

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

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ODS were the second most important GHG over 1955-2005

ODS are halogen gases containing chlorine and/or bromine with potential to break down ozone in the stratosphere

- mainly used for refrigerants, air conditioners, fire extinguishers.
- emissions rapidly increased over second half of 20th century until introduction of Montreal Protocol (1987)
- are potent greenhouse gases on a molecule by molecule basis (~20,000x more radiatively efficient than CO₂)

ODS provided 25% of the anthropogenic radiative forcing over 1955-2005, one third as large as CO₂

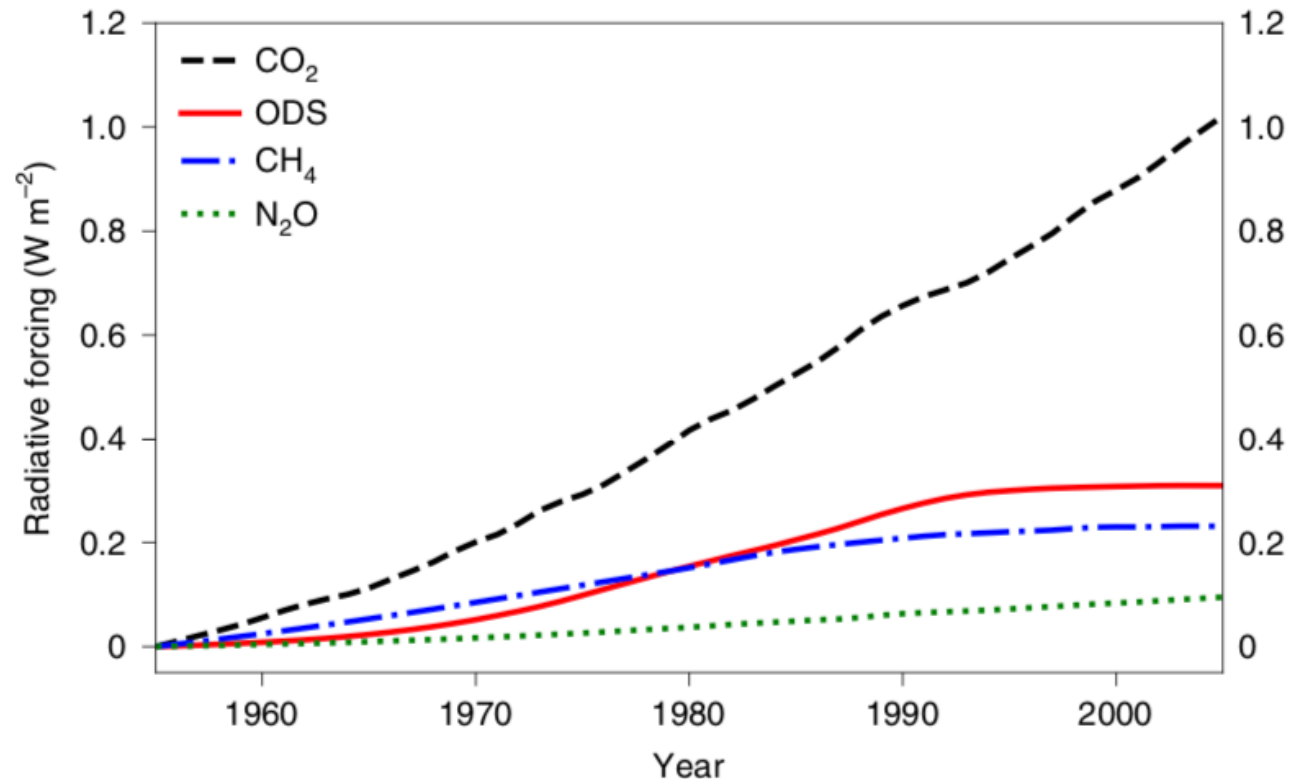


Fig. 1 | Radiative forcing of GHGs for 1955-2005. Global radiative forcing of the four principal well-mixed GHG from 1955 to 2005, as computed¹⁶ from the data available at <http://www.pik-potsdam.de/~mmalte/rcps>.

Fixed ODS, O₃ runs with CESM-LE

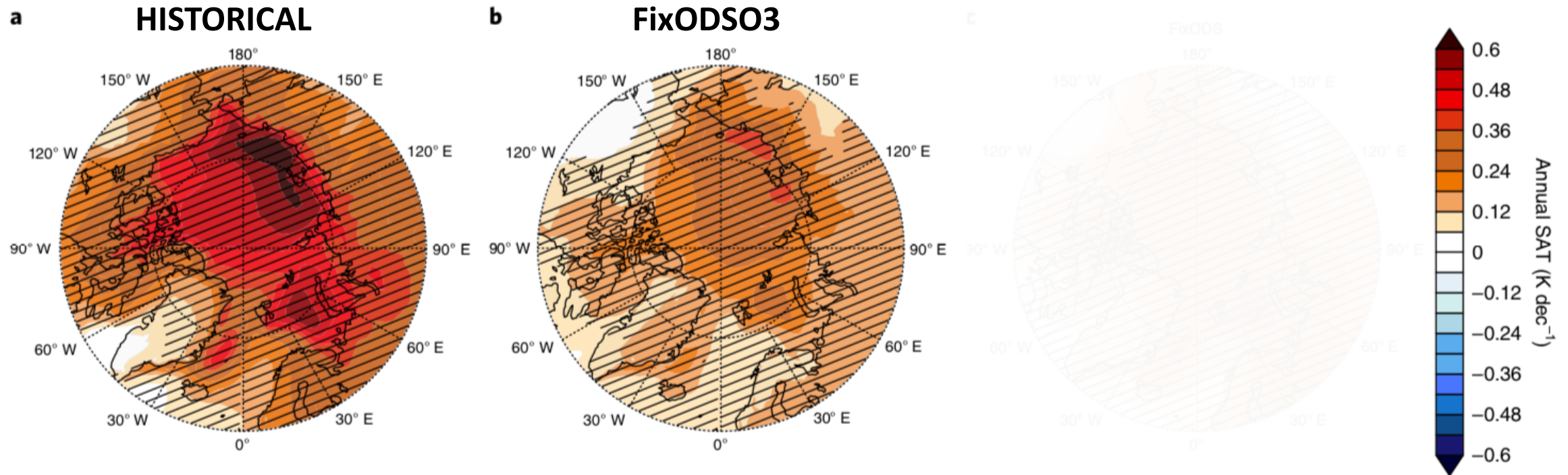
To understand the contributions of ODS to Arctic climate change we perform a 10-member ensemble of historical transient runs 1955-2005 **where ODS and ozone concentration were fixed at 1955 values (FIXODSO3)**

All other forcings (CO₂, methane etc...) evolve as in the CESM-LE.

By taking the difference with 10 members from the CESM-LE, we can isolate the contribution of ODS.

Ensemble mean will give an estimate of the forced response.

With ODSs held fixed, forced Arctic surface warming reduces by half



Polar cap temp. increase,
1955-2005

1.59°C

-49%

0.82°C

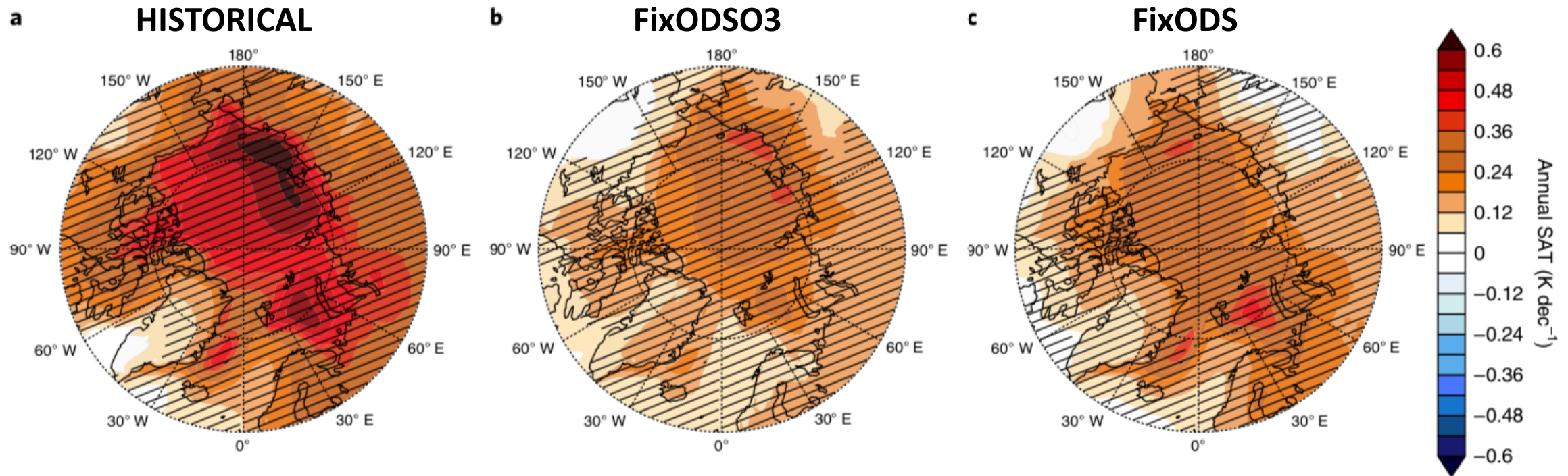
Global temp. increase,
1955-2005

0.59°C

-33%

0.39°C

Same result if ODS held fixed but ozone concentrations unchanged from historic runs



Polar cap temp. increase,
1955-2005

1.59°C

-49%

0.82°C

-45%

0.87°C

Global temp. increase,
1955-2005

0.59°C

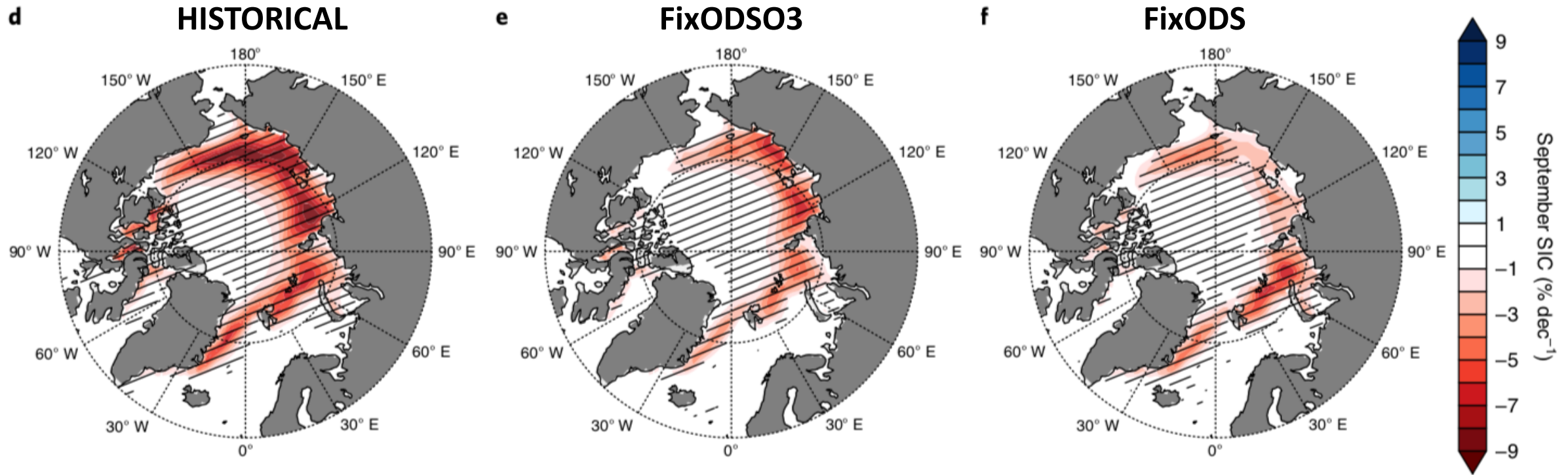
-33%

0.39°C

-32%

0.40°C

With ODS held fixed, forced Arctic September sea ice loss reduces by half



September sea ice
extent change, 1955-
2005

$-1.45 \times 10^6 \text{ km}^2$

-48%

$-0.76 \times 10^6 \text{ km}^2$

-47%

$-0.77 \times 10^6 \text{ km}^2$

Key take-aways

- Although less abundant than CO₂, ODS are potent greenhouse gases.
- In runs in which ODS were held fixed at 1955 values, **forced Arctic warming and sea ice loss were reduced by a half.**
- Arctic warming is due to radiative effects of ODS, not through effects on ozone.
- Internal variability is large in the Arctic, but signal is much larger.
- Same result from two different climate models (see paper)
- ODS can have an outsized effects due to large cancellation between cooling from aerosols and warming from CO₂.

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