Evaluating Climate Signals on Global Coastal Shoreline Positions

A commentary on "Influence of El Niño on the variability of global shoreline position" by Almar and colleagues (2023).

Jonathan A. Warrick[1], Daniel Buscombe[2], Kilian Vos[3], Karin R. Bryan[4], Bruno Castelle[5], Andrew Cooper[6,7], Mitch D. Harley[8], Derek W.T. Jackson[6], Bonnie Ludka[9], Gerd Masselink[10], Margaret L. Palmsten[11], Amaia Ruiz de Alegria-Arzaburu[12], Nadia Sénéchal[5], Christopher R. Sherwood[13], Andrew D. Short[14], Erdinc Sogut[13,15], Kristen D. Splinter[8], Wayne J. Stephenson[16], Jaia Syvitski[17], Colin D. Woodroffe[18], and Adam P. Young[19]

[1] *U.S. Geological Survey, Santa Cruz, CA, USA*
[2] *Marda Science, contractor to U.S. Geological Survey, Santa Cruz, CA, USA*
[3] *New South Wales Department of Planning and Environment, Australia*
[4] *School of Science, University of Waikato, New Zealand*
[5] *Univ. Bordeaux, CNRS, Bordeaux INP, EPOC, UMR 5805, Pessac, France*
[6] *School of Geography and Environmental Sciences, Ulster University, UK*
[7] *School of Agricultural, Earth and Environmental Sciences, University of Kwazulu-Natal, South Africa.*
[8] *Water Research Laboratory, University of New South Wales, Australia*
[9] *Department of Environmental Resources Engineering, Cal Poly Humboldt, Arcata, CA, USA*
[10] *Coastal Processes Research Group, University of Plymouth, UK*
[11] *U.S. Geological Survey, St. Petersburg, FL, USA*
[12] *Institute of Oceanographic Research, Autonomous University of Baja California, Ensenada, México.*
[13] *U.S. Geological Survey, Woods Hole, MA, USA*
[14] *School of Geosciences, University of Sydney, Australia*
[15] *Department of Geology and Geophysics, Woods Hole Oceanographic Institution, MA, USA*
[16] *School of Geography, University of Otago, Dunedin, New Zealand*
[17] *Institute of Arctic and Alpine Research, University of Colorado, Boulder, USA*
[18] *School of Earth, Atmospheric and Life Sciences, University of Wollongong, Australia*
[19] *Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA*

Under Review at: **Matters Arising, Nature Communications**

Commentary on Almar et al. (2023): https://doi.org/10.1038/s41467-023-38742-9

24 July 2023

Almar and colleagues[1] are correct in stating that, "*understanding and predicting shoreline evolution is of great importance for coastal management*." Amongst the different timescales of shoreline change, the interannual and decadal timescales are of particular interest to coastal scientists as they reflect the integrated system response to the Earth's climate and its natural modes of variability. Therefore, establishing the links between shoreline change and climate variability at the global scale would be a major achievement. However, we find that the work of Almar et al.[1] does not achieve this goal because: (i) the satellite-based method does not meet the current standards of practice and produces inaccurate results, (ii) the spatial coverage of the shoreline dataset is not adequate for a global analysis, (iii) the relevance of the statistical analyses between the shoreline data and independent variables is questionable, and (iv) the findings do not capture physical patterns of shorelines developed from field-based observations.

Here we provide summary information for each of these points:

(i) The water line (or "shoreline") measurement technique of Almar et al.[1] does not follow current standard practices[2–7] including tidal correction, and the resulting data compare poorly with coastal monitoring measurements. Correlation coefficients (r) between the satellite-derived and field-derived shoreline data are only 0.38 to 0.61 (mean = 0.51), suggesting that the technique explains only 14 to 37% (mean = 26%) of the variance of actual shoreline measurements (Fig. S6). That is, almost three-quarters of the variance in actual shoreline positions is not captured by the Almar et al.[1] data. This can be compared to correlations from standard techniques used in other global-scale analyses that capture 67 to 87% (mean = 78%) of the variance of actual shoreline measurements (see Fig. S1 in Vos et al.[2])

This problem is highlighted by the creation of unrealistic seasonality for Narrabeen Beach, Australia (compare thin lines in Fig. S6i) and the failure to capture the largest accretion event of the records, which occurred in 2005 at Torrey Pines, California (compare thick lines in Fig. S6g; Almar et al.[1] incorrectly ascribed this event to beach nourishment). If the technique does not demonstratively measure most of the actual shoreline variability, erroneously produces seasonality signals, and fails to capture significant accretion events, then its use to describe global patterns of shoreline variability is likely to lead to inaccurate or misleading results. Almar et al.[1] acknowledge that their shoreline results include “hydrodynamic variabilities,” however these variabilities are likely dominated by the confounding effects of tides for many sites[7]. These shortcomings render the technique unsuited for a global analysis.

(ii) The shoreline dataset includes only one transect every 0.5°, or every 55,000 meters on average, to match the resolution of the oceanographic forcing data. This grossly undersamples the world’s shorelines. A single transect at this scale cannot be used to explain regional shoreline patterns because beaches vary greatly in their behavior, orientation, exposure to waves, proximity to sources of fluvial sediment, and human-related modifications. For example, not only can neighboring beaches separated by headlands behave differently due to differences in orientation and exposure, but opposing ends of large embayments can show out-of-phase behaviors due to beach rotation from redistribution of sediment[8,9]. As such, the spatial undersampling by Almar et al.[1] also increases the chance for spurious results because of the arbitrary location of the transects. In contrast, it is standard practice to map the position of the shoreline at scales of approximately 100 m and employ statistical methods to summarize shoreline behaviors at coarser resolutions as shown by regional and global studies[2–6].

(iii) Several questions remain regarding the statistical analyses between the shoreline data and the independent variables. The globally averaged correlation (r) of the sea level, wave, and river model was 0.49 (Fig. 1a) and an ENSO-based model resulted in r = 0.43 (Fig. 3a). Thus, only ~24% and ~18% of the variance in the shoreline data was explained by these variables. Although these correlations are low but statistically significant, it is important to ask why these correlations exist. Are they a result of actual shoreline changes related to these independent variables? Or are these spurious correlations that result from the inaccurate shoreline data that were not corrected for tidal and other water level effects? To address this, it should be recognized that tides and other water level factors are significantly correlated with ENSO[2,10,11], which raises the possibility that the correlations result from residual tidal effects in the shoreline data. In the end, we recognize that ENSO conditions can influence waves, and that waves can strongly influence beach morphodynamics[2,12]. However, it appears that the statistically significant results of Almar et al.[1] may have been caused by problems in the shoreline data.

(iv) If a simplified model of global shoreline patterns is to be useful to managers and planners, it should capture the general physical patterns identified by field research and be relevant at the local scale. The results in Almar et al.[1] fail to do this as described in item (i) above. In addition the results suggest that "sea-level dominance" is the overwhelming control on the world's shorelines (e.g., Central Africa, western Australia, most of the Pacific Rim, and the Mediterranean; Fig. 1b), which contrasts with dozens of scientific studies showing that waves or rivers dominate the morphodynamics at these settings[2,13,14]. Similarly, river dominance was found for some coastal areas that physically do not receive littoral-grade sediment from their rivers owing to broad, low gradient coastal plains (e.g., much of eastern Australia and part of eastern North America; Fig 1b). These highly unusual results are contrary to the wave dominance that exists broadly for coastal shorelines worldwide[13].

Finally, open data are an important element of modern science. Although the authors noted that, "data are made available upon request", we propose that data publication would have provided a more accessible and lasting option, and it would have been more consistent with Nature's stated mandates for specific datasets and their endorsement of the Enabling FAIR Data initiative for the Earth, space, and environmental sciences[15]. Larger shoreline databases and their processing codes have been published openly, and public-facing viewers of these data serve as good models for getting information to coastal managers and citizens[2,7].

Combined, the insufficient data and weak correlations suggest that readers should be skeptical of the conclusions from Almar et al.[1] As noted above, many of these conclusions are counter to fundamental understanding of coastal systems, and the general conclusion and headline finding that ENSO is a globally important driver of shoreline change is misleading.

We look forward to more rigorous analyses of the trends and causes of coastal change from data that have reasonable uncertainties and are published openly. These kinds of studies are critical to our understanding of coastal habitats and the future of coastal communities during the modern era of human population growth, climate change, and sea-level rise. Coastal managers and citizenry are looking to the scientific community to provide actionable information at both local and regional scales based on rigorously tested and freely available data. Given the importance of this science, future efforts to increase the understanding of coastal systems and carefully reassess the conclusions of Almar et al.[1] will be needed.

Competing Interests

None of the authors have competing interests in the publication of this article.

Author Contributions

JAW led the writing and editing. All others provided background information, intellectual contributions, editing, and/or writing of the manuscript.

References

1. Almar, R. *et al*. Influence of El Niño on the variability of global shoreline position. *Nat Commun* **14**, 3133 (2023).
2. Vos, K., Harley, M. D., Turner, I. L. & Splinter, K. D. Pacific shoreline erosion and accretion patterns controlled by El Niño/Southern Oscillation. *Nat. Geosci.* **16**, 140–146 (2023).
3. Mao, Yongjing., Harris, D. L., Xie, Zunyi. & Phinn, Stuart. Efficient measurement of large-scale decadal shoreline change with increased accuracy in tide-dominated coastal environments with Google Earth Engine. *ISPRS Journal of Photogrammetry and Remote Sensing* **181**, 385–399 (2021).
4. Mentaschi, L., Vousdoukas, M. I., Pekel, J.-F., Voukouvalas, E. & Feyen, L. Global long-term observations of coastal erosion and accretion. *Scientific Reports* **8**, (2018).
5. Konstantinou, A. *et al*. Satellite-based shoreline detection along high-energy macrotidal coasts and influence of beach state. *Marine Geology* **462**, 107082 (2023).
6. Castelle, B., Ritz, A., Marieu, V., Nicolae Lerma, A. & Vandenhove, M. Primary drivers of multidecadal spatial and temporal patterns of shoreline change derived from optical satellite imagery. *Geomorphology* **413**, 108360 (2022).

7. Bishop-Taylor, R., Nanson, R., Sagar, S. & Lymburner, L. Mapping Australia's dynamic coastline at mean sea level using three decades of Landsat imagery. *Remote Sensing of Environment* **267**, 112734 (2021).

8. Burvingt, O., Masselink, G., Russell, P. & Scott, T. Classification of beach response to extreme storms. *Geomorphology* **295**, 722–737 (2017).

9. Harley, M. D., Turner, I. L. & Short, A. D. New insights into embayed beach rotation: The importance of wave exposure and cross-shore processes. *J. Geophys. Res. Earth Surf.* **120**, 1470–1484 (2015).

10. Gurubaran, S. Interannual variability of diurnal tide in the tropical mesopause region: A signature of the El Nino-Southern Oscillation (ENSO). *Geophys. Res. Lett.* **32**, L13805 (2005).

11. Yasuda, I. Impact of the astronomical lunar 18.6-yr tidal cycle on El-Niño and Southern Oscillation. *Sci Rep* **8**, 15206 (2018).

12. Yates, M. L., Guza, R. T. & O'Reilly, W. C. Equilibrium shoreline response: Observations and modeling. *Journal of Geophysical Research* **114**, (2009).

13. Castelle, B. & Masselink, G. Morphodynamics of wave-dominated beaches. *Camb. Prism. Coast. Futures* **1**, e1 (2023).

14. Anthony, E. J., Marriner, N. & Morhange, C. Human influence and the changing geomorphology of Mediterranean deltas and coasts over the last 6000 years: From progradation to destruction phase? *Earth-Science Reviews* **139**, 336–361 (2014).

15. Announcement: FAIR data in Earth science. *Nature* **565**, 134–134 (2019).