Interactive comment on "Continuous in situ measurements of anchor ice formation, growth and release" by Tadros R. Ghobrial and Mark R. Loewen

Authors Response to **Referee #3** (received and published: 25 August 2020)

The authors wish to thank Referee #3 for the constructive comments and suggested corrections to the discussion paper. We have responded to each of the comments from the reviewer. The comments from the reviewer are in black font and our responses are in red font.

1. **Referee #3:**
   The authors have conducted a novel field study of anchor ice formation, growth and release that clearly addresses a knowledge gap in the literature. They have provided a thorough review of the current state of knowledge of anchor ice processes and have complemented this very well with their new field measurements. The paper is well written and will be of interest to many people in the river ice engineering field.
   Authors Response:
   Thank you for your positive feedback on our paper and for highlighting the significance of the presented results.

2. **Referee #3:**
   The authors note that several previous investigators have discussed correlations between anchor ice characteristics and the flow Froude or Reynolds number. Perhaps it would be useful to report these two values for each of the events summarized in Table 2.
   Authors Response:
   This is a very useful suggestion. Unfortunately, during these measurements, we did not measure local velocities and depths. We did make measurements of these flow parameters in the following year of measurements and will include them in future publications.

3. **Referee #3:**
   There is discussion on the uncertainty of measured parameters (ie. crystal growth rate, thickness). Perhaps this could be added. I suspect that while the camera resolution (ie. pixel size) might suggest a high degree of accuracy, the problems associated with the depth of field when measuring the anchor ice thickness might be more significant.
   Authors Response:
   We agree that a discussion on the sources of uncertainty is needed. This comment was also raised by Referee #1. We identified three the sources of uncertainty: (1) the camera resolution, (2) the precision in detecting the same crystal between consecutive images, and (3) image clarity when trying to identify the in-focus anchor ice that we tracked to measure growth rates. We agree that the high camera resolution only indicates the maximum possible accuracy and that other factors will govern the actual measurement accuracy. Images clarity did affect the uncertainty in tracking individual crystals and top of ice accumulation. When tracking individual crystals, we printed and overlapped each

pair of consecutive images (after applying a percentage of transparency to the image in MATLAB) to confirm that the same crystal was identified throughout the series of images. We do have high confidence in this procedure when identifying individual crystals (Stage 1). For Stage 2, frazil deposition, high concentrations of frazil crystals in the flow as well as higher turbidity levels, increased the uncertainty in detecting the top edge of the in-focus frazil deposition. This leads to the third source of uncertainty the accuracy of the scaling factor. The in-focus section of the substrate used for scaling anchor ice sizes was 40 cm away from the face of the lens. We estimate that the vast majority of observed anchor ice was located between 30 to 50 cm away from the camera, ±10 cm from the focus distance. If we considered these two extreme cases (i.e. ± 10 cm), the resulting expected error in estimating anchor ice dimensions (crystals or depth of deposition) would be approximately ± 25%. We will include a section in the discussion addressing the sources of uncertainty.

4. **Referee #3:**
   I am unfamiliar with the local hydraulics, so I am unable to differentiate between the normal diurnal water level variations because of upstream hydropeaking versus staging during anchor ice formation and de-staging during anchor ice release. Were the impacts of anchor ice of sufficient magnitude to be observable in the water level measurements?
   Authors Response:
   Based on our knowledge of the site, we do not think that anchor ice formation and release have any significant effects on the change in water levels. The diurnal variation of water levels appears to be entirely controlled by the hydropeaking from the dam's operation upstream. This was observed during the first three deployment. During DEP-4 (Events E and F), the continuously rising water levels were attributed to the staging-up due to ice cover formation downstream. We did discuss our assessment of the water level data in Page 14 line 28 to Page 15 line 4.

5. **Referee #3:**
   Line 2 of the abstract – even though line 1 notes both turbulence and supercooling, line 2 starts over and says that supercooled water generates frazil ice and does not mention the concurrent requirement of sufficient fluid turbulence.
   Authors Response:
   Thank you for your comment. Line 2 of the abstract will be updated to read:" In supercooled turbulent water…".

6. **Referee #3:**
   Stage 4 is listed as the release phase (Pg 10, line 25) however, on Figure 11 Stage 4 is shown to have a very rapid increase in thickness, as opposed to a drop in thickness down to zero.
   Authors Response:

Thank you for clarifying this. The label for Stage 4 in Figure 11 was to highlight the start of the "lifting" release mechanism before the total removal of the anchor ice accumulation. We will update the figure caption to clarify this issue.

7. **Referee #3:**
   Page 12, line 25 – Did Kempema and Ettema report observed water temperature measurements at the wedge wire screens? If the water was more supercooled this could also explain the higher growth rate.
   Authors Response:
   Unfortunately, Kempema and Ettema did not measure water temperatures in their setup. We attributed their higher growth rates to higher flow turbulence (the wedge wire screen being installed 23 cm above the bed).

8. **Referee #3:**
   Page 14, line 1 – The substrate thermometer looked to be covered in anchor ice in the photo, which may prevent it from providing an accurate measure of the water temperature. Did you compare with the thermometer mounted higher up on the frame?
   Authors Response:
   Yes, we did compare results from both sensors and the data showed that water temperature measurements from both sensors were almost identical within the stated accuracy of the sensors. Therefore, we decided to only show the data from the sensor on the substrate since it is closer to the anchor ice formation.

9. **Referee #3:**
   Page 16, line 6: is the first sentence too general? You've listed a few field measurements of anchor ice growth in your lit review section.
   Authors Response:
   Yes, we agree with your comment. We will update the sentence to read:" The first continuous field measurements of the anchor ice cycle including, initiation, growth and release mechanisms were captured in this study".

10. **Referee #3:**
    Page 16, line 9: the mode name 'rapid' could be more descriptive in my opinion.
    Authors Response:
    The only alternative to "rapid" that we thought might be applicable was "instantaneous". However, because our images were taken every 5 min we did not think it was accurate to call this instantaneous release.

11. **Referee #3:**
    Pg. 1, Line 14 – rewording is required: '… have been reported to study'; 'but'
    Authors Response:
    Agreed. The sentence will be reworded to read: "Although detailed laboratory experiments studying anchor ice have been reported in the literature, but very few field measurements of anchor ice processes have been reported.".

12. **Referee #3:**
Pg. 1, Line 26 – repetitive 'defined'
Authors Response:
Agreed. The sentence will be reworded to read: "Anchor ice is described as ice that is attached or "anchored" to the bed of natural water bodies (rivers, lakes or sea floors) as defined by World Meteorological Organization (1970).".

13. **Referee #3:**
Pg. 3, Line 23 – increase with increasing Froude number; lines 24 – 26 – changing from present to past tense a couple of times. This also occurs at other locations within the manuscript.
Authors Response:
Thank you for catching this mistake. The sentence in line 22 will read:" anchor ice growth rates and densities increased with increasing Froude number." We will also review the manuscript to verify consistency in using the correct tense.

14. **Referee #3:**
Pg. 3, line28 – 'have been reported' rather than 'has been reported'.
Authors Response:
Updated.

15. **Referee #3:**
Pg. 3, line28 – 'have been reported' rather than 'has been reported'.
Authors Response:
Updated.

16. **Referee #3:**
Pg. 4, line 2 – reword '…provided many valuable information'.
Authors Response:
Agreed. The sentence will read:" Despite these limitations, field studies have significantly advanced our knowledge of anchor ice processes".

17. **Referee #3:**
Pg. 4, line 34 – reword '… crystals showed grew preferentially…'.
Authors Response:
Agreed. The sentence will read:" In both cases, the crystals showed preferential growth perpendicular to the flow.".

18. **Referee #3:**
Pg. 14, line 33 - … release of event C anchor ice
Authors Response:
Thank you for catching this mistake. We will update the sentence to read:" The release of event C anchor ice coincided with a peak in the daily water levels of 3.38 m."