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Reply to 'Limited Late Antique cooling'

Büntgen *et al.* reply — We agree with Helama *et al.* in their call for further research into the climate of the first half of the Common Era. However, we argue that they underestimate the combined efficacy of environmental, archaeological and historical indicators in establishing a prolonged period of cold summers across much of the Northern Hemisphere landmass between 536 and about 660 AD, which we term the Late Antique Little Ice Age (LALIA)¹.

Although corresponding to the period of highest volcanic² and lowest solar³ activity during the first half of the Common Era, Eurasia's LALIA^{1,4–6} was probably not uniform in space and time, because of the dominant role of internal climate variability. Externally forced climate model simulations for the past two millennia are needed to provide insight into the physical mechanisms of positive feedback loops between ocean, sea-ice and atmosphere, which possibly prolonged the volcanically forced, sharp onset of the LALIA that disrupted civilizations across the Northern Hemisphere. Summer cooling during the later part of the LALIA was possibly amplified by another — as yet unattributed — eruption in 626².

Glacier fluctuations offer widespread indications for the LALIA⁷, though have not been considered by Helama *et al.* There are also a number of limitations in the records Helama *et al.* cite in opposition to the extent of the LALIA: the Solongotyn Davaa and Yakushima Island tree-ring chronologies contain one sample at the time of interest; the Great Basin composite explains less than 20% of instrumental temperature variance; the Finnish Lapland data lost long-term amplitude changes during standardization; and the GISP2 ice core record that has an absolute dating bias exceeding a decade during the seventh century. Where such limitations prevail, the true nature of past climate fluctuations cannot be adequately resolved.

Moreover, we challenge the definition and usage of the term Dark Ages Cold

Period⁸. Today most archaeologists, historians and natural scientists are reluctant to use the expression 'Dark Age', which became popular in the nineteenth century to describe pejoratively an imagined episode of savagery and ignorance in western-central Europe, characterized by sparse archaeological remains and scant written sources. Instead, historians currently designate the interval from about 300–700 as the Late Antiquity, not only for the Roman/Byzantine and Persian/Islamic empires, but also for other regions. It is imperative that scientists adjust their terminology to reflect the current scholarship in other disciplines.

We further consider that the concept of a Dark Ages Cold Period is limited by its unknown trigger, precise onset, and duration. Although increased climate variability characterized the fourth and fifth centuries^{1,4–6,8}, abrupt changes and associated forcing agents have not yet been described. Thus, the emergence of new climatological data and historical concepts allows us to refine the climatologically vague Dark Ages Cold Period as the LALIA.

With these points in mind, we conclude by concurring with Helama *et al.* on the pitfalls of deterministic and reductionist approaches to placing archaeological findings and historical events in the context of environmental fluctuations, including climate change⁹. □

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