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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Pacific climate reflected in Waipuna Cave dripwater hydrochemistry" *by* Cinthya Nava-Fernandez et al.

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Dear Referee,

Thank you for the very helpful comments which we consider in our revised manuscript. Please find below our point-by-point response to all your comments and those of reviewer 1. We submit a substantially revised manuscript following these comments, which indeed helped to improve our paper. We believe that this contribution will be well-regarded by readers of HESS, and hope you find it suitable for publication.

Thank you for your time and consideration,

Sincerely, Cinthya Nava Fernandez, on behalf of all co-authors.

Anonymous Referee #1 Received and published: 27 January 2020 This manuscript reports the results and interpretation of a multi-year cave monitoring study in an ENSO-sensitive region of New Zealand. With a few minor exceptions, largely relating to oddly used commas, the writing is clear and the paper is well organized. The figures are appropriate and nicely constructed. I list specific comments below, none of which should require much work to incorporate. As I mention a couple of times, it seems odd that barometric pressure data were not included. The authors reference a 2008 study of the same cave and I argue strongly that data from this study should be included here, even if they don't overlap with the years that CO2 and dripwater were measured here.

Specific Comments Line

29 – and CO2 concentration Done

35 – diffuse flow, fracture flow, and combined flow Done

37 – is buffering the right word? Perhaps homogenization? Done, we rephrased the sentence

49 – atmospheric-oceanic Done

55 – does eastern NZ refer only to the North Island? If not, then leave as is, but given that a lot of paleoclimate work (pollen, glaciers, speleothems, etc) has been done on the South Island, it is important to distinguish between N Island-only signals and those that impact all of NZ. We agree in highlighting the importance to distinguish between both islands. In line 55 'NZ' refers to both islands, but for the next sentence the effects of La Niña conditions are specifically related to the North Island. We specify this more clearly now in the text.

61 – short time span (beginning early 1800s) Done

61 – priority, both because Done

62 – I would add that we still don't really understand the nature of ENSO over the last few millennia and ENSO-sensitive sites capable of providing meaningful reconstructions are highly valued. We agree and added a short hint in the main manuscript (red text): Since the nature of ENSO over the last few millennia remains poorly understood, ENSO-sensitive study sites that provide long, robustly datable proxy reconstructions are urgently needed.

68 – either write atmospheric-oceanic or atmosphere-ocean Done

70 – I don't understand this claim; can't one calibrate d18O in snow atop glaciers v temp? Coral geochemistry vs SST? Marine core top calibration is commonly done. Tree rings seem to be one of the few records truly complicated by modern calibration owing to (likely) CO2 fertilization effects.# To explain this more clearly we adjusted the main text as follows: Speleothems provide reliable continental palaeoclimate records because they allow for modern calibrations linking palaeo-data from stalagmites with meteorological and direct in-cave monitoring, thus making it possible to trace climatic signals from the surface to the speleothem at timescales from seasonal (Frappier et al., 2002) to orbital (Meckler et al., 2012; Mattey et al., 2008).

77 – hydrology, and hydrochemistry is critical Done

78 – in speleothems because numerous studies have shown imperfect replication between coeval stalagmites or plate-grown calcite, as well as differences in dripwater chemistry. d. Done, we added this: Monitoring of modern cave environments, encompassing ventilation, hydrology and hydrochemistry is critical for reliable interpretations of palaeo-environmental proxies preserved in speleothems because numerous studies have shown imperfect replication between coeval stalagmites, as well as differences in dripwater composition (McDermott, 2004; Fairchild et al., 2006a; Breitenbach et al., 2015).

85 – in my opinion, speleothem paleoclimate work is shifting toward an understanding that cave hydrology/dripwater geochemistry is a prerequisite for meaningful interpre-

tation of speleothems. However, it is not enough. Speleothem records must also be replicated. I would like to see some mention of that here. We agree with the reviewer that replication is of great value, but we argue that a lack of agreement between two stalagmites from the same cave does not mean that this cave does not carry environmental and climatic information. It simply means that detailed monitoring is vital to understand the underlying physical processes that lead to these differences. We added a clarifying note in the main text: The characterization of infiltration pathways is an essential prerequisite for delineating the processes that can modulate dripwater chemistry, i.e. the degree of water-rock interaction taking place in the epikarst and the climate signal transferred by the dripwater to the speleothems. The climatic signal transferred to speleothems can vary even between speleothems from the same chamber, which emphasizes the need for detailed monitoring. As every stalagmite records the conditions that occur in the epikarst and are transported by the feeding dripwater, in-depth understanding of the forcing mechanisms is vital to understand the differences between non-replicating records.

89 – please differentiate more fully between fracture flow and "iii) conduits with high flow rates" We explain this in more detail now: The physical proprieties of the karst zone define the different levels of porosity which is primarily characterised by intergranular pore space, while secondary porosity is associated with joints and fractures, and tertiary porosity with solution-enhanced conduits (Ford and Williams, 2007). Seepage water experiences one or a combination of these different porosity levels, which determine hydrological pathways (Fairchild and Baker 2012).

99 – increasing PCP depending on their partition coefficients in calcium carbonate Done, we added a short explanation: Flow routing to speleothem drip points is the first-order control on dripwater hydrochemistry, with particular relevance for trace elements and other proxies of prior calcite precipitation (PCP) (Fairchild et al., 2000; Wassenburg et al., 2012). PCP serves as a proxy system for moisture availability (Magiera et al., 2019), and affects a range of trace elements, which may either become more

concentrated (increasing X/Ca) or diluted in solution (decreasing X/Ca) with increasing PCP depending on their partition coefficients between solution and calcium carbonate (Hartland and Zitoun, 2018).

104 – here you write "south-western", but earlier you use SW. Be consistent, but don't hyphenate southwestern Done

105 – not sure Borneo is the southwestern Pacific. It's equatorial to slightly NH This is correct and now adjusted in the text.

118 – need a verb after iii). Done, the new main text reads as follows: Our study has three consecutive objectives: i) characterisation of the dripwater chemistry, including major and trace elements (Mg/Ca and Sr/Ca) and isotope geochemistry (ïĄď17O, ïĄď18O, ïĄďD and d-excess); ii) identification of the mechanisms controlling dripwater chemistry; and iii) understanding the relationship between dripwater chemistry and variations in precipitation, and seasonal and interannual (ENSO) climate conditions.

130 – are you sure "typic orthic allophanic" is the appropriate way to describe these soils? Yes, we follow the soil classification established by the TRC (Taranaki Regional Council) in the cover soil map for Waipuna Cave location. S-map Soil Report (Manaaki Whenua Landcare Research) https://smap.landcareresearch.co.nz

143.- and recorded Done

149 – 22 km is a pretty long distance. Why include this station? Why not just the one 13 km from the cave? We use Othorohanga station data because other datasets contain gaps. Othorohanga station is in a neighbouring area that shows similar rainfall patterns and this meteorological record has the most complete record of all variables considered in our work during the monitoring period.

150 – please expand on the methods for monthly rainwater collection? What was used to minimize evaporation? Thanks for spotting this. This sentence was not deleted by mistake since we have very few rain water measurements which we chose not to

discuss in this paper and this information has been removed.

170 – was counted Done

174 – of variation (CV) Done

178 – of dripwater and stream water Done

233 – CV has already been defined Done

247 – I understand that the data are significant to three places, but it is distracting to include values in the hundredths place for delta values. It is easier to remember and no less significant to the story if you write "varied between -3.0 and -2.4‰ $...-5.9 and-5.2 for d18O...00258 - . We agree, and we changed this accordingly$

261 – why not include mean and standard deviation here? Much more informative than range alone. We have added some more detail in the main text to allow for better evaluation, but we think that the range is the more informative parameter in this context, as it quantifies the total observed variation in the dripwater d18O signal over the sampling period. The standard deviation around the mean is here less helpful, as it condenses the information too much in the sense that individual observations are smoothened. Even a few observations in either direction contain helpful information, which is better reflected in the total range. The main text now reads: Between September 2016 and June 2017, drip sites WP 1-1, WP 1-2, WP 1-3, WP 1-4, WP 1A, and WP 1B show little variability in dripwater d18O and dD, ranging 0.5 ‰ (-5.4 to -5.9 ‰ in d18O and 3.9 ‰ (-28.8 to -32.7 ‰ in dD, with mean values of -5.61$\pm$0.04‰ (2s) and -31.01 $\pm$0.4‰ respectively. Although low, this range is still greater than the analytical error of 0.16 ‰ and 1.4 ‰ respectively (Fig. 8b and c and Supplement S3). From July 2017 to January 2019 virtually no variability was observed in d18O and dD (Fig. 8b and c and Supplement S3). The dripwater d18O and dD in that period range 0.3 ‰ (-5.4 to -5.7 ‰ in d18O, and 2.16 ‰ (-29.2 to -31.3 ‰ in dD, with mean values of -5.61$\pm$0.05‰ (2s) and -30.47 $\pm$0.18‰Ṫhis range is virtually at the analytical uncertainty level. By

contrast, the three drip sites with the shortest lags, WP-2, WP-3, and WP-4, exhibit higher variability in d18O and dD. In particular, sites WP-2 and WP-3 show a marked increase (0.5 ‰ in d18O between December 2016 and January 2017 (Fig. 8a), d17O varies in the same way as d18O (Supplement S4).

266 – PCP has already been defined Done

267 – see my earlier comments regarding reporting the hundredths (or thousandth!) place Done

285 – this correlation deserves at least a little bit of explanation. Would have been nice if the cave monitoring had included barometric pressure. . . We agree that barometric pressure would have been a valuable parameter to monitor directly, and we consider this for our future work. Unfortunately, it was not logged with our available devices. The correlation is discussed in detail in the discussion section, whereas here we include only a very brief explanation. Cave air pCO2 varied from a minimum of 438 ppm in September 2016 to a maximum of 930 ppm recorded in March 2019 (Fig. 11b). Cave air pCO2 is positively correlated with cave air temperature (R2 = 0.67, p = 0.045). The highest air pCO2 values are registered when cave air temperature reaches its maximum in summer and decrease when cave air temperature is lowest in winter (see the implications in discussion Section 5.4).

288 – this is a long, but incomplete, sentence. “This work is aimed” Thanks for pointing this out. We adjusted this as follows: This work aims to evaluate the hydrochemical response of Waipuna Cave to environmental dynamics, and to test its suitability for speleothem-based palaeoclimate reconstructions. We explore the links between the physiochemical parameters measured in Waipuna Cave and rainfall and temperature changes at seasonal to inter-annual timescales.

290 – physiochemical? Done

308 – I am not convinced the data “confirm” anything, but they do “suggest” or “argue

for” fracture flow Done

329 – this discussion of amount effects in the rain data is too abbreviated. The origins of amount effects have been demonstrated to reflect any of a suite of drivers, including storm track, and these should be fleshed out here in more detail. Done, we added a short discussion: The distribution of the rainwater oxygen and hydrogen isotopes along the LMWL (Fig. 7) does not reveal a clear seasonal pattern. However, when comparing rainfall d18O values with the amount of precipitation across the entire monitoring period (Fig. 12, black line), we observe a positive relationship (R2 = 0.56, p = <0.0001). The strongest correlations between rainfall amount and ïĄď18O values are observed in austral spring and summer (R2 = 0.68 p = 0.0002, and R2 = 0.89 p = 0.0001, respectively) when temperature is highest in the Waikato area (Fig. 12, green and orange lines). Among the various climatic and geographical effects on the isotopic composition of rainwater, the ‘amount effect’ has been shown to significantly influence rainwater d18O in sub-tropical regions. The amount effect is the empirical negative correlation between rainfall amount and rainwater d18O (Dansgaard 1964), which arises from the partial re-evaporation and thus isotopic enrichment of rain droplets falling through relatively dry air below the cloud during periods of reduced precipitation (Dansgaard, 1964; Risi et al., 2008; Lachniet 2009; Breitenbach et al. 2010). This process affects the isotopic signature in rainfall observed in the Waitomo region in spring and summer, but not during the winter season when re-evaporation from falling rain is minimal due to high relative humidity (this is reflected in lower R2-values in from April to September, Fig. 12). In the wet season rain droplets are less affected by re-evaporation and remain unaltered with respect to d18O. The seasonally contrasting isotope signatures govern the empirical amount effect (Breitenbach et al. 2010). These observations suggest that regional atmospheric conditions, associated with ENSO dynamics or strength of the Westerlies, can impose their signature on the isotopic composition of precipitation.

337 – why the open paren? Fixed

382 – again, it would have made a great deal of sense to have installed a barometric

pressure logger within and outside the cave to address questions of ventilation. As mentioned above, this parameter has unfortunately not been logged. However, the temperature difference (DT) between surface and cave air, in combination with the geomorphology of the cave, allows the characterization of ventilation. The density contrast between both air masses has long been understood as important mechanism for cave ventilation (De Freitas et al. 1982, Smithson 1991, Kowalczk & Froelich 2009). Temperature monitoring has been successfully used to investigate ventilation in several (and sometimes quite complex) caves (Breitenbach et al. 2015, Ridley et al. 2015, Riechelmann et al. 2019).

385 – put references in parentheses Done

387 – Wood Cave, located # km (direction) from Waipuna Cave, We mentioned Harrie Wood Cave because it is in a similar climate setting, however this cave is located in Australia.

412 – Replot some of the data from Fernandez-Cortes et al., 2008 in this paper to illustrate the effects of air pressure. We abstain from replotting the data of Fernandez-Cortes et al. because the impact of air pressure on cave ventilation has extensively been discussed elsewhere (please refer to Fairchild & Baker 2012, pages 109-114 and 122-127, and references therein, as well as the references we list in our response and the main manuscript). We use Fernandez-Cortes et al. only as reference to 'barometric caves', we adjusted the sentence to make this more clear. Although our study does not have pressure data, the model based on the changes of air density driven by changes in air masses has been shown to act in several of caves throughout the world e.g. Obir Austria (Spötl et al. 2005), Texas US (Banner et al. 2007), NE India (Breitenbach et al. 2015), Almeria Spain (Gazquez et al. 2017), and NW Germany (Riechelmann et al. 2019). Monitoring of temperature and CO_2 between June 2017 and June 2018 shows that Waipuna Cave ventilation is driven by changes in the density of internal and external air in response to seasonal external temperature (Fig. 11), i.e., Waipuna Cave is a barometric cave sensu Fernandez-Cortés et al. (2008) This behavior has

been observed in other caves globally.

428 – Is this section title, while poetic, a touch too flowery? The purpose of this section title is to highlight that – although in a subtle way – Waipuna cave is able to record changes in the dripwater chemistry associated to ENSO events. Waipuna Cave reacts quickly to even short and weak events such as the La Niña in summer 2017-2018. We think that the title encourages the reading and we would like to keep it as it is.

Figure 3 – please add to the figure itself the intervals for which no data are available. Don't rely solely on mentioning this in the caption. Done

References Banner J. L., Guilfoyle A., James E., Stern L. A. and Musgrove M.: Seasonal variations in modern speleothem calcite growth in Central Texas, USA. J. Sed. Res. 77, 615–622, https://doi.org/10.2110/jsr.2007.065, 2007. Breitenbach, S.F.M., Lechleitner, F.A., Meyer, H., Diengdoh, G., Mattey, D., and Marwan, N.: Cave ventilation and rainfall signals in dripwater in a monsoonal setting- a monitoring study from NE India. Chem. Geol., 402,111–124, doi.org/10.1016/j.chemgeo.2015.03.011, 2015. Fernandez-Cortes, A., Calaforra, A., and Sanchez-Martos, F.: Hydrogeochemical processes as environmental indicators in drip water: study of the Cueva del Agua (Southern Spain), Int. J. Speleol. 37, 41–52, 2008. Freitas, C. R. De., Littlbjohn, R. N., Clarkson, T. S. and Kristament, I. S.: Cave climate: Assesment of airflow and ventilation, Journal of climatology, 2, 383-397, https://doi.org/10.1002/joc.3370020408, 1982. Gázquez, F., Calaforra, J. M., Evans, N. P., and Hodell D. A.: Using stable isotopes (d17O, d18O and dD) of gypsum hydration water to ascertain the role of water condensation in the formation of subaerial gypsum speleothems. Chem. Geol. 452, 34–46, doi.org/10.1016/j.chemgeo.2017.01.021, 2017. Kowalczk, A. J. and Froelich, P. N.: Cave air ventilation and CO2 outgassing by radon-222 modelling: How fast do caves breathe?, Earth Planet. Sc. Lett., 289, 209-219, https://doi.org/10.1016/j.epsl.2009.11.010, 2010. Riechelmann, S., Breitenbach S. F. M., Schröder-Ritzrau, A., Mangini, A. and Immenhauser, A.: Ventilation and cave air pCO2 in the Bunker-Emst Cave System (NW Germany): implications for speleothem proxy data. J. Cave Karst Stud., 81, 98-112. DOI:10.4311/2018ES0110, 2019. Ridley, H. E., Asmerom, Y., Baldini, J. U.L., Breitenbach, S. F. M., Aquino, V.V., Prufer, K. M., Culleton, B. J., Polyak, V., Lechleitner, F.V., Kennett, D. J., Zhang, M., Marwan, N., Macpherson, C. G., Baldini, L. M., Xiao, T., Peterkin, J. L., Awe, J and Haug, G. H.: Aerosol forcing of the position of the intertropical convergence zone since AD 1150, Nat. Geosci., 8, 195-200, https://doi.org/10.1038/ngeo2353, 2015. Smithson, P.A.: Inter-relationships between cave and outside air temperatures, Theoretical and Applied Climatology, 44, 65-73, https://doi.org/10.1007/BF00865553, Theor. Appl. Climatol. 1991.

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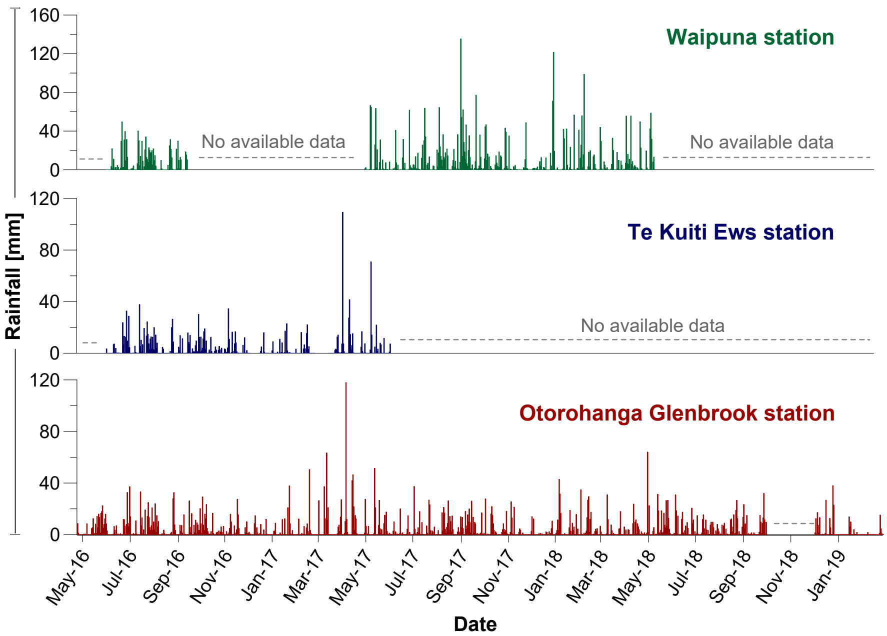

Fig. 1. Figure 3. Daily precipitation from the Waipuna meteorological station (no data is available for October and November 2018 due to instrument failure), Otorohanga Glenbrook and Te Kuiti Ews stations (da