Response to David Harning

We would like to thank David Harning for taking the time to read our manuscript and for posting a comment. We have included the comments below along with our responses.

Comment: Richter et al. present an interesting alkenone-derived proxy dataset, which is nicely paired with a lake energy balance model to help determine proxy seasonality. However, in light of other work indicating the spring/summer seasonality of alkenones in Iceland and the known human impact on the Icelandic landscape during the last 2 ka, I think there is room for some of the text (mostly discussion) to be revised.

Alkenone seasonality: I find it difficult to rationalize the cold season bias for alkenone seasonality in VGHV given 1) the minor changes NH winter insolation anomalies (and minimal winter sunlight in Iceland) relative to NH summer insolation, and 2) that alkenone Uk'37 values in a Holocene lake record from NW Iceland track the first-order decrease in NH summer insolation (Harning et al., 2020). I think it would be valuable to discuss the differences between the NW and S Iceland alkenone records in terms of their relation to seasonal insolation values and what this may mean for their interpretation. Reviewer 1 mentions exploring satellite imagery as well, which I second, as it may reveal differences in the timing of ice out between NW and S Iceland that may account for some of the differences. Additionally, the authors could compare against the long instrumental temperature record from Iceland, which has been used to show that biogenic silica in a west Iceland lake (Haukadalsvatn) correlates best with April/May temperatures (Geirsdóttir et al., 2009).

Response: As demonstrated in our lake energy balance model and previous work by Longo et al. (2016, 2018), lake water temperatures during the main period of alkenone production (i.e. ice-off) are sensitive to air temperatures during the winter and spring. Results from Longo et al. (2020) also show that this long-term trend in winter-spring insolation recorded by Group I alkenones holds true throughout the Holocene in Alaska. Unfortunately, the low-resolution alkenone record (resolution c. 1,000 years) in Harning et al. (2020) make it difficult to resolve whether the record is primarily recording spring or summer insolation during the last 2000 years, which overlaps with our record. Further, ice-off dates in Skorarvatn (late April-May, Harning et al., 2020) occur later than ice-off dates in VGHV (early to mid-April) due to the colder temperatures and sea-ice formation off the coast of Northern Iceland. As described above, this may account for the difference in seasonal sensitivity. The differences in the interpretation of alkenone records from Iceland, highlights the need for an *in situ* study of alkenone production in Icelandic lakes. In line with your suggestion, we expanded on the comparisons between northern and southern Iceland in our discussion, section 4.1.

As discussed in our response to reviewer 1, the purpose of the lake model is to determine the sensitivity of lake water temperatures and ice-melt to different processes. Further, the alkenone bloom actually starts prior to when the lake is completely ice free (Longo et al., 2018), and therefore knowing the exact date of ice-off will not alter our conclusions. In terms of comparing ice-off dates between NW and S Iceland, we agree that this might be interesting to pursue in future studies.

Comment: Regarding the model, I imagine summer insolation values also influence the timing of ice out. If summer insolation is decreasing, could this lead to more persistent lake ice over VGHV? Several studies on North Iceland marine SST proxy records, including alkenones, have noted a similar "warming" over the last 2 ka (e.g. Moossen et al., 2015;

Kristjánsdóttir et al., 2017), possibly as a function of sea ice lasting longer into the spring/summer, resulting in algal blooms occurring later in the season during relatively warmer months (e.g. Cabedo-Sanz et al., 2016). Could this possibly explain some degree of the warming observed in VGHV? If the record does indeed reflect winter warming, I'd suggest also comparing with a relatively new winter subsurface temperature record from the North Iceland Shelf (Harning et al., 2019).

Response: As demonstrated in our lake model and previous work by Longo et al. (2020) in Alaska, decreasing summer insolation does not result in more persistent lake ice cover and most of the changes in lake ice cover are in fact driven by temperature changes during the winter and spring season. As discussed in our response to reviewer 2, VGHV freezes every winter meaning that the minimal lake water temperature is reached and the lake water temperatures are essentially "reset."

We will consider discussing the Harning et al. (2019) winter subsurface temperature record in our modified text (section 4.1). As noted in the previous comment the presence of sea-ice and effects of the East Greenland Current may have a stronger influence on the subsurface temperature record from the North Icelandic Shelf, which might contribute to differences observed between North and South Iceland.

Comment: Landscape disturbances: The authors mention several times that VGHV's alkenone record is not affected by additional confounding variables (e.g. L44-46, L270-273). However, culture experiments from other haptophyte species (which admittedly are not the biological source of those in VGHV) show that Uk'37 values are sensitive to additional factors, such as nutrients and light (e.g. Prahl et al., 2003). From the existing proxy records from VGHV we know that human settlement in the catchment beginning at _1.1 ka BP had a significant impact on the surrounding landscape, including changes in vegetation (pollen) and an increased contribution of terrestrial material to the lake (C/N) (Blair et al., 2015). Presumably these changes could also have delivered more nutrients to the lake, so could it be possible some of the changes in alkenone unsaturation (and/or RIK37 values, L164-166) are also influenced by human-settlement related disturbances? In addition, tephra fall can also destabilize the landscape (Larsen et al., 2011; Eddudottir et al., 2017) so I wonder if VGHV's proximal location to the active volcanic zone and the heavy tephra loading during the last 2 ka may also impact nutrient flux and associated changes in Uk'37. In any regard, I think exploring the relationship of the new alkenone record with the existing proxy records (Blair et al., 2015) would be a valuable addition to the manuscript. As the record stands right now without the full Holocene for perspective of natural climate variability, it's difficult to confidently assign the changes observed to simply climate rather than some combination of that and human disturbances.

Response: We have a separate paper discussing the impacts of environmental disturbances on the lake sediment record and how we disentangle human impacts from climate related changes (Richter at al., *in review*). To summarize our main conclusions from this paper and as briefly discussed in section 3.1, we are able to isolate the climate influenced signal from human impacts by removing data points that are influenced by Group II Isochrysidales. In lakes, changes in species composition (i.e. Group I vs. Group II), and therefore alkenone production, are primarily influenced by salinity and trophic conditions (Longo et al., 2018; Yao et al., 2019; Plancq et al., 2018, 2019). As major salinity changes are highly unlikely to have occurred in VGHV over the past 2,000 years, we assume that most of the changes in species composition are driven by a change in nutrient inputs. An increase in RIK_{37} values, and therefore Group II Isochrysidales, occurs after 874 CE, around the time early Norse settlers arrived in Iceland. We independently constrain these early human impacts using long-chain *n*-alkanes to track major changes in vegetation composition (Richter et al., *in review*). The timing of human impacts on VGHV is very well-constrained, and although landscape and other changes did impact the haptophyte community, after correcting for species mixing we observe no large shifts in our temperature record at 874 CE.

Unfortunately, there are no available cultures from Group I to validate that Group I alkenone production is not influenced by changes in nutrient conditions or light. However, as demonstrated by previous studies, alkenone production by Group I Isochrysidales is primarily influenced by changes in spring lake water temperatures (Longo et al., 2016, 2018; Plancq et al., 2018, 2019; Yao et al., 2019). In terms of volcanic tephra layers, we see no correlation between changes in our alkenone record (either RIK_{37} or U^K_{37}) and tephra layers identified in the VGHV sediment core over the past 2,000 years.

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