Point-by-point response to editor and reviewer concerns by corresponding
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April 10, 2020

tc-2019-264:

Surface emergence of glacial plumes determined by fjord stratification

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https://doi.org/10.5194/tc-2019-264

Dear anonymous Reviewer #2,

We would like to thank the reviewer for their helpful and constructive comments, and for taking the time to review our manuscript. In the following we give a point-by-point response to each comment and hope that the reviewer finds the manuscript to be improved. We would also like to refer you to the responses to the other reviewer for more improvements and changes to the manuscript.

COMMENTS / AUTHOR'S ANSWERS

1. Section 2.1 It is not clear whether data was obtained within the plumes from the XCTD's deployed by helicopter. Previous published studies have shown a significant difference between XCTD-profiles deployed in the center of the plumes and the near-by ambient water. Fig. 5 indicates that no profiles were obtained within the plumes. Please clarify whether data was obtained from within the plumes.

Thanks for pointing out this important issue. In 2013, the 12 xCTDs deployed by the helicopter entered the water within the surface expression of the plume (Fig. 4), as did 8 of the CTD casts from the boat. Because the rising core of the plume is likely narrow and confined against the ice, these casts may not have stayed inside the plume all the way to the sea floor. These 'in-plume' casts have been extensively described and analysed by Mankoff et al. (2016); see e.g. their Figure 5, which indeed shows a significant difference in properties inside and outside of the plume. During the 2012 campaign, just 2 xCTDs were deployed by the helicopter and, although not certain (due to the lack of a plume surface expression), they seemed to fall within or near the plume pool.

In Fig. 5, we don't include any casts from within the plume because we wish to highlight the ambient waters that are providing the boundary conditions for the rise of the plume. In Fig. 10, we do include casts from inside the plume because we are comparing these observations to the output of the plume model.

We have clarified these points on lines 73, 132-134, and in the caption of Fig. 5.

2. The model investigates the role of stratification and the relation between discharge rates and the neutral level. However, it applies the ambient stratification obtained from CTD-profiles. In relation to the comment above, it has been found that the stratification in the plume is significantly different from the ambient conditions. It is not clear how representative the applied stratification in this study is for the near-plume conditions. An analysis of horizontal gradients towards the plumes observed from the CTD-profiles is needed for assessing this important issue.

First, it is important to point out that the boundary conditions for the plume model should be the ambient waters through which the plume is rising. The stratification within the plume itself is what the plume model is trying to simulate and therefore should not be used to set the ambient/boundary conditions for the plume model.

The reviewer is correct however that the ambient conditions felt by the plume, presumably the fjord waters very close to the plume but not inside it, might differ from those further away (say a few km from the front). Spatial variability in SF water properties has been analysed for 2012 and 2013 by Stevens et al. (2016) and Mankoff et al. (2016), respectively, and so we do not think it would be appropriate to include a similar analysis in our manuscript. We have, however, conducted an analysis of how sensitive our plume model results are to how we set our ambient stratification in each year.

For this analysis, following Stevens et al. (2016), we have grouped CTD casts within 150 m of the calving front and close to the plume (150 m - D1), casts within 150 m of the calving front but at the other side of the calving front (150 m - D2), and casts along the velocity transect ~1.5 km from the calving front (1500 m - R1). We then ran the plume model in each year with ambient conditions defined using these 3 groups of CTD casts and realistic subglacial runoff (Fig. R3). In 2012, NBD varied between 20 and 26 m, and in 2013 between 13 and 15 m depending on the ambient conditions used. MHD ranges from 0 to 3 m in 2012 and is always 0 m in 2013.

These tests show NBD/MHD are quite insensitive to how we define our ambient conditions. This may already have been guessed based on the small differences between ambient CTD profiles taken at different points in the fjord (Fig. R3). Most importantly, the characteristic plume heights are deeper in 2012 than in 2013 for any definition of the ambient conditions (Fig. R3). For the results in our manuscript and for simplicity, we decided to prescribe ambient conditions for the plume model as the average over all CTD casts in each year, excluding those from within the plume. Fig. R3 shows that this definition is sufficient.

We have now clarified how we define the ambient conditions for the plume model (L118-119, 242-243 and caption of Fig. 5) and included a discussion of these sensitivity tests in L334-342.

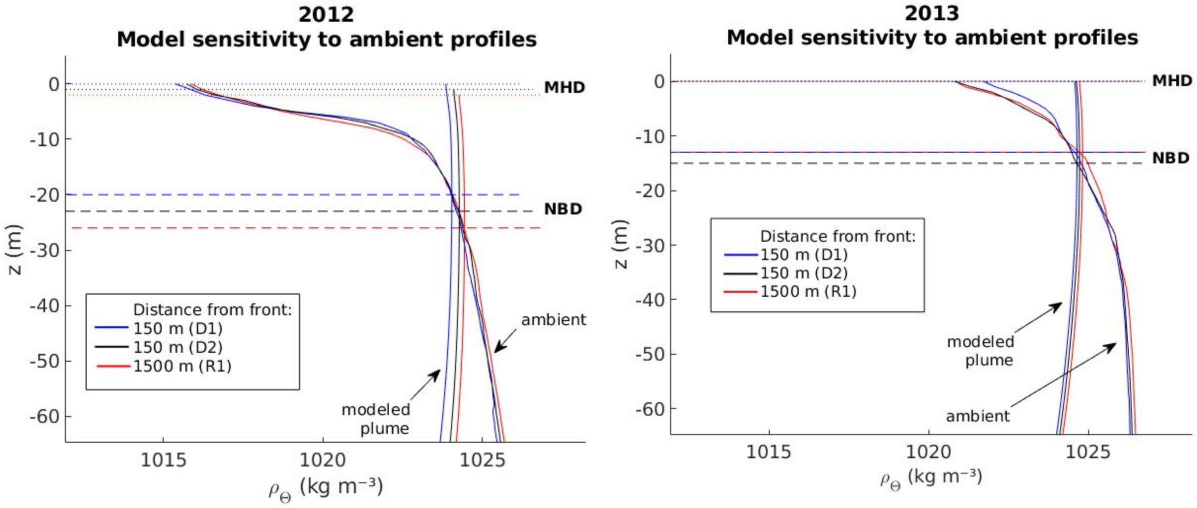

Figure R3. Sensitivity of modeled characteristic plume heights to the ambient water properties observed at different distances from the front, in 2012 (left) and 2013 (right). Coloured continuous lines are modeled plume and ambient density (as indicated) while coloured dashed and dotted lines represent modeled NBD and MHD, respectively. D1 and D2 are main and secondary plume locations, respectively (defined in Stevens et al., 2016). Subglacial runoff is held constant at the values used in the main paper (Q_{sg} = 101.7 m^3/s in 2012 and Q_{sg} = 101.9 m^3/s in 2013).

3. Eq 2 and Fig. 11: Fig. 2 implies a scaling depending on a and b. However, the found parameters of a and b does not result in a physical dimension of Eq 2 in accordance with the dimension of Z. Thus, the found relation does not represent a scale of the physical system but is related to the model-parameterisation and the applied parameters. It should be clarified to what extent this relation depends on the applied parameters in this specific model setup.

We have now revised both the height and the melt rate scalings so that the constant A and the quantities raised to the powers a and b are all dimensionless (section 2.3.3). With this recasting, the relation does contain fundamental scales of the physical system and it is clear how model parameters affect the scalings, but we have not had to change any of our analysis or results (e.g.

Fig. 11). To avoid overcomplicating the manuscript at this point, we have placed details of the scalings in a new appendix (Appendix A).

4. Figure 7: This is a very interesting figure. However, information about the tides and winds during the observational periods are missing.

The amplitude of the barotropic and baroclinic tidal currents, derived from an ADCP deployed in the middle of the fjord in summer of 2012, are approximately 0.01 m/s and 0.06 m/s respectively (R.M. Sanchez, personal communication). These currents are much smaller than those observed in the jet, ~ 0.3 m/s and shown in Fig. 7 , thus we do not expect that removal of the tidal velocities would significantly change the structure of the jet. The jet structure, in turn, is used mostly to identify the water masses that are carried away from the glacier in the jet.

Unfortunately, no local wind observations are available for the duration of the 2012 and 2013 surveys. During both surveys, however, wind conditions and sea-state were largely calm and permitted surveys to be conducted from small boats and autonomous vehicles. This observation, together with the highly localized nature of the jet, support the conclusion that the jet is associated with subglacial discharge plume, and is not a wind-driven feature. The numerical simulations of Slater et al. 2018, who are able to reproduce the jet with no wind forcing, support this conclusion.

Following your comments, we have included this information in section 3.1.3 (L217-226).

5. L360 "We have provided evidence that surface melting of a marine-terminating glacier, and the associated subglacial discharge, together with the fjord's stratification exert a strong control on the dynamics of subglacial discharge plumes with implications for melting of the glacier face and export of meltwater". I do not consider the model simulation as an "evidence". The model results may support the hypothesis, but the applied model has not been validated against observations. The general model formulation is based on plume theory and it has been applied in several studies, but, as the authors point out, there are several assumptions in the choice of model parameters. Please modify the conclusions accordingly.

We respectfully disagree with the reviewer on this particular point. First, this statement is not based solely on the model simulation. Figs. 4, 7 and 10 provide observations of differing plume and jet dynamics in 2012 and 2013, and we have attributed this to differing fjord stratification, which is also observed. The plume model is used to provide a dynamical understanding of our observations. Second, we do think that the model has been (at the very least partly) validated against observations; as described in section 3.3 (i) modeled NBD is close to the observed jet depth, (ii) modeled MHD matches the photographs of plume-patch presence/absence, and (iii) modeled plume T-S properties at NBD and MHD are close to xCTD observed T-S properties. Third, although there are several assumptions in the choice of model parameters and boundary conditions, our results are largely insensitive to these choices (e.g. the entrainment coefficient - see new lines 328-333, and the ambient conditions - L334-342, see response to comment above).

We do think, therefore, that the highlighted statement and our conclusions are warranted, but we have reworded this statement (line 405) to emphasize that we are basing this statement on both observations and the plume model, with the plume model used to provide a dynamical understanding of why the plume differed in the two years.

The reviewer is of course correct that the scalings we derive are based purely on the plume model (although our observations and numerous other applications in the literature provide support that the plume model is sensible). We have now made it clear in the conclusions that the scalings are based on the plume model and not the observations (see response to next comment).

6. L417: It is concluded: “We found that plume vertical extent is proportional to $(N^2)^{-0.4}Q_{sg}^{0.24}$, while total submarine melting is proportional to $(N^2)^{-0.43}Q_{sg}^{0.49}$. These highlight the important role played by fjord stratification, and the subglacial discharge flux, in the dynamics and impacts of subglacial discharge plumes.” These findings are not based on observations, cf. my previous comment. It should be clarified that these relations are not constrained by data but related to the applied model parameters.

We agree - it is important to make clear the distinction between the general point of plume dynamics being affected by fjord stratification (which is evidenced by our observations and supported by the plume model), and the quantitative scalings (which are based only on the plume model). And since they are based on the plume model, the quantitative scalings are indeed related to the applied model parameters. These points have now been made clear in the conclusions (section 5).

MINOR COMMENTS / AUTHOR’S ANSWERS

L71: “No statistical differences were found between CTD/xCTD casts taken on different days...”. Statistical difference (?) has to be clarified.

The mean temperature and salinity among CTD casts taken on different days are not statistically different since a one-way ANOVA (ANalysis Of VAriance) indicates $p > 0.05$. This has been clarified on L75.

L73. “Temperature and conductivity values are converted to conservative temperature (Θ) and absolute salinity (SA) respectively (IOC, SCOR, and IAPSO 2010) using...”. The references in parenthesis are not included or explained.

Reference included in L577 (Reference list).

L231: replace sigma-theta with theta.

Replaced - thank you for spotting this mistake.