Reply to 'Waves do not contribute to global sea-level rise'

Melet et al. reply — The quantification of adaptation needs to sea-level hazards at global-to-regional scales is a major research challenge. Our global-scale analysis[1] contributes to understanding the drivers of interannual-to-multidecadal coastal water level changes by reporting that at first order, wave contributions are sizeable. Typically these contributions have not been accounted for, and thus we advocate for their inclusion to provide more accurate assessments[2] of the vulnerability of the coasts. We clarify below three main points regarding our analysis and its implications.

First, coastal water-level changes result from different processes acting over a range of timescales. Wind-wave-induced coastal water level changes are largest for short timescales (wave period or wave-group timescales). However, wave set-up and swash can be modulated at interannual-to-multidecadal timescales by: changes in offshore wave height, period and direction due to surface wind changes[3]; changes in geomorphology[4] (such as beach orientation, nearshore bathymetry); and changes in currents and water depth[5–7]. Our analysis focused on the first point, highlighting that wave contributions should be considered not only for extreme events, but also in analyses of interannual-to-multidecadal coastal sea-level changes and rise.

Second, policy-relevant water-level changes are those that result from a combination of processes that cause shoreline changes, including wave set-up and swash, and from both climate change and internal variability. But as wave set-up is always positive at the coast, whereas swash is oscillatory, their contributions were shown separately, providing a more direct comparison between set-up and altimetric sea level[1]. Trends induced by internal variability were highlighted to discuss the future evolution of wave set-up and altimetric sea level. It should be noted that even estimates of coastal sea-level rise due to steric effects and melting glaciers have been substantial due to internal variability over the past two decades[8–10]. Although wave climate projections remain uncertain, some robust patterns of longer-term wave-regime changes emerge in climate change projections[11]. In any case, wave climate changes are expected in response to climate change and will be transmitted to water-level changes at the coast through changes in wave set-up and swash.

Third, we acknowledge that our estimates are associated with large uncertainties. We aimed to be transparent on this point by mentioning the main limitations of our methodology, separating the contributions from wave set-up and swash, and reporting the large sensitivity of our estimates to choices in foreshore beach slope values and empirical parameterizations. Although Aucan et al.[12] criticize the parameterization values used, no worldwide estimate of foreshore beach slopes is available[13–15]. In the SHOM report they cite[16], beach slopes rely on a parametric beach profile model and on assumptions regarding sediment grain sizes, using only four beaches as a benchmark. As recognized by that report's authors, this method does not deliver a reliable global estimate of beach slopes.

Beach slopes generally range between 0.01 and 0.20 (ref. [17]). Although a slope of 0.1 might lie in the upper range for intermediate beaches, and despite limitations in empirical formulations of wave set-up and swash, this value allows an order of magnitude estimate for a global-scale analysis. A sensitivity analysis using slopes ranging from 0.05 to 0.15 in the generic, state-of-the-art empirical formulation of set-up and swash[1,18] completes our main analysis. For dissipative conditions (generally including beaches with lower slopes, <0.02) we did use the dissipative-specific formulation[1,18] also used by Vitousek and colleagues[5]. Using a slope of 0.05 (or 0.02) instead of 0.10 with the generic formula reduces wave set-up by a factor of 2.0 (5.0), swash by a factor of 1.3 (1.5) and run-up by a factor of 1.55 (2.1). Using the dissipative-specific formulation instead of the generic one with a beach slope of 0.1 reduces set-up by a factor of 2.4 and swash by a factor of 2.0 (not 5 as stated by Aucan et al.[12]). The main message of our study is therefore robust regardless of the formulation used, but our results call for future research efforts to refine estimates of wave set-up and swash.

Only long-term observations of wave set-up and swash could validate interannual-to-multidecadal changes, which are the focus of our study. However, despite numerous coastal wave measurements (from buoys, for example) existing, sustained efforts are still required to collect observations such as video monitoring or LIDAR to monitor run-up over longer periods[19]. ❐

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