Anonymous Referee #1
Referees comments (RC) in grey. Our reply (AC) in black.

Dear Referee,

Thank you for considering out data useful and for constructive comments and helpful suggestions.

RC: In summary, the data seem technically sound and worthy of publication. But the authors first need to put in considerable effort to improving the text and tightening the arguments.

We have put substantial effort in improving the language. Especially the discussion chapter has major changes in order to clarify the arguments.

RC: Stages 1 through 3 appear to have been introduced in an earlier paper. They are discussed throughout the paper, but then only defined in section 5.2. Why not bring these stages up and define them in the introduction, so readers know the characteristics of each stage from the outset.

AC: We have added the following to the end of the 2nd paragraph in the Introduction: Stage 1 is characterized by a moderate surface lowering in the upper part of the glacier and is followed by a relative thickening further downglacier in stage 2. Stage 3 corresponds to the period of well-known surge characteristics.

Note that Sund et al. 2009 only addressed elevation changes during these stages. This contribution also supplies velocities, which are treated in the discussion.

RC: In the discussion, it seems something is found in common with multiple surge mechanisms, which in the past have been treated as distinct. While this may be the case, a careful, logically consistent argument is lacking on top of the overall poor writing.

We have restructured parts of the discussion. Among other:

Sect. 5.2 and 5.3 are restructured, and the arguments tightened, in order to provide a more logical sequence:

5.2 Mass transfer and velocities during surge (stages 1-3)

The regions experiencing the initial lowering on Zawadzkibreen and Polakkbreen (Figs. 3b and 5b) are the same as where the greatest accumulation was observed (Fig. 3a and 5a). Similar behaviour was observed on Kroppbreen, Svalbard (Sund et al., 2009). On Zawadzkibreen the onset of surface lowering in the upper part, was accompanied by increased velocities. Progressive velocity and geometry changes diverging from a normal flow regime were also reported from the upper part of Variegated Glacier (Raymond and Harrison, 1988) and West Fork Glacier, Alaska (Harrison et al, 1994). Yet, on Zawadzkibreen the transition from a quiescent to a more active phase was more distinct. The fact that mass in the accumulation area is removed faster than it is gained, implies that velocities have risen above balance velocities in this area. Hence ice flux was larger than balance flux, as is defined for surge state. Comparison between Fig. 4a and Fig. 4b shows that by 2003 an initial downglacier thickening, which formed a diffuse surge front at ~9 km, had already occurred also in the trunk of Zawadzkibreen. We propose that also in polythermal glaciers the surges are initiated well up in the temperate area and that the downglacier propagation is an effect of a chain reaction.

We suggest the following course for the NGS surge development, spanning over several years. An overview of the progress of events is shown in figure 10. Areas gaining the largest amount of mass during quiescence will reach enhanced gravitational forcing prior to the surrounding areas. In stage 1 this results in locally increased velocity in areas with temperate bed conditions followed by a relative increase in frictional heat at the bed that generates more subglacial melt water (Fowler et al., 2001). Basically at this stage, we anticipate the englacial water storage to be relatively similar to that present during quiescence. Still, some crevasses may also open at this or a later stage, allowing more water to penetrate to the bed and reinforce the process. The somewhat higher amount of water available at the bed influences the basal motion (e.g. Iken, 1981; Bartholomaus et al., 2008). A surge nucleus is formed and an initial drawdown occurs and areas immediately downglacier, where velocities has not yet risen, gain more inflow of ice. In stage 2 the local temporary increase in ice thickness in a new area, influenced also by higher levels of subglacial meltwater as well as release of englacially stored water from further upglacier, leads to an amplification of the process. The increased ice flow in additional areas may open new crevasses, further enhancing the water flow into the glacier. The above outlined process continues and expands over an increasing area. A positive feedback effect is induced and the initial surge nucleus propagates downglacier (Budd, 1975; McMeeking and Johnson, 1986). The effect of the frictional heat will be most important when sliding and basal drag are intermediate (Raymond, 2000). A blockage of the subglacial drainage system and change to a distributed drainage system (Robin and Weertman, 1973; Kamb, 1987; Eisen et al., 2005) caused by compression between the increasingly activated and the not yet activated ice masses, enables the surge nucleus to grow. Superimposed (on this) are the seasonal variations where the summer drainage system contracts in autumn and trap water which is eventually released (e.g. Lingle and Fatland, 2003). Water storage in Svalbard glaciers is among other found in Scott Turnerbreen, Svalbard that surged ~1936 (Hodgkins, 1997) and Tillbergfonna, where sublacial water was trapped near the terminus (Hagen, 1987). Towards the end of stage2 or early in stage 3 large amounts of englacial water is released, as described by Lingle and Fatland (2003), At this stage, in addition to sliding, fast flow could arise also from deformation of saturated subglacial sediments which can accommodate an inefficient drainage system (Clarke et al., 1984; Murray et al., 2000; Harrison and Post, 2003).

5.3 Glacier surface expressions

Formation of a bulge at the thermal border between temperate and cold ice is known from other glaciers, e.g. Trapridge Glacier, Canada (Clarke et al., 1984). On Zawadzkibreen a visible bulge formed in stage 2 (Fig. 3c) when the activated upglacier surge nucleus reached what we interpreted to be a thermal dam. At this stage the situation has its equivalent with the time of the study of Bakaninbreen, Svalbard (Murray et al., 1998). No clearly visible bulge appeared on Polakkbreen or Nathorstbreen. We relate the lack of bulge in some branches to difference in individual glacier properties such as thermal regime. We suggest that the rate of downglacier thickening here is governed by the temperature conditions of the downglacier ice as well as differences in sliding conditions.

Zawadzkibreen probably had substantial cold margins or large areas of cold basal ice, while Ljosfonn – Nathorstbreen was only moderately affected by a cold bed and had a faster propagation of increased velocities (although still moderate) and less surface elevation changes as also suggested by Murray et al. (2003a). The termini of such glaciers may slowly start to advance or experience increased calving rates. The radio echo soundings along the centre line of Nathorstbreen by Dowdeswell et al. (1984) (Figs. 1 and 9) indicated ice thicknesses up to 400 m and an up to 200 m thick cold surface layer in the lowermost 18 km, from the terminus position before the surge.

In previous studies upglacier propagation of velocities and crevasses has been related to upglacier propagation of the surge (e.g. Meier and Post, 1969; Hodgkins and Dowdeswell, 1994; Murray et al., 2003b; Pritchard et al., 2005). We suggest a different interpretation here. Our results show that in stage 3, when upglacier propagation of crevasses occurred, the mass displacement and surge had progressed downglacier for several years. Areas with ice thickness increases and compressive flow during stage 2, subsequently experience surface lowering and extended flow as the surge propagates further downglacier during stage 3. At this stage glacier velocity has reached the highest levels during surge development, leading to a rapid extension of the upglacier ice. Yet, the pattern of upglacier propagation will also depend on the individual geometric and thermal properties of the glaciers. Hence the upglacier propagation of velocities does not represent an upglacier propagation of the surge from the initiation area, but a re-action in the last stage of the ice displacement.

Meier and Post (1969) reported that surges in tributary glaciers could trigger surges in the main trunk glacier. We argue that this only occurs if the main trunk is in stage 1 or 2 and is thus “ripe to surge”. When the Dobrowolskibreen surge propagated to the terminus, it possibly “released” the joint terminus of NGS from its frozen northern lateral margin. This did not occur when Skobreen, Svalbard surged into the main trunk glacier Paulabreen. The latter was not influenced upglacier (Sund, 2006). Just prior to the Skobreen surge, no mass displacement took place in (upper) Paulabreen, while it had already been through a partial surge c. 30 year before. Another example is Ingerbreen’s surge into the confluence Richardsbreen, Svalbard. It affected the joint front, but did not release any surge in the upper part of the latter (Sund et al., 2009). Medvezhiy Glacier, Pamirs was reported to have surged before the calculated critical mass was achieved when the damming ice disappeared (Osipova and Tsvekov, 1991). The results in this study also show that glaciers in a system may influence each other by muting the magnitude of the surge due to damming effects, but can also enhance the force of the surge if their late quiescence and early surge stage coincide.

P18, L26 paragraph is moved further back

P19, L30: sentence is deleted.

RC: Each and every figure should be called out in sequential order (for example, after figure 1, the next figure referenced is figure 5). The out of order references to figures should be dropped, or the figure numbering redone.

AC: Figures have been reordered from 1 to 9 and one more is added, figure 10.

RC: Figure 1. A larger, higher resolution version would be helpful.

AC: The figure versions published in TCD were in higher resolution.

Figure 2 color bar says dz/dt, but that would imply thousands of meters (i.e., (90-36)years x 40 m/yr). I strongly advise merging Figures 2 and 4, it would be easier to compare them. Also would be nice to include outlines of other glaciers in the system.

Thank you for pointing out this mistake. Fig 2 and 4 colour bar annotations are revised. We have though not merged figures 2 and 4 for two reasons: Our intention is not to directly compare these two figures. In 5.3 we emphasize there are differences in surface characteristics and expressions between the individual glaciers. These are a result of variation in geometrical properties, as well as possibly thermal regime. We also suggest that Polakkbreen has gone through a partial surge during the build-up period of Zawadzkibreen. This means Polakkbreen shows an accumulation pattern that is more evened out compared to Zawadzkibreen.

We think the order treating Zawadzkibreeen with elevation changes (in fig. 2) and additional velocities in fig. 3 (New figure numbers are 3 and 4) is a more logical sequence (Polakkbreen is mentioned subsequently). Referee 2 did not request any changes to the figures. If the referee still insists, it is of course no problem to merge the two figures.
Nevertheless, we have included a SPOT image as background to figure “a” in these two figures.

RC: The figures in general could use some work. Several have small text that is hard to read. Figure 6 – Use larger font for dates (currently barely legible) and color bar.

AC: Larger fonts are applied to Fig. 2 and 6 and colour bars are also moved below figures.

RC: In addition, some kind of sketch map showing the sequence of events might really help.

AC: A sketch map been added, where we have tried to point out the main events during the development of the surge. The figure caption refers to sections in the manuscript text.

RC: I have made numerous comments where things could be fixed because they are grammatically incorrect or where a different choice of words would improve readability. In addition to these, there were numerous other places where some wordsmithing would be helpful.

AC: We are very grateful and would like to thank the referee for a detailed grammar correction of the manuscript.

The page and line numbering in our reply is according to the preliminary submitted manuscript (the TC template) as this is according to the reviewers comments.

We have generally accepted and revised all suggestions provided for textual changes. We comment a few, which are not exactly according to suggestion, here.

RC: (…) I think it is more appropriate to remove “indicating a re-action following from the already” and replace with “coinciding with” (i.e., the crevasses form when the flow is extending, not afterwards)
P1,L23-24: The advance was followed by upglacier propagation of crevasses, indicating a re-action following from the already displaced mass and extending flow.

AC: Changed to: The advance was followed by upglacier propagation of crevasses, indicating the middle and subsequently the upper part of the glaciers reacting to the mass displacement.

RC: P2,L26: Also, start sentence with “Some surges in polythermal. . .” as I don’t think a hydraulic mechanism can be ruled out for all polythermal glaciers.

AC: We agree, but here we are referring to the opinions of the references. Thus, we have kept it as a general statement “Surges in polythermal glaciers were explained by changes…”

RC: Pg20L10=11 “On Monacobreen, Svalbard more than doubled velocities were observed during winter 1991/92” -> “Elsewhere in Svalbard, Monacobreen observed velocities more than doubleding during winter 1991/2”

AC: This is now changed as it refers to velocities observed on Monacobreen (a glacier) to:
On Monacobreen, Svalbard velocities more than doubled during winter 1991/92 (Murray et al., 2003a).

RC: Pg20L16 “sudden advance of NGS starting in October” At the start of the section, it was stated that the sudden advance started in the winter (this seems more like Fall).

AC: In Svalbard autumn and spring is short (September and May-June) and from a glaciological point of view winter, indicated by a reduction in glacier velocities, often occurs already by end of August (given that weather conditions follow the normal).

<u>Comments accepted and modifications made</u>

Specific Pg1,L19 remove “s” from “glaciers” Pg1,L22 – After >5. . .. tidewater during winter. Not enough context here for it to be clear what “into tidewater” means (i.e., did it transition from a land-terminating to tidewater). Please clarify. Pg 1, several instances of c. for circa, but circa applies to time not distance (use approximately or _ except L28 where it is ok). Pg1,L23-24. Pg1L26, Might be good to add “glacier” before area. Pg 2L7 “perceptions of” instead of “on” P2L12 consider change to “10-1000 times quiescent phase velocity”. The way it is worded it could be interpreted that the surges is part of the quiescent phase. P2L13 “,” after surges. P2L16 Consider “During the quiescent-stage buildup, the glacier’s. . ..” P2L20 Consider “efficient” in place of “fast” P2L22 Replace “glaciers displaying” with “glaciers display an” P2L24 Change to “. . .also have led to. . .” P2L26 Would read better to remove “which are controlled by a thermal mechanism”. If left, then which should be changed to that.

Pg3L7 remove “the” before NGS Pg3L11try “perspectives of” rather than “perceptions on” Pg3L15 add “the” before “temporal” Pg3L17 “crevasses” -> “crevassed” Pg3L21 find an alternative for “c.” as described above. There is one on the next line too. For efficiency, I will stop calling them out, but please search and replace globally. Pg3L22 “glacier flows” or “glaciers flow”, I think the latter is meant here. Pg3L23 “they enter” not “they enters” P3L31 “in these” instead of “of these” P4L3 “has” -> “have” P4L9 add “locations of” before “maximum water depths” P5L5 remove “on the order of”, after rounding the wavelengths are all 5.6cm. P5L23 “was” not “were” (ie. ASTER is singular; alternatively could add images after ASTER and keep were). P5L29 Remove sentence with “Furthermore” and add “, which is generally directed north-south for polar satellites” Pg7L16 “output . . . is. . .” (not are) Pg7L23 “individual glacierS” PgL25 Processing . . . was. . .. Pg8L2/3 Portions. . . are exposed P8L4 “this points to” -> “indicates” Pg8l17 delete “of” before “just” Page8L24 remove “s” from “aircrafts” Pg8L26 “2009, appearing in about one third of the entire NGS. . .” unclear, only 1/3 of terminus advanced? P9L2 “was extending 8 km further” -> “extended 8 km farther” P9L13 “represent(drop s)” Pg10L5 “,” before “which” Pg10L7 “has” -> “had” Pg11L17 Sentence beginning with “Neither. . .” needs rewording. Pg11L21 “,” before “which” Pg11L19 Suggest “experienced a drawdown of” -> “thinned by” (i.e., more active voice). Similarly try “while the lowermost reaches thickened the most (_25m) ” P11L21 “,” before “which” P11L27 add “the” before “end” and before “begging” in the next line P12L9 “in situ” explain how drawdown was observed – trimlines, GPS,. . .? P12L20 “October” a new section is being started, so specify year to avoid ambiguity. P13L1, “,” before “which” P13L2 add “an” before “additional” P13L5 “frontal velocities” ??? if so be clear P15L7 “no significant amounts” of turbid water or ice mélange ??? P15L7 Insert “On” before 18 and add “a” after 2011 P15L16 There should be a brief introductory paragraph between Section 5 and subsection 5.1. P15L19 “Upper regions” unclear do you mean upper part of the catchment or upper part of the ice column. Be specific. P15L26 Be clearer and more specific about where the frozen to the bed section was. P15L27 Replace “also coincides” with “also is consistent” P15L29 replace “;” with “,” and consider tightening up the wording of this sentence. P16L4 “The ELA of Zawadzkibreen was found to be higher than the 350 m a.s.l. indicated by Hagen. . .” suggest rewording to something like “Our estimate of the Zawadzkibreen ELA is higher than the 350 m a.s.l. indicated by Hagen. . .” to make clear you are comparing your estimate. P16L7 “the” before “cirque” the rest of the sentence could use some work to make the part about lee sides follow from the cirque. P16L11 change “is” to “are” or make regions singular. P16L13 be more specific about what pattern i.e., “same pattern of accumulation” P16L14 “not” -> “non” then insert “,” before “the surface. . .” P16L19 “Comparisons” ??? of what, be more specific P16L22 “the lowering onset in the upper” this makes no sense (some words are missing). P16L24 “has” -> “had” P16L24 change to “ice flux was” (be consistent with tense) P16L31 “This resultS” P17L2 “and generating” try replacing with “that generates” P17L3 “impacts on” try replacing with “influences” P17L5 Paragraph break here doesn’t make much sense. The next line is about stange 1, then the second sentence starts with stage 2. If you want a new paragraph here, start with stage 2. P17L6 replace “at this” with “during Stage 1” P17L7 Don’t use “;” to separate stages, especially when describing with multiple sentences and across paragraphs. Make transition with something like “During Stage 2, an initial. . .” P17L8 remove “temporary” this is an evolving process, temporary is implied. Would read better if “and hence temporary increased ice . . .” was replaced with “, increasing ice. . .” P17L9 replace “short term” with “rapid” if meaning the change happens quickly (as opposed to the ice thickens, but remains thick for only a short time). P17L13 would be simpler to replace “may result in opening of” with just “may open” P17L14 get rid of “;” P17L19 It seems like some kind of sentence is required after the one on Variegated Glacier to tie this fact to the present case (i.e., were there multiple velocity increases on NGS?). Right now this sentence reads like a random fact. Pg18L12 “occur” not “occurs” P18L29 “is not representing” -> “does not represent” P18/19L1 “The characteristics only reflect a time-section of the entire surge.” What characteristics??? Be more specific. P19L5 “on how” -> “that” P19L5-15. This paragraph starts stating past observations indicate tributary surges can cause surges in the trunk. They then argue that this can only occur in stage 1 and 2. Apparently in support of this, the text then jumps to a discussion of how the trunk behavior has not caused surges in the tributary, which is the opposite of the original point about tributaries, causing trunk surges. This logical inconsistency needs to be fixed. P19L30 “We emphasize the geometrical development of NGS leading to this event”. Without being more specific, this sentence really doesn’t make any kind of relevant point. Pg20L3 “and also” -> “that” Pg20L4 “In Hornsund (Fig. 1) as well, the weather even. . .” » “At Hornsund(Fig.1), the weather event also. . .”

Pg20L15 “in consistence” -> “consistent”
Pg20L17 “row”-> “progression”
Pg20L18 “lead” -> “led” P20L20 “promoted expediting”-> “expedited”
P20L23 “points to” -> “indicates” or “suggests” P20L26 “occurring at the same time as” -> “coincident with” P20L28 add “,” before “which” Pg22L19 “row” -> “progression”