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Substantial twentieth-century Arctic warming caused by ozone-depleting substances

Lorenzo Polvani^{1,2}, Michael Previdi², Mark England^{1,3}, Gabriel Chiodo^{1,4}, and Karen Smith^{2,5}

¹Applied Physics & Applied Mathematics, Columbia University, New York, NY, USA (lmp@columbia.edu)

²Lamont Doherty Earth Observatory, Columbia University, Palisades, NY, USA

³Scripps Institute of Oceanography, San Diego, CA, USA

⁴Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

⁵Environmental Science, University of Toronto, Scarborough, ON, Canada

The rapid warming of the Arctic, perhaps the most striking evidence of climate change, is believed to arise from increases in atmospheric concentration of greenhouse gases since the industrial revolution. While the dominant role of carbon dioxide is undisputed, another important set of anthropogenic greenhouse gases was also being emitted over the second half of the twentieth century: ozone-depleting substances (ODS). These compounds, in addition to causing the ozone hole over Antarctica, have long been recognized as powerful greenhouse gases. However, their contribution to Arctic warming has not been quantified to date. We do so here by analyzing ensembles of climate model integrations specifically designed for this purpose, spanning the period 1955-2005 when atmospheric concentrations of ODS increased rapidly. We show that when ODS are kept fixed the forced Arctic surface warming, and the forced sea ice loss, are only half as large as when ODS are allowed to increase. We also demonstrate that the large Arctic impact of ODS occurs primarily via direct radiative warming, not via ozone depletion. Our findings reveal a substantial, and hitherto unrecognized, contribution of ODS to recent Arctic warming and highlight the importance of the Montreal Protocol as a major climate change mitigation treaty.