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Climate of the Past
Discussions

Interactive comment on "Technical note: Optimizing the utility of combined GPR, OSL, and LiDAR (GOaL) to extract paleoenvironmental records and decipher shoreline evolution" *by* Amy J. Dougherty et al.

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The authors would sincerely thank Chris Hein for his thoughtful and thorough review. These comments, along with others posted online and emailed privately, will help hone an improved manuscript should it be accepted for revision.

In following with Climate of the Past's guidelines, this response will be structured such that each revision/comment will be addressed in numerical order following the sequence: a) comments from referee, b) author's response, and c) author's changes

in manuscript.

General Revision #1: a) Consider the addition of groundtruthing as a fourth approach, equally as important as LiDAR, OSL, and GPR. b) While the idea of a grand slam is an appealing one, groundtruthing is not seen as a standalone technique per se. Rather coring or topographic profile collection (for example) as a means of groundtruthing remotely sensed data, is seen as an integral component of GPR and LiDAR methods. While LiDAR, GPR, and OSL can all be used individually or in various combination, it is not recommended that GPR or LiDAR is used without being groundtruthed (or at the very least state the omission and consider when interpreting the data). Coring or outcrop mapping used to ground-truth GPR and topographic profiling using levels, lasers, or GPS to ground-truth LiDAR are all techniques that can be used alone or in combination with other methods (e.g. air photograph analysis or radiocarbon dating) to study coastlines. Ultimately, our counter argument would be that groundtruthing of non-invasive subsurface data is not a critical fourth component to GOaL approach, but rather an essential element whenever remotely sensed high-resolution stratigraphic or topographic data is used (therefore embedded in GPR and LiDAR methods). c) No changes are planned for incorporating groundtruthing as a fourth approach. The point will be clarified about groundtruthing remotely sensed data is not just mandatory for the combined GOaL approach but whenever GPR or LiDAR is used.

General Revision #2: a) Recognize the limitations of certain field sites and conditions which may make any one of the three (or four) "hat trick" components not possible, or not the best approach for a given site. b) It is recognized that the combination of GPR, OSL and LiDAR is not always the best approach or even possible for a given site. However, for those sites where these techniques are able to be used this paper aims to provide insight on how to optimize their utility. We are not insinuating, nor state within the paper, that this is an "ideal" approach for all sites. What is inherent, but seems to be made more explicit, is that the optimizing of this GOaL approach was conceived for sandy prograded barriers. Following on from the discussion of the previous comment the use of GPR, OSL, and LiDAR does not preclude the use of other methods and in some cases necessitates it. Of course where there is organic material for radiocarbon dating, use that instead of or with OSL. c) Having said that, we will include the limitations of GPR, OSL and LiDAR suggested by the reviewer. We will also make clear that this is approach and discussion is geared toward sandy prograded barriers that are meant to complement other studies using various techniques to document the morphology, stratigraphy and chronology of other coastal systems (such as the examples provided by the reviewer: Long et al (2012; QSR 48:61-66) and Billy et al (2015; Geomorphology 248:134-146). This will also include mention of chenier plains as discussed in the response to the comments by Marc Hijma. With regard to the expense of the GOaL techniques, it is agreed that they are still costly. However, the price has come down and access has increased rapidly as of late. This is likely to continue into the future and the aim of this paper is to suggest a few basics moving forward that can optimize the combined use of these methods. General Revision #3: a) Consider adding examples from additional global sites; this does not need to be in the discussion of the three "case studies" as those are meant to be focused on single papers. b) This is a very good suggestion that does indeed broaden and strengthen the paper. In addition to some of references that were meant to be included, the response to this interactive discussion (both in the form of online comments and private emails) provided suggestions for other papers that will also be included. It is true that when drafting the paper the idea was to use the three most recent examples that use GOaL specifically to study sea level, storms, and sediment supply as case studies. However, along the lines of Marc Hijma comment, it will be nice to reiterate some previous examples of successful studies mentioned earlier in the paper as reference when individually discussing study sites specifically on sea level, storms, and sediment supply. c) Additional references (such as those suggested in this review as well as the comment by Zhixiong Shen) will be included in the paper from sites spanning the globe.

General Revision #4: a) Consider a more measured treatment of the Oliver et al (2017a,b) studies. b) Since the submission of this manuscript to Climate of the Past, an

extensive comment on Oliver et al. (2017a) has been published and a similarly detailed discussion paper on Oliver et al. (2017b) has been accepted with minor modifications (Dougherty, 2018a,b). These comment papers allow a nuanced conversation of the data and interpretations presented in each that was simply not possible nor appropriate for this technical note. This allows us to refer to these comment papers for a fuller discussion when identifying the potential pitfalls encountered when GPR, OSL and LiDAR are not used optimally. This technical not will focus specifically on how interpretations can be questioned when GPR data is not groundtruthed with cores as well as when rendering of LiDAR (and topographic profiles extracted from the remotely sensed data) masks or distracts from important aspects of the morphology. The importance of groundtruthing is agreed, as per the discussion above, and presnetaion publicly does matter if it is influencing interpretation (see discussion in Specific Comment #6 below). While it is uncomfortable to critique specific studies, it is necessary in order to have a rigorous scientific debate. Because of the critical nature of this aspect of the paper, it was important to us that it was published in a way that the authors of the Oliver et al. (2017a, b) papers could comment or correct anything that might be misleading. We are grateful for Climate of the Past's open access and interactive review process which allowed this option. Authors associated with both papers were made aware of this technical note addressing methods used in their papers before it was submitted and it is known that the lead author has viewed this Climate of the Past submission (as informed by ResearchGate). c) The two sections referring to the Oliver et al. (2017a,b) studies will be redrafted so that specifics to the study sites are minimized. Many of the points raised by the reviewer are addressed with greater context in the comment papers and since they would not be included in a revised draft of this paper if accepted, we will not reply to specific aspects here. Rather outline the main points that will be addressed in the revision of these two sections and points raised by the reviewer that pertains to them. Ultimately, trying to focus these sections on the transferrable lessons for the best practice use of the GOaL techniques (as suggested by the reviewer).

3.2 Storms To determine a storm record requires eroded paleo-beachfaces to be clearly identified within the stratigraphy. This requires coring of these storm layers and using these cores to groundtruth the GPR and make gain adjustments. Failure to do this can result in ambiguous interpretation of storm plaeo-beachfaces. A new example of GPR data will be added that shows GPR data with high gain applied masking the storm layers. This same data with the gain reduced according to an overlain core reveals obvious storm layers. This will demonstrate the potential to interpret an over exaggerated storm history for sites that do not core or adjust gain, such as Oliver et al. (2017b).

3.3 Sediment supply and coastal evolution In order to discuss changes in evolution through time and not confuse these with alongshore variations, a single shore-perpendicular transect line from the oldest to the youngest part of the barrier is optimal. This GOaL paper advocates for using LiDAR to determine where the best location is to collect this transect. Then collect GPR along this transect and use this morphostratigraphy to target the best location to collect OSL. We agree with the reviewer that integrating two or more parallel lines improves the robustness as well as allowing a discussion about alongshore variation through time. However, this is not our point or the reason for the multiple lines drawn in Figure 7d. Rather these lines were extracted from the rerendered LiDAR to demonstrate how it can be used to determine the best location to extract the best transect to span the entire history. This process clearly shows that the western profile is the most complete. Comparing this one transect to those presented by Oliver et al. (2017a) identifies gaps within the morphologic data at points where the evolution shifts towards the beginning of barrier inception and in the most recent period. The LiDAR shows the accommodation space changes through time and identifies that anomalously large foredune ridges formed during this time. However, GPR and OSL were not collected for these areas of interest. The gaps in the topographic record, GPR stratigraphy and OSL chronology during these two points in time raises the question of whether the interpretation of halted progradation is due to ceased sediment supply or just a result of a lack of data. At the very least identifying that these gaps exist and considering the implication is crucial to any discussion about barrier

evolution and the role of sediment supply. This does not negate sizable amount of data presented for the other area of the work that no doubt went into collecting it. Rather that following the simple order and suggestions presented in this GOaL methodology might have helped optimize this dataset by first targeting shifts in evolution using LiDAR morphology, detail how these sections of the barrier formed using detailed stratigraphy from GPR and then dating the timing of these changes using targeted OSL samples.

Specific Comments #1: a) P6, L9 & Figure 2: this is focused on the utility of LiDAR, not the details of this study. However, it is not clear that the multiple sets of "prograded barrier islands" shown here were never a single island / beach-ridge plain. This is a great example of possible reworking of a non-continuous record, a limitation in reconstructing the evolutionary history of a progradational site, or the paleoenvironmental records contained within. This in fact may be a case for the use of subsurface data (GPR) to search for, e.g., landward-dipping beds at the landward side of each of those "islands" to try to infer if they formed as separate transgressive-regressive islands. LiDAR data here may in fact tell an incomplete story. b) The main point of this section was to demonstrate how LiDAR can provide improved images of the morphology of coastal system and their surroundings to inform where to collect GPR. This approach was used at Rangitaiki Plains, but the GPR aspect was excluded so that LiDAR could be the focus. Based on this comment, it seems pertinent to add that this informed GPR collection. The combination of these data, along with previous studies of the area, was used to determine the evolution of this complex coastal system. The evidence for this series of prograded barrier islands is that the landward extent of each naturally transition into back-barrier deposits. These cohesive muds were more resistant to erosion and therefore preserved the morphology of the rear portions of these barrier islands as compared to the more easily erodible sandy beach and dune facies evidence by the reworking of the seaward side of these barrier islands. Beach-dune interface mapped in the GPR of these barriers show elevational offset of up to 5 m between sets of ridges. Their episodic formation is dated by volcanic ash and pumice layers deposited on these barrier islands and their associated back barrier environments (Selby and

Pullar, 1971). c) This discussion will be modified to clarify points raised above. Also an alternative LiDAR image with different rendering will be added to Figure 2. This will help to refocus this discussion on the utility of LiDAR and not the details of this specific study by emphasizing the point that how data is presented impacts identification of barrier features.

Specific Comments #2: a) P8, L8-9: this statement would be stronger if supported with examples or details of how beachface mapping can be used to infer sea level, etc. b) Nice suggestion. c) References of examples will be added to this sentence and an image of data that demonstrates beachface mapping will be added to Figure 7.

Specific Comments #3: a) P8, L14: suggest being more specific. What about the change in reflection geometry indicates storms? b) Noted that the use of "distinct geometries" is not very specific. In fact, storm-eroded beachfaces can be hard to distinguish on shape alone as evidenced in the Oliver et al. (2018b). c) A sentence will be added that states that storm eroded beachfaces display more flat-lying lower beachfaces and steeper upper beachfaces, but that the distinction form swell accreted paleo-beachface geometry is easier to detect on the basis of signal strength. Also the addition of GPR data to demonstrate this will be added to Figure 7.

Specific Comments #4: a) P8, L19-26: If the authors are going to discuss these aspects of GPR processing and interpretation (including the necessity of ground-truthing, as discussed earlier), then it is also worth noting some additional key processing steps for proper GPR interpretation. For example, migration, ideally using field common-midpoint (CMP) surveys, to determine radar velocities. b) It was very intentional not to specifically talk about processing steps, even very basic ones (as discussed in the GPR section). This is done for many reasons, one of which is that there are many different software packages, GPR brands and unit configurations (even within brands). Using the example above, some systems have transceivers and therefore cannot do common-midpoint survey; while some software packages process in terms of velocities and others use dielectric constants. We found it important to not get into specifies or

advocate for any one approach. There is already a lot of literature out about processing and even recommended steps in coastal settings. What people will use is likely a product of the equipment they have access to. In each case the user should research papers that use the same configuration and software, then use the methods from papers that provide good examples as a base to start processing their data. The end goal is to present the data in a way that best represents the subsurface stratigraphy that it is imaging and highlight the specific aspect that is the focus of discussion. To this end, we feel that gain and groundtruthing are two crucial aspects that have not been emphasized enough and therefore highlight them here. c) No addition of other processing steps will be discussed. Authors will review section explaining this decision and increase clarity about the reasoning.

Specific Comments #5: a) P10, L10: "calculations from the LiDAR data". It may be worth noting that this would not have been possible without ample stratigraphic data from sediment cores, especially given the limited GPR penetration. b) Yes to determine the total volume of barrier sands requires cores through the entire sequence. The references to calculations from the LiDAR data are specifically about the volume above MSL, similar to volume calculations for the envelope of change of modern shorelines form beach profile data. This is stated in the second mention on page 14, but oddly not the first on page 4. Thank you for drawing attention to this initial omission. c) We will add 'volume of barrier sediment supplied above mean sea level' from page 14 to the first mention of volume calculation on page 4.

Specific Comments #6: a) P12, L15: "gain control is high in the GPR data". That could just be the way in which the GPR data are shown in published form; that can be a challenge to get right. Presumably the GPR data were analyzed in high detail, and through careful tuning of gains to ensure best analysis resolution. Only those authors can speak to this. This same interpretation could be applied to criticisms of Oliver et al (2017a) noted on P14, L7-8 (LiDAR color scheme chosen for publication display). b) Gain can be a tricky step to get right and really requires cores or some idea of what is being imaged in order to properly display the amplitude of change recorded in the GPR. Even without any groundtruthing to refer to, if the focus of the interpretation is that every beachface reflection represents a storm and ridges are formed by eolian processes, then at the very least the GPR should display the difference between beach and dune facies. We do not presume to know what the authors did with regard to the data, but can only speak to what is presented. What is known is that regardless of the detail of analysis or tuning of gains, ultimately the 'interpreted' data consists of every reflection being simply traced with no distinction of signal strength or barrier facies. With respect to the LiDAR, a similar response could be made that the presentation of the data should best reflect what the authors want the readers to focus on. While it is not known if other color schemes were trialed during analysis, the rendering chosen and topographic profiles extracted do not highlight increased accommodation space or the anomalously large sizes of the foredunes that formed during the specific time periods in question. c) Changes made to Figure 7 to clarify the point about the importance of gain. In addition to trying to demonstrate this with the core, outcrop, and GPR in Figure 3, Figure 7 will be amended to try a different approach to display the importance of gain adjustments. LiDAR with a different rendering has been added to Figure 2 to reiterate the importance of color scheme.

Technical Corrections #1: a) P2, L20-21: the point concerning collaboration between scientists with specific expertise in each of the tools (some of which [e.g., GPR or pre-processed LiDAR data] are perhaps easy to use, but not easy to use well!) described in an important one. b) This is a nice distinction that the ease of acquisition of these data, does not translate to ease of correct use (but the turn of phrase "easy to use, but not easy to use well!" is much better). c) This point will be added to the text.

Technical Corrections #2: a) Figure 5 caption: "prograded normally for a while". This is unclear, unspecific, and qualitative. (the term "normally" is applied on P11, L7 as well, and does not seem to necessarily indicate "normal [sediment surplus driven] progradation". Correct?). "drastic shift in evolution observed . . ." this is not clear from the

data presented, nor is it clear what would qualify as a "drastic" change b) This concept of how to term a barrier that is prograding in a consistent fashion, is something the authors discussed when it was initially referred to it as 'classic' progradation. We tried regular, uniform, ect. and agree the use of the word normal is not optimal. It is actually meant to indicate "normal [sediment surplus driven] progradation" that results in the tell-tale series of relic foredune ridges apparent in the air photograph. Within the last millennia the relic foredune ridges that formed between 1,700 and 1,000 yr BP were eroded and large transgressive dunes forms on the landward and seaward edges of the blowout. Over the last 1,000 years progradation also differs forming low-lying hummocky incipient dunes rather than larger distinct foredune ridges. In combination, this data defines a drastic shift in evolution over the last millennia as compared to previous ones. c) Changes will be made to the manuscript to clarify this point.

Technical Corrections #3: a) P11, L15: Costas et al 2016 is listed twice b) Thanks for catching this Endnote user error c) Delete one

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