Reply on RC4

Romina Llanos et al.

Author comment on "Recent significant decline of strong carbon peat accumulation rates in tropical Andes related to climate change and glacier retreat" by Romina Llanos et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2022-47-AC4, 2022

In order to be able to respond to each of the referee's observations and comments, I will put all of them in "normal" font, and our responses to them in bold italics, to make sure we respond to everything.

The authors use 4 short peat cores from 2 high-elevation Peruvian peatlands to discuss recent changes in carbon accumulation rates (CARs). They found very high apparent rates of carbon accumulation at these sites. They document a decrease in CAR after 1980 that could be caused by an increase in annual temperature; they corroborate this hypothesis with $d^{13}C$ values from the peat cores. The authors assume that $d^{13}C$ values are proxies for temperature (this assumption comes from a different article). Overall, this is an interesting study that could be appropriate for CofP readership, but I am afraid it is not ready for publication. I have numerous methodological issues (some may be flaws), which are described below. In particular, the CAR calculations may not represent true recent changes in carbon dynamics. Likewise, I have serious doubt about the application of the temperature transfer function to the $d^{13}C$ of bulk (?) peat. I hope the comments below are of use to the authors, who should definitely review their study and submit at a later time.

Idea: It would be interesting to read about why you think these young peat deposits started developing less than 100 years ago -- could make for a good discussion of the article.

We thank the referee for their comments to improve the manuscript.

We also apologize for the fact that we did not make it clear, that our Andean peatlands did not appear only 100 years ago. In fact, several papers (Engel et al., 2014; Schitteck et al., 2016) based on long core studies in the Andes show that peatlands existed throughout the Holocene. In APA1 peatland, we sampled, for example, core peat that are 2500 cal years BP (Huaman et al., 2020).

However, we aimed to study a much more recent period, so we chose to make short cores based on other studies (p. e., Benavides et al., 2013; Benavides, 2014) which showed that cores of about 30 cm covered the last ~100 years.

GENERAL COMMENTS:

STUDY AREA: I would have liked to read more about the hydrology of the area, its

vegetation, whether it is pristine or impacted by local communities (and animals), etc. Why did you choose those 2 sites should also be covered, as well as brief descriptions of those 2 sites (including the coring sites themselves). As of now, this section lacks important information.

We chose to work at these sites due to the dominance of Distichia in both peatlands, the difference in altitude and because this species is well preserved in this Andean environments.

We will add more information about the study area (see below).

"The Apacheta region is characterized by being a mountainous area, with peatlands located in the valleys and sections with gentle slope, at altitudes since 4100 m asl. In this area, the main economic activities of the local population are agriculture and livestock. Agriculture takes place at low altitudes and grazing of livestock in the peatland zone, due peatlands provide year-round forage production for grazing native domestic camelids (llama and alpaca) and for livestock species (particularly sheep). Evidence of grazing activity has been observed in the study area although with little visible impact on peatlands.

Two tropical high-elevation peatlands (APA 1: 13º 21' 4.61'' S, 74º 39' 31.75'' W, 4200 m asl; APA 2: 13º 20' 35.66'' S, 74º 39' 41.04'' W, 4420 m asl) were studied in Apacheta region in the central Andes of Peru (Fig. 1). APA 1 is located in a sub-catchment with an area of 3.3 km^2, with an elevation ranging from 4200 to 5000 m asl, while APA 2 sub-catchment had an area of only 2.14 km^2, with an elevation ranging from 4350 to 4850 m asl. The topographic relief is variable, ranging from soft to slightly undulating and overlain with slopes of moderate to strong decline. Edaphologically, the study sites are mainly composed of relatively medium texture deep soils developed upon volcanic rocks (porphyritic andesite) from Apacheta formation (Nm-ap_s) (INGEMMET, 2002).

In this region, Distichia muscoides Nees & Meyen (Juncaceae) is the predominant cushion peatland species, and it is present on most high-elevation peatlands in the central Peruvian Andes (Schittek et al., 2015), however other plant species are also found, such as Plantago tubulosa, Aciachne pulvinata, Scirpus rigidus, Calamagrostis rigescens, Calamagrostis spp., Hypochaeris sessiliflora, Hypsela reniformis. D. muscoides is a dioecious semiaquatic plant that grows in dense cushions (Buffen et al., 2009; Skrzypek et al., 2011; Schittek et al., 2018). Distichia leaves are 3 to 7 mm-long, are inserted densely along the stem and form hard monticules (diameter: ~2 m), which are compact mats surrounded by flooded hollows that are permanently bare of vegetation (Balslev, 1996). This species is well adapted to the high-elevation Andean climate and is able to survive diurnal cycles of freezing and thawing (Buffen et al., 2009). The cushion-forming species Distichia muscoides Nees & Meyen dominates many high elevation bofedales in Chile (Squeo et al., 2006), Peru (Skrzypek et al., 2011; Salvador et al., 2014), Ecuador (Chimner and Karberg, 2008), and Colombia (Benavides et al., 2013). Distichia cushions may have started to form as a single individual, producing a large number of shoots and rhizomes, which later transformed into smaller groups as the underground parts of the plant died off (Schittek et al., 2018). The cushion-forming species Distichia muscoides Nees & Meyen dominates many high elevation bofedales in Chile (Squeo et al., 2006), Peru (Skrzypek et al., 2011; Salvador et al., 2014), Ecuador (Chimner and Karberg, 2008), and Colombia (Benavides et al., 2013).

Between the cushions of APA 1 an APA 2 peatlands we found small and shallow pools of water, that are characteristic of this type of ecosystem. The mean pH

and conductivity, measured in these pools during the fieldwork, were 5.93 and 45.4 μS cm⁻¹ for APA 1 and 6.01 and 39.2 μS cm⁻¹for APA2, respectively.

The climate of the Apacheta region is typical of tropical high mountains with little seasonal variations in temperature and large seasonal precipitation variability with rainy and dry seasons. Based on data from the Apacheta station located near the two Andean peatlands of this study, about 1.6 km, at 13° 20' 51" S, 74° 38' 44" W and 4150 m asl, the study area presents an average annual precipitation of 830 mm for the period 1991–2012 CE and is marked by seasonal precipitation, with the wettest months being from October to March (monthly average: 114 mm). This seasonal pattern of rainfall reflects the occurrence of South American Monsoon during South Hemisphere summer. The mean annual temperature of the upper part of the basin is 6.4 ºC for the period 2000–2014 CE, with monthly averages ranging from 4.8 to 7.6 ºC; and the annual average relative humidity is 70.3% (for the period 2009–2013 CE) (GORE Ayacucho, 2015)."

METHODS: Lots of important information is missing (see the list below).

RESULTS:

(1) the trends in CAR that "slow down" in the early 1980s might be due to an autogenic process: the young peat has not decomposed and compacted yet, making TOC values smaller than the older peat. This would potentially yield lower CARs...

We found the opposite. Constant high TOC values over the two APA1 cores, and high values with a rising trend after the 1980's for the two APA2 cores (Figure 1 in SM).

(2) the changes in d¹³C are not considering the Suess effect. Other factors impacting d¹³C should also be tested/discussed, including hydrological changes.

The problem is: there is no precipitation changes registered in the climate data, so it is difficult to use this argument for $\partial^{13}C$ changes.

The most recent atmospheric $\partial 1^{3}C$-CO2 data for the period 1850-2015 (Graven et al., 2017) indicate a trend of -0,01 ‰ yr⁻¹ to be compare to the -0.047‰ yr⁻¹ (APA1-C5) and -0.044 ‰ yr⁻¹ (APA2-C4) we observed in our cores. However the referee is right in remembering the Suess effect on atmospheric $\partial^{13}C$-CO2 and we will integrate it in our calculations. This will not change the temperature values much because they are not based on absolute $\partial^{13}C$ values but on the differences between $\partial^{13}C$ values from one sample to another.

SPECIFIC COMMENTS

ABSTRACT:

lines 14-15: "...since glaciers have been recognized as one of their vital water sources" -- this is true for some Andean peatlands, but certainly not for MANY of them. This statement is therefore too general and misleading.

We agree.

line 23: a "new" proxy... the reference you are using is over 10 years old! not so "new" (and they were not the first ones to use it either...).

For us, 11 years is not particularly old, but we have no problem removing the term "new".

INTRODUCTION:

line 35: This statement about "all carbon in the atmosphere" is incorrect!! "The amount of C stored in peatlands is similar to the total C stocks in all living biomass or in the atmosphere"

According to Yu et al., (2016) the information we put in the manuscript is valid, it refers to the quantity of carbon, not CO_2.

line 68: what are you referring to here? "between 500 and 700m in length"

This is a citation from Rabatel et al. (2013) who measured a retreat of the front of the glacier of 500 to 700m. This means that the length of the glaciers has decreased by 500 to 700m.

line 72: this is not a "new" method!!

OK.

STUDY AREA

line 77 / Figure 1: I'm a bit surprised by your delienation of the watersheds; I'm not familiar with this region, but why is watershed 1 so large and watershed 2 so small? Is watershed 2 in fact part of watershed 1? I don't understand why you are reporting the size of the watersheds...

We thank the referee for this comment and in the new version we have included these data in the text.

The exact coordinates of the investigated sites are now specified and we detected a mistake in APA1 position on the map figure 1. APA 1 Cores: Lat. -13,35128; Long. -74,65882; APA 2 Cores: Lat. -13,34324; Long. -74,66140.

Now the sub-catchment areas have been recalculated after a supplementary field work (March-April 2022) and indeed APA1 is much smaller since it is not drained by Apacheta River which is located several meters below the peatland. The sub-catchment area of APA1 is only 3.3 Km^2 while for APA2, the sub-catchment area, inserted in APA2 one, is 2.14 km^2 (please see Figure RC4.1: The sub-catchment area of APA1, and Figure RC4.2: The sub-catchment area of APA2, in SUPPLEMENT).

The purpose of delimiting the two basins is to be able to compare peatland areas and carbon accumulation rates (please see Table RC4.1: Data comparison between both peatlands (APA1 and APA2)).

METHODS:

line 105: why are the cores shorter than the PVC tubes?

The size of the tubes (50 cm) is larger than the cores because it is necessary to leave a part of the tubes outside the peat in order to remove them manually.

We chose to work in a more current period to emphasize this period, based on

the Huaman et al 2020 core that worked in the same place with a longer core (2500 years BCE) and that highlighted the big differences between the last 60 years and the rest of the core. To clarify this point, we will change the sentence to: "For this study, four peat cores were collected: APA1-C1(34 cm) and APA1-C5 (29 cm) from the site APA1 located at 4200 m, and APA2-C3 (35 cm) and APA2-C4 (34 cm) from the APA2 site at 4420 m."

Are the peat deposits only 29 to 35 deep? If so, you need to mention this important "detail".

No, the peat deposits are longer at APA1 site (see Huaman et al 2020) and APA2 (no published data), but our aim objective was to work the most recent periods (last 60 years) so we only made core samples of 30 cm.

line 110-113: please add references to the methods you describe.

We agree.

line 120: why not use a Bayesian approach? It seems like the standard in paleoecological studies these days. Bacon can accomodate for your postbomb dates.

The first assumption of Bayesian method for age models is that "the chronology can be broken down into events" (Bronk Ramsey, 2019, Radiocarbon 51:337-360). It means that the sedimentation is formed by a succession of discrete sedimentary events, i.e. sediment layers that constitute the sedimentary sequence. This is generally true for sedimentary deposits but does not apply to peat growth. Mainly in tropical peat and in Distichia peat in particular, which is growing all along the year. For that reason, the Bayesian method cannot be applied in these peats and the best way to build the age model is by spline cubic interpolation.

line 129: by convention, you must report against which international standard your $d^{13}C$ values were calibrated against! (VPDB?).

Yes, $\delta^{13}C$ values were expressed relative to international standards VPDB.

Also, and perhaps more importantly, how did you sample and prepare for $d^{13}C$ measurements? Did you measure the bulk peat, the Distichia leaves, or something else?

We measured the $\delta^{13}C$ in the bulk peat.

Did you extract the cellulose or not?

No, we do not extract the cellulose.

What weight did you use in the lab?

For the $\delta^{13}C$ analysis we use about 2 - 3.5 mg of material. All analyses were performed in duplicates.

A lot of information missing here... that would hinder replication of your study.

We apologize, but in the new version of the manuscript the answers or precisions to all of these comments will be included.

line 131: you should use organic matter density (rather than dry bulk density) to truly

estimate CAR... You can do it since you have OM% from the LOI measurements...

To calculate the CAR based on growth rate (cm yr-1) we have multiplicated it by the bulk density to obtain the total accumulation rate (g cm-2 yr -1) and then by OM percentage multiplicating by 100-LOI%. Bulk density by OM% is the OM bulk density, so, in fact our calculation of the CAR is based on the organic matter density.

lines 134-135: you need to explain the mechanism that links d^{13}C with temperature... If I remember the Skrzypek study, they used an elevational gradient to build their relationship, which means that temperature may NOT be the main factor, but rather changes in pressure...

According to Skrzypek et al. (2011) and Engel et al. (2014) temperature is the main factor responsible for ∂^{13}C variations (see below):

"Several authors have investigated the meaning of the ∂^{13}C value in peat and peat-forming plants, especially in the Sphagnum genera (including Menot-Combesetal., 2004; Loader et al., 2007; Moschen et al., 2009; Brader et al., 2010; Tillman et al., 2010; Skrzypek et al., 2013) and have considered environmental factors such as air temperature, humidity, precipitation, vapour pressure deficit and atmospheric CO2 concentration. Despite the possibility of a combined influence of a few factors, the air temperature of the growth season seems to be the major factor governing ∂^{13}C of Distichia macrofossils well pre- served in peat sediments (Skrzypek et al., 2011). Our initial calibration, based on an altitudinal transect that intersects the core collection site, indicated that the observed decrease of ~0.97 ± 0.23‰ in the stable carbon isotope composition of Distichia peat reflects a 1°C increase in the mean air temperature of the growing seasons at the ground level. The temperature at the ground level at high altitudes largely reflects insolation. In contrast, no obvious relationship was observed between precipitation and the stable carbon isotope composition of Distichia peat (Skrzypek et al., 2011)." Engel et al., 2014.

lines 135-136: this sentence does not make sense to me; what do you mean? "This value was similar to the previously reported range for other species (included Sphagnum peat: -0.5 to -0.6‰/°C)"

Other peatland species also exhibit a negative ∂^{13}C gradient as a function of temperature, e.g. -0.5 to -0.6‰/°C for Sphagnum peat (Skrzypek et al., 2010).

line 139: why did you use 600 mb in this case?

Due to the altitude of our study area. It is located at 4000 - 4200 m asl, and this is related to a barometric pressure of approximately 600 mb (West, 1996; Paul & Ferl, 2005). Salzmann et al. (2013) in a study on glacier changes and climate trends in southern Peruvian Andes, also used NCEP/NCAR data for their analysis.

Are there known limitations/issues with using the NCEP/NCAR reanalysis in the high Andes that should be documented?

Of course there are many limitations in NCEP reanalysis, principally in a mountainous area, because these reanalysis data have a poor special resolution and then the topography is not well represented. This product is unable to take into account local process, like mountain breeze. In fact, our objective was to compare our data with regional climatological data to understand the relationship between regional climate and the peat functioning. The hypothesis

is that recent climate changes have influence the peat development. Higher resolution data which, in reality, are produced by a downscaling with the same initial number of observation data, do not seems better in this case.

RESULTS

Table 1: you say that you report "2 sigmas", but clearly you do not. Instead, you only report the calibrated age - it's unclear if this is the mean, median, or most probable age provided by Clam. Since those are post-bomb dates, it would be useful to know the most plausible age ranges (on either sides of the postbomb calibration curve).

We are sorry, we forgot to give the two sigmas values, this will be corrected. The calibration has been done again using the most recent pos-bomb curve (Hua et al., 2021). We used Oxcal to calibrate the 14C data. Here are the new age models.

Figure 2: I cannot tell which dates (and error bars) belong to which cores! would it be possible to have 4 panels (one for each core)? It could go in the supplementary file...

According to the suggestions made by Referee 1, we recalibrated the age with the most recent curve published by Hua et al. (2021) using the mixed curve recommended for South American Monsoon region (Bomb21SH3). All other data has been recalculated in agreement.

New age models (new Figure 2) are shown in Figure RC4.3 (in SUPPLEMENT). No significant changes were found.

lines 163-165: you say that "there was a general upward trend in TOC content from the peat basal depth of the cores from both studied peatlands to approximately 13 cm (the early 1980s) and then the TOC values decreased to the top of the cores (2015 CE)". This is likely because the uppermost samples are "fresher", being that they have not undergone decomposition and compaction. This is likely why your recent CARs are lower than your older CARS... In other words, this could all be an autogenic signal that has nothing to do with a temperature change.

The content of organic matter and thus carbon increases towards the top of the APA2 cores and is relatively constant for APA1 cores. The peat decomposition during time would lower the CAR accumulation downcore (please see Figure RC4.4: Organic matter content (%) for the 4 cores, in SUPPLEMENT).

line 174: mean CAR were higher at APA1 than at APA2 - probably because APA1 has high bulk density?! It would be worth to calculate organic matter density for a fairer comparison of those sites.

Yes, the mean bulk density is 44% higher at APA1 (0.11 g cm^{-3}) than APA 2 (0.076 g cm^{-3}), but this is not the only reason why the CAR is higher, the mean growth rate is 54% higher at APA1 (0.87 cm yr^{-1}) than APA2 (0.57 cm yr^{-1}). APA1 is also richer in organic matter (96.2%) than APA2 (91.7%). This leads to a difference in MO densities (0.10 gMO cm^{-3} for APA1 and 0.07 gMO cm^{-3} for APA2) that has been taken into account in the calculations as explained above.

line 189: did you consider the Suess effect at your sites? It is expected that d^{13}C become more negative over time because of fossil fuels mixing in the global atmosphere... "At both peatlands, there was a general trend to more negative δ^{13}C values from the basal depth to the top of the cores". Getting rid of the Suess effect would be very useful. Then, I see that your 2 cores tell different stories: one of them (the red line on Fig 5) would show

increasing d^{13}C values vs. the blue curve would show a decreasing d^{13}C trend. As mentioned in my intro, I am not convinced that these are temperature records. These could relate to hydrological changes: could it be that one site is becoming wetter)blue line) vs the other one is becoming drier (red line)? Please look into the literature that discusses stomatal closure.

The most recent atmospheric ∂13C CO2 data for the period 1850-2015 (Graven et al., 2017) indicate a trend of -0,01 ‰ yr-^{1} to be compare to the -0.047‰ yr-^{1} (C5) and -0.044 ‰ yr-^{1} (C4) we observed in our cores. However, the referee is right in remembering the Suess effect on atmospheric CO2 ∂^{13}C and we will integrate it in our calculations. This will not change the temperature values much because they are not based on absolute ∂^{13}C values but on the differences between ∂^{13}C values from one sample to another.

As explained above there is no change in precipitation in the reanalyses and we do not see how to explain that APA1 would become wetter while APA2 would become drier. For such short time scales, it is not differences in topography or drainage area that may have influenced the observed changes and no anthropogenic action on the drainage network was observed. Skrzypek et al. (2011) has shown that temperature influences ∂^{13}C of this kind of peatlands and others, and this explains well the variations observed in our cores.

DISCUSSION

lines ~ 200: you should read the paper by Benfield and Yu, Distichia deposits from Columbia were analyzed... You'll see that they also document very high recent CARs.

Yes, we know this paper. Those authors found high accumulation rates for the Colombian site that confirms our findings. This reference will be included in the discussion.

lines 195-205: you cannot compare your core tops with Holocene-aged cores and say that your cores have greater CARs! This is obvious: short peat hasn't decomposed much, especially compared to old sites... Figure 6 is a misrepresentation and flawed way to compare these data. For a fairer discussion, only look at recent CARs from around the world... There are plenty of data to play with!

Ok, we will redraw this figure with recent CAR data only.

I did not comment on the rest of the discussion, as I question the validity of the results.

Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2022-47/bg-2022-47-AC4-supplement.pdf