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Discussions

# *Interactive comment on* "Brief Communication: Can recent ice discharges following the Larsen-B ice-shelf collapse be used to infer the driving mechanisms of millennial-scale variations of the Laurentide ice sheet?" *by* J. Alvarez-Solas et al.

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We would like to thank the Reviewer, John Andrews, for interesting and constructive comments. Please find our response to individual points below, which will be addressed in the revised manuscript.

Referee Comment (RC): "In many respects this is a commentary as opposed to a review. The basic glaciological question about Heinrich events is whether an ice shelf in the Labrador Sea is a necessary condition for the repeated build-up and collapse of



the ice sheet though Hudson Strait."

Authors Comment (AC): First, it is important to note that our paper is not meant to only discuss the triggering of Heinrich events, but it is intended to highlight a mechanism that could explain the millennial-scale variability of the Laurentide in general (including its contribution to the peaks between Heinrich events that are present in IRDs; e.g., see Fig. 8 in Hodell et al., 2010). Second, we disagree that the existence of Heinrich events must imply a "repeated build-up and collapse of the ice sheet through Hudson Strait", because this seems to assume that a MacAyealian oscillator (binge-purge) is operating, which we argue is not the case (see next point). Instead, we would ask whether an ice shelf in the Labrador Sea is a necessary condition for the repeated iceberg discharges that generate Heinrich (and other) layers composed of IRDs mainly originating around Hudson Strait.

RC: "The paper by Alverez-Solas et al. Appears to assume that the existence of an ice shelf is known and proven, hence the basic thrust of the paper is to examine the role of the ice shelf in the subsequent history of the Hudson Strait ice stream. The readers of this article should first note that the suggestion by Hulbe et al (2004) was challenged by Alley et al (2005); indeed, despite the "field" research in the Labrador Sea on the stratigraphy and sedimentology of Heinrich-event sediments I am not aware of many papers that makes an argument for an ice shelf."

AC: We agree that the challenge made by Alley et al. (2005) concerning the Hulbe et al. (2004) paper should have been mentioned in the text. This will be solved in the new version of the manuscript. The triggering mechanism of H-events proposed by Hulbe et al. (2004) is indeed disputed by Alley et al. (2005) because (among other things) the existence of the Labrador Sea ice shelf had not been proven, which still remains an open question. Given that the data about the existence of the ice shelf do not provide a clear answer, models can be very helpful. Here we have presented simulations of the Laurentide Ice Sheet carried out with a hybrid ice sheet/shelf model, which allows us to include floating ice and a better representation of ice streams (as compared to previous

’shallow-ice’ studies; see Bueller and Brwon 2009; Peyaud et al., 2007). It turns out that for a wide range of assumed ice-shelf basal melting rates, the model consistently produces an ice shelf in the Laborador Sea. Furthermore, Alley et al. (2005) secondly disputed Hulbe et al. (2004) in order to defend the so-called MacAyealian oscillator mechanism (essentially binge-purge). The main motor of oscillations under the binge-purge mechanism relates to the fact that basal velocities (and therefore heat production at the temperate base of the ice sheet) are a function of surface slope. This is highly unrealistic (as the very flat but rapid ice streams in Antarctica seem to indicate) and is an artifact of using an enhanced flow factor to represent ice streams under the shallow-ice approximation. In fact, once ice streams are treated as dragging ice shelves, and longitudinal stress is accounted for (which provides a better representation of fast ice flow; see Bueler and Brown 2009; and Alvarez-Solas et al., 2011 and Windsborrow et al., 2004 for a comparison), this type of oscillation is no longer able to occur in the model. This issue will be discussed more deeply in the revised manuscript.

RC: "In a general sense the picture of of what constitutes and H-event is dominated by the notion of iceberg rafting as the dominant sediment process (Heinrich, 1988). However, what we now term Heinrich events were first described by Chough, Hess and Aksu in a series of papers in the 1970’s and 1980’s which focused on the role of turbidites originating on the slope outside Hudson Strait and related to the massive North Atlantic Mid-Ocean Channel (NAMOC) (Chough, 1978; Aksu and Mudie, 1985; Chough et al., 1987; Hesse et al., 1990) (see Andrews, 1998 for review), and the importance of detrital-rich carbonate facies (DC facies) as a signature for what we now term H-events. So the real question in my mind is this: what conditions existed in Hudson Strait, and possibly Hudson Bay, that led to massive outburst floods and the creation of major turbidite flows? It is notable that the paper does not reference a single paper that deals with the nature of H-events in the Western North Atlantic, other than the review paper by Hemming (2004) and the recent paper by Marcott et al (2011), which also assumes the existence of an ice shelf in the Labrador Sea."



AC: The Reviewer is correct to point out that we did not mention sediment processes related to the production of IRDs and we will discuss this in the revised manuscript. Indeed, as discussed by Andrews (2000), there are three possible explanations for the peaks of IRDs found in the middle of the North Atlantic: (1) an increase in iceberg flux with a steady sediment content; (2) a change in sediment concentration with steady iceberg flux; and (3) a change in the location (and/or rate) of iceberg melting. Explicit numerical consideration of case (2) is challenging, since we lack important information concerning basal ice – sediment interactions and models are only now beginning to include these processes. Furthermore, we believe the most likely explanation for the signal of IRDs in the North Atlantic is an increased iceberg production at the source (case 1), reflecting dynamic variability in the Laurentide Ice Sheet. Additionally, when an ice shelf is considered, case (1) and case (3) become linked because a potential oceanic temperature change will both affect the ice shelf (with potential break-up) and change iceberg melt rates.

RC: "Alley et al (2005) noted some of the objections to the notion of an ice shelf in the Labrador Sea. What is now needed is a concerted effort to establish whether there is evidence for or against this hypothesis."

AC: We agree that a concerted effort to find new evidence concerning this point would be very valuable. However, in the meantime, models can say something about this question. Please see above.

RC: "The current paper does indeed point to the fact that the modern analog is in AntarcticaâĂŤthat being said then the answer to the question needs to be sought in a comparison and contrast between the lithofacies and their characteristics from the Labrador Sea versus their Antarctic counterpoints (Anderson et al., 1991). Analogs can also work both waysâĂŤis there any evidence around Antarctica, with its numerous ice-shelves, for the presence in the sedimentary record for H-like events? I did a search in the “web of science” using the keywords “Antarctica” and “Heinrich” or “H-“ and did not get a single reference."

AC: While the analogy works in both ways, its validity does not require the existence of similar events having happened in the past glacial periods in Antarctica, since the conditions needed to produce such discharges may not have occurred. Nonetheless, heavily cited evidence does exist. For example, Kanfoush et al. (2000a,b) evidence Antarctic millennial-scale iceberg discharges (interpreted as an ice-sheet instability - see also the comment by Clark and Pisias 2000-) through IRDs registered in the South Atlantic. We will reference these works in the revised manuscript.

RC: "It would thus appear that ice streams, buttresed by ice shelves are not a necessary condition for Heinrich events."

AC: Thus, the conclusion we must draw is that, based on our model simulations, the existence of buttressed ice shelves is a necessary condition for millennial-scale Laurentide iceberg discharges (including Heinrich events).

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