Author comment RC2

Review: Rapid mass loss and climate-driven dynamics of the Juvfonne ice patch, Norway (2010 2025), Andreassen et al, 2026

General comments

This manuscript informs the reader about the ongoing decline in the areal extent and volume of the Juvfonne ice patch in the mountain massif Jotunheimen, Southern Norway. The authors have carefully mapped the outlines of this (currently) ~0.1 km^2 ice patch from year to year, using differential GNSS, drone photography and aerial imagery. Changes in surface elevation have been monitored using lidar surveys and UAV surveys and ice thickness variations have been determined using data from GPR surveys. Moreover, the authors report on an extensive mass balance program on Juvfonne, carried out in 2010-2025. The climatology of the Juvfonna area has been assessed from weather station data, allowing estimates of the importance of snowdrift for the winter balance as well as estimates of key factors and processes governing snow and ice melt on Juvfonne.

All in all, the manuscript describes an impressive suite of observations on this vanishing ice patch and the Juvfonne results are presented in the general context of glacier changes in the Jotunheimen massif. The results are informative and mostly well worked out, with the exception of small mistakes in simple calculations presented in the text. In addition, more detailed information concerning the mass-balance measurements should be given (or referred to, if such results from Juvfonne have been published elsewhere). See comments on this below. The authors also need to address several points concerning the English language of the paper.

Given that these suggestions for improvements are taken into account, the paper should be published in *The Cryosphere*. The disappearance of Juvfonne and several other small glaciers in Norway is not only interesting in the context of global warming impacts on mountain glaciers, but also has important implications for archaeological studies of artefacts appearing at retreating glacier margins, often dating from pre-historic times.

Response: We thank the reviewer for the positive and helpful comments to our paper. In the following we give a point-by-point response in blue italic.

***Other changes:** In addition to addressing the reviewers' comments as detailed below, we conducted a new UAV survey on 13 August 2026. This allowed us to incorporate the latest 2026 field observations into the revised manuscript. Consequently, we have updated the following figures and associated text:*

- *Figure 4: Updated with the 2026 orthophoto (replacing 2025).*
- *Figure 5: Updated with the 2026 ice patch extent and area calculation.*
- *Figure 6: Updated elevation change maps for the periods 2023–2026 and 2011–2026 (replacing 2023–2025 and 2011–2025).*
- *Figure 7b: Added the 2025 orthophoto as a background layer for improved visual context.*

The original figures can be viewed for comparison in the published preprint (egusphere-2026-3152.pdf).

Specific comments

L27 show => shows *Response: Done*

L33-34 "Juvfonne prevails due to drifting snow and is controlled by topography and can fill up after years with surface lowering."

This sentence needs polishing, explain how it is "controlled by topography" and what is meant by stating that Juvfonne can "fill up". *Response: we have modified this sentence 'Juvfonne is sustained by topographically controlled snow drift and can replenish after years of surface lowering.*

L35 with a few warm summers => within a few warm summers (or: during a few warm summers) *Response: We have rewritten this to 'Most of its remaining ice may vanish within a few warm summers.'*

L37 Glaciers come in a wide range... => Glaciers exist within a wide range…
Response: We changed from 'come' to 'occur'.

L41 and have a self-regulating mechanism allowing them to survive => where a self-regulation mechanism allows them to survive
Response: Changed to 'where a self-regulating mechanism enables their survival-

L44 They normally have no or very limited movement => They normally display no or very limited movement *Response: Done*

L46 with numerous signs from hunting and travelling => indicating past signs of hunting and travelling *Response: Reviewer 1 also commented on this sentence. we changed to 'providing extensive evidence of past hunting and travelling*'

L49 or the Ötzi man => or the iceman Ötzi *Response: Done*

L52 ...Norway's average temperature will rise most in winter...=> ...the temperature increase in Norway will be greatest in winter… *Response: Thank you. Corrected.*

L69 To discuss Juvfonne´s behaviour within regional trends... => To discuss the changes Juvfonne has been undergoing in the context of regional trends… *Response: We changed to 'To assess Juvfonne's changes in the context of regional trends by comparing its elevation and area changes with those of neighbouring glaciers.'*

L75-77...at the Galdhøpiggen summer ski centre on the glacier Vesljuvbrean with the Juvvasshøe and Juvflye meteorological stations (Fig. 1a)... Suggest change to:

...at the Galdhøpiggen summer ski centre on the glacier Vesljuvbrean. The automatic weather stations at Juvvasshøe and Juvflye are both located <1 km from Juvfonna (Fig. 1a). *Response: we slightly revised this sentence. 'The ice patch is located near Galdhøpiggvegen, Norway's highest road, which reaches ~1850 m a.s.l. at the Galdhøpiggen Summer Ski Centre on Vesljuvbrean Glacier and is situated close to the Juvvasshøe and Juvflye meteorological stations (Fig. 1a).'*

L78 an area of 0.086 km2 and altitudinal range from 1852 to 1985 m a.s.l.=> an area of 0.086 km^2 with an altitudinal range between 1852 and 1985 m a.s.l.
Response: we changed it to 'ranges in elevation'

L79-80...at its little ice age (LIA) maximum and had a maximum thickness of 17-19 m in 2009...=>

...at its Little Ice Age (LIA) maximum and a maximum thickness of 17-19 m in 2009… *Response: Done*

L89 and then a second one in 2012 was excavated => and then a second one was excavated in 2012
Response: Done

L113-114 in spring 2010 and comprises winter balance measurements in 25-71 points,

=> in spring 2010, comprising winter balance measurements at 25-71 points,
Response: We change 'in' to 'at'

L115 a glacier-wide mass balance => the glacier-wide mass balance
Response: Done

L116 Winter accumulation and balance measurements => Winter accumulation and winter balance measurements *Response: Done*

L117 "Snow depth is measured by probing to the previous summer surface."

How accurately can the observers determine if they are probing the previous summer surface? Do they not sometimes encounter ice layers above the summer surface, formed during warm autumn spells? Please clarify. *Response: yes, this can happen. We have added reference to Kjøllmoen et al (2025) that we elsewhere refer to also in this section and also added the sentence 'Uncertainties in the point measurements are probing to the summer surface (probe may penetrate the summer surface layer or stop at layers above the summer surface and recording or reading may be incorrect) and errors in the snow density and stake measurements (Andreassen et al., 2018).'*

L119"Snow density is determined from a pit near the stake (Fig. 1a)..."

The authors are asked to take the following points into consideration and/or give references to publications where these issues have been addressed:

What is the vertical resolution of the density measurements? Is the density measured all the way down to the previous summer surface at S2 each year? What are the typical values of mean density of the annual layer? How is it justified to use density values from a single point to calculate SWE at all points on Juvfonne? What is the typical depth of the winter layer at stake 2?

Response: See point above, we now also here refer to our standard publication Glaciological investigations in Norway (e.g. Kjøllmoen et al, 2025) and give reference to Andreassen et al (2018) where uncertainties in the glaciological programme are given for 10 glaciers in Norway.

What kind of ablation stakes are placed in the glacier? Is it ensured that these do not melt into the ice during summer? *Response: We use aluminum stakes and refer to Andreassen et al (2018) for these uncertainties although we do not go into detail on uncertainties in glaciological mass balance measurements in this paper. Uncertainties in mass balance programmes can be a paper on its own.*

The Getis-Ord Gi* method should be described for the general reader, as well as the term: False discovery rate corrections. *Response: Text has been added at the end of chapter 3.1 and the first chapter of 4.5 has been rewritten. The false discovery rate has been deleted (relates to the implementation of Getis-Ord i ArcGIS.*

L151

with the 2016 survey suffering from some doming and have lower accuracy.

=> with the 2016 survey suffering from some doming and believed to have lower accuracy.

Response: This sentence was removed as we conducted a new survey in August 2026 and new text has been added. Our revised 2016 DSM was computed using the TimeSIFT method (Feurer and Vinatier, 2018 : https://hal.science/hal-01919788v1) based on a new 2026 survey with a footprint similar to the 2016 imagery, and is now free of the obvious doming. STD on off-glacier terrain (which we would refrain from calling stable given the permafrost degradation in the area) is 16cm. Since we

have a new 2026 DTM and orthophoto we have included results for 2011-2026, 2023-2026 instead of 2011-2025 and 2023-2025. The manuscript has been updated with recalculated results for periods 2011-2016 and 2016-2019.using the revised 2016 DTM revealing only minor changes in dH over the ice patch (within 10-15 cm for the 5 and 3 year periods).

except for Kjelen and Juvfonne that were digitised orthophotos acquired on 26 August 2019....

=>

except for Kjelen and Juvfonne, for which digitised orthophotos acquired on 26 August 2019 were used… *Response: Changed to except for Kjelen and Juvfonne, whose outlines were digitised from orthophotos acquired on 26 August 2019 (see Table 1 for details).*

L178

To assess uncertainty... => To assess uncertainty in ice thickness measurements…

Response: we changed to 'To assess uncertainty in the ice-thickness measurements,'

L188

Juvvasshøe (1894 m a.s.l.) is a full meteorological station...

=> (perhaps more appropriate to write):

Juvvasshøe (1894 m a.s.l.) is a meteorological station situated within the elevation range of Juvfonne and complete with instruments measuring air temperature, humidity, air pressure, wind speed and direction, and incoming and outgoing shortwave and longwave radiation…

Response: Thank you for this suggestion. We agree that replacing "full meteorological station" with an explicit specification of the measured parameters and its elevation context improves the clarity and precision of the description. We have updated the sentence accordingly: "Juvvasshøe (1894 m a.s.l.) is a meteorological station situated within the elevation range of Juvfonne, equipped with instruments measuring air temperature, relative humidity, air pressure, wind speed and direction, as well as incoming and outgoing shortwave and longwave radiation."

L190 exposed in all directions => exposed from all directions (perhaps better)
Response: Thank you for the suggestion. We agree that this phrasing is more natural and have updated the text to "exposed from all directions".

L232 Maybe state in the beginning of this paragraph that 2009-2010 was the first glaciological year covered by mass balance measurements (instead of mentioning this in line 235).
Response: This sentence is now removed as suggested by reviewer 1 as this was already mentioned earlier.

L241-242 (caption, Fig. 3)

"Point mass balance at stake 2 at Juvfonne 2010-2025 and the mean, given as winter balance (bw), summer balance (bs) and annual balance (ba)."

No mean value seems to be indicated in the figure! Please clarify. *Response: the mean ws given after 2025. See x-axis.*

L244 The title of this section and much of the discussion in the paragraph on P10 seems to indicate fluctuations in the ice patch itself, whereas it seems clear from the text and Figs. 4 and 5 that it is remaining winter snow at the margins that is responsible for increased size of the "ice patch" in, say, the years 2016 and 2017. The text should convey more clearly the information that the ice mass itself is not expanding in those years.
Response: we removed glacier and added snow and ice to make it clearer. Note that in the methods section we write that 'Measurements represent the outermost continuous boundary of snow or ice.' so this already mentioned in the methods section.

L272

reveals => reveal *Response: We changed it to Differencing of the lidar- and UAV-derived DTMs reveals changes...*

L280-281

Two sentences that say the same thing! One of them should be removed.
Response: we of course agree to not have two sentences saying the same thing. However, we now changed the figure to show 2023-2026 and this effect is removed. We rewrote this part and refer to both 2023-2025 and 2023-2026.

L283

based on the combined 2011 and 2025 extent => based on the difference between the DEMs from these two years *Response: we added over the period 2011-2026 and rewrote slightly to make it clearer.*

L290 - caption for Fig. 6

Maybe state that the man-made tunnel is located on the eastern side of the ice patch and is indicated with a (skewed) rectangle. *Response: Thanks for this suggestion. We added text and a T in panel (c) and we also added a reference to Fig. 2. where T is shown.*

L295

...maximum thickness of 8.3 m located in... => maximum thickness of 8.3 m at a location in…
Response: Done

L301-302

"Based on a current (2025) volume of 20 m^3 and an estimated volume of 73 m^3 in 2011, Juvfonne has lost approximately 73% of its volume in this period."

The volume figures are really strange and the authors probably meant to write $2*10^5$ m^3 and $7.3*10^5$ m^3. This must be corrected, and the area and thickness figures used in each case should be given as well. *Response: Indeed the volume is 0.20 km3 and 0.71 km3. We are sorry about this error and have corrected it and added more details on the calculations. The estimated volume loss in % is the same.*

L305 - caption for Fig. 7

It is hard to locate a "star pattern in grey" on the figures.
Response: We have tried to improve the color difference and also added the 2025 orthophoto in the background of the interpolated map (b).

L311

The maximum snow depth was measured in 2020 with 5.78 m.

=>

The maximum snow depth value was 5.78 m, measured in 2020 at a location...[state the location, f.ex. relative to stake 2.] *Response: Added 'at ~1920 m a.s.l. ~180 m west of stake 2 close to the margin'.*

L311-312

"The snow depths minimum and maximum are similar to the bw measured at stake 2."

This is a strange sentence. The winter balance (bw) is calculated from the snow depth and the (mean) density at the same location. The authors probably mean to say that the min and max values of snow depth are comparable to those obtained at stake 2, or what? Please clarify!
Response: Agreed that this was difficult to understand, we took out the sentence as we here focus on the snow patterns.

L318

We did not include the two last years of record, 2024 and 2025, where snow was redistributed

=>

We did not include the two last years of record, 2024 and 2025, in which snow was redistributed
Response: Changed to 'during which snow was artificially redistributed'

L321-322

Explain the results presented in Figure 8 and the relationship to the data presented in Figure S3. Is a "Hot Spot" simply a point where high snow depth is obtained and "Cold Spot" a location with low snow depth? *Response: As response to this comments and several comments by reviewer 1, we have added text both in methods and results to clarify. including here 'The Getis-Ord Gi* method was used to identify clusters of high values (Hot Spots) and low values (Cold Spots). '*

L336-337

"Before 7 February the air mass at Juvfonne was warm and humid with a high sea level air pressure."

This is a bit of an overstatement, unless "before" refers only to the brief warm spell on 6 February.
Response: That is a good and true observation. Here we meant to refer to the period from 5 Feb. until the morning of 7 Feb., which is warmer than 4 Feb. and during the cold front passage. However, these temperatures are indeed not warm. Considering that this sentence causes confusion and only has a tiny contribution in describing the situation before the cold front passage, which is the important feature and still clearly identifiable from the pressure, wind and temperature, we find it is best to completely remove the two sentences: "Before 7 February the air mass at Juvfonne was warm and humid with a high sea level air pressure. The peak in air temperature and relative humidity on 6 February is probably caused by warming due to insolation."

L340

There is a short period of one day with cold and humid conditions

=> There is a short period of approximately 24 hours with cold and humid conditions
Response: Good idea. We have incorporated your suggestion, since it represents the uncertainty in the duration of the cold air between the two fronts well.

L344

Figure 10 caption - state that the data are from the Juvvasshøe weather station. *Response: Thank you for pointing this out. We have updated the caption of Figure 10 to explicitly state that the data were recorded at the Juvvasshøe weather station.*

L354

there is a clear connection between wind speed and direction to snow accumulation.

=>

wind speed and direction correlate well with the amount of snow accumulation. *Response: We appreciate the reviewer's suggestion and have considered it carefully. However, we would prefer to retain "connection" rather than "correlation" in this instance. Because no formal correlation analysis was conducted, and given that wind direction represents circular data (0° = 360°) requiring specialized circular-linear statistical tests, using the word "correlate" could be misleading to the reader. The wind roses (Fig. 10) are intended to visualize the observational shift in wind patterns across snow accumulation categories, rather than to quantify a formal statistical correlation..*

L359-360

"Most likely, erosion due to blowing snow is the key reason why the overall snowfall values are low."

This presumably refers to the snowfall values recorded at the station Juvvasshøe - the authors surely do not want to imply low values of snowfall at Juvfonne. Please amend the sentence accordingly.
Response: Thank you for pointing this out and allowing us to clarify. The sentence refers to the continuous snow depth measurements from the automated sensor (SR50A) located outside (but nearby) the ice patch, rather than Juvvasshøe or Juvfonne itself. Due to wind scouring in the open terrain, this off-patch sensor records relatively low snow accumulation (typically 70-140 cm), whereas snow transport and deposition onto Juvfonne yield 3 to 6 times higher accumulation at the ice patch. This information was already included in different parts of the manuscript. But to clarify we have revised the sentence to explicitly specify the off-patch sensor: "Most likely, wind erosion of blowing snow at the nearby off-patch snow depth sensor is the key reason why the recorded snow accumulation values there are low compared to Juvonne."

L386-387

"By this time, Juvfonne typically reaches its annual minimum extent (Fig. 5), and the surrounding terrain has the least snow cover."

This sentence is not very precise, it makes it sound like the size of the patch of glacial ice varies seasonally. But normally that is not the case for an ice mass that has been steadily declining in size. - But it is true that the combined extent of ice and surviving snow cover is normally at a minimum in September. *Response: The point here is the minimum snow cover, we thus changed to 'By this time, both Juvfonne typically reaches its annual minimum extent (Fig. 5), and the surrounding terrain has the least snow cover.'*

L393

The annual variations in air temperature is illustrated... => The annual variations in air temperature are illustrated...*Response: Done*

L398-399

"The comparison of two decades (2001– 2010 vs. 2011– 2020) reveals an approximate 1.5% increase in CPDD values, predominantly in late spring and early autumn."

Does this mean that CPDD values are 1.5% higher during 2011–2020, as compared to 2001–2010 ?
Response: Yes, that is correct. We have adjusted the text to describe that change more clearly: "The comparison of two decades reveals an approximate 1.5% increase in CPDD values, predominantly in late spring and early autumn, from 2001-2010 to 2011-2020."

L399-400

"The correlation (coefficient of determination) with point mass balance bs and ba at stake 2 are -0.56 (0.32) and -0.41 (0.17), respectively."

Unclear formulation, state clearly that the first of the two figures is r and the one in parentheses r^2.
Response: Thank you and we agree. With these additions of r and r^2 after their description and writing "r=-0.56 (r^2=0.32) and r=-0.41 (r^2=0.17)" instead of "-0.56 (0.32) and -0.41 (0.17)" this should be clear.

L409

the exhibits a consistent positive trend => the SMPI exhibits a consistent positive trend *Response: Thank you. As also noted by Reviewer 1, we have corrected this typo in the revised manuscript to read:*

"Over this 16-year observation period, the index exhibits a consistent positive trend (p = 0.086)."

L432

we assessed the repeat lidar surveys => we investigated the repeat lidar surveys

L493

"Storbreen reduced from 0.0154 km^2 to 0.0985 km^2 (82%) and Lendbreen from 0.429 to 0.175 km^2 (145%)."

Careful here. The figures given for Storbreen indicate an increase in size by 540% ! Thus the first figure should probably be 0.154 km^2 and the decrease in that case amounts to 36% (not 82%).
Response: Thanks for catching these errors. Storbreen reduced from 0.154 km2 to 0.085 km2 which is 45% which is now corrected

The decrease of Lendbreen is ((0.429-0.175)/0.429)*100 = 59% (not 145%) - it is more appropriate to calculate area change relative to the original size than to the final size
Response: Agreed and corrected.

L509 - caption for table 1

Galhøpiggen => Galdhøpiggen *Response: Done*

Check figures in the table - the dA figure for Kjelen (31.8%) is wrong, should be 33%.*Response: this is due to rounding, the values using three decimals are 0.145 and 0..099 and thus 31.8%. We have updated the table with three digits and rounded numbers to three decimals to avoid hidden details.*

L522-523

"... but we cannot determine any trend over Juvfonne over the observation period."

Trend in what? Summer snowfall occurrences (cf. L521) ? Please specify what is meant here.
Response: Thank you for pointing out this ambiguity. We were referring specifically to the frequency/occurrence of summer snowfall events (which temporarily reset albedo and interrupt ablation). While individual summer snowfalls clearly mitigate melting (e.g., as reflected in the albedo time series from Juvvasshøe), the strong interannual variability across the observation period (e.g., 2018 with only one event vs. 2020 with multiple events) prevents the detection of a statistically significant trend in their occurrence.

We have clarified the sentence in the revised manuscript as follows: "While data from Juvvasshøe demonstrate the protective impact of individual summer snowfall events (Fig. S11), we cannot detect any statistically significant trend in the frequency of summer snowfalls over the observation period due to high interannual variability."

L552-553 According to this definition it is not required to have present flow to be a glacier.

=> According to this definition flow at present time is not a necessary condition for an ice mass to be classified as a glacier. *Response: We changed to 'According to this definition, an ice mass need not be flowing at present to be classified as a glacier.'*

L570 during all the Holocene => during the entire Holocene period *Response: corrected*

L571 and serving as a key stabilizing factor. => serving as a key stabilizing factor. *Response: corrected*

L573 "particularly when accounting for three-dimensional effects."

What is meant here by "three-dimensional effects" ?
Response: We removed this statement as it did not make sense here. Thanks for pointing it out.

L602

with an estimated reduction of 73% of the ice patch between 2011 and 2025.

=> nwith an estimated reduction of 73% of the ice patch volume between 2011 and 2025.
Response: Done

L612 snow removal. (cf. Dyrrdal et al., 2025). => snow removal (cf. Dyrrdal et al., 2025).
Response: Done

L662 will be submitted to WGMS. => will be submitted to the World Glacier Monitoring Service (WGMS). *Response: Done*