Reply to the comment by A. Sáez et al. on ‘Climate in the Western Cordillera of the Central Andes over the last 4300 years’ by Engel et al. (2014)

The interpretation of the insoluble particles origin in the Central Andean ice cores represents a research challenge worth further debate. The enhanced dust concentration in the Quelccaya ice cap was originally associated with periods of dry conditions that favour the mobilization of dust, particularly from drying lakes and wetlands, and its accumulation on glaciers (Thompson, 1980). The relation between moisture conditions and dust content in the Andean ice cores was subsequently validated for longer time-scales and insoluble mineral dust particles were used as the indicator of regional aridity over the Lateglacial and Holocene (e.g., Thompson et al., 2003 and references therein; Knüsel et al., 2005; Vimeux et al., 2009; Kellerhals et al., 2010). Also, the dust record from the Sajama ice cap was initially attributed to the changes in climate conditions, net ice accumulation and local volcanic activity (Thompson et al., 1998). Subsequently, volcanic eruptions were denoted as a primary source of dust in the Sajama ice core based on the results of X-ray fluorescence and the advanced geochemical analyses from the lake Chungar sedimentary records (Moreno et al., 2007; Giralt et al., 2008). Sáez et al. emphasize the non-climatic origin interpretation of dust particles in the Sajama core in their recent comment (Sáez et al., 2015). Authors develop their reasoning based on alleged discrepancy between the number of dust/arid events recorded in the Carhuasanta peat (Engel et al., 2014) and Sajama ice cores (Thompson et al., 1998, 2000). The argument stated by Sáez et al. (2015) that Sajama ice dust record reflects mainly volcanic activity sounds convincing. However, it does not seem to be directly pertinent to questioning the interpretation of the Carhuasanta peat core (Engel et al., 2014).

In our study, we used two main proxies for the interpretation of palaeoclimatic conditions in the peat core from the Carhuasanta Valley at the foot of Nevado Mismi in the southern Peruvian Andes (located ~400 km NW of Chungar Lake and Nevado Sajama, Fig. 1). The first proxy, the stable carbon isotope composition ($\delta^{13}C$) of Distichia peat, reflects mainly the relative variation of the mean air temperature during subsequent growing seasons (Skrzypek et al., 2011), and allows reconstructions of palaeotemperature changes. The second proxy, peat organic carbon concentration (C % wt), records mainly wetness in the valley, directly corresponding to the changes in runoff in the upper part of the catchment. In the sampling location, it reflects mainly the changes in precipitation and to lesser extent the changes of temperature (melting of episodic snow cover). Distichia plant grows in a semiaquatic environment and Distichia peat consists of macrofossil formed by continuously growing plants, similar to Sphagnum peat bogs (e.g., Engel et al., 2010). The surface of the peat bog is occasionally flooded and mineral particles deposited on the plants reduce relative carbon percentage. Therefore, C% signature indicates relative changes in wetness. The $\delta^{13}C$ value was used in our study as a primary proxy for the reconstruction of relative temperature variations over the last ~4 ka years and subdivision of climatic periods in the Carhuasanta record (Fig. 11 in Engel et al., 2014). Therefore, the seven periods (A–G) described in the Carhuasanta peat core reflect temperature variations and not wetness changes as perceived by Sáez et al. (2015) in their comment.

The correlation between the Carhuasanta core and the Nevado Sajama and Chungará records is complicated by their location in...
Carhuasanta record (Fig. 2). Therefore, only approximate aligning of the records will be possible using numerical approaches (e.g., Blaauw, 2012).

In summary, we agree that the palaeoclimatic implications of the Sajama ice core record are challenging and that further research is necessary for its validation and integration with other records from the region. Similarly, temporal changes in local moisture changes in the Central Andes and forcing mechanisms of these changes remain partly unknown and need to be investigated in greater details. On the contrary, we disagree with the Sáez et al. (2015) critique of Carhuasanta record interpretation (Engel et al., 2014). Primarily because palaeotemperature periods (A–G, Engel et al., 2014) do not necessarily correspond with aridity periods (Sáez et al., 2015) and also due to the Late Holocene age uncertainties of the Chungar record (Giralt et al., 2008) that prevent robust cross correlation of individual climatic periods.

References


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Fig. 2. Comparison of drier phases (grey shading) in the Carhuasanta peat core based on Engel et al. (2014) with the Sajama dust record (Thompson et al., 1998). The diamonds with error bars and grey vertical hatch show AMS 14C calibrated ages and the uncertainties of the Carhuasanta record (from Engel et al., 2014). The circles with error bars for the Chungar record after Giralt et al. (2008). The A–G divisions are palaeotemperature periods as in Engel et al. (2014).

different climate zones. The Carhuasanta valley is cut in the north-facing slope of the continental divide with the precipitation values between 600 and 800 mm per year (Fig. 1). By contrast, the Nevado Sajama and Chungará sites are located close to the northern tip of an extremely arid zone (so-called the Arid Diagonal) that separates regions with different atmospheric circulation and moisture sources (Zech et al., 2009). The Sajama and Chungará sites receive <350 mm and the inter-annual precipitation variability in this region is high (Hardy et al., 1998; Moreno et al., 2007). The precipitation and ice accumulation on the Sajama ice cap is thus limited to a few weeks per year (Hardy et al., 2003). For these reasons, not necessarily the same climatic conditions were recorded over the past thousands of years in these two regions. Moreover, age uncertainties preclude precise aligning of the records. The Late Holocene chronology of the Chungará record relevant for our study period of the last 4.3 ka is based only on four AMS ages distributed between 2050 and 3645 ka (Giralt et al., 2008). Age uncertainties of these radiocarbon dates range between 500 and 910 years being an order of magnitude larger compared to the uncertainties of the Carhuasanta record (Fig. 2). Therefore, only approximate aligning of the records will be possible using numerical approaches (e.g., Blaauw, 2012).

In summary, we agree that the palaeoclimatic implications of the Sajama ice core record are challenging and that further research is necessary for its validation and integration with other records from the region. Similarly, temporal changes in local moisture changes in the Central Andes and forcing mechanisms of these changes remain partly unknown and need to be investigated in greater details. On the contrary, we disagree with the Sáez et al. (2015) critique of Carhuasanta record interpretation (Engel et al., 2014). Primarily because palaeotemperature periods (A–G, Engel et al., 2014) do not necessarily correspond with aridity periods (Sáez et al., 2015) and also due to the Late Holocene age uncertainties of the Chungar record (Giralt et al., 2008) that prevent robust cross correlation of individual climatic periods.
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