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Climate of the Past
Discussions

Interactive comment on "Volcanism and climate change as drivers in Holocene depositional dynamic of Laguna del Maule (Andes of central Chile – 36° S)" *by* Matías Frugone-Álvarez et al.

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Response to referee #2

I write this reply on my behalf of my coauthors. We appreciate the work carried out by Leonie Peti to review our manuscript and for his helpful comments that have greatly improved it. We believe we have addressed all reviewer comments and concerns and we agree with most of these. In this document we explained how we have changed the manuscript accordingly.

General Comments referee #2: Frugone-Álvarez et al. present a thorough, multidisci-

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Discussion paper

plinary study on multiple sediment cores from the Laguna del Maule (LdM) lake in the Chilean Andes. The paper is rich in new multi-proxy data (Chronology, Stratigraphy, Bathymetry, Seismic, Sediment description, Tephra and Sediment micro-XRF, pollen) and extensive supplementary material building on previous investigation of a shorter record. The integration of these datasets and regional comparisons are used to derive large scale atmospheric and hydroclimatic changes in the Holocene of South America. The figures are detailed support the manuscript well. This paper contributes to closing the gap of our understanding of environmental and climatic changes in the Southern Hemisphere and is very suitable for Climate of the Past. I recommend publication after some minor revisions.

I have outlined some comments below. Technical corrections/suggestions on the main text and the supplementary material are attached as pdfs with comments.

1. Specific Comments referee #2:

Specific Comments 1.1 I compliment the authors on citing R packages but version numbers (on packages and R itself) should be included too.

Reply specific comments 1.1 : Done.

Specific Comments 1.2 I would really like to see the data presented in this paper shared in an online repository. “The data from proxies and facies are available from the authors upon request.” is unsatisfactory and does not ensure data availability for the long-term future.

Reply specific comments 1.2 : Done. The data will be available on CP Repository as indicated in the manuscript.

Specific Comments 1.3 Chronology. I want to compliment the authors on incorporating age uncertainty in the plots of proxy data (Figs. 7,8) and the discussion as well as considering the short-comings of the current age model.

Reply specific comments 1.3 : Thank you. We are very aware the uncertainty of the

LdM chronological model and we wanted in this manuscript both, to underline it and to show how environmental and climate reconstructions still can be made.

Specific Comments 1.4 It is unfortunate that no tephrochronology could be established, especially in such a volcanically active region. Tephrochronology has a high potential to strengthen the chronology but also to modify it with possible changes in the interpretation, especially considering the differences between the Singer et al 2008 36Cl ages and the presented 14C age model. I would suggest to highlight that the main conclusions of the paper (as the focus lies on the Mid to Late Holocene) are independent of this discrepancy to avoid discrediting the interpretation.

Reply specific comments 1.4 : We greatly appreciate the comments regarding the geochronologial aspects, as they are critical for understanding the record. In order to improve the reading and structure of the ms., in the revised version the conclusions section has been changed following the comments of the reviewer as:

“The LdM record provides a high-resolution reconstruction of depositional evolution of a volcanic lake in the South-Central Andes during the Holocene based on sedimentological, geochemical and biological indicators from a sediment core. The composite LdM sediment sequence includes distal lacustrine, volcanic and massive wasting deposits. Six lithostraphic units have been defined in the northern area of the basin and correlated with five seismic units. Lacustrine Turbidite LT2 (Unit 6) is composed of massive black silt facies whereas LT1 sediments (Unit 4) are browner, coarser material with abundant macrophyte remains and also mm-size pumice clasts. Biogeochemical differences between LT1 and LT2 could imply different depositional processes (seismic and volcanic) and/ or provenance. Although some discrepancies between our age model and the dating of volcanic episodes (Singer et al., XXXX) remain concerning the timing of some major hydrological events (blockage of the outlet by lava flows, highest lake level indicated by shorelines around the lake and drainage of the lake), the composite LdM sequence spans the Holocene, after the catastrophic drainage of the lake basin likely due to upstream erosion of the Maule River. Volcanic facies occur as lapilli

(6 layers) and ash (23 layers). Their compositional features suggest a late Holocene transition towards more silica-rich magma compositions. In spite of the chronologic uncertainties, the LdM record indicates lower lake levels during the early Holocene with millennial scale bioproductivity changes coherent with lower summer insolation and increased aridity. Higher bioproductivity occurred during the Middle Holocene (from ca. 8.0 to 6.0 cal ka BP), synchronous with the phase of aridity described for the tropical and temperate latitudes of South America. During the Middle to Late Holocene, the LdM record indicates relatively higher lake levels, consistent with increased moisture after 4.0-3.0 cal ka BP, caused by the inception of the current ENSO/PDO-like dynamics in central Chile. The Medieval Climate Anomaly is characterized by increased bioproductivity whereas the Little Ice Age shows a two-phase structure with cold/wet intervals between CE 1300–1450 and CE 1600–1850 interrupted by a warmer climate between CE 1450-1600. The LdM record also suggests that millennial-scale Holocene climate and water availability in central Chile was largely ruled by variations in the summer insolation. Complex interrelations between solar irradiance and dynamic changes in regional patterns of internal climate variability such as the ENSO/PDO-like, SWW and the SPA, however, seem to exert a major control at centennial to decadal scales."

Specific Comments 1.5 The age model plot in Fig. 5 needs to show the panels with iterations, accumulation rate and memory, which are included in the default output from Bacon and hold important information for the chronology development.

Reply specific comments 1.5 : Done

Specific Comments 1.6 Why was a prior of 80 a/cm chosen as a prior for the accumulation rate? An approximate estimate of the ca. 260 cm in the LdM sequence without layers of instantaneous deposition and almost 14 ka would suggest something closer to 50 a/cm. How does the posterior distribution look (see panels in age model plot by Bacon, comment above)?

Reply (see below)

Specific Comments 1.7 And why was a segment length of 4 cm ("thick") chosen? I understand this value is rather arbitrary but can have quite some influence on the resulting chronology. This should be discussed/acknowledged, or at least the information of those extra panels provided by Bacon should be included in Fig. 5 to be able to judge the performance of the age model.

Reply specific comments 1.6 and 1.7: We greatly appreciate the reviewer′s comments regarding the geochronologial aspects, as they are critical for the climate and environmental implications of the record. All depth-age models need to at least define some parameter (a priori information) to generate it. In Bacon, the accumulation rate prior is a gamma distribution defined by two parameters: mean (named acc.mean in Bacon, and provided by the user in yr/cm), and shape (acc.shape). Hence, we have prioritized that our model crosses the last dating of the record. These parameters are: acc.mean=80; res=20; acc.shape=1.5; mem.strength=4; mem.mean=0.7 and thick=4. In any case, small changes in the parameters "acc.mean", "acc.shape" and "thick" do not generate important differences in our model (see figure below). Although all models should be tested using any sensitivity analysis to evaluate the magnitude of the effect of the different parameters on the error, and to explore potential interactions among parameters (see Valero-Garcés et al., 2019) .

Valero-Garces, B. L., González-Sampériz, P., Gil-Romera, G., Benito, B. M., Moreno, A., Oliva-Urcia, B., ... & Arnold, L. J. (2019). A multi-dating approach to age-modelling long continental records: The 135 ka El Cañizar de Villarquemado sequence (NE Spain). Quaternary Geochronology, 54, 101006.

Specific Comments 1.8 Micro-XRF data. It is not always clear if log ratio transformed micro XRF data are used for the subsequent statistical analyses, simple ratios or raw data (see also comment in the pdf regarding ln(x) or ln(x y) or centralised log ratio). Please double check as that may impact the results/interpretation.

Reply specific comments 1.8 : We appreciate your comments. We used the ln(x), where x is a XRF raw data or ratio without transformation .

Specific Comments 1.9 Line 116-117. How was it decided to use a cut off value of 1000cps for elements to be excluded from the dataset? I imagine this has a significant influence on the interpretations, especially since some interesting elements are excluded this way. In this context, I did not understand clearly whether the volcanic facies (tephra and lapilli) and LT layers are included in the calculation of the mean. If yes, this surely favours some elements in a potentially dubious way.

Reply specific comments 1.9 : The AVAATECH X-Ray Fluorescence II core scanner has a higher detection limit with the lighter elements as Al or Si, whence we have considered data lower to 1000 (cps) as not reliable. Furthermore, the XRF scanner has other detection problem related to grain size, air and water content in the sediment matrix. Therefore, we use counts per second greater than 1000 cps to analyze the elements that are least affected by these processes. Then, we use multivariate analysis to understand the behavior of the most abundant elements in the matrix in all facies, including the volcanics. However, the statistical treatment of data considers each type of facies separately so we try to differentiate the volcanic versus sedimentary processes in them.

Specific Comments 1.10 Line 250 Clastic-related elements in the first eigenvector are explained mostly by silicates from the volcanic watershed. If I understand correctly, the volcanic facies were excluded, so this refers to reworked volcanic material in the other facies? But why is Si not dominant (according to the listed elements) if the detrital signal of the first eigenvector (which I agree with) is to be explained by silicates?

Reply specific comments 1.10 : The eigenvector associated with the higher eigenvalue is interpreted as the signal from watershed sediments that are transported into the lake and that are mostly fine volcanic material. The Si (PC1 loadings: 0.26; PC2 loadings: 0.0210; PC3 loadings: 0.4590) not important explaining the first two PCAs, so the program automatically excludes the presence of Si in the figure S7 but it appears in table S2. Si in the sediment comes from silicates but in many facies mostly from diatoms, so the interpretation of the Si XRF data is complex. We have decided to use for BioSi and not Si XRF in the discussion as indicator of diatom productivity and not use Si XRF as indicator of silicate input due to the double source (silicates and diatoms).

Specific Comments 1.11 I am curious about the calibration between ICP-OES and micro-XRF samples. How did the authors ensure that the correct points were compared with each other? Are the discrete samples scanned or how does one know that a discrete sample (of which thickness? Same as the micro-XRF resolution?) matches exactly with a specific scanning step? However, this is not very important (in the context of the paper) as I do not see where the calibrated fully quantitative data are used instead of just the semi-quantitative XRF core scanning data.

Reply specific comments 1.11: We use the average data corresponding to the cm where e.g the organic carbon had been analyzed. We realized that this generated an added error, which is why we gave up this method to calculate concentration calibrations and we used semi-quantitative XRF data.

Specific Comments 1.12 Volcanism. Line 541 Volcanic/seismic activity are used interchangeably. Is there any chance the authors could discriminate between the triggers?

Reply specific comments 1.12: In future work we will try to address this issue. A study focused only on this point is necessary, which was beyond the objectives of this work. Microfacies and microstructures analysis could potentially enable the recognition of the triggers. It seems that local earthquakes during large eruptions could have generated the destabilization of littoral zone in the lake responsible for the turbidites but events earthquake-induced due, for example, to large mass wastings or by intraplate (intraslab or crustal) earthquakes associated to a Holocene uplift and Troncoso Fault cannot be ruled out.

Specific Comments 1.13 Does the inferred change in magma composition in the Late

Holocene have any impact on the depositional dynamic of LdM, the climate or societies (given the topic of the special issue this is included in)?

Reply specific comments 1.13: This is also beyond the scope of our study, as more detailed geochemical analyses are needed to fully understand the volcanic processes. We have added in the introduction and discussion the possible impacts of change on the depositional dynamic of LdM in the climate or societies.

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Interactive comment

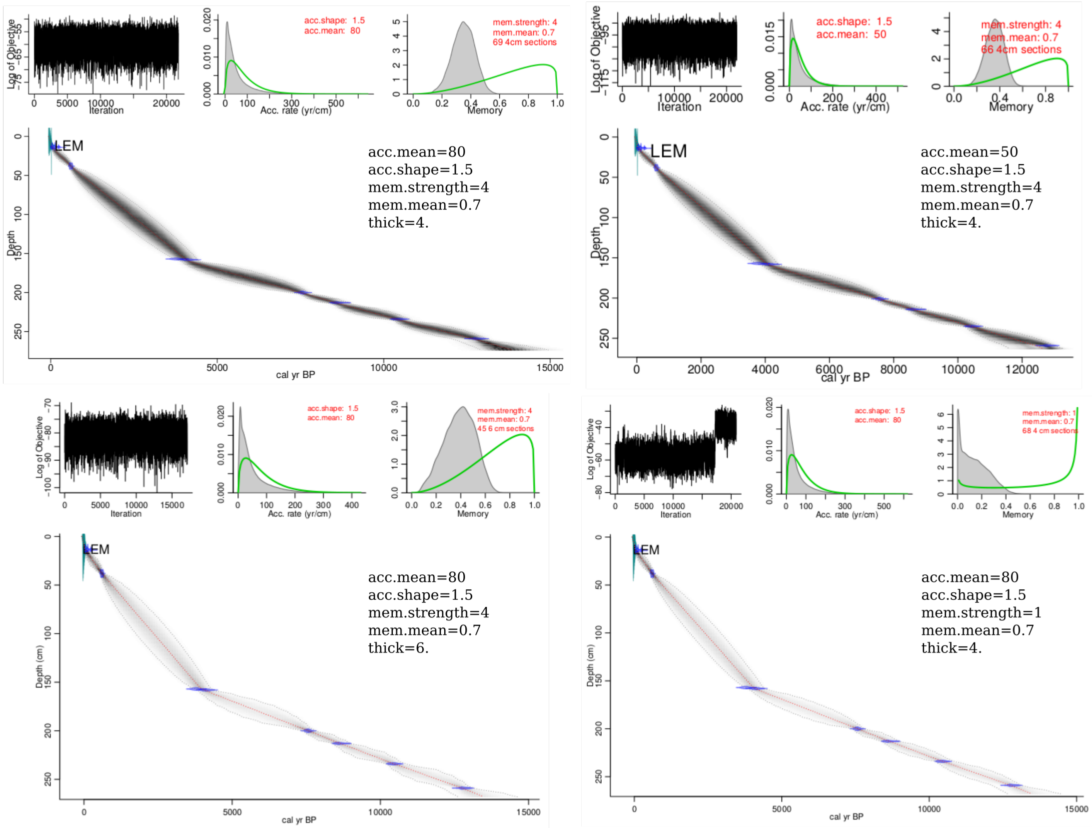

Fig. 1. Evaluating the magnitude of the effect of the different parameters in age-depth model

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