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Greenhouse gas forcing a necessary, but not sufficient, causation for the northeast Pacific marine heatwaves

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Over the last decade, the northeast Pacific experienced strong marine heatwaves (MHWs) that produced devastating marine ecological impacts and received major societal concerns. Here, we assess the link between the well-mixed greenhouse gas (GHG) forcing and the occurrence probabilities of the duration and intensity of the North Pacific MHWs. We investigate whether GHG forcing was necessary for the North Pacific MHWs to occur and whether it is a sufficient cause for such events to continue to repeatedly occur in the 21st Century. To begin with, we apply attribution technique on the long-term SST time series, and detect a region of systematically and externally-forced SST increase -- *the long-term warming pool* -- co-located with the past notably Blob-like SST anomalies. We further show that the anthropogenic signal has recently emerged from the natural variability of SST over the warming pool, which we attribute primarily to increased GHG concentrations, with anthropogenic aerosols playing a secondary role.

After we demonstrate that the GHG forcing has a dominant influence on the base climate state in the region, we pursue an event attribution analysis for MHWs on a more localized region. Extreme event attribution analysis reveals that GHG forcing is a necessary, but not sufficient, causation for the multi-year persistent MHW events in the current climate, such as that happened in 2014/2015 and 2019/2020. However, the occurrence of the 2019/2020 (2014/2015) MHW was extremely unlikely in the absence of GHG forcing. Thus, as GHG emissions continue to firmly rise, it is very likely that GHG forcings will become a sufficient cause for events of the magnitude of the 2019/2020 record event.