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Vegetation feedbacks during drought exacerbate ozone air pollution extremes in Europe

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This study highlights a previously under-appreciated “climate penalty” feedback mechanism - namely, substantial reductions of ozone uptake by water stressed vegetation – as a missing piece to the puzzle of why European ozone pollution episodes have not decreased as expected in recent decades, despite marked reductions in regional emissions of ozone precursors due to regulatory changes. The most extreme ozone pollution episodes are linked to heatwaves and droughts, which are increasing in frequency and intensity over Europe, with severe impacts on natural and human systems. Under drought stress, plants close their stomata to reduce water loss, consequently limiting the ozone uptake by vegetation (a component of dry deposition), leading to increased surface ozone concentrations. Such land-biosphere feedbacks are often overlooked in prior air quality projections, owing to a lack of process-based model formulations. Here, we use six decades of observations and Earth system model simulations (1960-2018) with an interactive dry deposition scheme to show that declining ozone removal by water-stressed vegetation in the warming climate exacerbate ozone air pollution over Europe. Incorporated into a dynamic vegetation land – atmospheric chemistry – climate model, the dry deposition scheme mechanistically describes the response of ozone deposition to atmospheric CO_2 concentration, canopy air vapor pressure deficit, and soil water availability. Our observational and modeling analyses reveal drought stress causing as much as 70% reductions in ozone removal by forests. Reduced ozone removal by water-stressed vegetation worsens peak ozone episodes during European mega-droughts, such as the 2003 event, offsetting much of the air quality improvements gained from regional emission controls. Accounting for vegetation feedbacks leads to a three-fold increase in high surface ozone events above 80 ppbv (8-hour average) and a 20% increase in the sensitivity of ozone pollution extremes (95^{th} percentile) to increasing temperature. As the frequency of hot and dry summers is expected to increase in the coming decades, this ozone climate penalty could be severe and therefore needs to be considered when designing clean air policy in the European Union.

Notes: This study is currently under review for possible publication in Nature Climate Change.