

## Response to Referee 1

R: This manuscript has been largely revised and improved based on the review comments. I have accepted the statements of authors to my review comments. I do not have any more concerning and suggestions to the manuscript. The analytical data measured in several institutions in the manuscript are high quality and reliable, because the details of analytical conditions and methods of all instruments are described. The spatial variations of the load (Table 2) and the volume-weighted mean concentrations (Table 3) of ion chemical component in the snowpack in Svalbard are quite valuable data set to research the transportation of chemical substances to Svalbard. Moreover, the phenomena of chlorine depletion and bromide enrichment are also important information to understand atmospheric conditions in Svalbard. Therefore, I believe that the quality of the manuscript is enough good for the publication as a measurement report of the ACP.

*A: Thanks for the comments. We think that your revision have improved the quality of our manuscript.*

R: Please check some parts of the manuscript before publication. Line 422. The authors used the ratio (1.17) of Cl/Na in seawater for the calculation of Cl depletion. The value of 1.17 is the mole ratio. In this manuscript, “weight units” are used for a load of chemical substances. Please confirm the calculation of the value of Cl depletion.

*A: Thanks for the comment and for this reason we clarify it adding the value (1.8 w/w) in the main manuscript. In the first paragraph of section 4.2, we used Cl-to-Na ratio as w/w while in the second part, we consider Cl depletion calculated using the formula proposed by Zhuang et al. (1999) in equivalent concentration. In the table 2, we report the value of Cl depletion, calculated using the initial concentration of Na and Cl in equivalent. I confirm our data.*

R: Please correct the valence of Na into 1 (+) in Line 113 and 523.

*A: Sorry for this terrible mistake, we corrected it.*

## Response to Referee 2

R: The manuscript is a revised version. It is a measurement report and presents new data on the spatial variability of the snowpack chemical composition across Svalbard. The authors analysed snow pit samples taken from 7 glaciers across the archipelago for major ions and stable water isotopes aiming at improving our understanding of which processes (natural and anthropogenic) influence the snowpack chemical composition and its spatial and altitudinal distribution patterns. Comparing data on the total ionic load and stable water isotope composition among all sites the authors assessed the role of short- and long-range aerosol transport for the snowpack chemical composition on Svalbard.

The revised version has substantially improved compared to the original one and should be accepted for publication after the authors have considered some minor revisions and technical corrections.

General comments:

I thank the authors for explaining why they omitted a detailed analysis of the data on layer resolution in this manuscript. Given that the authors intend to accomplish another paper that deals with the detailed layer-by-layer investigations of the Svalbard glaciers I agree to keep this manuscript as a measurement report.

By adding information about previous studies on stable water isotopes on Svalbard to the introduction there is now a better balance between both foci of the manuscript – chemical impurities and stable water isotopes. The description of the stable water isotope analysis (chapter 2.4) and why stable water isotopes are generally used in this study has also clearly improved. I now better understand the value of including the stable water isotopes into your study. However, the main weight of the paper still lies on the chemical impurities although the title might imply something different. But since the authors now clearly state in the manuscript that the stable water isotopes are used as supporting data, I think this is not a big concern anymore.

I very much appreciate the detailed description of the different glacier sites and their characteristics as this allows to assess the presented data also with respect to the site-specific differences and/or similarities.

I thank the authors for explaining why they chose a layer-specific sampling strategy and therefore a different sampling resolution at the different sites. I now better understand the advantage of this approach with respect to the aim of the study.

*A: We would like to thank the referees because they improved the quality of this manuscript with their revisions.*

### Specific comments:

R: Title: Although the title has been modified by adding the word “seasonal” I still suggest to clearly indicate that the data refers to one single accumulation season (2015-2016), i.e. to clearly indicate the timescale of the study directly in the title. This way it would be easier for the reader to directly see what to expect from the paper.

*A: As suggested by referee, we modified the title as:*

*Measurement report: Spatial variations in ionic chemistry and water stable isotopes in the snowpack on glaciers across Svalbard during the 2015-2016 snow accumulation season*

## 1. Introduction:

R: L 101: I think the citation is wrong here. It should be “West et al., 2010”. This reference has to be listed under “W” in the reference list, and not under “J” as it is done at the moment. Please change this.

A: *We agree with referee, we corrected it.*

R: L 105 What do you mean by “excellent environmental conditions”? Please rephrase or specify. I also think there is some information missing after “Greenland” such as “annual isotope cycles are well preserved...”. Please check.

A: *We agree with referee, we had to rephrase: “The preservation of un-interrupted annual isotope cycles varies depending on the site: in sites such as central Greenland annual isotope cycles are well preserved, while in sites with high intra-seasonal variation variations or with different pre- and post-depositional processes the annual layers can be difficult to distinguish (Igarashi et al. 2001).”*

R: L 108 The subject is missing before “carried out the observation...”. I guess there should be some reference added, since the next sentence starts with “These authors...”. It is unclear who you mean. Please check.

A: *Thanks for the comment because we recognized a mistake probably occurred using Endnote software. We corrected the references. In the previous sentence, the correct citation was (Pohjola et al., 2002), while the missing subject was Igarashi et al. (2001).*

R: L 99-111 Has there been any previous study of stable water isotopes in surface snow from Svalbard that is as comprehensive as yours? If not, I think it is worth to stress here that there is a lack of data regarding the stable water isotope composition of surface snow and that your survey is a substantial contribution to fill that gap. I am aware that you mention the comprehensiveness and uniqueness of the survey in the following paragraph (and also at the beginning of chapter 3.2), but I think it is worth to stress also the lack of data on stable water isotopes from Svalbard snow in the introduction. This would enhance the importance of your data in this study and for future studies.

A: *Thanks for the suggestion, and we added this suggested sentences in the introduction: “At the moment, there is a lack of data regarding the stable water isotope composition of surface snow from Svalbard and this survey is a substantial contribution to fill that gap.”*

## 2. Methods:

R: L 152-154 Rephrase to: “Even though this is the highest point in our survey, the air temperature can pass above zero during the summer resulting, although not significant, in the relocation of ions (Pohjola et al., 2002; Vega et al., 2016). “

A: *Thanks, we modified it as suggested.*

R: L 160-164 I would very much appreciate if you could add the information provided in your answers that “all snow pits have been collected from the glacier central line in order to minimise the side accumulation effect due to orography” as this is a valuable detail regarding the sampling strategy.

A: As suggested by referee, we added the sentence reported in our answers.

### 3. Results:

L 274-275 I am not sure whether I caught right what the authors want to say here as the phrasing is a bit confusing. Please rephrase to: "... since deposition can still occur before the beginning of the snow melt season."

A: Yes, the meaning of sentence is correct and we modified it as suggested.

R: L 278 What do you mean with "the other regions"? Please specify or delete "the" to make it unspecified.

A: We removed "the" to make it unspecified.

R: L 307 Stable water isotopes are shown in Table 3, not in Table 2 as indicated in the text. Please correct this.

A: Thanks, this a mistake come from the previous version of Tables. We corrected it.

R: L 316-317 For clarity please add "of all snow pits" after "mean  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values", as it was in the previous version of the manuscript.

A: We add "of all snow pits", as suggested by referee.

Actually, for AF I do not entirely agree that there is no statistical difference between the mean  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values of the different snow pits as a 2‰ difference in  $\delta^{18}\text{O}$  and 15‰ in  $\delta\text{D}$  is quite significant to me. For example, from Table 3 I can see that at ALB the differences between the different snow pits are even lower than at AF, although the altitudinal distances between the different snow pit sampling sites is comparable to those of AF. Please justify your statement. Otherwise, I think it is worth to mention that the altitudinal pattern in the stable water isotope composition of the snowpack at AF is different to the other glaciers as it was done in the previous version of the manuscript. I then suggest to add just one sentence about possible reasons for the different pattern at AF to the discussion (chapter 4.4, see comment below).

A: We agree with referee and we add a sentence to suggest a possible reason.

*"The relationship with elevation was is similar for both isotopic ratios in the collected dataset, with except AF that the isotopic signals might be influenced by additional processes since it is an isolated ice cap mainly surrounding from ocean or sea ice in winter."*

### 4. Discussion

L 454 I did not find the data from the Norwegian Meteorological Institute in the reference list. Please cite properly, e.g., cite a related publication or the webpage and last access date of the data.

A: To clarify the reference, we added the web site "<https://cryo.met.no/en/sea-ice>."

R: L 462-463 Please make a new sentence for better readability: "... on Spitsbergen or on Austfonna. The relationship with elevation is ...".

A: We did the suggested split.

R: As mentioned above, please add here that the relationship with elevation, i.e., that mean  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values decrease with altitude, is true for all glaciers except AF and discuss shortly some possible explanations, that might be also speculative, for this.

A: *As mentioned above, we added this sentence: "The relationship with elevation was is similar for both isotopic ratios in the collected dataset, with except AF that the isotopic signals might be influenced by additional processes since it is an isolated ice cap mainly surrounding from ocean or sea ice in winter."*

R: L 459 Same as before. Stable water isotopes are shown in Table 3 instead of Table 2.

A: *Sorry, we corrected it.*

R: L 486 Accumulation zones of which glaciers? All seven glaciers? Please specify.

A: *We specified "all seven glaciers"*

## 5. Conclusions

I strongly suggest to write the paragraph from L 524 to L 535 in present tense.

A: *We modified the paragraph in the present tense.*

### Technical corrections:

R: Please make also sure to use present tense when discussing your results. Change to present tense in the following sections/sentences: L 343-346, L 350, L 371-373, L 381-385, L394, L 411-413, L 431-434, L 445, L 457-459, L 462-463, L 468-471, L 482-483, L 488-492, L 498-502, L 505-507

A: *As suggested by referee, we use the present tense in all suggested sections.*

In some paragraphs the reference to the Table with the data you are discussing is missing. For clarity, please add the reference to Table 5 in the following parts: sentence in L 358-359, sentence in L 382-385, sentence in L 411-413; pleas add the reference to Table 3 in L 467-469.

A: *As suggested by referee, we added the reference to the Tables in the suggested points.*

L 86: Rephrase "summer melting" to "summer melt".

L 102 Change "snowpits" to "snowpit" (Singular).

L 103 Change "depth/time relation" to "depth-time relationship".

L 106 Change "variation" to "variations" (Plural).

L 109 Add space between "could" and "not".

L 116 Add "the" before "snowpack".

L 118 Add a verb – "is" or "was" – before "... the most comprehensive survey...".

L 134 Add space between "ice" and "cap".

L 135 A verb is missing before "... one main central dome...". Probably "has" needs to be added.

L 142 Add space between "400" and "m".

L 144 Change “thinness” to “thickness”. Rephrase to “... and a maximum of 450 m”. Add dot after the brackets.

L 150 Add “the” before “island”.

L 151 Finish the sentence after “500 m” and start a new sentence. There are also some letters mixed up. Please correct to: “The total accumulation area of the entire ...”. Change “in the beginning” to “at the beginning”.

L 172 Please rephrase to: “... and were directly filled into ...”.

L 176 Please rephrase to: “... when we compare three different areas of the same glacier...”.

L 223-224 Change to “... are reported by Barbaro et al. (2017).”

L 227 Delete “and” before “coupled to a ...”

L 246 Change “to evaluate” to “to be evaluated”.

L 259 Change “determinations” to “determination” (Singular)

L 274-275 Please rephrase to: “...can still occur before snow melt begins.”

L 309 Add “the” before “SWE of each layer...”

L 315 Rephrase to: On KVG, ALB, HDF and LF,  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  values in snow...”.

L 317 Add “on” before “AF, WB and HB there was ...”.

L 324-325 Change to “Virkkunen et al. (2007) and Vega et al. (2015a) quantified...”.

L 329 Delete the space between “is” and “wide”.

L 352 Change to “(0.32; Figure 5; Millero et al., 2008)”.

L 383 Change “correlations between the bulk loads...” to “correlations of the bulk loads ...”

L 407 Add “the” before “snowpack”.

L 413-414 There is a doubling of the reference. Change to “Whitlow et al. (1992) found an ...”.

L 416 Change “as well” to “as well as”.

L 426-427 Rephrase to: “reaching more northerly locations.”

L 440 Change to “findings of Jacobi et al. (2019) ....”.

L 471 Rephrase to “... shows that significantly different values are only obtained in snow pits ...”.

L 472 Delete one dot after “snow pots”.

L 502 Replace “suggest” by “indicate”.

L 503 Change “warm event” to “warm air event”.

L 504 Rephrase to: “On the contrary, when cold air masses (Arctic type) dominate, snowfall events are relatively limited due to the low air humidity causing a lower efficiency of wet scavenging.”

L 507-508 Delete “is” before “should”.

L 509 For better readability start a new sentence after “wet deposition” instead of separating sentences by semicolon.

L 510 Change to “mask the proposed relationship”.

L 518 Add “a” before correlation.

L 539-542 Please rephrase to: “These findings confirm that the optimal sites to study the effects of long-range pollution deposition in Svalbard are those at higher elevations, such as the accumulation zones of HDF or LF, because they are the sites least impacted by local aerosol emissions.”

L 544 Delete “there” after “chemical composition”.

L 794 (Figure 1) Rephrase to: “... except on KVG glacier where an extra snowpit was sampled within the ablation zone.”

L 814 (Figure 3) Add a dot at the end of the Figure captions.

Figure 7 In the Figure change “significativity” to “significance”.

*A: Thanks for the precise comments because they help us to improve the quality of our manuscript. We modified the manuscript, following the referee suggestions about the technical corrections.*

L 307 Change to “mean  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  values are ...”

*A: Sorry but we can not do that because the meaning is different. Here, we have to define the meaning of “the SWE-weighted mean  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ ”.*

R: L 472-475 It is not clear where the bracket at the end of the sentence starts. Please check which information should be in brackets. I also suggest to make two sentences instead of separating the different parts by semicolon.

*A: As suggested by referee, we divide the sentences in two parts as follows: “This is confirmed by the Kruskal-Wallis test, i.e. rank-based ANOVA, calculated with two groups of  $d$  values divided by the latitude threshold  $79.2^\circ\text{N}$  ( $z = 4.23$ ,  $p < 0.04$ ). In fact, drawing the latitude threshold anywhere between  $78.7$  and  $79.7^\circ\text{N}$ , a statistically significant difference with  $p < 0.05$  is obtained.”*

R: L 894 (Table 5) From the phrase “estimated based from” it is not clear to me what you want to say: “Non-sea-salt (nss) components were estimated based on seawater ratios to ...” or “Non-sea-salt (nss) components were estimated from seawater ratios to ...”? Please check.

*A: Thanks for the comment. To clarify the sentence, we modified as follows: “Non-sea-salt (nss) components were estimated based from seawater ratios:  $\text{Ca}^{2+}/\text{Na}^+$  is 0.038 while and  $\text{SO}_4^{2-}/\text{Na}^+$  is 0.252 (w/w; Millero et al., 2008).*