Stratospheric impacts on tropospheric ozone trends

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Summary at https://bit.ly/36vsgUT

Code and Data available via Centre for Open Science https://osf.io/m2akh/

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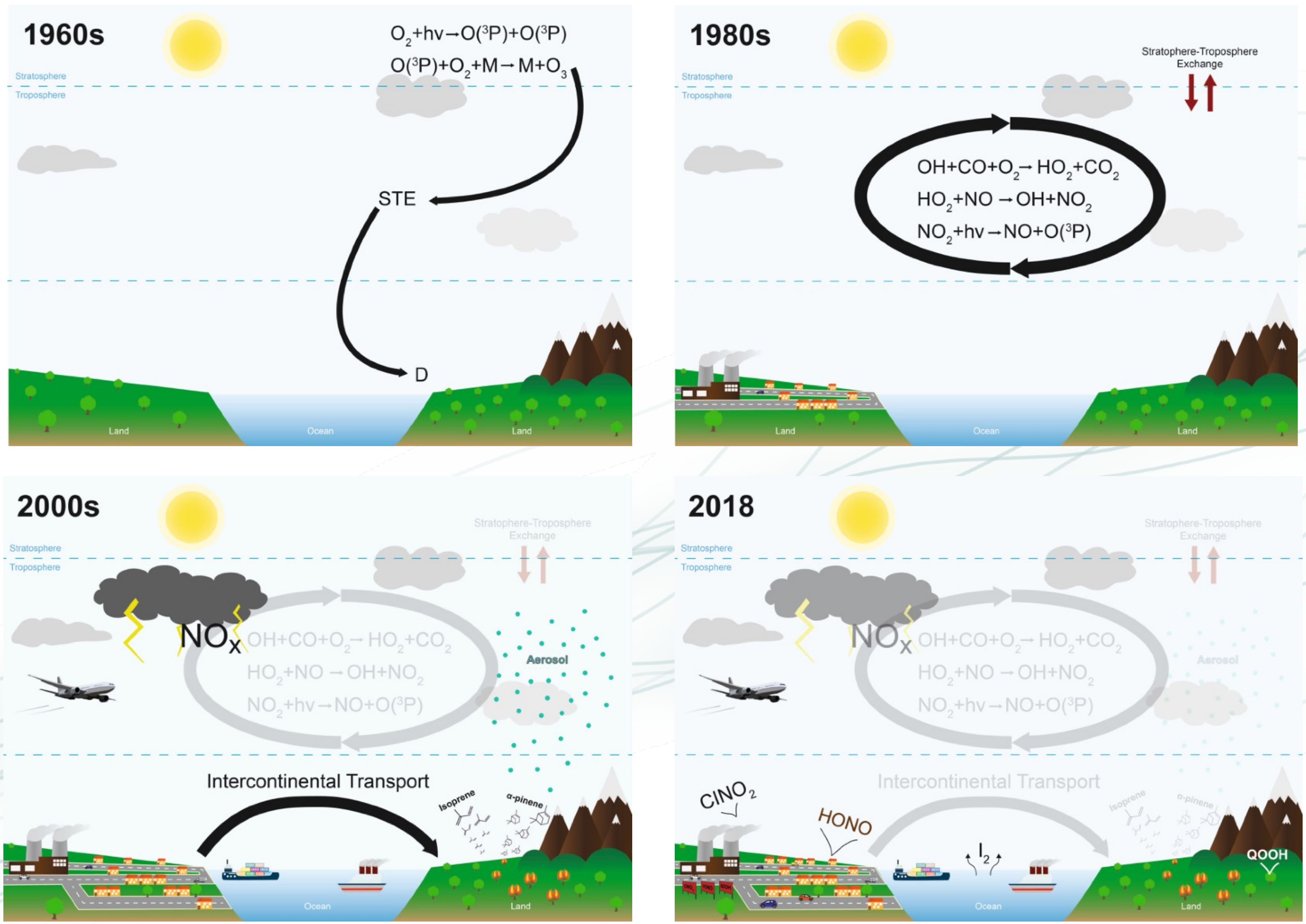
paultgriffiths

Tropospheric ozone in CCMs - developing complexity



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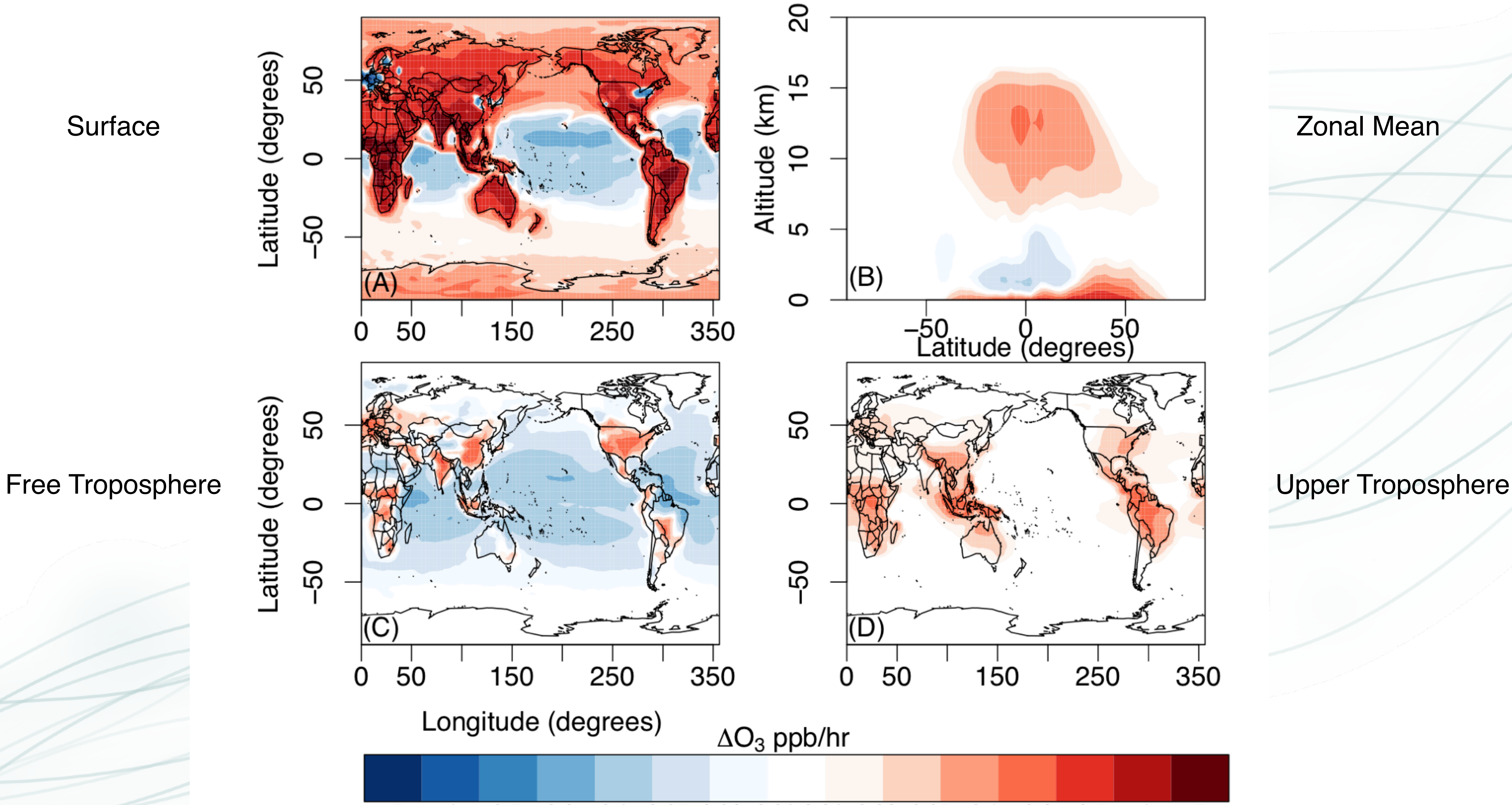

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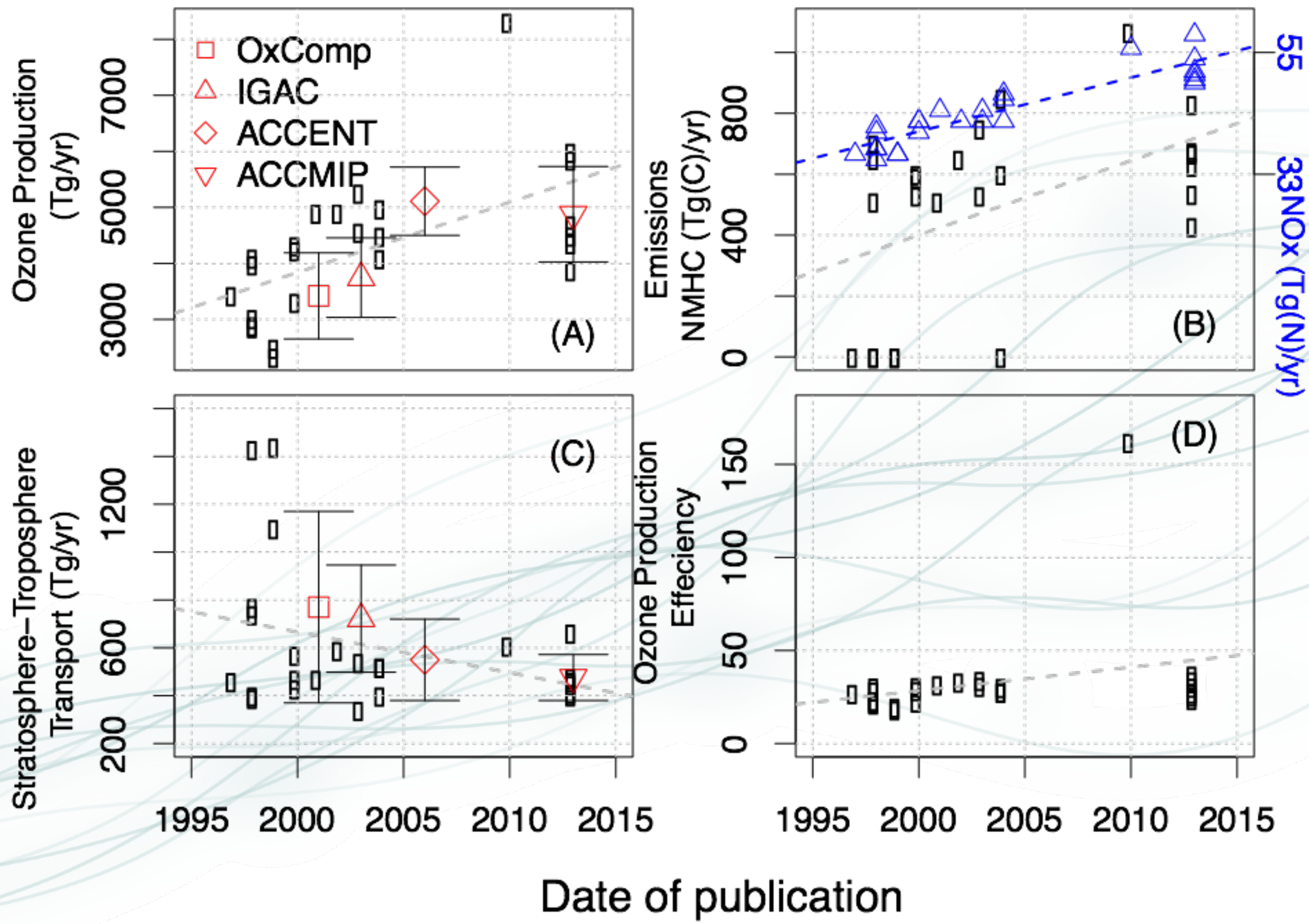

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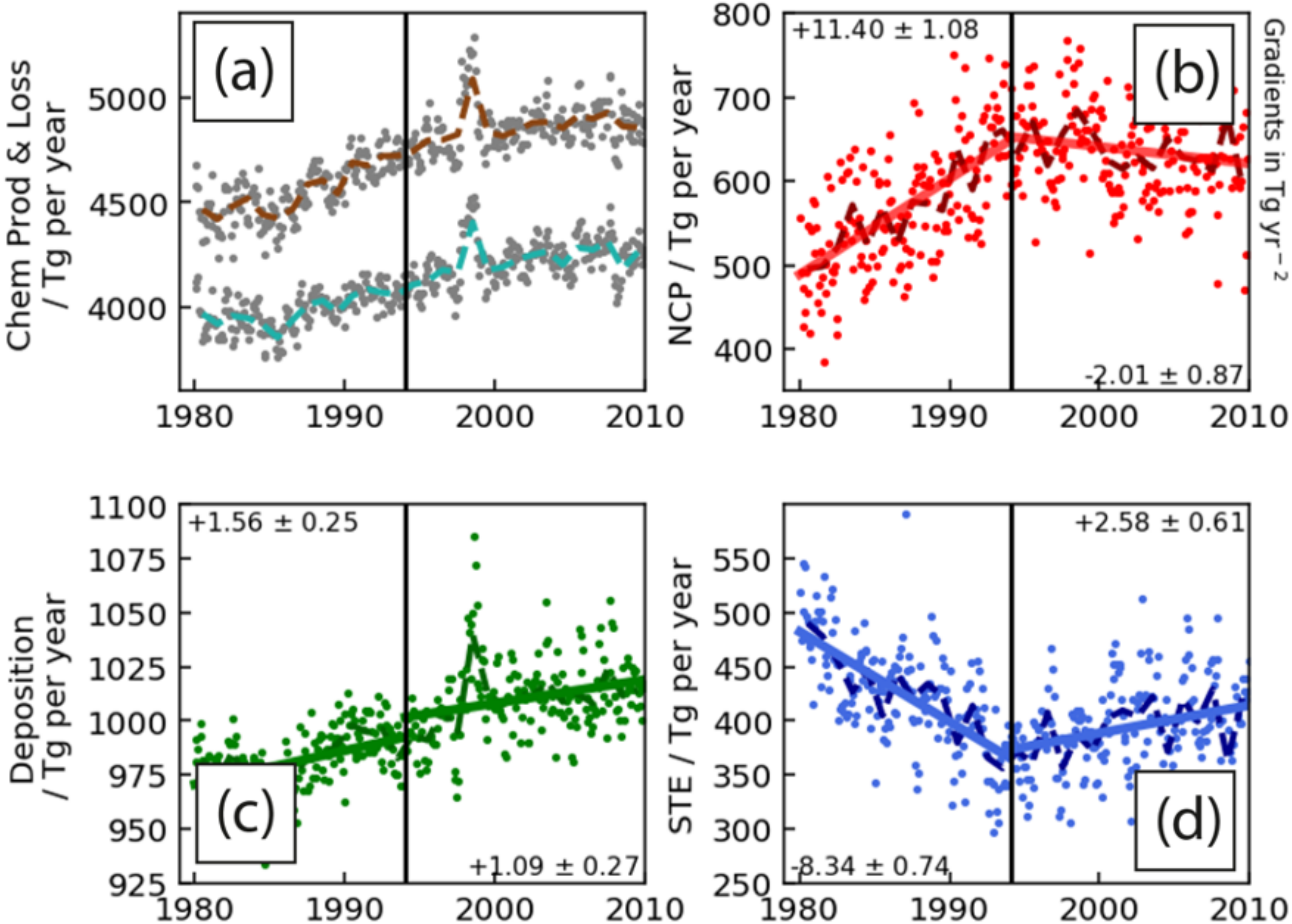
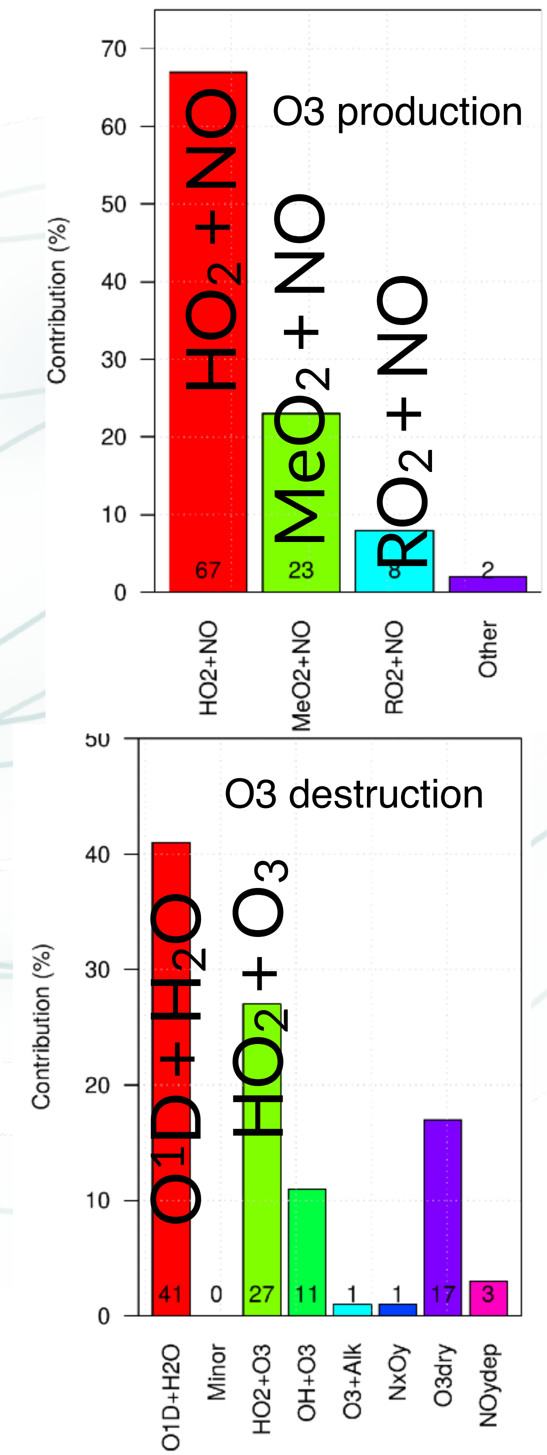
Tropospheric ozone budget in CCMs - large, opposing terms





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Tropospheric ozone in UKCA CCMI REFC1SD simulations

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CCMI REFC1SD

- Chemistry-Climate Model Intercomparison Project, sponsored by Future Earth's IGAC and the WCRP's SPARC projects
- In support of the WMO/UNEP Ozone Assessment 2018
- Specified REF simulations - 'How well do models reproduce past behaviour?' (REFC1) and 'Analyse projections of tropospheric and stratospheric ozone' (REFC2) as well as SEN (sensitivity experiments).
- 'Standard set of specific forcings' - supplied anthropogenic emissions (MACCity, Granier et al. 2011), biomass burning, GHG/Ozone Depleting Substance concentrations etc, SSTs and sea-ice (atmosphere-only experiments).
- REFC1SD - specified dynamics simulations covering the period 1980-2010, using 'nudging' to meteorological re-analysis data and overlapping with satellite observation period. 'More directly compared to observations'
- We performed two experiments: HIST and fODS_LBC

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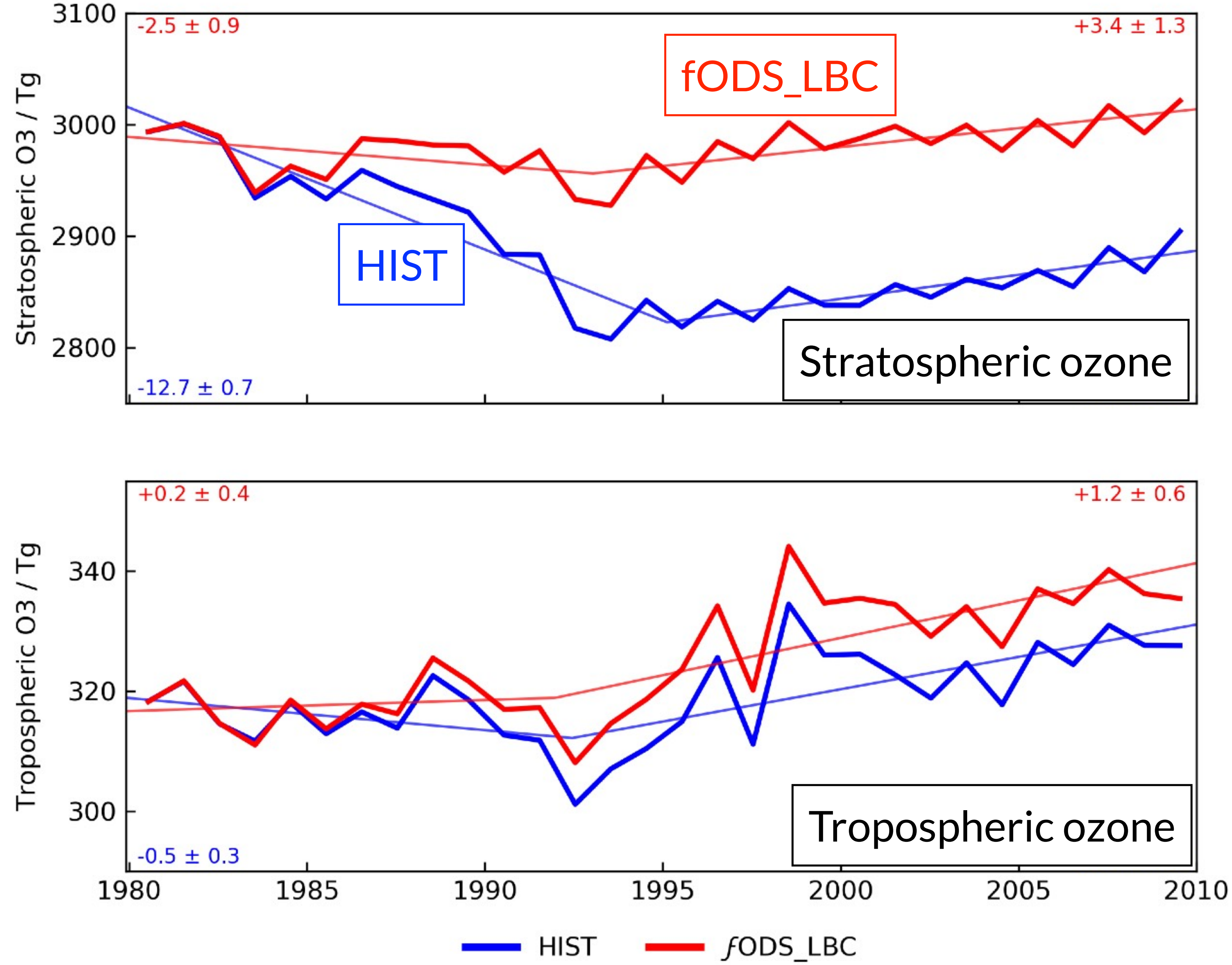
CCMI REFC1SD - evolution of ozone burden

- We performed two experiments: HIST and fODS_LBC
- HIST - anthropogenic emissions and ozone-depleting substances evolve along their historic trajectory.
- fODS_LBC - as HIST but ODS are held constant at 1979 levels.
    - NB These are surface mixing ratios, which propagate upwards
- Blue line shows the HIST stratospheric (upper panel) and tropospheric ozone (lower panel).
- Can see that holding ODS at 1979 levels arrests ozone depletion.



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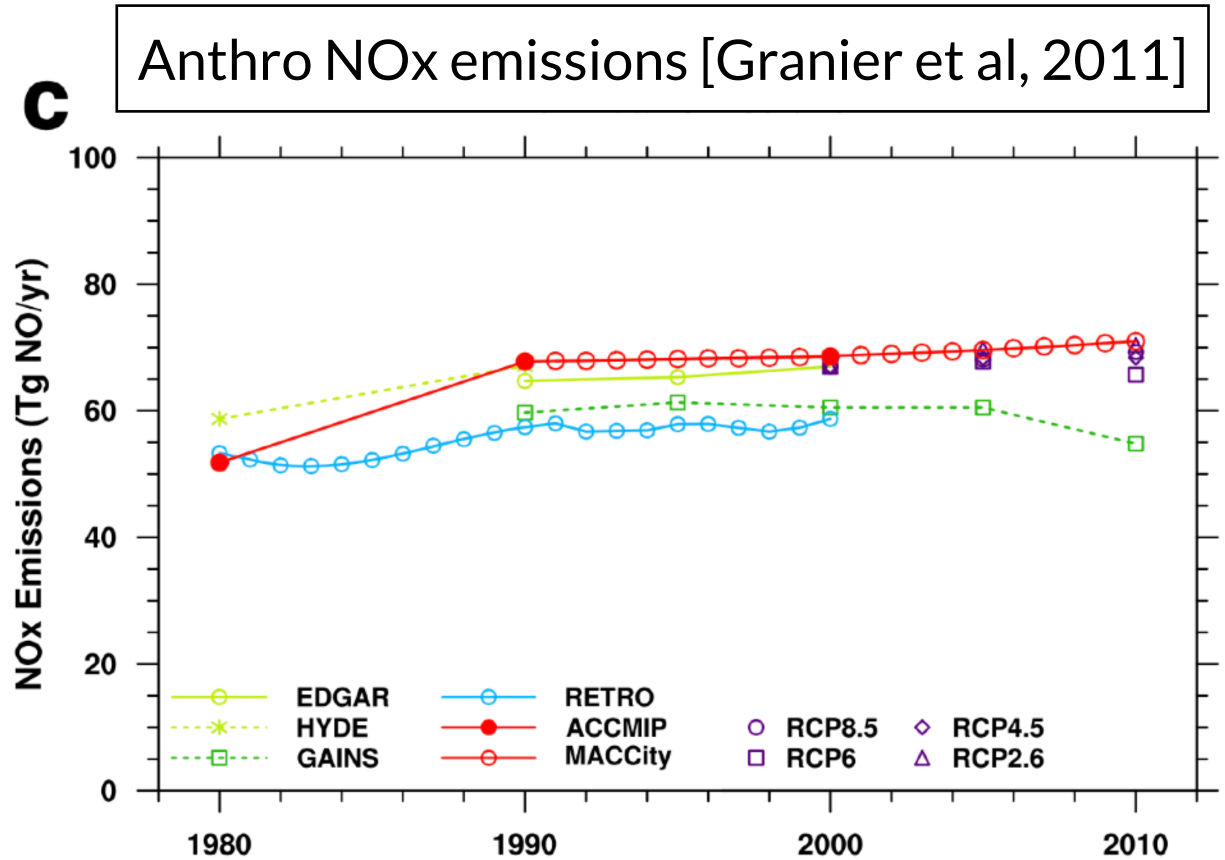
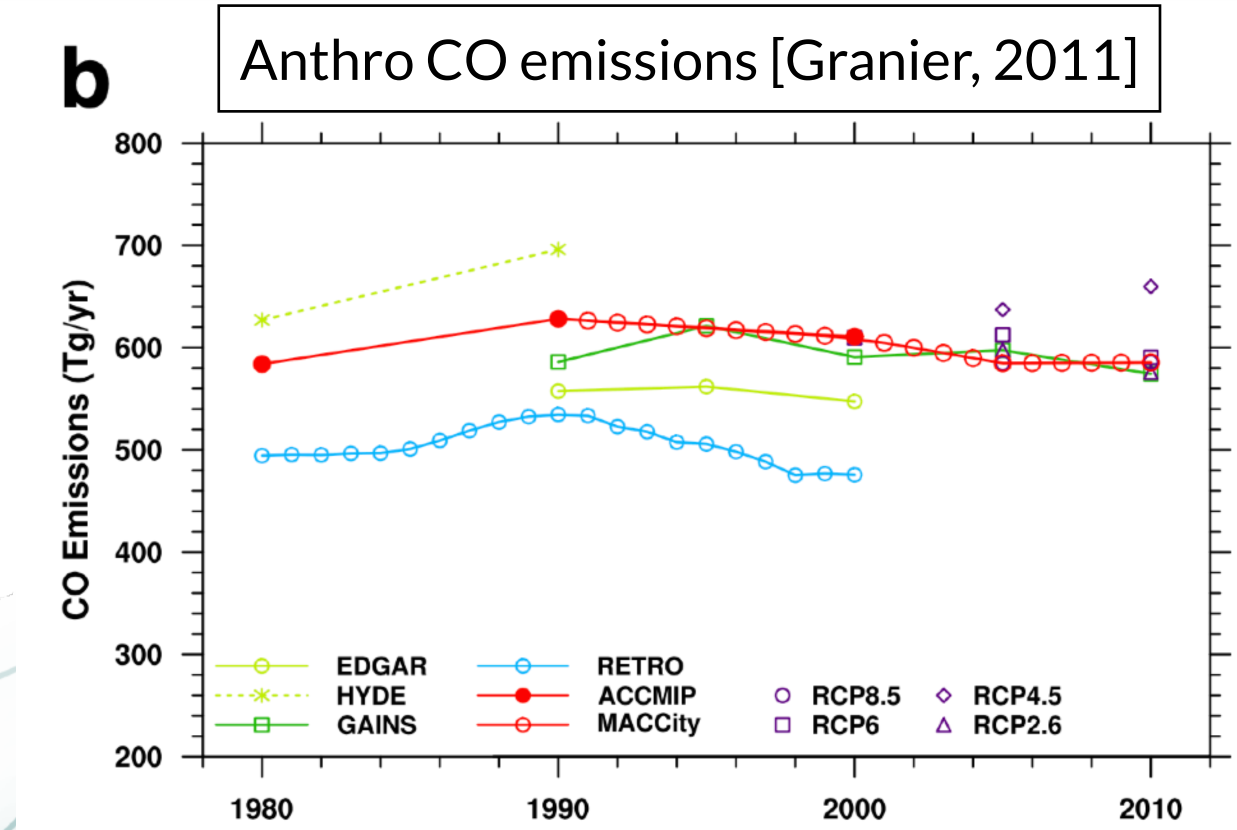
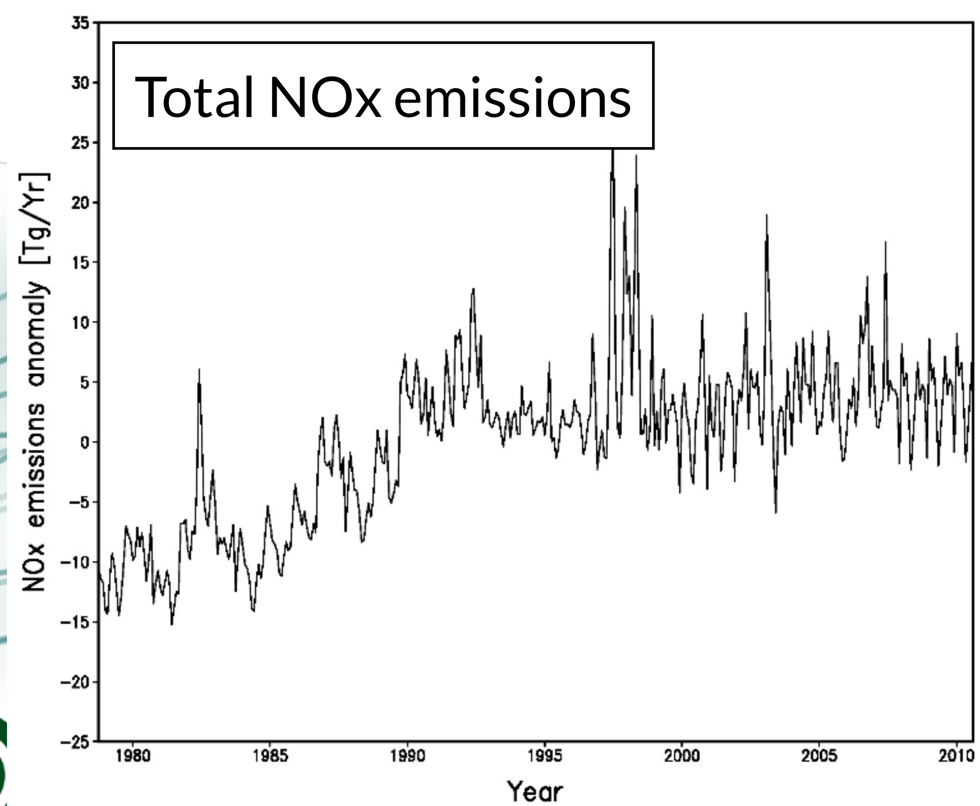
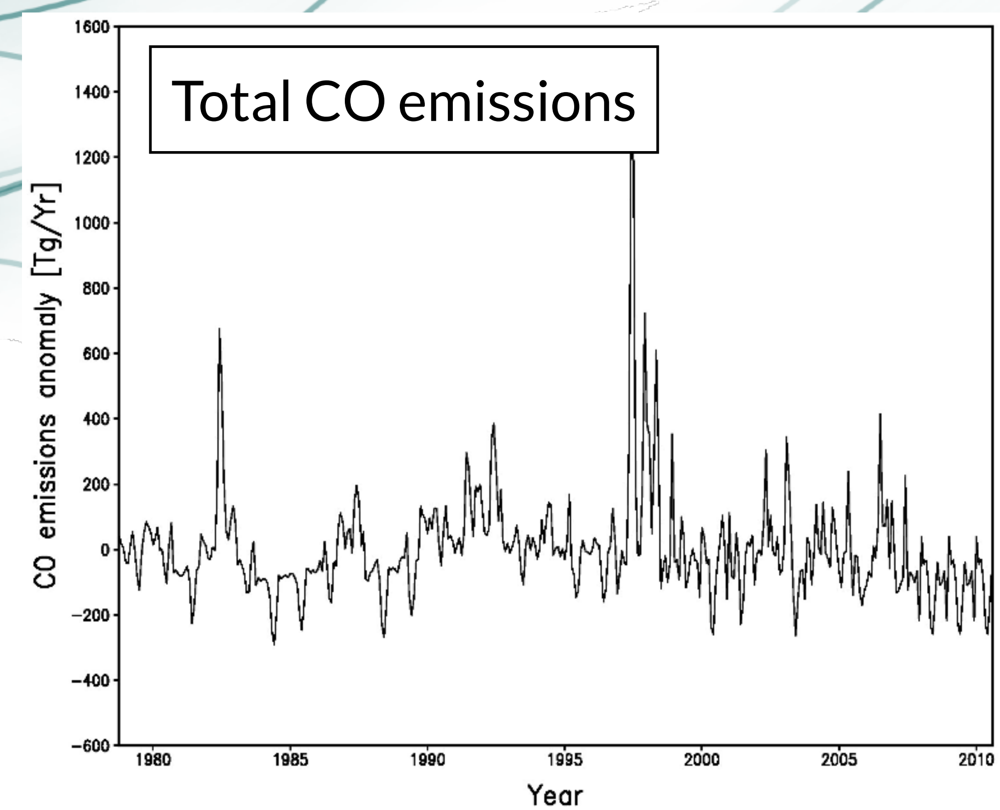
Anthropogenic NOx and CO emissions vs total NOx and CO HIST emissions



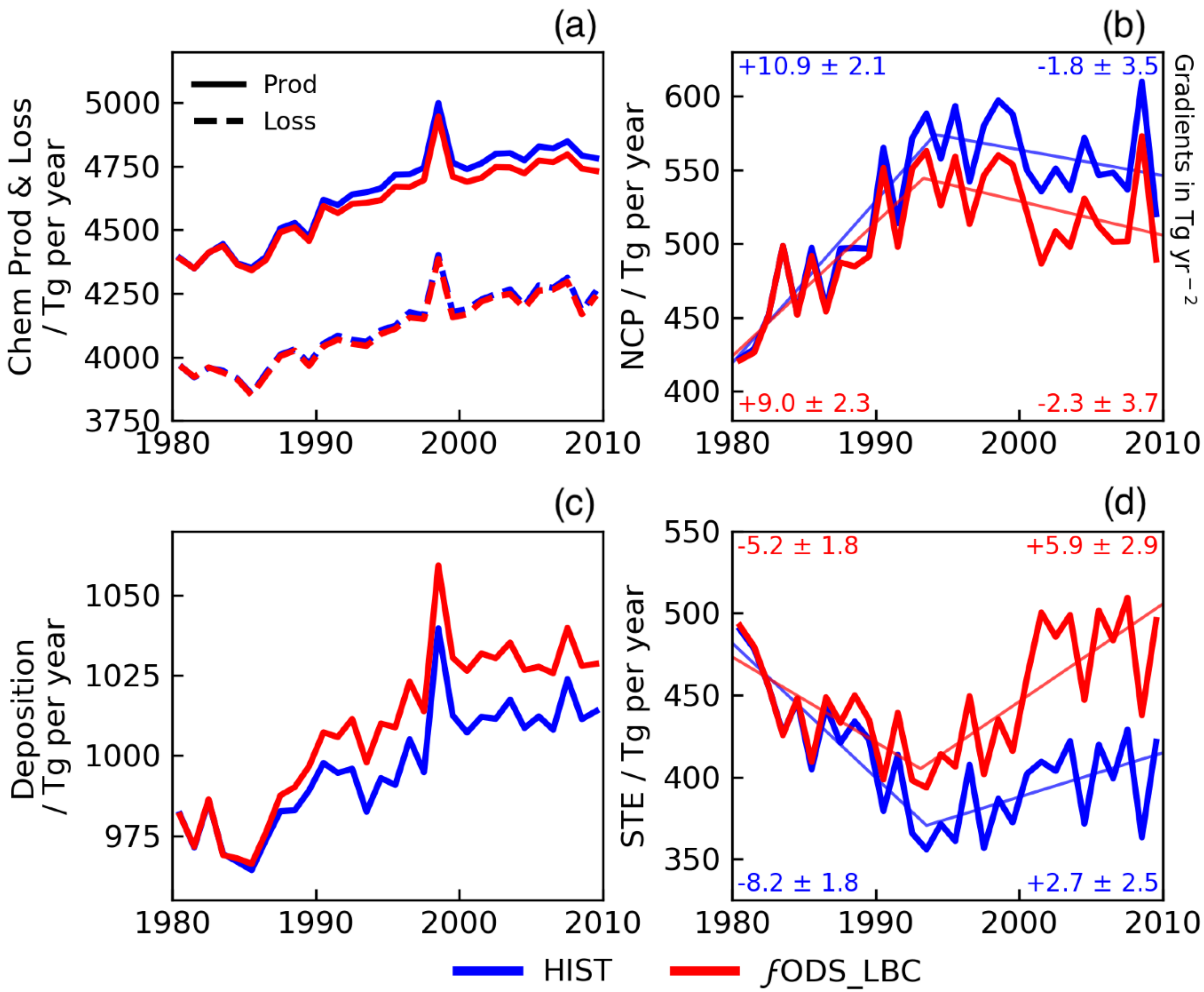






NB 1997 spike in NOX and CO emissions representing large-scale fires

CCMI REFC1SD - evolution of ozone budget



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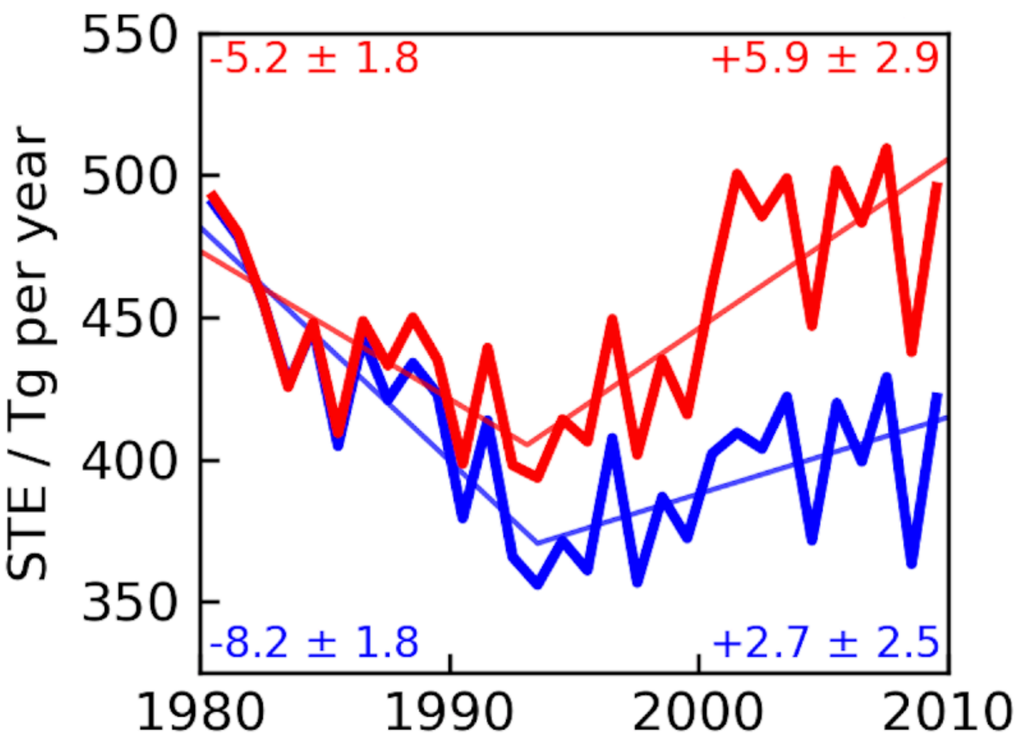
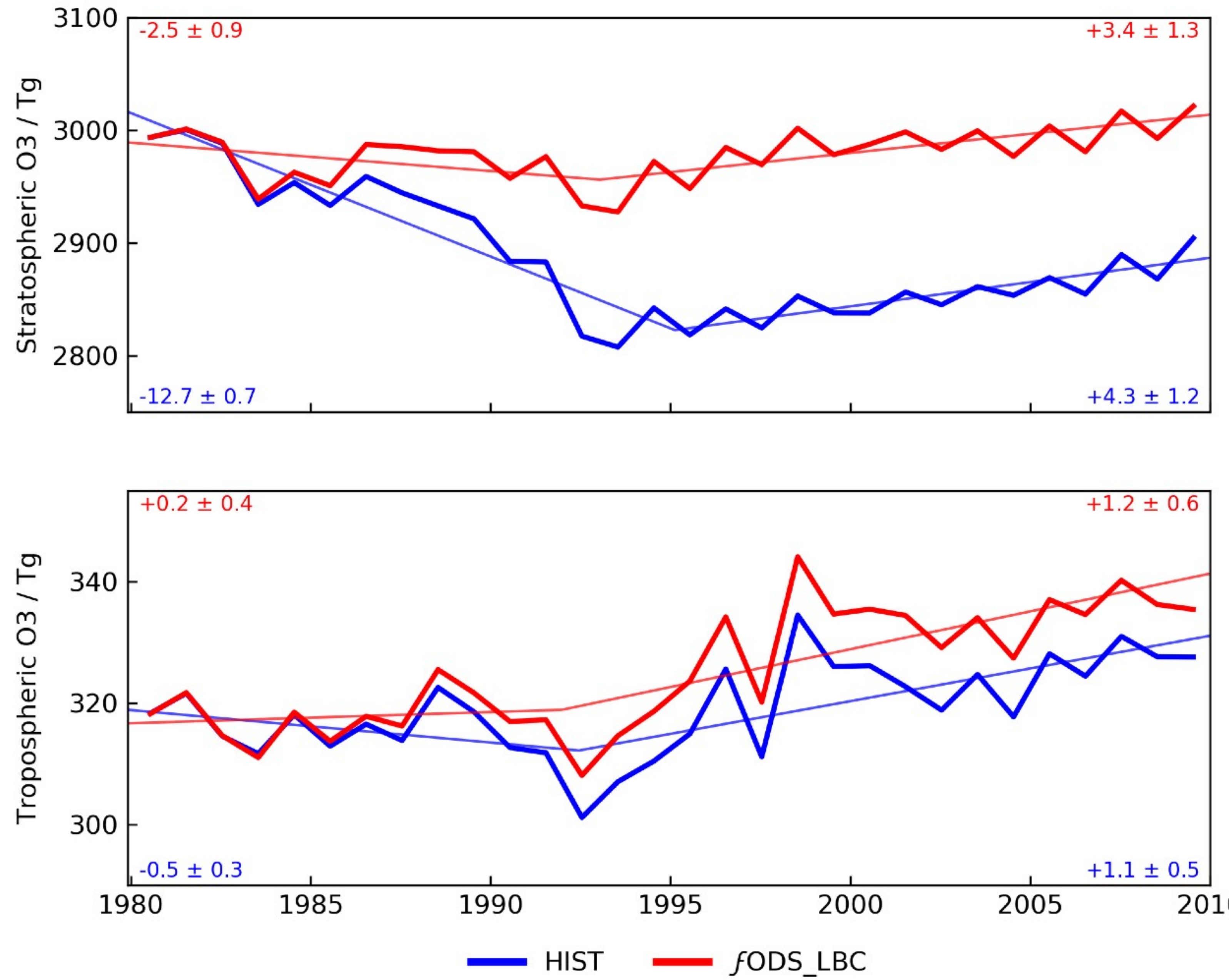
Evolution of ozone budget - influence of stratosphere





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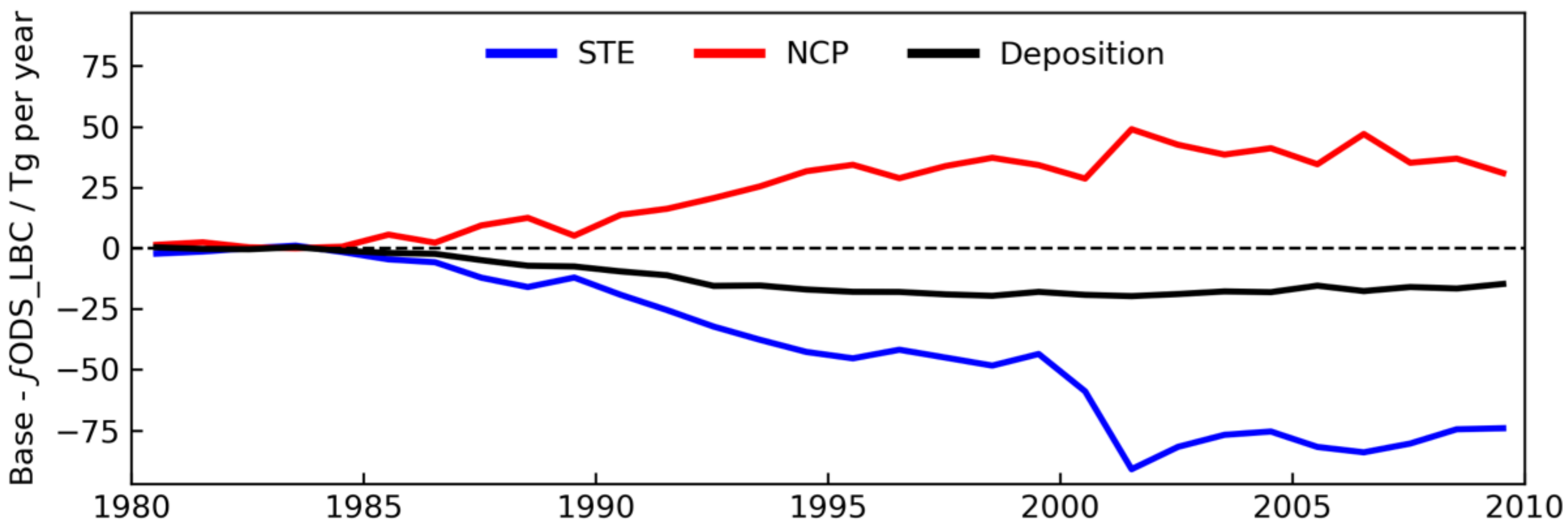
Input of ozone into the troposphere declines as stratospheric ozone depletion increases, declines by lower amount in fODS_LBC runs. This input recovers in HIST after 1994 as Montreal Protocol comes into effect and ozone begins to recover

Summary



BASE(NCP) > fODS(NCP)

BASE(STE) < fODS(STE)

- The differences for each in the year 1980 are near zero, as the simulations start from the same initial conditions.
- They diverge after ~5 years, consistent with the time it takes for the surface ODS mixing ratios prescribed by the LBC to be transported into the polar stratosphere.
- After 1985, STE is lower in the HIST simulation by around 75 Tg yr^{-1} between 2000-2006, reflecting the lower stratospheric ozone burden,
- NCP is up to 50 Tg yr^{-1} higher, reflecting the increased photochemical production of ozone.
- Deposition of ozone follows the tropospheric burden, and so is lower in the HIST simulation by ~20 Tg yr^{-1}.
- **More vigorous ozone production in the troposphere offsets partially the decrease in transport from above.**

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Tropospheric ozone in (UKESM1)CMIP6 REFC1SD simulations

Paul Griffiths, Lee Murray, Guang Zeng, James Keeble, Fiona O'Connor, Matthew Shin, Oliver Wild, Paul Young, Alex Archibald, Sungbo Shim, Jane Mulcahy, N. Luke Abraham, Mohit Dalvi

and Ben Johnson, Gerd Folberth, Catherine Hardacre, Olaf Morgenstern, Joao Teixeira, Steven Turnock, Jonny Williams (UKCA AerChemMIP team)

and Vaishali Naik, Louisa K. Emmons, Ian Galbally, Birgit Hassler, Larry W. Horowitz, Jane Liu, David Tarasick, Simone Tilmes, and Prodromos Zanis (CMIP6 paper co-authors)

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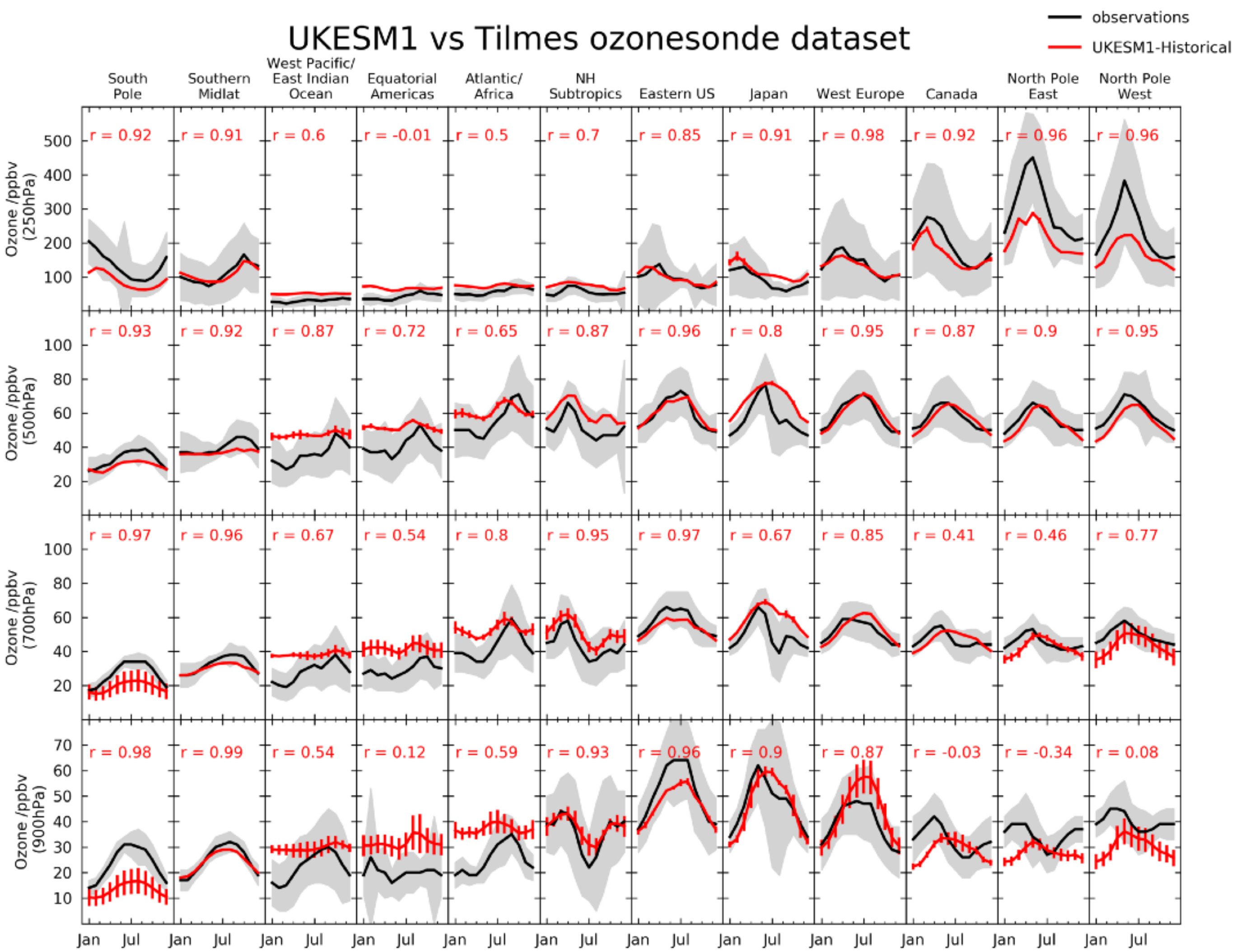
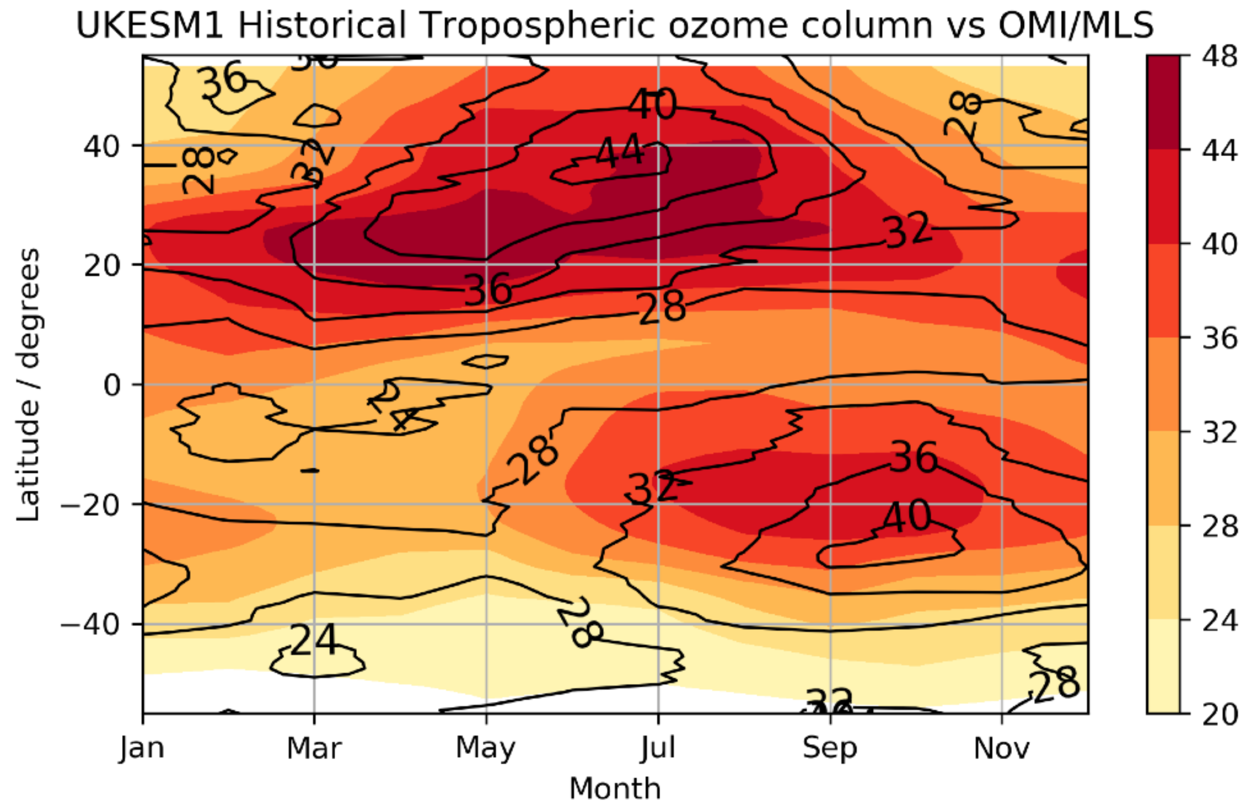
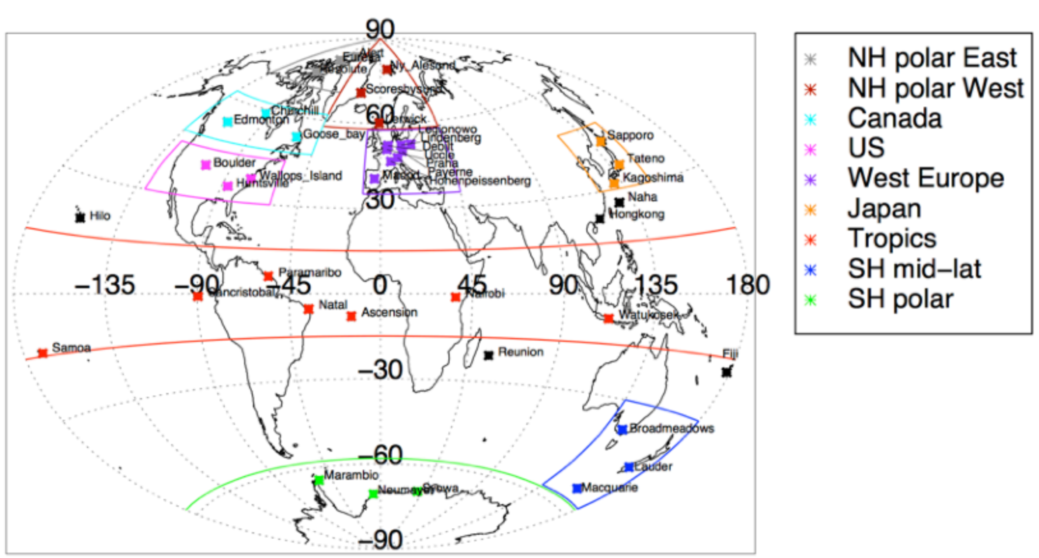
How does UKESM1 tropospheric ozone compare against observations?



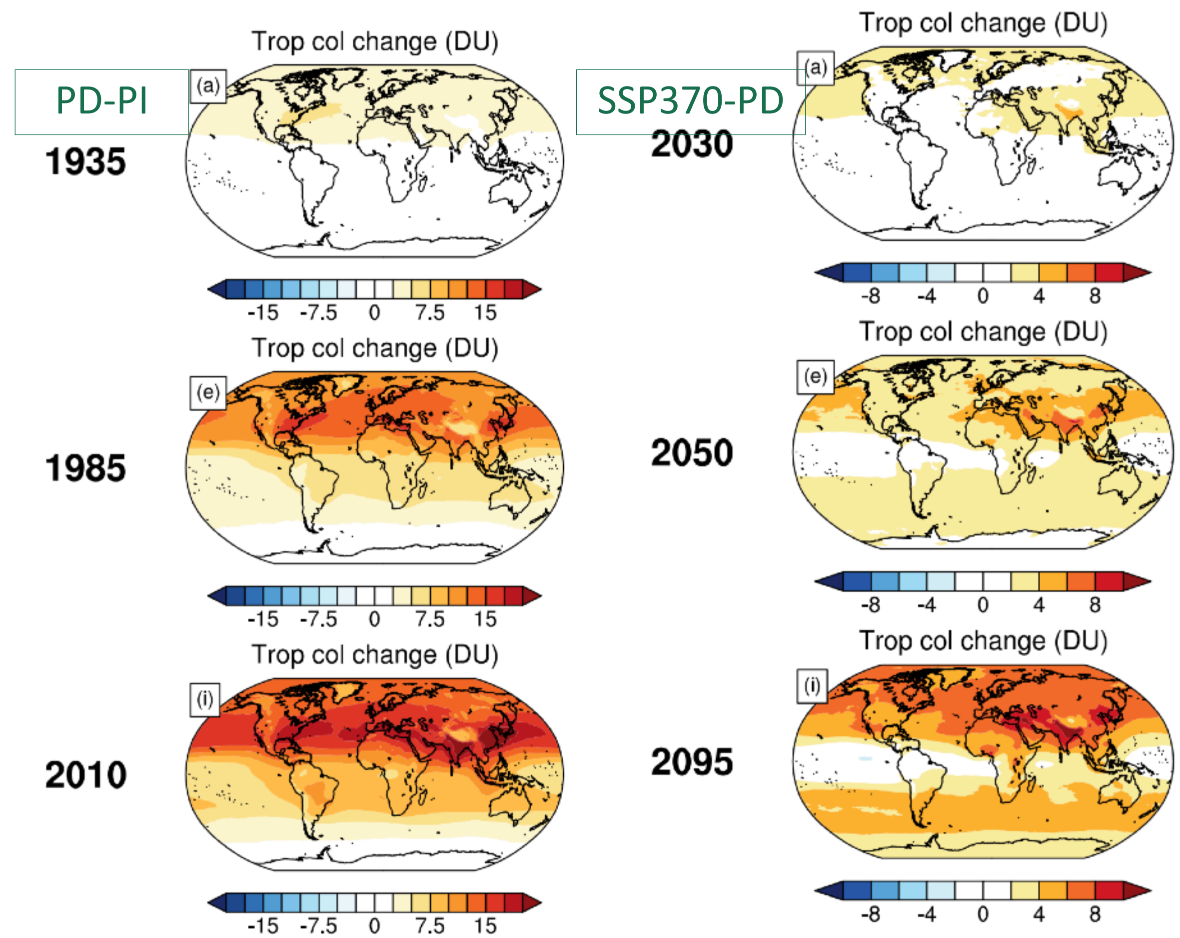


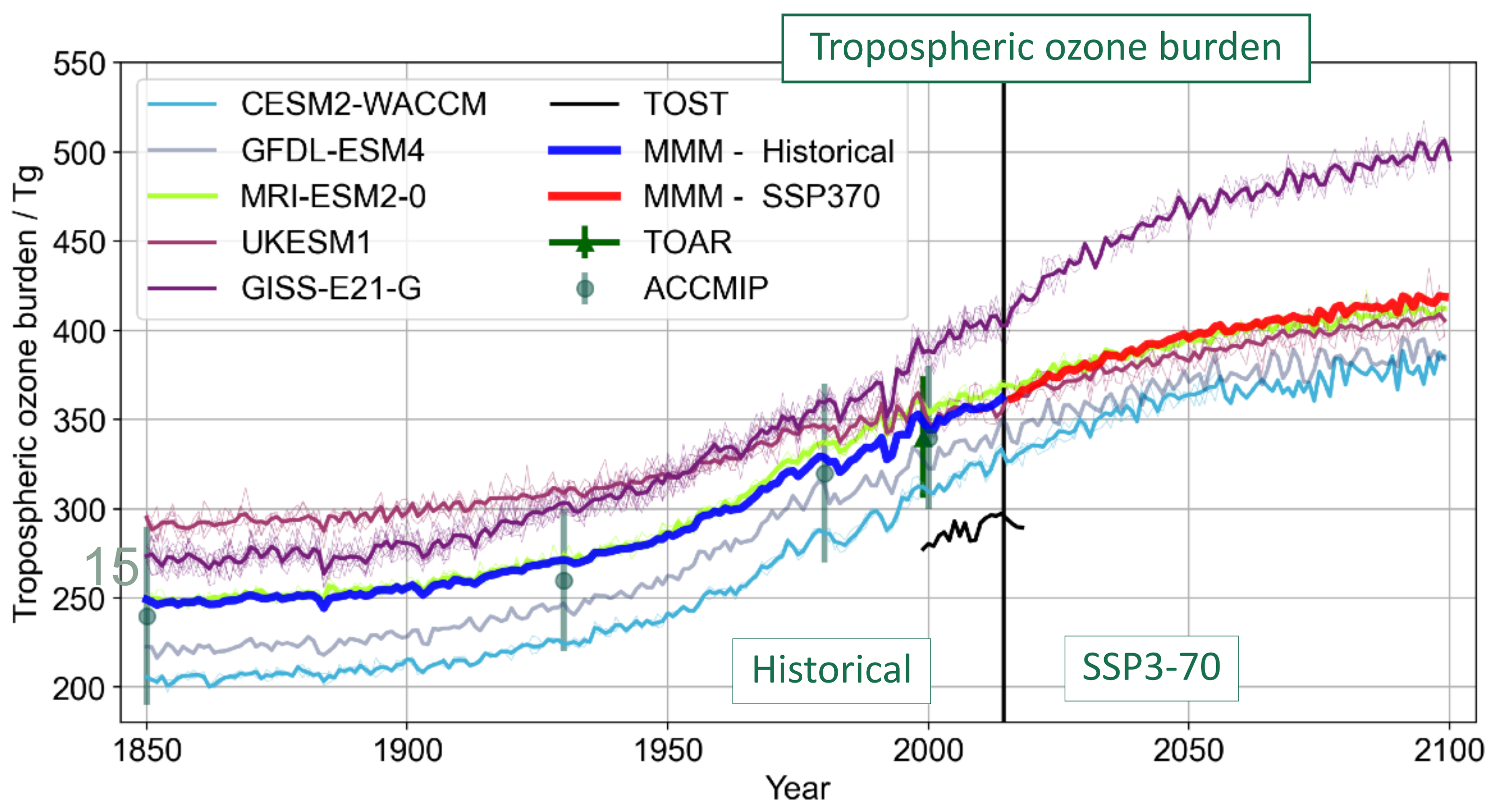


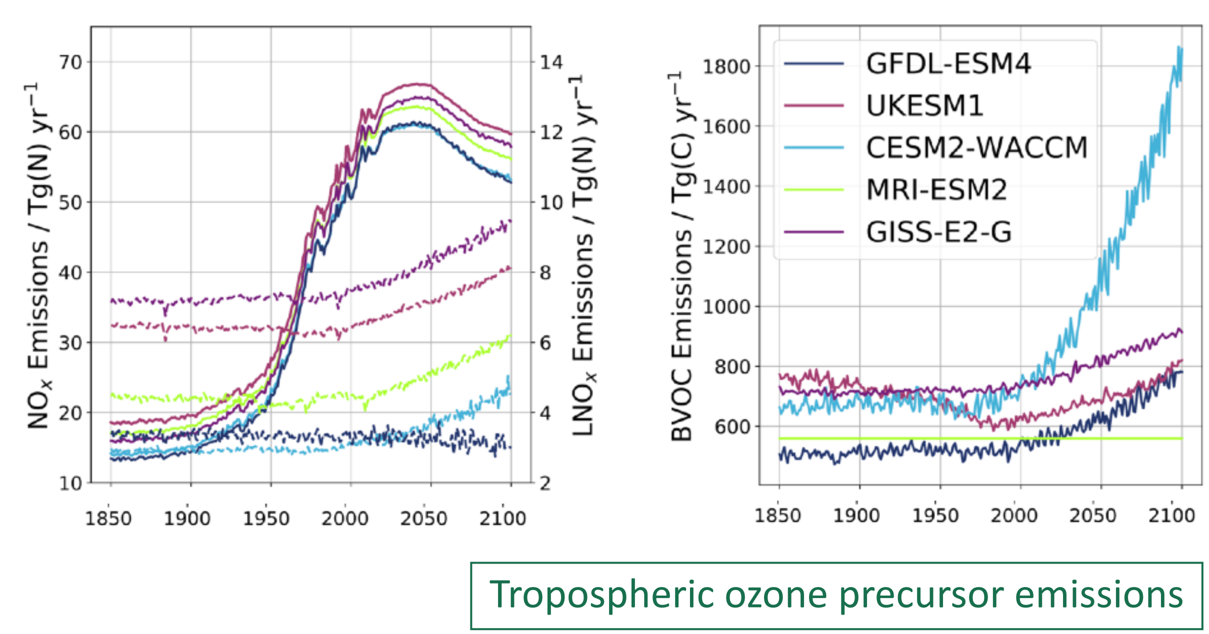
- UKCA tropospheric ozone compares well with observations, particularly in-situ measurements.
- Integrated quantities, such as column amounts, sensitive to tropopause definition.

How does tropospheric ozone burden evolve in CMIP6?

- Analysis so far has focused on CMIP Historical and ScenarioMIP SSP3-70 experiments, for which suitable diagnostic output was available.
- Picture has changed little since CMIP5, MM range is also similar.
- Ozone burden increased by about 40% from 1850 levels of 240 Tg (MMM) with steepest rate of increase around 1960.
- In SSP3-70, the rate of growth of the burden declines further, as NOx emissions start to fall along this pathway after 2050.
- Nevertheless, strong local changes in ozone seen regionally at the end of the century.

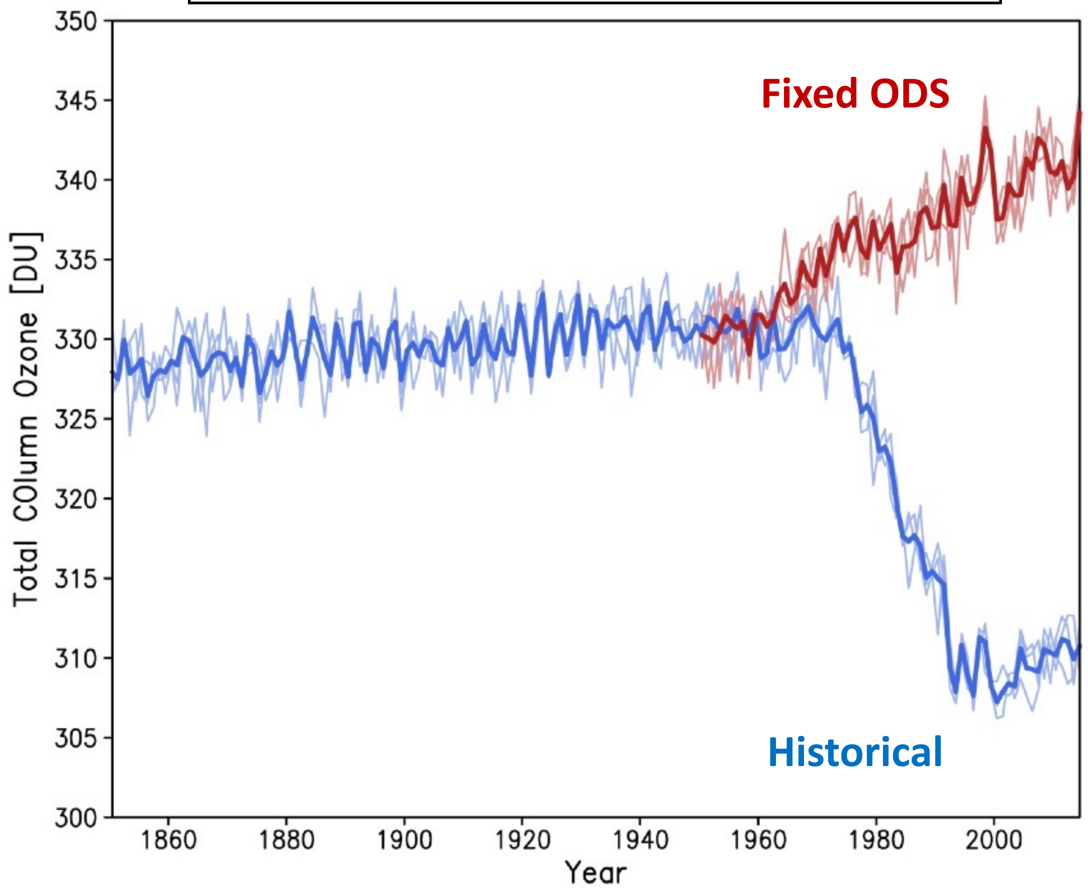




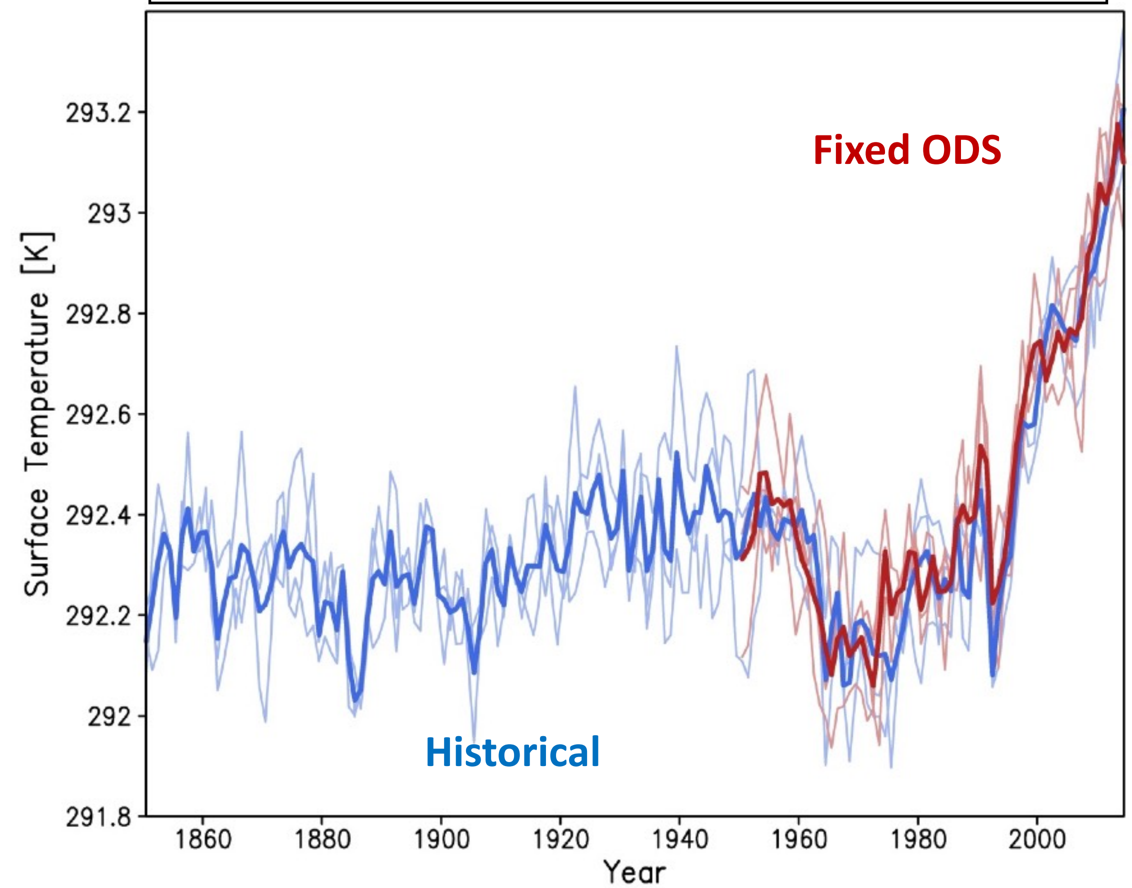


What about the stratosphere? (Figures courtesy James Keeble)

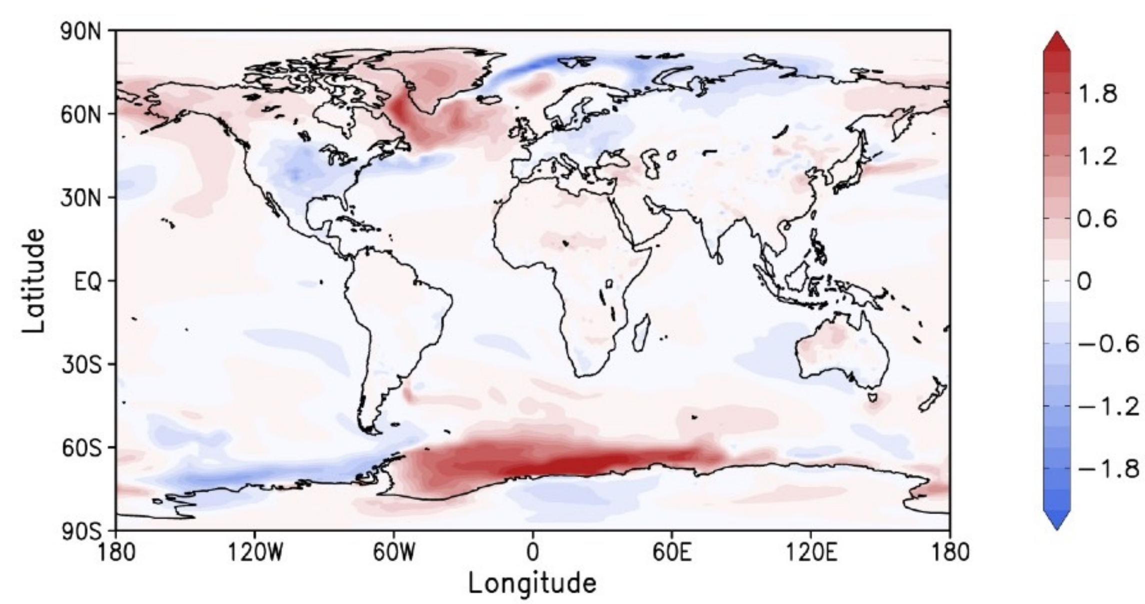
Total (strat+trop) ozone column



Annual mean surface temp (60S-60N)



Surface temperature difference, averaged 2000-2014



- Little difference in60S-60N averaged annual mean surface temperature
- Some evidence that temperature response to Pinatubo dependent on stratospheric chlorine loading
- Compare spatial pattern of temperature difference for last 14 years
- Large temperature differences in Southern Ocean, important for sea ice changes
- Evidence of NAO signal

Summary

- Tropospheric ozone is controlled by chemical production and destruction, physical deposition and transport from above into the troposphere.
- Stratospheric ozone depletion resulted in more in-situ ozone production and destruction, but also reduced input from above. These acted in opposing senses with the result that stratospheric ozone depletion had a minor impact over the period 1979-2010.
- Looking at CMIP6 data, we see important roles for methane, NOx (particularly LNOx) and changing land-use (modifying deposition).
- Stratospheric ozone recovery is increasingly important to tropospheric ozone burdens in the later 21st Century.
- There are indications that this may couple to other aspects of the climate system via e.g. ozone RF, modification of cloud albedo, secondary organic aerosol and ecosystem function.

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Thank you

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