Correspondence

Comment on "Climate in the Western Cordillera of the Central Andes over the last 4300 years", by Engel et al. (2014)

Engel et al. (2014) present a new approach to understand Holocene climate changes in the Central Andes. They reconstruct the relative temperature changes in the Western Cordillera for the last 4,300 years by characterizing the $\delta^{13}C$ composition of a plant species occurring in the Carhuasanta peat sedimentary record (Peru, 15º 30' S). The authors were able to apply such innovative approach because no significant organic matter degradation was detected. A significant feature of their climatic reconstruction is the identification of up to 7 arid short events (Fig. 1). This new Holocene climate record is timely and welcome since it will help to better understand the centennial hydrological and temperature changes in the region. Engel et al. (2014) identify these 7 short arid events in other regional climatic reconstructions derived from lake sediments, speleothems, peat bog and ice cores from the Central Andes between 7 and 18ºS. One of these regional climatic reconstructions is based on the concentration of dust particles in the Sajama ice core studied by Thompson et al. (1998). The rationale of their approach was that high dust concentrations indicate regional arid conditions (Thompson et al., 1998, 2000). Figure 1 clearly shows that only 4 of the Carhuasanta dry periods (B, C, E and G) match with the Sajama dust record, whereas 3 of them (A, D and F) do not have a clear counterpart in the ice core.

The lack of correlation between the Sajama dust record and the Carhuasanta climatic reconstruction therefore suggest an alternative explanation, instead of interpretations based on paleoclimatic forcing alone. Although dust content of the Nevado Sajama ice record was initially interpreted as an indicator of the arid phases of the Holocene (Thompson et al., 1998, 2000), subsequent work showed that two main mechanisms and sources generate large amounts of dust in the Central Andes (Moreno et al., 2007; Giralt et al., 2008). First, the remobilization of huge amounts of dust from ephemeral lakes and wetlands that become salt flats during arid phases imply a climatic-based process. By contrast, the second mechanism invokes volcanism. The volcanic eruptions of the Andes are characterized by the generation of large amounts of ash that can reach distances of hundreds to thousands of kilometers (Heinold et al., 2012). The only active volcano during the Holocene close to the Sajama record was the Parinacota Volcano (Wörner et al., 1998, 2000; Clavero et al., 2004; Hora et al., 2007). During its Holocene evolution large amounts of ash scattered over a large geographical area, affecting all kind of sedimentary environments in several distinct phases. The relatively deep Chungará Lake, located at the base of Parinacota, provided a unique setting to record the Late Holocene Parinacota volcanic activity (Sáez et al 2007, Moreno et al., 2007; Giralt et al. 2008). Our work in Chungará during the last decade demonstrated that the lake formed after a debris avalanche during the partial collapse of the Parinacota Volcano that dammed the Lauca River at about 18 cal. kyr BP. Afterwards, the volcanic activity was greatly reduced during the early Holocene. The reconstruction of the Holocene eruptions showed that the volcanic activity of Parinacota restarted at about 8000 cal. yrs BP, depositing up to 10 identifiable tephras interbedded within the lacustrine sediments (Fig. 1). The straight-line distance between the Parinacota Volcano (18º 10' S, 69º08' W) and the Nevado Sajama (18º 06' S, 68º53' W) is less than 30 km (Fig. 2) and the occurrence of seasonal westerly wind patterns in the area transported large amounts of ashes from the Parinacota Volcano to the Sajama ice cap. Interestingly, the comparison between the reconstructed volcanic eruptions obtained from the multiproxy study of the Chungara Lake sedimentary sequence with the Sajama Nevado dust profile shows a clear correspondence between the two sequences (Fig. 1, Giralt et al., 2008). Therefore, we consider that the dust record in the Nevado Sajama ice is nothing more than a reflection of eruptions of Parinacota Volcano and not of Holocene arid phases.

The impacts of these large Holocene Parinacota eruptions on other terrestrial sedimentary environments located in the area of influence or even the local climate is not well understood but deserves further attention.

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Alberto Sáez*
Faculty of Geology, Universitat de Barcelona, Barcelona, Spain

Santiago Giralt
Institute of Earth Sciences Jaume Almera - CSIC, Barcelona, Spain

Armand Hernández
Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal

Roberto Bao
Faculty of Sciences, Universidade da Coruña, A Coruña, Spain

Juan J. Pueyo
Faculty of Geology, Universitat de Barcelona, Barcelona, Spain

Ana Moreno
Pyrenean Institute of Ecology - CSIC, Zaragoza, Spain

Blas L. Valero-Garcés
Pyrenean Institute of Ecology - CSIC, Zaragoza, Spain

*Corresponding author
E-mail address: a.saez@ub.edu (Alberto Sáez)

FIGURE CAPTIONS

Figure 1. **A**. Comparison of Carhuasanta carbon (%C and d13C) proxies (modified from Figure 11 in Engel et al., 2014). Letters from A to G indicate the seven major periods defined by Engel et al (2104). **B.** Dust particles content of the Nevado Sajama ice core record (modified from Thompson et al., 1998), with an amplified view of this record for a better comparison with the Carhuasanta record (left). **C.** Chungará Lake reconstruction of the evolution of the volcanic input in Chungará lake for the last 10,000 cal years BP obtained from a Principal Component Analysis carried out using magnetic susceptibility, X-Ray Fluorescence, X-Ray Diffraction, Total Carbon, Total Organic Carbon, Total Biogenic Silica and gray-colour curve data (modified from Giralt et al., 2008). Asterisks denote the location of the main ash layers in the Lago Chungara sediments (Sáez et al., 2007). Gray bands show the excellent agreement between Nevado Sajama Ice Record and Chungará Lake.

Figure 2. Satellite image of the area of Central Andes including location of Parinacota Volcano (PN), Chungará Lake (CH) and Nevado Sajama (SJ) witch geologic relations are discussed in the text (image from Google Earth: https://www.google.es/maps/@-18.1632779,-69.0348582,32204m/data=!3m1!1e3).