Ozone impact on vegetation resulting from different Methane Pledge scenarios

G. Hayman[1], R. Oliver[1],
F. O'Connor[2], G. Folberth[2], S. Turnock[2],
C. Mathieson[2], C. Smith[2] and P. Griffiths[3]

(1) UK Centre for Ecology & Hydrology; (2) Met Office Hadley Centre; (3) UKCA & U. Cambridge

UK Centre for Ecology & Hydrology

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Acknowledgements

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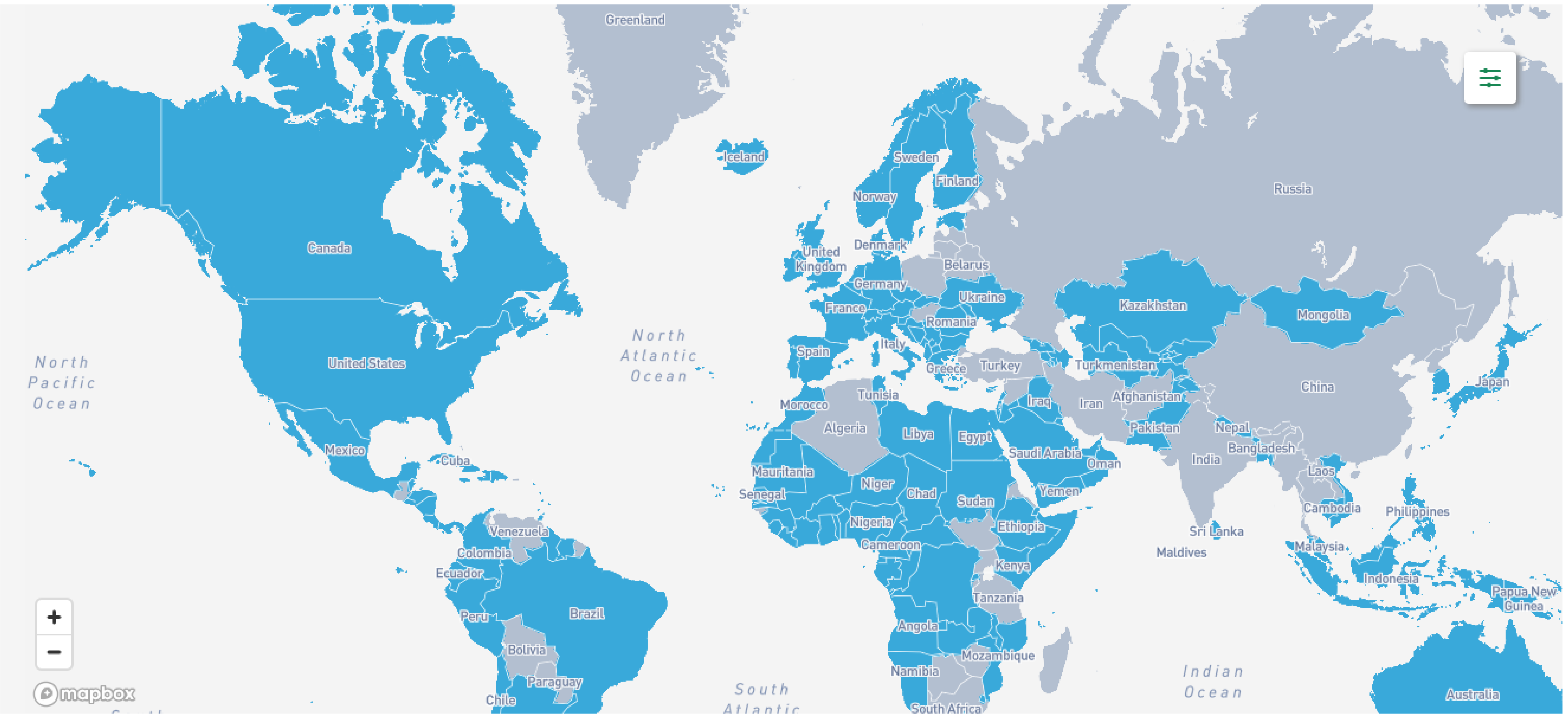
Global Methane Pledge

- Methane is a powerful but short-lived Greenhouse Gas that accounts for a third of net warming since the Industrial Revolution
- Reducing methane emissions from energy, agriculture, and waste is the single most effective strategy to achieve the goal of limiting warming to 1.5°C



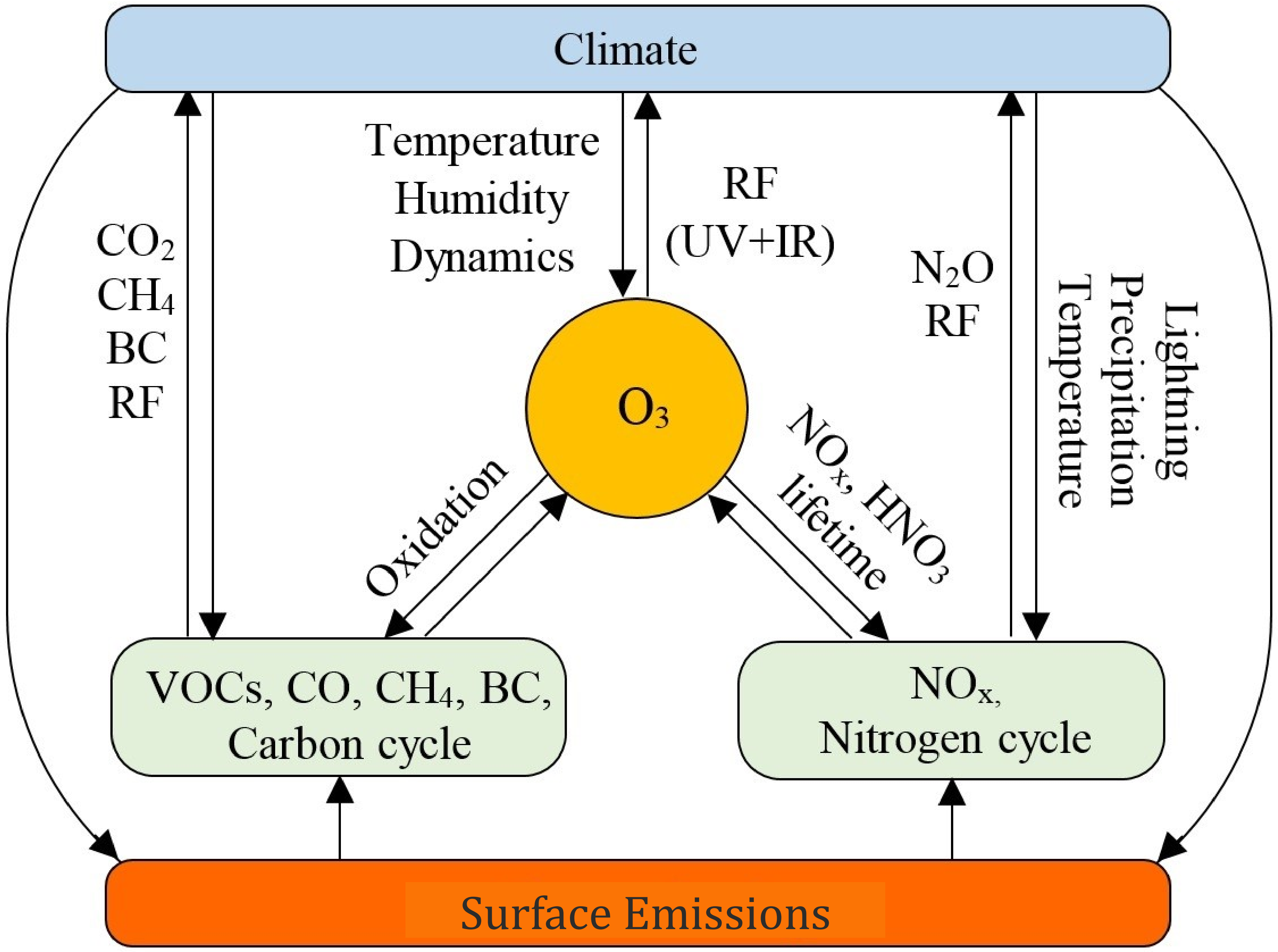
https://www.globalmethanepledge.org/#pledges

- Co-benefits include improving public health and agricultural productivity
- ‘Pledge’ countries agree to cut their methane emissions by 30% by 2030 (2020 base)
- 158 participating countries accounting for 50% of global CH_4 emissions (March 2024)
- Excludes some large CH_4 emitters (e.g. Russia, India, China)

Methane Pledge study

Approach

- UKESM used to investigate effect of different Methane Pledge scenarios on climate (radiative forcing), atmospheric composition, vegetation and human health
- JULES ES runs undertaken to investigate ozone vegetation damage, as not enabled in UM-coupled JULES (and hence UKESM)



UKESM set-up

- UKESM1.0, with methane emissions-driven configuration (Folberth et al., 2022)
- Atmosphere-only runs, with a repeating ‘2020’ climatology of sea surface temperatures and sea-ice distribution
- Run lengths to reach ‘steady state’: 70-100 years

JULES ES runs

Set-up

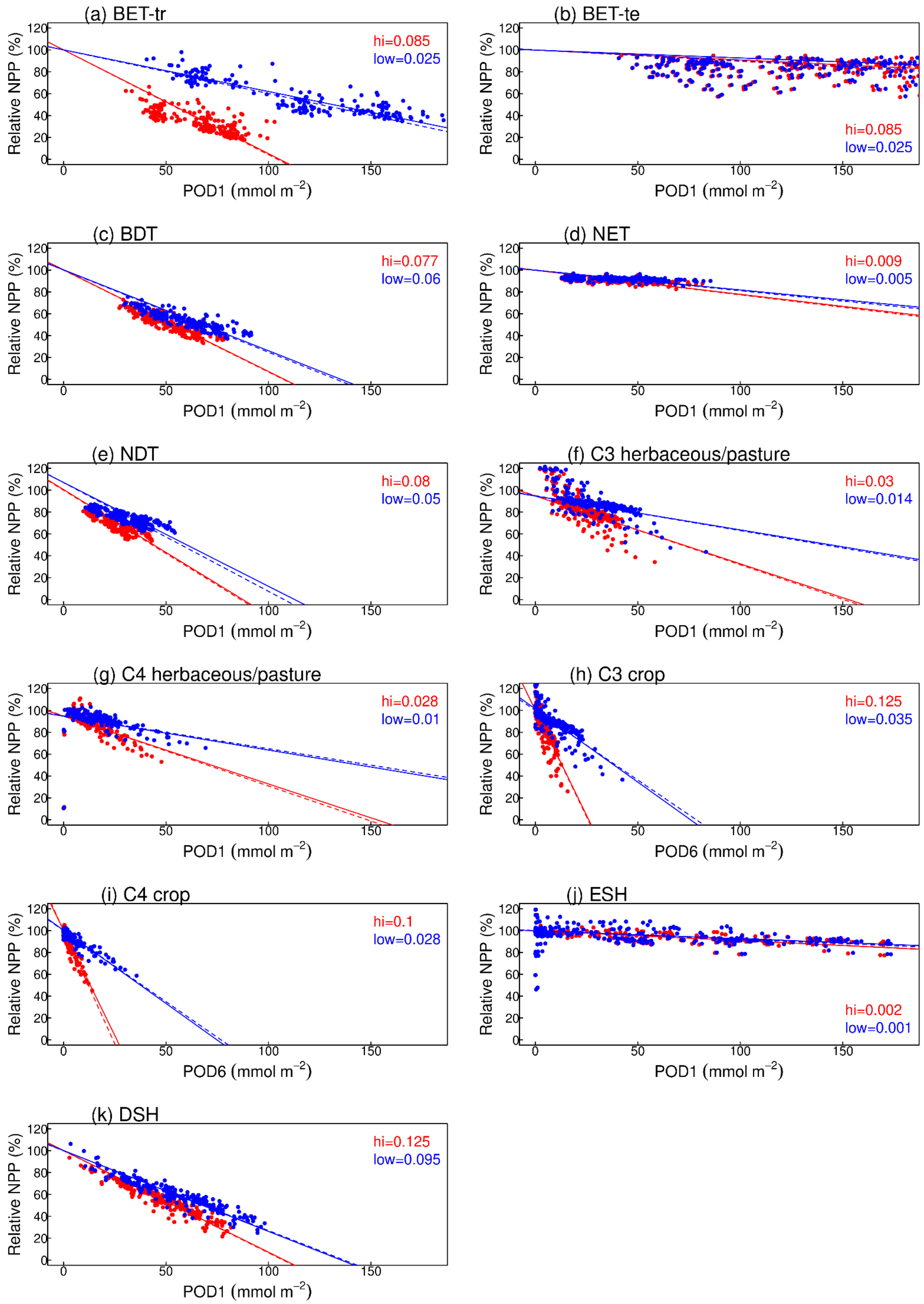
- As far as possible, matched to the 'JULES set-up' in the UKESM runs
- Driving meteorology and O_3 fields taken from the corresponding UKESM run
- For each JULES ES run: (a) no vegetation O_3 damage; (b) vegetation O_3 damage – low O_3 sensitivity; (c) vegetation O_3 damage – high O_3 sensitivity
- As no dynamic vegetation (triffid not on), focus on carbon fluxes

Runs

- base case
- 2030: current legislation: 'counterfactual' (**cf**)
- 2030: maximum feasible reduction in CH_4 (**ch4**)
- 2030: global methane pledge + India, Russia & China (**top3**)
- 2030: global methane pledge + top 10 non-pledge countries (**top10**)
- 2030: maximum feasible reduction in CH_4 & NO_x (**nox**)
- 2030: maximum feasible reduction in CH_4 & aerosols (**aer**)
- 2030: maximum feasible reduction in CH_4 & near-term climate forcers (**ntcf**)
- 2030: maximum feasible reduction in CH_4, VOCs & CO (**voc**)

Ozone Vegetation Damage

- Calibration of JULES O_3 response factor (**a**) for **high** and **low** O_3 sensitivity, for Farquhar photosynthesis and Medlyn stomatal conductance scheme.
- Observed dose response functions (DRFs) are only available for a limited number of vegetation types
- For each PFT, **'a'** calibrated to replicate the observed decline in biomass from exposure to O_3 above PODy (phytotoxic O_3 dose above a threshold of 1 mmol m^{-2} or 6 mmol m^{-2} for crops)
- Relative change in modelled net primary productivity (NPP) plotted against the cumulative uptake of O_3 above PODy, with iterative adjustment of **'a'** to find the slope that best matches the DRF regression slope



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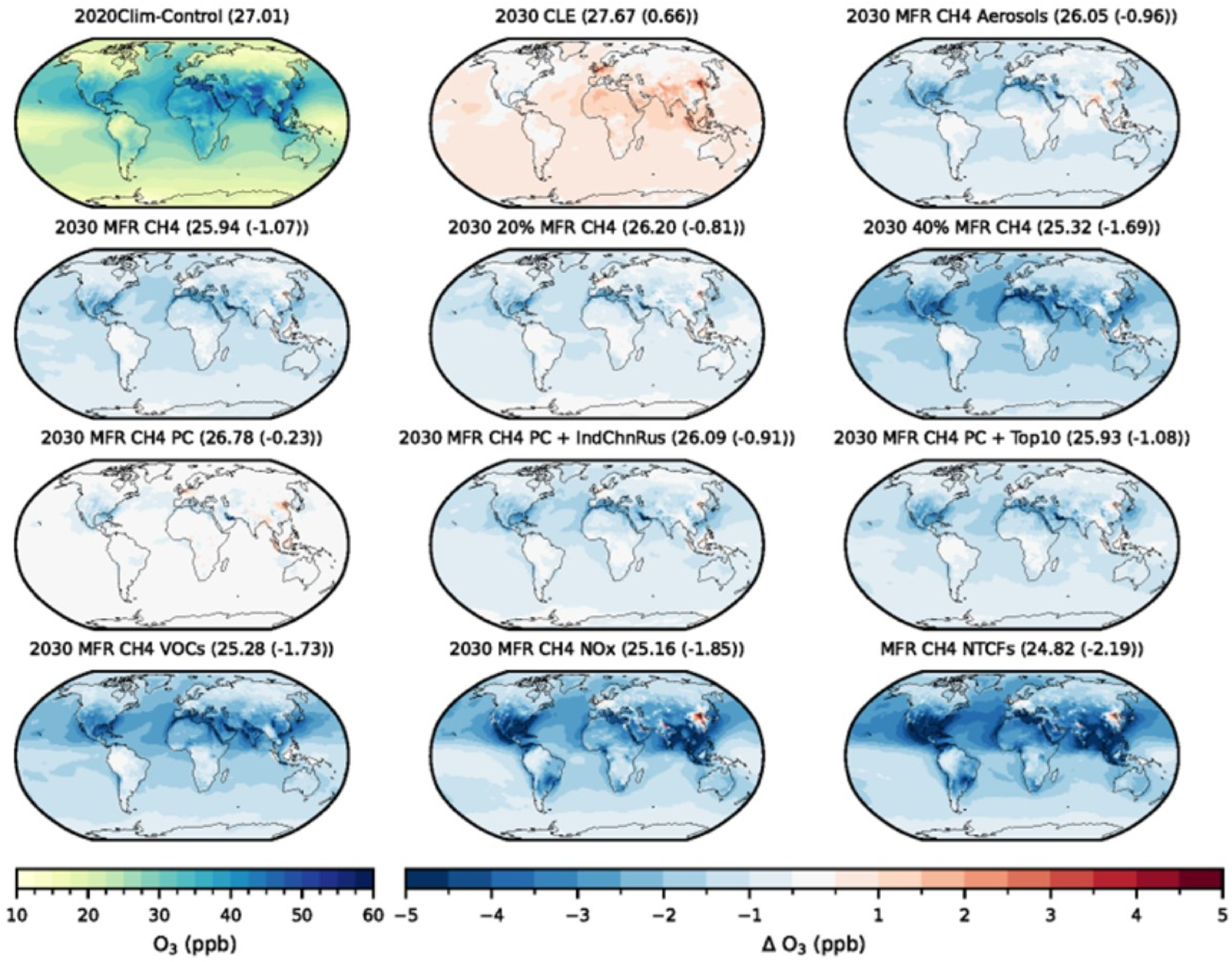
Surface ozone fields from UKESM runs



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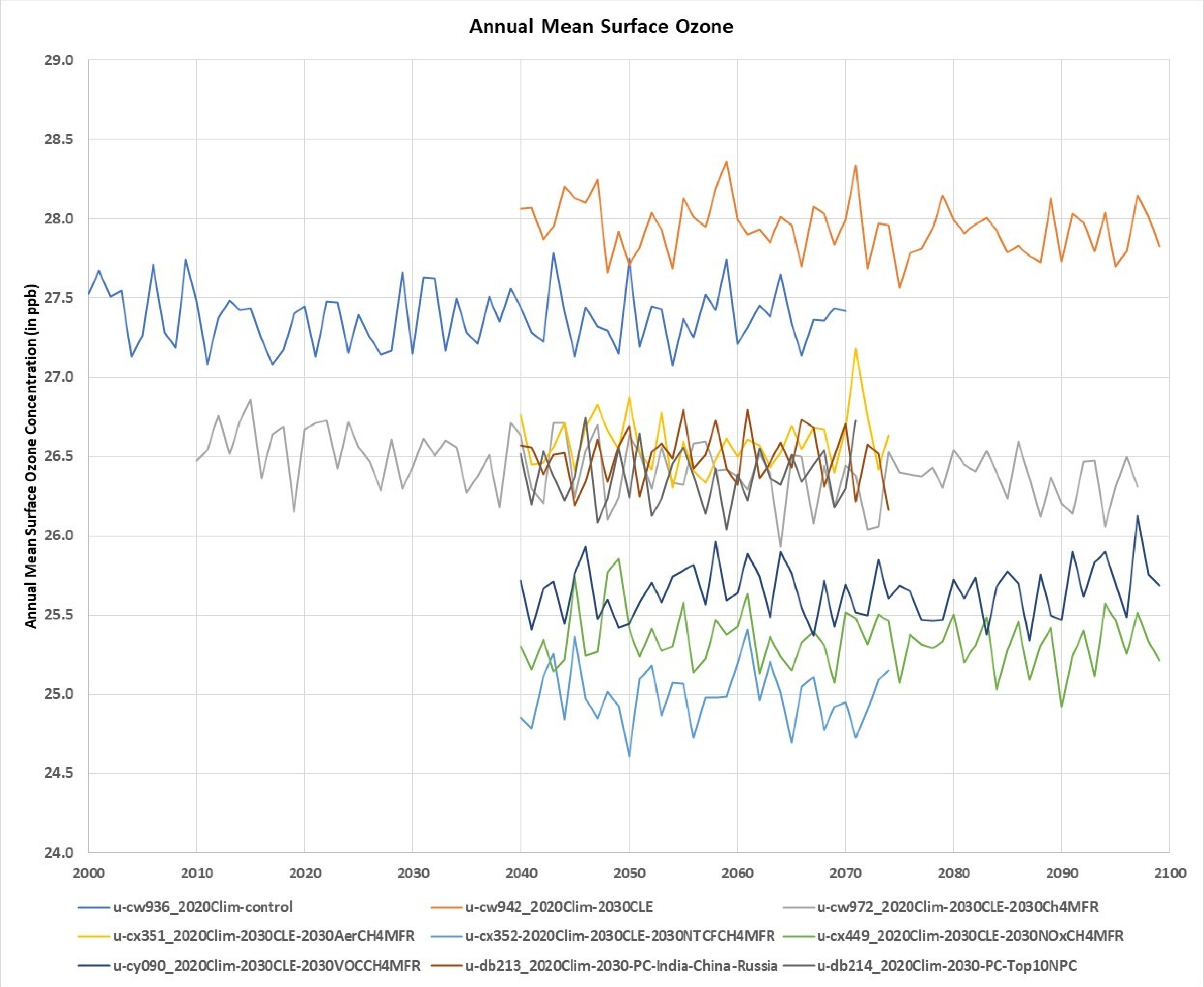
Surface ozone fields: global annual mean



cf (u-cw942)

base case (u-cw936)

aer (u-cx351)
ch4 (u-cw972)
top3 (u-db213)
top10 (u-db214)

voc (u-cy090)

nox (u-cx449)

ntcf (u-cx352)

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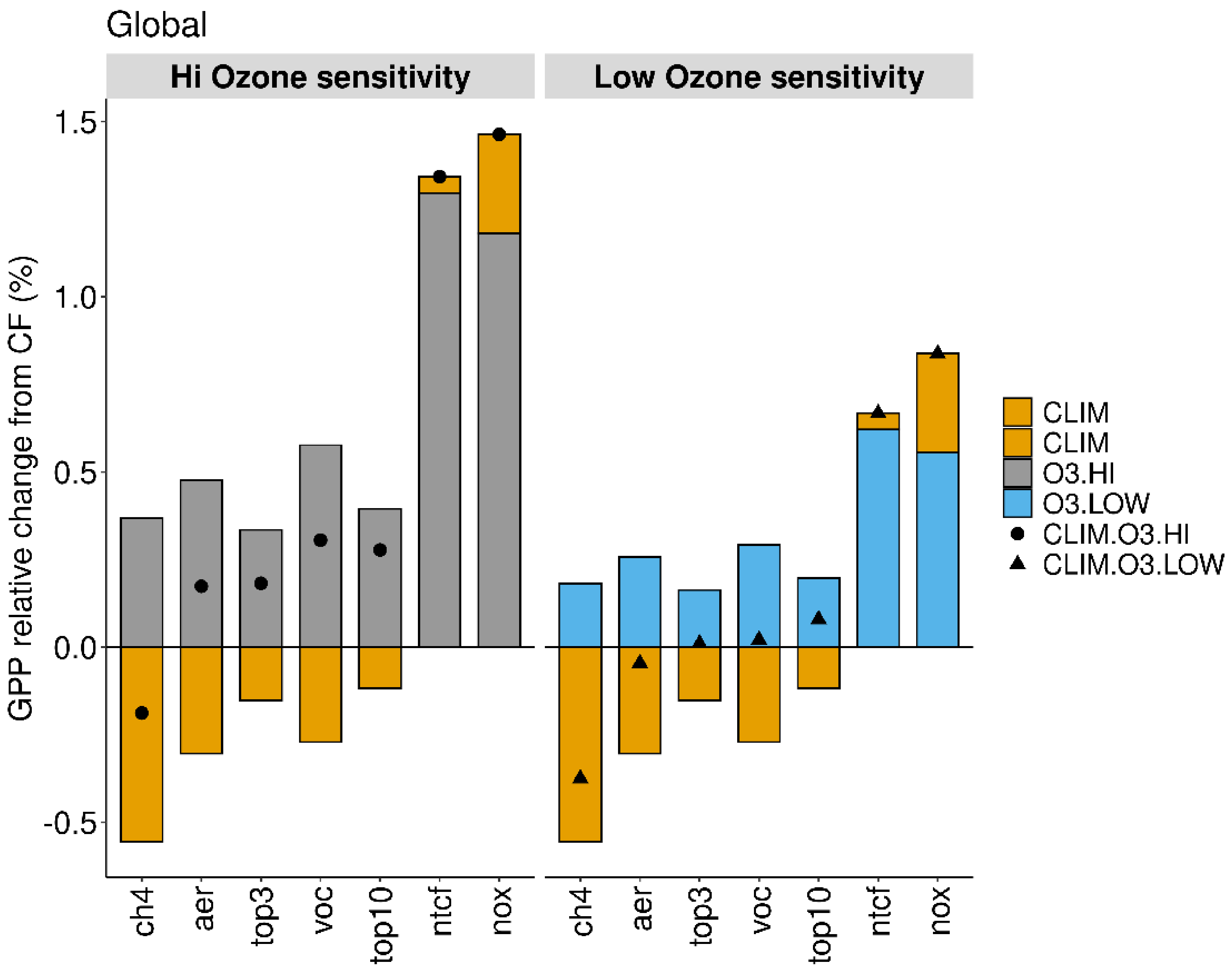
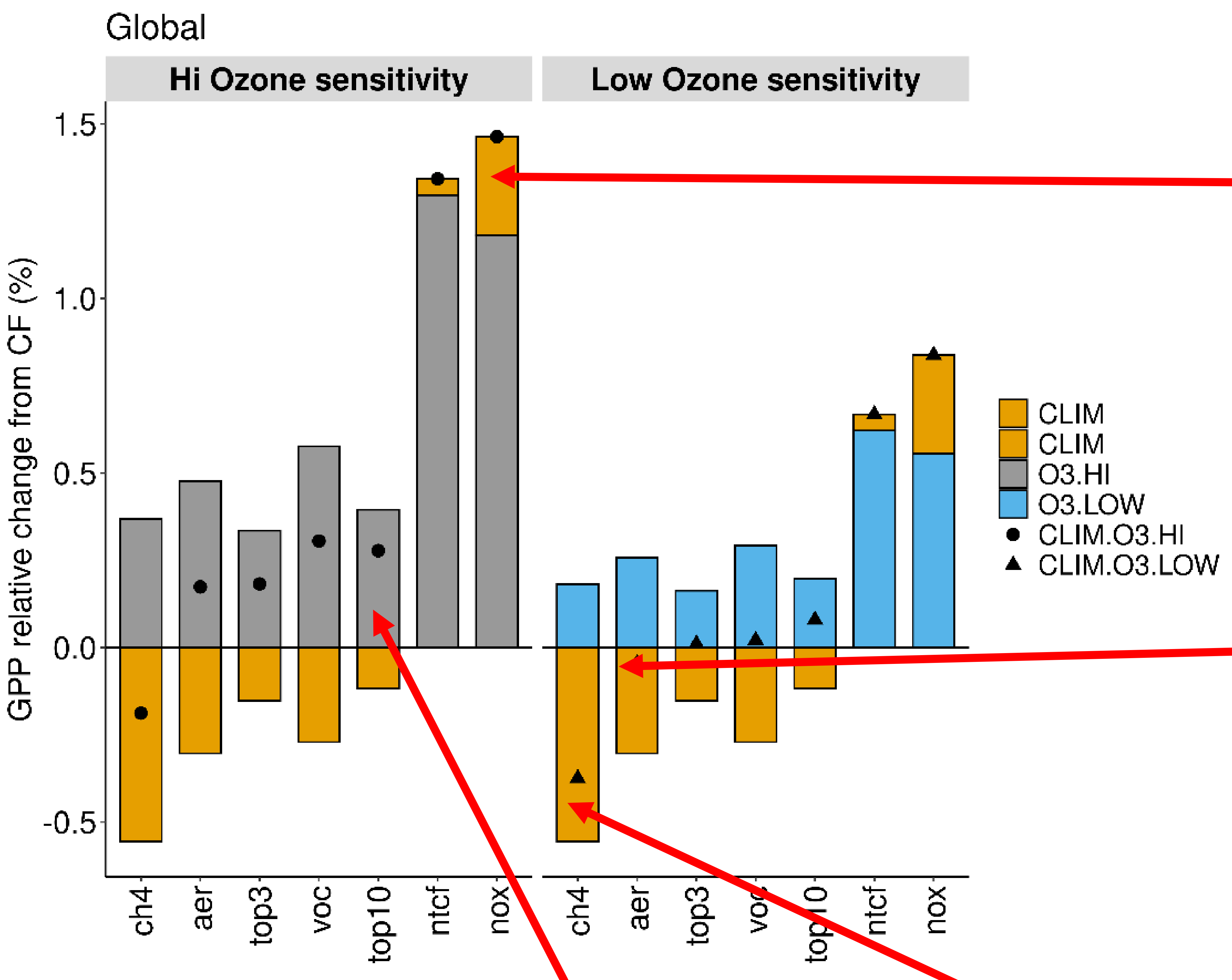
Impact on Gross Primary Productivity (GPP)

	Mean annual global GPP (PgC yr^{-1})		
	No ozone	Ozone Hi sensitivity	Ozone Low sensitivity
cf	140.8 ± 1.74	126.02 ± 1.42	130.34 ± 1.53



Methane emission reductions impact global GPP via direct effects of ozone on plant physiology and indirect climate effects, both of which influence vegetation growth and productivity. The net effect on GPP is a trade-off between the two.

Impact on Gross Primary Productivity (GPP)



Including other non-pledge countries (**top3** and **top10**) further benefits global GPP leading to increases of between 0.02 to 0.23 PgC yr yr^{-1} (0.02 to 0.18 %) and 0.11 to 0.35 PgC yr yr^{-1} (0.08 to 0.28 %) respectively compared to the **cf**.

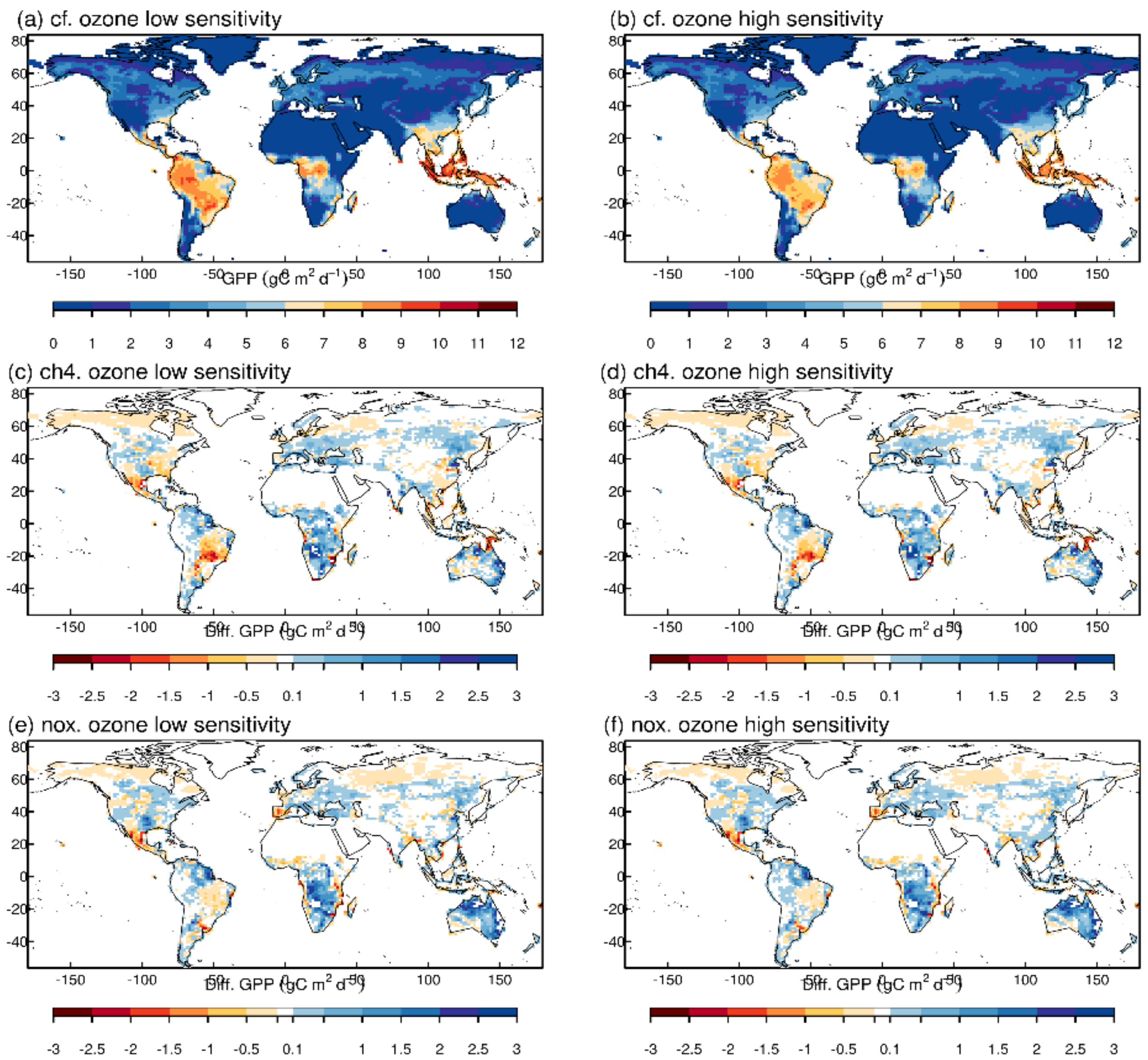
Global GPP is enhanced by 1.09 to 1.85 PgC yr^{-1} (0.84 to 1.47 %) with reductions of both CH_4 emissions and the co-emitted ozone precursor NO_x (**nox**). Reductions in surface ozone concentrations are larger when NO_x emissions are also reduced and globally there is a climate benefit from NO_x reductions.

Reductions of other co-emitted ozone precursors (aerosols, **aer** and non- CH_4 VOCs, **vocs**) in addition to methane emissions reductions sees an enhancement of global GPP compared to the **cf**, but this is much lower than the enhancement seen with reductions in NO_x, because of the smaller decrease in surface ozone concentrations and a global net-negative climate effect.

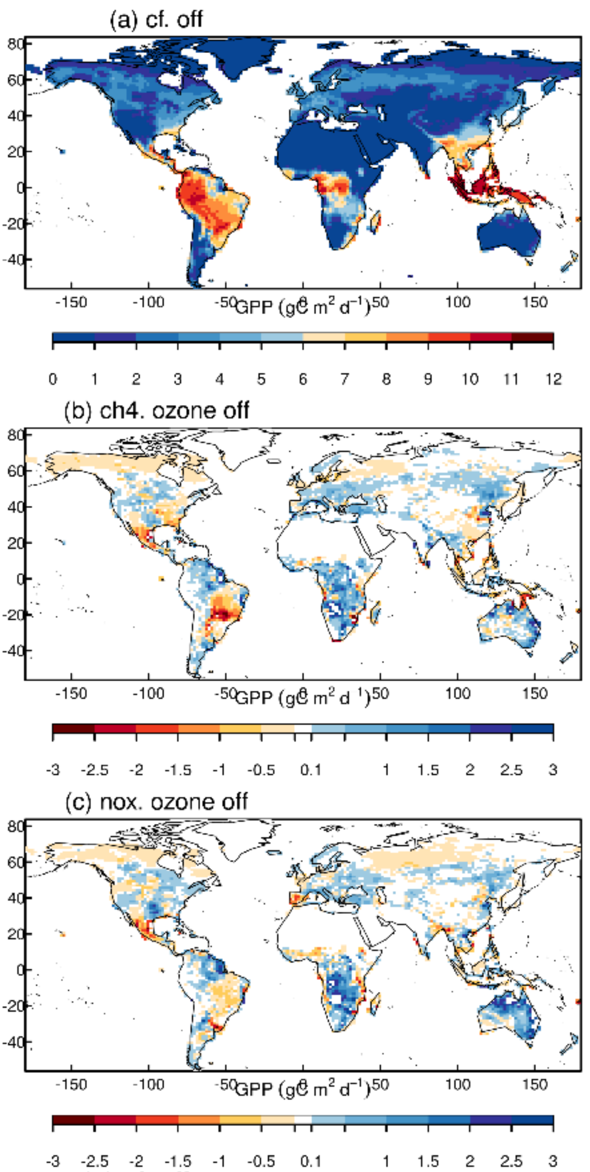
The maximum feasible reductions of CH_4 emissions (run **ch4**) result in a loss of global GPP of between 0.24 to 0.49 PgC yr^{-1} (0.19 to 0.38 %), compared to the business-as-usual scenario (**cf**). This results from large negative regional climate impacts on GPP, which dominate the positive benefit of reduced surface ozone concentrations on plant productivity.

Regional impacts: role of different drivers

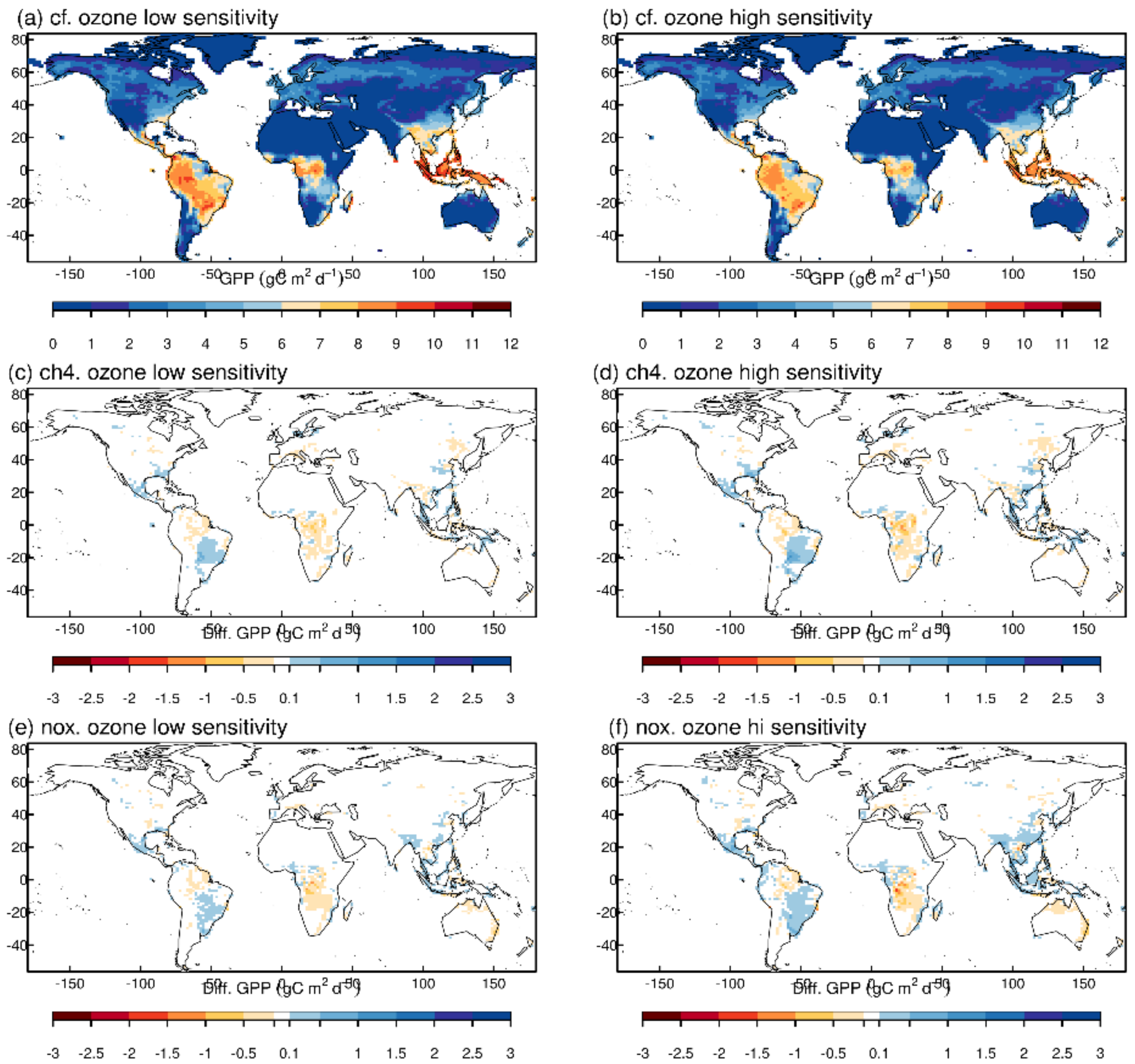
GPP change relative to CF due to net effect of climate and ozone

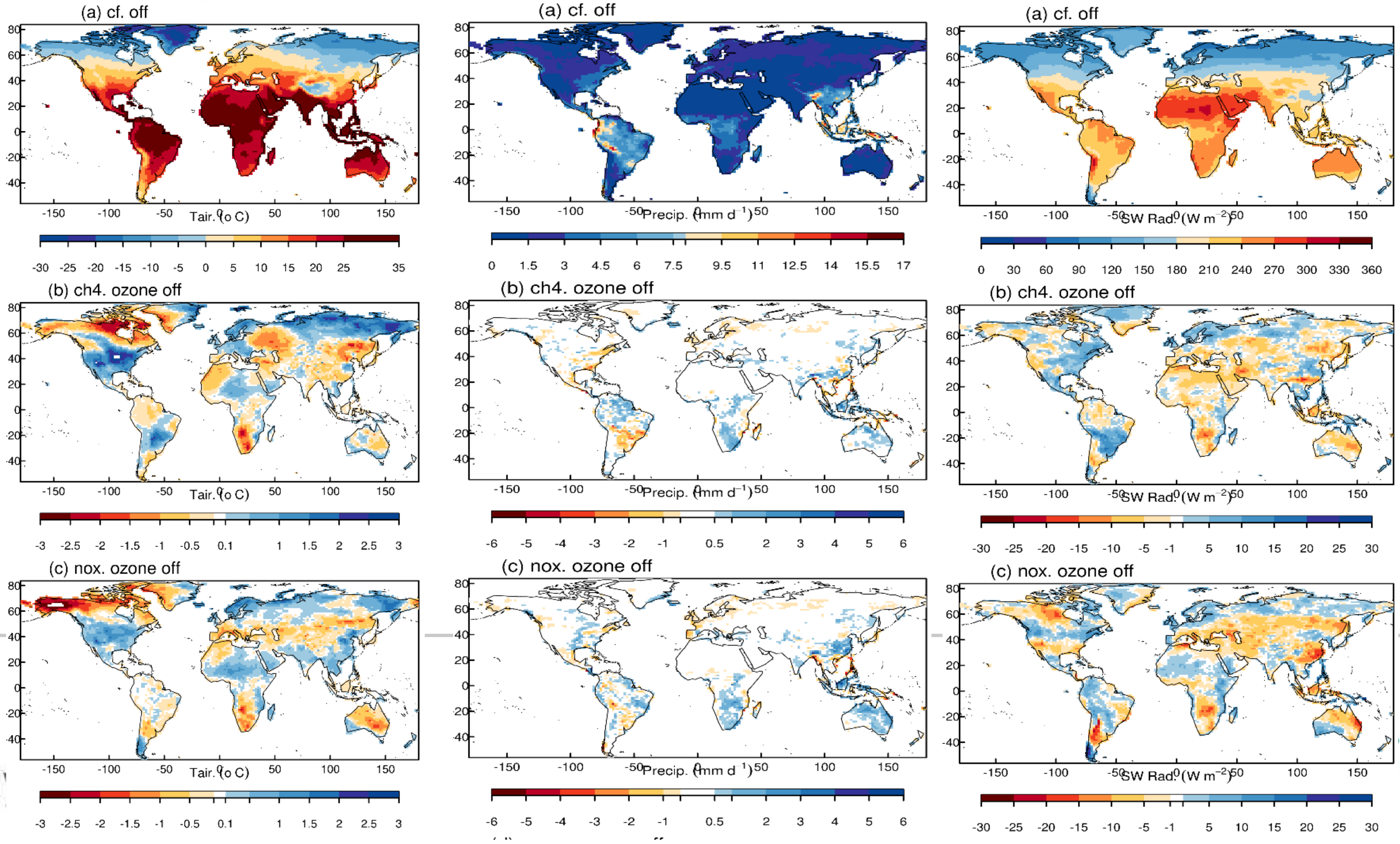


GPP change relative to CF due to effect of climate



GPP change relative to CF due to effect of ozone



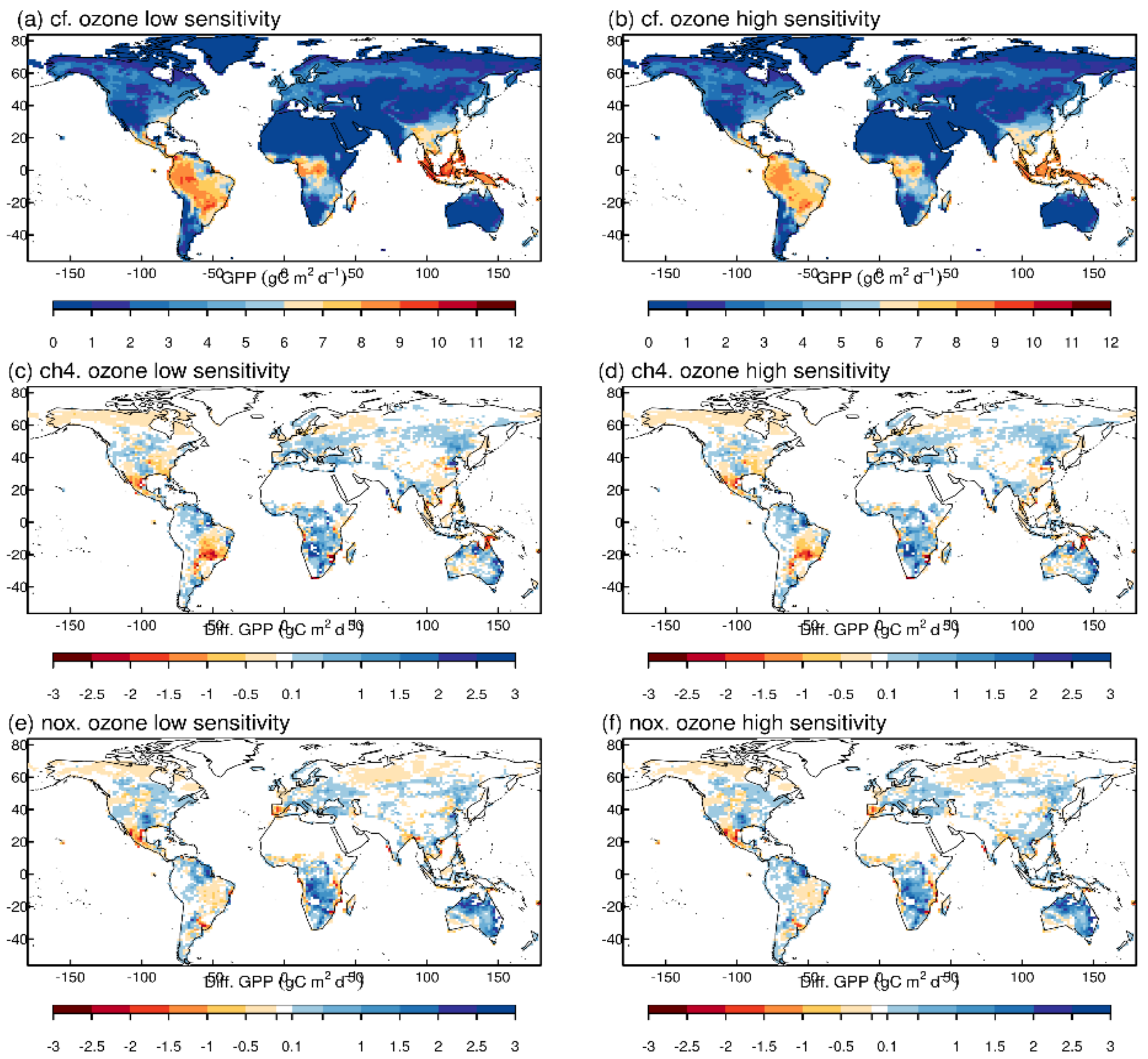


Change relative to CF in

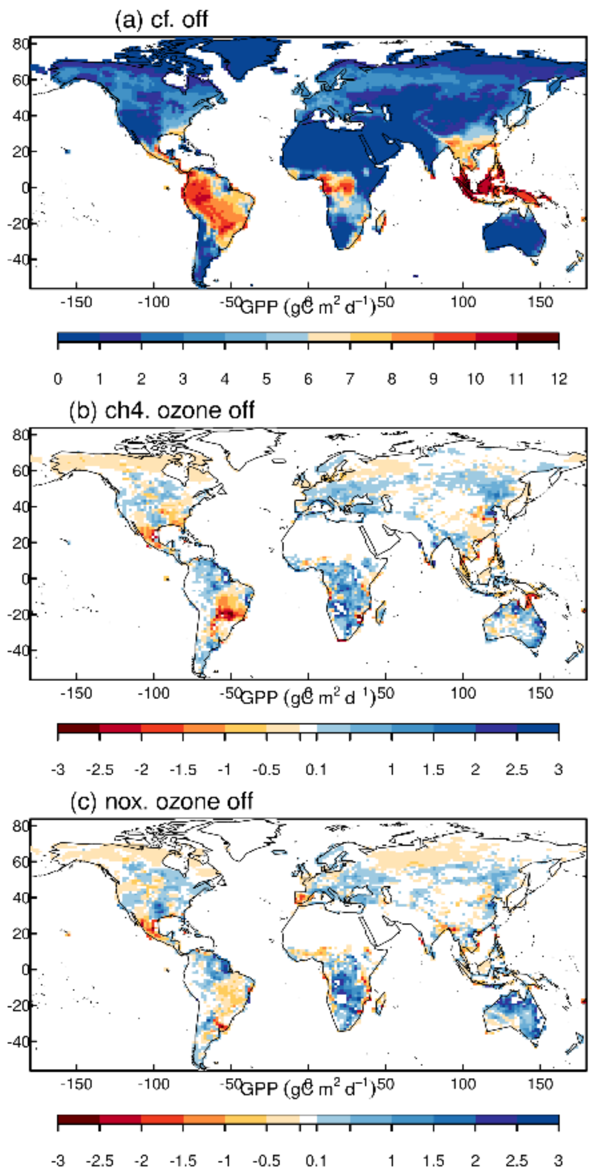
Air Temperature Precipitation SW radiation

Regional impacts: role of different drivers

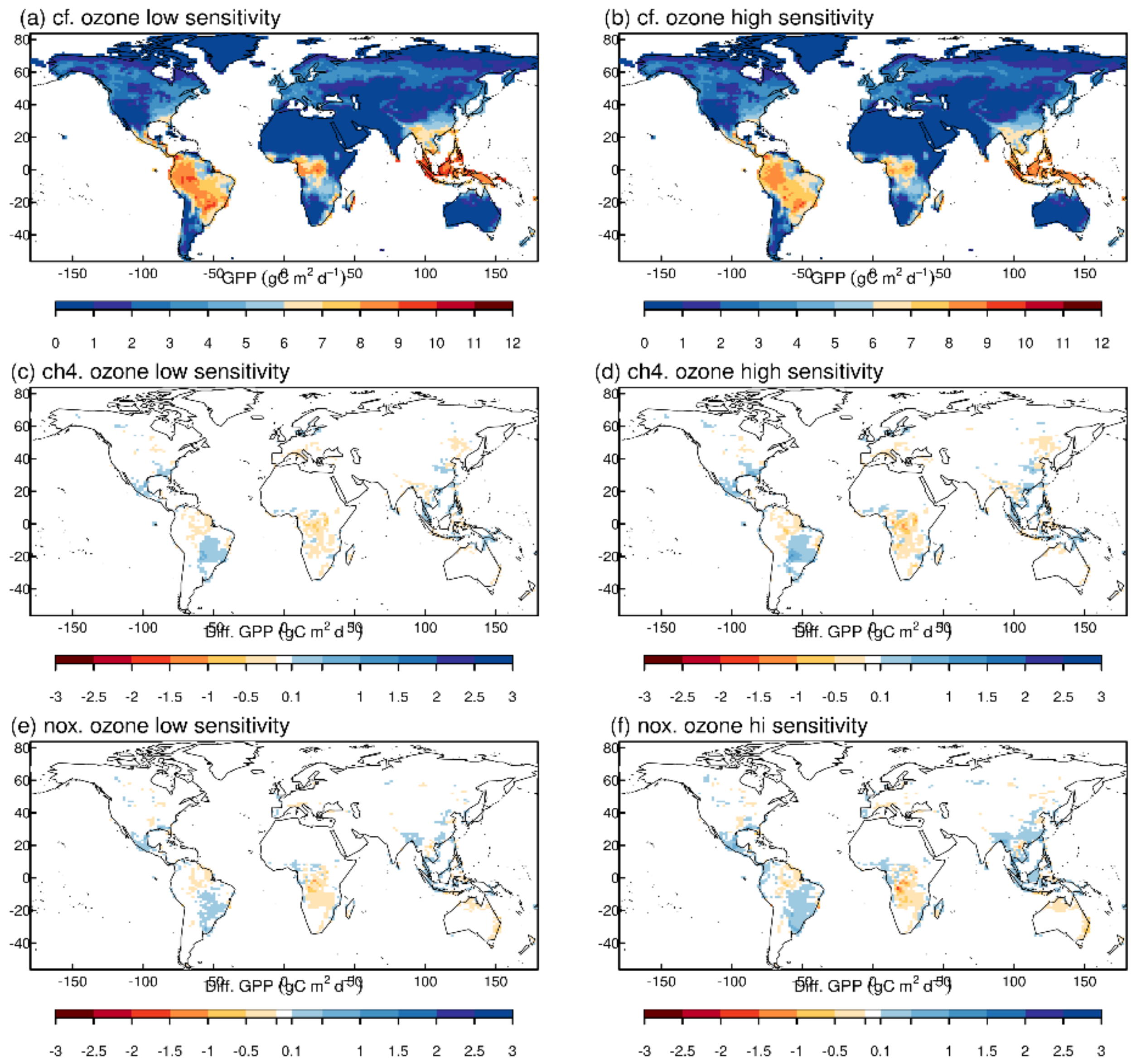
GPP change relative to CF due to net effect of climate and ozone

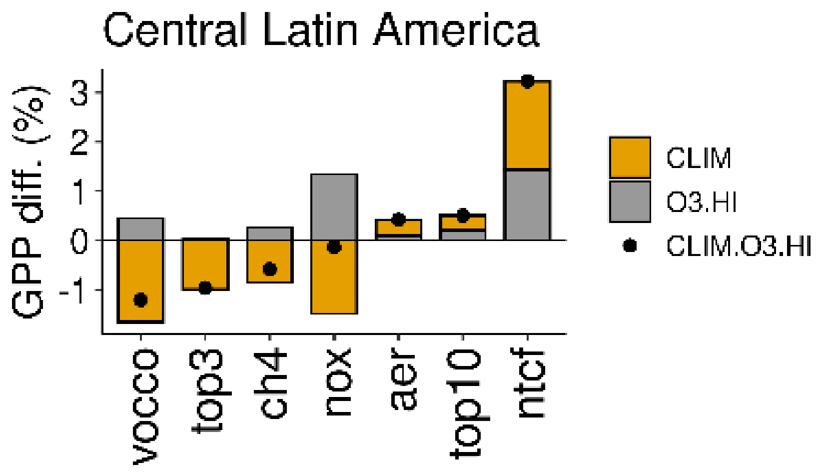


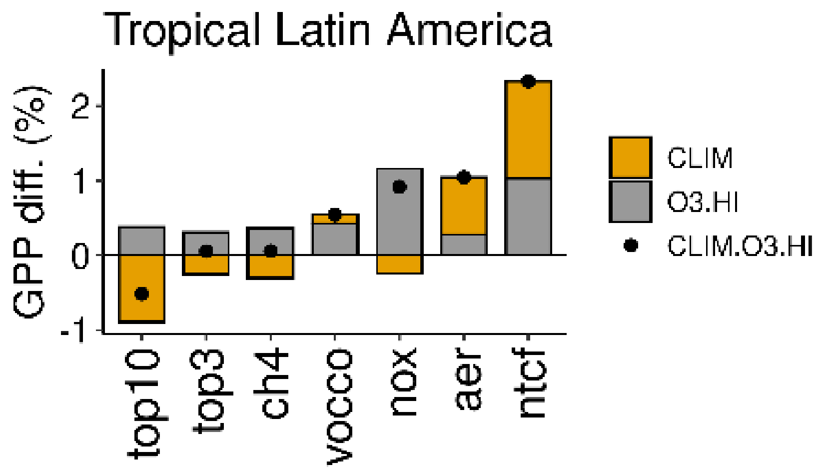
GPP change relative to CF due to effect of climate

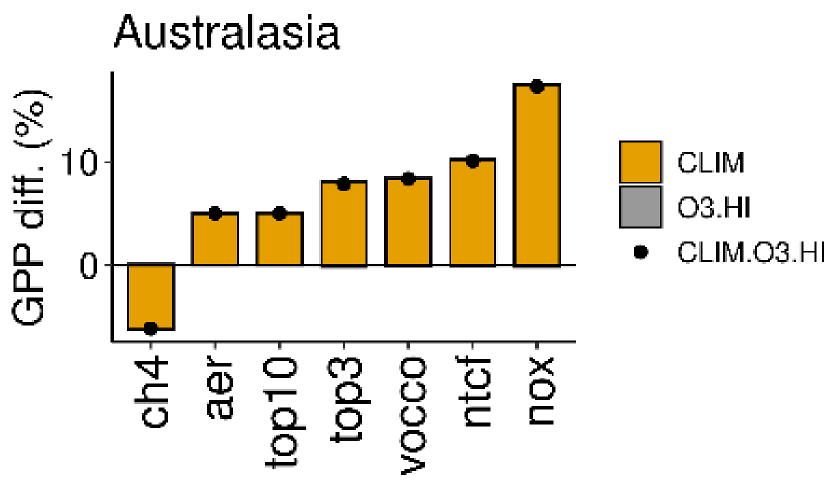


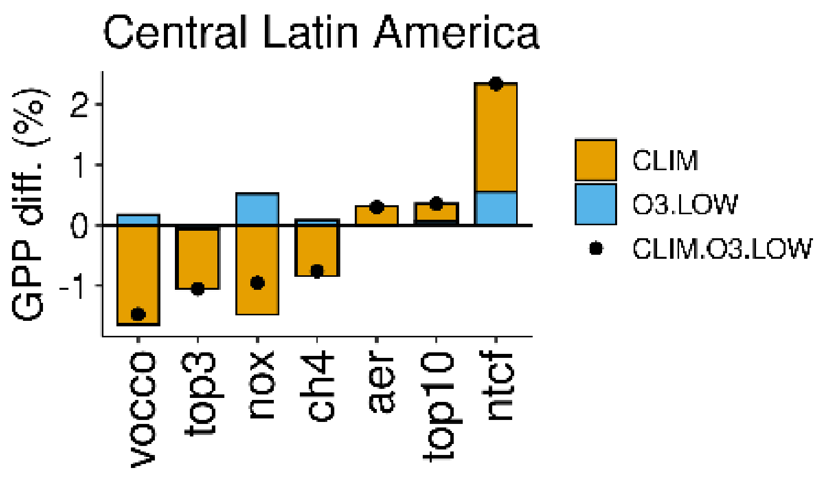
GPP change relative to CF due to effect of ozone

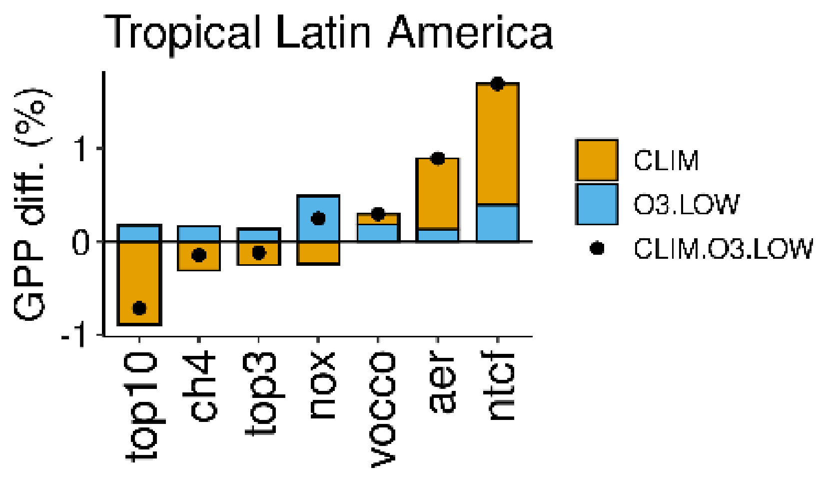


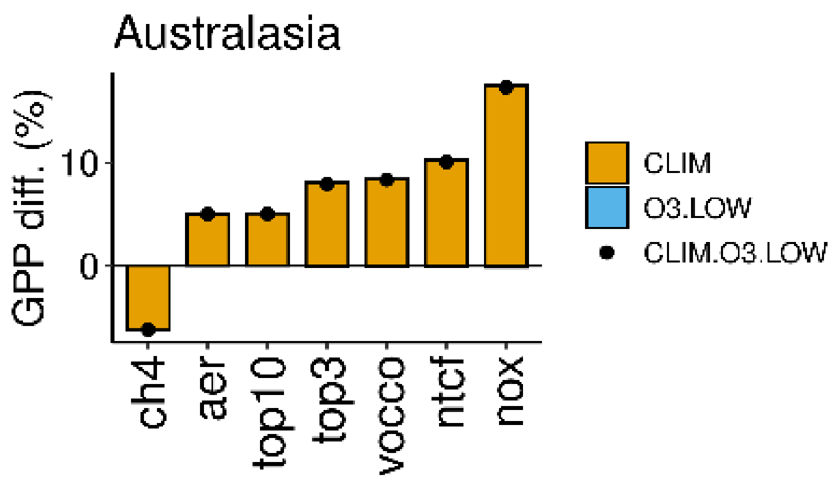












Summary

- JULES ES runs undertaken to assess the impact of ozone vegetation damage from CH_4 emission reductions, as part of a Methane Pledge study
- Developed revised set of ozone vegetation damage parameters
- Impact on global GPP via direct effects of changes in surface ozone concentration on plant physiology and indirect climate effects, both of which influence vegetation growth and productivity
- Work in progress on the regional impacts

Ozone Vegetation Damage

PFT	O_3 sensitivity	Sensitivity parameter (a)	POD_y	DRF slope Observed	DRF slope Modelled	Ref. for DRF	Observed DRF species
BET-tr	High	0.085	1	-0.949	-0.95	TropOz	Mixed tropical tree spp.
	Low	0.025	1	-0.381	-0.4	TropOz	Mixed tropical tree spp.
BET-te	High	0.001	1	-0.09	-0.11	Buker et al., (2015)	Med. evergreen oak
	Low	0.0009	1	-0.072	-0.1	Buker et al., (2015)	*20% less sensitive
BDT	High	0.077	1	-0.93	-0.93	CLRTAP	Birch and Beech
	Low	0.06	1	-0.74	-0.75	CLRTAP	*20% less sensitive
NET	High	0.009	1	-0.22	-0.23	CLRTAP	Norway spruce
	Low	0.005	1	-0.18	-0.19	CLRTAP	*20% less sensitive
NDT	High	0.08	1	-1.15	-1.2	Hoshika et al., (2020)	Hybrid Larch F1
	Low	0.05	1	-0.95	-1.0	Hoshika et al., (2020)	Japanese Larch
C_3	High	0.03	1	-0.62	-0.63	CLRTAP	Temperate grassland
	Low	0.014	1	-0.31	-0.32		*50% less sensitive
C_4	High	0.028	1	-0.62	-0.68	CLRTAP	Temperate grassland
	Low	0.01	1	-0.31	-0.30		*50% less sensitive
ESH	High	0.002	1	-0.09	-0.089	Buker et al., (2015)	Med. evergreen oak
	Low	0.001	1	-0.072	-0.079	Buker et al., (2015)	Med. evergreen oak
DSH	High	0.125	1	-0.93	-0.93	CLRTAP	Birch and Beech
	Low	0.095	1	-0.74	-0.73	CLRTAP	*20% less sensitive
C_3-crop	High	0.125	6	-3.85	-3.8	CLRTAP	Wheat
	Low	0.035	6	-1.34	-1.3	CLRTAP	Potato
C_4-crop	High	0.1	6	-3.85	-3.8	CLRTAP	Wheat
	Low	0.028	6	-1.34	-1.3	CLRTAP	Potato

Impact on Gross Primary Productivity (GPP)

	Mean annual global GPP (PgC yr^{-1})									
	No ozone			Ozone Hi sensitivity				Ozone Low sensitivity		
cf	140.8 ± 1.74			126.02 ± 1.42				130.34 ± 1.53		
	PgC yr^{-1} (%) change from CF									
	Climate		Ozone Hi		Net Hi		Ozone Low		Net Low	
ch4	-0.78	(-0.55)	0.54	(0.36)	-0.24	(-0.19)	0.29	(0.18)	-0.49	(-0.38)
aer	-0.43	(-0.31)	0.65	(0.48)	0.22	(0.17)	0.37	(0.26)	-0.06	(-0.05)
top3	-0.22	(-0.16)	0.45	(0.34)	0.23	(0.18)	0.24	(0.17)	0.02	(0.02)
voc	-0.38	(-0.27)	0.77	(0.58)	0.39	(0.31)	0.41	(0.29)	0.03	(0.02)
top10	-0.17	(-0.12)	0.52	(0.40)	0.35	(0.28)	0.28	(0.21)	0.11	(0.08)
ntcf	0.06	(0.04)	1.63	(1.30)	1.69	(1.34)	0.81	(0.62)	0.87	(0.67)
nox	0.40	(0.28)	1.45	(1.18)	1.85	(1.47)	0.69	(0.55)	1.09	(0.84)