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Interactive comment on "Sources, cycling and export of nitrogen on the Greenland Ice Sheet" *by* J. L. Wadham et al.

Anonymous Referee #1

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This paper aims to quantify the nitrogen sources and export from a Greenland Ice Sheet catchment and to extrapolate the export results from this catchment to the entire Greenland Ice Sheet (GrIS). The nitrogen data comprises 62 samples of bulk runoff, 39 samples of ammonium extractions from suspended sediment, 28 samples from supraglacial water, a total of 13 samples of surface ice and cryoconite water, six samples of basal ice, and a total of 13 incubation experiments. Given the logistic difficulties in obtaining this kind of data in a remote area throughout an ablation season, the nitrogen dataset is valuable and adequate to address the aim to quantify the nitrogen sources within the catchment. However, the analysis becomes more problematic with respect to cycling and export; and hence the rough extrapolation to the entire GrIS becomes very questionable.

I have some major issues with this paper:

1) I find it problematic that Hawkings et al. (2015) have already published some of the key data and calculations for the Leverett Glacier catchment. Hawkings et al. (2015) estimate the exchangeable ammonium flux and the DIN flux for 2012 using both discharge weighted mean (DWM) and electrical conductivity. Together with fluxes for total solutes, Si and P, these fluxes are extrapolated back in time to the years 2009, 2010 and 2011. With regards to nitrogen, Hawkings et al. (2015) find that the "annual nitrogen flux is more sensitive to changes in ice sheet water discharge than particle flux" and "inorganic nitrogen (86 % +/- 9.8 %) . . . are higher in extreme melt years than for average years. This is significant and demonstrates the potential for nutrient release by a warming climate".

It is incomprehensible to me why the Hawkings et al. (2015) paper is not referenced, and why I as a reviewer was not informed about this highly relevant publication no matter what the status of the Hawkings et al. (2015) paper was at the time of submission. In my opinion it would have been ethically correct to provide the editor and reviewers with an opportunity to assess the redundancy of parts of these papers. Why is the data and calculations presented as novel data and calculations, when they are in fact published in another paper? Both papers are written by almost the same group of authors. The paper by Hawkings et al. (2015) was accepted by Geochemical Perspectives Letters on June 19, 2015, and published on June 23, 2015, whereas this Biogeosciences paper was submitted on September 21, 2015.

As some of the key data and calculations are already published, the originality and impact of this paper are severely reduced. Clearly, many parts of the paper must be rewritten and refocused. For instance, Hawkings et al. (2015) have already discussed potential future changes in nitrogen flux (chapter 3.3). If the authors choose to rewrite the paper, then the focus should be on the novel parts of the data; i.e. the nitrogen sources. However, I am uncertain whether there is enough new data in this paper to warrant a separate publication. The rough and questionable extrapolation to the entire Greenland Ice Sheet is not sufficient.

In addition, the findings by Lawson et al. (2014) on export of nitrogen-rich organic matter should be presented in the Introduction chapter to clearly identify the gap of knowledge.

2) Another major issue is the lack of information about discharge and catchment area. Solid estimates of nitrogen concentrations, discharge measurements throughout the ablation season, and a realistic estimate of the catchment area are needed to perform the upscaling of fluxes to the entire Greenland Ice Sheet. Of these, only the nitrogen export estimates are addressed in some detail.

The discharge measurements must be described more rigorously and uncertainties in discharge should be included in total uncertainty estimates of the annual and upscaled fluxes. On P6L4-5, it is said that stage was recorded throughout the 2012 melt season (May-October), but only the first part of the runoff time series is presented in Figure 2d. Readers need to see the entire time series to get an impression of the amount of runoff after the sampling period (May 11 – July 15). Also, why does not this paper mention that the discharge from Leverett Glacier in 2012 was extreme compared to previous years (Hawkings et al., 2015)? This is rather important information, if nitrogen fluxes correlate with discharge. Why is the "runoff flux for June, July and August in 2012 from LG (2.2 km3)" (P11L13-14), when Hawkings et al. (2015) report an annual runoff flux of 2.03 km3 (their Table 1)?

It is even worse with regards to the estimated catchment area. It is postulated that it is 600 km2 (P4L4 and P13L17) without any references or a figure showing the catchment area. I tried to find out how this estimate was derived. Hawkings et al. (2015) use the same catchment area and write that "the catchment area was determined from a surface digital elevation model (Palmer et al., 2011)". Their Figure 1 shows that the entire catchment area is located well below the equilibrium line altitude for the years 2009-2012. Clearly, the use of surface digital elevation models to estimate the catchment area of relatively small ice sheet catchments constrained within the ablation area is an inappropriate method, as it does not include the upper accumulation area that

supplies ice to the lower ablation area. Assuming an equilibrium state accumulation-area ratio AAR0 between 50 % and 60 % (Dyurgerov et al., 2009), a more realistic, but still very rough, estimate of the catchment area will be between 1200 km2 and 1500 km2. The estimate of the catchment area has immense impact on the results of the upscaling and must be defined and discussed in detail. In Google Scholar, I checked some of the papers that have referenced Palmer et al. (2011) and it seems that many papers have used a catchment area of 600 km2 to calculate fluxes from the Leverett Glacier catchment. This leaves me very skeptical to many results and conclusions in a series of papers, and this is definitely not an example to follow. Unless the authors can show strong convincing arguments for using a 600 km2 catchment, I recommend that they include an estimate of the accumulation area in the total catchment area in future publications.

Minor comments:

Title: The title does not reflect the main content of the paper. The title should reflect that the main focus and data is related to the Leverett Glacier catchment. In my opinion, the rough extrapolation to the Greenland Ice Sheet is merely a simple order-of-magnitude upscaling procedure, which is too questionable to serve any real purpose without an order-of-magnitude error estimate.

Title: The paper contains very little on nitrogen cycling, i.e. flux estimates of the various pathways.

P2L19: Be specific to which "large Arctic river" the data refers to, and why this specific river is relevant in this context.

P4L16-17: Are the coordinates for Nuuk or Leverett Glacier?

P6L4-10: Insert uncertainties of the discharge determination.

P6L10-14: It is not clear to me, what the turbidity sensor was used to determine.

P6L16: Is the relationship between nitrogen concentrations and discharge constant

throughout the ablation season in other glacier catchments? If not, it may be necessary to make some kind of seasonal correction.

P6L17: Is there a potential bias due to the daily collection of water samples at 10:00? I imagine that there will be some diurnal hysteresis in a river system such as this one. Have the authors or other authors addressed this issue?

P6L18: What is the reason for only collecting water samples at 18:00 during subglacial outburst events? Is there a potential bias related to this sampling strategy? Also, I am not entirely sure what is meant by subglacial outburst events, so a definition and some information about their duration and frequency will be appreciated.

P7L2: What is the Leverett/Russell Glacier catchment? Is it just because the Leverett Glacier catchment has two names, or is it a subcatchment of the Leverett Glacier catchment? It is not shown in Figure 1 or in Hawkings et al. (2015).

P7L4-6: How did you wrap foil around 30 m x 30 m x 30 m ice blocks? I guess that there is a problem with units here.

P7L4: How many blocks were collected and where were they collected?

P7L7: It will be more informative to use cm3 rather than cm2.

P8L25: Insert Glacier after Leverett.

P9L24: What are the transect samples? If you have additional relevant data on total nitrogen, it should be included in this paper.

P10L23: At what temperature was the sediment oven-dried?

P11L5: Why were the nitrogen fluxes just calculated for the period from June to August? Why not the entire ablation season? Does this exclusion of the early and late ablation season have an effect on the upscaling?

P11L6-7: I checked the Mikkelsen and Hasholt (2013) reference to see whether it was a

valid citation in this context. The reference contains data from 2007 to 2010. It does not include anything to suggest that “LG contributed just under one half of the cumulative glacial runoff to Watson River in summer 2012”. It is clearly an invalid reference. I have not time to check all references and it is not my job as a reviewer, but this makes me skeptical to the use of references in this paper. I have the impression that important relevant papers are left out, while irrelevant papers are used to support arguments, which they actually do not support.

P11L9: What is the error of the discharge weighted mean concentration method? Why is the electric conductivity method (Hawkings et al., 2015) not used in this paper?

P11L21-22: “Currently, there are no other seasonal time series of nitrogen concentrations in runoff from large Greenland outlet glaciers” – A quick Google Scholar search on Greenland+river+nitrate revealed some papers that may contain relevant data on nitrate concentrations in Greenlandic rivers. I did not check the content of these papers, so I actually do not know whether they are relevant, but the authors may find it worthwhile to do a more thorough check of the current state of knowledge on nitrogen concentrations in rivers in Greenland.

P12L1-4: I cannot follow this argument. How can the 600 km2 Leverett Glacier catchment be representative for large catchments draining the ice sheet, if it does not include a part of the accumulation area?

P12L2: Insert the maximum-minimum range.

P12L9-10: This argument assumes the same glacial history all around the ice sheet margin. On P4L21-22, the authors mention that Leverett Glacier was positioned tens of kilometers further inland during the Holocene Thermal Maximum. Were all outlet glaciers from the Greenland Ice Sheet located further inland during the Holocene Thermal Maximum?

P12L10: Is it relevant for extrapolation to tidewater glaciers that Leverett Glacier is a

land-terminating glacier?

P12L10: How much nitrogen derives from the local bedrock? How much nitrogen is contained in other types of bedrock beneath the GrIS?

P12L13-16: This is exactly the kind of arguments that makes me concerned. If an incorrect catchment area was used in previous papers, then there are no good reasons to continue using it. This is not a valid argument for considering the Leverett Glacier catchment as representative for all large GrIS catchments.

P13L23: Is a termination of nitrogen fluxes in late July/early August supported by data from other catchments?

P15L3-4: So there is a bias caused by the collection of water samples at 18:00?

P15L24-25: There is an issue with wrong units here.

P16L4: Insert error estimates and discuss these.

P16L11-12: Is this correlation linear or exponential?

P16L12-27: This discussion on potential future changes in largely a repetition of Hawkings et al. (2015). The discussion in this paper needs to be different.

Table 1: What is meant by "Moulins (same period)"?

Table 2: What is meant by seasonal fluxes in the caption? The fluxes from the Leverett Glacier catchment should use the unit tons a-1.

References:

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