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Interactive comment on "Osmium isotope and trace elements reveal melting of Chhota Shigri Glacier, western Himalaya, insensitive to anthropogenic emission residues" *by* Sarwar Nizam et al.

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Note: RC and AR correspond to Referee's Comment and Author's Response respectively

RC: This manuscript concerns the geochemical characterization of cryoconite from a Himalayan glacier (western Himalaya). The authors applied several techniques to this aim: elemental and isotopic ones. The novelty of this work is the application of Re/Os isotopic systematic in order to evaluate the contribution of anthropogenic atmospheric

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emissions with respect to cryoconite composition. Combining several pieces of information from major, REE, trace elements and isotopic signatures, they conclude that cryoconite from the Chhota Shigri Glacier has a typical crustal signature, with only secondary inputs from anthropogenic emissions. I highlight my lack of competence to judge the methodological side of this work, in particular the one related to isotopic analyses. The authors seem quite confident and I have nothing to report, but I guess that an opinion from an isotopic geochemist would be desirable.

AR: Thanks for appreciating the methodology of the paper.

RC: In general, the manuscript is well written and easy to follow, but my impression is that this work, in its current form, would be more appropriate for a geochemistry journal. The Cryosphere should publish papers dealing with the diverse aspects of glaciology, including glacial geochemistry. With glacial geochemistry, I intend the geochemical processes which are somehow related to glacial environment. In this paper the authors present a detailed geochemical characterization of cryoconite, but they don't really link their findings with glacial (or supra-glacial) processes. For this reason, I believe that this manuscript should be published in a journal more focused on geochemistry, where their detailed geochemical analyses would be more appreciated. Otherwise the authors could deeply revise the manuscript, trying to better link their findings with glacial processes and highlighting the novelty of their method to evaluate the anthropogenic influence on cryoconite composition.

AR: Thanks for appreciating our writing style, and we are glad that the paper was easy to follow, even to a non-isotope geochemist. We understand the referee's concern. But we would like to emphasize again that our study for the first time demonstrates that dark-colored materials, in our case cryoconite, deposited on the surface of Chhota Shigri Glacier (CSG) in the western Himalaya is derived from natural sources. The particles are mostly locally sourced, with minor long-range inputs from the Thar and the Sahara Desert. This contrasts with many recent findings that show substantial anthropogenic input (e.g., Li et al., 2016, Sources of black carbon to the Himalayan–Tibetan

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Plateau glaciers, Nature Communication). In our opinion this is a significant finding, as we show that the surface of CSG is essentially free of anthropogenically emitted particles, but yet, CSG is losing glacial mass at an average rate of 0.50 meter water-equivalent per year (0.43 m w.e. yr-1) over the last two decades, which is higher than the central (0.35 m w.e.ye-1) and eastern Himalayan (0.43 m w.e. yr-1) glaciers that receive a substantial contribution of anthropogenic sources generated from the Indian subcontinent. We would like to highlight that CSG is considered to be a benchmark glacier in the western Himalaya, and it is one of the cleanest in terms of debris cover and glacial impurities. Our study proves glacial mass wastage rates in CSG is insensitive to glacial impurities. Therefore, we strongly feel that our study would be much more appreciated in the glaciological community as using state-of-the-art geochemical tools (first Os isotope dataset in the high-altitude Himalaya) we ultimately decipher the glacial environment. The study would lose its audience and impact if we submit the paper in a Geochemistry based journal.

RC: In addition, they should also shorten the side related to geochemistry (and this is a pity since the data are good, but not very suited for this journal), taking into consideration the possibility not to present all their data, which are so many. For example, figures 6-7-8 and the associated discussion could be removed, I don't' think that their removal would worsen the quality of the paper. Non-geochemists will have great difficulties to follow the paper if the manuscript would be published as it is now. If the authors want to publish their work in The Cryosphere, I suggest to them to select a limited dataset to present here (for example isotopic data and normalized elemental patterns) and focus their attention on the discussion about the anthropogenic influence on cryoconite composition.

AR: This is a very good suggestion. A lot of material (including figures 6, 7, 8) can be easily removed from the main text. We agree that removing these figures and their associated write-up would not impact by any means worsen the quality of the paper. Therefore, if given a chance, the manuscript can be shortened only by highlighting the

anthropogenic influence on cryoconite composition.

RC: The authors should also compare their results concerning elemental analyses with previous results (see for example Owen et al., 2019; Baccolo et al., 2017; Lokas et al., 2016; Singh et al., 2013) and better investigate the fact that cryoconite from the Chhota Shigri Glacier seems quite pristine, while other studies focused on Himalayan glaciers and cryoconite showed that pollution is strongly present.

AR: Precisely, that is what we would like to highlight, we already stated this with Li et al. paper (e.g., Li et al., 2016, Sources of black carbon to the Himalayan–Tibetan Plateau glaciers, Nature Communication) study. Thanks for pointing us toward new references that would further support our claim, and highlight the importance of this study.

RC: One thing which is not clear to me is the link throughout the entire manuscript of pollution, glacier mass balance, carbonaceous compounds. These are important topics, but this work does not deal with them, so I believe it would be more appropriate to remove them. Considering the above, I cannot support the publication of this work in The Cryosphere in its current form.

AR: We would revise as per the referee's comments. Here we would like to highlight that a separate independent study was carried out by our group on the same set of cryoconite samples. In the Nizam et al., 2020 paper using the distribution of organic carbon (OC) activation energy and 14C activity we demonstrated that 98.3$\pm$ 1.6% and 1.7$\pm$ 1.6% of the OC in the cryoconite samples studied here are derived from biomass and petrogenic sources, respectively. As cryoconite is a mixture of dust, soot, and microbes, this and the Nizam et al., 2020 study completes all the geochemical spectrum of CSG cryoconite including organic and inorganic impurities. We would like to highlight the Nizam et al., 2020 paper was published as a cover page article in Environmental Science and Technology. So, we do have some link with the carbonaceous compounds, but we agree, that we do not quantitatively deal with mass balance issues. We would be happy to introduce better clarity in the manuscript with addition/omission

of text, as and when required.

Specific comments: RC: Please improve the abstract, now it is the most difficult part of the manuscript to follow. It is not very explicative I guess that you could drastically shorten it. The important things to say are: 1- Himalayan glaciers are rich in supra-glacial debris, also linked with human activities; 2- you have geochemically characterized cryoconite samples from a Himalayan glacier, also applying cutting edge methods (osmium isotopes); 3-your results show that cryoconite on your glacier has a fully crustal signature, regardless the data you consider (major and trace elements, osmium isotopes); 4- provide some information about the scientific significance of such results.

AR: We agree that the abstract could have been shortened. Please see the revised abstract below: The western Himalaya and the Karakoram region hold ca. 70% of the total ice volume of the Himalaya that seasonally melts which is, in part, controlled by the presence of supra-glacial debris. However, the source, origin, and pathways of this supra-glacial debris on the ice surface of Himalayan glaciers remain poorly constrained. Here, we present major and trace element geochemistry, rhenium-osmium (187Os/188Os) isotopes composition of cryoconite: a dark-colored aggregate of mineral and organic materials-on the ablation zone (4100-4900 m a.s.l.) of the Chhota Shigri Glacier (CSG) in the western Himalaya. Using multiple lines of geochemical evidence, we show that the surface of CSG is essentially free of anthropogenically emitted particles, contrary to many previous findings. Given that CSG has limited debris cover (ca. 3.4%) and the presence of anthropogenically derived particles were not appreciably detected, we conclude that accelerated mass loss in the CSG is considered to be primarily related to the increase of the Earth's near-surface temperature in direct response to global warming.

Page 1 RC: Line 11-16: please rephrase, these sentences are very difficult to follow and not grammatically perfect.

AR: Thanks for the suggestion. We will rephrase it in the revised manuscript.

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RC: Line 16: you introduce emission residues and then you suddenly turn to metals. Please better introduce metals as one of the most important anthropogenic species spread in the environment.

AR: Noted, and will be revised.

RC: Line 20-21: “a benchmark glacier for process understanding in the western Himalaya” what does it mean?

AR: Chhota Shigri Glacier (CSG) is considered to be a benchmark glacier in the western Himalaya (Wagon et al., 2007; Pandey et al., 2017) as (i) it is medium-sized (15.7 km2 over a 34.7 km2 catchment (ii) limited debris cover ($\sim$ 3.4%) (iii) lies in the crucial area alternately influenced by the southwest monsoon in summer and by the westerlies in winter and (iv) extensively studied over the last 2 decades. So, CSG is considered as a benchmark glacier by the Indian and the International community. We would explicitly state this in the revised manuscript.

RC: Line 22: maybe change “composition” with “signature”?

AR: Noted, will be corrected in revised draft.

RC: Line 23: change “compositions” with “values”

AR: Noted, will be corrected in revised draft.

Page 2 RC: Line 8-10: you write “Given that the presence of anthropogenic emission residues on the Himalaya is linked to driving climate change, enhanced glacier melting, and downstream water resources,.. .”. I don’t really agree with this passage. The most important process linked to the presence of anthropogenic species on glaciers is the increase of human atmospheric emissions, mostly related to industrial activities and transport. What is the link between climate change and anthropogenic pollution on glaciers? Please reformulate this passage. Also, the role of glacier melting and downstream water resources is not clear in driving the presence of anthropogenic species on Himalayan glaciers.

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AR: We agree with the referee's point and will revise the text. For example, "Presence of anthropogenic emission residues on the glacial surface has been linked to enhanced glacier melting..." The paragraph will be rephrased, removing the ambiguous term 'downstream water'.

RC: Line 14-19: the authors state that scientific research on anthropogenic species found on Himalayan glaciers mostly focused on carbonaceous compounds and that studies dealing with metals are not common. This is not true! There are tens of papers showing that the concentration of many elements into glacier ice, in particular heavy metals, has increased in the last decades. If the authors look in scholar for the words "ice core asia metals", they will find heaps of interesting papers to cite.

AR: The referee's argument is true, but available studies are mainly restricted to the central/eastern Himalaya and Tibetan regions. But we understand his/her concern and will downplay our statement accordingly. We would like to highlight that the rhenium-osmium (187Os/188Os) isotopic data-that are widely used proxy to track contribution from catalytic converters fitted in automobile exhaustsâĂŤare new and probably the first dataset over the Himalayan glaciers.

RC: Line 19-22: also this statement is not correct. For example, look at Beaudon et al., 2018 (Central Tibetan Plateau atmospheric trace metals contamination: A 500-year record from the Puruogangri ice core), you will find that also for metals there are some works discussing their probable source.

AR: We will keep this in mind when revising the manuscript.

Page 3 RC: Line 3-5: "given that Re-Os isotopes are independent to the rate and magnitude of emission, biological or physiochemical fractionation during transport, complex orography, and meteorological parameters." I would simplify as follows: "given that the Re-Os isotopic signature is strongly conservative. It mostly depends on the emission source of the considered material and for this reason, it is adopted in provenance studies (add a ref about this point)."

AR: Noted, and will be revised.

RC: Line 23: “and is therefore an excellent site to study long-distance emission inputs.” Why? I don’t get the point, please explain better.

AR: Chhota Shigri glacier has the lowest debris coverage in its ablation zone (ca. 3.4%), it is one of the cleanest glaciers (in relation to debris cover). Therefore, chances that the long-range transported anthropogenic particles will be diluted with an overwhelming local signature will be minimal. Thus, we stated that it is an excellent site to study “long-distance emission inputs”. We would clarify this in the revised text.

RC: Line 25: “4050 and 6263”

AR: Noted, and will be revised

RC: Line 25-26: “a benchmark glacier for process understanding in the western Himalaya” also this passage is not clear. Why is it considered a benchmark glacier? What processes are you talking about?

AR: Chhota Shigri Glacier (CSG) is considered to be a benchmark glacier in the western Himalaya (Wagon et al., 2007; Pandey et al., 2017) as (i) it is medium-sized (15.7 km2 over a 34.7 km2 catchment (ii) limited debris cover ($\sim$ 3.4%) (iii) lies in the crucial area alternately influenced by the southwest monsoon in summer and by the westerlies in winter and (iv) extensively studied over the last 2 decades. So, CSG is considered as a benchmark glacier by the Indian and the International community. We would explicitly state this in the revised manuscript.

Page 4 RC: Line 4: “comprises”

AR: Noted, and will be revised

Page 6 RC: Line 15: “sample powder”

AR: Noted, and will be revised

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RC: Line 26: “sample duplicates”

AR: Noted, and will be revised

Page 11 RC: Line18: “are common”

AR: Noted, and will be revised.

We hope that after these responses, the manuscript we will be allowed to carry out a detailed revision of the manuscript, followed by submission in The Cryosphere.

References Li et al. 2016. Sources of black carbon to the Himalayan–Tibetan Plateau glaciers. Nat. Commun. 7, 12574. Nizam et al. 2020. Biomass-derived provenance dominates glacial surface organic carbon in the western Himalaya. Environ. Sci. Technol., 54(14), 8612–8621. Pandey, et al. 2017. Regional representation of glaciers in Chandra Basin region, western Himalaya, India, Geosci. Front., 8(4), 841–850. Wagnon et al. 2009. Four years of mass balance on Chhota Shigri Glacier, Himachal Pradesh, India, a new benchmark glacier in the western Himalaya, J. Glaciol., 53 (183), 603–611.

Please also note the supplement to this comment:
https://tc.copernicus.org/preprints/tc-2020-165/tc-2020-165-AC1-supplement.pdf

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