# A high marsh transfer function for sea-level reconstructions in the southern Bay of Biscay.

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## Introduction

Current concerns regarding global sea-level rise associated with anthropogenic warming of the atmosphere and oceans and its impacts on coastal resources have increased the interest on past sea-level changes. The mean global rate of sea-level (RSL) rise has been estimated at ~1.8 mm yr$^{-1}$ for the last century (Holgate, 2007). Since 1993, satellite altimetry data provide estimates of ~3 mm yr$^{-1}$ (Leuliette *et al*., 2004). It is not clear yet whether the recent sea-level acceleration represents a change in the long-term trend or reflects decadal variability (Bindoff *et al*., 2007). Various authors estimate that sea level reached modern rates approximately at 1850 (Douglas, 2001), around the end of the 19th century (Jevrejeva *et al*., 2006), during the 1920s (Peltier and Tushingham, 1989), or 1935 (Church and White, 2006). Some studies have even proposed decelerations within the 20th century (Woodworth, 1990). Instrumental records of sea-level change are generally too short and provide insufficient spatial coverage to give definitive answers to this debate.

Recent geological-based research offers great potential to supplement the temporal and spatial global database of instrumental (tide-gauge) observations of sea-level change. Proxy records from salt marshes around the North Atlantic Ocean have provided the first indications that modern rates of sea-level rise (last ~100 years) in this region may be more rapid than the rate of rise in preceding centuries, and that the timing of this acceleration may be indicative of a link with human-induced climate change (Gehrels *et al*., 2005; 2006). So far, these high resolution sea-level reconstructions have only come from the western and northern margins of the North Atlantic. Because multi-decadal patterns of sea-level change are spatially highly variable across the globe, it is important to obtain comparable sea-level reconstructions from other regions. This study aims to provide high-resolution sea-level data from the eastern Atlantic to examine the issue of recent changes in the RSL rise. The model here proposed will increase the precision of the sea-level reconstructions and it will improve the time resolution for the last 200 years based on foraminiferal transfer functions from high marsh sediments.

Marshes in Basque coast are few and fragmentary. They are restricted to the inner parts of the small estuaries that sporadically interrupt the continuous cliffs that characterize this coastal area. Marsh reclamation for agricultural and disease-eradication purposes was initiated in the 17th century, and was particularly intense since the second half of the 19th century. However, during the last few decades agriculture has been in decline and previous cultivated areas have been abandoned. The lack of dyke maintenance has allowed tidal estuarine water to invade these once artificially isolated areas and, consequently, halophytic vegetation is rapidly recolonizing them. All study sites come from estuaries (Barbadun, Plentzia and Urdaibai) with similar mesotidal ranges (2.5 m).

## Materials and Methods

We collected 73 surface sediment samples and six 50cm-sediment cores for micropalaeontological analysis in the Muskiz, Isuskiza, Ostrada, Txipio, Mape and Axpe-Busturia marshes. Sampling sites were chosen as representative of different marsh subenvironments in terms of elevation above mean sea level and distance from the main estuarine channel, including different vegetated and unvegetated areas. We measured topographic elevation for all modern samples and cores and this information is presented relative to the local ordnance datum. Tidal inundation frequency at each study area was calculated and compared with the closest tide gauge, and elevations relative to Mean Higher High Water (MHHW) were standardized. Hence, the elevations are expressed as a standardized water level index (SWLI). Microfossil, geochemical, $^{210}$Pb, and $^{137}$Cs data have been obtained from these samples. Description of sample preparation and analysis is presented in Cearreta *et al*. (2002).

## Results

Detrended Cannonical Correspondence Analysis of the training set with SWLI as the only environmental variable has produced a gradient length of 3.38. This indicates a unimodal nature of the foraminiferal abundance data with respect to SWLI. Thus, we used a unimodal-based method of regression and calibration, known as weighted averaging partial least squares (WA-PLS). The WA-PLS transfer function produces results for five components. The choice of component depends upon the prediction statistics (RMSEP and r$^2$) and the principle of parsimony, i.e. choosing the lowest that gives an acceptable model. Using component three, the relationship between observed and tidal foraminiferal-predicted elevation was very strong, a result that illustrated the robust performance of the WA-PLS transfer function ($r^2_{jack}$=0.76). These results indicated that reconstructions of former sea levels are possible (RMSEP$_{jack}$=12.5).

We have further explored possible models that reconstruct palaeomarsh surface elevation. Model 2 uses only foraminiferal species typical from marsh environments, while Model 3 uses samples above a standardized water-level index of 160,

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thus removing lower elevation samples. Model 2 performs significantly better (component 1; $r^2_{jack}$=0.81; $RMSEP_{jack}$=11.6) as a result of including only species that respond to elevation, reducing therefore the noise of the dataset. Model 3 has low RMSEP (component 3; 7.5) but also low $r^2_{jack}$ (component 2; 0.75) because of the lower number of samples and the reduced length of the elevational gradient.

The precision of this transfer functions is comparable to other foraminifera-based transfer functions from the northern Atlantic Ocean. Following back transformation of the SWLI values, Models 1, 2 and 3 have a precision of ±0.19 m, ±0.18 m and ±0.11 m, respectively.

## Discussion

Recent sedimentation trends (ca. 1850AD to present) typically employ shorter-lived radionuclides ($^{210}$Pb, $^{137}$Cs). The activity of $^{210}$Pb in each sediment layer declines with its age due to radioactive decay. Based on $^{210}$Pb half-live (22.3 years), this technique is restricted to the last 120 years. $^{137}$Cs and Pb concentrations are then used to increase the reliability of the age model generated by $^{210}$Pb-calculated sedimentation rates. There is an excellent agreement between all three methods, and therefore, we have used their sedimentation rates-derived ages in the sea-level reconstruction. Preliminary results based on regression analysis through the mid-point of the reconstruction provides a general trend of 2.4±0.4 mm $yr^{-1}$ for the period 1884-1997 with none or little variation during the 19th century. However, we have to consider the full vertical errors derived from the reconstruction, and therefore the error introduced into the calculated trend (±78 mm), and the restriction in the interpretation of the 19th century sea-level reconstruction derived from the low number of sea-level index points and their large temporal errors. On the other hand, the Santander tide gauge provides a trend of 2.18±0.41 mm $yr^{-1}$ for the period 1944-2001, supporting our reconstruction. This is a very similar pattern to that of the tide-gauge record at Brest (France). These results seem to imply none or little variation of the sea-level during the 19th century in the Bay of Biscay with a sea-level rise of 22 ± 4 cm during the 20th century in the southeastern area.

The likely increase in the rate of sea-level rise at the change of centuries is roughly coincident with the temperature increase during the 20th century (Bindoff *et al*., 2007). This is also coincident with the onset of rapid recent sea-level rise reported for northeastern North America occurring between 1880 and 1920 (Donnelly *et al*., 2004). The similar timing for the onset of the recent sea-level rise at both sides of the (north)Atlantic Ocean signals the global significance of this sea-level acceleration. The different rates of sea-level rise detected could be related to the different characteristics of the water masses and the influence of the North Atlantic Oscillation (Gehrels *et al*., 2006).

## Conclusions

Whilst accelerated rates of global relative sea-level rise are potentially one of the most devastating impacts of future climate change, our understanding of multi-decadal climate-ocean relationships is poor. This contribution seeks to address this knowledge gap by combining tide gauge and high-precision foraminifera-based transfer function reconstructions of RSL. We have produced three transfer functions with a precision of between 0.19 m and 0.11 m. We placed the foraminifera-based prediction of palaeomarsh elevation into a temporal framework through the $^{137}$Cs, Pb concentrations, and $^{210}$Pb-derived sediment accumulation rates. The resulting relative sea-level reconstructions imply a sea-level rise for the 20th century of 22 ± 4 cm, which is in general agreement with the local tide-gauge records and the long-term regional gauge from Brest. In a region where sea-level data are very scarce even for the second half of the 20th century, this study offers an alternative method to reconstruct former sea levels at centimetre-to-metre vertical resolution scale and decadal-to-centennial age resolution scale.

## Acknowledgements

E. Leorri was supported by a postdoctoral grant from the Basque Government and by the Conseil Général of the Vendée (F). This work has been partially funded by the UNESCO06/08 and IT-332-07/GIU06-10 research contracts and it represents a contribution to IGCP project #495.

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