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Centennial-scale variations of the Peruvian Oxygen Minimum Zone during the last 7000 years in response to changes in tropical climate

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Introduction

The evolution of Oxygen Minimum Zones (OMZs) has been extensively studied at glacial-interglacial and millennial timescales (e.g. De Pol Holz et al., 2007; Robinson et al., 2007; Chazen et al., 2009; Gutiérrez et al., 2004) but multidecadal and multiannual variations have not been described for periods anterior to the last millennium.

The history of the Peruvian Oxygen Minimum Zone is tightly linked to ENSO. Indeed, the apparition of modern ENSO dated at around 5000 years BP has been detected through stronger variability in water column denitrification (Chazen et al., 2009). However, certainly because of discrete sampling, this study did not capture the intensification of ENSO which occurred 2000 years ago as observed on other records (Conroy et al., 2008). We here refine the relationship between ENSO and the Peruvian OMZ over the last 7000 years through a unique study at the lamination scale.

Peruvian OMZ fluctuations over the last 7000 years and its link with ENSO

Core M772-003-2 records four major intervals over the last 7000 years:

7000-5300 yrs BP:

- **Decreasing trend in denitrification** (Fig. 3a) until a **minimum around 5400 years BP → weakened OMZ**
- **Increase in rainfall** (Fig. 3b) **and decrease in productivity** (Fig. 3c) **→ Transition from La Niña-like to El Niño-like mean conditions in the Peruvian Upwelling System (PUS)**

5300-4400 yrs BP:

- **Increase in OMZ intensity around 5300 years BP** (Fig. 3a)
- Low precipitations and strong productivity → **La Niña-like conditions dominant between 5300 and 4400 years BP**

4400-2600 yrs BP:

- Slight decrease in productivity and OMZ intensity, increase in rainfall → **El Niño-like conditions more predominant**

2600-0 yrs BP:

- **Increase in OMZ intensity and productivity between 2600 and 2200 years BP**
- **Clear oscillations** in productivity, denitrification and rainfall **over the last 2200 years**

Two-step transition between the modern and mid-Holocene states of the Peruvian OMZ :

- **Strong increase** in OMZ intensity and productivity around **5300 years BP**, previously considered as the onset of the modern state of the Peruvian OMZ (Chazen et al., 2009)
- **Weaker increase** between **2600 and 2200 years BP**, followed by alternating periods of intensified and weakened OMZ → **onset of the modern state of the OMZ 2200 years ago**

Both increases in OMZ intensity (blue shaded areas on Fig.3) in phase with **decreases in the frequency of El Niño events** (Fig. 3d and e)

→ **Increased OMZ intensity when El Niño events are less frequent under La Niña-like mean conditions**

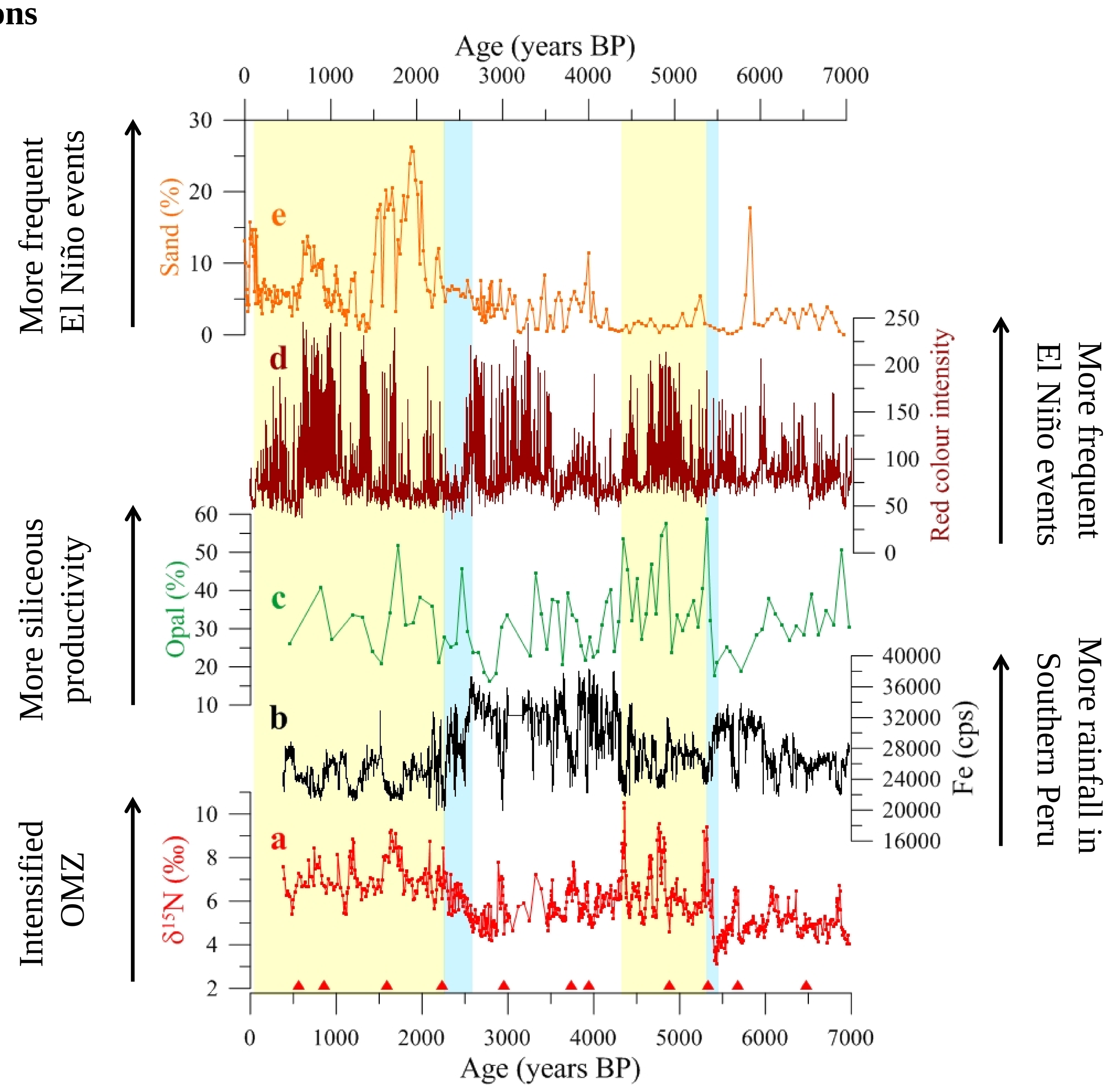

Figure 3: Evolution of OMZ intensity (a), rainfall (b) and productivity (c) in southern Peru compared with records of ENSO activity (d: Laguna Pallcacocha, Ecuadorian Andes, 2°S, Moy et al., 2002; e: Laguna El Junco, Galapagos Islands, 0.8°S, Conroy et al., 2008). The red triangles represent the [14]C ages available.

Core location and description

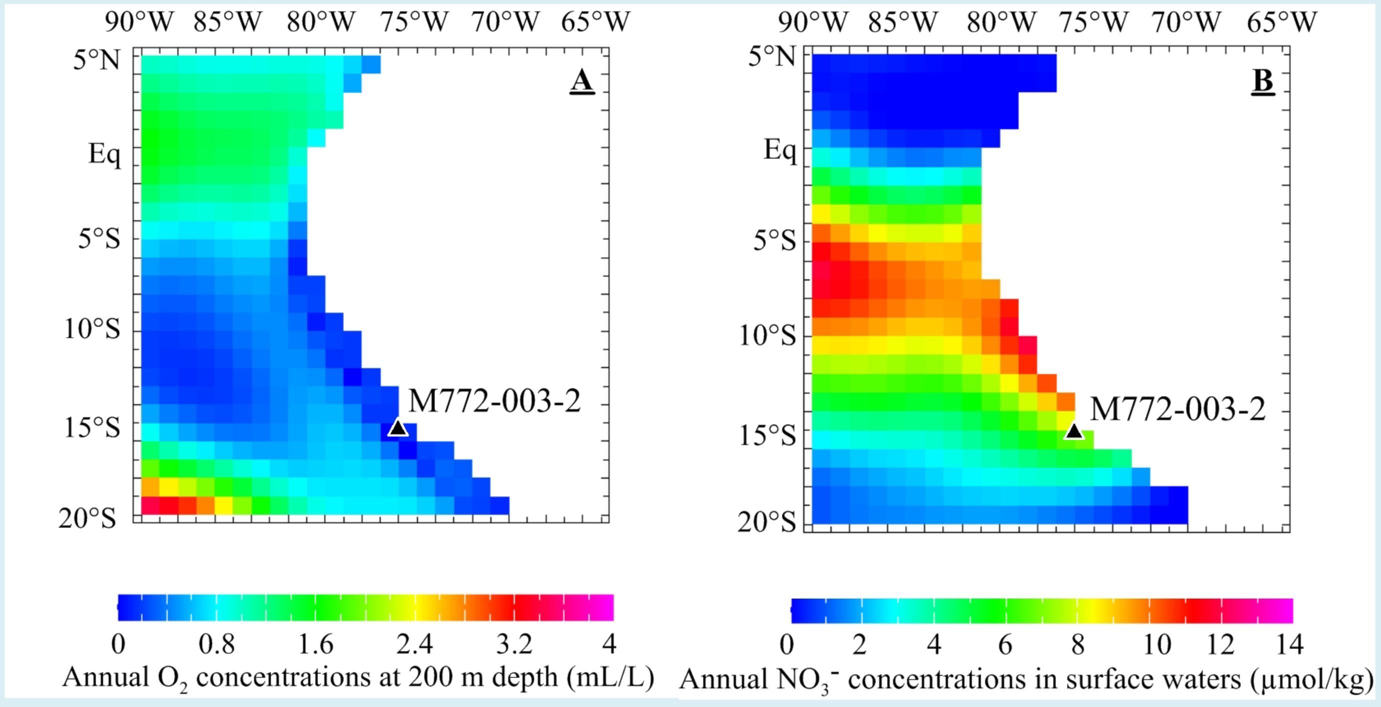

Figure 1: a) Oxygen concentrations at 200 m depth; b) Nitrate concentrations in surface waters. We here represent the values measured annually between 1935 and 1978 (Levitus, 1982).

We analyzed the first 4.83 m of a laminated piston core located within the modern OMZ (core M772-003-2; 15°S; 271 m water depth; Fig.1). Core chronology, based on eleven [14]C dates performed on humic acid, indicates that the 5 first sections cover the last 7000 years. X-ray radiographies show that sediments are organized in millimeter-scale laminations and pluri-centimeter to decimeter-scale bands with variable densities throughout the core (Fig. 2). All laminations were individualized and sampled, using visual observations and X-ray radiography. One lamination represents 10 years of sedimentation on average. Each lamination was analyzed for major and minor elementary composition (XRF core-scanning), bulk $\delta^{15}N$ and diatom assemblages.

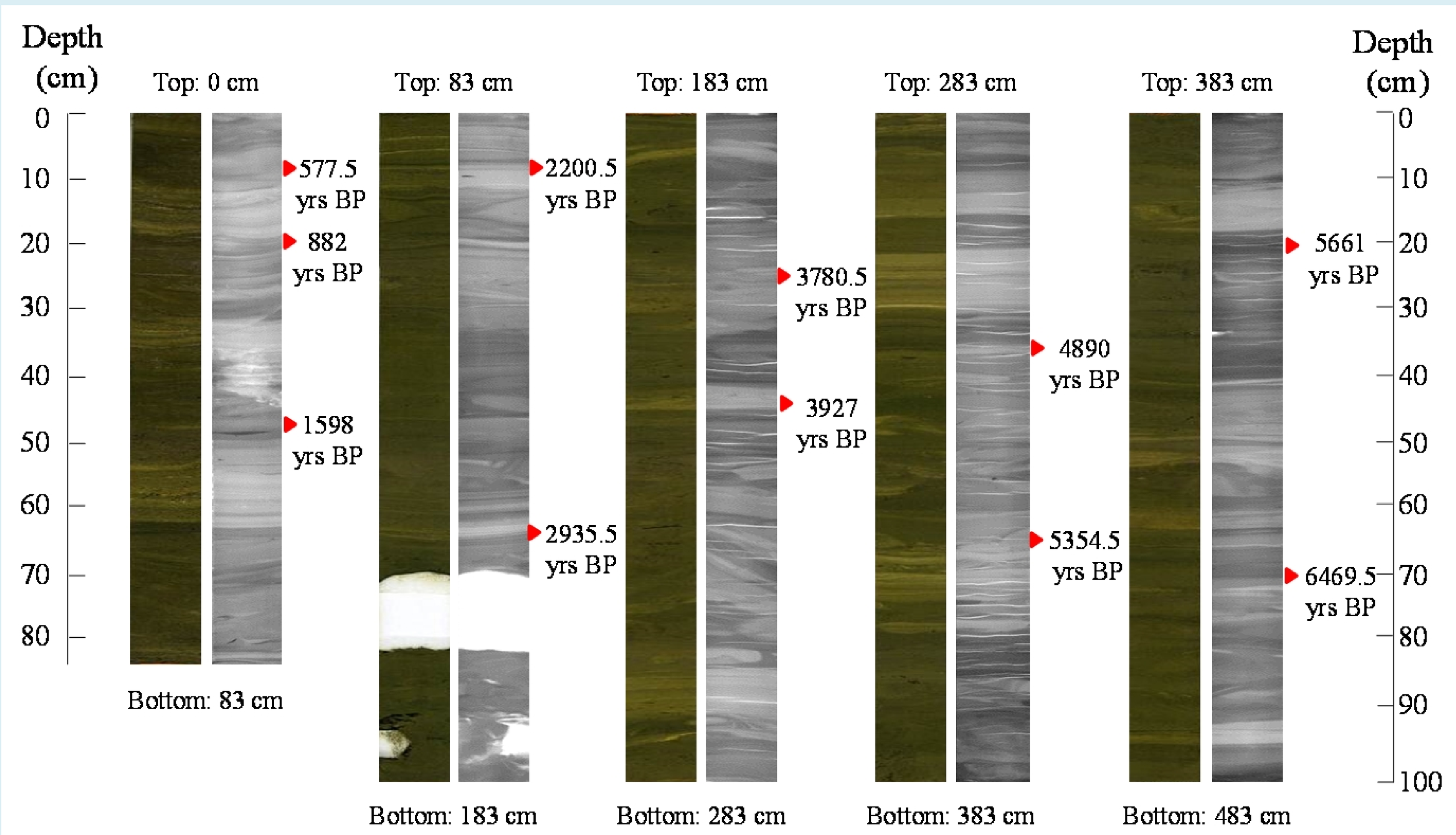

Figure 2: X-ray radiographies of the first 4.83 m of piston core M772-003-2

Zooming on the last 3000 years

- **La Niña-like mean conditions in the PUS** (low precipitations, strong productivity and intense OMZ) **over five intervals** (light sediment bands, gray areas on Fig. 4) .
- **La Niña-like conditions** when **the zonal SST gradient increase in the Pacific Ocean** (Fig. 4d) **and dry conditions** are observed **in North America** (Fig. 4e).
- **Centennial-scale variations in the mean state of the PUS controlled by the Walker circulation**

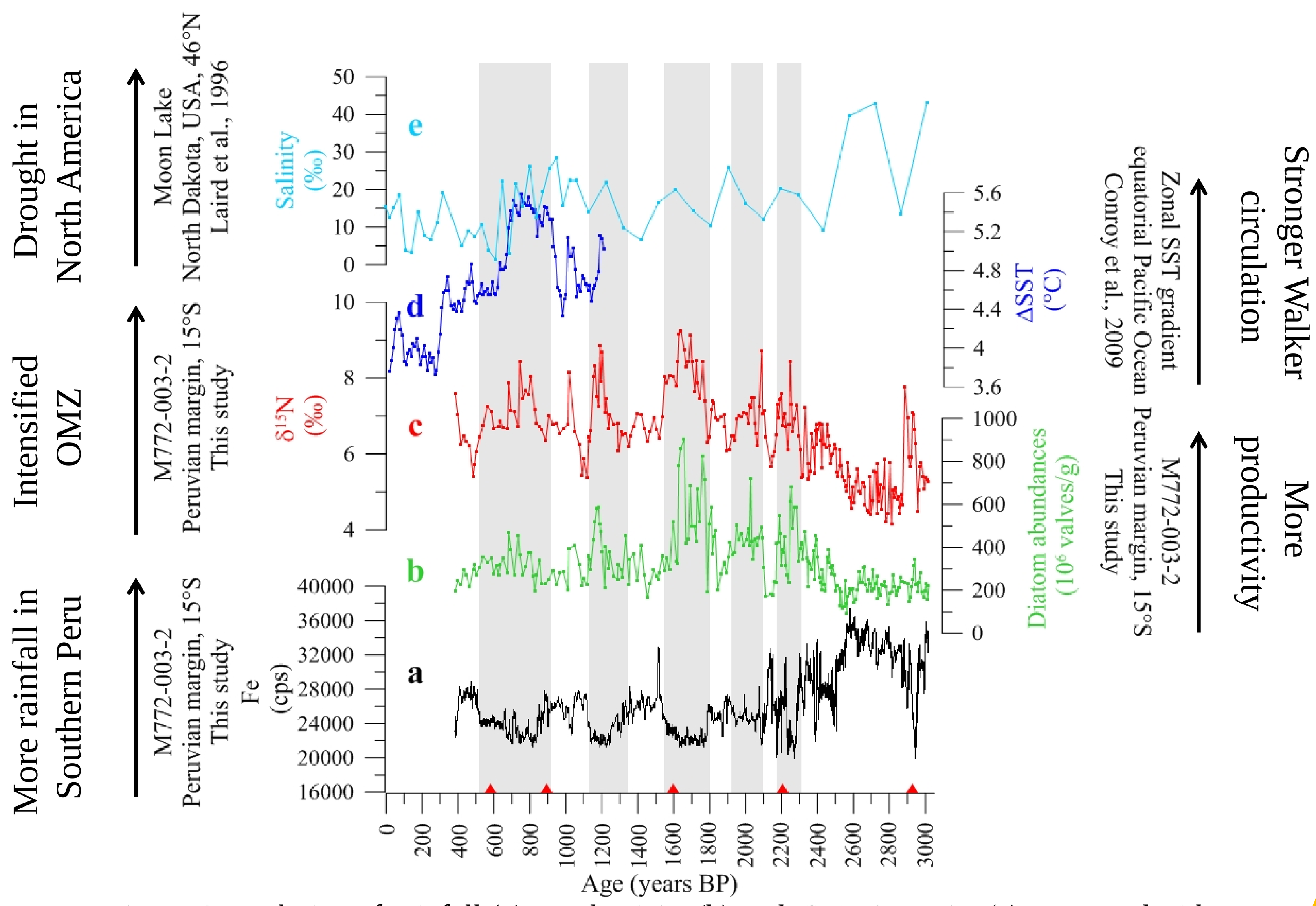

Figure 4: Evolution of rainfall (a), productivity (b) and OMZ intensity (c) compared with records of the zonal SST gradient in the Pacific Ocean (d; Conroy et al., 2009) and salinity in Moon Lake, North Dakota, USA, 46°N (e; Laird et al., 1996). The gray shaded areas represent periods dominated by La Niña-like mean conditions.

Conclusion

This study is the first tracing changes in the mean state of the Peruvian Upwelling System at the scale of the laminations over several millennia. We here show that the OMZ associated to the PUS intensified twice in times of dominant La Niña-like mean conditions and reduced frequency of El Niño events. At the centennial timescale, La Niña-like mean conditions predominate when the Walker circulation is enhanced. The alternation between periods dominated by El Niño-like and La Niña-like mean conditions could also be triggered by changes in solar irradiance, which control ENSO either directly or through its teleconnection with climate oscillations in the North Pacific. Model studies are needed to test these two hypotheses.

References

Chazen C. R., Altabet M.A., Herbert T.A. Abrupt mid-Holocene onset of centennial-scale climate variability on the Peru-Chile margin. *Geophysical Research Letters* **36** (2009).

Conroy J.L., Overpeck J.T., Cole J.E., Shanahan T.M., Steinitz-Kannan M. Holocene changes in eastern tropical Pacific climate inferred from a Galapagos lake sediment record. *Quaternary Science Reviews* **27**, 1166-1180 (2008).

Conroy, J. L., Restrepo, A., Overpeck, J.T., Steinitz-Kannan, M., Cole, J.E., Bush, M.B., Colinvaux, P.A. Unprecedented recent warming of surface temperatures in the eastern tropical Pacific Ocean. *Nature Geoscience* **2**, 46–50 (2009). doi:10.1038/ngeo390.

De Pol Holz R., Ulloa O., Dezileau L., Kaiser J., Lamy F., Hebbeln D. Melting of the Patagonian Ice Sheet and deglacial perturbations of the nitrogen cycle in the eastern South Pacific. *Geophysical Research Letters* **33** (2007).

Gutiérrez D., Sifeddine A., Field D.B., Ortlieb L., Vargas G., Chavez F., Velazco F., Ferreira V., Tapia P., Salvatecci R., Boucher H., Morales M.C., Valdés J., Reyss J.-L., Campusano A., Boussafir M., Mandeng-Yogo M., Garcia M., Baumgartner T. Rapid reorganization of ocean biogeochemistry off Peru towards the end of the Little Ice Age. *Biogeosciences* **6**, 835-848 (2009).

Laird, K. R., Fritz, S. C., Grimm, E. C., Mueller, P. G.. Century-scale paleoclimatic reconstruction from Moon Lake, a closed-basin lake in the northern Great Plains. *Limnology and Oceanography* **41** (5), 890-902 (1996).

Levitus, S. E.. 1982. Climatological atlas of the world ocean. *NOAA Professional Paper* **13**, US Government Printing Office, Washington DC.

Mollier-Vogel E. Peruvian Oxygen Minimum Zone dynamics during the last 18 000 years. *University of Kiel, Germany, PhD thesis* (2012).

Robinson, R. S., Mix, A., Martinez, P. Southern Ocean control on the extent of denitrification in the southeast Pacific over the last 70ka. *Quaternary Science Reviews* **26** (1), 201-212 (2007). doi: 10.1016/j.quascirev.2006.08.005