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Probing the unfathomable: ensemble boosting for physical climate storylines of unseen heat extremes

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The Pacific Northwest heat wave is one of a series of record-shattering heat extremes that, based on the previous observational record, may have been deemed impossible. Here we address the question of whether the potential for such an extreme heat wave could have been foreseen using simulated physical climate storylines.

We use a novel approach, called ensemble boosting, in which a fully-coupled free-running climate model (CESM2) is used to develop physical storylines of very rare heat extremes under present-day conditions. In ensemble boosting, the most extreme events in an initial-condition large ensemble for the near future are re-initialized with slightly perturbed atmospheric initial conditions to efficiently generate events that are even more extreme, with the goal of sampling events with magnitudes that have not been seen before.

We demonstrate that, with this approach, CESM2 can efficiently simulate events that reach or even exceed the magnitude and duration of the 2021 Pacific Northwest heatwave anomaly. The atmospheric circulation anomalies associated with the most extreme simulated heat waves in the boosted ensemble are remarkably similar to the observed event. We further evaluate the anomalies in the surface energy and water budgets that contribute to the most intense simulated events. We conclude that based on this approach, heat waves unseen in the observational record can be simulated in models, at least in some regions. After probing this approach for the Pacific Northwest heatwave, we apply it to other mid-latitude regions where extreme heat events of much higher magnitude than has been observed are plausible in the near future.

The ensemble boosting approach is computationally efficient, and it preserves physical consistency both in time, in space and across variables. This has the major advantages that the drivers can be directly evaluated against observed events and the generated storylines can be used in impact studies that require physical consistency, e.g. for the evaluation of humid heatwaves or compound events, for assessing wildfire risks or for ecosystem modelling.