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Montreal Protocol to delay ice-free Arctic by a decade

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Recent work has shown that a rapid rise in the emission of ozone depleting substances resulted in substantial Arctic warming and accelerated Arctic sea ice loss over the second half of the twentieth century. However, ozone depleting substances have been heavily regulated since the Montreal Protocol entered into effect in 1989, and their atmospheric concentrations have been stabilized and are now decreasing. This raises the obvious and important questions of the impact of the Montreal Protocol on climate change in the Arctic.

More specifically we are here interested in quantifying the impact of the Montreal Protocol on the date of the first ice-free Arctic summer (defined as the first occurrence of Arctic sea ice extent below 1 million km^2). The timing of the ice-free Arctic is of great interest both to stakeholders in the Arctic and to the scientific community.

To address this question, we have performed and analyzed ten-member 'World Avoided' companion ensembles to the CESM Large Ensemble (using RCP8.5 forcings) and to the CESM Medium Ensemble (using RCP4.5 forcings). The companion ensembles are identical to their CESM-LE and CESM-ME counterparts, respectively, except for the levels of ozone depleting substances which do not decrease following the Montreal Protocol, but instead increase at a rate of 3.5% a year. This allows us to isolate the effect of the Montreal Protocol on Arctic sea ice trends by simulating what would have happened if it had never been enacted (hence the name, 'World Avoided'). We examine both RCP8.5 and RCP4.5 forcings, to quantify the uncertainty related to emissions scenarios over the coming decades.

We find that without the Montreal Protocol the mean date of the first ice-free Arctic advances from 2041 to 2033 for the RCP8.5 forcings, and from 2050 to 2035 for the RCP4.5 forcings. Thus, enacting the Montreal Protocol has delayed the onset of an ice-free Arctic by approximately one decade. This signal is robust when accounting for the high levels of internal variability in Arctic sea ice trends. Our results are also robust to different definitions of 'ice-free Arctic'. Overall our results highlight the importance of the Montreal Protocol as a major climate mitigation treaty, even for the Arctic, where no ozone-hole has formed.