Increasing coastal flood risk is one of the major consequences of mean sea-level rise (SLR) and will make costly adaptation, and in extreme cases migration to higher ground, inevitable. Extensive research has been directed toward reconstructing past SLR and developing global and regional SLR projections (Church et al. 2013). These projections are used in impact and adaptation studies (e.g. Hinkel et al. 2014) to facilitate risk-informed decision making. However, in order to understand coastal impacts under current and future climate and socio-economic conditions, not only robust SLR projections are required but also a profound knowledge of the drivers and occurrence of present-day and future extreme sea levels (ESL), as ESL drive the impacts (Bindoff et al. 2007). SLR already threatens several small island states in the Pacific and Indian Oceans and, depending on how much sea level will rise in the coming decades and centuries, other coastal areas will become uninhabitable. This will be a gradual process that can be anticipated. ESL on the other hand occur randomly and accurate forecasts become only available a few days or hours before the impacts occur. Recent events like Hurricanes Harvey and Irma have revealed how vulnerable and ill-prepared many coastal communities are for such extreme events. Therefore, adequate adaptation has to take into account SLR and ESL as well as the uncertainties inherent to both of them (see below for more details).

ESL (excluding tsunamis) result from tropical or extra-tropical cyclones as a combination of high tides and storm surges, and in many cases a dynamic wave component. Tide gauges located along the world’s coastlines that have been recording water levels for many decades or even centuries provide the most accurate source of information on ESL, but they are unevenly distributed (with most of them located in North America and Europe) (Menéndez and Woodworth 2010) hampering broad-scale (up to global) assessments. Hydrodynamic numerical models, on the other hand, can simulate ESL data for all coastlines, but they are computationally very expensive, especially when applied for large areas, and they rely on accurate bathymetric data and high-resolution (in space and time) wind information, as the most important driver for storm surges; both are often unavailable.

Hence, at continental and global scales there has been a limited number of studies of present-day and future ESL. This is also reflected in the assessments by the Intergovernmental Panel on Climate Change (IPCC) that include dedicated SLR chapters in all five reports, yet no, or only relatively short sub-chapters on ESL with limited information. In the Fifth Assessment Report (AR5) (Church et al. 2013) multiplication factors were derived for many tide gauges around the globe, indicating the increase in frequency with which certain extreme levels will be exceeded under different SLR scenarios. This was an important improvement compared to the AR4 (Bindoff et al. 2007), which did not provide such information on future ESL changes. However, the statistical approach that was used relies on the simplified assumption of a constant change in the frequency for all extreme events; i.e. the frequency of moderate events will change in the same way as the frequency of the most extreme events. The same statistical approach has been used in other global studies where present-day and future ESL and associated impacts were assessed (Hinkel et al. 2014, Muis et al. 2016).

A recent publication by Buchanan et al. (2017) addresses this issue. The authors employed a much more sophisticated and rigorous statistical methodology to assess the variation in multiplication factors (or amplification factors, as referred to in the study) across different levels of extremes, with a focus on the contiguous United States (US). Importantly, they found that SLR will result in stronger increases in the number...
of moderate (or high-frequency) events in some places, e.g. Charleston or New York on the east coast, whereas other areas will experience a more rapid increase in the number of rare extreme (or low-frequency) events, e.g. Seattle on the west coast. On average, across all study sites, there would be a 25 fold increase in the expected annual number of present-day 100 year events (i.e. events that currently have a 1% chance of occurrence in any given year) by 2050 under a moderate SLR scenario (representative concentration pathway (RCP) 4.5). Under a high-end SLR scenario (RCP8.5) the average increase could be 40 fold, with strong variations across sites ranging from 1–1314 fold. This highlights how SLR and, in particular, the accompanying changes in ESL, will lead to a rapid increase in flood risk along the US coast over the next few decades. However, the numbers reported cannot be directly translated to changes in flood frequencies, because whether or not flooding occurs strongly depends on the presence of coastal defenses and future adaptation efforts. In addition to assessing changes in ESL frequencies, the authors also highlighted the importance of the uncertainties inherent to the extreme value analysis, which have often been ignored in impact studies, and demonstrated how they can be accounted for alongside the uncertainties in SLR projections.

The new study fills a gap in our understanding of how SLR will modulate extreme events. It joins a number of other recent broad-sale assessments of ESL. Most notably, in a global study Wahl et al (2017) considered both extreme value analysis and numerical models that were used to simulate storm surges at coastline stretches where no observations exist to quantify ESL and their uncertainties. They also assessed changes in ESL frequencies with SLR. Interestingly, although both Buchanan et al and Wahl et al took different angles and the studies were conducted independently, the key conclusions were the same: (1) the popular Gumbel distribution oversimplifies how SLR modulates extremes by assuming constant changes in the frequency across all levels; the Generalized Pareto distribution (GPD) not only makes better use of the available data, by following a peaks-over-threshold approach, it also provides more realistic results for changes in the frequency of rare extreme events. (2) ESL uncertainties are at least as important as uncertainties in SLR projections, and exceed them in many regions (Wahl et al 2017). Hence, both SLR and ESL need to be integrated to fully assess impacts and adaptation needs.

Most ESL investigations (including the ones by Buchanan et al and Wahl et al) assumed no, or negligible future changes in storminess and that SLR will be the only relevant driver for changes in the frequency of extremes. This assumption is largely based on the analysis of historic data (Menéndez and Woodworth 2010), which also show that in some locations long-term trends in ESL have occurred in the past (Marcos and Woodworth 2017) superimposed onto multi-decadal variations (Marcos et al 2015, Wahl and Chambers 2015 and 2016). Studies for entire coastline stretches, including global investigations, were also impeded by complications in using broad-scale hydrodynamic models to simulate past and future storm surges. However, with recent developments in modelling approaches and computational resources examining the potential impacts of changes in storminess has become feasible, as exemplified by studies of Muis et al (2016), who used the first dynamic global storm surge model to simulate past water levels for the global coast, or Vousdoukas et al (2016), who simulated future storm surge changes along the entire European coast. The latter showed that future ESL changes can be significant in certain areas, adding to, or damping the effects of SLR; such information needs to be accounted for in coastal management and adaptation plans in addition to SLR projections. Another important improvement to the investigation of ESL has been the inclusion of the dynamic wave component into global ESL assessments (Vitousek et al 2017), since wave runup and setup are important drivers of erosion and flooding risk along many coastline stretches. This increasing number of studies on contemporary and future ESL shows that the scientific community has taken on the challenge of providing better and much needed projections of future changes in ESL and coastal flood risk to decision- and policy-makers for local, regional, and global planning efforts, and this should also be reflected in the next IPCC assessment.

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