# Spatial and Seasonal Impact of Major Volcanic Eruptions on European Temperature over the Last Centuries

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## Introduction

Volcanic eruptions are an important natural cause of climate variations. The surface temperature response to explosive volcanic eruptions during the reliable instrumental period has been studied extensively at the hemispheric and global scale. A new compilation of 500 year spatio-temporal highly resolved temperature reconstructions (Luterbacher et al. 2003), recently developed for the European land areas, offers extended insight into the impact of major volcanic eruptions on a regional scale.

## Data and Methods

The seasonal European land surface temperature data set used in this study extends from 1500 to 1998. The temperature estimations are based on a combination of early instrumental station series and documentary proxy evidence revealed to be trustworthy over the last centuries (Luterbacher et al. 2003). Fifteen major tropical volcanic eruptions are selected combining two measures of past volcanic activity, the Volcanic Explosivity Index (VEI) (Newhall and Self 1982) and the Ice Core Volcanic Index (IVI) (Robock and Free 1995).

Superposed epoch analysis is performed to identify the mean climate response to large volcanic eruptions. Taking the eruption year as key date, we calculated seasonal temperature anomaly fields with reference to the five years preceding the eruption. Composite anomaly fields were established for every summer and winter in the five years following the eruptions (Fig. 1).

In a next step, we calculated European land surface average temperature anomalies for an extended period of 19 years (9 pre- and 9 post-eruption years) (Fig. 2). The significance of the composite response is established by a Monte Carlo resampling procedure. For each eruption event a new distribution is generated by random reshuffling of the 19 years period. The resulting composite distributions are used to determine the statistical significance of the actual composite response (Table 1). This method preserves the distribution and simply destroys any preferred temporal ordering (Adams et al. 2003).

## Results and Discussion

The composite temperature field of the second summer (Fig. 1, left panel) following the 15 eruptions reveals significant cooling in most parts of Europe. A very distinct cooling effect (up to 2°C) occurs in Northern Europe. Over the Mediterranean no effect can be noticed. The tropospheric summer cooling is directly caused by aerosol radiative effects (Kirchner et al. 1999).

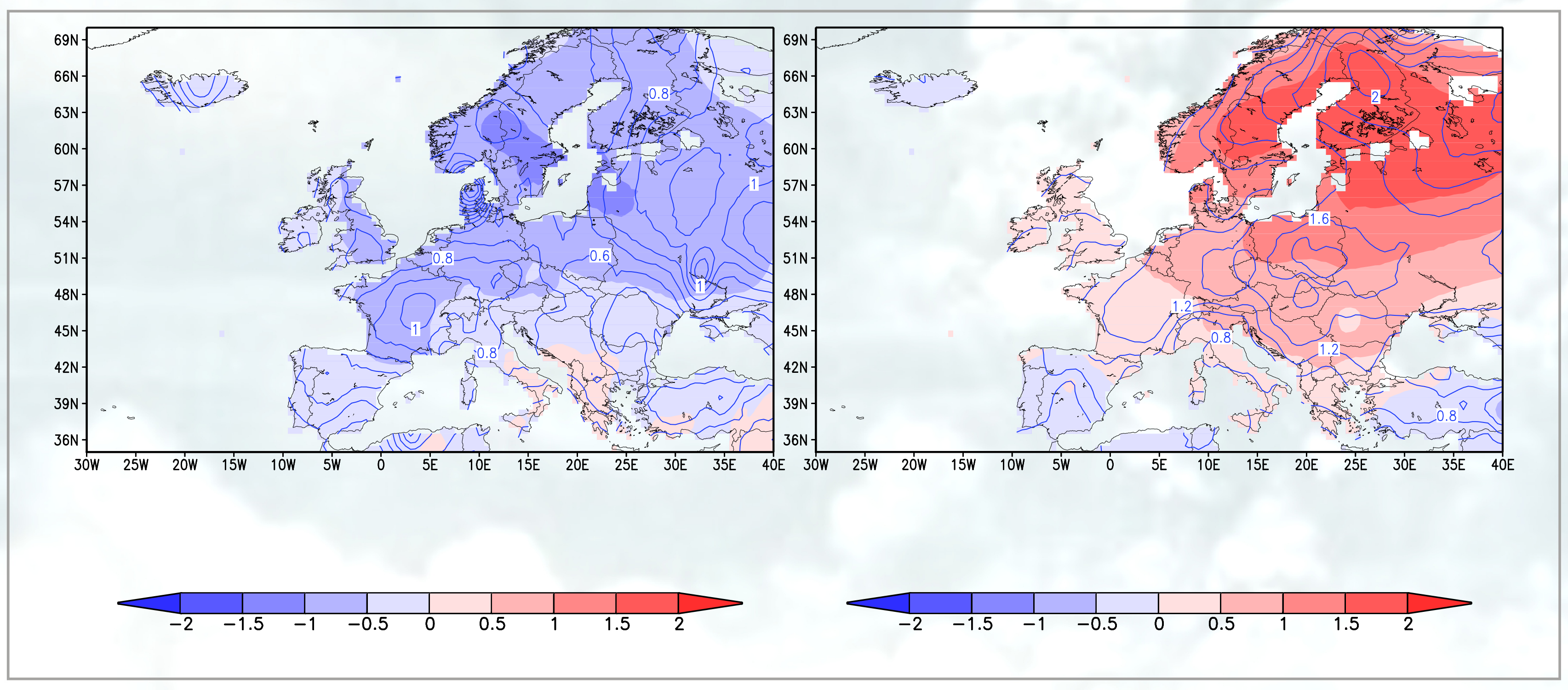

***Figure 1:*** *Composite European land surface temperature anomaly field (°C, shaded) of the second summer (left panel) and second winter (right panel) following 15 selected major volcanic eruptions during the period 1500—1998. The standard deviations are given in contours.*

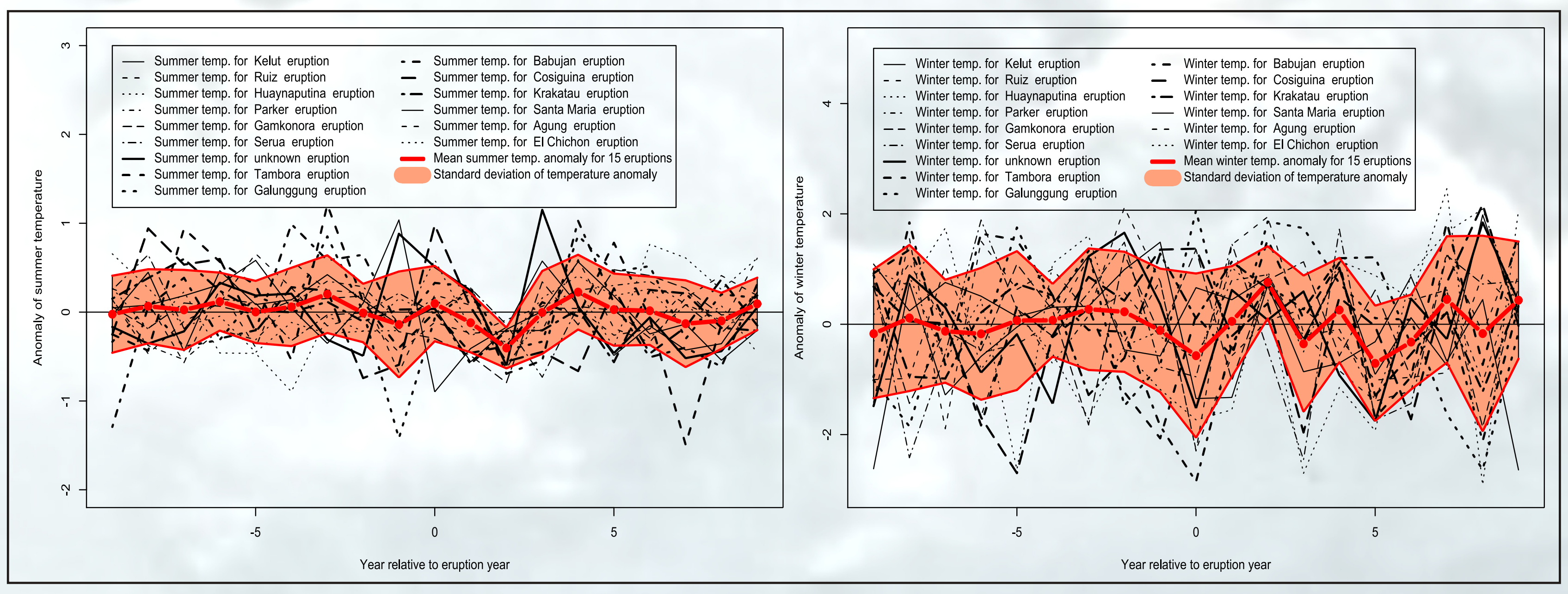

***Figure 2:*** *Normalised European average land surface temperature anomalies (°C) (left, summer; right, winter) for 15 tropical volcanic eruptions and composite mean land surface temperature anomalies (thick red line) with standard deviations (shaded).*

| Year | Summer | Winter |
|---|---|---|
| 0 | P | N |
| 1 | N | P |
| 2 | N** | P** |
| 3 | N | N |
| 4 | P* | P |
| 5 | P | N* |
| 6 | P | N |
| 7 | N | P |
| 8 | N | N |
| 9 | P | P |

***Table 1:*** *Results of the normalised composite temperature for the 9 post-eruption summers and winters. Years with positive composite temperatures (P) at the 95% and 99% confidence level are marked by P* and P**, respectively; Years with negative composite temperatures (N) at the 95% and 99% confidence level are marked by N* and N**, respectively.*

The composite temperature pattern in the second winter (Fig. 1, right panel) after the eruptions indicates a strong warming, in particular in Northern Europe (more than 2°C) and somewhat cooler conditions over the Mediterranean. The warming is associated with a SLP pattern resembling a strong positive NAO mode (not shown). We assume that this reflects a dynamic response to the strengthening of the equator-to-pole temperature gradient in the lower stratosphere, caused by radiative heating of the aerosol layer in the tropics (Kirchner et al. 1999). An additional explanation could be a strengthened polar vortex through aerosol-induced tropospheric cooling in the subtropics (Stenchikov et al. 2002). The composite temperature fields of the first summer and winter following the eruptions show similar although less pronounced patterns (not shown).

The spatial averaged temperature anomalies indicate the same distinct summer cooling and winter warming after volcanic eruptions (Fig. 2). The summer cooling affects three, the winter warming two post-eruption years, respectively. The summer cooling reaches a maximum effect in the second post-eruption year where all 15 eruptions show a cooling trend and the mean summer temperature is significantly cooler at a 99% confidence level (Table 1). The winter warming effect culminates likewise in the second winter succeeding an eruption with a significantly warmer composite temperature (99%). In the fourth summer and the fifth winter a 'rebound' effect can be noticed. The mean European temperature of the fourth summer is significantly warmer (95% confidence level) whereas a significant winter cooling can be observed in the fifth winter following an eruption.

## Conclusions

- The European surface summer temperature response to explosive volcanic eruptions over the last 500 years reveals a **significant cooling** effect with its maximum in the second summer. This can be explained by radiative cooling due to scattering by stratospheric aerosols.
- The composite winter temperature pattern following tropical eruptions indicates a **strong warming**, especially pronounced over Northern Europe.
- The results suggest a significant **'rebound'** into the opposite conditions both for summer and winter temperatures in the forth year and fifth year, respectively, before the temperature variations return to a pre-eruption state (cf. Adams et al. 2003).

### References

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### Acknowledgements

This work was carried out as part of the NCCR Climate project PALVAREX. We thank C. Ammann for his helpful suggestions and his support.