EGU General Assembly

Beach-foredune ridges as proxies for climate-induced wave direction changes in South Atlantic during Late Holocene

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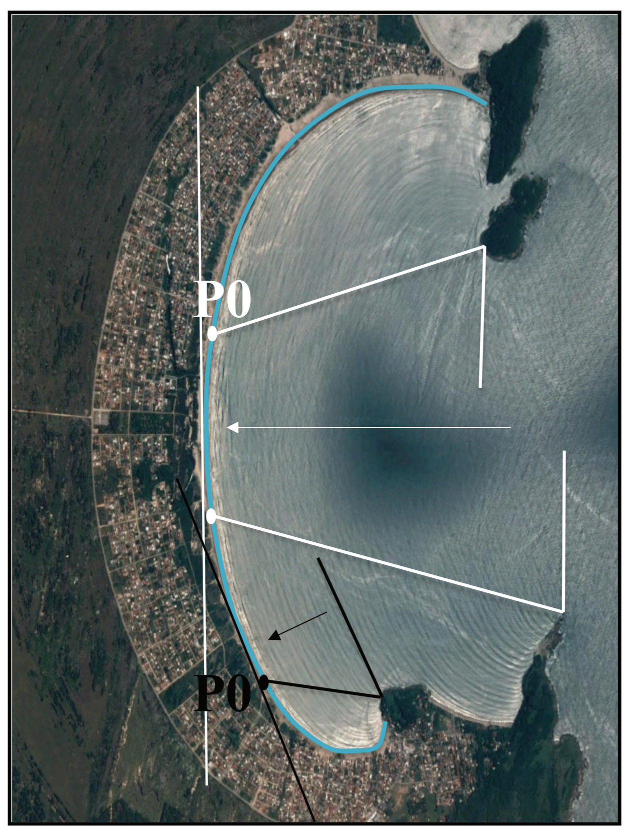
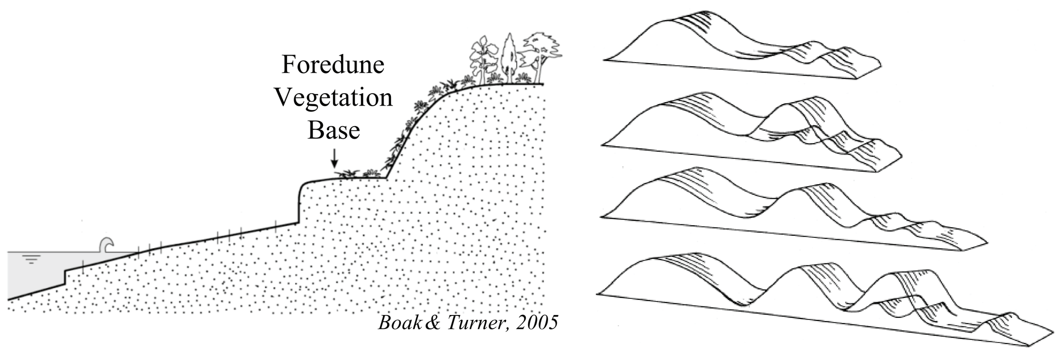
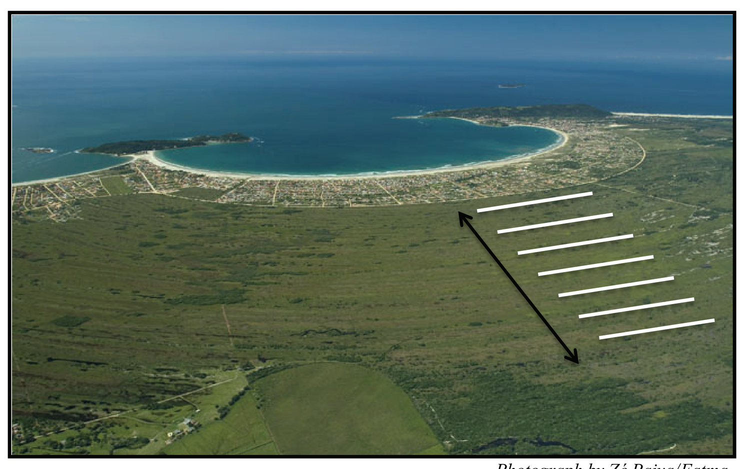
INTRODUCTION

Recent studies have shown that variability in global wave climate results from the influence of climate changes on wave-generating atmospheric systems. These findings highlight the need for an improved understanding of long-term wave-climate cycles. Here we apply a novel use of the morphology of former shorelines preserved in beach-foredune ridges (BFR) to reconstruct changes in predominant wave directions in the Subtropical South Atlantic during the last 3000 years. BFRs are geological records of paleo-beach planforms that were once foredunes oriented by the incident mean directional wave energy flux (EFθ), predominant over a period of approximately 3 decades. By extension, BFR sets are potential multi-decadal-scale proxies for offshore wave climate and associated atmospheric patterns over the adjacent ocean basin.







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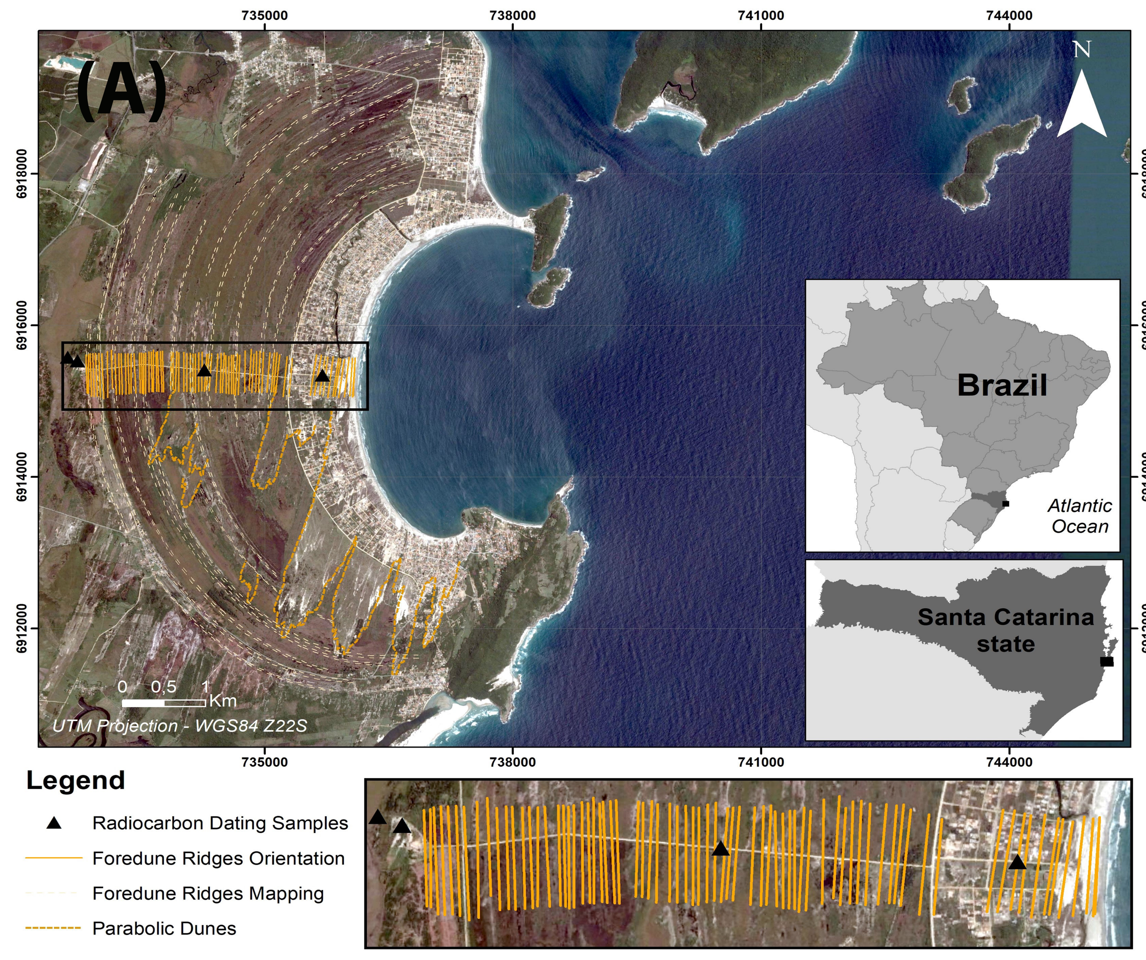
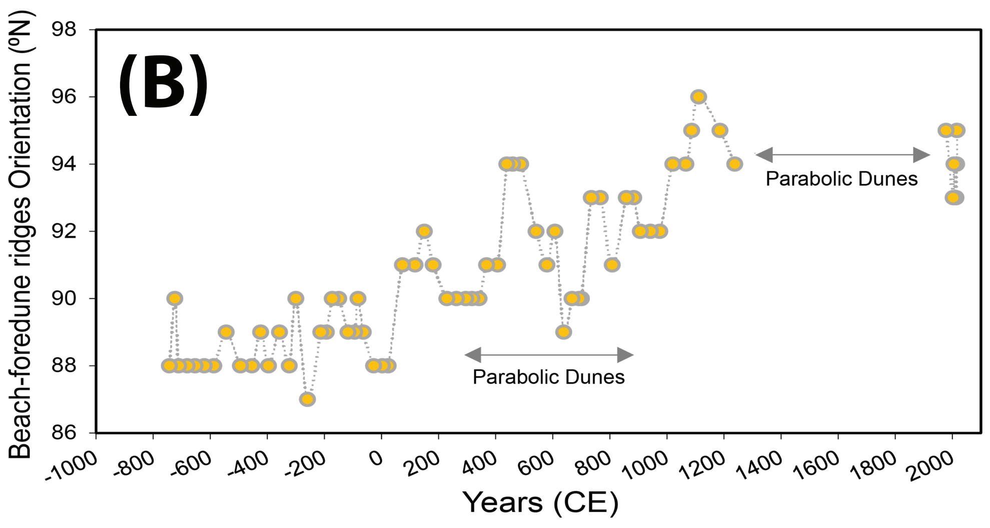
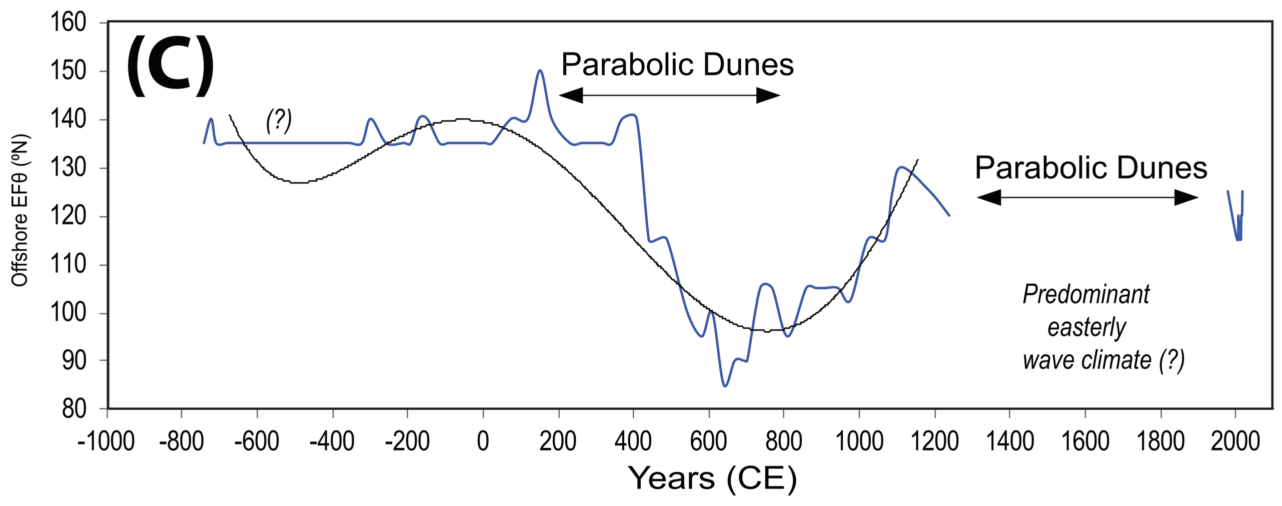
WAVE DIRECTION PROXY



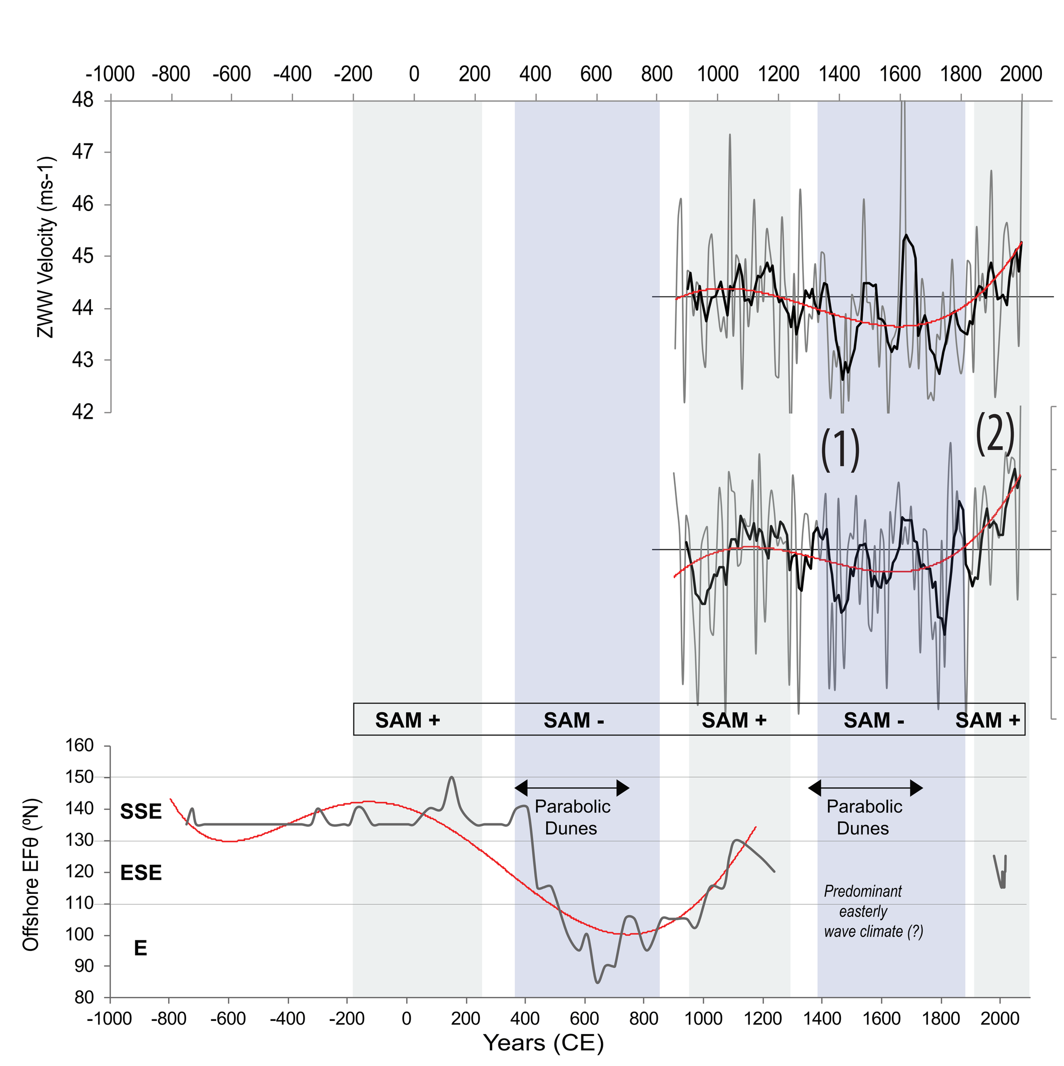


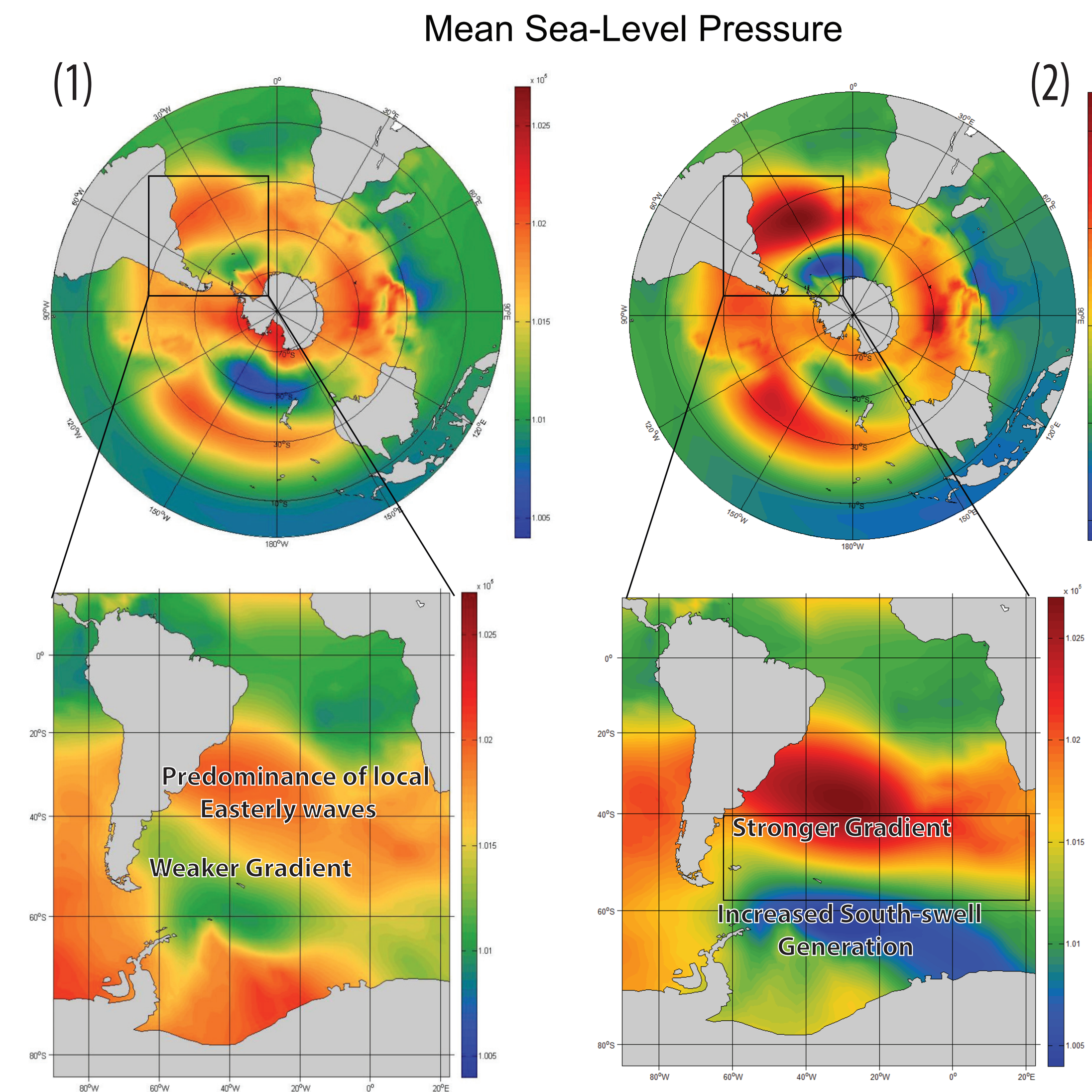


A beach-foredune ridge (BFR) sequence at Pinheira Strandplain (Santa Catarina, Brazil) (Fig.A) was mapped and the orientation of each ridge (Fig.B) was obtained from a 500 m-long strech on the central region, where the influence of the headlands shadow zones is minimal. The mean directional wave energy flux (EFθ) was obtained by modelling the wave propagation from deep to shallow water in every 5° bins for the offshore waves originating from 45 to 180 compass degrees. Results showed that offshore waves from the east (E) to south-southeast (SSE) (85 to 150°) reach the shoreline with the highest EFθ among all sectors and reach the 5m depth with wave directions varying between 89 and 95°, in agreement with the BFR orientation range. Thus, the orientation of each BFR served as a proxy to identify predominant offshore wave direction (Fig.C). Centennial-scale cycles were observed and investigated against climate changes.

WAVE DIRECTION AND ATMOSPHERIC VARIABILITY

The mean wave direction series was compared to ~1000 years of decadal means of mid-latitude mean sea-level pressure gradients (ΔMSLP) and zonal westerly wind velocities estimated from the CESM1-CAM5 "Last Millennium Ensemble (LME)". Results showed that multi-centennial cycles of oscillation in predominant wave direction occurred in accordance with stronger (weaker) South Atlantic mid-latitude mean sea-level pressure and zonal westerlies winds, favouring wave generation zones in higher (lower) latitudes and consequent southerly (easterly) wave climate dominance. It was identified the Southern Annular Mode as the main climate driver responsible for these changes, responding for 43% of the variance in the Subtropical South Atlantic atmospheric patterns in the last 1000 years.





CONCLUSIONS

(1) Our data reveal that climate changes over the Late Holocene induced modifications to wave conditions at the scale of an ocean sub-basin. This suggests a likelihood of substantial future shifts in wave climate in response to forecasted 21st century climate change;

(2) The response of waves to climate-change-associated atmospheric variability differs across ocean basins, highlighting the need for study of long-term changes in wave climate at the regional-scale;

(3) This new approach presented here, relying on wave-energy and wave-direction changes preserved in the orientation of palaeo BFR orientations, provides a new proxy for paleo-oceanographic reconstructions;

(4) In the South Atlantic, multi-centennial cycles of wave direction were observed to be correspondent with the variability of the mid-latitude ΔMSLP and westerlies jets , most likely in response to the Southern Annular Mode variability.

ACKNOWLEDGEMENT

A.P.S. and A.H.F.K. acknowledge the Brazilian Ministry of Environment for funding through the SMC-Brazil project. A.H.F.K. acknowledges the Rede Clima, INCT MarCOI "Oceanografia Integrada e Usos Multiplos da Plataforma Continental e Oceano Adjacente – Centro de Oceanografia Integrada (COI)", CNPQ (PQ2-CNPQ 301963/2015-0, PQ1D CNPQ 301597/2018-9, CNPQ 441545/2017-3) and, CAPES Brazil-Finance Code 001 and Capes/PROEX 88881.146046/2017-01 for financial support.

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