Tropospheric ozone in UKESM1 and other CMIP6 models

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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)

Based on DOI: 10.1525/elementa.2020.034 and 10.5194/acp-2019-1216

Code and Data available via Centre for Open Science https://osf.io/3hsz6/

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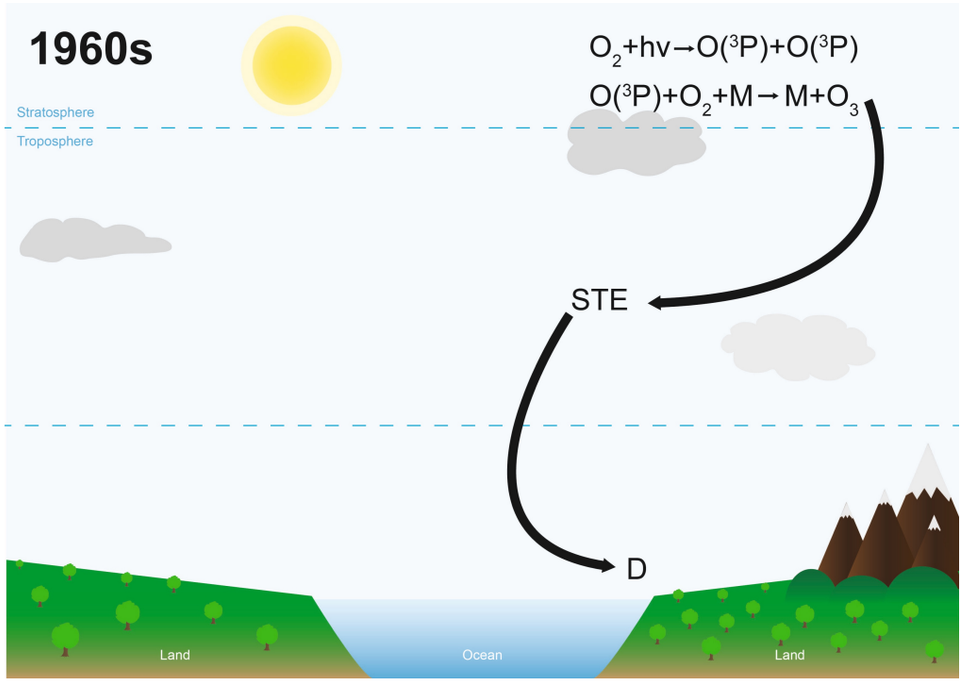
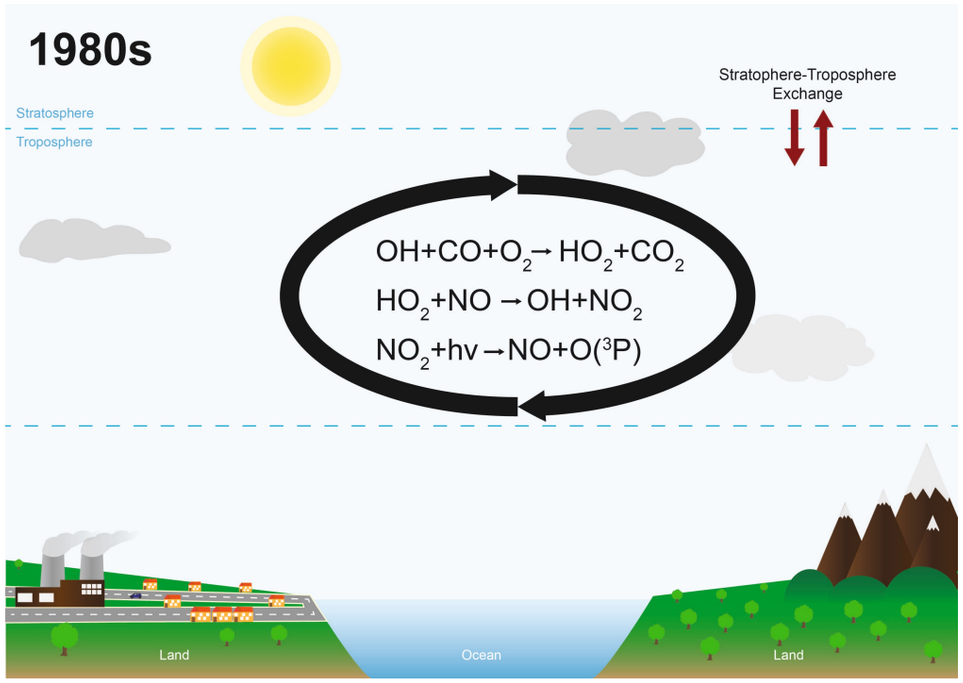
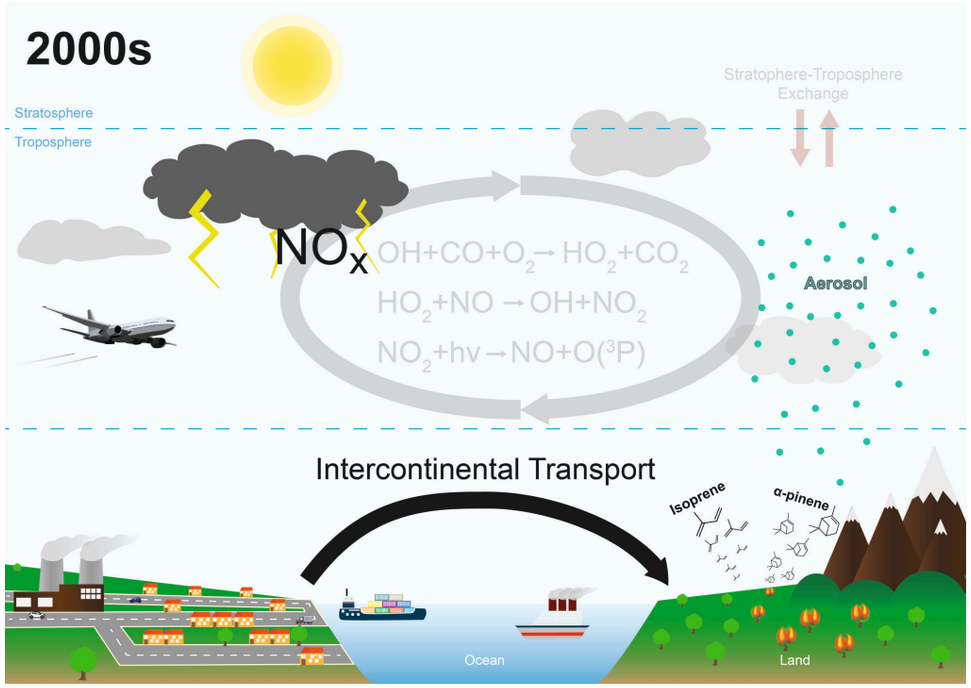
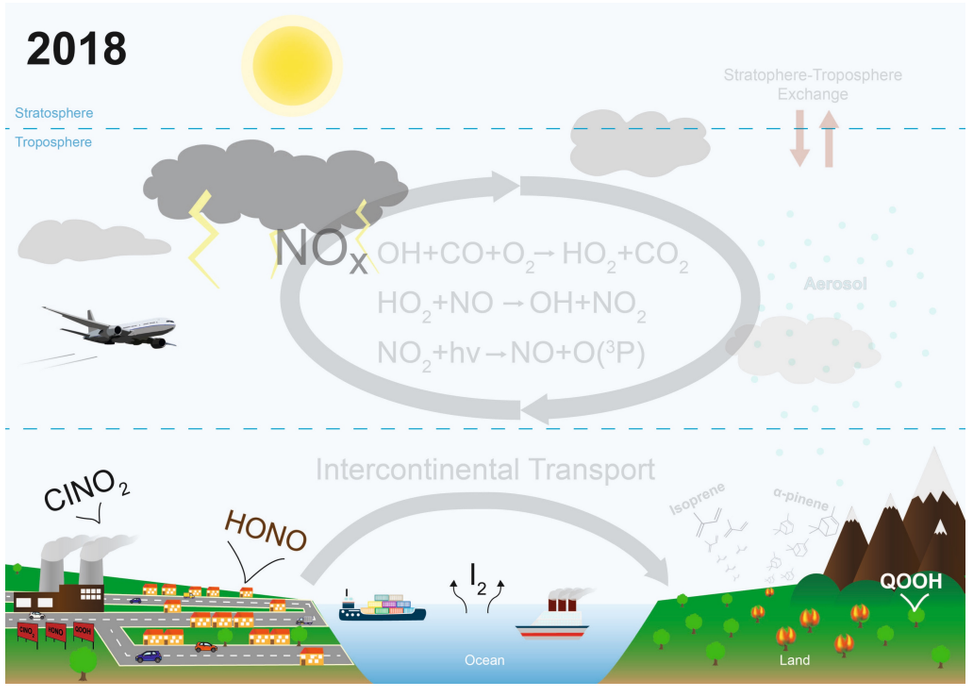
paultgriffiths

Ozone in CCMs – developing complexity





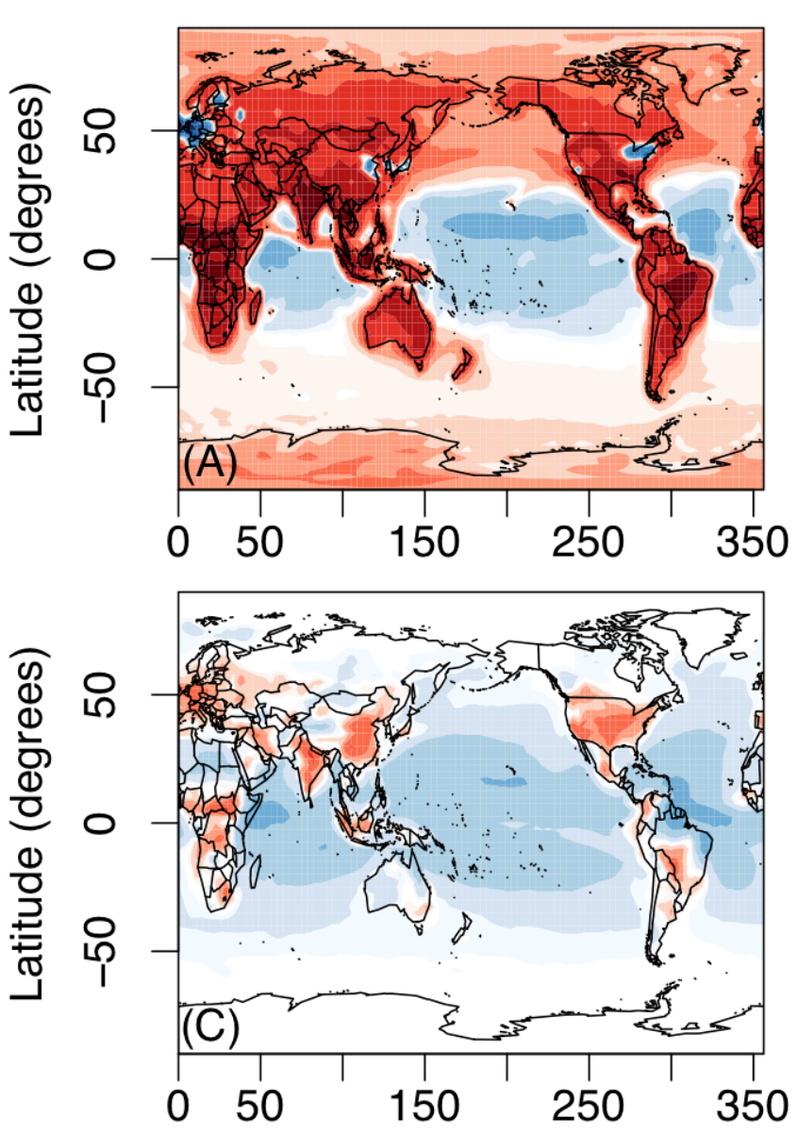


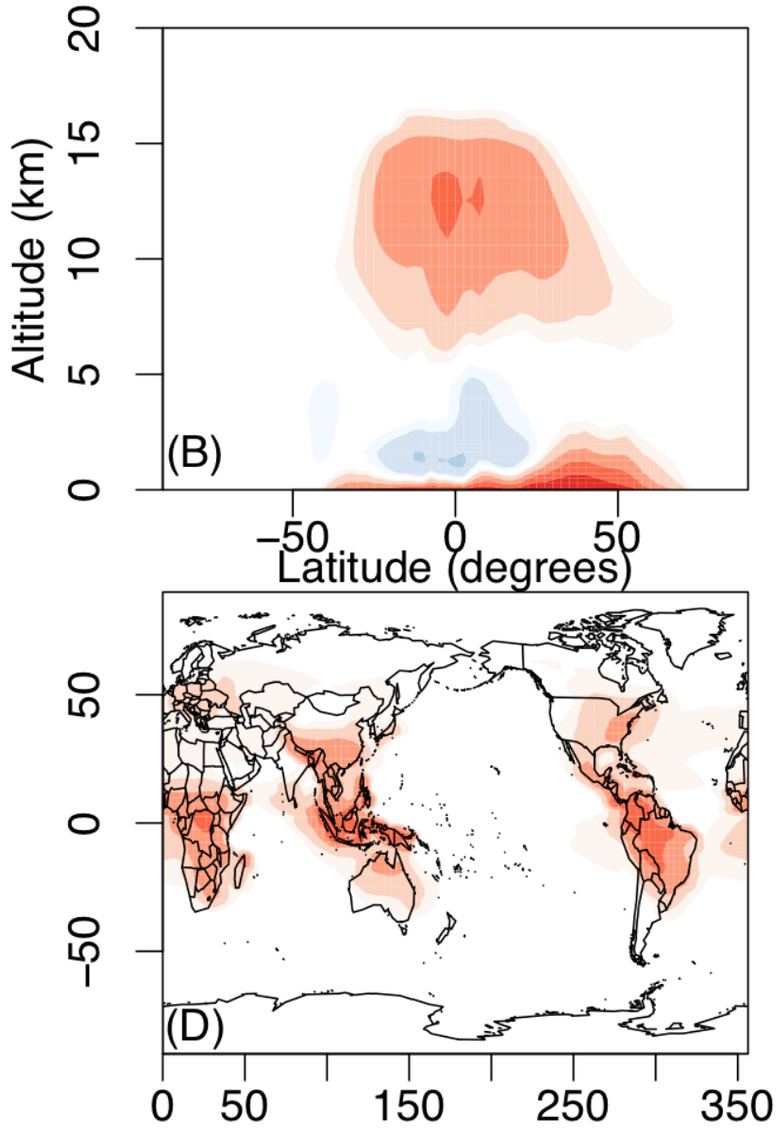


Archibald et al., TOAR “Budget”, Elementa 2021

Multimodel ozone tendency - TOAR Budget

Surface





ZM

FT

UT

Longitude (degrees)

ΔO_3 ppb/hr

−5 −1 −0.5 −0.2 −0.1 −0.05 −0.02 −0.01 0.01 0.02 0.05 0.1 0.2 0.5 1 5

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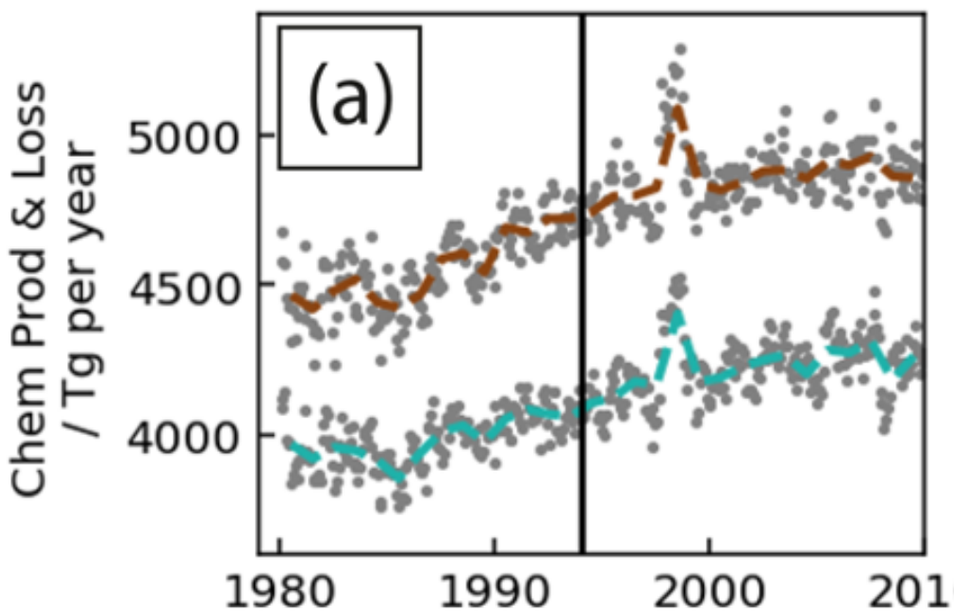
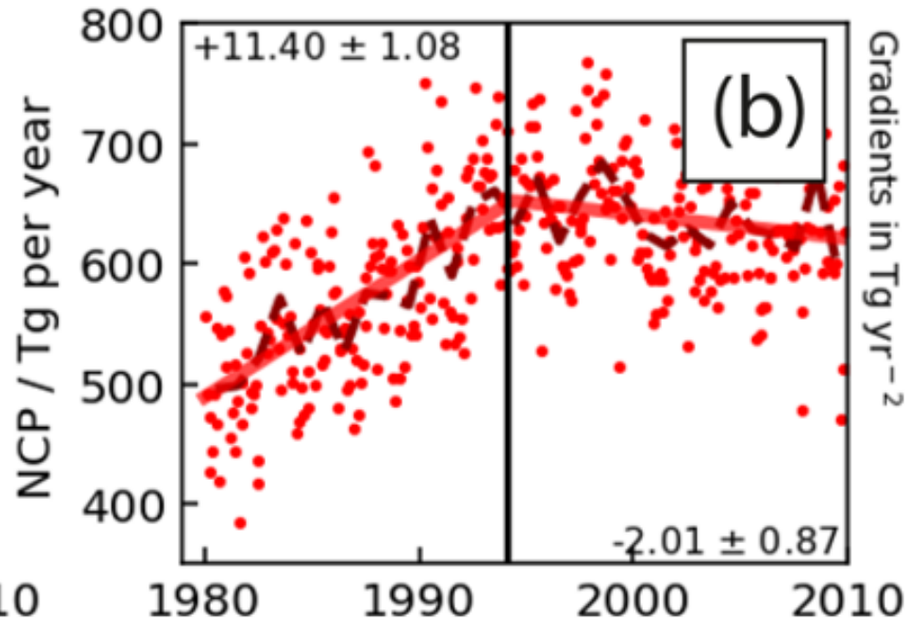
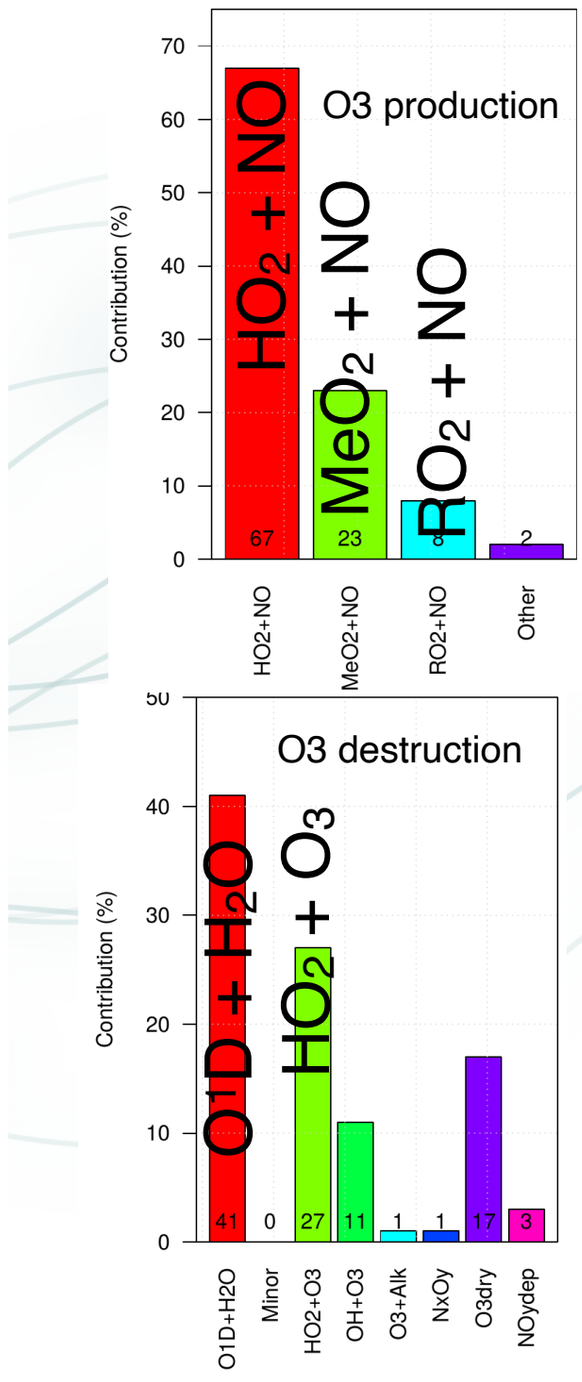
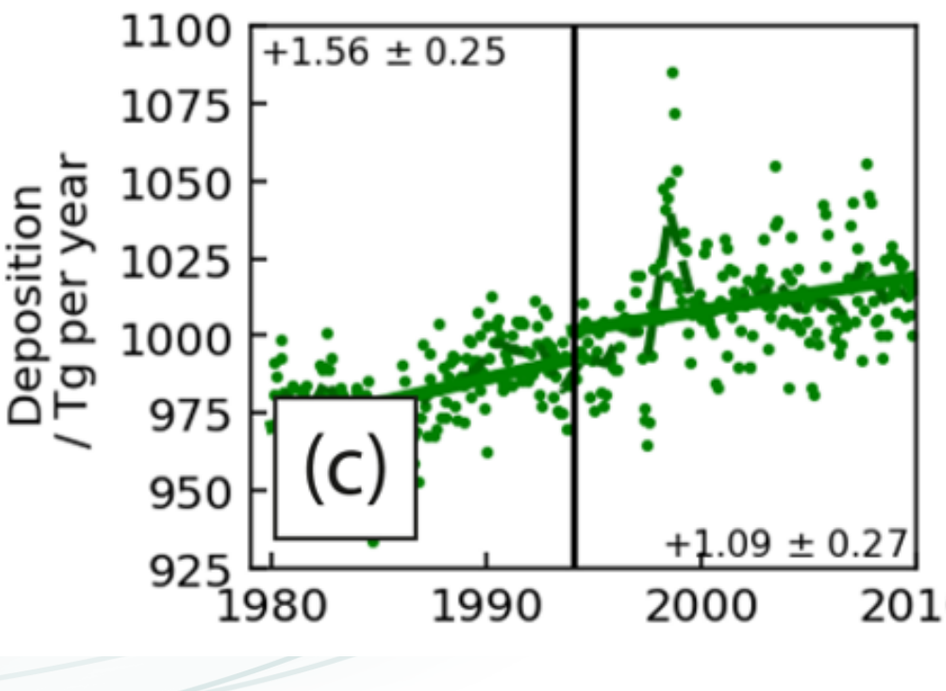
Archibald et al., TOAR "Budget", Elementa 2021

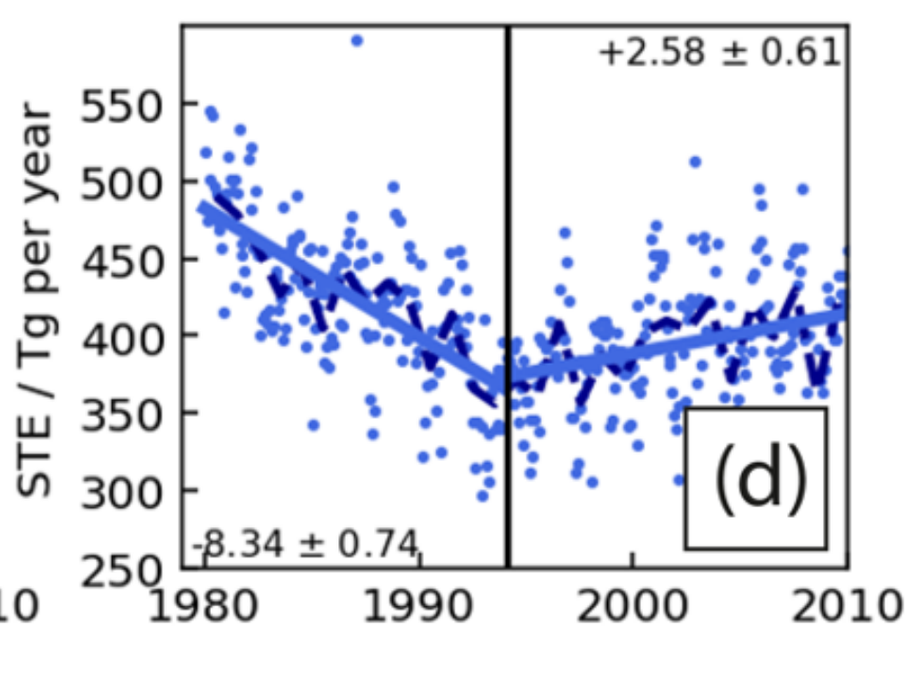
Tropospheric ozone budget in CCMs - large, opposing terms











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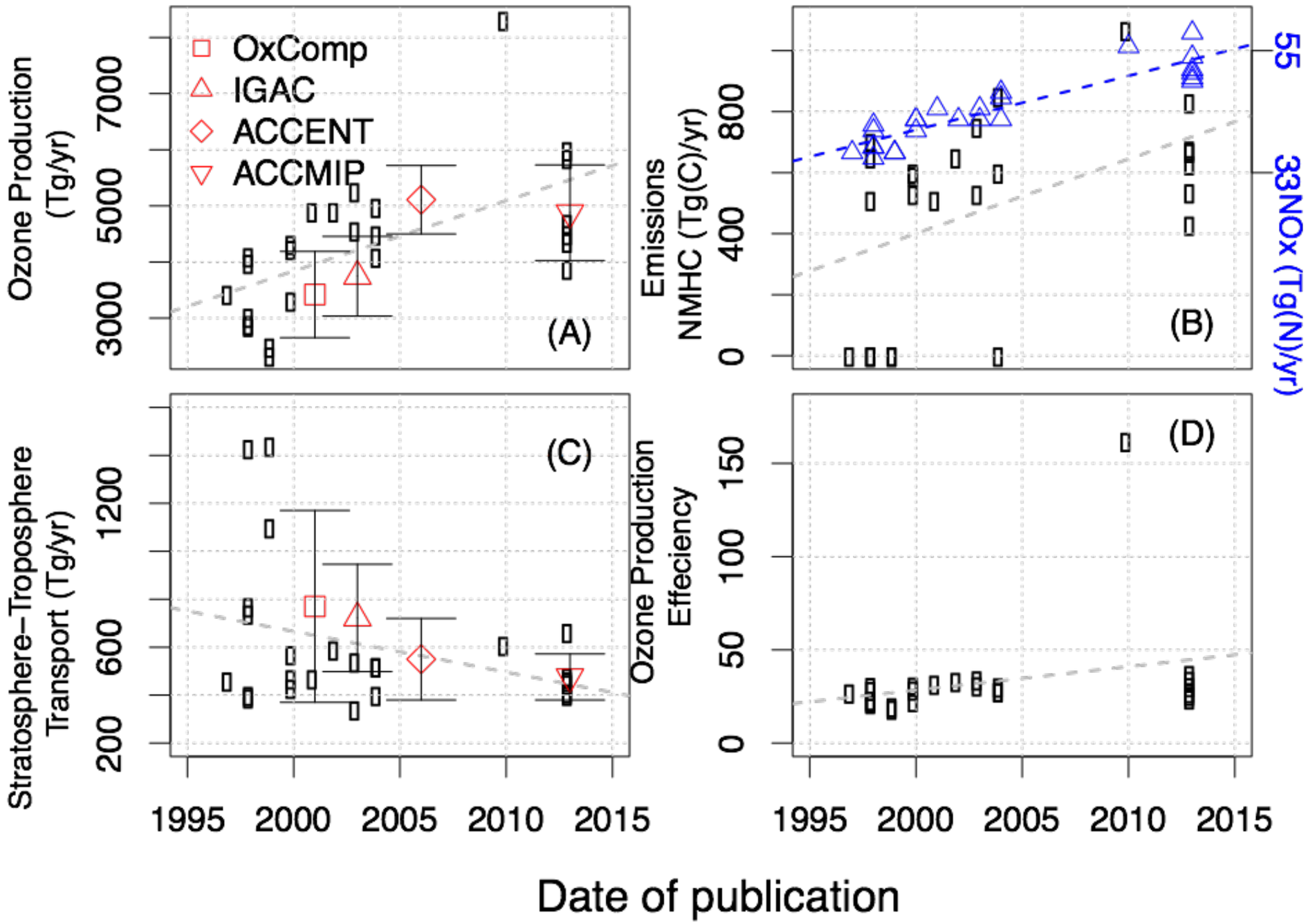
Griffiths et al., DOI: 10.1029/2019GL086901

Ozone in CCMs – developing complexity



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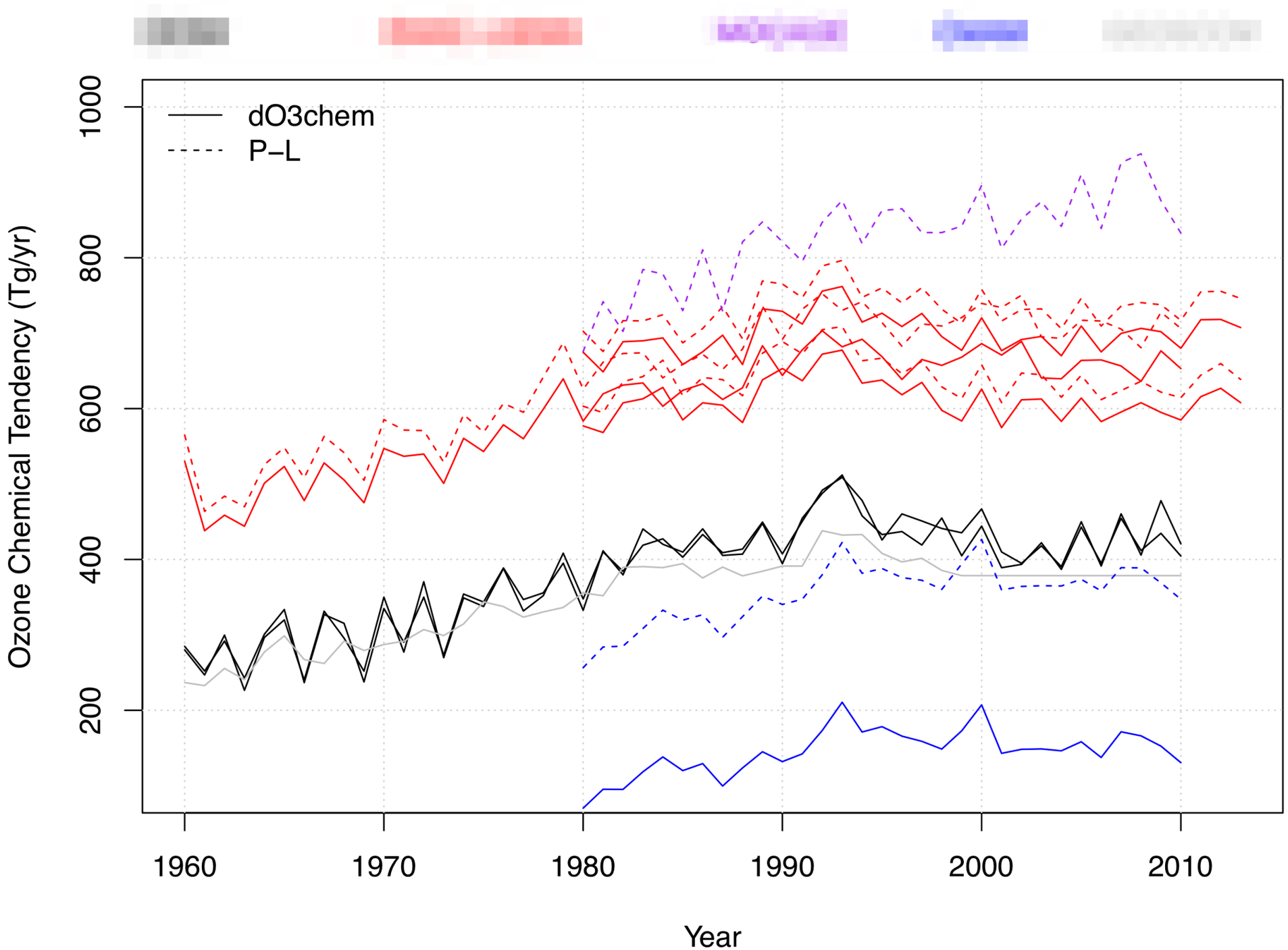
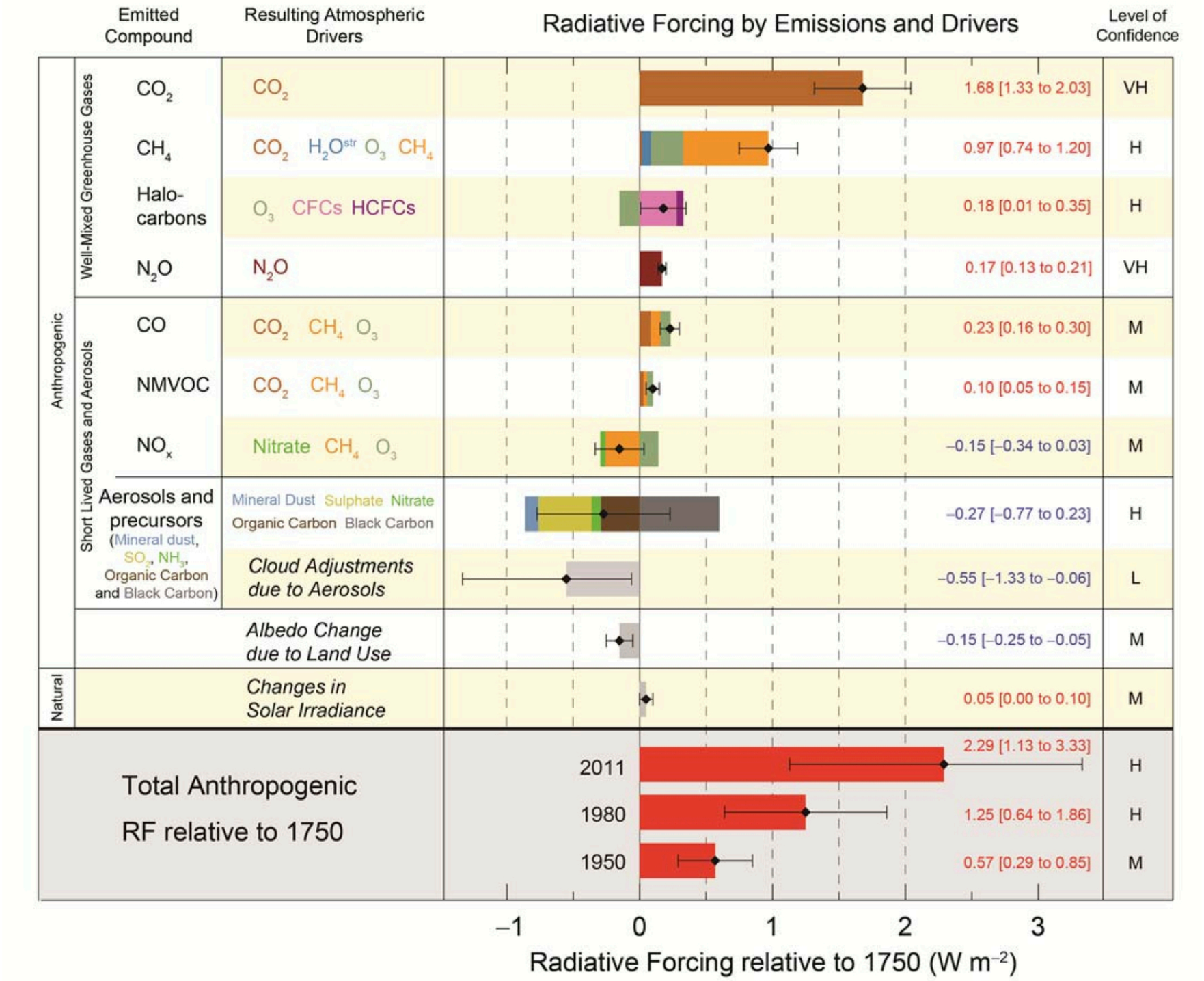
Archibald et al., TOAR "Budget", Elementa 2021

P-L in CCMI models - don't always agree!

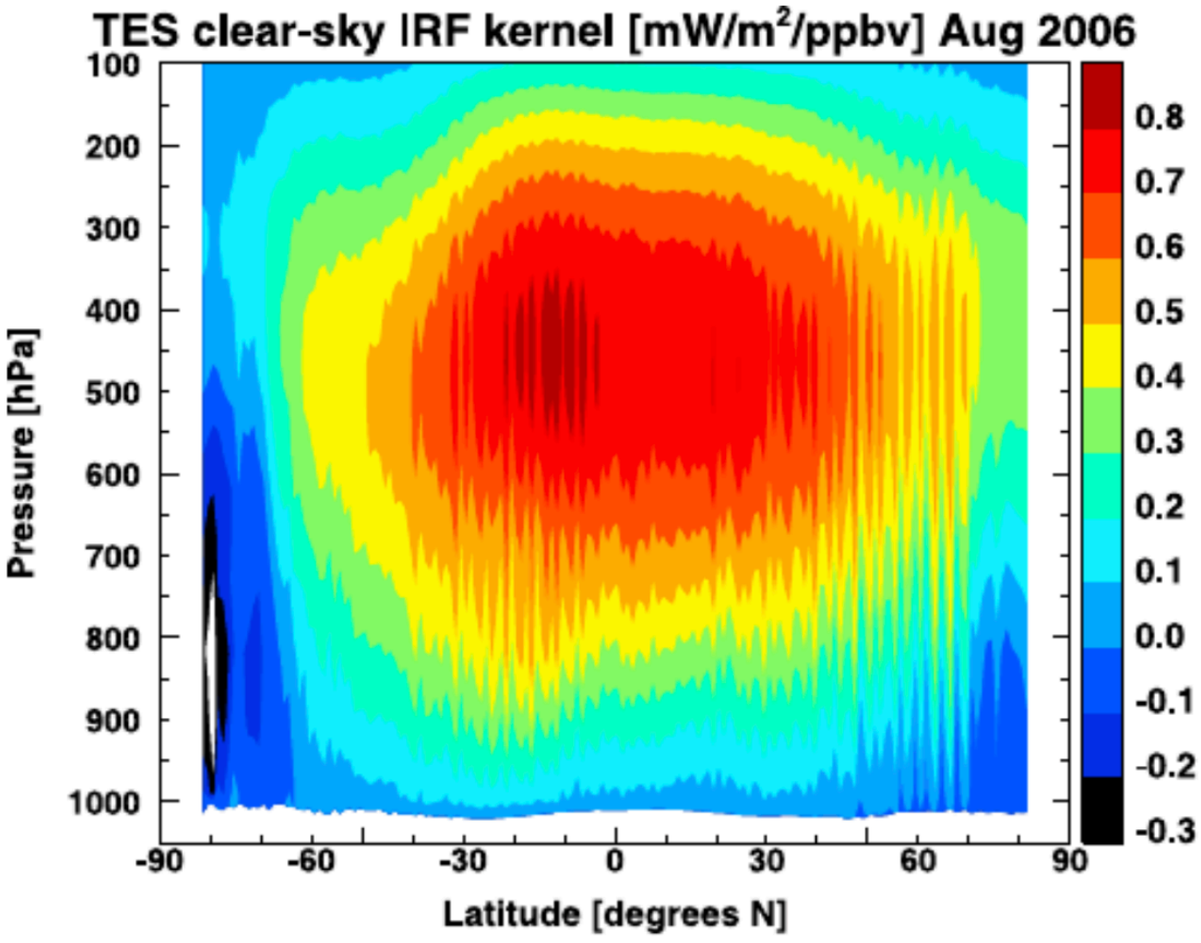


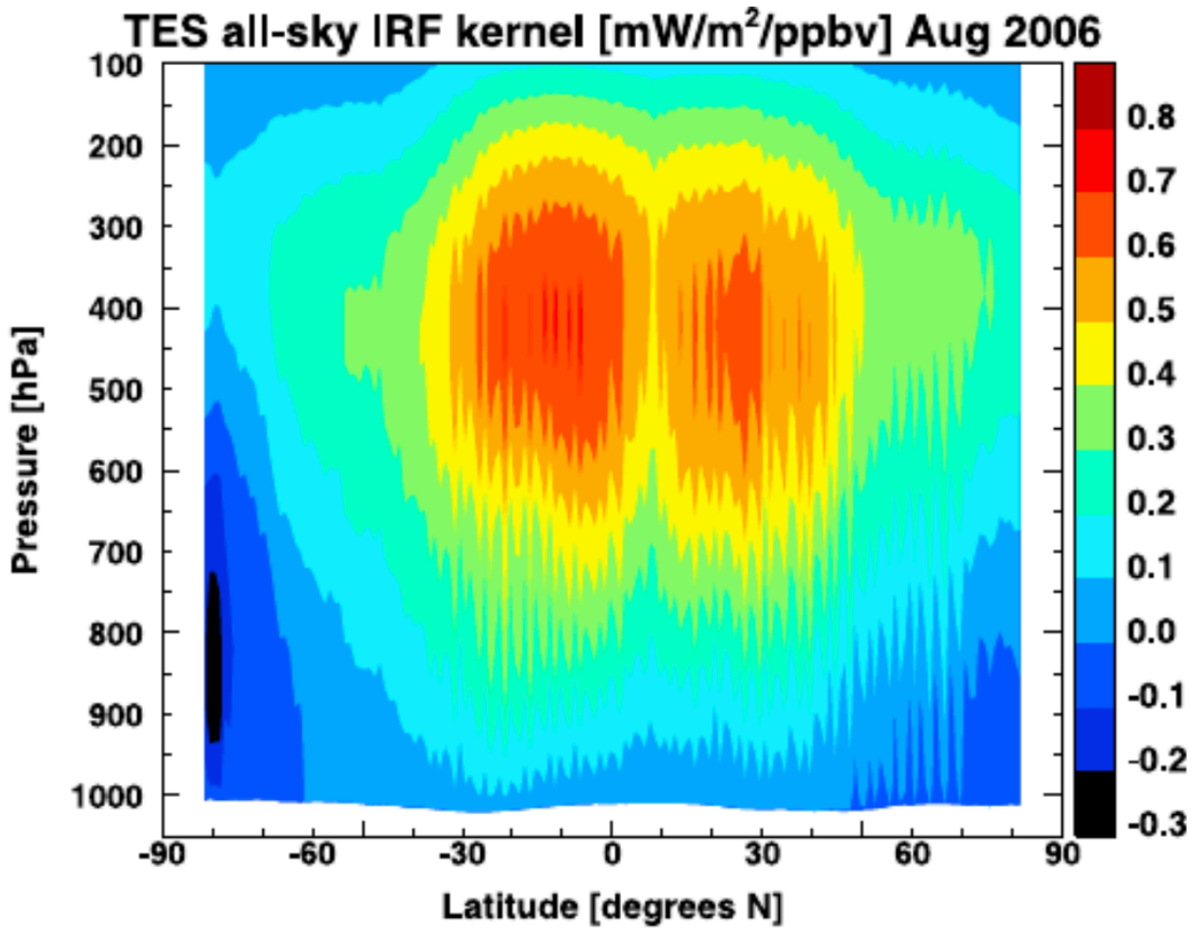
Effective radiative forcing - CMIP5 picture



- The radiative forcing can be used to estimate the resulting global temperature change via $\Delta F = \lambda \Delta T$

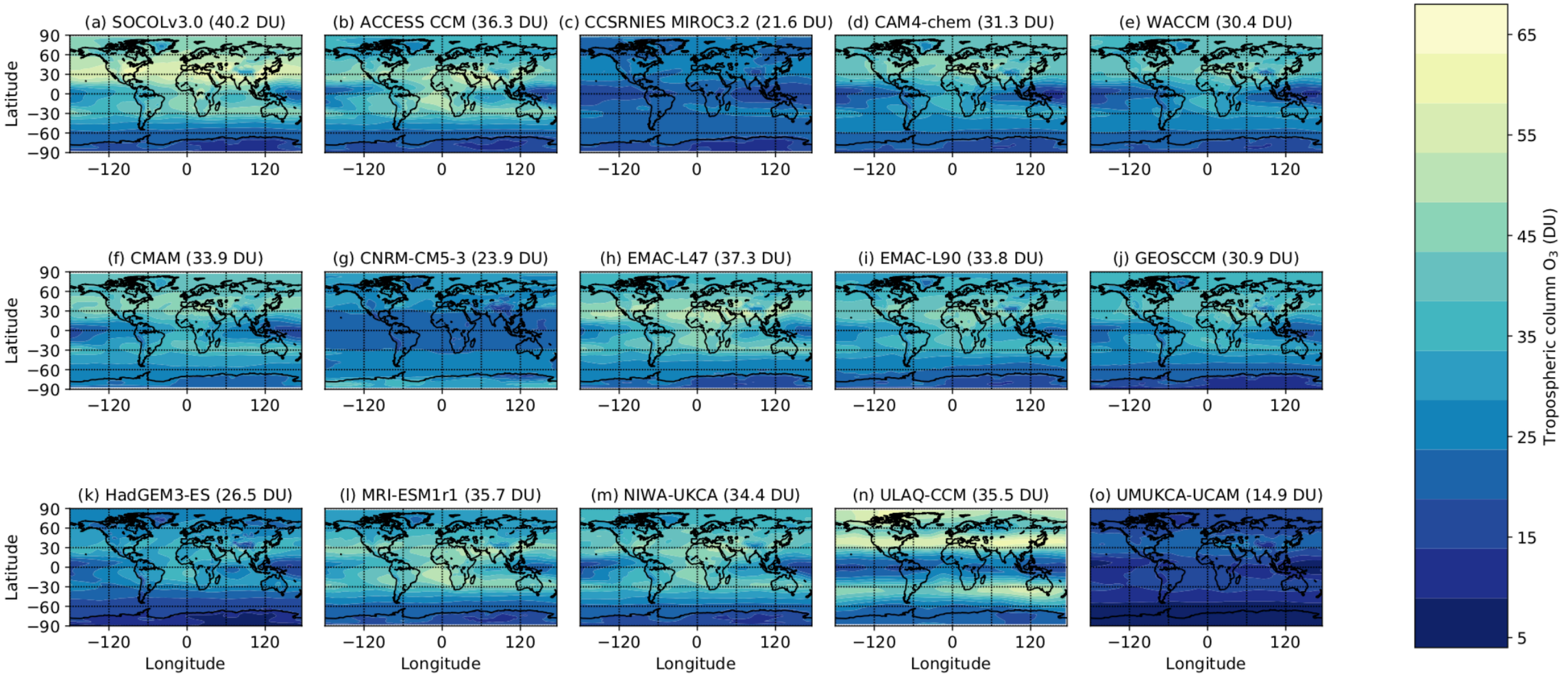
Ozone IRF - depends on altitude





Aghedo et al. (2012), “Vertical distribution of ozone IRF from satellite…”

UKCA Tropospheric ozone column in CCMI (2018)



Revell et al., 2018

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Tropospheric ozone in CMIP6

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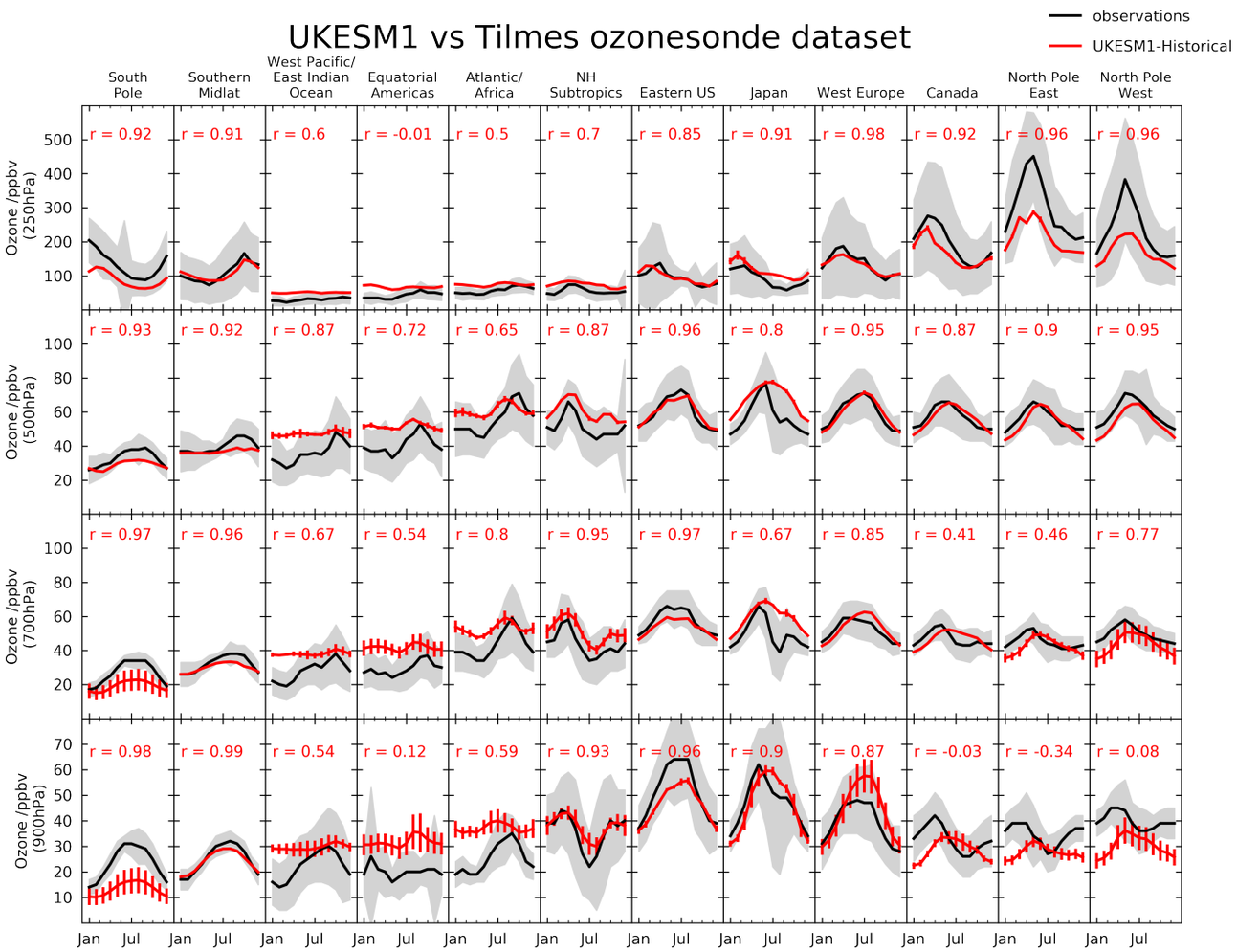
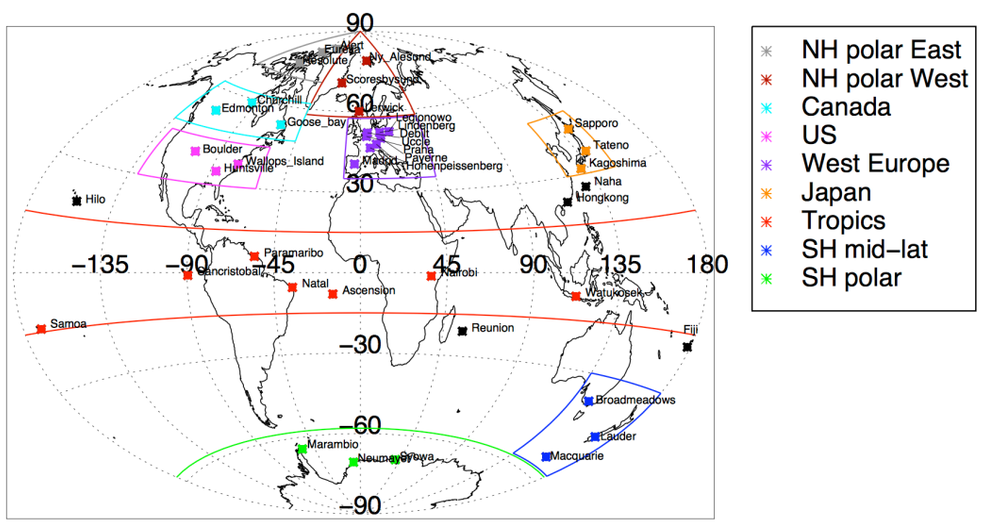
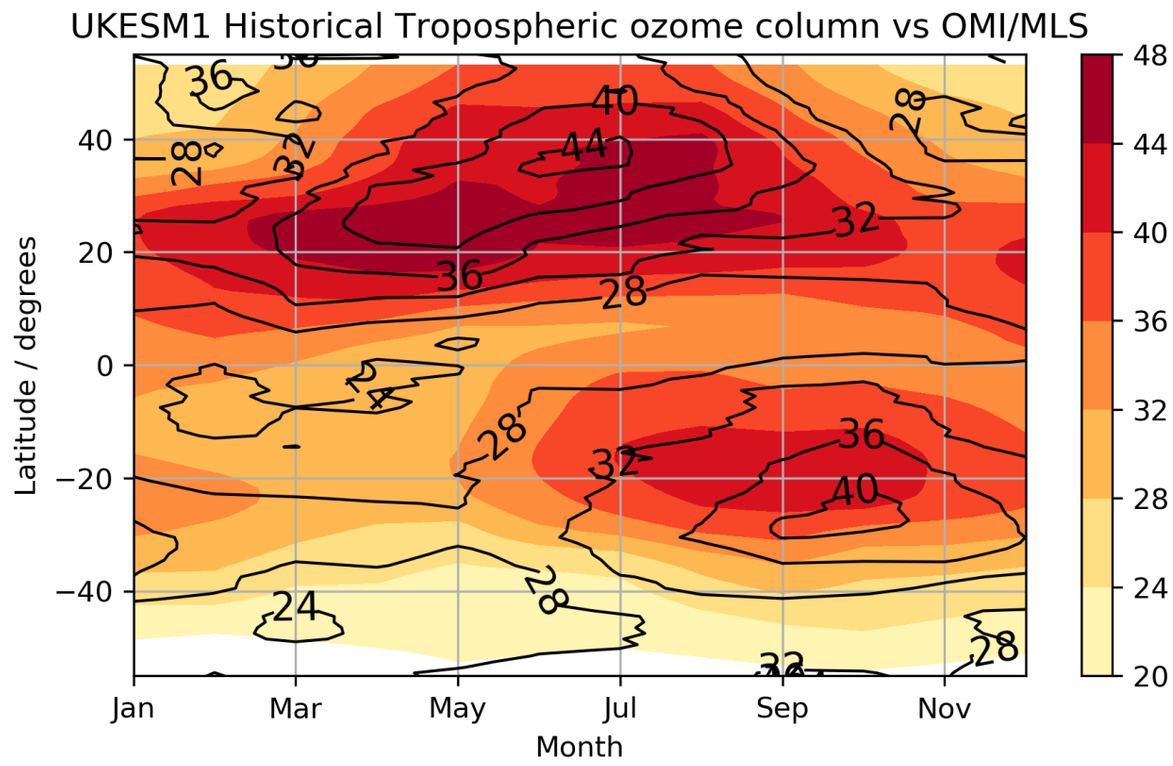
How does UKESM1 tropospheric ozone compare against observations?



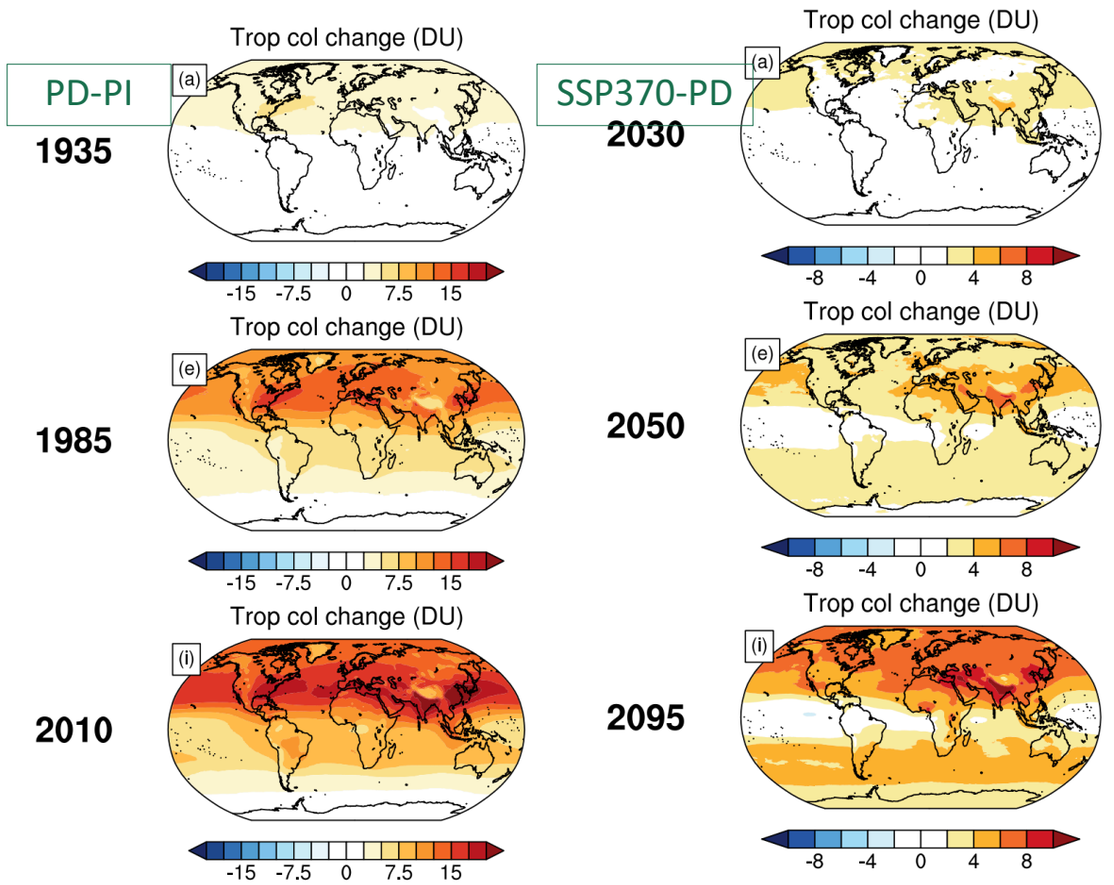




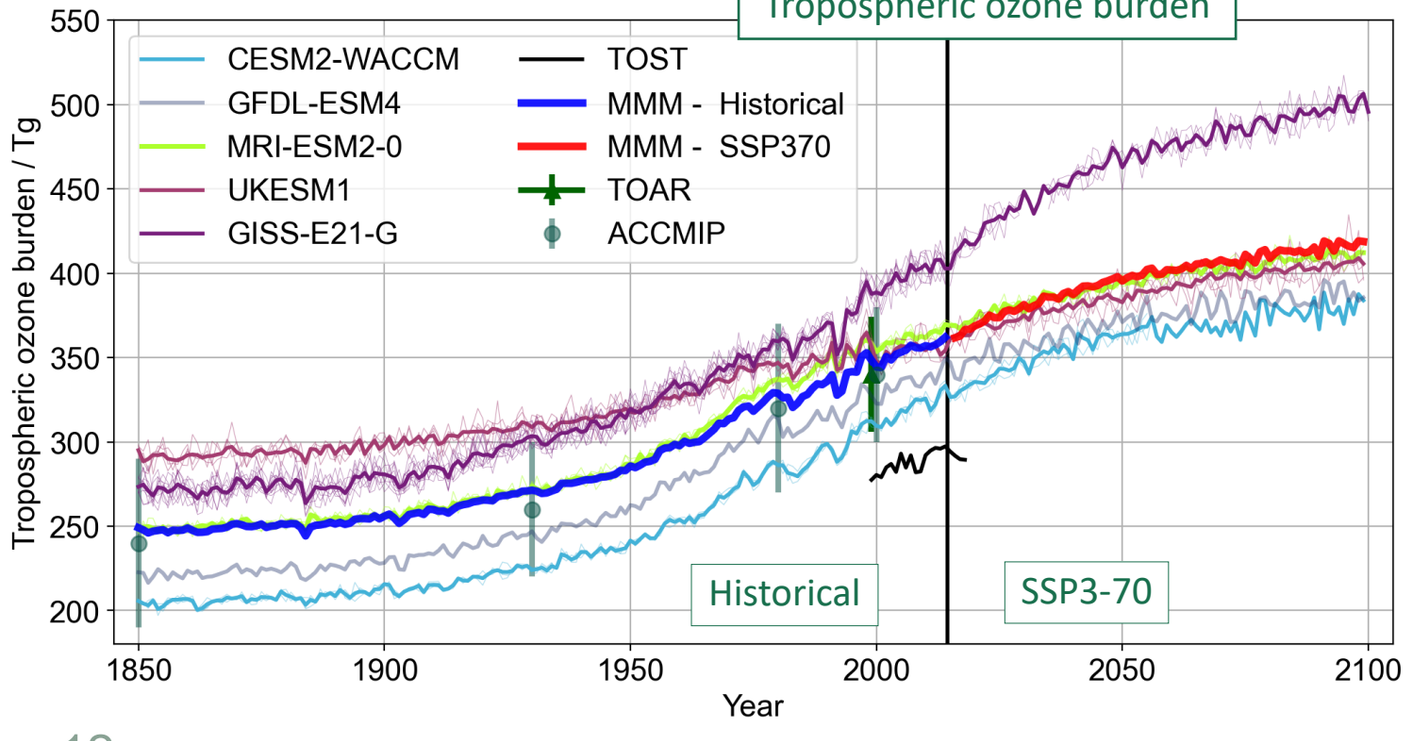
- UKCA tropospheric ozone compares well with observations, particularly in-situ measurements.
- Integrated quantities, such as column amounts, sensitive to tropopause definition.

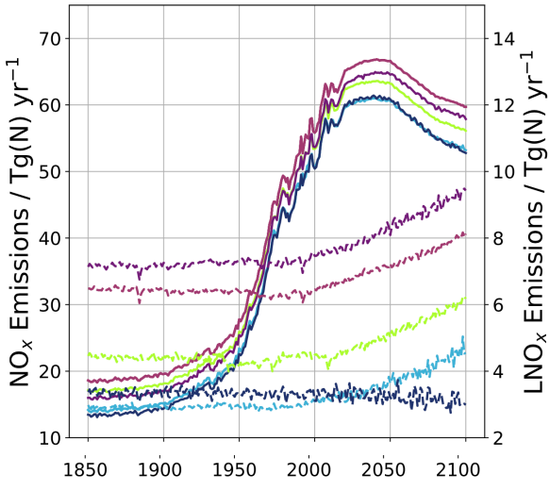
How does tropospheric ozone burden evolve in CMIP6?

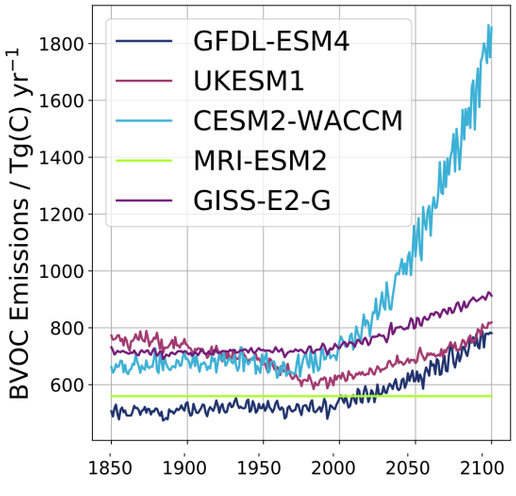
- Analysis so far has focused on CMIP Historical and ScenarioMIP SSP3-70 experiments, for which suitable diagnostic output was available.
- Picture has changed little since CMIP5/CCMI, MM range is also similar.
- Ozone burden increased by about 40% from 1850 levels of 240 Tg (MMM) with steepest rate 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.



Tropospheric ozone burden







Tropospheric ozone precursor emissions

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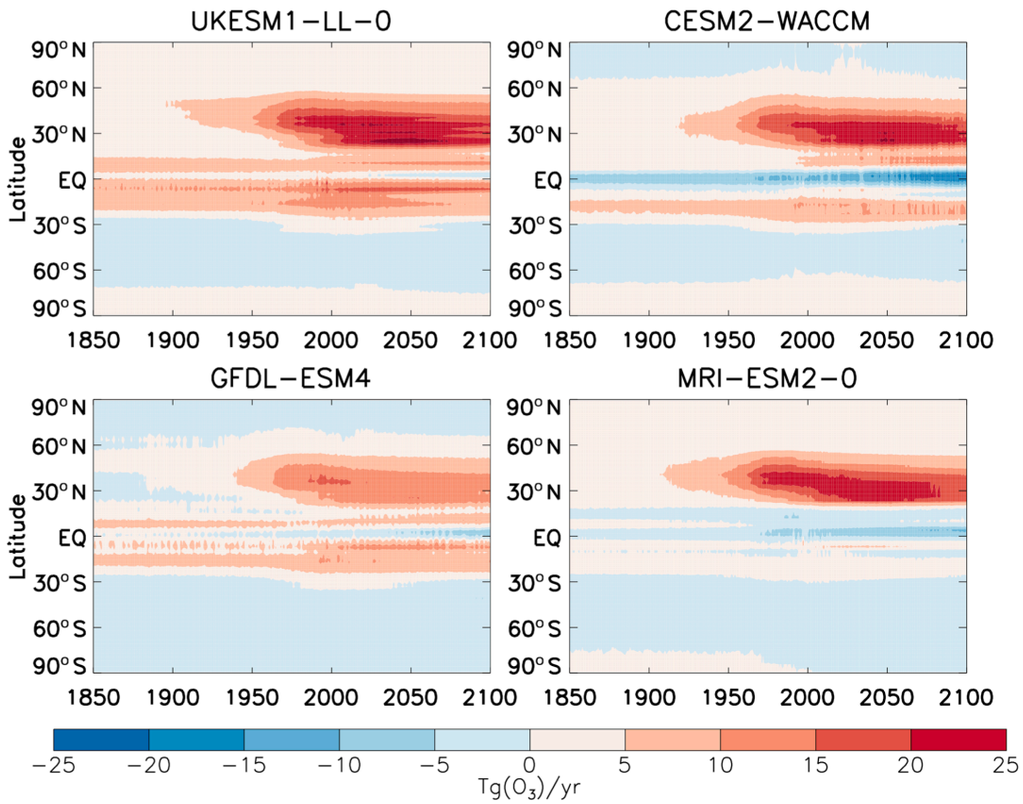
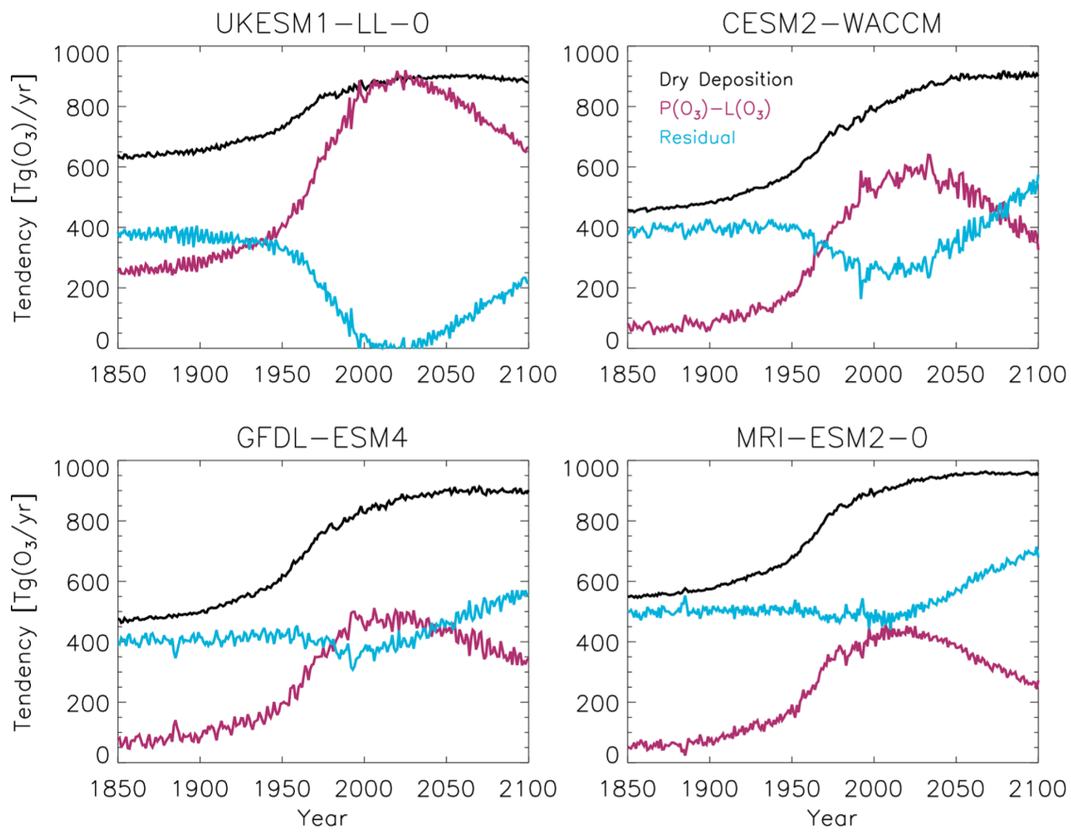
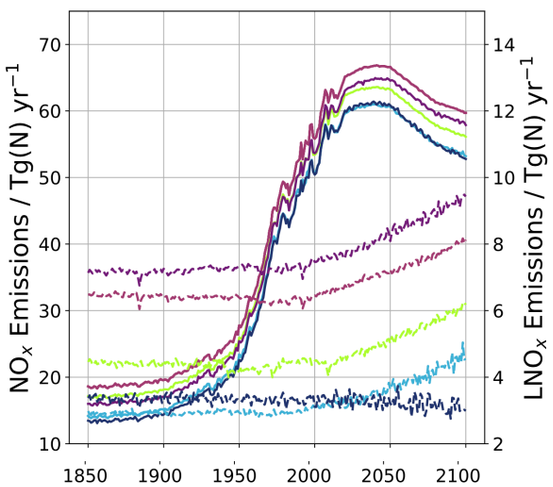
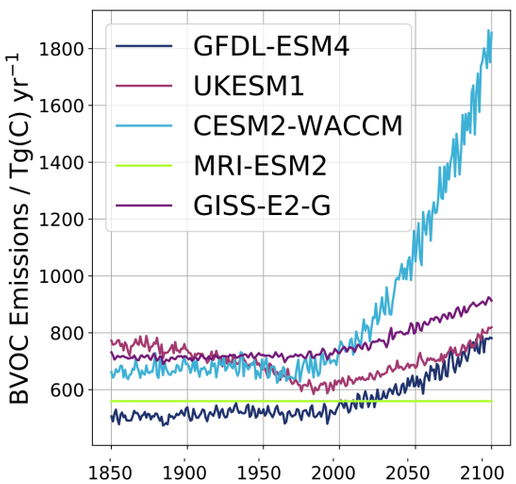




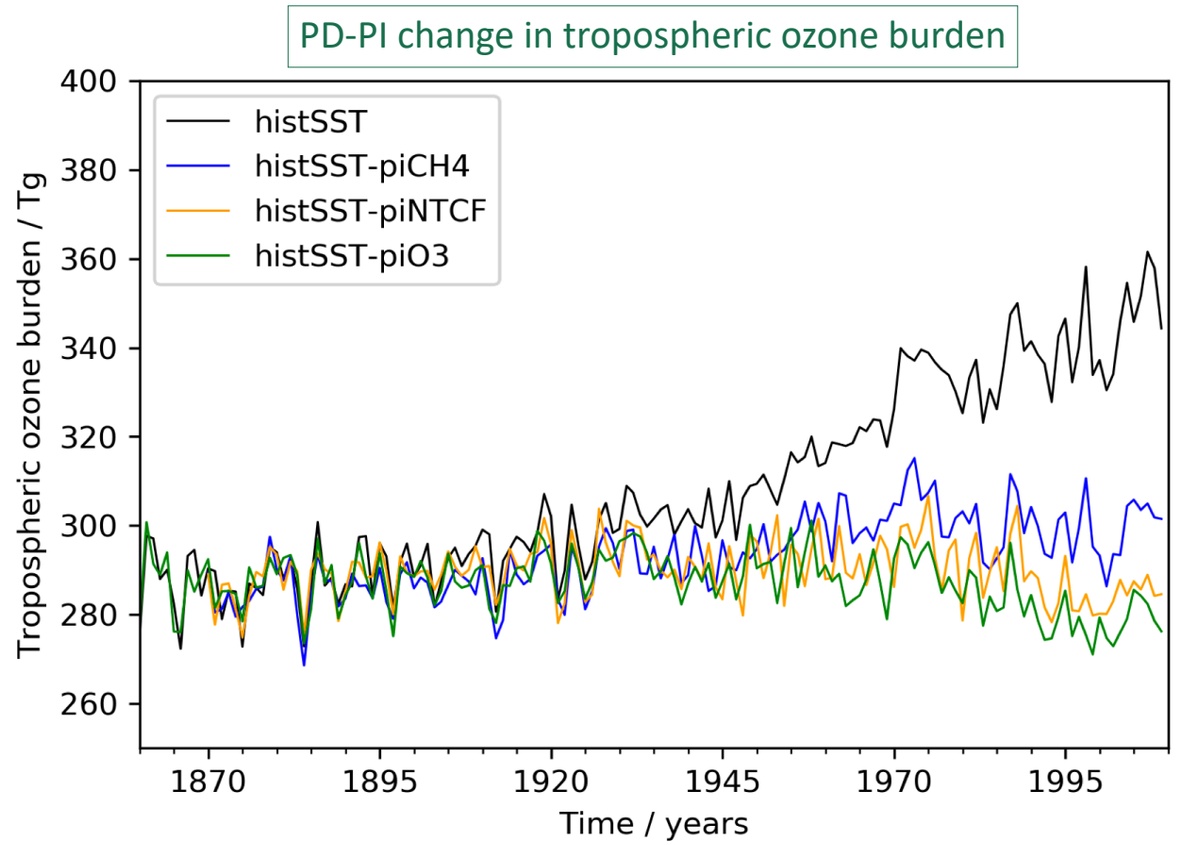




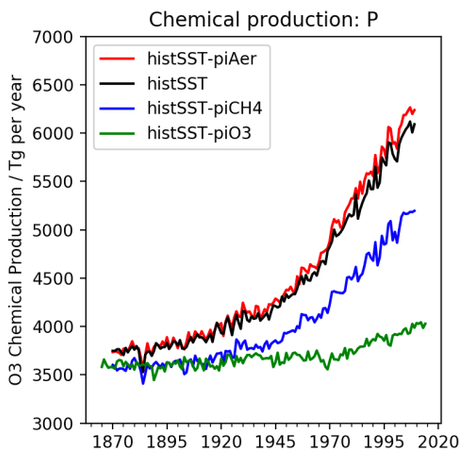
Tropospheric ozone precursor emissions

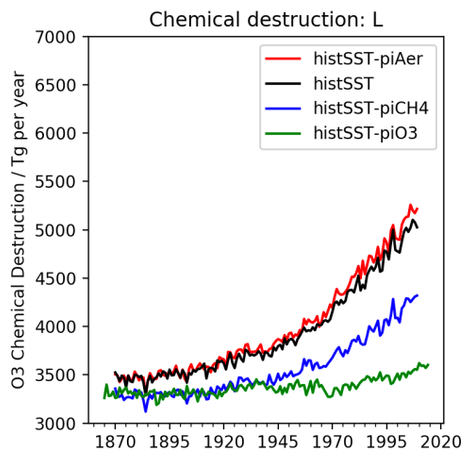
Attribution of tropospheric ozone burden changes

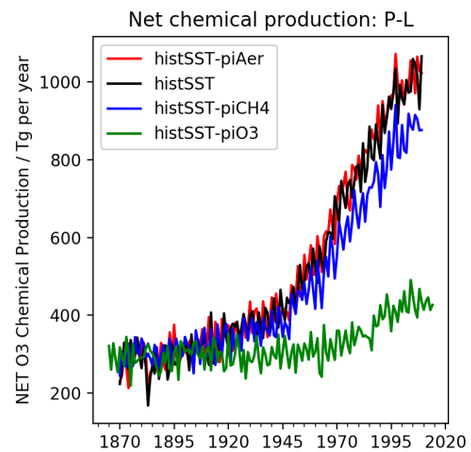
- AerChemMIP is a CMIP6 sub-project aimed at isolating effect of chemically active gases and aerosol on climate via tiered attribution experiments.
  - Selected components held at 1850 levels, other forcings evolve along historical trajectories.
  - Using atmosphere-only configuration with SSTs from historical experiments
- Initial results – 10% change in ozone burden when CH_4 held at PI levels, with larger changes to individual terms in chemical ozone budgets; 20% change when ozone precursors held at 1850 levels. P-L only part of the story.



Experiment_ID	CH4	N2O	Aerosol Precursors	Ozone precursors	CFC/HCFC	Tier
histSST	Hist	Hist	Hist	Hist	Hist	1
histSST-piNTCF	Hist	Hist	1850	1850	Hist	1
histSST-piAer	Hist	Hist	1850	Hist	Hist	2
histSST-piO3	Hist	Hist	Hist	1850	Hist	2
histSST-piCH4	1850	Hist	Hist	Hist	Hist	1
histSST-1950HC	Hist	Hist	Hist	Hist	1950	1
histSST-piN2O	Hist	1850	Hist	Hist	Hist	2



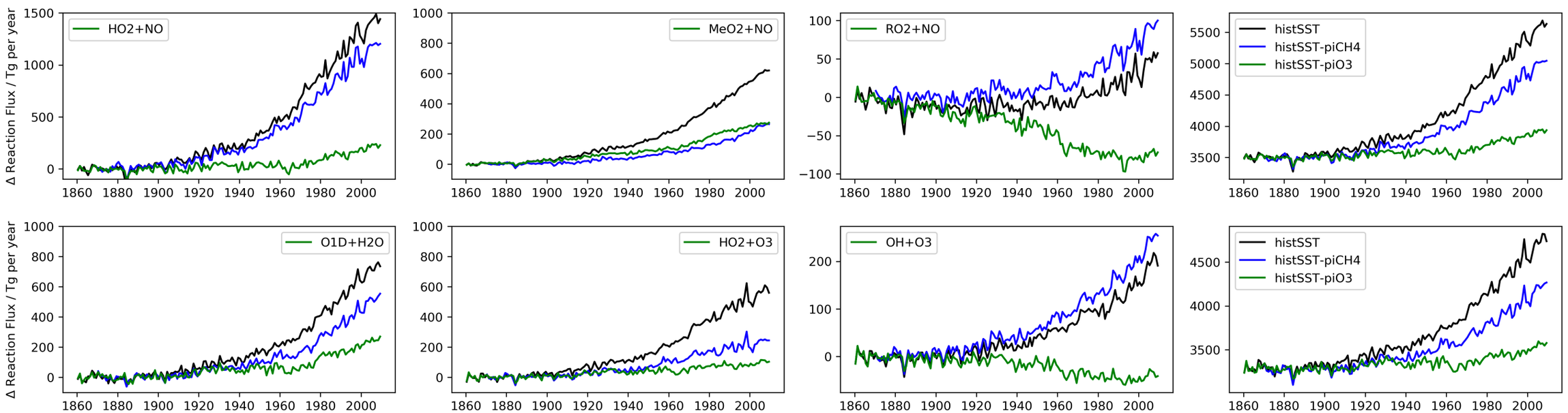




Attribution of tropospheric ozone burden changes

- Breaking the ozone budget down into P and L allows attribution of the impact of e.g. PI to PD CH4 concentrations.
- A single species can have impact on both P and L, e.g. CH4, which shows large differences in both P and L, with the largest impact due to different species, shown here as the change from PI to PD of individual ozone production/destruction fluxes.

EXP	PO3 PI	LO3 PI	O3(P-L) PI	O3 PI	PO3 PD	LO3 PD	O3(P-L) PD	O3 PD	ΔO3 PD-PI	Δ(P-L) PD-PI	ΔPO3 PD-PI	ΔLO3 PD-PI
	Tg yr^{-1}	Tg yr^{-1}	Tg yr^{-1}	Tg	Tg yr^{-1}	Tg yr^{-1}	Tg yr^{-1}	Tg	Tg	Tg yr^{-1}	Tg yr-1	Tg yr^{-1}
histSST	3616	3320	295	**287.4**	5671	4748	923	**346.3**	58.9	628	2055	1428
histSST-piCH4	3577	3284	292	**285.0**	5105	4226	878	**298.9**	13.9	586	1528	942
histSST-piO3	3608	3309	298	**286.7**	3996	3567	429	**278.9**	-7.8	131	388	258



Thank you

UKESM/UKCA Science Advances - prep for CMIP7

Meeting **tomorrow (Friday 26th)** 0830-1130

Please email me - paul.griffiths@ncas.ac.uk - for an invite!

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