PI to PD anthropogenic forcings in UKESM1, including attribution of the methane forcing

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Atmospheric Science Conference, Birmingham, July 2019

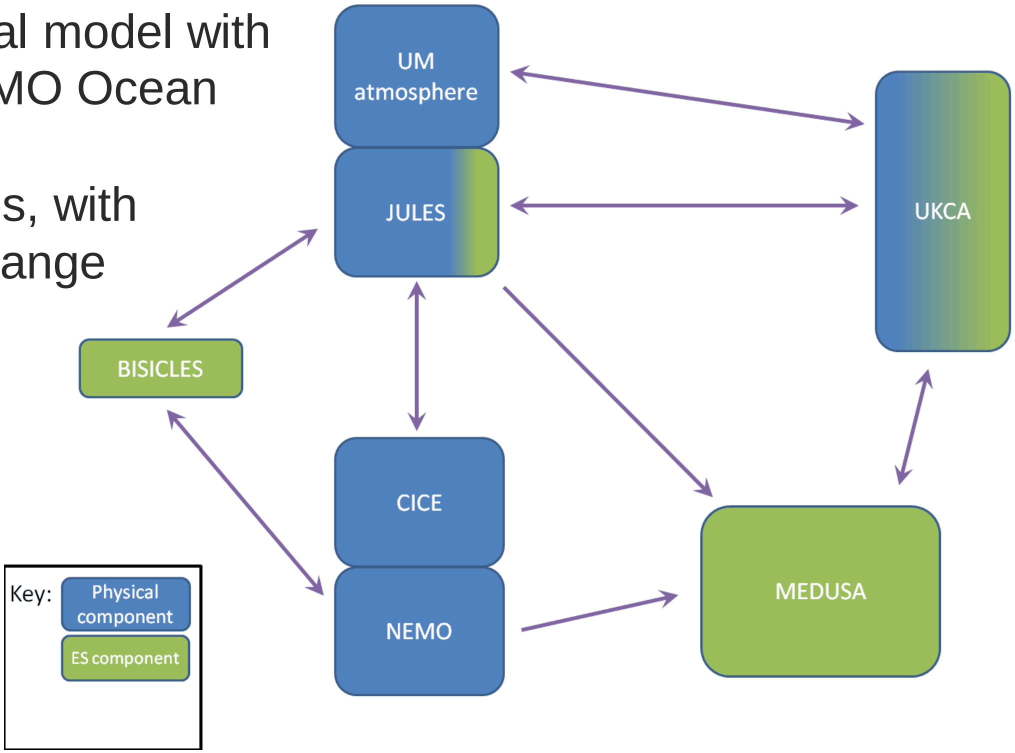
Outline of Presentation

- Brief overview of UKESM1
- Define ERF & outline AerChemMIP/RFMIP
- Pre-Industrial to Present-Day ERFs
- Focus on : ① Aerosol forcing
  ② Apportionment of CH_4 forcing
- Conclusions

Overview of UKESM1

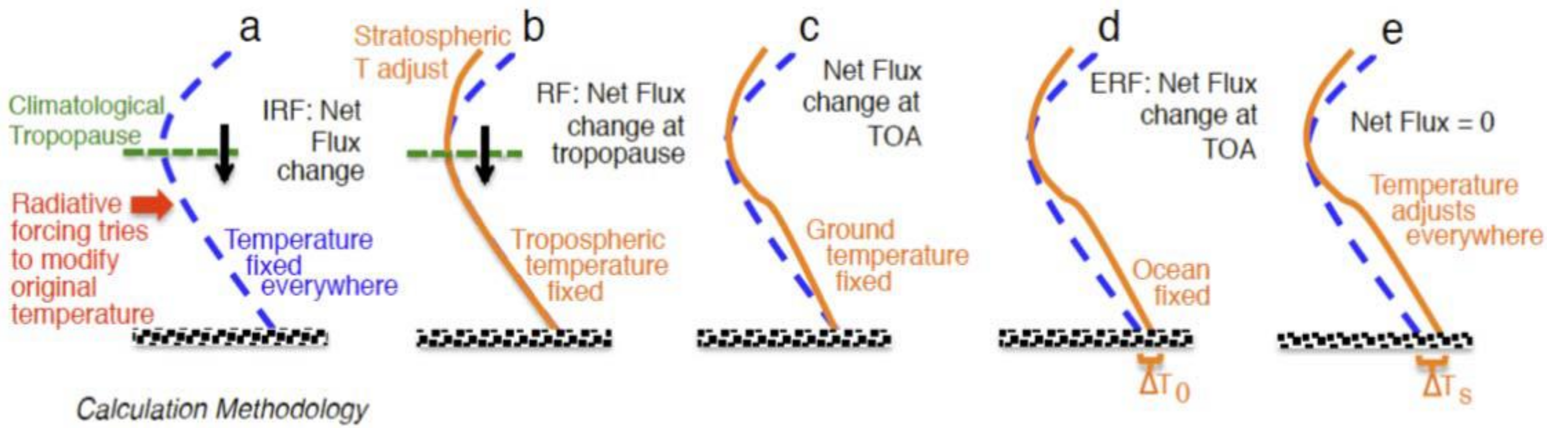
UKESM1 – United Kingdom's Earth System Model

- HadGEM3-GC3.1 is the core physical model with N96 resolution (~140km) and 1° NEMO Ocean
- Terrestrial carbon and nitrogen cycles, with dynamic vegetation and land-use change
- UKCA Tropospheric-Stratospheric chemistry, coupled to two-moment aerosol scheme, GLOMAP-mode, with sulphate, black carbon, organic carbon, and sea salt
- Mass-based 6-bin dust scheme
- Ocean biogeochemistry MEDUSA



Sellar et al., Under review, JAMES

Effective Radiative Forcing



Calculation Methodology

Online or offline pair of radiative transfer calculations within one simulation	Difference between two offline radiative transfer calculations with prescribed surface and tropospheric conditions allowing stratospheric temperature to adjust	Difference between two full atmospheric model simulations with prescribed surface conditions everywhere or estimate based on regression of response in full coupled atmosphere-ocean simulation	Difference between two full atmospheric model simulations with prescribed ocean conditions (SSTs and sea ice)	Difference between two full coupled atmosphere-ocean model simulations

$$ERF = IRF + \sum_i A_i$$

UKESM1's Contribution to RFMIP and AerChemMIP

UKESM

- Aiming to do all AerChemMIP experiments except piClim-NH3 (No ammonium nitrate scheme)
- Aiming to do Tier 1 RFMIP experiments
- Collaboration between:

  Met Office Hadley Centre (MOHC)

  National Centre for Atmospheric Science (NCAS)

  Korean Meteorological Agency (KMA)

  National Institute for Water and Atmosphere Research, NZ (NIWA)

Met Office Hadley Centre

National Centre for Atmospheric Science
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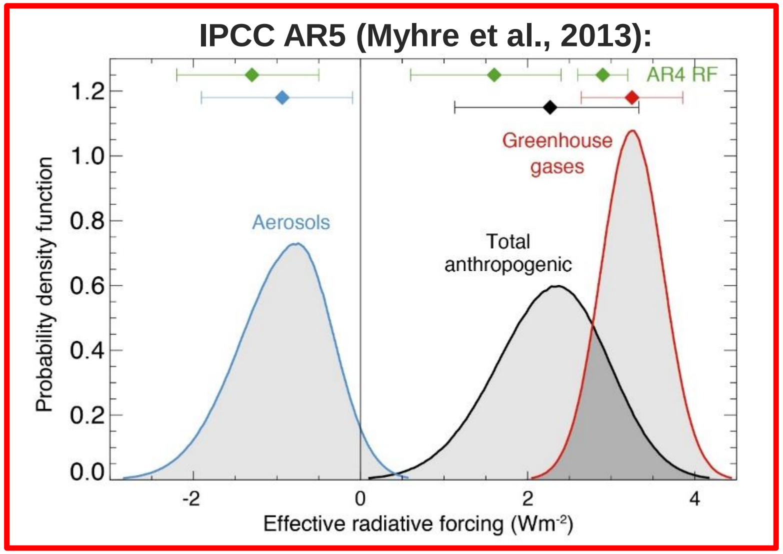
KMA
Korea Meteorological Administration

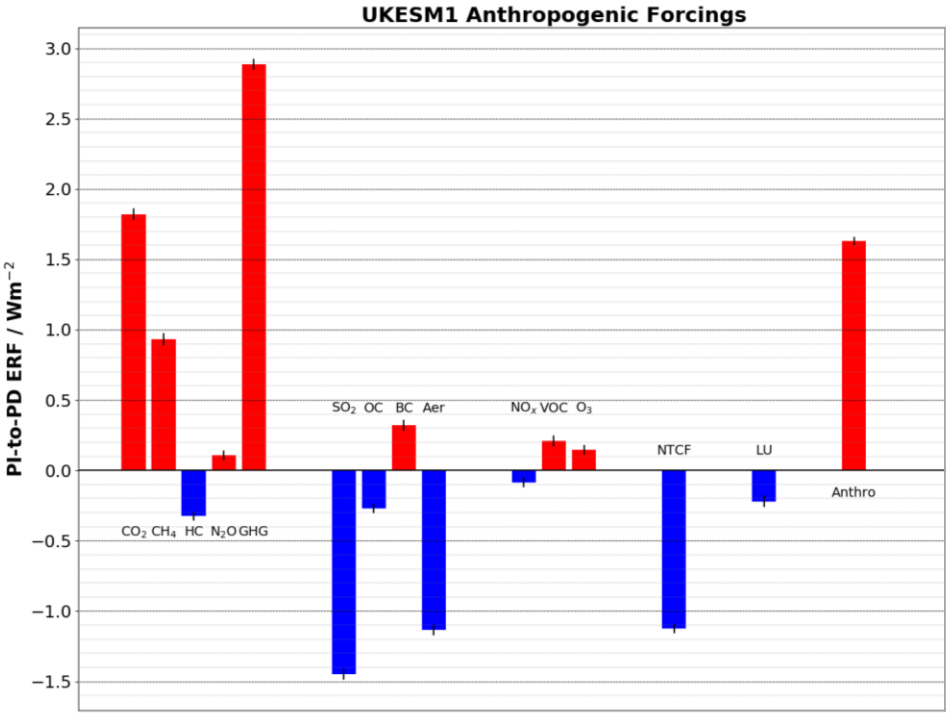
NIWA
Taihoro Nukurangi

Pre-industrial to Present-Day ERFs



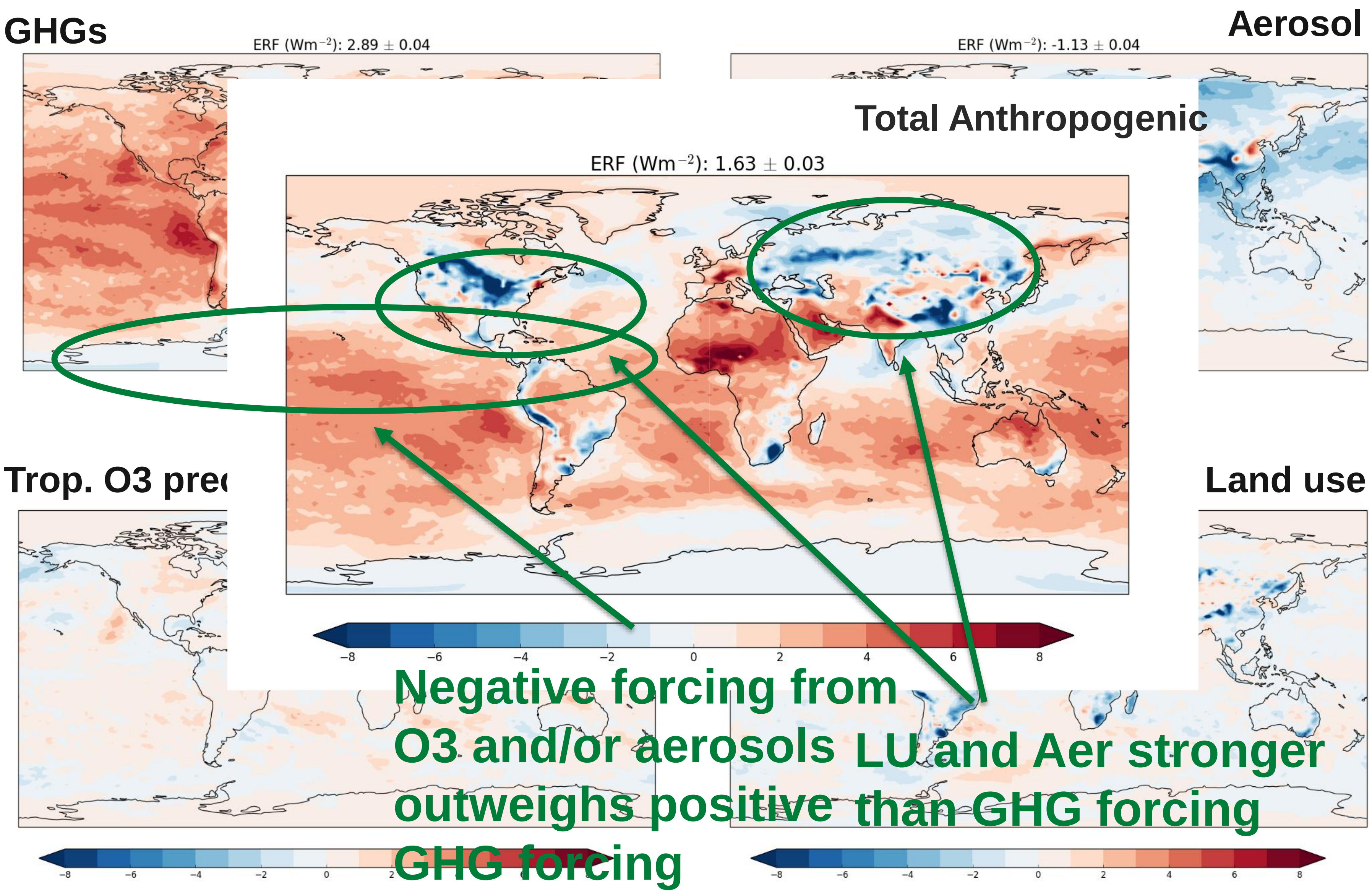
Diagnosed from the difference in net TOA from paired UKESM1 experiments following AerChemMIP & RFMIP protocols

Forcing Type	ERF
GHG	+2.89
Aerosol	-1.13
Trop. O3 precursors	+0.15
LU	-0.22
Total Anthro	+1.63*



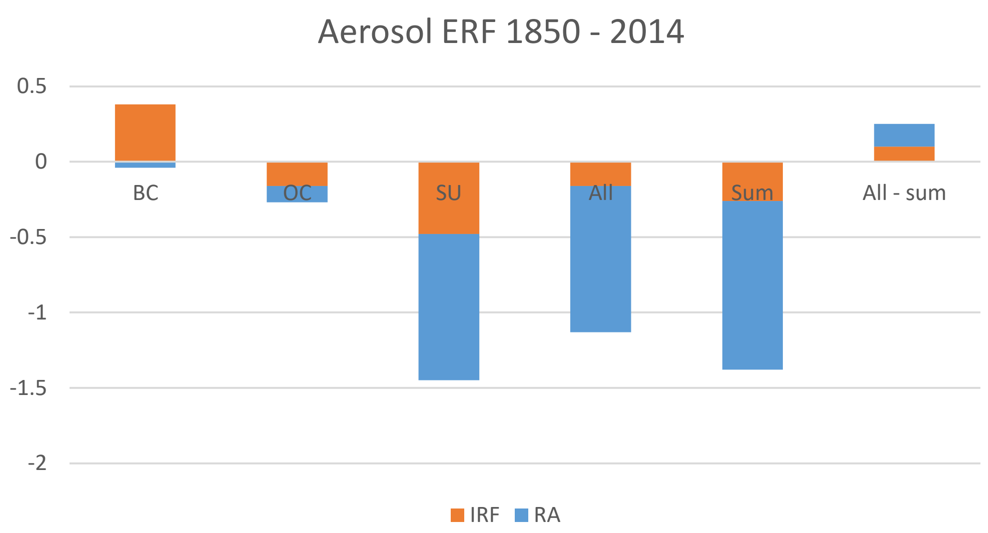
*Needs to be re-run with corrected LU

Global Distribution of Forcings



Breakdown of Aerosol ERF (1)

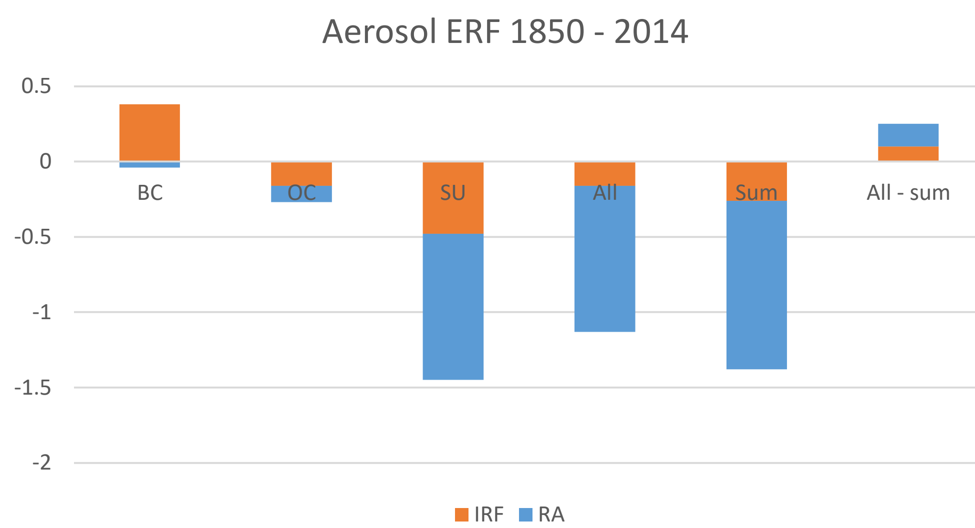
Forcing Type	ERF
Aerosol	-1.13
BC	+0.34
OC	-0.27
Anthropogenic SO2	-1.45
SUM: SO2+BC+OC	-1.38



- Sulphate ACI is the strongest negative contribution to aerosol forcing
- BC absorption almost offsets scattering by SU and OC
- The ACI therefore dominates the negative aerosol forcing, with the SU being the main part of that
- Forcings don’t add up quite linearly so that the “all” aerosol forcing is 0.25 Wm^{-2} less negative than the sum of individual aerosol forcings

Breakdown of Aerosol ERF (2)

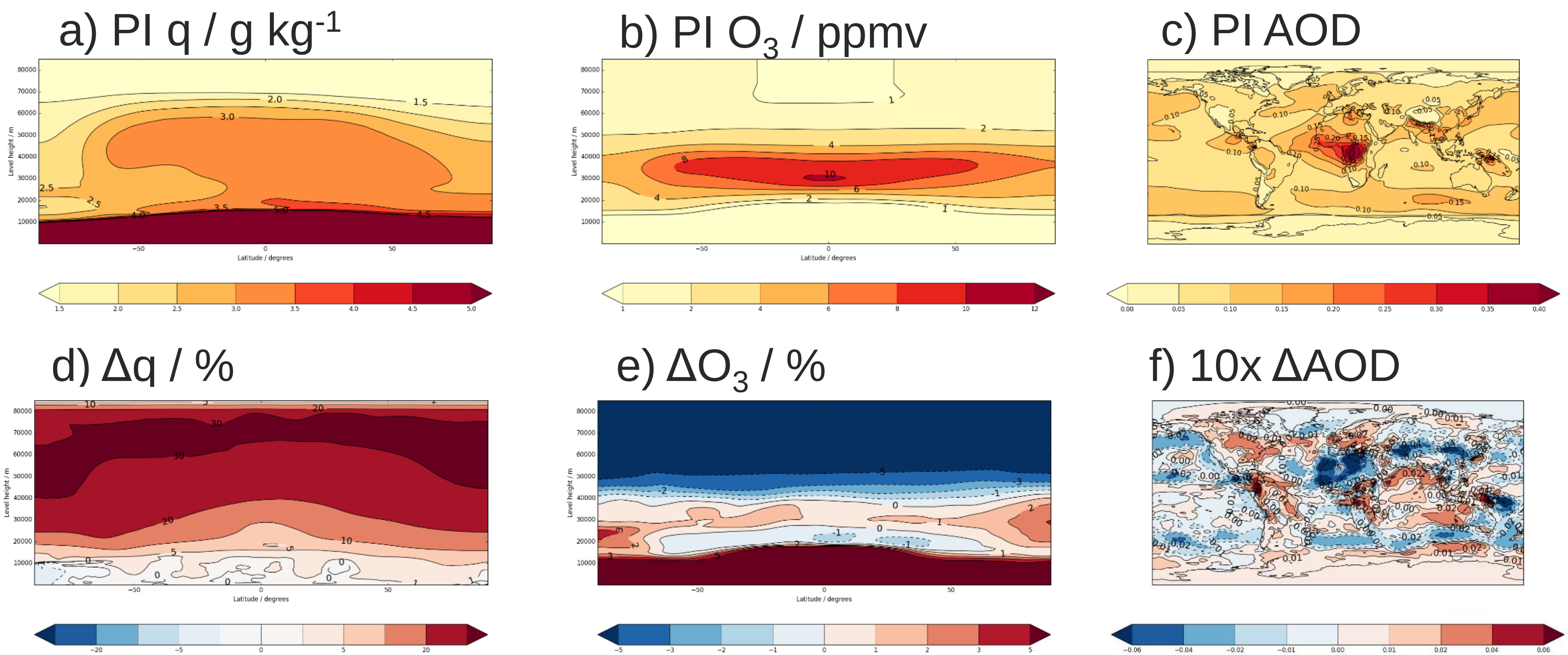
Forcing Type	ERF
Aerosol	-1.13
BC	+0.34
OC	-0.27
Anthropogenic SO2	-1.45
SUM: SO2+BC+OC	-1.38
Anthropogenic SO2 (H2SO4 bugfix)	-1.33



- Sulphate ACI is the strongest negative contribution to aerosol forcing
- BC absorption almost offsets scattering by SU and OC
- The ACI therefore dominates the negative aerosol forcing, with the SU being the main part of that.
- Forcings don’t add up quite linearly so that the “all” aerosol forcing is 0.25 Wm^{-2} less negative than the sum of individual aerosol forcings → ***This may potentially be affected by H2SO4 bug which reduces SO2 ERF by ~0.12Wm-2***

Breakdown of Methane ERF (1)

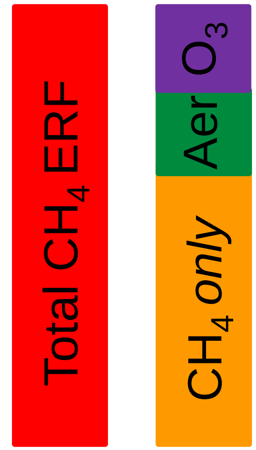
Perturbation	NET	LW_{CS}	SW_{CS}	LW_{CRE}	SW_{CRE}	NET_{CS}	NET_{CRE}
ΔCH_4	+0.93 ±0.04	+0.72 ±0.02	+0.14 ±0.02	-0.39 ±0.02	+0.46 ±0.03	+0.86 ±0.03	+0.07 ±0.03



- ERF is dominated by LW CS forcing, with the CRE in the SW and LW offsetting each other
- PI-to-PD CH_4 perturbation → Changes in stratospheric q, O_3, and aerosol

Breakdown of Methane ERF (2)

Agent	ERF1	ERF2
Total CH_4	+0.93 ± 0.04	+0.95 ± 0.06
ACI	+0.20 ± 0.06	+0.16 ± 0.03
ARI	-0.07 ± 0.06	0.0 ± 0.03
O_3	+0.21 ± 0.05	+0.20 ± 0.03*
Strat. q	0.0 ± 0.06	0.0 ± 0.03*
CH_4 *only*	+0.59 ± 0.03	+0.59 ± 0.03



(ERF1) Additional pairs to attribute total ERF to individual forcing agents by elimination

(ERF2) Additional pairs to calculate forcing for each agent/interaction individually

- Additional paired experiments to apportion the total methane ERF to different forcers
- Forcings appear to add linearly
- Methane *alone* accounts for more than 60% of the total methane ERF
- Earth System interactions, including chemistry-aerosol coupling, increase the PI-to-PD CH_4 ERF by more than 50%

Now look at ① methane-only forcing

② Aerosol forcing, *solely* driven by methane

* Simulations still running!

Methane-only forcing (1)

Andrews et al. (2014)

Agent	NET	LW_{CS}	SW_{CS}	LW_{CRE}	SW_{CRE}	NET_{CS}	NET_{CRE}
CH_4	+0.50	+0.74	-0.13	-0.23	+0.12	+0.61	-0.11

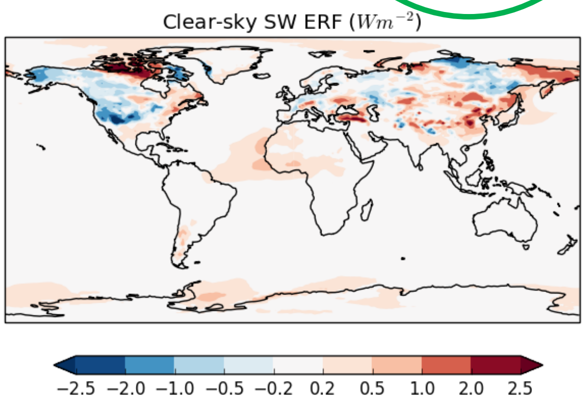
HadGEM2 1860-2005 ERF, *with no* SW treatment of CH_4

This work

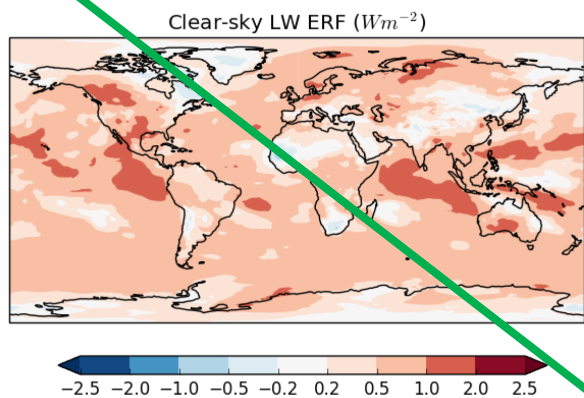
Agent	NET	LW_{CS}	SW_{CS}	LW_{CRE}	SW_{CRE}	NET_{CS}	NET_{CRE}
CH_4	+0.59 ±0.03	+0.60 ±0.02	+0.09 ±0.02	-0.30 ±0.02	+0.20 ±0.04	+0.69 ±0.03	-0.10 ±0.03

UKESM1 1850-2014 ERF, *with* SW treatment of CH_4

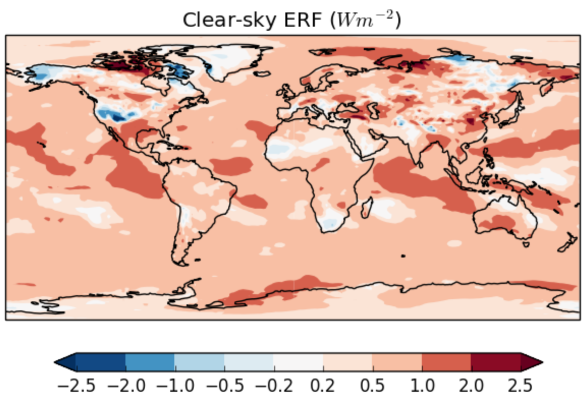
CS SW



CS LW



CS SW&LW



Using a simplified expression for CH_4 RF (Etminan et al., 2016) gives: +0.56±0.07 Wm^{-2}

BUT with only a small contribution in the SW (i.e. 0.03 Wm^{-2} or 6 %)

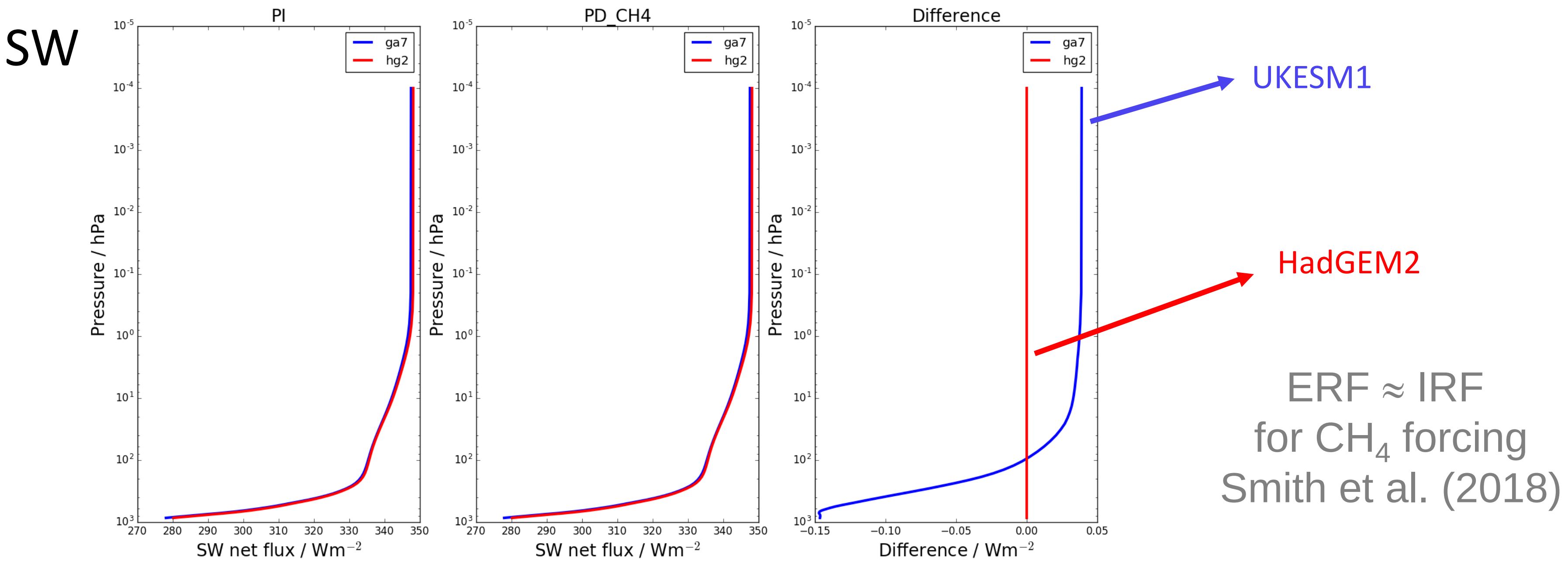
Discrepancy in CS components

Methane-only forcing (2)

Use RFMIP PI Baseline Test Case to investigate CS forcing in HadGEM2 and UKESM1:

PI CASE – run stand-alone SOCRATES with HadGEM2 and UKESM1 spectral files
PI CASE with PD CH4 – run stand-alone SOCRATES with HadGEM2 and UKESM1 spectral files

Each Test Case has 100 profiles – when averaged, give approximate annual-mean global-mean IRF



- Small positive forcing in the CS SW: Consistent with ERF experiments and line-by-line calculations (Etminan et al. 2016)
- HadGEM2 CS SW forcing should be zero! CS SW forcing was actually due to dust response!

Thanks to J. Manners and O. Jamil for RFMIP stand-alone set up

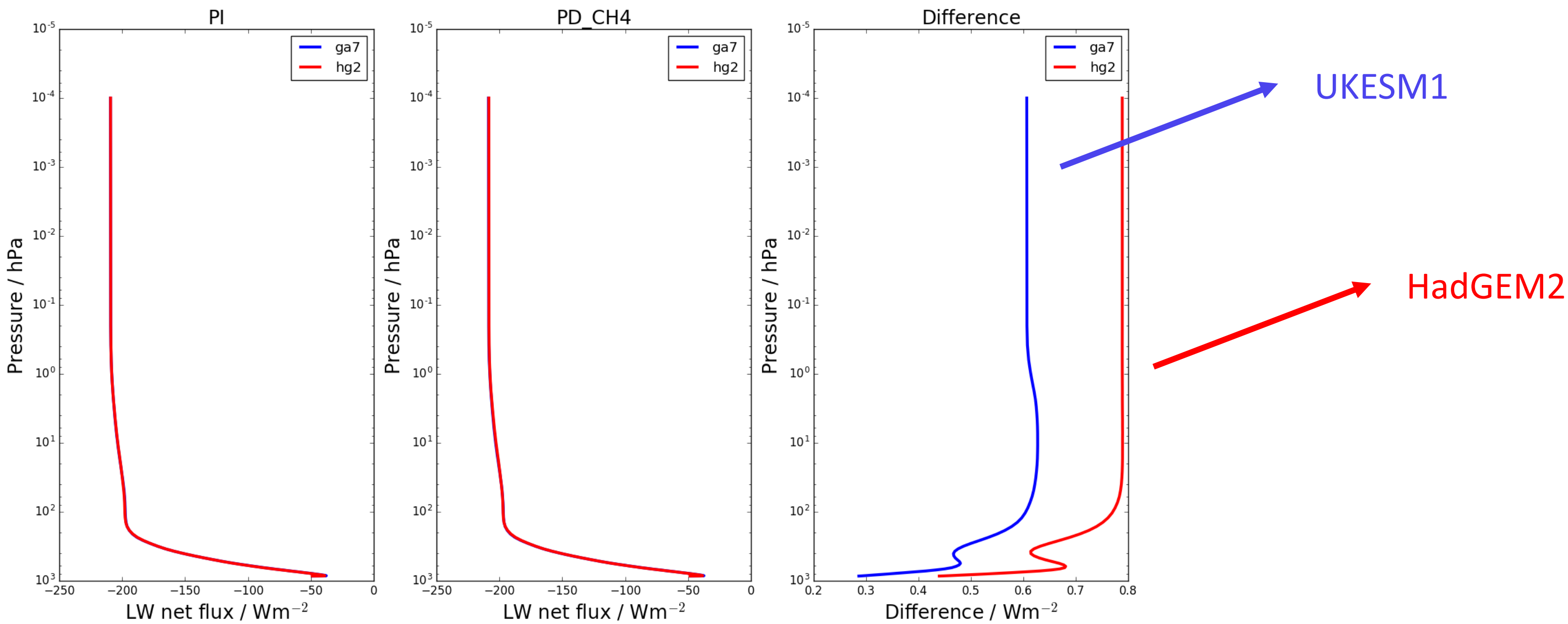
Methane-only forcing (3)

Use RFMIP PI Baseline Test Case to investigate differences in CS forcing between HadGEM2 and UKESM1:

Test Cases: 1. **PI baseline** – run stand-alone SOCRATES with HadGEM2 and UKESM1 spectral files
2. **PI baseline with PD CH4** – run stand-alone SOCRATES with HadGEM2 and UKESM1 spectral files

Each Test Case has 100 profiles – when averaged, give approximate annual-mean global-mean IRF

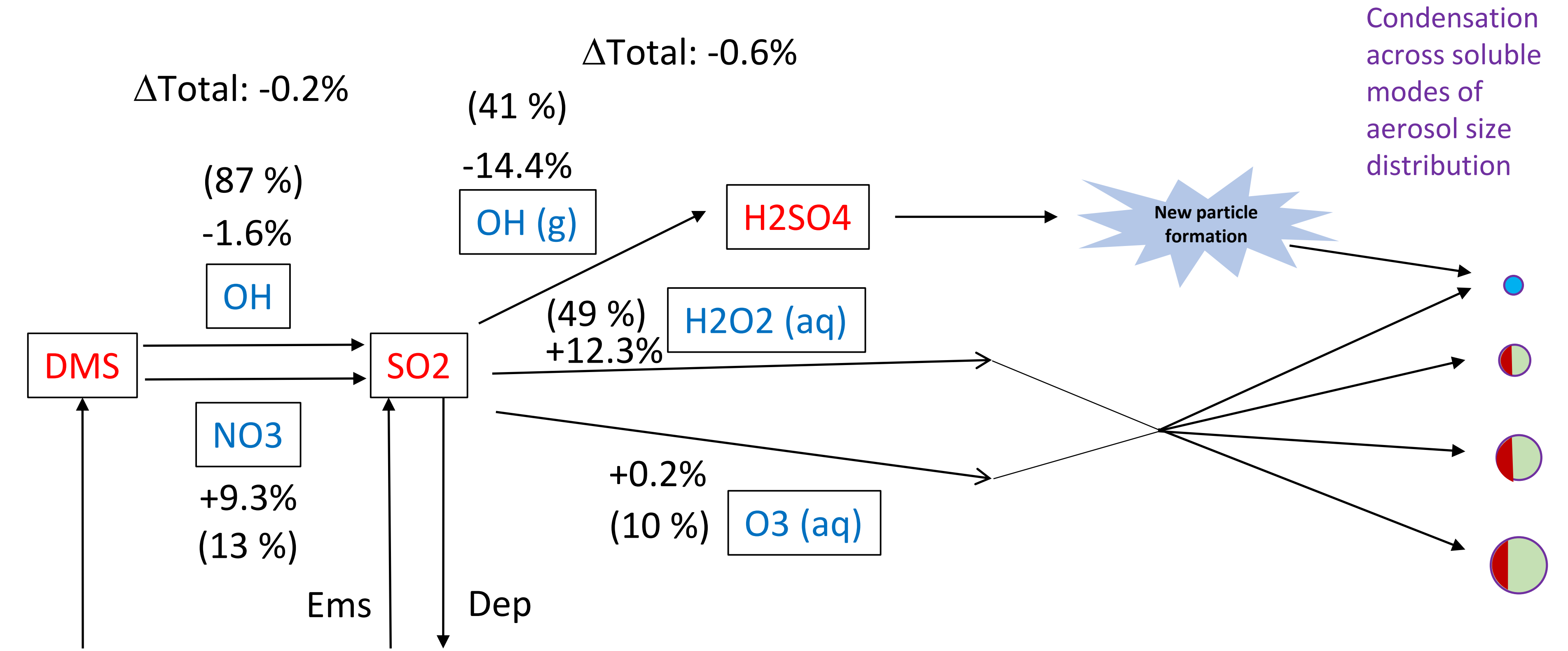
LW



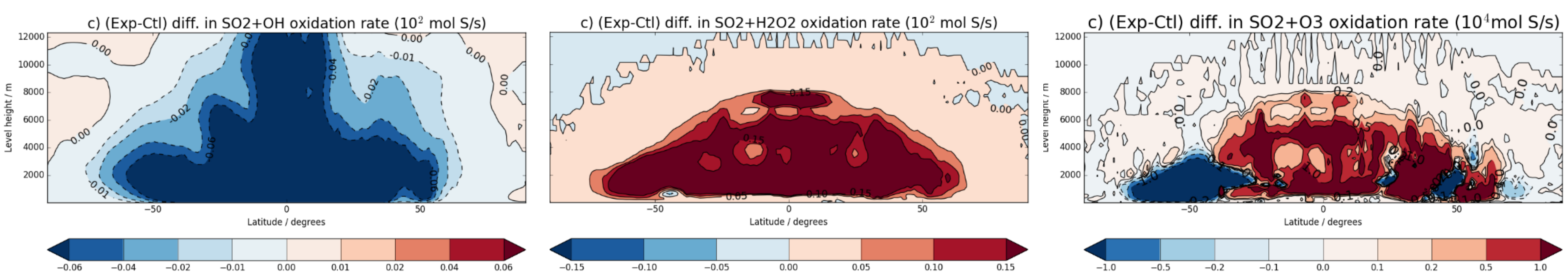
- Spectral change in the LW explain differences in HadGEM2 and UKESM1 CS LW forcing (Walters et al., 2019)

Thanks to J. Manners and O. Jamil for RFMIP stand-alone set up

Aerosol forcing attributable to methane (1)



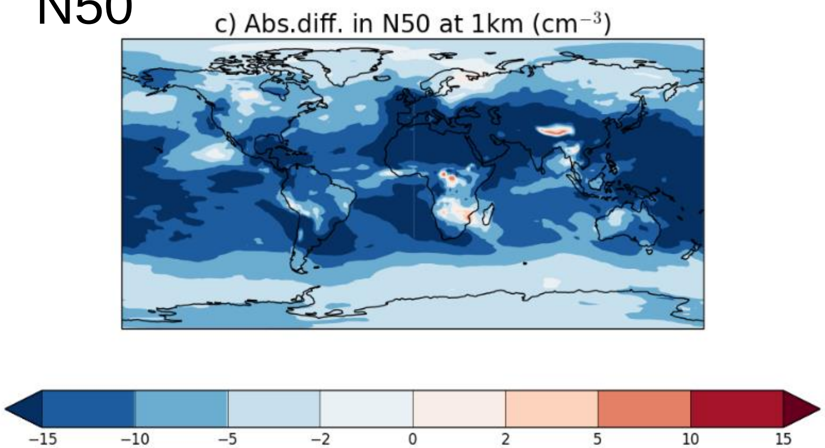
-14.4 % +12.3 % +0.2 %



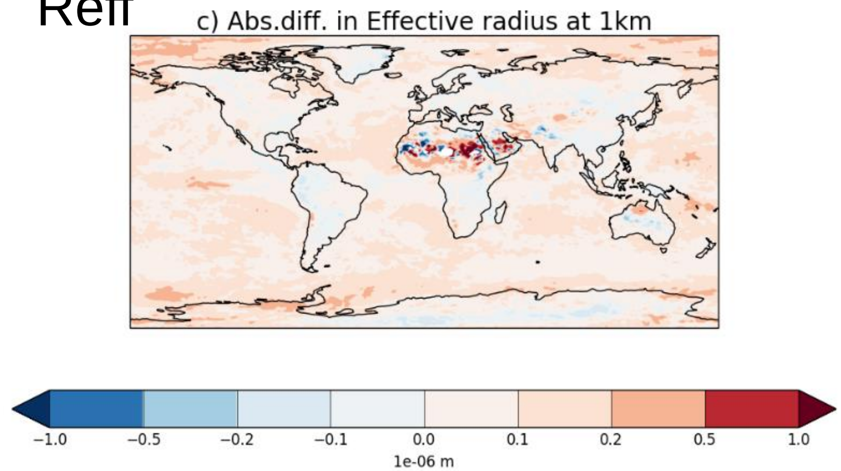
SO2+OH SO2+H2O2 SO2+O3

Aerosol forcing attributable to methane (2)

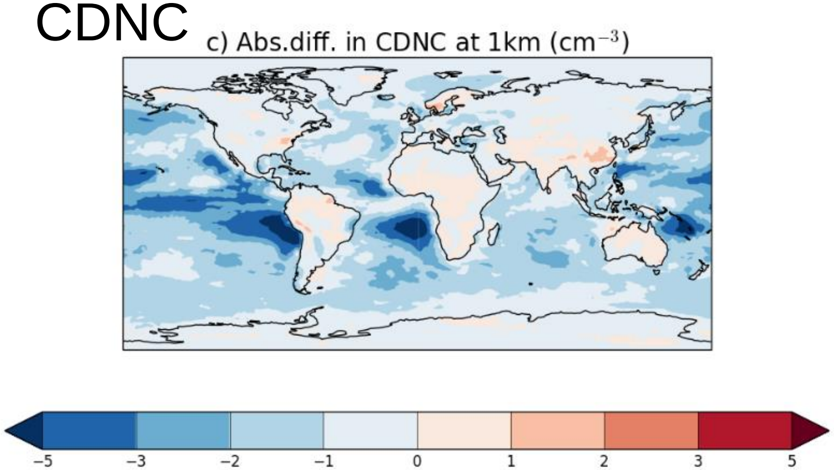
N50



Reff



CDNC



Methane perturbation:

→ Increase in cloud effective radius

→ Clouds become less reflective

→ Consistent with positive aerosol forcing

Conclusions

UKESM

- Net anthropogenic forcing is negative over NH continents (LU & aerosols)
- O3/Aerosol forcing outweighs positive LLGHG forcing over SH high latitudes
- Aerosol forcing dominated by ACI & mainly driven by SO2
- Methodoloogy for apportionning total forcing to different agents (e.g. methane)
- Methane perturbation → Changes in SO2 oxidation pathways
  → Reduction in CCN and CDNC
  → Increase in cloud effective radius
  → Positive aerosol forcing
- Earth-system interactions, including chemistry-aerosol interactions, are important for quantifying climate forcing

Thank you to everyone who has contributed!

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KMA
Korea Meteorological Administration

NIWA
Taihoro Nukurangi

Extra Slides

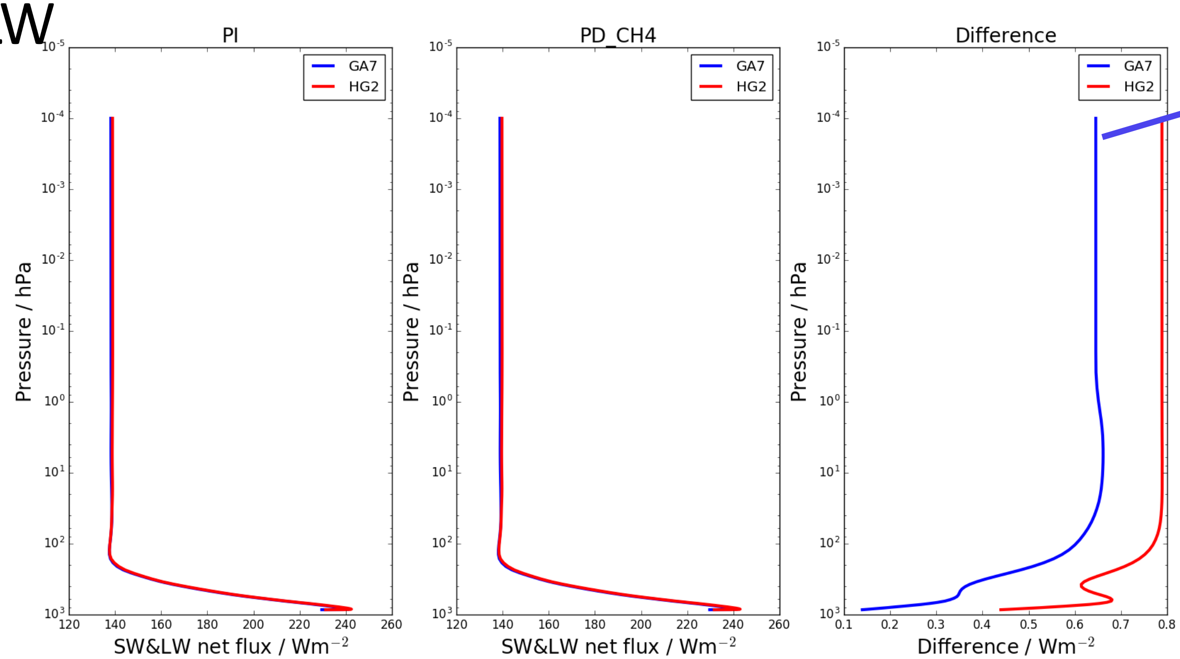
Offline SOCRATES runs (3)

Use RFMIP (Pincus et al., 2016) Test Cases to investigate differences in forcing between HadGEM2 andUKESM1:

Test Cases: 1. **PI baseline** – run stand-alone SOCRATES with GA7/UKESM1 and HadGEM2 spectral files
2. **PI baseline with PD CH4** – run stand-lone SOCRATES with GA7/UKESM1 and HadGEM2 spectral files

Each Test Case has 100 profiles – when averaged, give approximate annual-mean global-mean instantaneous radiative fluxes

SW&LW



GA7/UKESM1

HadGEM2

From these calculations, the clear-sky HadGEM2 forcing should be larger than GA7 by 0.14 Wm^{-2}

But the reported HG2 CS SW forcing of -0.13 Wm^{-2} cancels it out!

What is the cause of that anomalous HadGEM2 forcing?

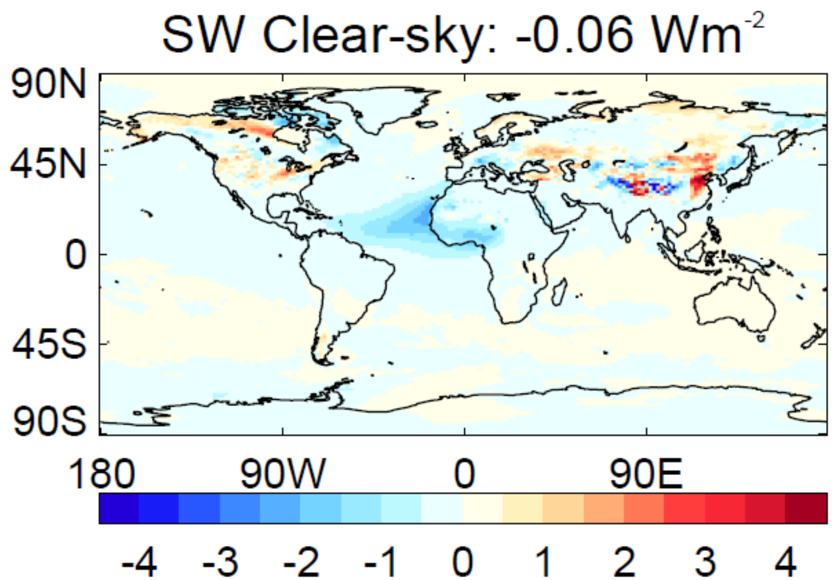
HadGEM2 CS SW forcing

HadGEM2: one ensemble member

Lack of constraint over land leads to a highly variable dust response and
a negative SW forcing!

Forcing ***not*** attributable to methane

No dust response evident in UKESM1 experiments

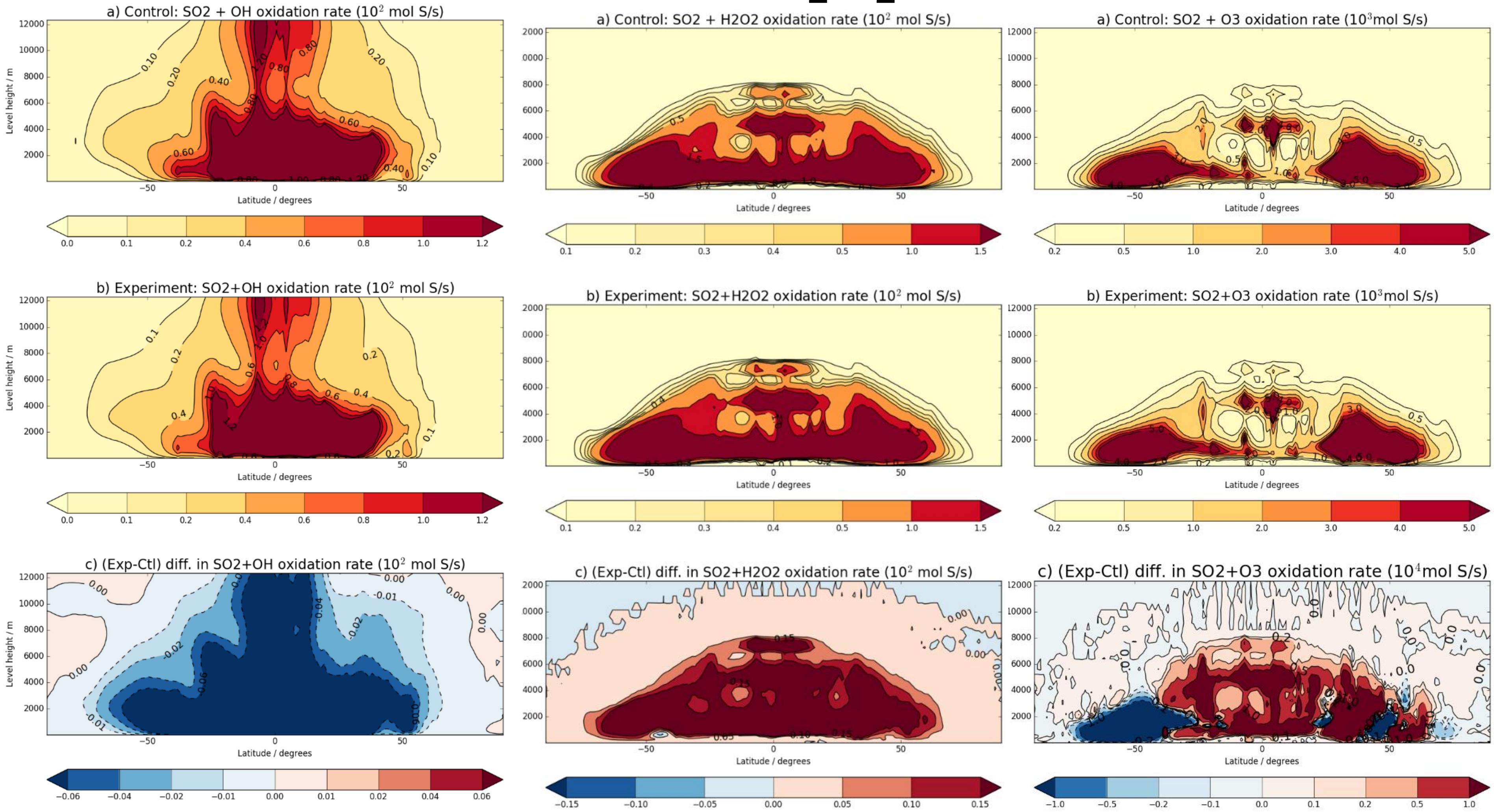


	LW_{CS}	SW_{CS}	LW_{CRE}	SW_{CRE}	NET_{CS}	NET_{CRE}
Ens 1	+0.72	-0.04	-0.21	+0.10	+0.68	-0.10
Ens 2	+0.67	-0.07	-0.28	+0.14	+0.59	-0.14
Ens 3	+0.83	-0.28	-0.20	+0.12	+0.55	-0.07
Mean	**+0.74**	**-0.13**	**-0.23**	**+0.12**	**+0.61**	**-0.11**

Courtesy of Tim Andrews

SO_2 oxidation

OH | H_2O_2 | O_3



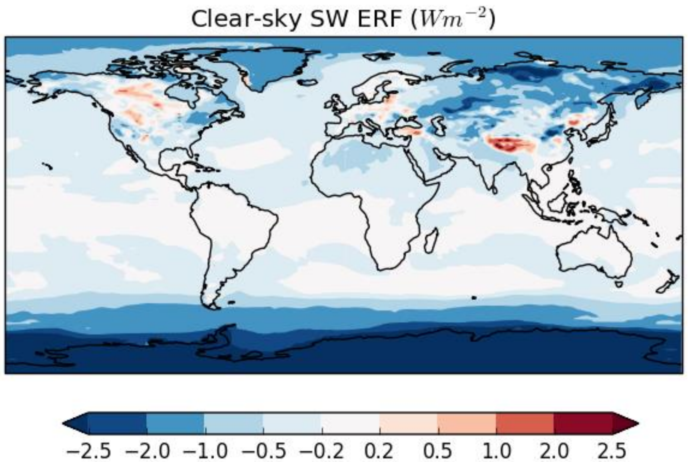
HC ERF

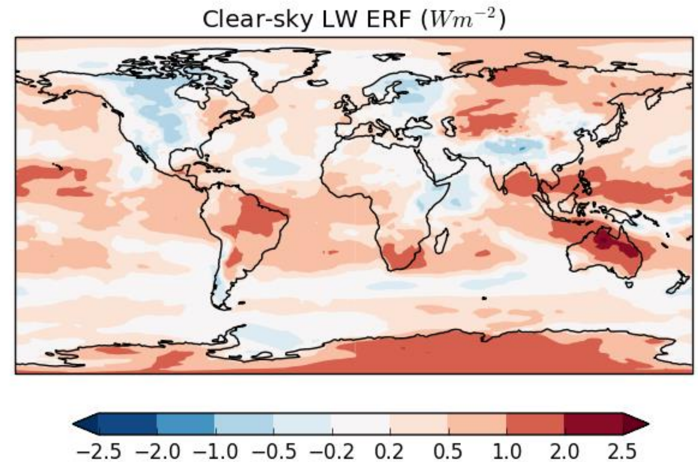
Agent	NET	LW_{CS}	SW_{CS}	LW_{CRE}	SW_{CRE}	NET_{CS}	NET_{CRE}
HC	-0.33	+0.40	-0.50	+0.21	-0.44	-0.10	-0.22

SW

LW

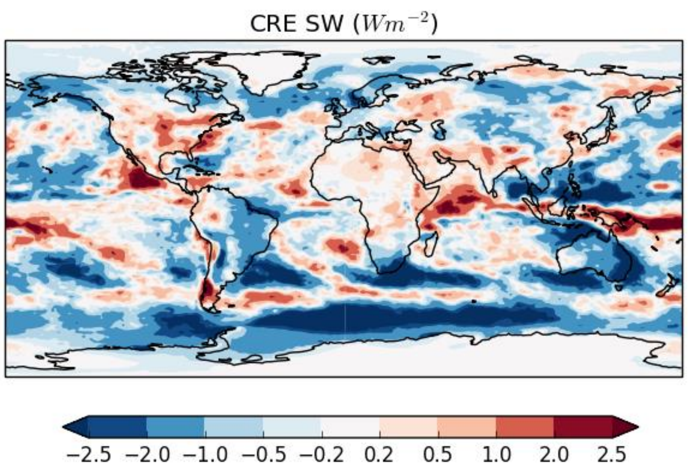
CS

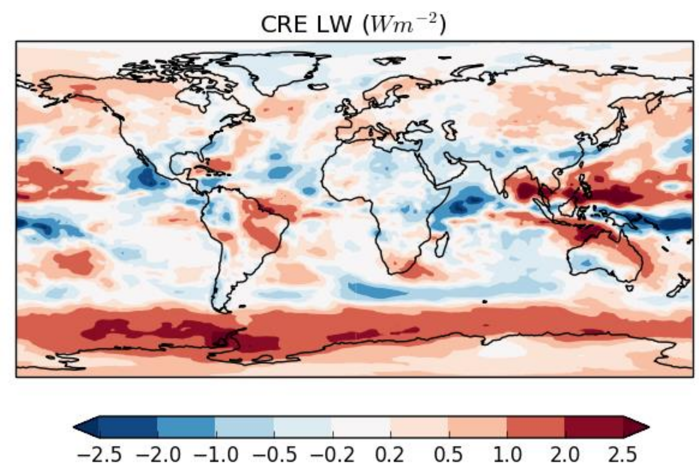




CS

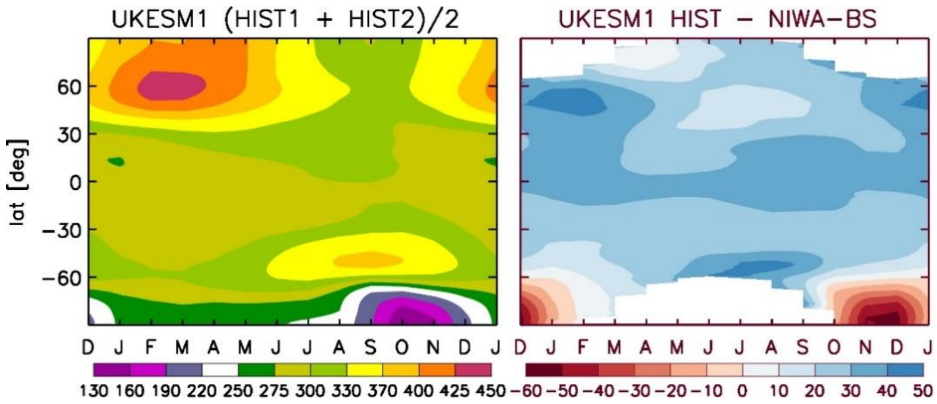
CRE



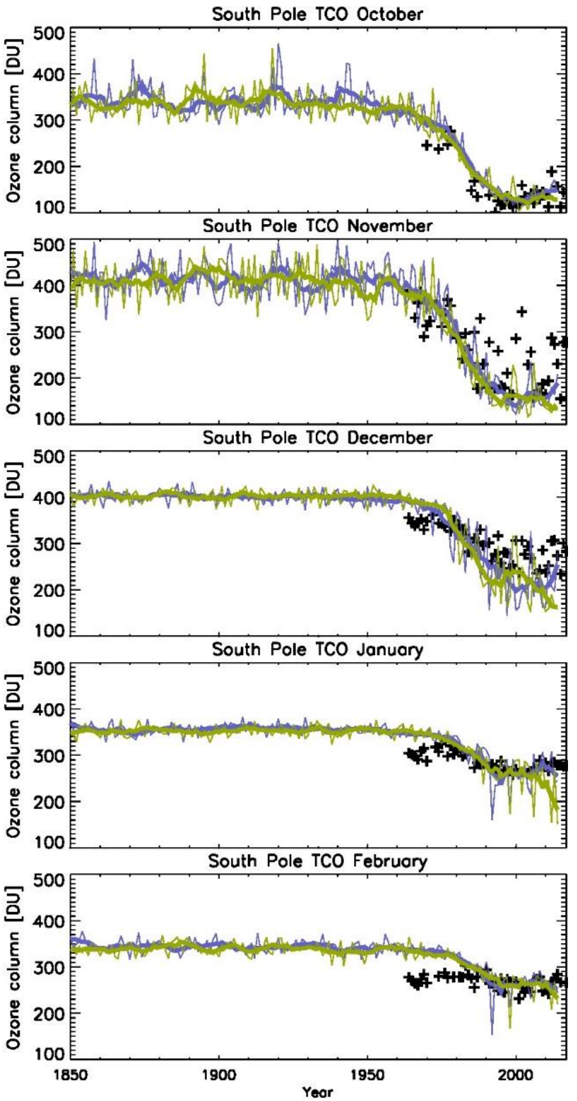


CRE

Stratospheric Chemistry Performance



Comparison of 20-year modelled climatology vs NIWA-BS TCO v3.4

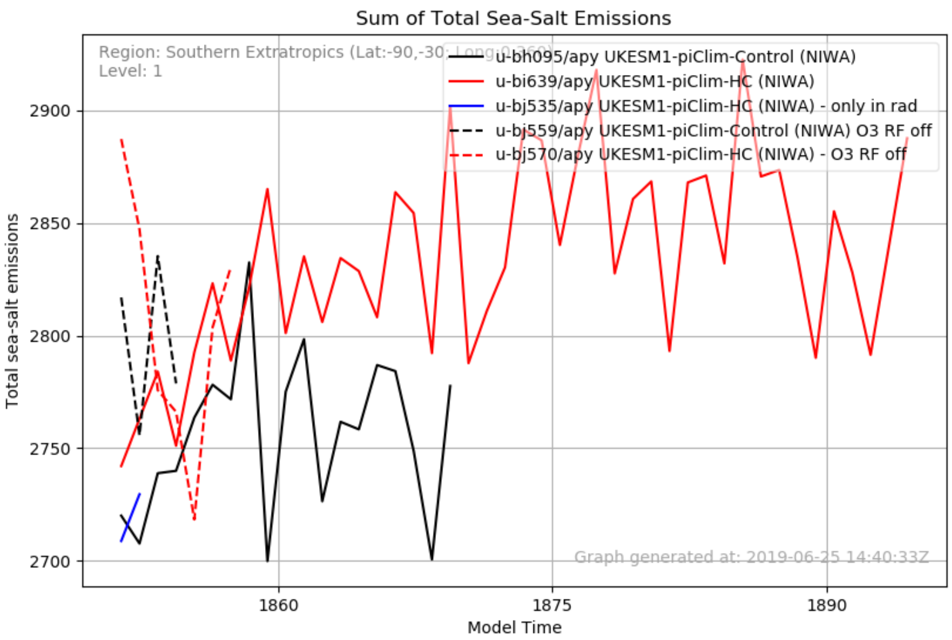


Comparison with Dobson record at South Pole

- Model underestimates O3 by up to 60 DU in Nov/Dec over Antarctica
- Good agreement with S. Pole record in October
- In Nov/Dec, the model only tracks the deepest O3 holes & does not reproduce the observed variability
- Model produces too large negative trends during spring and summer at high latitudes in both hemispheres

Sellar et al., Under review, JAMES

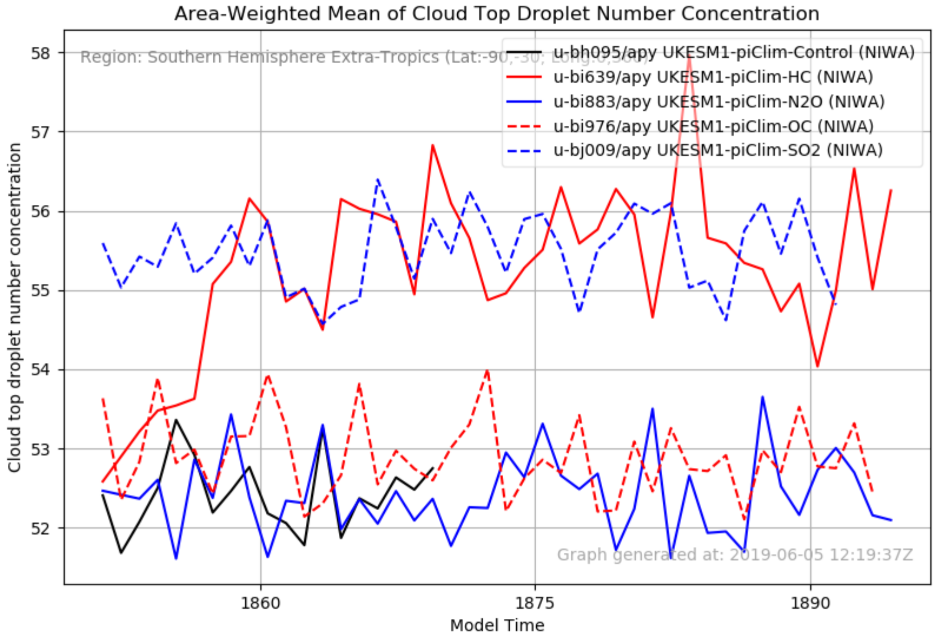
HC ERF – Another cause of negative forcing? Aerosol forcing through ARI?



SH extra-tropics seasalt emissions

Can use double call diagnostics to separate ARI from ACI

HC ERF – Another cause of negative forcing? Aerosol forcing through ACI?



SH extra-tropics CDNC

SH extra-tropics R_{eff}