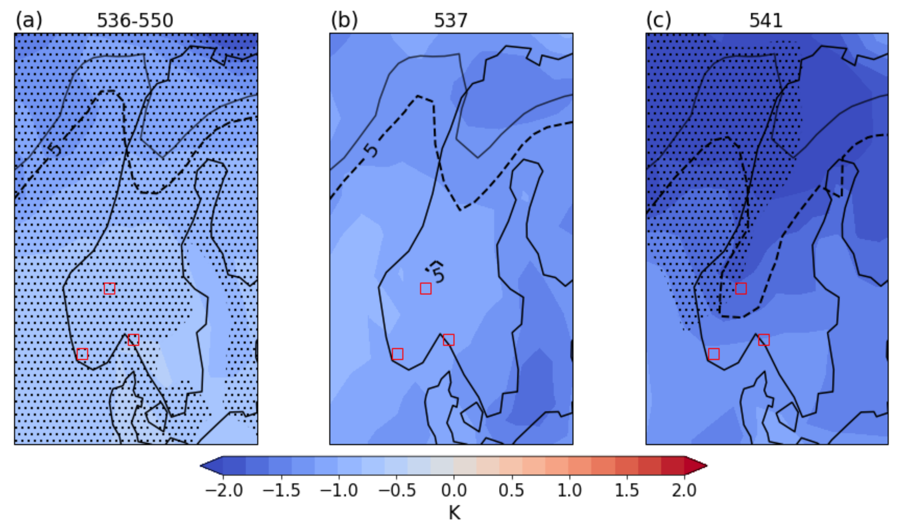

Figure 4. Mean temperature for April-September for 15 years after the eruptions and 1 year after each eruption. The 5°C line is given for the control and the plotted time. Significant values are stippled (2σ). Red squares indicate the study sites.

GDD model

GDD = Growing Degree Days
The accumulated sum of daily mean temperature from April to September (the growing season in Norway)

Each crop has it's own GDD requirement to ripen.
If the accumulated temperature for an area falls below the crop's requirement we can conclude the harvest would fail.

GDD is dependent on:

- Temperature (-0.6°C per 100 m.a.s.l.)
- Length of growing season (days with > 5°C)
- Precipitation
- Latitude (-20 GDD per degree > 60°N)
- Altitude
- Solar radiation

Because the model simulates > 2°C cooling after the 540 CE eruption, we take a worst case scenario of **3°C cooling** in the GDD model. The results are described below for each area (Fig 5).

Requirements for Barley, oats, rye and wheat

- **Fron**: between 1070 - 1519 GDD
  Harvests are likely to fail especially for oats and wheat.
- **Høgsfjorden**: between 1123 - 1766 GDD
  Minimum requirements are met for barley, oats, and rye, but lower crop yields can be expected. Wheat will fail.
- **Sarpsborg area**: between 1123 - 1766
  None of the cereal types will be affected by the volcanic cooling.

This is all still based on models.
Now we will validate the GDD model by analysing pollen diagrams from nearby bogs.

Pollen that indicate human activity are plotted in Fig. 6 below.

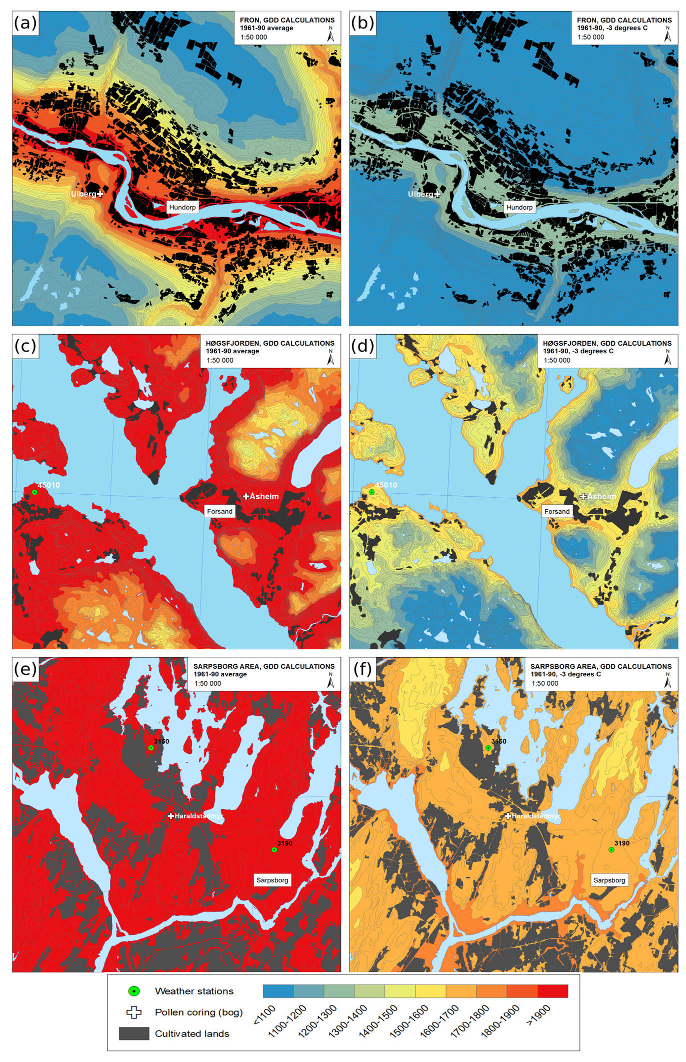

Figure 5. 1961-1990 mean GDD for a) Fron, c) Høgsfjorden and e) Sarpsborg, and with a 3°C cooling (b,d and f).

Synthesis

Here we picked the individual model ensemble simulation that is most likely based on pollen, archaeological data and historical evidence.

- Tree-ring reconstructions from northern Scandinavia show **>3°C cooling**
- **Pollen data shows a decline in human indicators.**
- Archaeological finds indicate **farm abandonment** in the areas that had difficulties growing crops, whereas other sites were not abandoned.
- Ergot was found in the Høgsfjorden area, indicative of **wetter conditions**. Historical evidence from eastern Sweden also indicate wetter conditions.
- An **overall decline in population after the 536/540 CE eruptions** is evident from ^{14}C dating of archaeological sites across southeastern Norway.

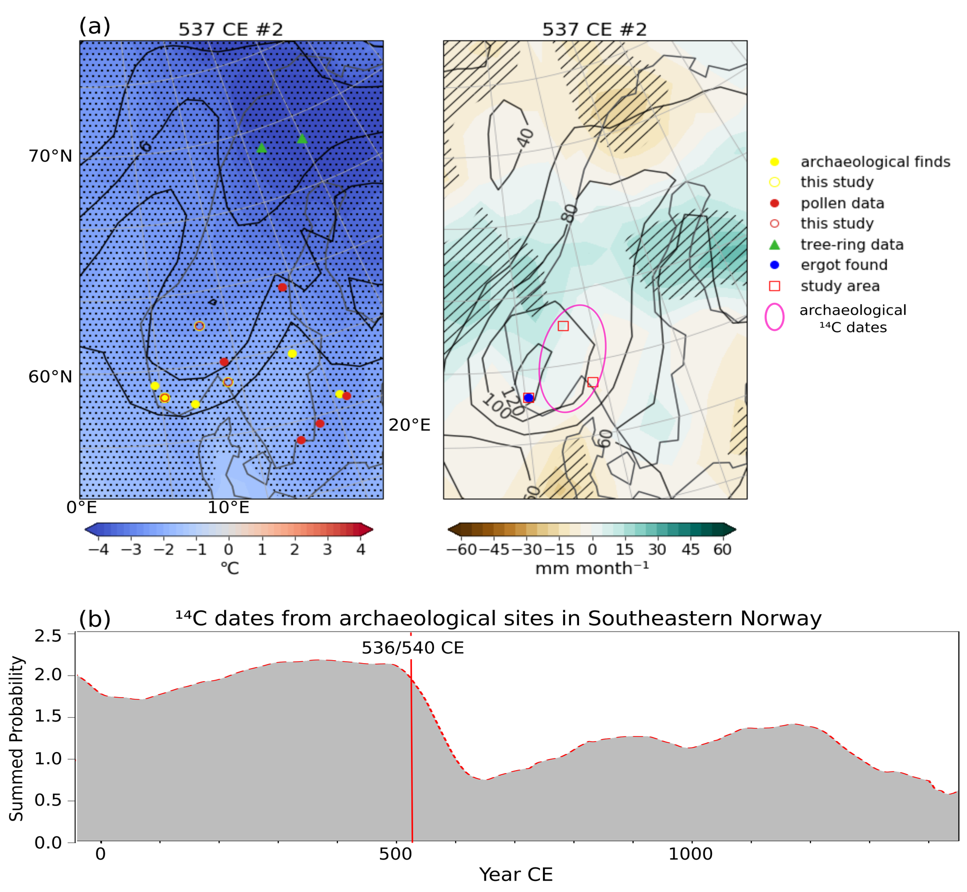

Figure 7. Bringing together the model response for temperature and precipitation, pollen data, archeaological data and historical records from other publications.

Pollen diagrams

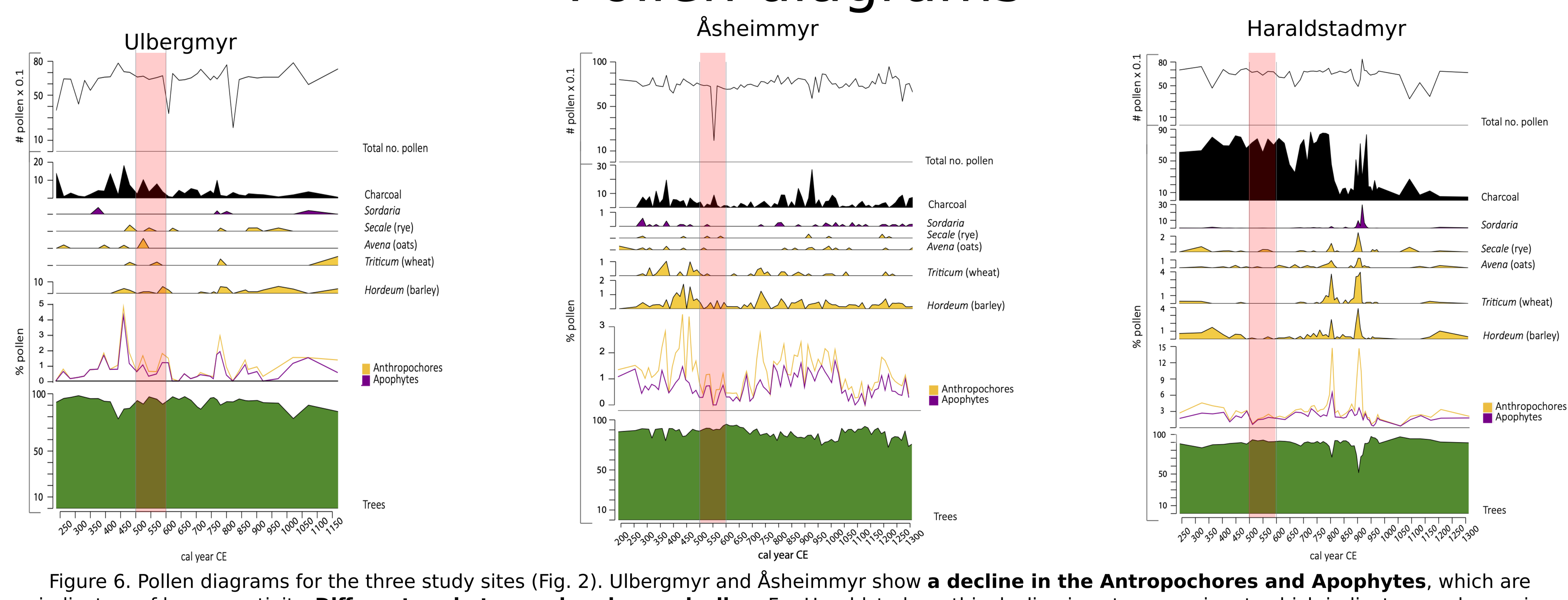

Figure 6. Pollen diagrams for the three study sites (Fig. 2). Ulbergmyr and Åsheimmyr show **a decline in the Antropochores and Apophytes**, which are indicators of human activity. **Different grain types also show a decline**. For Haraldstadmyr this decline is not as prominent, which indicates no change in cultivation for this area.

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