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Signals and memory in tree-ring width and density data

Jan Esper[a,*], Lea Schneider[a], Jason E. Smerdon[b], Bernd R. Schöne[c], Ulf Büntgen[d,e,f]

[a] Department of Geography, Johannes Gutenberg University, 55099 Mainz, Germany
[b] Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, USA
[c] Institute of Geosciences, University of Mainz, 55128 Mainz, Germany
[d] Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland
[e] Oeschger Centre for Climate Change Research, Bern, Switzerland
[f] Global Change Research Centre AS CR, Brno, Czech Republic

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ABSTRACT

It has been suggested that maximum latewood density (MXD) should be used instead of tree-ring width (TRW) data to reconstruct post-volcanic cooling effects. A thorough assessment of high frequency signals and potentially differing memory effects in long MXD and TRW chronologies, in response to large volcanic eruptions, is still missing, however. We here present a compilation of MXD and TRW chronologies from 11 sites in the Northern Hemisphere, covering the past 750+ years, and containing significant June–August temperature signals. Basic assessment of the data using Superposed Epoch Analysis reveals a temporally extended response in TRW, by 2–3 years, to large volcanic eruptions, though post-volcanic cooling patterns vary considerably within the Northern Hemisphere network. Comparison with instrumental temperature data demonstrates the TRW chronologies underestimate cold conditions associated with large volcanic eruptions, a bias that is mitigated in the MXD data. While species composition (pine, spruce, larch) has no detectable influence on the cooling patterns, trees from high latitude sites (>60°N) indicate a stronger and delayed (1–2 years) response to large eruptions, compared to the lower latitude sites (<60°N). These basic findings caution against using TRW data for quantitatively estimating post-volcanic cooling and for comparison against the simulated climate effects of volcanic eruptions in models.

1. Introduction

Volcanic eruptions have been identified as a major natural forcing of the climate system (Oppenheimer, 2011). The aerosols released by large, explosive eruptions tend to cool the earth's surface, but warm the lower stratosphere. Surface cooling results from scattering of incoming solar radiation, i.e. less radiation reaches the ground. Stratospheric warming is triggered by increased absorption of radiation, i.e. more radiation is transferred into sensible heat in 10+ km above ground (Robock, 2000). These processes ought to last for about three years following a large eruption that injects aerosols into the stratosphere (Cole-Dai, 2010 and references therein).

Whereas the climatic effects of volcanic aerosols are assessed based on differing lines of evidence, estimates of the magnitude and persistence of post-eruption cooling are accompanied by large uncertainties. Estimates based on the analysis of satellite and instrumental station data are constrained by the limited number of eruptions during the period of observation (Sear et al., 1987; Self et al., 1981). This limitation is overcome by using annually resolved tree-ring data covering the past centuries to millennia, thereby enabling the assessment of more eruptions and supporting the differentiation from internal climate variability (Briffa et al., 1998; D'Arrigo et al., 2009, 2013; Esper et al., 2013a,b; Fischer et al., 2007; Salzer and Hughes, 2007). However, the noise inherent to proxy data substantially increases the uncertainties of cooling estimates derived from this line of evidence.

Noise in tree-ring data can be differentiated into (i) the unexplained, non-climatic (non-temperature) variance typically reducing the magnitude of reconstructed cooling events, and (ii) biological memory effects likely biasing the persistence estimates of cooling events. While the unexplained variance and consequences thereof are widely recognized in the paleoclimatic literature (Esper et al., 2005; Lee et al., 2008; Von Storch et al., 2004), memory effects are much less acknowledged (Anchukaitis et al., 2012), even if detailed in standard dendrochronological

* Corresponding author. Fax: +49 6131 3924735
E-mail address: esper@uni-mainz.de (J. Esper).

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