Bertrand et al – CP-2011-103
The authors' replies are indicated in italics below.

Reviewer 1 (C1960-2011)

This is a straightforward article that documents a range of good complimentary data sources that serve as proxy-indicators for the behaviour of Gualas glacier on the Northern Patagonian Icefield. I applaud the fact that this range of data have been drawn together by the authors in an effective way. The data are all discussed effectively, and in sufficient detail to capture the essence of what they document. Overall, sound interpretations of the data are made to infer probable glacier behaviour and causes, drawing from their own work, and the extant literature that can further inform these arguments. I recommend the article be published; it would be suitable in its current form though I make the following suggestions for the authors.

First, it might be possible to streamline, condense some of the preliminary discussion, and technical details. I point to no specific areas, but I feel the core arguments could still be made without some of the detail given suitable referencing in some instances.

We thank reviewer 1 for his/her positive and encouraging comments. Following his/her suggestions, we looked for paragraphs that could be shortened in the methodology and discussion sections. We removed some details about the acquisition of the seismic data (section 3.8) and referred readers to a paper published in the Holocene (Fernandez et al) for more technical details. We however believe that including the methodological details in the manuscript is important because it allows readers to assess the quality of our results. No paragraph could be shortened by adding new references in the discussion section. Reviewer 2 did not seem to find the methodology and interpretation sections too long.

Second, the (admittedly slight) possibility that the fluctuations are internally dynamic of surge-type is not really discussed. This seems unlikely given the known glacial behaviour of the area, but one sentence to exclude it based on the local evidence and the apparent regional synchrony with other glaciers from the region is worth including.

A sentence indicating that the apparent synchrony in western NPI glacier fluctuations tends to indicate that they are mainly driven by climate, and are not surging-type glaciers was added. See section 2.

I have spotted one grammatical typo:
Higher winter precipitation before 1900AD were also described by Neukom et al. (2010a).
Line 5 Page 2958 "Higher winter precipitation before 1900AD were also described by Neukom et al"
Line 5 Page 2958 should I think be: "Higher winter precipitation before 1900AD was also described by Neukom et al"

We agree. This was corrected.

Reviewer 2 (C1992-2011)

General Comments

This is an interesting and very valuable contribution to the literature on glacier and climate change in Patagonia. It uses multiple techniques to assess the fluctuation history of the Gualas glacier and makes inferences from these about the likely climate drivers. Overall it forms a high quality and comprehensive addition to the study sites in Patagonia and is of at least regional significance, given that the authors have reconstructed variations of a major glacier of the NPI throughout much of the Holocene. This has not been achieved before and this helps to answer questions about Southern Hemisphere climate change, and to test competing hypotheses concerning Holocene glacier chronologies (such as the Mercer‐type and Aniya‐type chronologies).

However, I do note that a related paper has been recently published in The Holocene by Fernandez et al (and including Bertrand in the author list). This latter paper is on the same glacier, and uses the same marine core to reconstruct glacier variations and climate change over the Holocene period. I therefore have to ask in what ways is the present manuscript materially different from the paper already published? If the authors can make it clear that the present manuscript adds considerably to The Holocene paper, then I think it should be published. as a consequence, the authors need to: 1 more explicitly discuss the findings of the earlier Holocene paper, and, 2 show how the present manuscript adds significantly to the story.

We confirm that a "related" paper by Fernandez et al is in press in the journal "Holocene", as indicated in our manuscript (see section 3.8). The paper by Fernandez et al is indeed based on data obtained during the same scientific cruise (NBP05-05). It is however based on the interpretation of seismic reflection data, it covers a different timescale with a different resolution, and it has fundamentally different objectives. The only results that are presented in both papers are the radiocarbon ages of core JPC14, and some grain-size data. The two manuscripts are therefore clearly distinct. In summary:

1. *The present manuscript focuses on high-resolution (geochemistry, magnetic susceptibility, grain-size) data of the last 5.4 kyr, it includes historical data and high-resolution measurements obtained on core PC27, and it compares the sedimentary record of Gualas glacier variability to independent temperature and precipitation records to assess the influence of climate on NPI glacier variability.*
2. *The "Holocene" paper presents a study of the entire sedimentary infill of Golfo Elefantes, i.e. the last 11.3 ±3.0 kyr, based on seismic profiles obtained during cruise NBP0505.*
3. *The goal of the "Holocene" paper is to study the geometry of the post-glacial sediments of Golfo Elefantes and assess millennial-scale variations in sediment supply and deposition mechanisms.*
4. *The main conclusions of the "Holocene" paper are (1) Golfo Elefantes remained free of ice during the last 11.3 kyr, (2) the arcuate terminal moraines that occur along the edges of Golfo Elefantes were formed during the waning stages of the local glacial maxima (Late Pleistocene), and (3) accumulation rates increased by one order of*

magnitude between the early Holocene–Late Pleistocene (~4.3–11.3 ka) and the late Holocene (~<1.4–4.3 ka). It is cited for these specific conclusions in the literature (see Harrison et al, in press, Quaternary Science Reviews).

In conclusion, the objectives, data, and results of the 2 papers are fundamentally different. The only shared datasets are the radiocarbon ages of core JPC14, and a few grain-size results.

A sentence summarizing the main results of the "Holocene" paper (Golfo Elefantes remained free of ice during the last 11.3 kyr, and the large moraines that occur along the edges of Golfo Elefantes were formed during the waning stages of the local glacial maxima) was added in section 2 (regional setting).

Specific Comments

I have two main comments.

1- At several places in the sediment cores changes in sediment supply or changes in sediment character are interpreted as representing advances or retreats of the Gualas glacier. For instance on page 2951 lines 12‐15 the authors suggest that high sediment accumulation rates reflect reworking of freshly exposed glacial sediments by proglacial streams, and therefore that the glacier was undergoing recession at this time. However, other possibilities for increased sedimentation cannot be discounted. It could reflect switching of the fluvial network, the resedimentation of unused sediment stores, increased sediment input from valley‐side streams or changes in glacial erosion driven by shifts in climate. The Gualas/Reicher system is highly dynamic and there is clear sedimentary evidence of large drainage events of the Reicher Lake which would have introduced sediments into the catchment to be deposited downstream. Overall, while I agree that paraglacial processes are likely to increase sediment accumulation other options should at least be discounted.

We agree that an increase in accumulation rate could be caused by other mechanisms, such as reorganization of the fluvial network or remobilization of unused sediment sources. This is why we wrote that "The high accumulation rates <u>most likely</u> result from the reworking…". The alternative processes were added to section 5.1. We however believe that these processes are sporadic and would only affect sedimentation and accumulation rates on short timescales. This argument was added to section 5.1.

2- As a result, the interpretation of glacier variations from the core sediments probably needs some additional caveats.

We agree that our interpretation in terms of glacier fluctuations is not the only one possible, but it is the most likely, as indicated in the manuscript. As indicated above, alternative explanations are now included in the manuscript. In addition, we paid attention to remaining careful in our interpretation by using the following terms through section 5: "likely", "if our interpretation is correct", "our results suggest", "may represent", …

Technical corrections (specific points are listed as page and line number).

• Haberle and Lumley (1998) is not referenced

Reference was added

• I could not see that Perdue et al (2007) was cited in the text.

The manuscript doesn't mention Perdue et al (2007). We mention Perdue and Koprivnjak, 2007 in the text, and the reference is correctly cited in the reference list.

• 2939, 8. Insert 'into' before 'three'.

We agree. "Into" was added.

• 2939, 22. I think that 'demonstrate' is too strong a word.

We agree. We replaced "demonstrate" by "suggest"

• 2940, 13. I don't understand this. The last two centuries form part of the Holocene.

We replaced the term "Holocene" by earlier. See "earlier NPI glacier fluctuations"

• 2940, 15. Harrison et al 2008 used OSL and CRN as well as radiocarbon dating.

We agree and we added the following sentence "In addition, attempts to reconstruct glacier fluctuations using cosmogenic radionuclides and optically stimulated luminescence techniques were only partly successful (Harrison et al., 2008)."

• 2940, 29. This is the first time that San Rafael glacier is mentioned. Where is this?

We added the following words "which are all located on the western side of the NPI"

• 2941, 2. Harrison is spelt wrongly.

We corrected this misspelling.

• 2941, 3. 'valid prior to the last century'....the Winchester and Harrison reconstructions looked at nineteenth century recessions.

We agree that Winchester and Harrison reconstructed glacier variability during the 20th and 19th centuries but their comparison with precipitation data (what this sentence and paragraph are about) is limited to the 1919-1989 period.

• 2941, 26. The Glasser at al. (2011) paper looks at a longer time period than Rignot et al (2003).

We agree. The "Glasser et al., 2011"paper looks at data from 1870, while the paper by Rignot et al looks at data from 1968 onwards. Both papers support our statement that "The mass balance of the NPI has been increasingly negative during the last decades"

• 2942, 16. Harrison and Winchester is 1998 not 1988.

We agree. This was corrected.

• 2947, 12. Delete ‘described’ and insert ‘interpreted as’.

We agree. This was modified following the suggestion of reviewer 2.

• 2948, 6. Delete ‘Lumney’ and insert ‘Lumley’.

We agree. This was corrected.

• 2952, 3. How do you know that the moraine is Holocene in age?

This statement is partly based on the recent paper of Fernandez et al (The Holocene, in press), which shows that “the arcuate terminal moraines that occur along the edges of Golfo Elefantes were formed during the waning stages of the deglaciation or the early Holocene”. Since the moraine that is located in front of the present-day Gualas river delta is ~7km to the East (i.e., inland) of the large Golfo Elefantes moraines, it must have formed during the Holocene. This statement and an additional reference to Fernandez et al. were added to section 2 (regional setting).

• 2952, 4. delete ‘high’ and insert ‘rapid’ or another word.

We agree. “High” was replaced by “Rapid”, as suggested by reviewer 2.

• 2952, 24 ‐ 26. Could the twelve thin layers represent periodic drainage from Reicher?

As indicated in section 5.1, we interpret these layers as the result of drainage of Gualas and/or Reicher proglacial lakes, caused by secondary advances of Gualas and/or Reicher glaciers. We agree that other processes could account for the drainage of these small proglacial lakes, but in such an environment with highly variable glaciers, there is a high chance that drainage is related to glacier variations. Periodic lake drainage would indeed increase the amount of water and sediment discharge but we believe that minor glacier advances are needed to rework coarse sediments.

• 2953, 8. Part of Gualas is still calving?

As clearly explained in Harrison and Winchester (1998), Gualas glacier has three ice fronts. Only Gualas West calves in its proglacial lake. Gualas East is land-based. By “land-based”, we meant “not calving into the fjords”, but we agree that part of Gualas glacier calves in a proglacial lake. We replaced the term “land-based” by “inland”.

• 2954, 2. insert ‘hypothesised’ before ‘record’.

We disagree with this comment and didn’t insert the term “hypothesized”

• 2954, 5 ‐ 8. Also dendrochronology and limited OSL and CRN dating.

We agree, which is why we indicated “<u>almost</u> exclusively dated by 14C”

• 2956, 2. The glacier is called San Quintin not Sin Quintin.

We agree. The mistake was corrected.

• 2956, 14 and 19. The authors are ‘Lumley and Switsur’.

We agree. The mistake was corrected.

• 2958, 4. Neukom et al. (2010a) is cited after Neukom et al. (2010b). It should be the other way around.

The citations Neukom et al 2010a and 2010b are correct. They are listed as such in the reference list since they are organized by alphabetical order, as recommended by the guide for authors of CP.

• 2965. Table 1 core depth column and ages. The ages do not correspond to core depths. This needs to be further discussed.

We do not understand this comment. The ages and core depths indicated in Table 1 are correct.

• 2975. Figure 7. How representative is the data from Gallegos River? The authors should use data from a range of proglacial rivers to compare the sedimentology of the core units.

We agree that the grain-size data of Gallegos river may not be entirely representative of the NPI proglacial rivers. We however note that (1) the grain-size distribution of Gallegos river sediments is dominated by silt-size particles between 6 and 20 μm, in agreement with results obtained on other proglacial river systems (Fenn & Gomez, 1989-Particle size analysis of the sediment suspended in a proglacial stream: Glacier de Tsijiore Nouve, Switzerland, Hydrol. Proc; Haritashya et al 2010-Particle size characteristics of suspended sediment transported in meltwater from the Gangotri Glacier, central Himalaya - An indicator of subglacial sediment evacuation, Geomorphology); and (2) grain-size results obtained using different methods are not directly comparable (e.g., Konert & Vandenberghe, 1997, Sedimentology 44). We therefore decided to leave the grain-size distribution data of Gallegos River in Figure 7, and we added references to Fenn & Gomez (1989) and Haritashya et al (2010) in the figure caption to indicate that this grain-size distribution is typical for proglacial rivers in general.

• 2978. The author is 'Harrison' not 'Harisson'.

We agree. The mistake was corrected.

In addition, references to papers "in press" and "submitted" were updated, and a reference to the following recent and relevant paper was added:

- *Post, A., O'Neel, S., Motyka, R.J., and Streveler, G.: A complex relationship between calving glaciers and climate. EOS, 92, 37, 305–306, 2011.*