Following advice from referee #1, we have revised the manuscript to clarify the limitations of our study with regard to snowmelt and the rationale behind selecting the ERA5 dataset. The cluster names have been modified, specifications on the Hydroclimatic Atlas of Southern Quebec have been added, and Figure 2 has been modified. Kindly see our responses to referees #2 and #3 for details on other modifications applied to the text.

Detailed responses to comments by anonymous referee #1 are given below, with the reviewer's comment in black and our response in blue. Quoted text from the revised manuscript is given in italics. The line and page numbers in the responses refer to the original version of the manuscript.

egusphere-2025-6192

Assessing the contribution of extratropical cyclones to river floods that caused property damage in Quebec, Canada

Responses to Anonymous Referee #1

Title: Assessing the contribution of extratropical cyclones to river floods that caused property damage in Quebec, Canada

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Overview: This paper describes as assessment of the contribution of extra-tropical cyclones (ETCs) that contributed to floods and insured damages across populated watersheds of Quebec, Canada during 1991-2020. The study makes use of various datasets including ETC storm tracks, European Centre for Medium-Range Weather Forecasts reanalysis (ERA5) precipitation data, streamflow data generated by the Hydrotel model, and provincial insurance claims for damages related to flood events. Over the 30-year study period, three-quarters of all floods occurred during spring with 72.7% being associated with the passage of ETCs in proximity of the flooded waterways. Storms originating from the Gulf of Mexico and central United States were particularly damaging with lesser impacts from ETCs originating elsewhere in North America. This effort suggests that ETCs play a central role in flooding within highly populated watersheds of Quebec particularly during spring in concurrence with snowmelt freshets.

The paper is well-written with clear figures illustrating key findings from the analyses. The following report provides guidance for some revisions that would improve the paper.

1. General Comments:

1.1 The Hydrotel model is applied to generate streamflow simulation to assess 2-year recurrence flood values across the watersheds of interest, many of which are ungauged. Many waterways in Quebec are regulated by hydropower infrastructure and as such it is unclear how Hydrotel implements regulation within its model structure to accurately simulate flood patterns in regulated waterways. Are there differences in the impacts of ETCs to floods and damage reports in regulated vs. unregulated waterways?

Thank you for your relevant remark. Data on the regulated river sections in Quebec are excluded from the publicly available Hydroclimatic Atlas of Southern Quebec reconstituted river outputs, and thus none were used in the study. This important information was not explicitly mentioned in the paper and should be added. Here is the proposed revised text (changes shown in bold):

- p. 6, lines 108–110: *These time series of retrospective daily streamflow estimates are available from 1970 to 2024* ***and do not include regulated river sections (Government of Quebec and Ouranos, 2022).*** *They focus on a region of southern Quebec spanning approximately 640,000 km^2 and located between 45–53°N and 57–80°W (see Figure 1 in Lachance-Cloutier et al., 2017).*

1.2 It is unclear why the ECWMF fifth generation reanalysis (ERA5) at the relatively coarse of resolution of 0.25° × 25° was selected for total precipitation and snowfall data instead of its land surface product, ERA5-Land, available at the finer resolution of 0.10° × 0.10°. Given the relatively small size of many watersheds of interest and the high spatial variability of the precipitation field, applying the ERA5-Land product would likely produce higher accuracy results.

Thanks for your comment. The use of the ERA5 reanalysis (Hersbach et al., 2020, 2025) rather than the ERA5-Land product (Muñoz-Sabater et al., 2021), is motivated by consistency with the dataset employed for the identification and tracking of extratropical cyclones (i.e., the NAEC Catalogue). In addition, hourly precipitation fields from ERA5-Land, provided on a regular 0.1° × 0.1° latitude-longitude grid, are derived through bilinear interpolation of the corresponding ERA5 precipitation fields. As such, they do not provide substantial added value for the purposes of this analysis.

To make this motivation clearer, we propose to add the following sentence at the end of Sect. 2.5:

- p. 7, lines 153–156: *Storms in the catalogue are identified through a MSLP local minimum, and must have a maximum vorticity (a measure of the spin of air particles, indicative of a region of convergence when positive) greater than 10^{-5} s^{-1} within a 200 km radius of the local minimum (Chen et al., 2022a; 2022b).* ***The ERA5 dataset was chosen as the source of precipitation data (as described in Sect. 2.4) due to its consistency with the NAEC Catalogue.***

1.3 It is stated on p. 16: "The majority of these flood ETCs were identified in spring, primarily due to the increased number of flood events during this season due to the contribution of snowmelt, as well as the longer search periods (averaging 24.0 days in spring, compared to 8.1, 6.8, and 6.6 days in summer, fall, and winter, respectively)." This would suggest that a dominant generating mechanism for floods in the study area is spring snowmelt exacerbated by precipitation ETCs. Was there an effort made to assess the relative contribution of direct rainfall vs. snowmelt to the floods experienced across Quebec from 1991 to 2020 ?

Thank you for your comment. We recognize that snow plays an important role in spring flooding in the region of interest, but the relative contribution of snowmelt was not analysed in this study as it falls outside its scope (as was mentioned in lines 93–94, 479–481, and 572–575). Since we did not evaluate the contribution of snowmelt in the study, we propose to revise section 4.3.1 as follows:

- p. 16, lines 330–332: *The majority of these flood ETCs were identified in spring,* ***a period prone to flooding due to snowmelt runoff – it should be recalled that this process is not taken into account in our analysis.***

We believe it is also important to remind the reader of this limitation at the beginning of the conclusion. We propose the following changes:

- p. 26, lines 540–542: *Although summer exhibited more extreme values, the lowest average ETC contribution (61.8 %) occurred in spring. This is hypothesized to reflect the additional contribution of snowmelt to flooding during this season,* ***although snowmelt itself was not explicitly assessed in this study.***

Perhaps the passage of an ETC at this time only coincides with the rapid onset of snowmelt, yielding only a modest contribution of the passing storm (if any) to the flood event.

We agree with the reviewer that when no ETC accumulated more than the designated threshold for rainfall during the search period for a flood event, no flood-ETC was identified. Therefore, an ETC cannot be labeled as a flood ETC if only snowmelt occurred. In fact, as stated in section 4.3.1 (p. 16, lines 333-336), 11.9 % (2,096) of all financial aid claims were not associated with an ETC. Most of these cases occurred in spring, where 17 events cumulating 1,973 claims were not associated with a flood ETC. We hypothesize that for these cases, snowmelt played a more important role, although further research (beyond the scope of this article) would be needed to confirm this.

1.4 Furthermore, as the principal mechanism for flood generation in most watersheds of southern Quebec is the spring freshet, perhaps the role of ETCs is under-stated in terms of their impacts to floods. ETCs during winter mostly deliver snowfall that accumulates in the seasonal snowpack. If snow accumulation is unusually high due to a succession of multiple ETCs during winter and then melts rapidly, one transient ETC during the spring freshet may only exacerbate the flooding.

Thank you for your comment. As mentioned above, this study focused on the direct effect of the ETC-associated precipitation to flooding, and it did not consider explicitly the snowmelt and prior ETC-related snow accumulation (as stated in section 5.1, p. 24 lines 479–481). We are aware that ETCs that bring significant amounts of snowfall can have a delayed impact on flooding that is difficult to evaluate. Here is the revised text:

- p. 3, lines 93–94: *Furthermore,* ***this analysis does not consider the impact of soil moisture and snowmelt runoff on the onset of flooding, even though these factors are known to influence it. We are also not concerned with the contribution of ETCs to snow accumulation on the ground, which can contribute to flooding when it melts. The focus is on the direct effect of ETC-related rainfall on flooding.***
- p. 24, line 481 (adding a sentence at the end of the paragraph): ***Another important aspect to consider is that the study did not evaluate the impact of ETCs bringing significant amounts of snowfall in the winter to flood events, since the delay between the precipitation and subsequent flooding can be several months.***

2. Specific / Technical Comments:

2.1 p 1, line 18: Spell out "US" and replace the ampersand with "and" here and elsewhere in the text when referring to regions of interest.

In the cluster names, the "&" was replaced throughout the text with an n-dash "–" between the regions, and "US" replaced with "United States", such that the following names are used:

- Western Canada–Pacific Ocean
- Ontario–Hudson Bay
- Quebec–Maritimes
- Central United States–Gulf of Mexico
- United States East Coast–Caribbean

Keeping the n-dash allows to compare two clusters in a same sentence without having confusion as to which areas belong to the same cluster, see following example from p. 19 (changes shown in bold):

- p. 19, lines 384–386: *The increased proportion of flood ETCs originated from the* ***Central United States–Gulf of Mexico*** *cluster (50.5 %), whereas the decreased proportions came from the* ***Western Canada–Pacific Ocean*** *(7.0 %), and* ***Quebec–Maritimes*** *(4.5 %) clusters.*

2.2 p 2, line 56: Revise to "traveled" for consistency with use elsewhere in the paper.

Yes, done.

2.3 p 2, lines 59-60: Should this be "Ottawa River basin" or the province of Ontario?

Yes, thank you for noticing this mistake, we are referring to the Ottawa River basin, the change has been made.

2.4 p 3, lines 90-91: "data" usually is considered a plural noun, please revise verbs to "provide", "allow" and "depend".

Yes, done.

2.5 p 6, line 129: There is also a large concentration of Quebec's population in the Gatineau area along the Ottawa River.

Yes, here is the revised text:

- *Consequently, in Quebec, the available data are concentrated in the southern part of the province, along the Saint Lawrence* ***and Ottawa rivers, as well as*** *Lac Saint-Jean, where most of the population lives.*

2.6 p 7, line 137: Write as "The watershed delineations".

Done, thank you.

2.7 p 7, line 143: Spell out "ECMWF" and "ERA5".

Yes, the full spelling of ECMWF should have been used on line 143, and the acronym on lines 152–153. The following changes have been made:

- p. 7, line 143: *Precipitation data were taken from the* ***European Centre for Medium-Range Weather Forecasts*** *(ECMWF)* ***reanalysis version 5 (ERA5)*** *(Hersbach et al., 2020, 2025).*
- p. 7, lines 152–153: *The algorithm used for storm detection is applied to the* ***ERA5 dataset*** *(Hersbach et al., 2025) that has a horizontal grid spacing of 0.25° × 0.25°.*

2.8 p 7, line 152: Here, "ECMWF" is spelled out but this should be shifted to line 143 instead, and henceforth "ECMWF" used in the text.

Yes, please see our answer to comment 2.7.

2.9 p 8, Figure 1: The legend above panel a) refers to the "BSQ domain" yet the figure caption does not describe which area this is.

This comment seems to refer to Figure 2. Yes, *"Passage of a storm inside the BSQ domain"* was mentioned above panel (a), yet is not described in the figure and instead should have read ***"Passage of a storm within the 1,000-km radius around the flood location"*** (described in panel (b)). Here is the revised Figure 2:

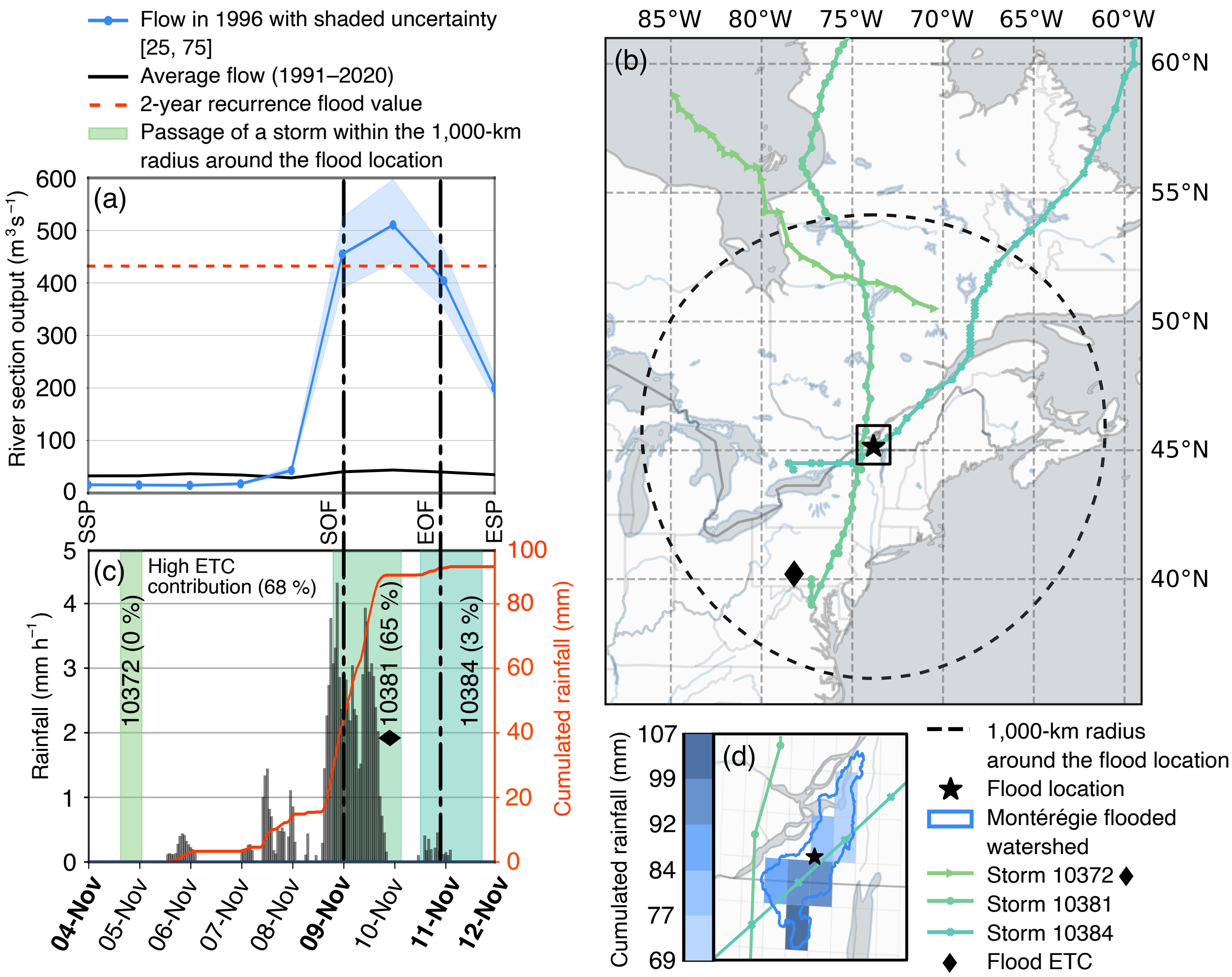

Figure 2. *Application of the methodology to the flood event of November 1996 in the Montérégie region. (a) River section discharge (blue) compared with the 2-year recurrence flood value (dashed red) for the flood event. (b) Storm tracks of ETCs entering the search domain (dashed black) between the SSP (start of the search period) and ESP (end of the search period) dates for the flood event and location of the flood (star). Tracks are shown for their entire lifetime (even components before and after they leave the domain). (c) Rainfall in the affected watershed for the local flood event with the contribution of the different ETCs and overall ETC contribution. The SSP, SOF (start of flood), EOF (end of flood), and ESP dates are shown in (a) and (c) and highlighted in bold in (c). The SOF and EOF dates are shown by the dash-dot lines in (a) and (c). The identified flood ETC is highlighted with a diamond (storm #10381) in (b) and (c). (d) Close up view of the Montérégie watershed affected by flooding, flood location* ***(centroid of the watershed),*** *and cumulated rainfall during the search period.*

Panel d) outlines the basin affected by floods but the basin is not identified in the caption aside from the “Montérégie region”.

This is not a mistake, since HydroSHEDS basins are identified with sequential numbers which are not helpful for understanding the figure. Instead, we propose to modify the legend beside panel (d) to read ***“Montérégie flooded watershed”*** instead of *“affected watershed”* to describe the watershed (see revised Figure 2 above).

2.10 p 9, line 174: Change to “a crude”.

Done.

2.11 p 10, line 207: Delete “In order” and begin the sentence with “To quantify”.

Done.

2.12 p 11, line 218: Revise to “data were”.

Done.

2.13 p 11, line 236: Instead of “mild”, consider using “low” throughout the paper.

We have applied the changes to lines 236, 314, and 471, as well as Figures 6 and S7 (in the Supplement).

2.14 p 14, line 294: Instead of “worst year”, perhaps state “most active year”.

Done.

2.15 p 16, Figure 6: Replace “mild” with “low”.

Done, see answer to comment 2.13.

2.16 p 16, lines 335-336: Spell out numbers less than 10 here, so “eight events”, “two events” and “three events”.

Yes, done.

2.17 p 19, line 375: Here and elsewhere, replace the ampersand with “and” when referring to regions of interest.

Yes, see our answer to comment 2.1.

2.18 p 19, line 389: Use the singular “storm” here.

Yes, done.

2.19 p 20, line 403: Insert “(BSQ)” after “Baseline Southern Quebec” given the abbreviation is used in one of the figure panels.

See our answer to comment 2.9, this acronym is not needed and should not have been used.

2.20 p 24, line 471: Replace “mild” with “low”.

Done, see answer to comment 2.13.

2.21 p 25, line 502: Delete the comma after “et al.”

Yes, done.

2.22 p 25, line 517: Spell out “NOAA” when first introduced in the text.

Yes, done.

2.23 p 26, line 532: The “Conclusions” section should be numbered like all other sections in the paper.

Done.

2.24 p 27, line 578: Change to “are not available”.

Done.

2.25 p 29, lines 609-611: Update the status of this reference, perhaps it is now published?

Yes, it is now published, the reference has been updated and the year revised to 2026.

2.26 p 30, line 661: Replace “Dat” with “Data”.

Done, thanks.

References

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