Mechanisms and drivers of the 2021 Pacific Northwest heatwave

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The Pacific Northwest is characterized by a temperate climate with mild to warm summers, yet in late June 2021, the region was ravaged by extreme heat and ensuing wildfires. With local daily maximum temperatures 20 °C above the long term mean, the occurrence of such a brute heatwave makes it imperative to understand the underlying physical processes. Using the Community Earth System Model, we simulate this exceptional event and disentangle its thermodynamic and dynamic drivers. A factorial experimental design based on the ExtremeX framework is employed, in which the mid and upper-tropospheric circulation and soil moisture are either prescribed using reanalysis (ERA5) data, or calculated interactively. With this setup, the lower troposphere can always respond to land and ocean surface fluxes. Our results indicate that, despite widespread drought conditions in the analysis region (including the metropolitan areas of Portland, Seattle and Vancouver) and surroundings, the dynamic contribution far exceeded the effect of anomalous soil moisture. We further disentangle the soil moisture contribution into initial and event-driven, and find that precipitation in the first half of June 2021 prevented even higher near-surface temperatures by weakening the initial effect. Overall, the analysis highlights the role of the anticyclone that governed the large-scale circulation, and whose intensity during summertime and within 45°N–60 °N surpasses any other event in recent decades. As such, this heatwave presents an opportunity to investigate whether our Earth System Model of choice is capable of generating similarly extreme heat at large spatial scales on its own, i.e. with fully interactive winds. While the mean intensity of hot anticyclonic summer events over land (45°N–60 °N) is underestimated with respect to our reference simulation with prescribed circulation, the model portrays stronger variability with an interactive atmosphere and hence generates heatwaves that rival and even surpass the large-scale temperature anomalies of the Pacific Northwest 2021 event. Our investigation also points to strong temperature anomalies aloft, which we track back in time with a Lagrangian trajectory model driven by ERA5 data. By doing so, we find evidence for intense latent heating of the air that would later be part of the anticyclone, and mixed into the unusually deep atmospheric boundary layer. We further demonstrate that in the absence of anthropogenic climate change, an otherwise identical heatwave would not have reached such extreme temperatures. Altogether, this study shows that for the right atmospheric configuration and fuelled by our changing climate, unprecedented heat may be unleashed even in regions traditionally considered devoid of excessive heatwaves.