The reviewer 2 stated that;

the title seems to be a bit misleading as the impact of freeze-thaw processes on soil respiration fluxes is not as obvious to me in the manuscript as stated in the title. Of course, it makes sense to partition the year-round measurements into different freeze-thaw stages (and for sure, there are flux differences between the freeze and thaw stages) and also it's worth to discuss the role of freeze-thaw processes on the fluxes. However, the main driver of these fluxes is still the soil temperature, which is already widely known. If the authors want to point out the significant role of freeze-thaw processes, they should state this more clear throughout the manuscript and bring more (statistical) evidence of it's impact on the fluxes. So far, the authors have shown an increase of soil respiration in the ZC substage, which might be attributed to the freezing process. However, the amount of outgassed CO_2 during this period make up much less than 5% to the annual budget and the data points during this period seem to be really sparse. During the WC, SW and ST stage the freezing and thawing processes seem to be of minor importance to the soil respiration, even though an impact during the SW stage is discussed but evidence for this impact is missing in the manuscript. Therefore, the authors might shift the focus of the manuscript towards a model-based budget of soil respiration on an annual basis (see next paragraph) or they bring evidence on a statistical basis on the regulation of freeze and thaw processes on Rs fluxes.

The reviewer made a valid point and we acknowledge that temperature is the key controlling variable for soil respiration at a large spatio-temporal scale. However, based on the analysis of the soil temperature and soil moisture variations at the experimental site, the novel approach in this paper was to divide the freeze-thaw process of the active layer into four stages: summer thawing stage (ST), autumn freezing stage (AF), winter cooling stage (WC), and spring warming stage (SW). The characteristics of heat transportation and moisture migration at each stage were different from each other (Figure 1 and A).

It is well known that the biggest characteristic of the freeze-thaw process of active layer is its complex variations in soil temperature and moisture. And different patterns in the changes in soil temperature and moisture at different freeze-thaw stages, in turn, affect soil microbial activities, aeration status, and biochemical properties, which ultimately regulates soil respiration (R_s). Our aim in this paper is to mechanistically understand this process in relatively in high resolution both spatially (depth profile) and temporally (whole year monitoring over 2 years). According to the reviewer's suggestions, we focused on the analysis of hydrothermal characteristics in different freeze-thaw phases and the R_s variations due to the soil temperature and moisture changes during the different freeze-thaw stages throughout the manuscript. We supplemented data on hydrothermal changes in the different freeze-thaw stages and their impacts on the R_s. The WC, SW and ST stages during the freezing and thawing process also substantially influenced the R_s, which we discussed further in detail.

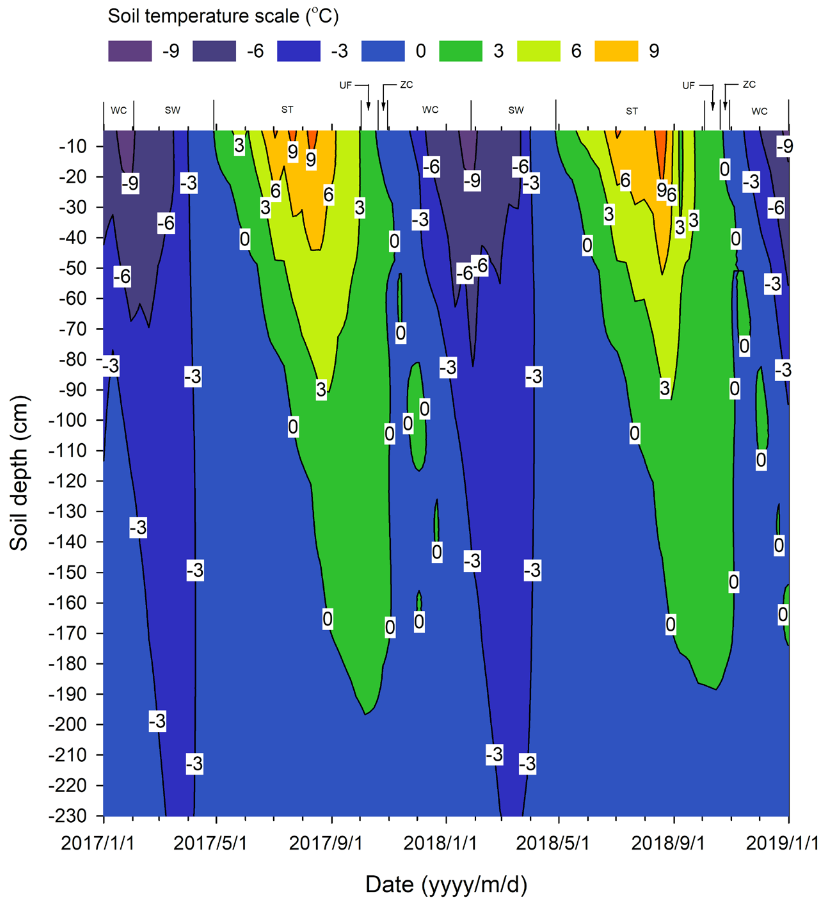

Figure 1. Soil temperature contour outlines of the experimental site in 2017 and 2018

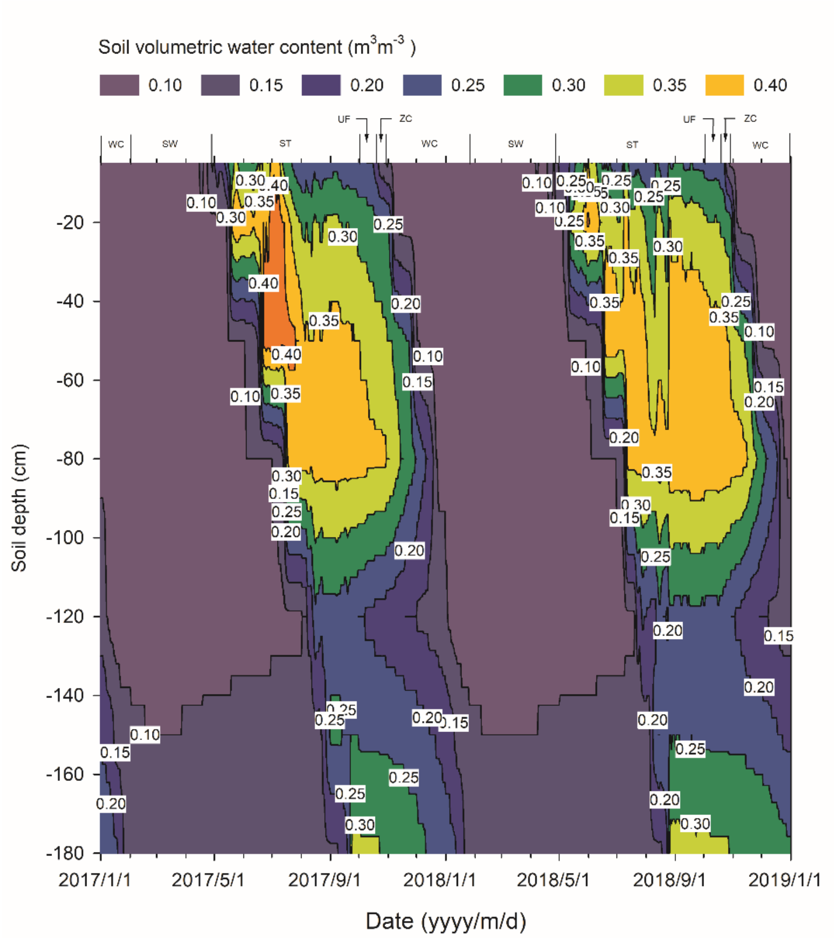

Figure A. Soil moisture contour outlines of the experimental site in 2017 and 2018

The flux data-set is impressive, especially as it is really difficult to conduct these chamber-based measurements during winter-time and regularly over a two-year period. Can the authors state something about similar data-sets in such areas (alpine, permafrost-affected)? Especially the winter-time soil respiration fluxes would be of interest to the reader here. How high/low are these fluxes compared to other regions and why? Aren't there other soil respiration fluxes from such areas from this pedon-scale? Then the authors should point out this uniqueness of the data-set as the winter-time Rs fluxes make up about 30% of the annual fluxes. A modeling of the Rs fluxes has been done, but from the text it remains unclear which model is used to calculate the budget (model from equation 1 or interpolation of average Rs flux rate (described at line 170)) and where the (modeled?) fluxes shown in figure 4 come from. However, to calculate an annual budget, an interpolation of average Rs fluxes seems to be not sufficient, while temperature-based respiration models are widely used to calculate flux budgets. Furthermore, the interannual-variability of the Rs fluxes between the two years might be worth to look at. Are there differences in the budgets and if so, why (e.g. it seems like the Rs fluxes from the SW stage are significantly higher in the second year)?

We appreciate the reviewer's comment on the difficulties in winter sampling. A similar report would probably be found in Zhang et al. (2015) which appeared in European Journal of Soil Biology. They measured the non-growing season soil CO_2 flux and calculated its contribution to annual soil CO_2 emissions in an alpine meadow ecosystem in the Fenghuoshan region of the Qinghai-Tibet Plateau. According to their study, the cumulative non-growing season soil CO_2

emission was 228-358gCO_2/m^2, accounting for 25-36% of annual emissions. Similarly, Wang et al. (2014, Global Biogeochemical Cycles) determined the non-growing-season soil respiration of an alpine grassland in the Haibei region of the Qinghai-Tibet Plateau and found the cumulative R_s was 82–89 g C m^{-2}, accounting for 11.8–13.2% of the annual total R_s. Not in an alpine ecosystem, but long time ago, Oechel et al. (1997) reported that non-growing season R_s accounted for 30-81% of the annual soil CO_2 emissions in Arctic soils. The cumulative non-growing season R_s and its contribution to annual total emissions in our study site were higher compared with those of Zhang et al. and Wang et al., but was close to the results of Oechel et al. These variations in different sites may be the results of microenvironment factors such as active layer depth, soil properties, durations of freeze-thaw processes, vegetation types, and other reasons such as different methods of CO_2 flux measurement.

To clarify the method for the calculation of the budget of R_s emissions we included additional description. In short, based on the R_s flux rate determined on the sampling days and those obtained by interpolating the R_s flux rate between the sampling dates in the different freeze-thaw stages, in combination with the average daily soil temperatures from the continuous records of the active layer observation site, we fitted the sensitivity of soil CO_2 flux at the different freeze-thaw stages of the active layer. According to the fitted R_s equations and the soil temperatures during the start-stop-time of the different freeze-thaw stages, the cumulative soil CO_2 emission of the different freeze-thaw stage and its contribution to the annual total soil CO_2 emission were calculated. In the Figure 4, the R_s fluxes were derived from the fitted R_s equations (Table 2) at the different freeze-thaw stages. According to the reviewer's suggestions, we revised the manuscript and made clear how to calculated the soil CO_2 emission budget.

In this paper, our main purpose was to elucidate R_s dynamics at different freeze-thaw stages and how much of the cumulative R_s emission at each freeze-thaw stage may contribute to the annual total CO_2 emissions during a complete freeze-thaw process. The inter-annual variation is of interest to us as well, but it is hard to make any conclusions based on 2 year's data only. Definitely, this warrants further investigation with longer-term field measurements.

Some more information on soil and vegetation composition of the chamber set-up would be helpful to the reader (especially when the fluxes are compared to those from other regions). What soils are generally found in this area? Are they organic-rich/poor? What is the active layer depth? How deep are the main rooting zones of the vascular plants? If the roots mainly reach e.g. about 20cm into the soil, the insertion depth of the PVC collar might be too low as lateral roots still reach into the chamber collar and may alter the measured respiration flux. Furthermore, the closure time of the chamber is of interest. Where they similar during winter and summer-time? If the plants inside the collars were removed just one day before the measurements started, there might be some artefacts due to this disturbance (Diaz-Pines et al., 2010) that need to be taken into account. In general, a critical review of the clipping method should get more attention and it should be stated why this method was applied instead of other less disturbing methods (Subke et al., 2006). Furthermore, the reader needs to know something about the flux calculation procedure? Was a linear or an exponential model used to calculate the fluxes? Based on which quality criteria (check Görres et al., 2014)?

Many thanks to the reviewer for his/her valuable suggestions. We added detailed information

about soil and vegetation composition of the chamber set-up. The supplemented context is as follows: "The soil types in the study site are primarily classified as MatticGelic Cambisols (alpine meadow soil) in Chinese taxonomy or as Cambisols in FAO/UNESCO taxonomy (Wang et al., 2014a). The mean annual temperature is -3.60 °C, which is colder than that of other areas in the QTP (Yin et al., 2017). The mean annual precipitation is 423.79 mm, 80% of which falls as rain, sometimes mixed with small hails during the growing season (from May to September). In winter, little snow falls but is quickly blown away and sublimated off due to high wind and low air temperature, so the study site is rarely covered by snow. The air pressure is approximately 550 hPa. The alpine meadow represents the most common vegetation type in this area (70%) (Wang and Wu, 2013;Zhang et al., 2015b). The alpine meadow ecosystem mainly consists of cold meso-perennial herbs that grow in conditions where a moderate amount of water is available. The ecosystem's vegetation mainly consists of *Kobresia pygmaea* (C. B. Clarke), *Kobresia humilis* (C. A. Meyer ex Trautvetter) *Sergievskaja*, *Kobresia capillifolia* (Decaisne) (C. B. Clarke), *Kobresia myosuroides* (Villars) Fiori, *Kobresia graminifolia* (C. B. Clarke), *Carex atrofusca Schkuhr subsp.* (minor (Boott) T. Koyama), and *Carex scabriostris* (Kukenthal) (Chen et al., 2017). By on-site surveying and sampling of the experiment set-up, the soil bulk density, soil organic carbon, and total N content at the 10-20cm depth were higher than those at the 0-10cm depth. The active layer depth was about 1.9m. The belowground biomasses were much greater than those of aboveground. Usually, the depth of the vegetation main rooting zone was around 10 cm. (Table A)."

Table A Biomass and soil properties at the experiment set-up

Item	Depth (cm)	Values
Bulk density (g cm^{-3})	0–10	0.89 ± 0.2
	10–20	0.98 ± 0.1
Soil organic C (kg m^{-2})	0–10	0.48 ± 0.06
	10–20	1.32 ± 0.04
Soil total N (g m^{-2})	0–10	41.3 ± 7.2
	10–20	117.6 ± 12.8
Above-ground biomass (kg m^{-2})		0.33 ± 0.04
Below-ground biomass (kg m^{-2})		2.41 ± 0.4
Depth of vegetation main rooting zone (cm)		10±3
Active layer depth (m)		1.90±0.2

Values are means (n = 5) ± standard deviation (SD)

Photo: Depth of the vegetation main rooting zone was about 10cm at the experimental site

Throughout the field measurements, we adopted the recommended settings by the LI-COR to determine the soil respiration flux during the winter and summer time. A typical measurement protocol was applied: Obs. Length: 2 mins, Dead band: 25 seconds, Pre-purge: 30 seconds, Post-purge: 45 seconds, Chamber Volume: automated, IRGA volume/total volume: automated. Chamber offset of the program was adjusted to 2 cm.

We did take into account the impact of vegetation clipping on soil respiration. To minimize the disturbance, we installed the collars one month prior to the experiment and left all the collars permanently inserted into the soil. In addition, after the above-plant was clipped and left undisturbed for more than 24 hours, we just began to measure the soil respiration. This "resting time" allowed the removal of any excess CO_2 released by roots disturbed during above-plant removed.

In our experiment, we used the LI-8100A Automated Soil Gas Flux System to determine the soil respiration (CO_2 flux). According to the principle of determining CO_2 flux by the instrument, the water-corrected mass CO_2 fluxes and descriptive statistics were automatically provided by the LI-8100 File Viewer Version 3.1.0. For each chamber measurement, the flux

was either calculated with a linear or an empirical exponential regression. The software compared for each measurement the normalized sums of the squares of the residuals of the linear and the exponential fit to find the best-fitting model (Figure B).

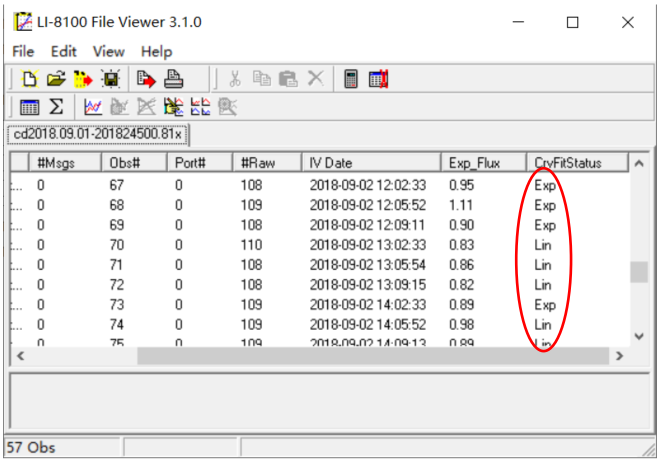

Figure B. Best-fitting linear or the exponential model chosen automatically by the software after comparing for each measurement the normalized sums of the squares of the residuals.

Based on the CO_2 flux datasets acquired by the instrument, the field environmental conditions, and the absence of dramatic changes in air temperature and humidity during each chamber measurement, we mainly adopted the following quality control criteria to discard potentially erroneous fluxes: (1) negative fluxes, which indicates substantial leakage; (2) fluxes with squares of the residuals of the linear fit greater than 1ppm CO_2.

Two tables are missing in the manuscript. As they seem to contain a lot of information on flux details, they may already answer some of the question that are stated in this review.

The reviewer made a valid point. We made a mistake in the original submission and included them in the revised manuscript. The two tables are as follows:

Table 1. The start-stop-time and duration of different freeze-thaw stages of the active layer

Stage		start-stop time (yyyy/mm/dd)	time of length (days)
ST		2017/4/29-2017/10/2	157
AF	UF	2017/10/3-2017/10/22	20
	ZC	2017/10/23-2017/10/30	8
WC		2017/10/31-2018/1/30	92
SW		2018/1/31-2018/4/29	89

Table 2. The R_s model, Q_{10} value and *SR* in different freeze-thaw stages

Stages		R_s model	Q_{10}	*SR* (gCO_2/m^2)
ST		$R_s = 1.04e^{0.08T}$ R^2=0.69	2.22	1041.85
AF	UF	$R_s = 1.15e^{0.061T}$ R^2=0.55	1.84	89.97
	ZC	$R_s = 2.14e^{0.087T}$ R^2=0.90	2.38	60.57

WC	$R_s = 2.14e^{0.159T}$ R^2=0.80	4.90	310.69
SW	$R_s = 0.73e^{0.053T}$ R^2=0.61	1.7	189.90

Other minor comments:

In the abstract some abbreviations are used without an introduction, which needs to be changed.
To clarify this, and we spelled out the words and the corresponding abbreviations of the different freeze-thaw stages (Please see the responses to reviewer 1's comments).

Line 40: At least one citation is needed here.
We agree to the point and add new citations in this sentence as follows: Furthermore, many studies have shown that the winter-time emissions contribute significantly to the annual CO_2 balances (Natali et al., 2019; Webb et al., 2016; Michaelson and Ping, 2003).

Line 114: To compare the fluxes from this region with other regions it would be good to say something about the soils (carbon contents, C/N, etc) beside a detailed vegetation description.
The reviewer made a valid point and we included detailed information about soil and vegetation composition of the chamber set-up as mentioned above and made a corresponding revision in the manuscript.

Line 119: What about the soil moisture probes at different depths? Why were they inserted as in the end just the SWC at 5cm was used?
The purpose we inserted soil moisture probes at different depths was to determine the changes in soil moistures at different depths during the freezing and thawing process of the active layer and to analyze the relationship the R_s and the soil moisture. However, our statistical analysis found that only the soil moisture at 5cm depth showed a weak correlation with the R_s with low R^2 value. As such, only SWC at 5cm was used in the following analysis.

Line 144: Are there no differences in vegetation cover, soils, etc. so that one measurement plot in the six 5x5m measurement plots can serve as replicates? If not, there might be a chance of discussing other impacts such as carbon content, vegetation cover and more on the Rs fluxes. Anyway, a detailed description of soils and vegetation is needed here.
The aim of this experiment was to explore how the freeze-thaw process of the active layer regulated the R_s dynamics. Based on the results of ground penetrating radar (GPR) scanning on our study experimental site, the geological condition was found to be relatively uniform. Thus the freeze-thaw process of the active layer would be similar around our experimental site. Due to limitation in the logistics in the field, we only set one active layer observation site with multiple soil temperature and moisture probes to observe the freeze-thaw processes.

We acknowledge that heterogeneity of environmental conditions such as soil chemistry, vegetation types, surface cover, and plant biomass would affect the R_s. To minimize the error from such spatial heterogeneity, we set up six subplots for measuring the R_s around the experimental site for observing the freeze-thaw process of the active layer. The measurements of R_s from the six subplots could represent the overall level of soil respiration in the study area.

Line 148: What have the authors done with re-growth of plants during the measurement period. For sure, there have been some.
Before each measurement, we clipped off the re-growth of plants in collars.

Line 159: Unfortunately, it remains unclear which model was used for calculating the contributions of Rs from each freeze-thaw stage to the annual budget. This must be stated clearly. So far it reads, that the resulting fluxes from equ.1 were used to describe the dependency of Rs on T, while for the budget calculation interpolated average fluxes were used. If a model exist, why interpolated averages were used then? May it would make more sense to use a temperature-based model and, as Q10 was also used in the manuscript and it is shown that there are differences between the different stages, to also include Q10 into a model (e.g. Eckhardt et al., 2019).
The reviewer made a valid point. To clarify this, we revised the manuscript accordingly. In short, based on R_s flux rate determined on the sampling days and those obtained by interpolating the R_s flux rate between the sampling dates in the different freeze-thaw stages, in combination with the average daily soil temperatures from the continuous records of the active layer observation site, we fitted the sensitivity of soil CO_2 flux at the different freeze-thaw stages of the active layer. According to the fitted R_s equations and the soil temperatures during the start-stop-time of the different freeze-thaw stages, the cumulative soil CO_2 emission of the different freeze-thaw stage and its contribution to the annual total soil CO_2 emission were calculated. In the Figure 4, the R_s fluxes were derived from the fitted R_s equations at the different freeze-thaw stages.

Line 179: ANOVA is described here but not referred to later in the text.
The reviewer made a valid point and we refer the ANOVA results in the text.

Line 228: Yes, there are freezing and thawing processes in the active layer, but the suggestion that they strongly regulate the Rs fluxes seem to be a bit speculative as the authors don't bring any evidence here (again, some statistics would be helpful), that there is a regulation of Rs fluxes by these processes (and should therefore be part of the discussion and not of the results). The only argument is that the freeze-thaw processes are taking place at the same time when the Rs fluxes are starting to rise (which might be simply due to rising temperature).
We acknowledge that temperature may be dominant controlling variable for soil respiration all year round. However, our temperature and moisture data in different stages indicate more complicated reactions in active layer. Probably, temperature would be the main driving force at regional or global scale, but the spatial scale we focused on here could be different. The nature of the freeze-thaw process in the active layer was the changes in soil temperature and moisture caused by the energy exchange between the ground and the atmosphere. The variations in soil temperature and moisture at the different freeze-thaw stages changed the biogeochemical process in the soil, which in turn affected the migration and transformation of soil organic carbon and the CO_2 release strength. So, the R_s showed different dynamics in the different freeze-thaw stages of the active layer. For example, we can see clearly from Figures 1 and 2 that R_s in ST stage and that in WC stage are same but soil temperatures are unidentical, suggesting that freezing-thaw stages play an important role in determining R_s in addition to temperature only.
We revised the sentence as follows: At the Beiluhe experimental site, R_s flux changed as the freeze-thaw processes of active layer developed, showing different dynamics in the different

freeze-thaw stages of the active layer (Figure 2).

Line 308: Can the autotrophic respiration act as reason for the differences in Q10 here? Due to the clipping of the vegetation in the chamber plots, there shouldn't be any, right?
We agree to the point. Although the grow of above biomass is minimal in winter, roots may active to add autotrophic respiration. As such R_s flux reported here contains autotrophic respiration of roots, which could be another reason for different Q_{10} value. We discuss this possibility in the revised manuscript.

Line 375: As there is no clear evidence for a regulation of the Rs fluxes, the authors should be more carefully use the term 'significantly' to describe this relationship (or refer to ANOVA?). For sure, there are significant differences between the Rs fluxes from the different freeze and thaw stages, but are they really driven by the actual freezing and thawing processes or just driven by different soil temperatures of the stages?
We agree to the point. In the manuscript, 'significant' was used in conjunction with the results of ANOVA test where P value is smaller than 0.05. We added the comparison of soil moisture to make it clearer. The essential of the freeze-thaw of the active layer was the changes in soil temperature and moisture. During the different freeze-thaw stages, changes in soil temperature simultaneously caused a phase change in soil moisture. Thus, the significant differences between the R_s fluxes from the different freeze-thaw stages were driven by the freeze-thaw processes of the active layer.

Figure 1: Additionally, the authors should include the freeze and thaw stages in the graph
We replotted Figure 1 to add freeze and thaw stages in it.

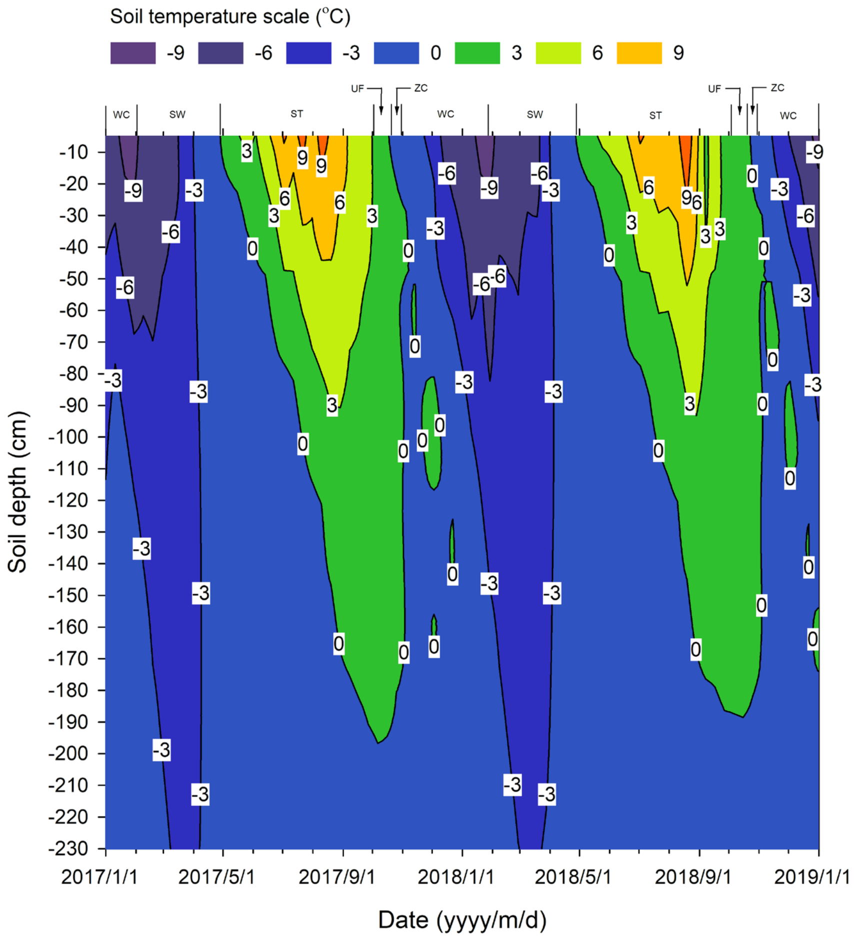

Figure 1. Soil temperature contour outlines of the experimental site in 2017 and 2018

Figure 2: The authors should use a consistent date string (compared to figure 1). Furthermore, drawed lines in the graph would give a better readability to see which Rs fluxes belong to which stage.

We agree to the point, and changed the date string in Figure 2, so that it is consistent with that in Figure 1. In addition, auxiliary lines were added in the Figure 2 to clearly illustrate the R_s in different freeze-thaw stages.

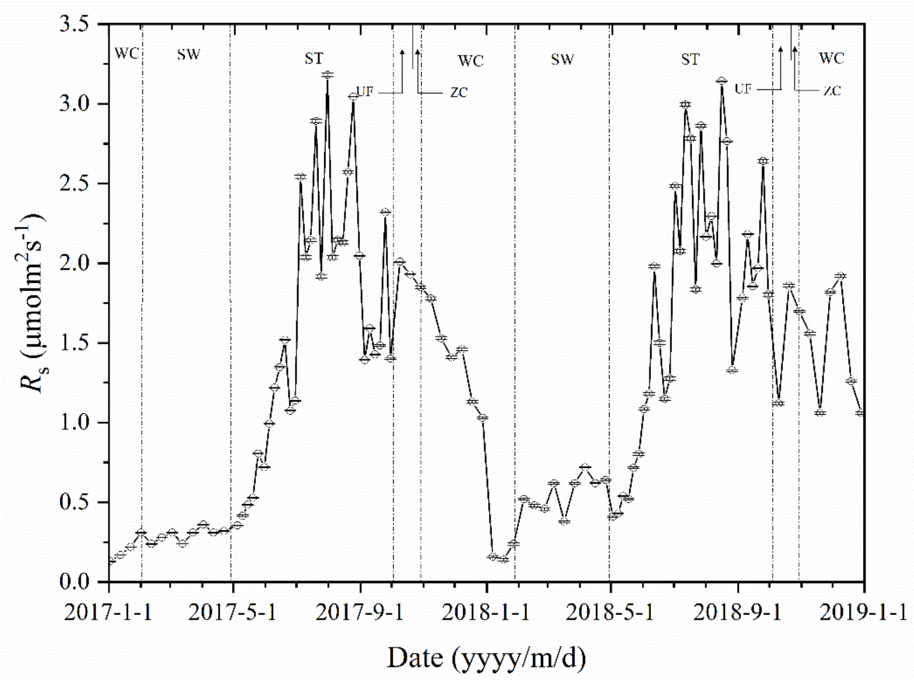

Figure 2. Variations of R_s flux at different freeze-thaw stages in years of 2017 and 2018. Error bars show standard error (n=6)

Figure 3: Which year are those flux contributions from? Why not for both years? May a mean value would be better practice?

We calculated the cumulative R_s emissions of the different freeze-thaw stages (ST, AF, WC and SW) basing on their start-stop dates and their corresponding contribution rates to the total R_s emission of a complete freeze-thaw cycle from April 29, 2017 to April 29, 2018. Therefore, Figure 3 represented the contribution rates of the cumulative R_s emission at the different freeze-thaw stages in a complete freeze-thaw cycle from April 29, 2017 to April 29, 2018.

In this study, the main aim was to discuss the influences of the freeze-thaw process on the R_s dynamics at the different freeze-thaw stages and their contribution rates to total R_s emission in a complete freeze-thaw cycle. The experimental duration, January 2017 to December 2018, contained a complete freeze-thaw cycle from April 29, 2017 to April 29, 2018, spanning two years of 2017 and 2018. As such, we didn't calculate R_s flux contributions by year.

Figure 4: From which model are these Rs fluxes shown here? Are the SWC values relevant (if so, why aren't they included in a model?; if not, why are they shown?)?

In the Figure 4, the R_s fluxes were derived from the fitted R_s equations (Table 2) at the different freeze-thaw stages. In Figure 4, our purpose was to discuss the effects of soil temperature and soil water content on R_s in each freeze-thaw stage. The soil moisture did have effect on the R_s in each freeze-thaw stage, and the correlation between R_s fluxes and SWC values was weak (R^2=0.02~0.21). Therefore, we prepared a figure with the general trends of R_s, soil temperature and soil moisture at 5cm depth of each freeze-thaw stage and analyzed the variations in R_s flux influenced by the soil temperature and SWC.