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Interactive comment on "Exceptional retreat of Novaya Zemlya's marine-terminating outlet glaciers between 2000 and 2013" *by* J. Rachel Carr et al.

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We thank Reviewer 1 for their constructive and positive comments, which we feel have improved the paper. We have addressed all of the comments and provide our responses below, along with a reiteration of the comments, for reference.

The paper describes marine-terminating glacier retreat on Novaya Zemlya (NVZ) between 1973/6 and 2015. That is, the content of the paper is much wider than its title, which rather reflects its main conclusion. This conclusion states (lines 680-682) that: "Retreat rates on marine-terminating glaciers were exceptional between 2000 and 2013, compared to previous decades. However, retreat slowed on the vast major-

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ity of ocean-terminating glaciers from 2013 onwards, and several glaciers advanced, particularly on the Barents Sea coast." In this regard my general questions are: (1) What are the intra-annual variations of glacier retreat rates on NVZ? (2) Are they comparable with the scale of deceleration observed in 2013-2015? RESPONSE: Seasonal variations are small, generally under 100 m (Carr et al., 2014). Assuming the calving season is 4 -6 months long, this would result in ∼15-25 m of frontal variation in a month, which is below the image resolution. All of our imagery for 2012 – 2015 (i.e. from the end of more rapid retreat and through the slow down) are within 1 month of each other, meaning that any changes related to seasonal variations and differences in image data will be below the image resolution and therefore would not affect the results. The deceleration in retreat in 2013-2015 ranges from 35 m -to >120m, which is greater than any seasonal effects we may have inadvertently included by having different image dates. Furthermore, we have similar (and in some cases larger) gaps between imagery during the rapid retreat (2000-2013), and do not see any re-advances or seasonal trends, only continued retreat. Finally, the slow-down / advance persists across many glaciers (with slightly different image dates) and over three years (2013-2015), making it unlikely that it simply results from capturing part of the seasonal calving cycle. (3) What are the trends and pattern in the NVZ glacier recession between 1973/6 and 2015 if evaluated not in linear measures but in area changes? RESPONSE: We are focusing on glacier recession, not area change, as stated in the paper, and this has been done in many previous publications on Novaya Zemlya and elsewhere in the Arctic (e.g. Carr et al., 2014; Howat et al., 2008; McKnabb and Hock, 2014; Moon and Joughin, 2008). It is not simply linear change, in that we use a series of different time intervals and also use the box method, to account for uneven recession of the terminus. Even if area change were included, we do not think it would show substantially different patterns, as the main area of change would be at the terminus (as it is at the lowest altitude and in contact with the ocean / lakes). The vast majority of each glacier catchment (by area) is bounded by slower moving ice, belonging to the other glaciers, and therefore is unlikely to change over time. Any such changes would be

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very difficult to detect, even with accurate DEMs and velocity data, and changes in these ice divides would be the subject for another paper. As well as the main area of continuous ice, the glaciers have narrow tongues, reaching down to the sea. Particularly on the Barents Sea coast, many of these are bounded by moraines / higher ground, meaning that any lateral changes would be limited. Where the glaciers are less constrained by topography, we would expect ice loss to reduce with elevation anyway, due to the altitudinal lapse rate, meaning that changes should be maximum at the termini. As stated above, we focus on terminus change in this paper, as previous studies have highlight its importance for driving dynamic changes, such as ice acceleration and dynamic thinning (e.g. Pritchard et al., 2009; Howat et al., 2007; Joughin et al., 2004), as well as its quick response to changes in forcing (e.g. Carr et al., 2013). In contrast, changes in area would reflect processes operating on a range of time scales, from rapid terminus response to e.g. ocean warming, through to longer-term surface mass balance change, and it would be difficult to separate these out. As such, glacier retreat, as opposed to area change, is the most appropriate measure for our study. It is highly desirable that data on the annual position of NVZ glacier fronts (presented now only in an unidentifiable form as different-color lines on Figure 5) will be available to readers as a separate tabular supplementary to the paper. The same is true for area changes if available. RESPONSE: We have added these data to the supplementary information (Supp. Tables 3-6), along with a table detailing the glacier ID, Randolph Glacier Inventory ID and name, where available (Supp. Table 1). Area changes are not available. Specific comments. line 57-58: Statement that ": : :the pattern of frontal position changes on NVZ prior to 1992 is uncertain and previous results indicate different trends: : :" seems to be to strong one, as all previous results indicate recession (Shumsky 1946, Chizov et al 1968, Koryakin 2013). RESPONSE: As referenced in the text, Zeeberg and Forman (2001) showed that half the glaciers on north Novaya Zemlya were stable between 1964 and 1993, so not all previous studies indicate recession. We have added the papers referenced here. line 90: It is not clear - does SER glacier belong to Sub 1 or to Northern ice mass? RESPONSE: It belongs to the

northern ice mass. However, it does not matter for the paper, as it is surge type, so excluded from the assessment of glacier response to climate (Line 122). line 90: Total number of glaciers should be checked as data in the Table 1 (above the line 949) shows different number(s) - by terminus type: 32+6+15 = 53 and by ice mass: 43+4+5 = 52. RESPONSE: Corrected. The numbers in the table were updated. line 118: ": : :The northern island also has two smaller ice caps, Sub 1 and Sub 2: : :" - There are not real ice caps but better say ice fields (or compound glacier systems). RESPONSE: Agreed. We now use the term 'ice field' or 'ice mass' throughout. line 139: "Due to the lack of Landsat imagery during the 1990s: : :" contradicts with line 130 which states that data were available annually ...between 1985 and 1998. RESPONSE: Line 130 should say 'between 1985 and 1989'. This has been corrected. line 163: E.K. Fedorova but not E.K. Fedrova. Im. is an abbreviation from Russian word "imeni" which means "named after". To avoid ambiguity it seems better to indicate (here and everywhere in the text) the weather stations by WMO ID (20744 and 20946), as another weather station also named after E.K.Fedorov (WMO ID 20292) is located in other arctic place - on Cape Chelyuskin. RESPONSE: IM. Was removed. We have added the WMO ID's here as suggested, but continue to use the names throughout the text, as readers unfamiliar with the numbers may otherwise need to keep referring back. Adding the WMO IDs here removes the ambiguity about the other, similarly named station. WMO IDs have also been added to the captions for Fig. 1 & 4, and to Supp Table 1, for clarity. line 169: Please, specify the data gaps on the Station Fedorova RSM00020946. RESPONSE: Seasonal averages were only calculated where data were available for all months and, by extension, annual averages were only calculated where all months of the year were available. This has been added (Line: 186). It would become very long-winded to specify every data gap in the text, so we have added the meteorological data as Supplementary Table 2, so that those who are interested can see the gaps. lines 315-318: As shown by (Koryakin 2013) for NVZ glaciers there is some relation of retreat with their altitude. Also considering only the linear change of glaciers does not give full picture of their fluctuations. Analysis of area change of glaciers might reveal different aspects

in fluctuation pattern/behavior/environmental control. RESPONSE: Here we focus on latitude and catchment area, as opposed to altitude, as we are looking at changes at the glacier termini. Most of the glaciers are marine-terminating, and therefore terminate at sea level, so this would not help us to assess controls on retreat patterns. We agree that looking at the overall change does not necessarily give a full picture of their fluctuations. However, this is assessed later in the paper, via the change point analysis and by presenting the time series for each glacier. The aim here was to see if latitude controlled overall retreat rate and our results show this was not the case. Similarly, our data show large variability in retreat rates at a range of time steps (e.g. Figs. 4 & 5), which also does not appear to relate to latitude. We do not think that looking at area would substantially effect the results, as outlined above. Line 591-592: Observed reduction in retreat rates might be result from increased ice velocities. RESPONSE: This is a possibility. However, with available data it is not possible to determine whether increased ice velocities are a response to rapid retreat, or whether reduced retreat is due to more rapid delivery of ice to the calving front. In either case, our point here is that the changes relate to the dynamics of the outlet glaciers, rather than upstream changes in the surface mass balance. Data on surface elevation change and ice velocities are also needed to understand the short-term dynamic behaviour of these outlet glaciers. However, this goes beyond the scope of this paper, and would be another paper in itself. We have added a sentence to this effect at Line 621. line 963: Strictly speaking the Northern ice cap is located to the north from INO. According the Russian nomenclature the Northern ice cap indicated on map is the Ice cap of Northern Island. RESPONSE: Thank you, we did not know this. In the text, we have stated that the name is 'ice cap of the northern island' (Line 89), but that we refer to it as the 'northern island ice cap' for brevity. We have updated the maps and figures accordingly. line 973: it is not clear does the length of box "necks" mean something or not? Also there is no box at Fig 2B for Kara L. Is it right? RESPONSE: We are not entirely sure what is meant here, but as stated in the caption, the red line is the mean and the blue lines are the upper and lower quartiles, meaning that the length between the two blues lines is the inter-quartile

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Discussion paper

range. If the reviewer is referring to the differences in the width of the red line between the different sub-plots, this is simply because there are four categories in B, compared to three categories in A & C, so the bars need to be narrower to fit on the plot. For Kara L, this was incorrect and due to some trailing zeros in the data. It has been corrected. Thanks for highlighting this. line 1003: Figure 5 is very interesting and most important, but its informativity is severely affected, since it is impossible to correspond the lines of different colors with specific glaciers (their names, or some other indicators, for example, RGI ID). RESPONSE: See above. line 1018: Thick black line is not specified in the caption of Figure 7. RESPONSE: Corrected Technical corrections. line 163 (and everywhere through the text): “Fedrova” should be “Fedorova”. RESPONSE: Corrected line 172 (and everywhere through the text, tables, figure captions, including text in supplementary file and title label placed on Supplementary Figure 1 B): “850 m” should be “850 mb”. RESPONSE: The units should be hPa and this has been corrected throughout. line 374: “+0.8 âŮęC” should be “+0.8âŮęC” (no space required). RESPONSE: No, following conventions for SI units, there should be a space between the numeric value and the unit. E.g. See http://ukma.org.uk/docs/ukma-style-guide.pdf. line 381: “7 %” should be “7%” (no space required). RESPONSE: See above. line 437: “SRE” should be “SER”. RESPONSE: Corrected line 992: title label at fig. 4C “Air Temperature: “Malaya Karmakuly” should be “Air Temperature: Malye Karmakuly”. RESPONSE: Corrected line 1031: “1981” should be “1980” RESPONSE: Corrected line 1032: “1991” should be “1990”. RESPONSE: Corrected line 1036: label at vertical axes Fig. 10A “Relative frontal position (km)” should be “Relative frontal position (m)”. RESPONSE: Corrected

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