UNIVERSITY OF CALIFORNIA UC RIVERSIDE

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Disentangling the impacts of stratospheric ozone depletion and tropospheric ozone increases on Southern Ocean interior warming

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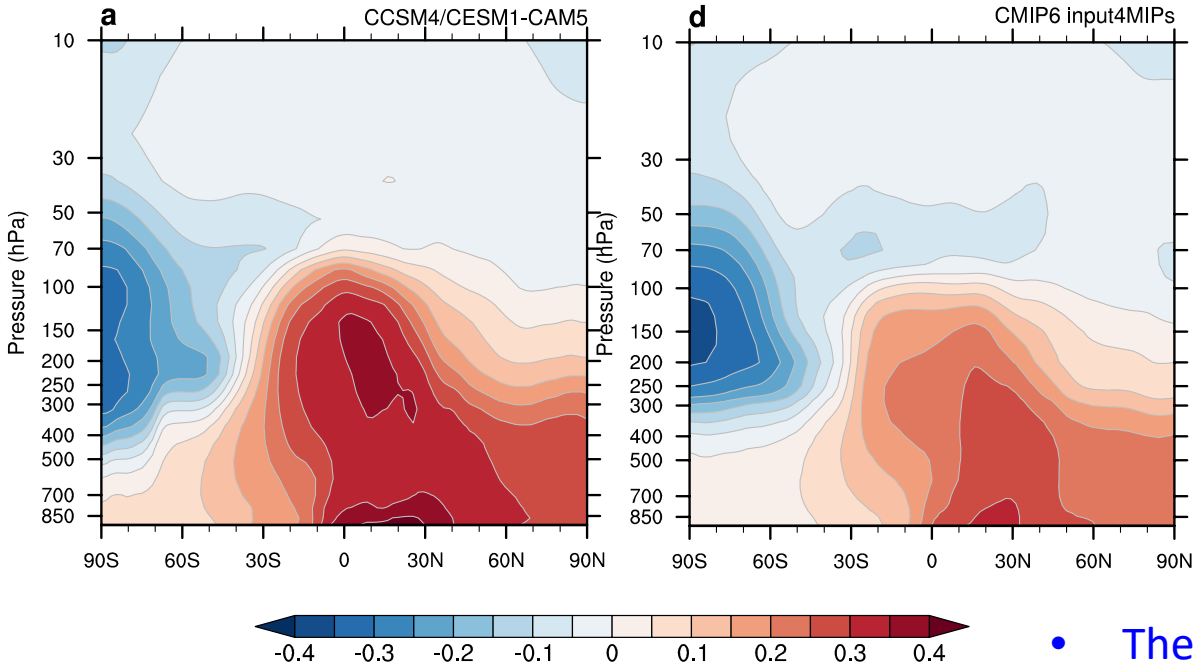
Historical ozone changes



$$\frac{O_3(1995–99) – O_3(1955–59)}{O_3(1955–59)}$$

The scientific question

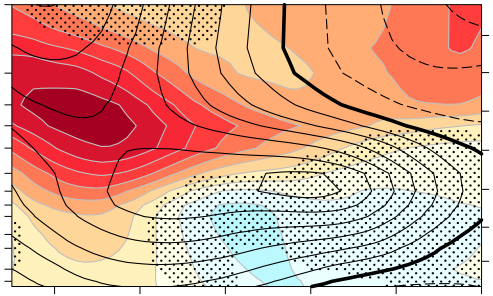
What are the effects of ozone changes on Southern Ocean heat uptake or interior ocean temperature change?

- Stratospheric ozone depletion
- Tropospheric ozone increases

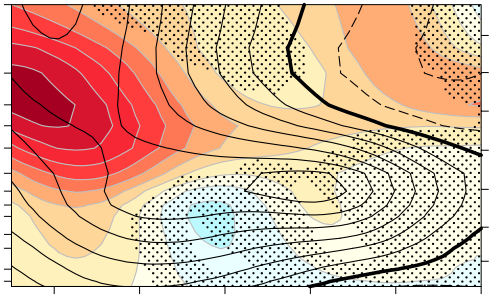
- The effect of stratospheric ozone depletion (e.g., Swart et al. 2018)
- **The effect of tropospheric ozone increases ?**

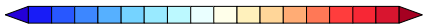
CMIP5 & CMIP6 ozone experiments

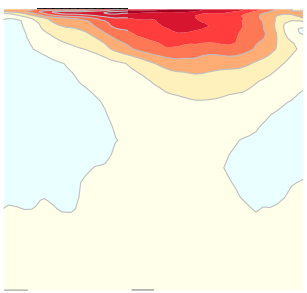
CMIP5
(strat + tropospheric ozone)



CMIP6
(stratospheric ozone)





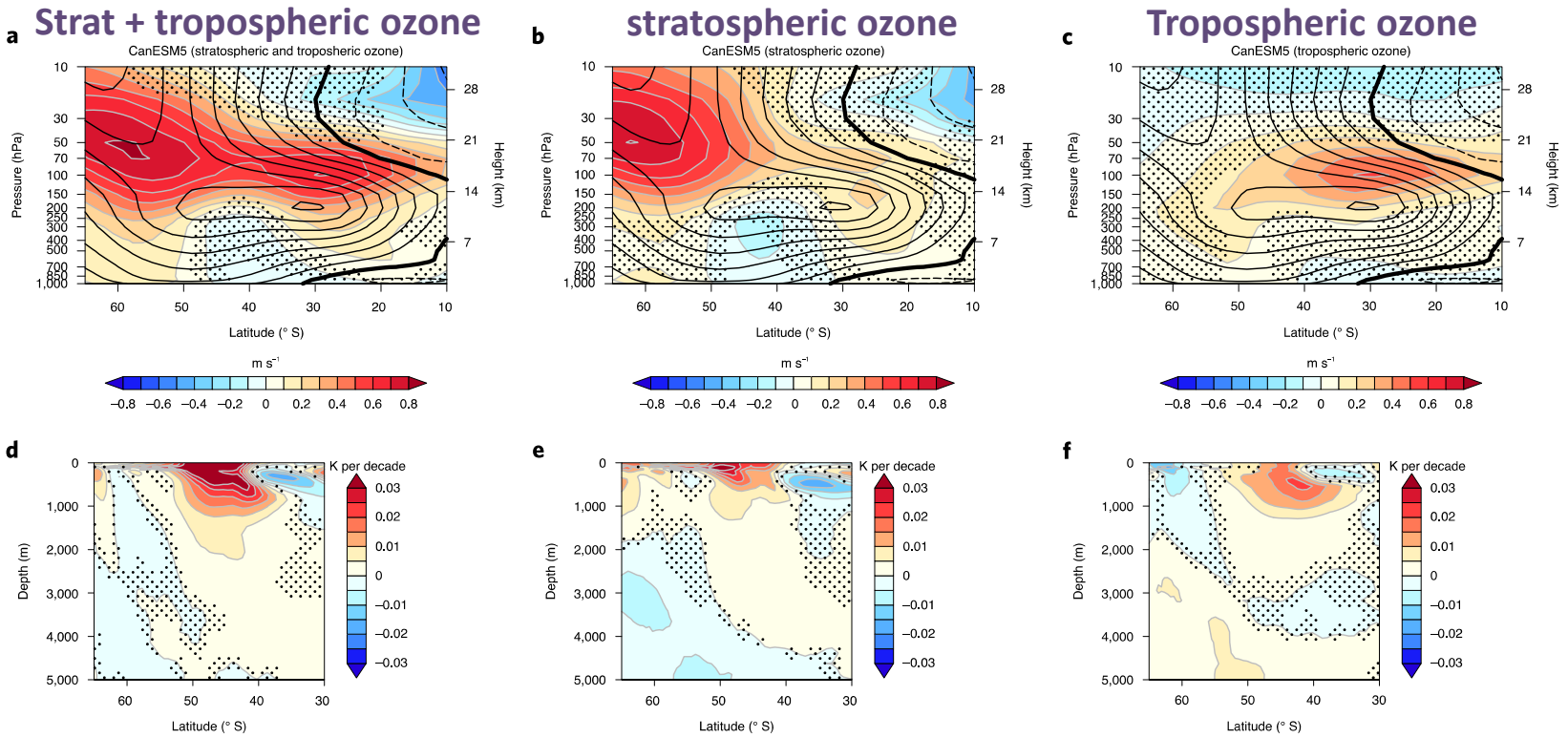


1955-2000 trend

CMIP5: CCSM4, CESM1-CAM5, FGOALS-g2, GISS-E2-H
CMIP6: CanESM5, GISS-E2-1-G, IPSL-CM6A-LR, MIROC6

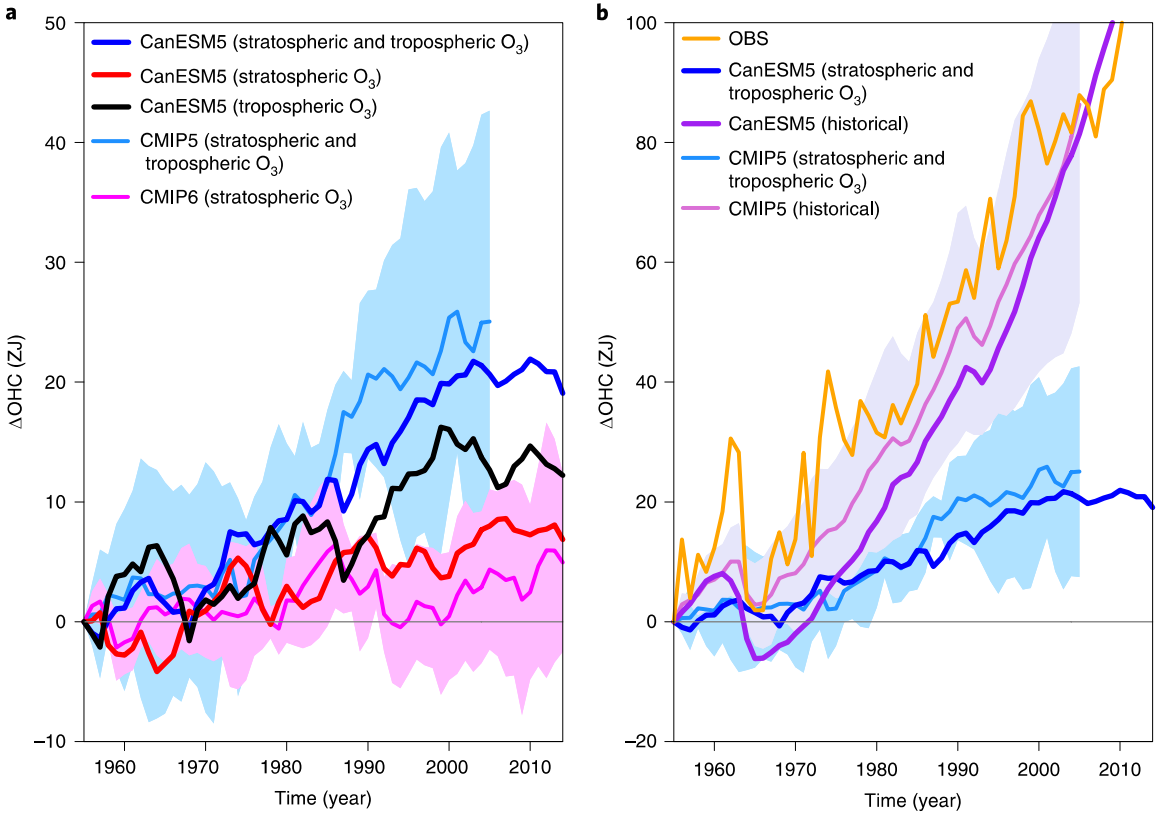
- Different ozone forcing
- Different ocean warming
- Tropospheric ozone effect?
- However, different models …

CanESM5 ozone experiments



- Southern Ocean interior warming is induced by both stratospheric ozone depletion and tropospheric ozone increases.

Ocean heat content (OHC) change



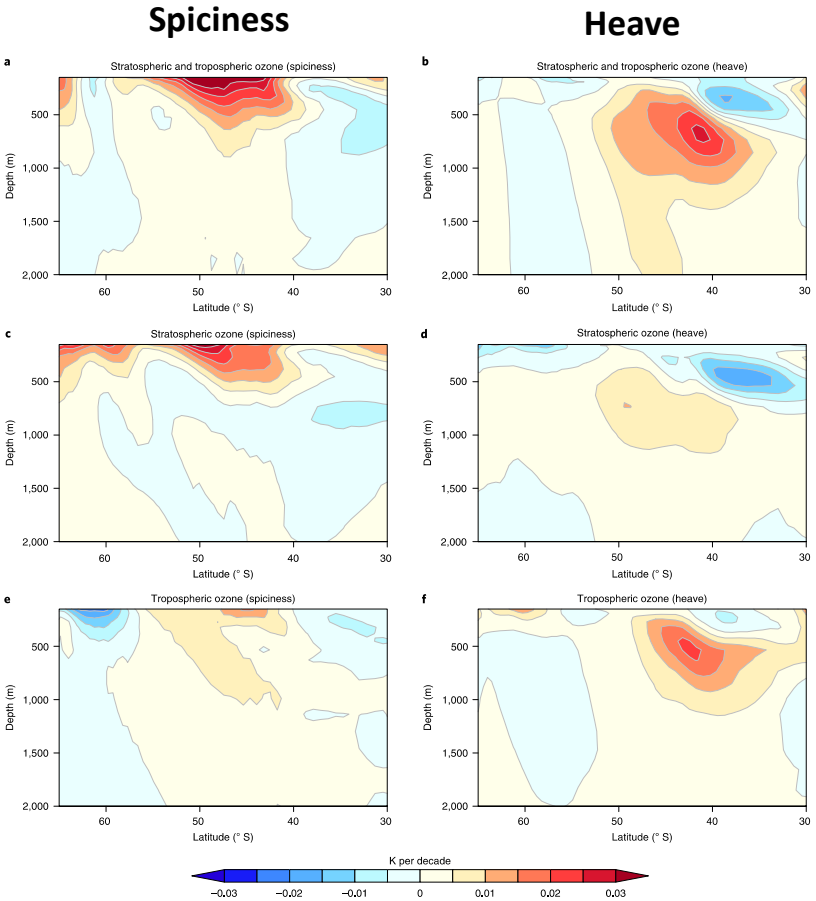
From CanESM5

- Total ozone changes contribute to 33.2% of the net historical OHC increase (0-2000 m, 30-60°S) over 1955-2000.
- 60% from tropospheric ozone increases
- 40% from stratospheric ozone depletion

From CMIP5 models

- Total ozone changes contribute to 38.4±10.4% of net historical OHC increase.

Physical Mechanisms



- Temperature changes at depth *z*, i.e., ϑ'/z can be decomposed as:

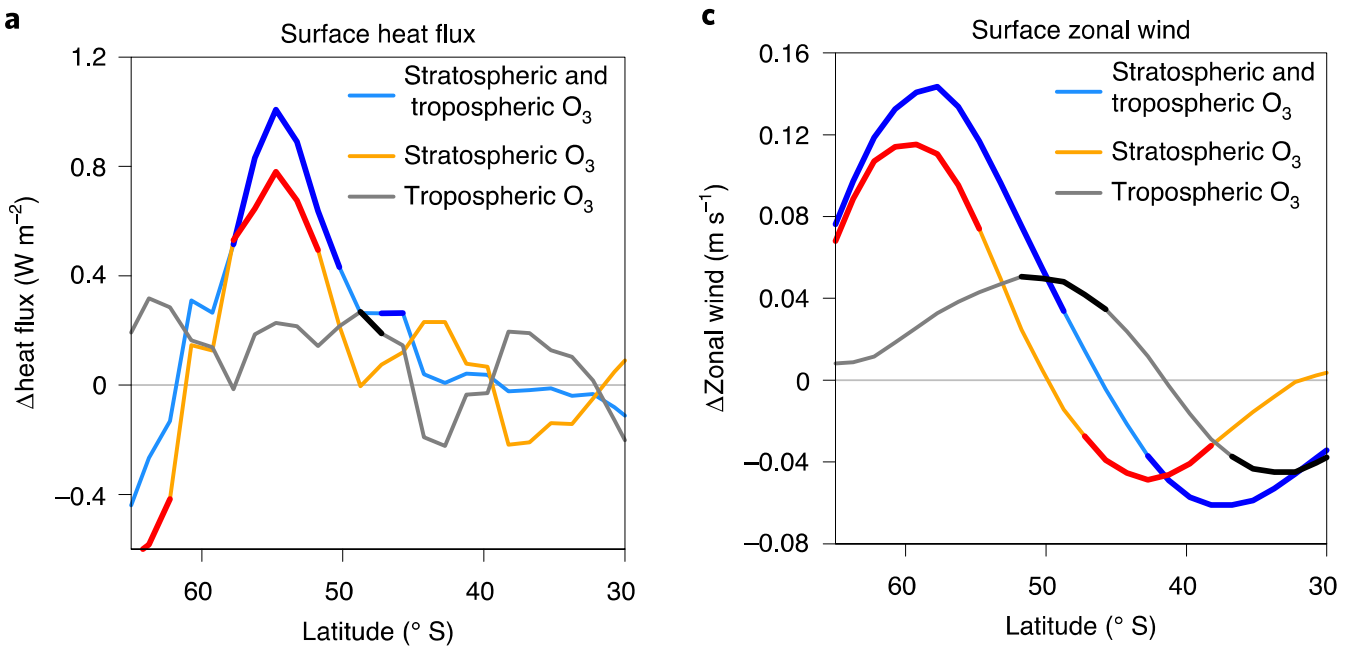
$$\theta'|_z \cong \theta'|_n + N'\theta_z$$

ϑ'/n - spiciness changes of temperature along neutral density surfaces

$N'\vartheta z$ - heave changes of temperature (similar for salinity)

- Stratospheric ozone depletion -> spiciness changes of temperature
- Tropospheric ozone increases -> heave changes of temperature

Surface heat flux and zonal wind changes



- The net surface downward heat flux increases at 40-60° S due to stratospheric ozone depletion -> warming spiciness changes in isopycnal outcropping regions
- Tropospheric ozone increases -> intensified surface westerly winds in lower latitudes where the wind-driven downwelling more effectively creates warming heave changes

Conclusion

- Both stratospheric and tropospheric ozone changes have contributed to Southern Ocean interior warming during the past decades, with the latter being more important.
- The ozone changes during 1955-2000 induced about 1/3 of the net simulated ocean heat content increase in the upper 2,000 m of the Southern Ocean, with around 3/5 attributed to tropospheric increases and 2/5 to stratospheric depletion.
- Tropospheric ozone increases promote a subsurface warming in the Southern Ocean primarily via the deepening of isopycnals, while stratospheric ozone depletion causes warming via spiciness changes along isopycnals.
- Tropospheric ozone is more than an air pollutant. As a greenhouse gas, it has been pivotal to the Southern Ocean interior warming.

Thank you!

Alfred P. Sloan
FOUNDATION

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