

Response to Reviewers

We thank the reviewers for their comments. All responses are below in blue text. Line numbers correspond to the changes accepted document.

Reviewer #1

This manuscript has been greatly improved, however there is still some confusion and imprecision about the definition of El Niño events which should be rectified before publication.

Comments

Line 200: Greater description of the ENSO indices used (with webpage references, if this is where the three indices are taken from) would help clarify the subsequent analysis. Line 200-201 is somewhat confusing, is there a lagged correlation between ONI indices and variables, and if so, is it months or one year? Or are the authors determining years to be considered El Niño or La Niña based on some threshold of number of months (and if so, what month is taken as the year start)?

Lines 173-174 - Clarified the collection of the indices from the NOAA database, and provided this information and a link to the data.

Line 176-178 – Yes there is a lagged correlation where the result is correlated back to the indices for each month over the duration of the previous year. We edited the text to clarify this process for the reader a bit more. It now reads ‘As the average month of observation for each year was September, the result variables for each year were correlated with the preceding months’ indices, one year before the annual September observation date (e.g. 1998 SCA is correlated with the indices starting in August 1998 and going backward to September 1997.’ Results are shown in Figure 5.

Line 150, 264, 268 and section 3.2: As noted, 1999 and 2017 contain no El Niño periods so cannot be defined as El Niño years, and defining 1997-1999 and 2015-2017 as El Niño events is therefore incorrect, and negates many of this paper’s conclusions. 1999 was a strong La Niña year, as noted elsewhere in this manuscript. Please check ENSO dates are precise throughout the manuscript, using e.g. https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php .

Section 3.2 -We did not intend to identify 1997-1999 as El Niño events. Line 239-241 states ‘To better assess the QIC’s response to El Niño events, we utilize our high-frequency (monthly) observations collected around the 1998 and 2016 El Niño events (i.e., between 1997–1999 and 2015–2017).’ The intent was to analyze and discuss how the QIC responded to the El Niño events, and thus we needed data from before and after, aka the 1997 and 1999 measurements. From the previous comment, we also defined the indices as Nino or Nina qualifying (Line 174-175).

In relation to this, section 3.2 refers in the first paragraph to the strong El Niño events of 1998, 2016 and 2023. The analysis of the first two events is consistent, as they both consist of strong El Niño indices over the preceding wet season, until around March/May of 1998/2016. 2023, however shows the opposite pattern, with strong La Niña indices over the preceding wet season. Given that the strongest El Niño months for 2023 occurred after the date of the satellite imagery from which this analysis has been used, I do not think it is reasonable to make conclusions about the effect of the 2023 El Niño at this point, unless all analysis has been conducted using only a few months of ENSO index leading up to the date of satellite image.

Line 233-238 – We added clarifying language to the results to indicate that while the El Niño in 2023 was not at its maximum, it was in fact in existence a few months before the 2023 measurement occurred. We could not measure it later in 2023 due to cloud cover and the consistency of our previous measurements.

Discussion about the differences surrounding these events is in the Discussion, Section 4.1. Specific discussion about the 2021-2022 La Niña begins at Line 324.

Figures throughout: Please define in the figure captions the meaning of all error bars and shading, and which data were used to construct these.

Figure 2, 3, & 6 are applicable to this comment. We have added the following to each caption ‘Error bars represent $\pm 3\%$ uncertainty calculated from comparisons to manual digitization.’

Minor comments

226: Please use SI units hPa rather than mb

Line 198 – Changed to hPa as requested

265-267: The statement that there is a steady decline over 3 consecutive years from both 1997-1999 and 2015-2017 contradicts lines 259-260 and figure 3, which show a rebound or partial rebound in the final year.

Line 240-242: We adjusted this statement as we are discussing the decline into the El Niño year. It now reads ‘We found that in both the 1997–1999 and 2015–2017 periods, the lowest SCA occurred during the El Niño years during the mid-September observation and that the decline of the QIC’s SCA began from the previous year’s September measurement.’

Line 278 and Table S4: which El Niño years are included here?

Line 278 – This is the middle of Figure 3, the years are available in the figure legend. To reference Table S4, we have updated the caption to reflect the usage of an ONI index ± 1.0 to classify the years as El Niño, La Niña, or Neutral. This is also discussed in Lines 321 where Table S4 is mentioned and we have clarified the mention of Table S4 in the text in Lines 257.

Table S5: MEI mislabelled as MVI.

Table S5 – Label changed to MEI

Reviewer #2

The authors improved the paper and addressed the main issues. Hence I have no further major comments. However, there are still many small errors interspersed throughout the paper, so I would urge the authors to thoroughly proof-read the paper one more time before publication. I listed a few mistakes below that caught my eye.

Line 66-67: Why include initials in this citation? Simply write: ‘(Hurley et al., 2015).’

Line 69 – citation adjusted to Hurley et al., 2015.

Line 66-67: Same comment – remove initials from citation: ‘(Thompson, 2017).’

Line 72 – Citation adjusted to Thompson, 2017.

Line 72: ‘Additionally, ice cores from multiple locations in Peru document this accelerating enrichment’. What enrichment? This sentence is not clear.

Line 74-77 – Enrichment of $\delta^{18}\text{O}$. Have clarified the sentence to read ‘This warming trend is also reflected in ice core stable isotope ($\delta^{18}\text{O}$) records from multiple locations in Peru (Thompson, 2017; Thompson et al., 2013, 2017). High-resolution ice core records indicate that the QIC is an excellent recorder of El Niño, characterized by elevated sea surface temperatures (SSTs) in the Eastern Pacific Ocean, with strong events recording isotopically enriched $\delta^{18}\text{O}$ (Thompson et al., 2011, 2017).’

Line 95-96: This is still wrong. You write: ‘European Centre for Medium Weather Range Weather Forecast (ECMWF), yet it should say: ‘European Centre for Medium- Range Weather Forecast (ECMWF)’.

Line 98-99 – Adjusted acronym definition to ‘European Centre for Medium-Range Weather Forecast (ECMWF).’

Line 148: This is the first time you use the abbreviation ‘OTSU. Please spell out what this means.

Line 140 – OTSU is not an abbreviation, but the surname of the scientist who developed the method. We have altered the sentence to read, ‘To delineate the snow cover area (SCA), the NIR band was assessed with an image segmentation algorithm, the Otsu method (Gaddam et al., 2022; Otsu, 1975).’ This is to clarify this statement and added the original reference from Otsu’s publication.

We also mention it on Lines 116, 154, & 155 and have adjusted the wording there as well.

Line 143: This is section 2.4, not 2.3.

Line 147 – Changed heading to 2.4

Line 148: This is the first time you use the abbreviation ‘SWIR’. Please spell out what this means.

Line 152 – Defined SWIR in text as short-wave infrared

Line 161: This is section 2.5, not 2.4.

Line 165 – Changed heading to 2.5

Line 196: these r-squared values are very low – are you sure the significance levels you indicate for such low values are correct? How can a r^2 value of 0.03 be significant at $p=0.01$?

Line 205– We re-checked and adjusted the p values. The r^2 values are low and the p values are not significant as stated in the text and reflected by the reported results.

Line 226: ERA 5 data show (plural)

Line 259 – Changed shows to ‘show’

Line 245: p-values are usually indicated with a small ‘p’. You do so in the first part of the paper, but here you suddenly start to capitalize ‘P’. Be consistent, as otherwise one might come to believe that

you are referring to two different metrics or variables. The same comment applies to the seemingly indiscriminate use of 'r' and 'R' throughout the paper.

Line 251 – p value has been changed to lowercase. All of notations of p values were checked to ensure consistency.

Figure caption 3: you write 'Percentage of snow cover..', yet the Figure shows absolute snow cover in km².

Figure 3 caption has been changed to 'Distribution of Snow Cover (km2) instead of percentage.

Figure caption 4: You write: 'Decrease in the QIC' SCA (red) and TA (blue) at the end of the dry season from 1985 (left) to 2023 (right)'. Yet you only show the decrease in the SCA. The TA (blue line) is the same in both images.

Figure 4 has been adjusted to show the decrease in total area and snow cover area in both years.

Line 299: Remove initials. Simply write: '(Hurley et al., 2019).'

Line 303 – reference changed to Hurley et al., 2019

Line 315-316: this sentence is unclear: 'decline from anthropogenic warming has resulted in the long-term decline of the SCA'. What do you mean with 'decline from anthropogenic warming'?

Line 317 – This is a confusing sentence, we have altered it to read 'This indicates that while the QIC's SCA is notably briefly reduced, and its decline exacerbated over the long term, by El Niño events, anthropogenic warming is the primary driver of the multi-decadal decline of the QIC's SCA and TA (Bradley et al., 2009; Rounce et al., 2023; Thompson et al., 2021; Vuille et al., 2018; Yarleque et al., 2018).'

Figure S5: I don't find such simple linear interpolations to be very useful or realistic assumptions. As ice caps shrink and become thinner, elevation-dependent feedbacks and edge effects will become increasingly more important, resulting in accelerated shrinking over time, especially given the large flat topography making up most of the remaining ice-covered area.

Lines 350-355 – We used Figure S5 to discuss this point, that if we assume constant loss that's what we'd expect to see happen, but we note there is potential for many other factors to influence this loss and it will likely not be a linear decline. We want to include figure S5 for the sake of future discussion as the QIC's total decline has been so close to linear for decades, how will it change when it becomes non-linear? There is a good potential for more studies into what caused that shift in its decline. We do note this in the text as well, that linear decline is unlikely.

Line 347: 'El Nino': add the 'tilde' symbol above the 'n'.

Line 344 – Tilde added above 'n'

Lines 387-388: This reference is still wrong. It lacks volume and page numbers or doi. Also the journal name is wrong. This article appeared in the journal 'Photogrammetric Engineering & Remote Sensing', not 'Terrestrial Photogrammetry'. Finally, the title is incomplete: The correct title is: 'Measurement of the Retreat of Qori Kalis Glacier in the Tropical Andes of Peru by Terrestrial Photogrammetry'.

Lines 398-399 – We have adjusted the reference to include volume and page numbers as well as correct the journal. There is no doi as the paper is only hosted on the Byrd center webpage as a scanned copy of the document or a hard copy.

Lines 446-448: This reference is missing half the authors. Please include the complete author list or abbreviate the author list in a way that makes it clear that not all authors are listed.

Lines 458-459 – This reference (Pepin et al, 2022) has been checked to list all authors and missing ones added to the reference listing.

Supplement: Please adjust the manuscript title. You are still using the old erroneous title.

Title adjusted to match manuscript

Supplemental Table 2: It makes no sense to indicate median elevation and ELA with an accuracy of millimeters. I think meters would be a better reflection of the uncertainty of these estimates.

Supp Table 2 – We have adjusted the ELA and median elevation to an accuracy of meters as suggested.