Synchronous variability changes in Alpine temperature and tree-ring data over the past two centuries

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The understanding of extremes and their temporal distribution is useful in characterizing the behaviour of the climate system, and necessary for understanding their social and economic costs and risks. This task is analogous to the study of pointer years in dendrochronological investigations. Commonly used dendroclimatological methods, however, tend to result in an equalization of variance throughout the record by normalizing variability within moving windows. Here, we analyse a larger network of high-elevation temperature-sensitive tree sites from the European Alps processed to preserve the relative frequency and magnitude of extreme events. In so doing, temporal changes in year-to-year tree-ring width variability were found. These decadal length periods of increased or decreased likelihood of extremes coincide with variability measures from a long-instrumental summer temperature record representative of high-elevation conditions in the Alps. Intervention analysis, using an F-test to identify shifts in variance, on both the tree-ring and instrumental series, resulted in the identification of common transitional years. Based on a well-replicated network of sites reflecting common climatic variation, our study demonstrates that the annual growth rings of trees can be utilized to quantify past frequency and amplitude changes in extreme variability. Furthermore, the approach outlined is suited to address questions about the role of external forcing, ocean–atmosphere interactions, or synoptic scale changes in determining patterns of observed extremes prior to the instrumental period.

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Understanding climatic extremes and temporal shifts in the occurrence of extremes in instrumental data is useful in characterizing the behaviour of the climate system and in understanding the social and economic costs and risks to society by such events. The warm and dry summer of 2003 in Europe triggered much discussion on the return intervals and characteristics of extreme events (e.g. Schär *et al*. 2004; Luterbacher *et al*. 2004; Rebetez 2004). This event occurred within the context of noticeably warmer regional instrumental temperatures during the past decade or so, relative to the past 240 years (e.g. Böhm *et al*. 2001), and relative to the past 500 years based on multi-proxy reconstructions (Luterbacher *et al*. 2004). Furthermore, this regional event occurred within the global setting of highest recorded temperatures since 1851 (Jones & Moberg 2003) and highest reconstructed temperatures since the so-called 'Medieval Warm Period' (Mann *et al*. 1999; Esper *et al*. 2002; Cook *et al*. 2004; Moberg *et al*. 2005).

Climatic extremes over a wide variety of time scales, from daily events to multi-decadal and longer periods, can be defined in a number of ways, including rarity, intensity or impact on environment and society (e.g. Beniston & Stephenson 2004). In simple terms, extremes can be defined as events occurring towards the tail ends of statistical distributions. However, assumptions about stationarity and time periods used to estimate distributions complicate this notion (Benestad 2004). For example, return frequency estimates for the summer of 2003 in Europe in Luterbacher *et al*. (2004) and Schär *et al*. (2004) differ by over three orders of magnitude, indicative of the sensitivity to such assumptions. Changes in the occurrence frequency of extreme events can be conceptually related to changes in the mean, the standard deviation (SD) or both of these parameters (Meehl *et al*. 2000), with changes in a distribution's width regarded to have a greater impact on the frequency of extreme events than changes in the mean (Katz & Brown 1992; Meehl *et al*. 2000). It has been proposed that the extreme 2003 European summer can best be explained by a shift in the SD of Alpine temperature variability (Schär *et al*. 2004), and it has been suggested that anthropogenic contributions have doubled the risk of such an extreme heatwave (Stott *et al*. 2004).

The instrumental record can be used to quantify changes in extremes in more recent times (e.g. Easterling *et al*. 2000 and references therein; Frich *et al*. 2002). However, to assess variations over many centuries, and to characterize the long-term evolution and characteristics of climatic change, proxy data are

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