“Terrigeneous material supply to the Peruvian central continental shelf (Pisco 14 S) during the last 1100 yr: paleoclimatic implications” by F. Briceno Zuluaga et al.

Answer to Anonymous Referee #1

We are thankful to the anonymous reviewer 1 for the critical and constructive comments, which will help to greatly improve our manuscript. We think that our paper provides a substantial contribution to scientific progress because in this paper we show evidence for a mechanistic understanding of the large changes that occurred in the Eastern Topical South Pacific during the last millennia. In the new version we will carefully revise the whole manuscript in order to separate the new contribution of this manuscript from the previously published works. In the submitted manuscript we did not explain in detail the methodology and omitted important aspects. In the new version of the manuscript we will explain in more detail the rationale behind our method. We will also include more information about the site and the composite record.

SPECIFIC COMMENTS

Remarks 1: The paper does not present any description of the sedimentary record (no sedimentary log), no description of physical setting of both cores (depth, bathymetry, seismic profile, physical parameters of the water column,: : :), no chronological information and no information about how the composite profile as been established. The paper only refers to other papers, but the information is spread over several paper and difficult to synthesize in order to follow the authors rationale.

Response 1: We agree with the reviewer that we didn’t include the full sedimentological characteristics of the cores used in this study since they have been fully described in other papers as in Gutierrez et al., 2006; Sifeddine et al., 2008 and Salvatteci et al., 2014) for core B06. In the revised version we will add more information about the site and the composite record as suggested by the reviewer.

Remarks 2: The paper should also explain what are the phenomenons behind the formation

of laminations.

Response 2: The Pisco continental sediments are characterized by a succession of darkness and lightness laminae. This laminae structure is related to a complex interplay of factors including temporal variations in the quantity of terrigenous sediments supplied to the shelf by rivers and then by bottom currents as well as variations in the fluxes of siliceous and organic components to the sediment floor,which in turn are a function of upwelling-driven productivity and dissolution in the water column (Brodie and Kemp, 1994, Salvatteci et al., 2014 Mar Geo). Finally, the existence of strong oxygen minimum zone (OMZ) inhibiting bioturbation (Gutiérrez et al., 2006) and low currents actions allow the hemipelagic sedimentation (Suess et al., 1987). We will add in the revised version of the manuscript more relevant information about the formation of laminations and how we can use them to assemble composite records.

Remarks 3: Moreover, it is impossible to find a description of core G-10 in the Salvatteci et al 2014 (Clim Past) from the reference list.

Response 3: The stratigraphic approach, sediment sub-sampling, age model of core G10 are presented in the supplementary data (SM1, SM2 and SM3) of Salvatteci et al., 2014b (Clim. Past). In the revised version of the manuscript we will include more information about core G10 and how the composite record was assembled.

Remarks 4: However, I found another paper by Salvatteci et al. 2014 in Marine Geology, describing the stratigraphy of core B-6, but there is no mention of G-10 in this paper. This latter paper shows that the link between two cores in this setting is difficult to do because of slumps induced by earthquakes. It is therefore critical to explain how the composite section has been built for this paper, and have a comprehensive description of the sedimentary sequence and the geological setting. It raises some concerns about the reproducibility and the traceability of results.

Response 4: We agree with the reviewer that is critical to explain how the composite record was assembled. We will do this in detail in the revised version. The paper by Salvatteci et al., Mar Geo, shows that it is difficult to establish the link between cores but it has been done for several cores off Pisco including B6 and G10 (see figure SM1 in Salvatteci et al CPD supplementary material). The paper published by Salvatteci et al (Mar geology) raises concerns reproducibility of the results only if a careful sediment logical description of the cores by X-ray images means is not done. For example two cores collected 300 km show the same centennial-scale variability during the last 700 years (Gutierrez et al. 2009). These two cores (one of them is B6) have independent chronologies based on several 210Pb and 241Am data points, several 14C ages, and the identification of sedimentological structures by X-ray images.

Remarks 5: Another problem is that authors are mentioning a southward redistribution of river sediments because of currents, a feature that is indeed credible.

However, authors should at least discuss the possibility of countourite that could occur in this kind of settings, i.e. continental slope. This is critical, because countourites are capable of moving/depositing sediment such as coarse silts and fine sands. Sedimentological analyses demonstrate that slope-parallel currents lead to winnowing of fine particles and (re)deposition of allochtonous material, which alters the grain-size populations, (see for instance Mulder et al., 2013) and the paleoclimatic reconstruction that are performed using these kind of sediments (for instance Keigwin, L. D., and M. A. Schlegel (2002)).

Response 5: The formation of countourite is one of characteristic off north Peru but not in the Pisco area because Reinhardt et al., 2002; Suess et al., 1987 and Gutierrez et al., 2006 have described the sedimentary facies in the Peruvian shelf as well as the role of currents in the erosion and redistribution processes over the Peruvian continental shelf. These works have showed that high resolutions sediment record should be present only in specific localities of the continental margin (high rate sedimentation zones). First, Suess et al, (1987) described the formation of two sedimentary characteristic facies between 6 – 10°S and 11 – 16°S. The first area (6 – 10°S, Salaverry basin) is characterized by the absence of sediment accumulation due to strong undercurrents. This area could be a good candidate for studying the contourites (if any) and the undercurrents effects considering the diagnostic criteria described in Rebesco et al., (2014). The second area (11 – 16°S, Lima Basin) is characterized by lens shape of depositional center of organic-rich mud facies favored by the oceanographic dynamic within the continental shelf, such as the position and velocity of the southward poleward current (Gutiérrez et al., 2006; Reinhardt et al., 2002; Suess et al., 1987). In addition to the works quoted above, high resolution profile was obtained with ecosounder Bathy 2000P during the “Paleomap 2006” cruise. The identified upper mud lenses are characterized by fine grain size, diatomaceous, hemiplegic mud and high organic carbon and the absence of erosive and bioturbation processes. We will add more information about this in the revised version of the manuscript.

Remarks 6: The grain size distributions presented here also are quite similar to the grain-size distributions smaller than 200 µm found in other countourites. This is a serious problem because the technique used here does not include the fraction > 200 µm. Therefore, it should be essential to provide the reader with quantities of sediment that were removed from the grain-size analysis because of this filtering. Authors should also justify why they used the Flow Particle Image Analyzer technology rather than regular techniques that are capable of analyzing the full size range of sediments, and demonstrate this is not important for the interpretation of the results.

Response 6: We apologize for this misunderstanding, we forgot to mention in the submitted version that particles coarser than 200 µm were never found in any samples after sieving. That means that the sediment samples do not contain such coarse particles, and that the grain-size distributions displayed in this study well represent the whole samples. As a consequence, the use of the Flow Particle Image Analyzer (with its restriction on measurable size ranges) has no consequence on the results and their interpretation. Moreover, such grain-size analyzer allows us to obtain images of all the detected particles and therefore, to check the efficiency of the chemical pretreatment of the samples, which is an important step in the grain-size analysis.

TECHNICAL COMMENTS

L61: GSD is not mixed since laminations are preserved, and I therefore suggest the following wording: "Grain size distribution in laminated marine sediments may indicate different sources and/or deposition processes, expressed as polymodal distributions.

Response: Thank you for the suggestion; we will modify this sentence as suggested.

L65: I suggest the following: "(: : :) identifying the different sedimentary processes and the past environmental conditions behind them (: : :)"

Response: Agree, we will change the sentence.

L96-97: I’m sorry, but there is little about the sedimentary processes sensu stricto in the paper. For instance, authors are not really explaining what type of current/process leads to deposition of riverine material.

Response: In fact, there is a wealth of information on sedimentary processes on the continental shelf explaining the dispersion and deposition that were eventually cited in the document. Optionally we could written a brief summary indicating works such as Reinhardt et al., (2002); Smith, (1983); Suess et al., (1987).

L101-111: The information presented here is not sufficient to have a self-sustaining paper. A lot more information about the cores and the site should be included in the paper.

Response: We agree with this suggestion and will include more information about the study area, the cores, the composite record to have a self-sustaining paper.

L112-121: I understand what you are aiming for, but the practical explanations remains unclear. Please rephrase this section.

Response: We will rephrase this part for a better comprehension.

L123-127: The sample thickness is missing. It is important because it would provide an idea of the number of laminations included in each analysis. It should be also a good idea to provide the variation of the number of laminations through time.

Response: Sample thickness in core B6 ranges from 0.5 cm to 1.0 cm, and usually includes 2-3 laminaes in core G10 each sample is 1 cm thick and usually include 3-4 laminae. In our manuscript we are not focusing on sub-decadal or decadal-scale time series. We focus on centennial-scale changes in terrigenous input and thus we were not interested at the laminae scale variations that will be an interesting work especially for the last 100 years of the record.

L127-129: It is essential to provide the reader with quantities of sediment that were removed from the grain-size analysis because of this filtering. The interpretation of the data highly depends on that.

Response: As mentioned above (Response 5), this information is unfortunately missing. We will add it in the text in section 2.1 - Grain size analyses as follows: "In practice, particles larger than 200 µm had never been encountered in any samples"

We apologize for this misunderstanding, we forgot to mention in the submitted version that particles coarser than 200 µm were never found in any samples after sieving. We processed the whole sample, nothing was removed from the sample. We will modify this accordingly in the revised version of the manuscript.

L185-186: Sun et al. (2002) indeed write that, but in the frame of loess sediments. The exact citation is: "In loess deposits, the wide size range of the fine component and the low degree of sorting suggest that they are slowly and continuously deposited throughout the year Â˙z. This is not applicable here.

Response: This assumption is applicable too for our scenario because the assumption that the fluvial input particles is a slowly and continuously deposited throughout the year.

L189: What are these favorable erosional soil properties? Are they consistent with the situation here?

Response: favorable conditions are for erosion are: lack of vegetation, low threshold friction velocity, surface roughness and low soil moisture. For more details, see Iversen and White, (1982) and Marticorena and Bergametti, (1995). Such conditions prevail in the studied area since the central coastal Peru consists of a sandy desert area characterized by no rain, a lack of vegetation and persistent wind (see, for instance, Haney and Grolier, 1991). This will be better addressed in the paper.

Haney, E.M. and M.J. Grolier, Geologic map of major Quaternary aeolian features, northern and central coastal Peru, IMAP 2162, USGS Publications Warehouse, 1991

L192: The sample that is the most influenced by wind in Stuut et al. 2007 (core GeoB7108) has a mode that is 400µm, something that the authors in this study would have missed because of the technique used. Moreover, the grain-size analyses interpreted by Stuut et al (2007) were only described for the samples from water depths >1000 m. Since cores are collected at much shallower depths in this study is the Stuut et al (2007) interpretation still valid? Again, this is critical to address this issue to support your interpretation.

Response: As already mentioned, we didn't miss any size-mode and our samples do not contain any particles coarser than those detected. On the other hand Stuut, et al (2007) related the presents of typical distribution of wind-blown transport near to ~80µm (~29°S North of Chile) which is consistent with our results. In this case the relationship between distance and wind force and conditions of sedimentation is more important than depth.

L193: Flores-Aqueveque et al., 2015; these authors are mentioning particle >100 µm and actually in their figure 7, they measured grains up to 400µm, which would not have been measured by the grain-size technique used in this study.

Response: We didn't miss any size-mode and our samples do not contain any particles coarser than those detected, we did not explain in detail in the submitted manuscript but will do in the revised version. Moreover, there is no Figure 7 in Flores-Aqueveque et al., 2015. So, we don't know to which paper the reviewer is referring.

L197-198: Is this last sentence really useful?

Reponse: Maybe not. Thus, this part could be rewritten to better understanding of the reader

L199-201: Contourite and hyperpycnal flows can transport these coarse grains. Moreover, some of the co-authors of this paper reported the presence of slumps in this area in another paper; slumps can transport coarse grains. Authors should carefully and comprehensively argue that these phenomena do not affect sedimentation here, otherwise their interpretation falls apart.

Response: Suess et al, (1987) described the formation of two sedimentary characteristic sedimentary facies between 6 – 10°S and 11 – 16°S. The first area (6 – 10°S, Salaverry basin) is characterized by the absence of sediment accumulation due to strong undercurrents. This area could be a good candidate for studying the contourites (if any) and the undercurrents effects considering the diagnostic criteria described in Rebesco et al., (2014). The second area (11 – 16°S, Lima Basin) is characterized by lens shape of depositional center of organic-rich mud facies favored by the oceanographic dynamic within the continental shelf, such as the position and velocity of the southward poleward current (Gutiérrez et al., 2006; Reinhardt et al., 2002; Suess et al., 1987). This should be explaining in details in the new version of the paper.

L219-220: McCave writes in the abstract: "We cannot use size distributions to distinguish the nature of the currents.

Response: In fact, the aim of this paper is not to see the nature of the currents but particles sources.

L230-231: Again, the composite record should be described in this paper.

Response: We agree with the reviewer, more details about the composite record will be added to the revised version of the manuscript

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Answer to Anonymous Referee #2

We are very grateful for the quite thoughtful anonymous reviewer 2. Clearly, the reviewer spent much time and effort as put on the part of the reviewer and we appreciate his/her comments very much, which will support to greatly improve our manuscript.

General comments:

Remarks 1: The manuscript presented by Zuluaga et al. use grain size distribution of two laminated sediment cores collected off Peru to reconstruct terrigenous material supply to the Peruvian shelf over the last ~ 1100 yr at high resolution. Although the manuscript falls within the scope of CP, to my knowledge, it does not add novel information about the past climate of the area.

Response: We think that our paper provides a substantial contribution to scientific progress because we show new evidence for a mechanistic understanding of the large changes of terrigenous input (fluvial vs Aeolian transport) that occurred in the Eastern Tropical South Pacific during the last millennia. In fact, our data of grain-size distribution provides an accurate and specific proxy of fluvial input changes which confirms the previous findings by Rein et al. (2004), Sifeddine et al. (2008) and Gutierrez et al. (2009) using mineralogical proxies. Moreover, we present new evidence for the variability of wind intensity and then atmospheric circulation in a temporal scale. We also provide an accurate proxy of runoff linked to the ENSO-like variability. In the new version we will carefully revise the whole manuscript in order to separate the new contribution of this manuscript from the previously published works and highlight their importance.

Remarks 2: Additionally, the manuscript lacks description of the sediments (at least a short lithological summary for both cores; lamination throughout? in part?), collection sites and detailed composite chronology. Moreover, the interpretation of grain-size data seems to be oversimplified for a continental shelf area that is geologically not that simple. More information on the physical setting of coring sites and transport mechanisms of particles from the continent needs to be provided.

Response: We agree with the reviewer that we didn’t include the full sedimentological characteristics of the cores used in this study. As it was discussed (with Referee 1) that these characteristics have been fully described in other papers such as Gutierrez et al., 2006; Sifeddine et al., 2008 and Salvatteci et al., 2014 for core B06. However, in the revised version we will add more information about the sedimentological characteristics as suggested by the reviewers. In the new version of the manuscript we will explain in more detail the rationale behind our method and explain in detail each aspect. Also, as it was discussed with the Referee 1, we can make a small overview of the most important oceanographic and sedimentary characteristics in finding a better understanding of the properties of the records.

In the full review and interactive discussion, the referees and other interested members of the scientific community are asked to take into account all of the following aspects:

1. Does the paper address relevant scientific questions within the scope of CP? YES

2. Does the paper present novel concepts, ideas, tools, or data? NOT REALLY

Response: We agree with the reviewer that is better explain the scope of the paper and mention that in fact there are no works of the sedimentological dynamic input as proxy of the behavior of the atmospheric variability i.e. precipitation (runoff) and continental wind intensity in high resolution in the eastern of Peru. Besides, the proxy we used, disentangling the data showed the evolution of the climatology mechanism (ITCZ-SPSH) in response of the principal climate periods and its relationship with both wind intensity and fluvial input variability. Important mechanisms for understanding the atmospheric-ocean dynamic in this area are relevant for the Humboldt upwelling system dynamic and the relationship with the ENSO conditions. In the new version we will carefully revise the whole manuscript in order to underline the new contribution from the previously published works. For the first time the origin and the mechanism of transport of the terrigenous materials in the continental shelf are elucidated and deciphered as direct indicators of the behavior of the atmospheric variability i.e. precipitation (runoff) and continental wind intensity.

3. Are substantial conclusions reached? NOT REALLY

Response: In the new version we will pay attention in guide better each one of the conclusions and its relevant importance. We think that our paper provides a substantial contribution to scientific progress of the paleoclimatology occurred in the Eastern Topical South Pacific during the last millennia.

4. Are the scientific methods and assumptions valid and clearly outlined? NOT REALLY

Response: The methodology used in this work (the Flow Particle Image Analyzer technology) has several advantages: First, each of the particles can be seen in each sample, which assures the analysis of mineral particles only, assessing the chemical attack efficiency and offering the possibility of elimination of the non-lithological particles. Images may be used to identify the origin of particles by their optical characteristics such as the case of black carbon (Flores-aqueveque et al., 2014). Moreover, if one ignores the images, this method provides grain-size information comparable to that obtained with a classic laser granulometer methodology. Finally, in the aim to indicate the different sources and/or deposition processes, several works use the deconvoluted gran size with success as Gomes et al., 1990; Prins and Weltje, 2012; Stuut et al., 2002, 2007; Weltje and Prins, 2003.

5. Are the results sufficient to support the interpretations and conclusions? It is not a self-sustaining paper

Response: Previous sedimentological studies in the upwelling area as Böning and Brumsack, 2004; Gutiérrez et al., 2006, 2008, 2011; Reinhardt et al., 2002; Salvatteci et al., 2012, 2013; Sifeddine et al., 2008; Suess et al., 1987 and others, showed that these markers can be used to reconstruct paleoceanographic/paleoclimatological variability. This area presents laminated sediments material without bioturbation and low currents erosion action (Gutiérrez et al., 2006; Reinhardt et al., 2002; Suess et al., 1987) which represents an area suitable for paleoenvironmental studies. Based on these studies, we applied a new grain-size proxy used as a marker of terrigenous input as used by Flores-Aqueveque (2015). The grain-size distribution is an accurate proxy to reconstruct aeolian transport as used in (Mulitza et al., 2010; Prins and Weltje, 2012; Stuut et al., 2002, 2007; Sun et al., 2002; Weltje and Prins, 2003).We will include more information about the study area, the cores, and the composite record to have a self-sustaining paper. We agree with the reviewer in the fact of including sedimentological characteristics section of the cores used in this study although this has been done in other papers (i.e. Gutierrez et al., 2006; Sifeddine et al., 2008 and Salvatteci et al., 2014).

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? NOT COMPLETELY; chronology not given; full range of grain-size not given.

Response: These two cores have independent chronologies based on several 210Pb and 241Am data points, several 14C ages, and the identification of sedimentological structures by X-ray images. Although this data was published in other works, we will show the chronological models in the supplementary material. On the other hand, we must apologize for forgetting to mention that particles coarser than 200 µm were never found in any samples. In fact particles >130 µm were very rare to find. As consequence our data, represent the full range of the grain size.

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? YES

8. Does the title clearly reflect the contents of the paper? YES

9. Does the abstract provide a concise and complete summary? YES

10. Is the overall presentation well structured and clear? YES

11. Is the language fluent and precise? NEEDS SOME WORK

Response: Thank you for the suggestion; we will work in this item as suggested.

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? YES

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? SEE BELOW, SPECIFIC COMMENTS

14. Are the number and quality of references appropriate? YES, although there seems to be too many references, and some are not relevant.

15. Is the amount and quality of supplementary material appropriate? NO. The suppl. Material should include the age model of both cores B040506 and G10-GC-01, and especially details on how the composite record was build. This is a critical point.

Response: We agree with this suggestion and as appointed before we will include this information in the supplementary material looking for a better understanding of the manuscript. On the other hand, more details about the composite record will be added to the revised version of the manuscript.

Specific comments:

Although the authors present new data (i.e. grain-size) for the Pisco shelf area, I have 3 main concerns that need to be addressed before this manuscript can be considered for publication:

1) Physical setting of the collection sites needs to be given as well as a summarized sediment description.

The manuscript lacks presentation of the sampling sites with respect to processes (other than eolian input) that may affect the transport of particles from the continent to the ocean (e.g., strong or weak bottom currents?, erosional processes, slumps/earthquakes, etc.).

Moreover, the Salvatteci et al. (2014 in CP) paper in its supplementary information reveals 2 slumps in core G-10, some clearly laminated sections and several banded intervals. X-radiographs of nine cores are shown in this publication (including G-10 and B-06), all of them showing intervals with slumps.

Citing Salvatteci et al. (2014 in Marine Geology vol 357): "… two possible mechanisms can explain the presence of the homogeneous sediments: slumps triggered by earthquakes and sediment instabilities, and/or sediment transported by strong bottom currents". … "Another mechanism that can be responsible for the re-deposition of sediment from upslope in some portions of the cores could be related to changes in the intensity of the Poleward Undercurrent which is stronger during El Niño events". … "All the cores evaluated in the present work show discontinuities and the addition of previously deposited material". With so many factors at play, isn't the interpretation of grain size in this manuscript somewhat oversimplified? By the way, I could not find the reference to the frequently cited Salvatteci et al. (2014) in the reference list.

Response: We agree with the referee in this point and in the new version of the manuscript we will write a section describing the sedimentological and oceanographic features that allow the hemipelagic sedimentation and the formation of the laminated sediments in the Pisco continental shelf. These features have been previously addressed deeply by Gutierrez et al., (2006); Reinhardt et al., (2002); Saukel et al., (2011); Scheidegger and Krissek, (1982); Smith, (1983); Suess et al., (1987) and we can make a description in the new version of the paper. Regarding the comment about the difficulties to link two sediment cores, the slump in different sediment cores in fact exist. Differences between records do not necessarily represent losses as not direct evidence of discontinuities was found, and maybe it is product of differences in the sedimentation rate as was appointed by (Salvatteci et al., 2014). Nevertheless we can reconstruct historical record using different cores of the same area (Pisco mud lens) as was the case here. The paper by Salvatteci et al., Mar Geo, shows that it is difficult to establish the link between cores but it has been done for several cores off Pisco including B6 and G10 (see figure SM1 in Salvatteci et al CPD supplementary material). The distribution and deposition of particles is consistent in both sediments cores. In this work we did not consider that slumps in the record for analysis and for the temporal windows showed here processes as bottom currents erosions appear to be negligible. Indeed, the sediment section chosen here to complete the record (S5 in the core G10) has no hiatuses and cover the MCA period. We will mark in the figures and include additional material about how the composite record was assembled. Finally we will include the correct reference for Salvatteci et al. (2014) in the final version.

2) Chronology. Detailed chronology for both cores used in this manuscript needs to be included as well as an explanation on how the composite record has been built. Given the issues raised in (1), this is critical! Please add X-radiographs of the cores and the composite, a table/fig. with the Pb210 and C-14 data, and the overlap/match between both cores.

Response: We agree with the reviewer that it is critical to explain how the composite record was assembled. We will do this in detail in the revised version. These two cores have independent chronologies based on several 210Pb and 241Am data points, several 14C ages, and the identification of sedimentological structures by X-ray images. In the new version we will include a table or figure with the chronological information.

3) Grain-size Analysis. a) Authors should state the advantages/disadvantages of using the chosen method (Flow Particle Image Analyzer) over other techniques. This goes in hand with the question: a) Is the >200 microns fraction not important off Peru, on a setting such as the continental shelf? If so, please tell us why.

Response: We apologize for this misunderstanding, we forgot to mention in the submitted version that particles coarser than 200 µm were never found in any samples after sieving. That means that the sediment samples do not contain such coarse particles, and that the grain-size distributions displayed in this study well represent the whole samples. On the other hand the Flow Particle Image Analyzer technology has several advantages: First each of the particles can be seen in each sample, which assures the analysis of mineral particles only, assessing the chemical attack efficiency and offering the possibility of eliminate the non-lithological particles. Images may be used to identify the origin of particles by their optical characteristics such as the case of black carbon (Flores-aqueveque et al., 2014). Finally, if the images are to be ignored, this method provides size information comparable to that obtained with a classic laser granulometer methodology.

b) Removal of opal. Have the authors checked that all opal was really removed? What is the opal content in Pisco sediments? (I believe these are sediments loaded with diatoms). Over the years it has become more and more evident that the removal of all opal from a sample is not an easy task. Please add a sentence or two about this issue in the methods section, making sure that the methodology employed has removed all opal from each sample.

Response Using the Flow Particle Image Analyzer technology allows us to capture images of all the particles passing through the cell measurement. We observed that opal had been fully removed from all the analyzed samples, which confirm the efficiency of the pretreatments we used.

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RELEVANT CHANGES MADE IN THE MANUSCRIPT:

It was rewritten part of the introduction with the aim to clarify the novelty and importance of this publication for the knowledge of paleoclimate in the region. Moreover, was written a new chapter called sedimentary settings to explain the favorable characteristics of the formation of laminated sediments at Pisco region. This chapter explains also the mechanism of input of the lithological terrigenous material over the continental shelf and the laminate formations.

In the same way it was added another chapter (Stacked record in Methods) to explain the principal characteristics of the sediments cores (chronology, homogeneous deposits, slumps and subsample) as well as the Method used for perform the record. Thus, new data was added as supplementary data for explain this characteristics (supplementary material 1 and 2). It has been enhanced the description of the grain size analysis in order to highlighting the use of lithological total fraction. Finally, was rewritten part of the discussion and all the conclusions for better explained the results and the contributions to the scientific progress of the paleoclimatology in the Eastern Topical South Pacific during the last millennium.

TERRIGEN~~E~~OUS MATERIAL SUPPLY TO THE PERUVIAN CENTRAL CONTINENTAL SHELF (PISCO 14°S) DURING THE LAST 1~~1~~000 yr: PALEOCLIMATIC IMPLICATIONS.

F. Briceño-Zuluaga[1,2], A. Sifeddine[1,2,3], S. Caquineau[2,3], J. Cardich[1,2], R. Salvatteci[2,3,5], D. Gutierrez[2,4], L.Ortlieb[2,3], F. Velazco[2,4], H~~ugues~~ Boucher[2,3], C~~arine~~ Machado[1,2].

[1] Departamento de Geoquímica, Universidade Federal Fluminense - UFF, Niterói, RJ – Brasil.
[2] LMI PALEOTRACES (IRD-France, UPMC-France, UA-Chile, UFF-Brazil, UPCH-Peru).
[3] IRD-Sorbonne Universités (UPMC, CNRS-MNHN), LOCEAN, IRD France-Nord, Bondy, France.
[4] Instituto del Mar del Peru IMARPE.
[5] Institute of Geoscience, ~~Department of Geology~~, Kiel University, Germany.

Correspondence to: franciscojavier@id.uff.br

Abstract

In the Eastern Pacific, lithogenic input to the ocean ~~is a~~ responseds to variations of the atmospheric and oceanic system ~~variability~~ and their teleconnections over different timescales. Atmospheric (e.g., wind fields, precipitation), hydrological (e.g., fresh water plumes) and oceanic (e.g., currents) conditions determine the transport mode and the amount of lithogenic material transported from the continent to the continental shelf. Here, we present the grain size distribution of a composite record of two laminated sediment cores retrieved ~~in~~from the Peruvian continental shelf, ~~covering~~ that record the last ~1~~1~~000 yr at a sub-decadal to centennial time-series resolution. We propose novel grain-size indicators of wind intensity and fluvial input that allow reconstructing the oceanic-atmospheric variability modulated by sub-decadal to centennial changes in climatic conditions. ~~We then discuss the paleo-environmental significance and the climatic mechanisms involved~~. Four grain size modes were identified. Two are linked to aeolian inputs (M3: 54.0 µm and M4: 91.0 µm on average), the third is interpreted as a marker of sediment discharge (M2: 10 µm on average), and the last is without an associated origin (M1: ~3 µm). The coarsest components (M3 and M4) dominated during the Medieval Climate Anomaly (MCA) and the Current Warm Period (CWP) periods, suggesting that aeolian transport increased as consequence of surface wind stress intensification. In contrast, M2 displays an opposite behavior, exhibiting an increase in fluvial terrigenous input during the Little Ice Age (LIA), in response to more humid conditions associated ~~to~~ with El Niño like conditions. Comparison with other South American paleoclimate records indicates that the observed changes are driven by interactions between meridional displacement of the Intertropical ~~c~~Convergence Z~~z~~one (ITCZ)~~, and of~~ the South Pacific Sub-tropical High (SPSH) and Walker Circulation at decadal and centennial time scales.

1. Introduction

~~Along the Peruvian coast, the Pisco region represents a quite intense upwelling zone. This is due to intense alongshore wind, driving coastal upwelling and ultimately increasing marine productivity.~~ The Pisco region (~14-15°S) hosts one of the most intense coastal upwelling cells off Peru due to the magnitude and persistence of alongshore equatorward winds during the annual cycle (Fig. 1B). Regional wind can be affected at interannual timescales by El Niño Southern Oscillation (ENSO) variability (i.e., enhanced or weakened during La Niña and El Niño events, respectively), as well as by the Pacific Decadal Oscillation (PDO) at decadal timescales (Flores-Aqueveque et al., 2015). ~~There are different sources and mechanisms controlling the~~ These factors also affect the inputs of terrigenous material input to the Peruvian continental shelf. Saukel et al. (2011) found that wind is the major transport agent of terrigenous material into the Peru–Chile Trench, between 5°S and 25°S. Flores-Aqueveque et al. (2012) showed that in the arid region of n~~N~~orthern Chile, transport of aeolian ~~-~~coarser particles (approximately ~100 µm) ~~transport~~ is directly related to interannual variations in the domain of the strongest winds. The Pisco region is also home to local dust storms called “Paracas”, which transport dust material to the continental shelf as a response to seasonal erosion and transport events in the Ica desert (~15°S). This process reflects atmospheric stability conditions and coastal sea surface temperature connections (Gay, 2005). In contrast, sediment fluvial discharge is more important in the n~~N~~orthern coast of Peru where there are large rivers, and it decreases ~~decreasing~~ southward where arid conditions are dominant (Garreaud and Falvey, 2009; Scheidegger and Krissek, 1982). This discharged material is redistributed southward by coastal currents along the continental shelf (Montes et al., 2010; Smith, 1983). In addition, small rivers exist in our study area, such as the Pisco R~~r~~iver, which ~~has increased~~ flow during strong ~~e~~El Niño events (Bekaddour et al., 2014). It has also been demonstrated that during El Niño events and coincident positive PDO, there is an increase in precipitation along n~~N~~orthern Peru and, consequently, higher river discharge, mainly from the big rivers (e.g., the Santa R~~r~~iver), whereas an opposite behavior~~trend~~ is observed during La Niña events and negative phase of PDO (Bekaddour et al., 2014; Böning and Brumsack, 2004; Lavado Casimiro et al., 2012; Ortlieb, 2000; Rein, 2005, 2007; Scheidegger and Krissek, 1982; Sears, 1954).

Grain size distribution in marine sediments may indicate different sources and/or deposition processes that can be~~,~~ expressed as polymodal distributions (e.g., Pichevin et al., 2005; Saukel et al., 2011; Stuut et al., 2005, 2002; Sun et al., 2002; Weltje and Prins, 2003, 2007). Th~~e~~~~is~~ polymodal distribution makes the classification of grain size composition an essential step in identifying the different sedimentary processes and the past environmental conditions behind them ~~grain size classes for reconstructing past environmental conditions~~ (e.g., climate, atmosphere and ocean circulation) (Alfaro et al., 2011; Bloemsma et al., 2012; Flores-Aqueveque et al., 2012, 2015; Pichevin et al., 2005; Ratmeyer et al., 1999; Saukel et al., 2011; Stuut et al., 2005, 2007; Sun et al., 2002). The grain-size distributions of lithogenic materials ~~of~~in marine sediments can thus be used to infer relative wind strengths and aridity on the assumption that more vigorous atmospheric circulation will transport coarser particles to a greater ~~short~~ distance and that the relative abundance of fluvial particles reflects ~~seasonal~~ precipitation patterns ~~excess~~ (e.g., Hesse and McTainsh, 1999; Parkin and Shackleton, 1973; Pichevin et al., 2005; Stuut and Lamy, 2004; Stuut et al., 2002).

A significant number of ~~published papers~~ studies have described the climatic, hydrologic and oceanographic changes during the last ~~2000~~ 1000 years ~~in~~on the Peruvian continental shelf ~~in the Eastern Pacific region~~ (Sifeddine et al., 2008, Gutierrez et al., 2011, Salvatteci et al., 2014b, Ehlert et al., 2015). ~~These climatic changes have affected the Humboldt Current circulation system and the precipitation pattern in the South Eastern Pacific in general, especially in the Pisco región~~ Evidences of changes in the Humboldt Current circulation system and in the precipitation pattern have been reported. ~~in general, especially in the Pisco region~~. ~~Agnihotri et al. (2008) suggested that the Peruvian Upwelling Ecosystem (PUE) is interspersed by periods of high and low productivity and denitrification, modulated by solar forcing at a centennial time-scale~~. ~~Salvatteci et al. (2014b) interpreted that~~ Salvatteci et al., (2014b) show that the ~~The~~ Medieval Climatic Anomaly (MCA) exhibits two distinct patterns of Peruvian upwelling ~~PUE~~ characterized by weak/intense marine productivity and sub-surface oxygenation, respectively, as a response to the intensity ~~to strength variation~~ of SPSH linked to the Walker circulation. ~~Whereas during the Little Ice Age (LIA), an increased sediment discharge was driven by a southward displacement of the Intertropical Convergence Zone (ITCZ)~~ During the Little Ice Age (LIA), an increased sediment discharge over the Pisco continental shelf was described, as well as a stronger oxygenation and lower productivity (Sifeddine et al., 2008, Gutierrez et al., 2009). In addition, during the Current Warm Period (CWP), the PUE exhibited 1) an intense Oxygen Minimum Zone (OMZ) and an increase in marine productivity, 2) a significant SST cooling (~0.3–0.4°C decade^{-1}), and 3) an increase in terrigenous material input (Gutierrez et al., 2011). ~~Those changes during the last Millennium in the South Eastern Pacific region seem to be linked to regional and local climatic phenomena, which had a significant impact on regional rainfall and local wind stress. Nevertheless, little is known about how the regional and local climatic variability impact sedimentation processes (i.e., Aeolian/Fluvial) in the Pisco region.~~

~~this study aims to reconstruct the variation of the supply of terrigenous material to the Central Peruvian continental shelf, to determine how regional and local river fresh water discharge and local/regional wind field conditions have affected sedimentary deposition processes in the continental Peruvian shelf region (Pisco region), and to unravel the climatic mechanisms behind these processes during the last ~1100 yr.~~ Here we present new data regarding the effective mode of transport of mineral fractions to the Pisco shelf during the last millennium, confirming previous work, and bringing new highlights about the climatic mechanism behind Humboldt circulation and atmospheric changes, especially during the MCA. Our results mark wind intensification during second part of the MCA and CWP, in contrast to a decrease of the winds intensity during the LIA and the first part of the MCA synchronous with fluvial discharge increase. Comparisons with other paleoclimate records indicate that the ICTZ displacement, the SPSH and the Walker circulation were the main drivers for the hydroclimate changes along the costal Peruvian shelf during the last millennium.

2. Sedimentary settings.

Reinhardt et al., (2002); Suess et al., (1987) and Gutierrez et al., (2006) described the sedimentary facies in the Peruvian shelf and the role of currents in the erosion process as well as the redistribution and favorable hemipelagic sedimentation of material over the continental shelf. These studies showed that high resolution sediment records are present in specific localities of the Peruvian continental margin. Suess et al., (1987) described the two sedimentary characteristic facies between 6 – 10°S and between 11 – 16°S. The first one 6 – 10°S (Salaverry Basin) is characterized by no hemipelagic sediment accumulation because in this zone the southward poleward undercurrent is strong. The second one, 11 – 16°S Lima Basin, is characterized by a lens shaped depositional center of organic-rich mud facies favored by oceanographic dynamics from the position and low velocity of the southward poleward current on the continental shelf (Reinhardt et al., 2002; Suess et al., 1987). High-resolution sediment echo sounder profiles further characterize the mud lens nature and complement the continental shelf information (Salvatteci et al., 2014a). These upper mud lenses are characterized by fine grain size, a diatomaceous, hemiplegic mud with high organic carbon, and the absence of erosive and bioturbation process.

The Pisco continental shelf sediments are a composite of laminated sediments characterized by an array of more or less dense sections of dark and light millimetric bands (Brodie and Kemp, 1994; Salvatteci et al., 2014a; Sifeddine et al., 2008). The laminae structure and composition result from a complex interplay of factors including the terrigenous material input (both aeolian and fluvial) the upwelling productivity and associated particle export to the seafloor (Brodie and Kemp, 1994; Salvatteci et al., 2014a). The anoxic conditions favored by an intense OMZ (Gutiérrez et al., 2006) and weak current activity at some areas (Reinhardt et al., 2002; Suess et al., 1987) encourage the preservation of paleo-environmental signals and consequently, a successful recording the climate variability.

Along the Peruvian coast lithogenic fluvial material is supplied by a series of rivers that are more significant to the north of the study area (Lavado Casimiro et al., 2012; McPhillips et al., 2013; Morera et al., 2011; Rein, 2005; Scheidegger and Krissek, 1982; Unkel et al., 2007). In fact, Smith, (1983) concluded that sedimentary material can be transported for long distances in an opposite direction of prevailing winds and surface currents in upwelling zones. In fact, the coastal circulation off Peru is dominated by the poleward Peru-Chile undercurrent (PCUC), which flows over the outer continental shelf and upper continental slope whereas the equatorward Peru coastal current is limited to a few dozens of meters in the surface layer (Chaigneau et al., 2013). On the other hand, several works have shown that precipitation, fluvial input discharge (Bekaddour et al., 2014; Bendix et al., 2002; Lavado-Casimiro and Espinoza, 2014) and the PCUC increase during the El Niño events (Hill et al., 1998; Strub et al., 1998; Suess et al., 1987). These observations suggest a potential for the fluvial particles to spread over the continental margin under wet paleoclimatic conditions (e.g., El Niño or El Niño-like). Lithogenic material in the study area might also originate from wind-driven dust storms or “Vientos Paracas”, which are more frequent and intense during Austral winters (Escobar Baccaro, 1993; Gay, 2005; Haney and Grolier, 1991) and the saltation and suspension mechanisms with which this material reaches the continental shelf.

3. Materials and Methods

3.1. Stacked record.

The B040506 "B6" (14° 07.90' S, 76° 30.10' W, 299 m water depth) and the G10-GC-01 "G10"(14° 22.96' S, 076º 23.89' W, 313 m water depth) sediment cores were retrieved from the central Peruvian continental shelf in 2004 during the Paleo2 cruise onboard the Peruvian José Olaya Balandra vessel (IMARPE) and in 2007 during the Galathea-3 cruise, respectively (Figure 1). We compared the age models and performed a laminae cross-correlation between the two cores in order to develop a continuous record for the last millennium (Salvatteci et al., 2014a) (Fig. 1S).The choice of these two cores was based on previous detailed stratigraphic investigations and available complementary multi-proxy reconstructions (Gutiérrez et al., 2006, 2009; Salvatteci et al., 2012, 2014a, 2014b; Sifeddine et al., 2008). The boxcore B06 (0.75 m length) is a laminated core with a visible slump at ~52cm and 3 thick homogeneous deposits (1.5 to 5.0cm thick) identified in the SCOPIX images. These intervals were not considered in our study (Fig. 1S). The presence of filaments of the giant sulphur bacteria *Thioploca* spp in the top of core B06 confirms the successful recovery of the sediment water interface.

According to the biogeochemical analysis in Gutierrez et al., (2009) (i.e., Palynofacies, Oxygen Index (Rock-Eval), total organic carbon and $\delta^{13}C$) B06 is characterized by a distinctive shift at ~30 cm. More details are provided by Sifeddine, et al. (2008), Gutiérrez et al. (2009) and Salvatteci et al., (2014a). The age model of B6 was inferred from five ^{14}C-calibrated AMS age distributions (Fig. 1S) and was shown that it covers the last ~700 yr. For the last century, which is recorded only by B06, the age model was based on downcore natural excess ^{210}Pb and ^{137}Cs distributions and supported by bomb-derived ^{241}Am distributions (Fig. 2S and Gutiérrez et al., (2009) The mass accumulation rate after ca. 1950AD was 0.036±0.001 $g cm^{-2} y^{-1}$ and before ca. 1820AD was 0.022±0.001 $g cm^{-2} y^{-1}$. On the other hand, the G10 is a gravity laminated sediment core of 5.22 m presenting six units and exhibiting some minor slumping. The G10 age model was based on thirty one samples of ^{14}C-calibrated AMS age distributions, showing that the core covers the Holocene period (Salvatteci et al., 2014b, 2016). Here we used only a laminate section between 18 and 51 cm that chronologically covered the MCA period (from ~900 to 1500) and presented no slumps (Fig. 1S).

The spatial regularity of the initial core sampling combined with the naturally variable sedimentation rate implied variable time rates between samples (150 samples in total). Each sample is 0.5 cm thick in B6 and usually includes 1-2 laminae. On the other hand in core G10: each sample is 1 cm thick including 3-4 laminae. The results considering the sedimentation rates showed that the intervals during MCA, LIA and CWP span between 18, 7, and 3 years, respectively. Because of differences in the subsampling thickness between cores and variable sedimentation rates, results are binned by 20 year intervals (the lowest time resolution among samples) after linear interpolation and 20-yr running mean of the original data set.

3.2. Grain size analyses

~~To isolate the mineral fraction, organic material, calcium carbonates and biogenic silica were successively removed sample using H_2O_2 (30% at 50°C for 3 to 4 days), HCl (10% for 12 hours) and Na_2CO_3 (1 M at 90°C for 3 hours). Between each chemical treatment, samples were repeatedly washed with deionized water and centrifuged at 4000 rpm until the solution became neutral (pH: 6-7) again. Finally, all samples were passed through a 200-µm mesh before analysis because only particles having equivalent diameters less than 200 µm can be detected by the analytical method used. After pre-treatment, the grain size distribution was determined with an automated image analysis system (model FPIA3000, Malvern Instruments in which FPIA stands for Flow Particle Image Analyzer, ALYSES facilities at IRD, Bondy-France). This system is based on a CCD (Charge Coupled Device) camera that captures images of all of the particles homogeneously suspended in a dispersal solution by rotation (600 rpm) in a measurement cell. After magnification (×10), the images are analyzed automatically and the equivalent spherical diameter (defined as the diameter of the spherical particle having the same surface as the measured particle) is determined. The optical magnification used (×10) implies that only particles with equivalent diameters between 0.5 and 200 µm are counted~~.

~~It is worth noting that this system gives the size distribution and also displays images of the individual particles. If one ignores the images, this method provides size information comparable to that obtained with a laser granulometer. Nevertheless, the images are very useful to check the efficiency of the pre-treatments, and if necessary, non-mineral particles or aggregated mineral particles can be manually removed from the size distributions. The whole measurement range is divided into 225 equal logarithmical steps. Because the size-bins selected by the manufacturer are quite narrow, the number of particles counted in some of them can be limited to just a few units, in which case the associated relative error can be very large. To reduce error, we decided to divide the number of size-bins by a factor of 5 (we use 45 instead of the 225 original ones) and also to group the number of particles counted in each class. Grain size distributions are expressed as volume distributions.~~

To isolate the mineral terrigenous fraction, organic matter, calcium carbonate and biogenic silica were successively removed from approximately 100 mg of bulk sediment sample using H_2O_2 (30% at 50°C for 3 to 4 days), HCl (10% for 12 hours) and Na_2CO_3 (1 M at 90°C for 3 hours) respectively. Between each chemical treatment, samples were repeatedly rinsed with deionized water and centrifuged at 4000 rpm until neutral pH. After pre-treatment, the grain size distribution was determined with an automated image analysis system (model FPIA3000, Malvern Instruments). This system is based on a CCD (Charge Coupled Device) camera that captures images of all of the particles homogeneously suspended in a dispersal solution by rotation (600 rpm) in a measurement cell. After magnification (×10), particle images are digitally processed and the equivalent spherical diameter (defined as the diameter of the spherical particle having the same surface as the measured particle) is determined. The optical magnification used (×10) allows the counting of particles with equivalent diameters between 0.5 and 200 µm. Prior to the FPIA analysis, all samples were sieved with a 200-µm mesh in order to recover coarser particles. Since particles > 200 µm were never found in any samples, the grain size distribution obtained by the FPIA method reliably represents the full particle size range in the sediment. A statistically significant number of particles (hundreds of thousands up to 300.000) are automatically analysed by FPIA providing particle size information comparable to that obtained with a laser granulometer, along with images of the individual particles. Using the images to check the efficiency of the pre-treatments, we ensured that both organic matter and biogenic silica had been completely removed from all the samples. Finally, particle counting were binned into 45 different size bins between 0.5 and 200 micron instead of the 225 set by the FPIA manufacturer in order to reduce errors related to the presence of very few particles in some of the preselected narrow bins. Grain size distributions are expressed as (%) volume distributions.

3.3. Determining sedimentary components and the deconvolution fitting model

As different particles ~~sediment~~ transport/deposition processes are known to influence the grain-size distribution of the lithic fraction of sediment material (e.g., Gomes et al., 1990; Holz et al., 2007; Pichevin et al., 2005; Prins et al., 2007; Stuut et al., 2005, 2002; Sun et al., 2002; Weltje and Prins, 2003, 2007; Weltje, 1997), identifying the individual components of the polymodal grain size distribution is decisive for paleoenvironmental reconstructions. The numerical characteristics [~~(~~e.g., amplitude (*A*), geometric mean diameter (Gmd), and geometric standard deviation (Gsd)] of the individual grain size populations whose combination forms the overall grain size distribution were determined for all samples using the iterative least-square method of Gomes et al., (1990). This fitting method aims to minimize the square difference between the measured volume-grain size distribution and the one computed from a ~~of particles counted in each size class and that recomputed from the~~ mathematical expression ~~(~~based on log-normal function~~s)~~. The number of individual grain size populations to be used is determined by the operator, and all statistical parameters (~~e.g.,~~ *A*, Gmd and Gsd) are allowed to change from one sample to another. ~~This presents a strong advantage compared to end-member modeling (e.g., of Weltje (1997)) in which the elementary distributions are maintained constant over the whole time series (the only changing parameter being their relative amplitude). Indeed, it is unlikely that the parameters that govern both transport and deposition of lithogenic sediments, and therefore grain size of particles, remain constant over time. This could lead to variations in statistical parameters (e.g., Gmd and Gsd).~~ This process presents a strong advantage compared to end-member modeling (e.g., Weltje 1997) in which the individual grain size distributions are maintained constant over the whole time series, the only fitting parameter being the relative amplitude, A. Indeed, it is unlikely that the parameters that govern both transport and deposition of lithogenic material, and therefore grain size of particles, remain constant over time. In turn, variations of these parameters are expected to induce change of the grain size distribution parameters such as Gmd and Gsd.

4. Results and discussion

4.1. Basis for interpretation

Both sediment cores (B06 and G10) exhibit roughly ~~a~~ bimodal grain-size distributions representing significant variation in amplitude and width. These modes correspond to fine-grain-size classes from ~3-15 µm and coarser grain size classes between ~50-120 µm (Fig. 3S). A principal component analysis (PCA) based on the Wentworth (1922) grain-size classification identifies four modes that could explain the total variance of the dataset (Fig. 4S). The measured and modeled grain size distributions show high correlations ranging from R^2=0.75 to 0.90, attesting that using 4 grain size modes is well adapted to our sediment samples and that~~thus~~ the computed ones may be~~model can provide~~ reliable for further interpretation~~s~~ (Fig. 2~~A~~). Lower correlations only occurred for 6 samples, ~~all~~that are characterized by small proportions of terrigenous material compared to biogenic silica, organic matter and carbonates. ~~Lower correlations only occurred when the proportion of lithological material proportion was small compared to silica, organic matter and bulk carbonate (6 samples)~~. In these cases, ~~This situation was is met when~~ the number of lithic~~ological~~ particles remaining after the chemical attack was small, which increased the associated relative error.~~ of these samples was significantly lower, placing it at the limit of statistical representation.~~ However, these samples have been included in the data set since~~because~~ they all presented a high contribution of coarser particles.

Grain size parameters are presented in Table 1. The first mode (M1), with a Gmd of approximately 3 ± 1 µm, and the second one (M2), with a Gmd of 10 ± 2 µm, are characterized by large Gsd (~2σ), indicating a low degree of sorting. Such low degree of sorting suggests a slow and continuous depositional process as occurs in other environments (Sun et al., 2002). The coarsest modes M3 and M4 display mean Gmd values of 54 ±12 µm and 91 ± 13 µm, respectively. These modes present Gsd values close to 1σ. The Gmd values of the two coarsest modes are consistent with the optimal grain size transported under conditions favorable to soil (lack of vegetation, low threshold friction velocity, surface roughness and low soil moisture) and low wind friction velocity (Iversen and White, 1982; Kok et al., 2012; Marticorena and Bergametti, 1995; Marticorena, 2014; Shao and Lu, 2000). Such conditions prevail in the studied area because the central coastal Peru consists of a sandy desert area characterized by no rain, a lack of vegetation and persistent wind (Gay, 2005; Haney and Grolier, 1991).

~~Geometrical standard deviation (Gsd) vs. Geometrical mean diameter (Gmd) (Fig. 2B). The first mode (M1), with a Gmd of approximately 3 ± 1 µm, and the second one (M2), with a Gmd of 10 ± 2 µm, are characterized by larger Gsd, indicating a low degree of sorting. According to Sun et al. (2002), sSuch a low degree of sorting (Gsd~2σ) suggests a slow and continuous depositional process (Sun et al., 2002). The coarsest modes M3 and M4 display mean Gmd values of 54 ±11 µm and 91 ± 11 µm, respectively. These modes presented Gsd values close to 1σ~~. ~~This is consistent with the optimal grain size transported under favorable erosional soil properties and low wind friction velocity (Iversen and White, 1982; Shao and Lu, 2000; Marticorena, 2014).~~

In the vicinity of desert areas, where wind-blown transport prevails, particles with grain size as high as ~100 µm can accumulate in marine sediments (e.g., Stuut et al., 2007; Flores-Aqueveque et al., 2015) or even in lacustrine sediments (An et al., 2012). Indeed, Stuut et al., (2007) reported the presence of distributions typical of wind-blown particles with ~80µm grain size (~29°S North Chile) that is consistent with our results. In the studied area, the emission and the transport of mineral particles are related to the strong wind events called “Paracas”. Paracas dust emission is a local seasonal phenomenon that preferentially occurs in winter (July-September) and is due to an intensification of the local surface winds (Escobar Baccaro, 1993; Haney and Grolier, 1991; Schweigger, 1984). The pressure gradient of sea level between 15°–20°S, 75°W is the controlling factor of Paracas winds (Quijano, 2013), along with local topography (Gay, 2005). Coarse particles found in continental sediments off Pisco cannot have a fluvial origin because substantial hydrodynamic energy is necessary to mobilize particles of this size (50-100 µm), and this region is devoid of large rivers (Reinhardt et al., 2002; Scheidegger and Krissek, 1982; Suess et al., 1987).

~~These coarse particles cannot have a fluvial origin because substantial hydrodynamic energy is necessary to mobilize particles of this size, and because this region is devoid of large-sized rivers (Scheidegger and Krissek, 1982). Rein et al., (2004), followed by Bekaddour et al. (2014), discussed the influence of the changes in the climatic regime as a control of the intensification and variability in the sedimentation of detrital material of fluvial origin in the region. Thus, the continental shelf off of Pisco receives coarse aeolian particles by saltation and suspension processes linked to Paracas events as well as fluvial particles from the few rivers that reach the coast in this region.~~

Therefore, the coarsest modes (M3 and M4) can be interpreted as markers of aeolian transport resulting from surface winds and emission processes ~~(e.g. Paracas events)~~ (Flores-Aqueveque et al., 2015; Hesse and McTainsh, 1999; Marticorena and Bergametti, 1995; McTainsh et al., 1997;

Sun et al., 2002) and ~~These two components (M3 and M4)~~ indicate a local and proximal source to aeolian material (i.e., Paracas winds). This interpretation is in contrast to the Atacama Desert source suggested by Ehlert et al., (2015) and Molina-Cruz, (1977). Ehlert et al. (2015), who used the same sediment core (B06), and also indicated difficulties in the interpretation of the detritical Sr isotopic signatures as an indicator of the sources. These difficulties can be associated with the variability of the $^{87}Sr/^{86}Sr$ due to grain size (Meyer et al., 2011). The finest M1 component (~3 µm) may be linked to both aeolian and fluvial transport mechanisms, or alternatively, may come from aggregates of other particles. Thus, because its origin is difficult to determine, and because its trend appears as relatively independent from the other components, we do not further use it.

~~The M2 component (~10 µm) is interpreted as characteristic of fluvial transport (Koopmann, 1981; McCave et al., 1995; Stuut et al., 2007). The fluvial origin of the M2 component is also supported by its trend along the core, which differs from those of M3 and M4 from aeolian origin. A fluvial origin of this M2 component is also supported by geochemical proxies, by an increase in the Ti content input (Sifeddine et al., 2008 and Salvatteci et al., 2014b) and radiogenic isotope compositions of detrital components (Ehlert et al., 2015), indicating more terrigenous transport during the LIA, where humid conditions are dominant. This M2 component is interpreted as linked to river material discharge, mostly from the north Peruvian coast, and redistributed by oceanic southward coastal currents (Montes et al., 2010; Rein et al., 2004; Scheidegger and Krissek, 1982; Unkel et al., 2007).~~

The M2 component (~10 µm) is interpreted as an indicator of fluvial transport (Koopmann, 1981; McCave et al., 1995; Stuut and Lamy, 2004; Stuut et al., 2002, 2007). Indeed, this is consistent with the reported by Stuut et al., (2007) for the fluvial mud (~8µm) in the South of Chile (>37°S) where the terrigenous input is dominated by fluvial origins. A fluvial origin of this M2 component is also supported by showing the same trend in the geochemical proxies, such as radiogenic isotope compositions of detrital components (Ehlert et al., 2015), mineral fluxes (Sifeddine et al., 2008) or %Ti (Salvatteci et al., 2014b), indicating more terrigenous transport during the LIA, when humid conditions were dominant. The M2 component is interpreted as being linked to river material discharge, mostly from the north Peruvian coast, and redistribution by the PCUC and bottom currents (Montes et al., 2010; Rein et al., 2004; Scheidegger and Krissek, 1982; Unkel et al., 2007).

4.2. Fluvial and aeolian input variability during the past ~1000 yr

Grain size component (M2, M3 and M4; Table 1) variations in~~along~~ the composite records (B06 and G10) express changes in wind stress and fluvial runoff at~~and wind stress~~ multi-decadal to centennial-scale ~~changes~~during the last millennium.~~ This variability allows ed the identification of three major climate periods: MCA, LIA and CWP in the last millennium~~. The sediments deposited ~~during the MCA exhibit two contrasting patterns of grain size distributions. In the first sequence, dated from 900 to 1170 AD, low values of *D*50 were found varying around 16±6 µm, and explained by 50 ± 10% M2, 18±7% M3, 21±8% M4 and 11±4% M1 contributions. A second sequence, dated from 1170 to 1450 AD, was marked by high values of *D*50 in the range of 28±17 µm, with average contributions of 14±6% for M1 and 41 ± 10% for M2, and values around 21 ± 9% for M3 and 24 ± 15% for M4. These results indicate high variability of transport particles during the MCA, with more fluvial sediment discharge from 900 to 1170, and increase of aeolian material input between 1170 and 1450 AD that suggest a last period of enhancement in the surface wind stress (Fig. 3A).~~ during the MCA exhibit two contrasting patterns of grain size distributions. A first sequence, dated from 1050 to 1170 AD has, low values of *D*50 that vary around 16±6 µm, and are explained by 50 ± 14% M2, 16±8% M3, 21±5% M4 and 13±5% M1 contributions. A second sequence, dated from 1170 to 1450 AD, was marked by high values of *D*50 in the range of 34±18 µm, with average contributions of 36 ± 8% for M2, 21 ± 10% for M3, 29 ± 15% for M4 and 14±6% for M1. These results indicate high variability of transport of particles during the MCA, with more fluvial sediment discharge from 1050 to1170, followed by an aeolian transport increase between 1170 and 1450 AD (Fig. 3).

During the LIA (1450 – 1800 AD), the deposited particles were dominated by fine grain sizes with a *D*50 varying around an average of 15 µm, explained by 53±15% M2 contribution. In contrast, the contributions of ~~The~~ M3 ~~presented an~~ averaged ~~contribution of~~ 19±9% and ranged from 4 to 45%, whereas M4 showed an average contribution of 14±11% and varied from 0 to 44% during the same period. ~~This significant~~The dominant contribution of the finest-sized particles of M2 suggests a high fluvial terrigenous input to the Peruvian continental shelf. It is important to note that M2 contributions increased from the beginning to the end of the LIA at ~1800 AD ~~(Fig. 3A)~~, suggesting a gradual increase in fluvial sediment discharge input relate to enhancement of the continental precipitation (Fig. 3C). Indeed, during the LIA, our results ~~agree with~~ previous ~~studies~~ interpretations of wet conditions along the Peruvian cast (Apaéstegui et al., 2014a; Gutiérrez et al., 2008; Salvatteci et al., 2014b; Sifeddine et al., 2008), ~~indicating wet conditions over the drainage basins~~. These results also imply that this period was characterized by weak surface winds, and hence a weaker coastal upwelling.

~~Finally, *D*50 variations show high variability during the last 250 yr of these two periods (1750 to 1850 AD and 1900 to 1960 AD within the CWP) characterized by high D50 values around 45 µm, with ~40% and ~30% M4 and M3, respectively. From 1850 to 1900 AD and from 1960 to 2000 AD in the CWP, *D*50 displayed values of approximately 20 µm explained by ~40% M2. Our results indicate a clear increase in coarse (M3 and M4) aeolian material deposition during the~~

~~CWP, especially from 1750 to 1850 AD and 1900 to 1960 AD. Moreover, it is noteworthy that during these two periods, coarser particles as large as ~120 µm (in M4 component) were found, indicating extreme wind stress events (Fig. 3F). On the contrary, the fluvial sediment discharge was the dominant transport mechanism between 1850 and 1900 AD, as well as between 1960 and 2000 AD. The finest particles exhibit a progressive increase during the last 50 years, suggesting an increase of the terrigenous sediment input from rivers discharge. A similar trend was observed in the total terrigenous flux record of Pisco and Callao (Sifeddine et al., 2008).~~

Subsequently, *D*50 variations show multidecadal variability during the last ~200 yr that is divided into three distinctive periods. The first one from ~1800 to 1850 AD shows dominance of coarse particles around 50 µm, explained by the high contribution of M3 and M4 (up to 45% and 50% respectively) during this period. These results suggest a period of drier climate and very strong wind conditions. The second one from 1850 to 1900AD displays values around ~20 µm explained by ~40% of M2, ~20% of M3 and ~20% of M4 that suggests that fluvial sediment discharge was the dominant transport mechanism, although not as significant as during the LIA. The third period spans from 1900 AD to the final part of record and covers the CWP. Our results reveal a dominance of coarse particles during the most of this period (D50 up to of 80 µm) that arise from high contributions of M3 and M4 (~40% and ~50% respectively). However a clear decrease of the D50 is displayed at the end of this period that is explained by a decrease of contributions of the aeolian component M4 (~20%), although the contribution of M3 and M2 remain relatively stable (~25% and 30% respectively). These conditions display no clear dominance of a given transport mode during this time. In addition, markeddly coarser particles (in M4 component) were very common during this time (the last 200yr) indicating a strong probability of extreme wind stress events (Fig. 3F).

4.3. Climatic interpretations

Our findings suggest a combination ~~between~~of regional and local atmospheric circulation mechanism changes, that~~which~~ controlled the pattern of sedimentation in the study region. Our record is located under the contemporary seasonal Paracas dust storm path, but it also records discharged fluvial muds, that ar~~, often~~ supplied by the rivers along the Peruvian coast. Hence, this record is particularly well suited for a reconstruction of continental runoff/wind intensity in the central Peruvian continental shelf during the last millennium. The interpretation of the changes in the single records of the components (M2, M3 and M4) and their associations (e.g., ratios) can reflect paleoclimatic variations in response to changes in atmospheric conditions. Here, we used the ratio between the aeolian components, defined as the contribution of the stronger winds over total wind variability: M4/(M3+M4). We consider~~used~~ this ratio as a proxy of the local wind surface intensity and thus as of the SPSH atmospheric circulation (Fig. 4F). Previous studies have similarly and successfully ~~In fact, the~~ used ~~of~~ grain-size fraction ratios as ~~a~~ paleoclimate ~~indicator for~~ proxies of atmospheric conditions and circulation ~~has been successfully applied~~ to explain ~~different~~other sediment records (Holz et al., 2007; Huang et al., 2011; Prins, 1999; Shao et al., 2011; Stuut et al., 2002; Sun et al., 2002; Weltje and Prins, 2003).

~~As explained above, the MCA was characterized by a sinuous peak structure that depicts two different climate stages. A first stage spanning from ~900 to 1170 A.D. is dominated by a high sediment fluvial discharge linked to a precipitation increase (Fig. 4E). This precipitation increase can be explained by the Southward displacement of the ITCZ (Fig. 4B) and a reduction of the SPSH circulation strong (weaker favorable upwelling winds or surface winds intensity) (Fig. 4F). This pattern linked to the reorganization of the atmospheric and ocean circulation, that is also underlined by Salvatteci et al. (2014b) using biogeochemical proxies from an ocean sediment record, showing sub-oxic sediment conditions (demonstrated by high values of the Re/Mo ratio), indicating a weaker OMZ intensity (Fig. 4C) probably associated with El Nino-like conditions. Less fluvial input (i.e., dry continental conditions) and more intense surface winds characterized the second stage of the MCA (~1170 A.D. to 1350 A.D.) linked to the intensification of SPSH as a response of a northward ITCZ-SPSH meridional displacement and more la Niña-like conditions. In fact, the wind intensity trend during this period is consistent with the warmer temperature recorder at the west of pacific during the las millennium (Fig. 4A). These latter features are in phase also with a period of strong OMZ off of Pisco (Fig. 4C), associated with more intense upwelling conditions from a more intense Walker circulation. In agreement with Salvatteci et al. (2014b), these patterns are consistent with persistent austral summer-like conditions.~~

As explained above, the MCA was characterized by a sine-like peak structure that depicts two different climate stages. During the first stage spanning from ~1050 to 1170 AD the fluvial input show a peak centered at 1120 AD linked to a precipitation increase accompanied by a decrease in wind intensity. Those results suggest a southward ITCZ displacement (Fig. 4E) as a response to more El Niño like conditions as suggested by Rustic et al., (2015) (Fig 4 G and H). In contrast, during the second stage the surface winds had their greatest intensity with a peak centered at ~1200 AD as a consequence of displacement of the ITCZ-SPSH system. The displacement of the SPSH core towards eastern South American coast intensified alongshore winds as a regional response to stronger Walker circulation. These features are in agreement with the ocean thermostat mechanism proposed by Clement et al., (1996). This mechanism produces a shallow thermocline in the eastern pacific (Fig. 4G and H) and consequently more intense upwelling conditions and a stronger OMZ offshore of Pisco recorded in low values of the Re/Mo ratio (Fig. 4D). These two patterns (i.e., enhanced fluvial transport/enhanced wind intensity) might have been triggered by the expression of Pacific variability at multidecadal timescales with the combined action of the Atlantic Multidecadal Oscillation (AMO). Indeed other works provide evidence during the MCA for low South American Monsoon System (SAMS) activity at multidecadal timescales driven by the AMO (Fig. 4F) (Apaéstegui et al., 2014; Bird et al., 2011; Reuter et al., 2009). Thus, besides the displacement of the ITCZ', the AMO could have modulated Walker circulation at a multidecadal variability during the MCA through mechanisms such as those described by Mcgregor et al., (2014) and Timmermann et al., (2007).

Our results combined with other paleo-reconstructions suggest that the LIA ~~exhibited~~ was accompanied by a weakening of the regional atmospheric circulation and of the ~~and winds favorable for~~ upwelling~~.~~ favorable winds. During the LIA, the mean climate state was controlled by a gradual intensification of the fluvial input of sediements to the continental shelf, thus indicating more~~wetter~~, El Niño-like conditions ~~consistent with the El Niño-like conditions~~ (Fig. 4E). These features ~~conditions~~ are confirmed by an increase of ~~in~~ the terrigenous sediment flux, as described by Sifeddine et al. (2008) and Gutierrez et al., 2009 (Fig 4D) and ~~demonstrated~~ by changes of the radiogenic isotopic composition of the terrigenous fraction (Ehlert et al., 2015). These ~~This increase in~~ wet conditions ~~is~~ are also marked by an intensification of the South American Monsoon System (SAMS) and the southern meridional displacement of the ITCZ, as evidence by~~. P~~paleo-precipitation records in the Andes and in the Cariaco Trench~~support these regional characteristics~~ (Apaéstegui et al., 2014a; Haug et al., 2001; Peterson and Haug, 2006). ~~These conditions were consistent and suggest a direct relationship with the southern meridional displacement of the ITCZ~~ (~~Fig. 4B~~). At the same time, a~~This feature is followed accompanied by the~~ prevalence of weak surface winds (Fig.4A~~F~~) and an increase of subsurface oxygenation driving ~~noticeable~~ sub-oxic conditions in the ~~sea~~ surface sediment are recorded (Fig. 4D~~C~~). These characteristics also support the hypothesis of the ITCZ-SPSH southern meridional displacement and are consistent with a weakening of the Walker circulation (Fig. 4G~~A~~).

The transition period between the LIA and CWP appears as an abrupt event showing a progressive positive anomaly in the wind intensity synchronous with a ~~and a strong and~~ rapid decrease in the fluvial input to the continental shelf (Fig. 4A~~F~~ and B~~E~~). This transitions~~suggests~~ suggest a rapid change of meridional~~the combination of a meridional~~ (ITCZ-SPSH) and ~~a~~ zonal ~~the~~ (Walker) circulation interconnection~~(ENSO) factors (Fig. 4A and B)~~, which controls the input of terrigenous material (Fluvial/Aeolian). Gutiérrez et al.(2009) found evidence of a large ~~The results suggest that precipitation pattern is affected more rapid and suddenly in comparison with the surface wind intensity. Gutiérrez et al. (2009) found evidence of a large~~ reorganization in the tropical Pacific climate with immediate effects on ocean biogeochemical cycling and ecosystem structure at the transition between the LIA and CWP. ~~The increase in the wind intensity~~ (Fig. 4F) ~~suggests northward displacement of the ITCZ-SPSH system, which in turn~~ The increase~~s~~ in the regional winds circulation ~~(~~favor~~ing~~ aeolian erosive processes~~)~~ ~~and~~ simultaneously leads to an increase in the OMZ intensity related to upwelling intensification (Fig 4C).

Finally, during the CWP (~1900 A.D. to present), ~~negative anomalies in~~ ~~the~~a~~-~~trend to seadying of ~~of~~ low fluvial input (Fig. 4~~E~~B) w~~ere~~as combined with an increase in wind intensity (Fig. 4~~F~~A) that was coupled to a strong OMZ. This setting suggests the northernmost ITCZ-SPSH system position ~~This setting suggests stronger modification in the atmospheric regime of terrigenous fluvial input when the ITCZ-SPSH system is at its northernmost position (Fig. 4E and F).~~ . This hypothesis is supported by other studies on the continental shelf of Peru (Salvatteci et al., 2014b) and also in the Eastern Andes where a decrease in rainfall of between ~10 – 20% relative to the LIA was reported for the last century (Reuter et al., 2009)~~This hypothesis is supported by other studies on the continental shelf of Peru (Salvatteci et al., 2014b) and also in the Eastern Andes where an increase in rainfall (between ~10 – 20%) was detected during the LIA, with respect to the subsequent 200 years (Reuter et al., 2009)~~. Enhancement of wind intensity is also consistent with the multidecadal coastal cooling and increase of ~~This trend is consistent with the increase in~~ upwelling productivity since the late nineteenth century (Gutiérrez et al., 2011; Salvatteci et al., 2014b; Sifeddine et al., 2008) and confirms the relations~~hip~~ between the intensification of the upwelling activity induced by the variability of the regional wind~~s~~ intensity from SPSH displacement ~~and circulation~~.

The increase in the wind intensity over the past two centuries likely represents ~~the~~a result of the modern positioning of the ITCZ – SPSH system and the associated intensification of the local and regional winds (Fig. 4F). The contributions of~~Nevertheless, the~~ aeolian deposition material (Fig. 3E and F) and in consequence the wind intensity and its variability during the last 100 yr are stronger than during the second sequence of the MCA (Fig. 4A~~F~~) under similar conditions (i.e., position of the ITZC-SPSH system,~~Fig. 4B~~). This variability ~~suggests~~implies an additional forcing mechanism in additions to the enhancement of the wind~~s~~ intensity, one that may be related to the current~~s~~ climate change conditions ~~This trend suggests an additional forcing in the intensification of the atmospheric circulation consistent with the pattern of climate change~~ (Bakun, 1990; England et al., 2014; Sydeman et al., 2014). ~~Finally, the decrease in runoff in the same period displayed by the M2 component reflects a tendency for drier regional conditions in comparison with the LIA period (Fig. 4E).~~ ~~However~~ Moreover, during the CWP, the wind intensity ~~intensification~~ showed a direct ~~close~~ relation~~ship~~ with ~~the~~ OMZ strength ~~variability~~ (Fig. 4A~~C~~ and ~~F~~D), ~~reinforcing the interpretation of wind intensification consequence of a strengthening of the SPSH.~~ that suggest an increase in the zonal gradient and thus in the Walker circulation on a multidecadal scale.

Our record shows that on a centennial scale, the fluvial input changes are driven by the meridional ITCZ position and a weak gradient of the Walker circulation, consistent with El Niño like conditions. In contrast, variations of the surface wind intensity are linked to the position of the SPSH modulated by both the meridional variation of the ITCZ and the intensification of the zonal gradient temperature related with the Walker circulation and expressing La Niña like conditions. A clear relation between the zonal circulation and wind intensity at a centennial time scale is displayed. All these features modulate the biogeochemical behavior of the Peruvian upwelling system.

~~Variations of the fluvial input exhibited a centennial pattern variability along the last millennium, showing an intense activity fluvial input during the first period of the MCA and during the LIA. Thus, a mean climate state period of wet conditions and reduced wind intensity in this time is indicated (Fig. 4E). In contrast, the second period of MCA and CWP exhibits little fluvial input and more vigorous wind intensity, being that the last one exhibited more the latter with larger positive anomalies. This variability suggests an additional mechanism to the enhancement of the winds intensity maybe relate to the climate change conditions. The inverse relationship A good match between the Ti content record from terrigenous input to the Cariaco basin (Fig. 4B) and the decadal and centennial variation in the fluvial input in to the Peruvian continental shelf supports the hypothesis that both systems are controlled by a common climatic mechanism, , e.g., This condition is related to the meridional ITCZ displacement as described by Haug et al., (2001), Hyeong et al., (2006), Peterson and Haug, (2006) and most recently by Sachs et al., (2009). Consequently, a southward/northward ITCZ displacement and is related with a weakening/enhancement of the SPSH system off Central and Southern Peru over the East Pacific would be expected. These conditions will contribute to the weakening or strengthening of the surface winds on multidecadal time scale. In turn, these conditions modulate the biogeochemical behavior of the Peruvian upwelling system. On the other hand, a clear relationship between the zonal circulation and wind intensity at centennial time scale is display. During the second part of the MCA and during CWP La Niña like conditions prevail at the same time strongest wind are exhibited these conditions might strong circulation under these features.~~

5. Conclusions

~~Four types of terrigenous components (M2, M3 and M4) related to different transport modes in the continental shelf along the last millennium were identified in a sediment record. The M2 mode is an indicator of hemipelagic fluvial input; meanwhile, the M3 and M4 components are related to aeolian transport. A vigorous transport of aeolian and fluvial components exhibits centennial variability and shows a relationship with atmospheric conditions. The MCA and CWP periods showed an increment in the wind intensity, whereas the LIA was characterized by intense fluvial input. Comparison between records reveals a coherent match between the meridional displacement of the ITCZ-SPSH system and the regional fluvial and aeolian terrigenous input variability. The aeolian input intensity and the anoxic conditions recorded by~~

~~marine sediments showed a close link that suggests a mechanism associated with SPSH displacement. Changes in sediment discharge to the continental shelf are linked to the southward displacement of the ITCZ-SPSH. A progressive intensification of the wind intensity recorded during the CWP can be related to the strength of the Walker circulation , favoring La Niña events, which allow for an increase in regional wind intensity and consequently OMZ intensification. Based on this trend, our record shows high decadal variability of terrigenous versus aeolian transport.~~

Study of the grain size distribution in laminated sediments from the Pisco Peruvian shelf has allowed the reconstruction of changes in wind intensity and terrigenous fluvial input at centennial and multidecadal time scales during the last millennium. The long-term variation of M2 (~10µm) mode is an indicator of hemipelagic fluvial input related to the regional precipitation variability. Meanwhile, the M3 (54±11µm) and M4 (91±11µm) components are related to aeolian transport and thus with both local and regional wind intensity. The temporal variations of these fractions indicate that the MCA and CWP periods were characterized by an increment in the coarse particle transport (M3 and M4) and thus an enhancement of the surface wind intensity, whereas the LIA was characterized by stronger fluvial input as evidence from an increase of fine (M2) particles. Comparison between records reveals a coherent match between the meridional displacement of the ITCZ-SPSH system and the regional fluvial and aeolian terrigenous input variability. The ITCZ-SPSH system northern displacement during the second period of the MCA and the CWP was associated with the intensification of the Walker cell and La Niña Like conditions, resulting in stronger winds, upwelling-favorable conditions, enhanced marine productivity and greater oxygen depletion in the water column. In contrast, the southward migrations of the ITCZ-SPSH system during the LIA correspond to an enhancement to the South American Monsoon circulation and El Niño like conditions, driving the increase in the precipitation and the terrigenous fluvial input to the Pisco continental shelf, lower productivity and increased oxygenation. Two patterns observed during the MCA, respectively marked by fluvial intensification and wind intensification, could have been forced by Pacific Ocean variability at multidecadal timescales. Further studies of the paleo-wind reconstruction at high time-resolution, combined with model simulation, are needed to better understand the interplay between the Pacific and Atlantic Ocean connection on climate variability as evidenced by Mcgregor et al., (2014) in the modern Pacific climate pattern.

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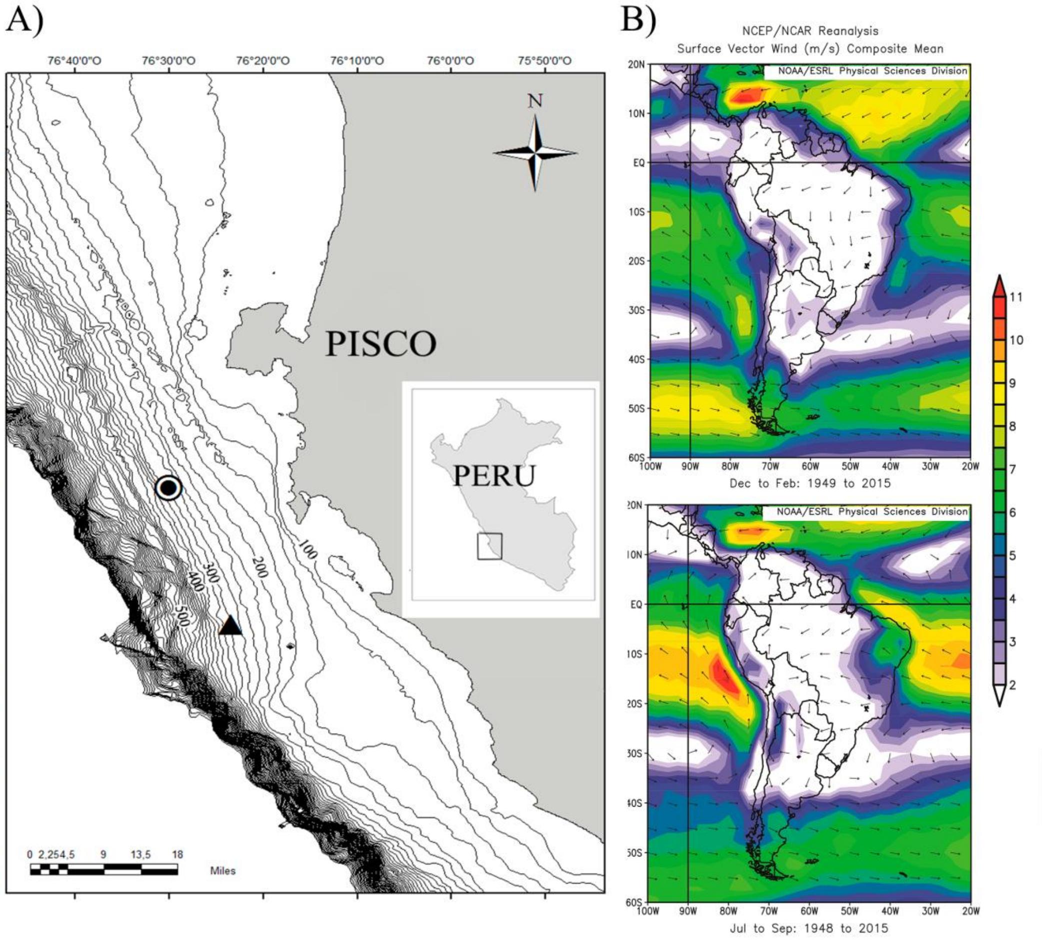
Table 1: Averaged parameters (geometric mean diameter (Gmd), amplitude (A) and geometric standard deviation (Gsd)) of the 4 log-normal modes (components) identified from measured size distributions of sediment samples (B6 and G10 cores).

M1			**M2**			**M3**			**M4**		
Gmd (µm)	A (%)	Gsd	Gmd (µm)	A (%)	Gsd	Gmd (µm)	A (%)	Gsd	Gmd (µm)	A (%)	Gsd
3 ± 1	16 ± 7	1.9 ± 0.2	10 ± 2	43 ± 15	1.9 ± 0.2	54 ± 12	20 ± 10	1.4 ± 0.2	90 ± 13	20 ± 13	1.2 ± 0.2

Table 2~~1~~. Minimum, maximum and average values to the grain size components in each unit obtained along the record in the Pisco continental shelf.

	First period MCA 900 – 1170 A.D.		**Second period MCA 1170 – 1450A.D.**		**LIA 1450 – 1800 A.D.**		**CWP 1900 A.D to present**	
Grain size componens	dV/dlnd (%)		dV/dlnd (%)		dV/dlnd (%)		dV/dlnd (%)	
	Av/Std.Dv.	Range (Min.-Max.)	Av/Std.Dv	Range (Min.-Max.)	Av/Std.Dv.	Range (Min.-Max.)	Av/Std.Dv.	Range (Min.-Max.)
M1	11 ± 4	7 - 19	14 ± 6,0	5 - 27	15 ± 6	6 - 29	18 ± 7	4 - 40
M2	50 ± 10	33 - 64	41 ± 10	23 - 62	53 ± 15	16 - 80	34 ± 10	13 - 63
M3	18 ± 7	6 - 28	21 ± 9	0 - 39	19 ± 9	4 - 45	23 ± 10	6 - 44
M4	21 ± 8	8 - 42	24 ± 15	0 - 55	14 ± 11	0 - 44	25 ± 13	0 - 56


A)
76°40'0"O
76°30'0"O
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76°10'0"O
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13°40'0"S
13°50'0"S
14°0'0"S
14°10'0"S
14°20'0"S
14°30'0"S
14°40'0"S
14°50'0"S
N
PISCO
PERU
100
200
300
400
500
0 2,254,5 9 13,5 18
Miles
B)
NCEP/NCAR Reanalysis
Surface Vector Wind (m/s) Composite Mean
NOAA/ESRL Physical Sciences Division
Dec to Feb: 1949 to 2015
NOAA/ESRL Physical Sciences Division
Jul to Sep: 1948 to 2015

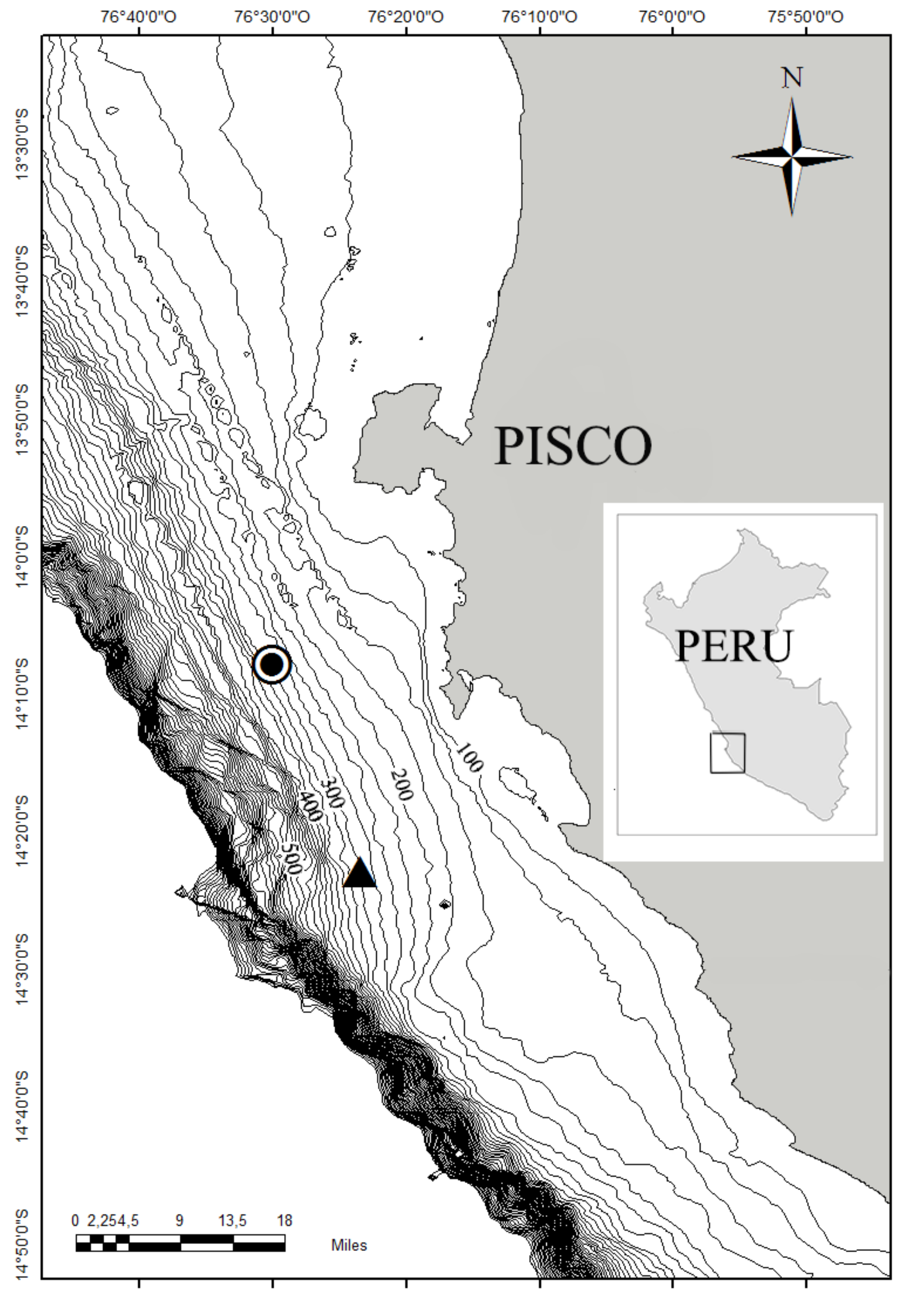
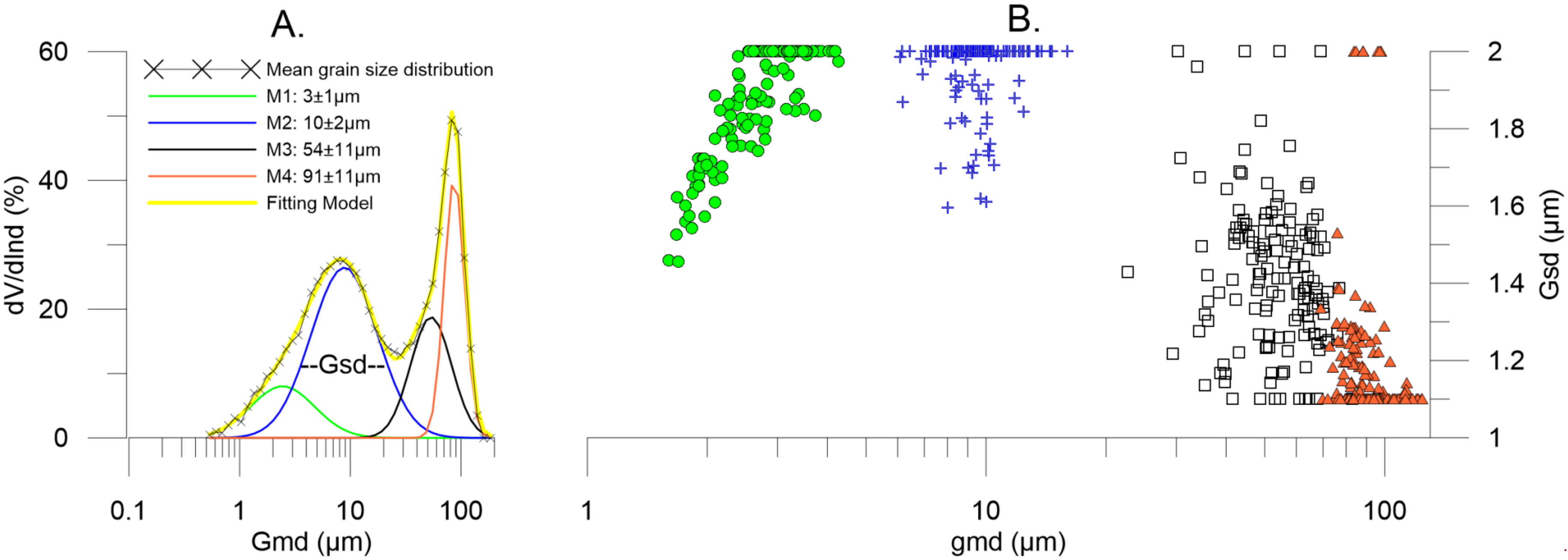
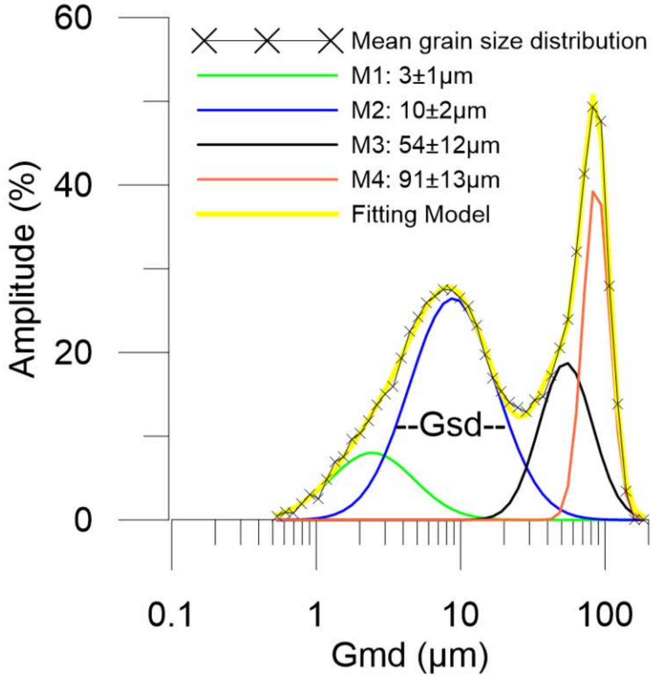


Figure 1. A) Location of the sampling of the sediment cores B040506 (black circle) and G10-GC-01(black triangle) in the Central Peru continental margin. Bathymetric contour lines are in 25m intervals from 100m to 500 m depth. B) Mean surface vector wind velocity (m/s) composite mean for summer (up) and winter (down) between 1948 and 2015 at South American. NCEP/NCAR Reanalysis data.~~Location of the sampling of the sediment cores B040506 (black circle) and G10-GC-01(black triangle) in the Central Peru continental margin. Bathymetric contour lines are in 25m intervals from 100m to 500 m depth.~~


A.
B.
Mean grain size distribution
M1: 3±1µm
M2: 10±2µm
M3: 54±11µm
M4: 91±11µm
Fitting Model
--Gsd--
dV/dlnd (%)
Gmd (µm)
gmd (µm)
Gsd (µm)
0
20
40
60
0.1
1
10
100
1
10
100
1
1.2
1.4
1.6
1.8
2



~~Figure 2. A) Description of the four modes fitted calculates (M1, M2, M3 and M4) for the mean grain size of the total record; in detail is showed an example of geometrical standard deviation (Gsd) and its frequency (dV/dlnd (%)) and B) The Gsd and geometrical mean diameter (Gmd) plotted of the unmixed components.~~

Figure 2: Comparison between a measured grain size distribution and the fitted curve using log-normal function and its partitioning into four individual grain size modes. The measured data is a mean grain-size distribution from all samples of B6 and G10 cores.

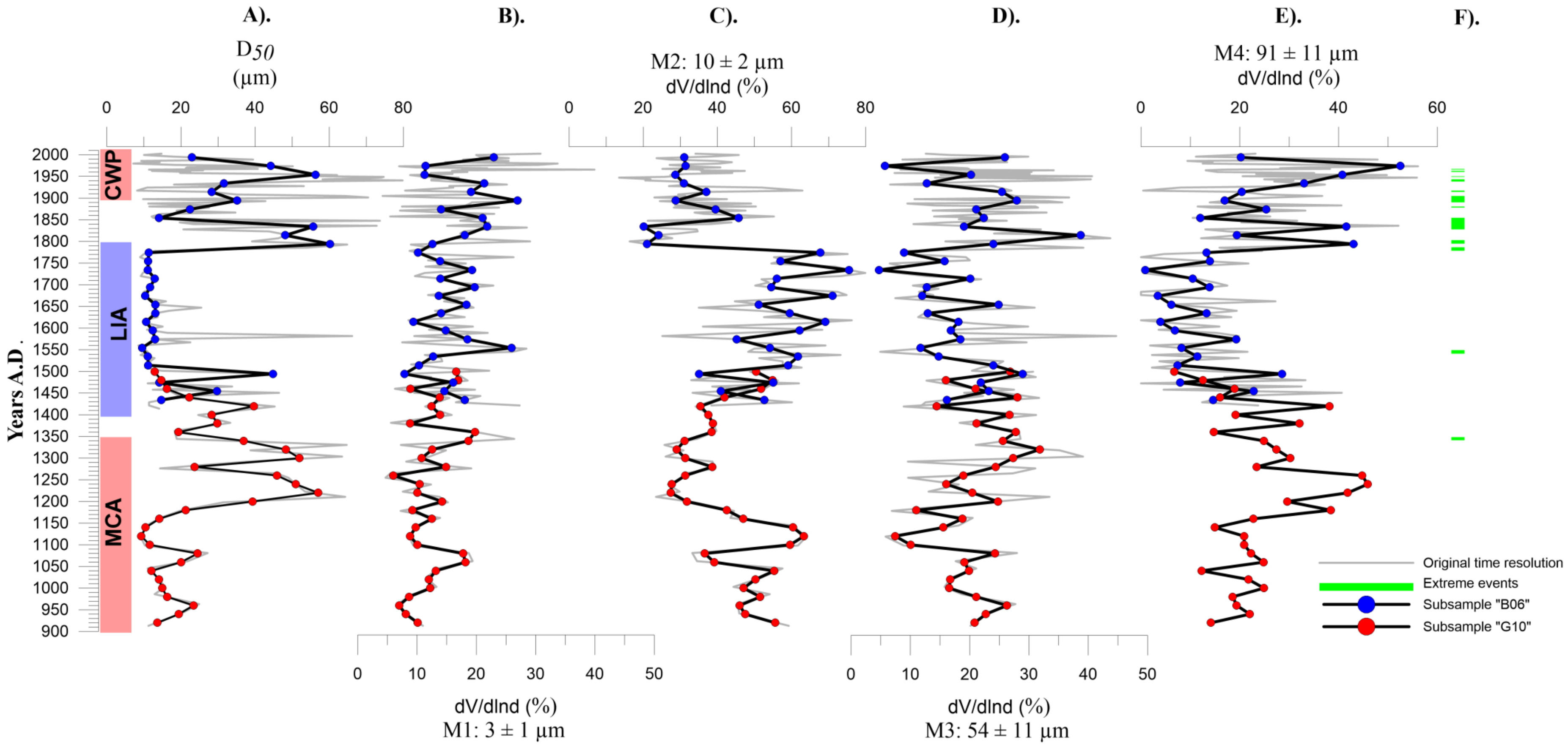
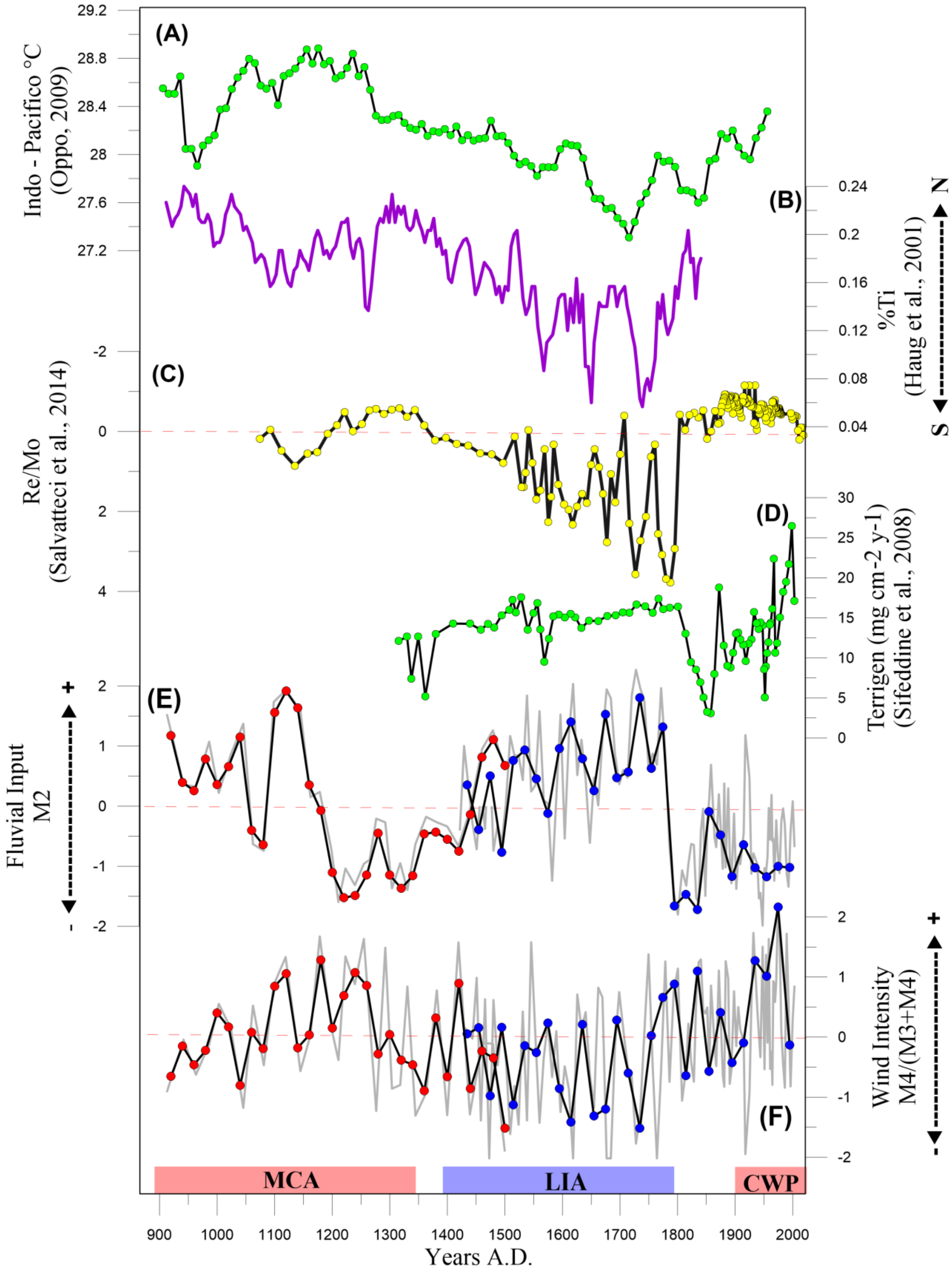
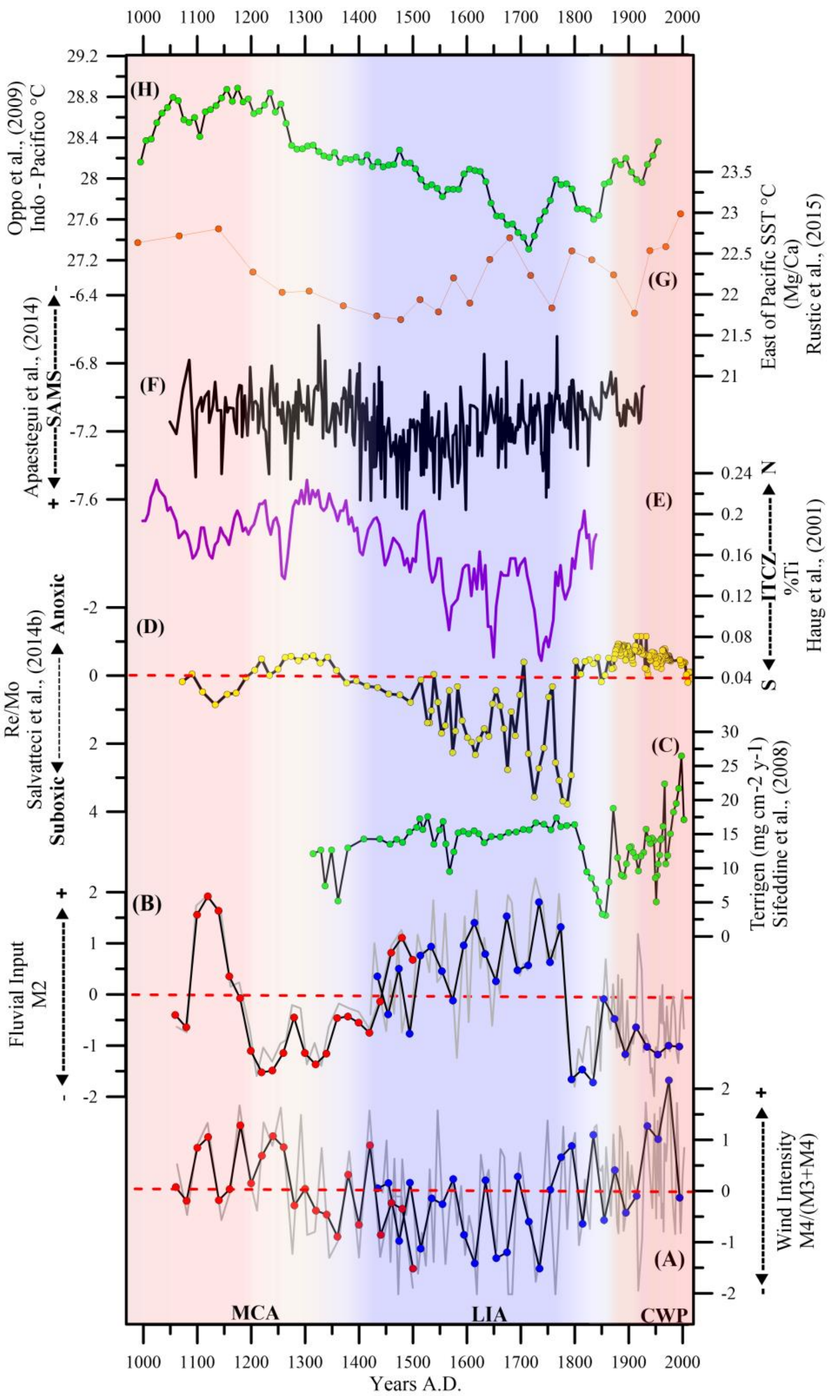


Figure 3. A) The median grain size (D50) variation along the record and variation in relative abundance of the sedimentary components: B) M1, C) Fluvial (M2), D) Aeolian (M3) and E) Aeolian (M4) of the grain size distribution in the record F) Represent the samples where was found very large particles related with extreme events.



(A)
(B)
(C)
(D)
(E)
(F)
Indo - Pacifico °C
(Oppo, 2009)
%Ti
(Haug et al., 2001)
N
S
Re/Mo
(Salvatteci et al., 2014)
Terrigen (mg cm-2 y-1)
(Sifeddine et al., 2008)
Fluvial Input
M2
Wind Intensity
M4/(M3+M4)
MCA
LIA
CWP
Years A.D.



~~Figure 4. Reconstruction of A) Indo-Pacific temperatures reconstruction (Oppo et al., 2009), B) ITCZ migration (%Ti) (Peterson and Haug, 2006), C) OMZ activity (Re/Mo anomalies) negative values indicate more anoxic conditions (the axis was reversed) (Salvatteci et al., 2014b), D) Terrigenous flux (total minerals) in Pisco continental shelf by Sifeddine et al (2008), E) Fluvial input (M2) anomaly reconstruction on the continental shelf, F) Wind intensity (M4/(M3+M4)) anomaly reconstruction.~~ A) Wind intensity (M4/(M3+M4)) anomaly reconstruction, B) Fluvial input (M2) anomaly reconstruction on the continental shelf, and records of C) Terrigenous flux (total minerals) in Pisco continental shelf by Sifeddine et al (2008), D) OMZ activity (Re/Mo anomalies) negative values indicate more anoxic conditions (the axis was reversed) (Salvatteci et al., 2014b), E) ITCZ migration (%Ti) (Peterson and Haug, 2006), F) SAMS activity reconstruction ($\delta^{18}O$ Palestina Cave) (Apaéstegui et al., 2014), G) Indo-Pacific temperatures reconstruction (Oppo et al., 2009).

Supplementary Information:

Stacked record.

According to Salvatteci et al (2014), the cross-correlation of stratigraphic laminated sequences involves the identification of common biogeochemical features in the cores compared of the same study area. The common biogeochemical features are used as a correlation point between these. The biogeochemical shift at AD 1820±15 described by Gutiérrez et al., (2009) and Sifeddine et al., (2008) in all sediment cores in the area was used as stratigraphic anchored. Thereafter a visual examination of the X-ray images was made to prepare a correlation following the tone patterns produced by the difference in density of the laminae. The sediment core B14 (collected in the Pisco continental shelf too) was used as reference because this core were better defined and have most complete laminar sequence and is the best preserved (Figure 1S).

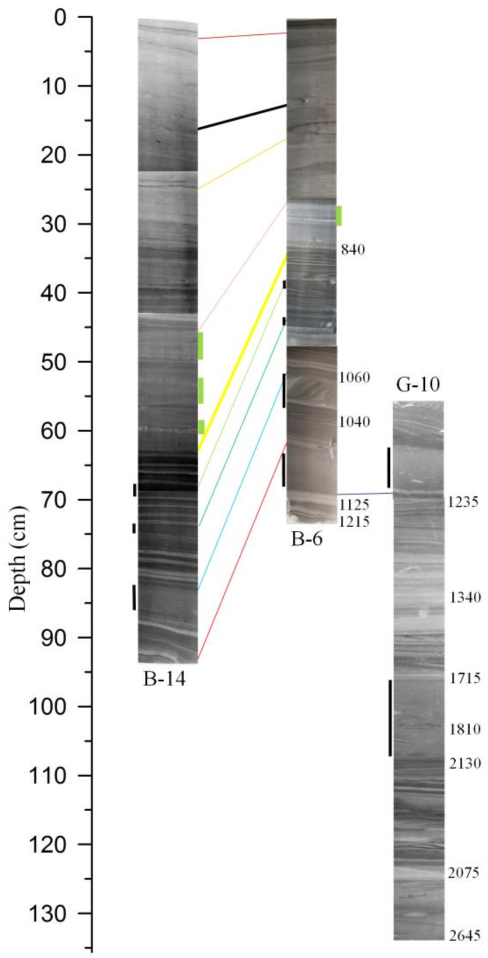


Figure 1S: Cross-correlation of stratigraphic laminated sequences (SCOPIX images) between the box core B14 (the undisturbed, and well-preserved laminae sequences), B6 and the gravity core G10 all retrieved in Pisco continental shelf. The SCOPIX images the colors were inverted, thus the darker (lighter) laminae represent dense (less dense) sediments. The numbers at the right side of the imagens represent the uncalibrated 14C ages. Yellow line indicate the position of the sedimentological/biogeochemical shift (Gutiérrez et al., 2009). The upper black bold line indicates the start of 241Am activity. The Black bars at the left side of the cores indicate homogeneous deposits, while green bars at the right side indicate the extent of the diatom layers. The stratigraphic markers are represented by the continuous colored thin lines that indicate possible (less obvious) correlations, methodology details in Salvatteci et al., (2014).

Downcore profile of excess ^{210}Pb and ^{241}Am in the Pisco boxcore B040506

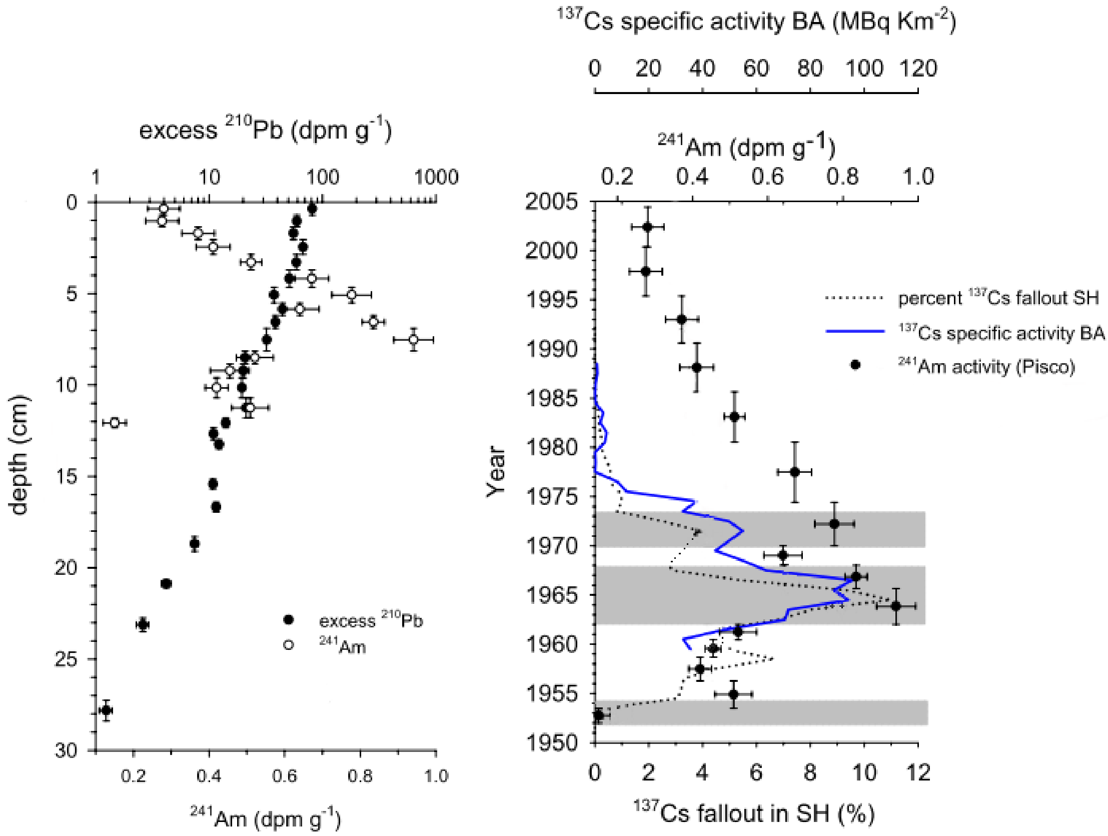


Figure 2S: Downcore profile of excess 210Pb and 241Am in the Pisco boxcore B040506. Reconstructed fallout of 137Cs in the Southern Hemisphere (UNSCEAR, 2000), and fallout specific activity of 137Cs in Buenos Aires (Ribeiro & Arribére, 2002). The prominent features of fallout change (onset and peak periods, shaded) were used to identify three time-markers in the downcore 241Am specific activity for both cores. Time intervals for each time-marker were estimated from excess 210Pb – derived sedimentation rate in the uppermost layer and sample layer thickness (taken and modified from Gutiérrez et al., (2009)).

Record of the entire grain size distribution.

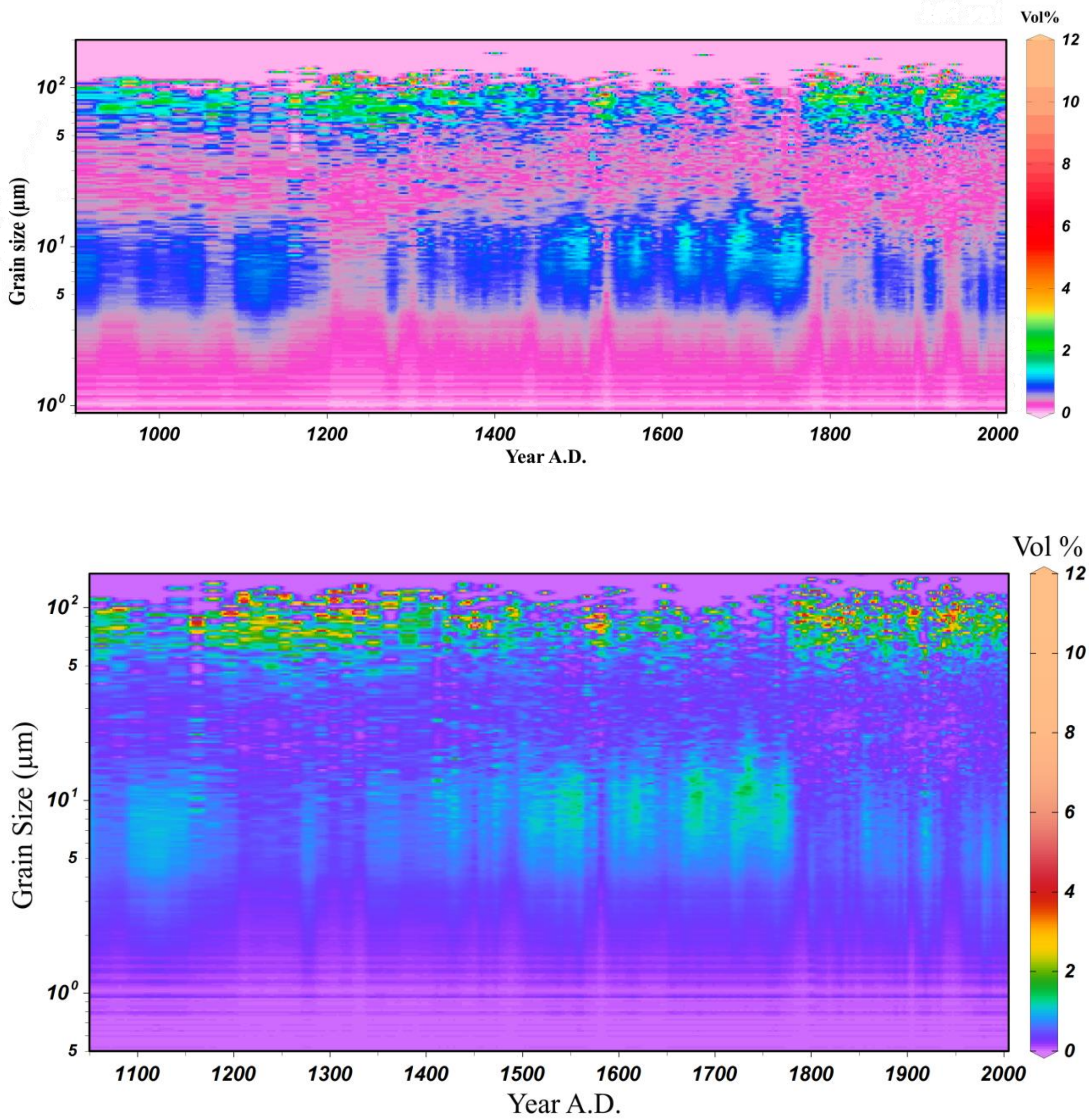


Figure 3S ~~Figure 1S~~: Grain-size data distribution corresponding to the entire record (overlapping of the B040506 and G10-GC-01 sediment core). Two modes of grain sizes are apparent. A first one with finest grains range from ~2 to 15 µm; and the second one with coarser grains varied between of ~50-120 µm.

Principal component analysis of grain size classification.

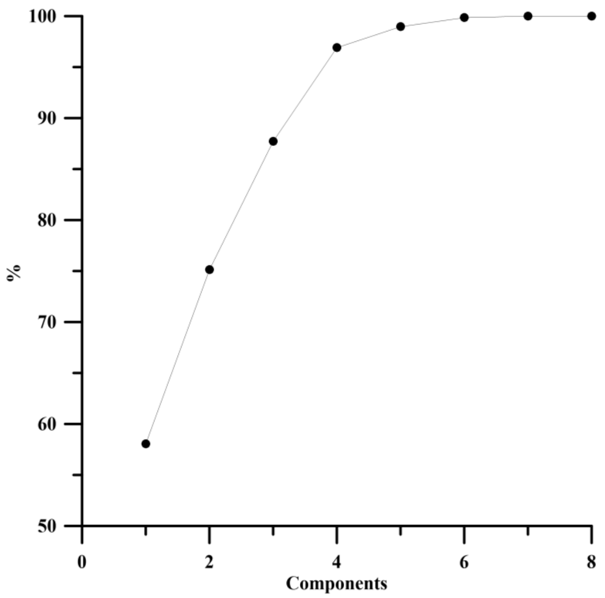


Figure 4S ~~Figure 2S~~: Variability proportion (coefficient of determination) obtained by principal components analysis (PCA) based on grain-size classification of Wentworth (1922). Four components can explain 97% of the total variability of the samples.

Supplementary Bibliography

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