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The growing exposure of Pacific coral reefs to compound extremes caused by marine heatwaves coalescing with low saturation state extremes

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The ocean has played a key role in mitigating the impact of climate change by taking up excess anthropogenic heat and CO_2 leading to warming and increased ocean acidity, which goes in hand with a reduction of the saturation state of seawater with regard to the mineral carbonate aragonite, *i.e.*, Ω_{AR}. While the threats posed by these long-term changes to marine organisms and ecosystems are well recognized, only more recently has the community realized that these threats might be much more imminent owing to extreme events. This is the result of these extremes exposing vulnerable ecosystems already today to conditions that lie in the far future when considering only the changes in the mean conditions. Of particular concern are so-called compound events, *i.e.*, conditions when both temperatures are extremely hot and the saturation states extremely low, as this compounding might be particularly threatening for marine ecosystems, especially for warm water coral reefs.

Here we use satellite records of sea surface temperature (SST) and satellite Ω_{AR} to map globally the occurrence of marine heat waves (MHW) and low saturation state extreme events and their compounding for the period 1985 and 2018. We use SSTs from the OSTIA product, while we take Ω_{AR} from the newly developed OceanSODA-ETHZ (monthly 1°x1°) observation-based product that extrapolates ship observations with satellite data. Our study focuses on the Pacific Ocean between 25°S and 25°N, a region with more than 1000 identified coral reefs. We define extremes using the approach of Hobday et al. (2018) with a fixed baseline determined from the entire record (1985-2018) and where extremes are below/above the 10^{th}/90^{th} percentiles for Ω/SST respectively.

The majority of the compound extreme events (too hot and too low saturation state) occur in the western tropical Pacific, with 757 of the 1206 reefs in the Pacific experiencing at least three months of compound extreme events over the entire period. The average duration of these compound extremes was 3.6 months, and the average area was 247 600 km^2 (roughly the size of the United Kingdom). The compound events had an average intensity of –0.13 for Ω_{AR} and 0.71°C, where the intensity is the anomaly from the climatology. The largest and longest lasting extreme event started in 2016 and lasted nearly three years, coinciding with the El Niño event over the same period, covering an area equivalent to Australia. These findings suggest that more than 60% of coral reefs in the Pacific Ocean are located in regions where heating events may have been compounded by decreased potential for calcification. Given the continuing increase in

atmospheric CO_2, the severity of this type of compound events is bound to increase in the future.