ATTRIBUTING RADIATIVE FORCING TO DRIVING EMISSIONS IN CRESCENDO EARTH SYSTEM MODELS

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G. Thornhill, W. Collins, R. Kramer, D. Olivie, F. O'Connor, M. Schulz, M. Michou, G. Mhyre, R. Checa Garcia

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DEFINITIONS OF ERF

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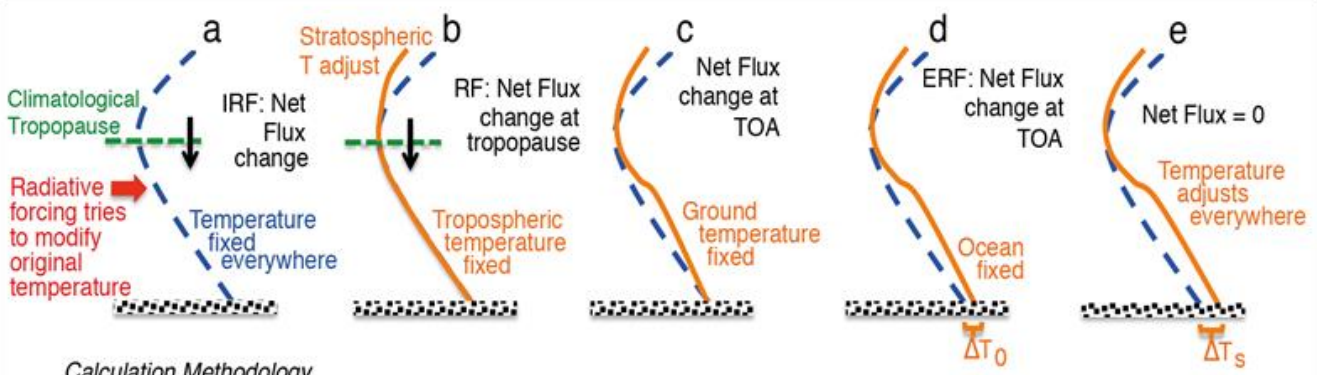
Definitions of Radiative Forcing

AR5, Chapter 8.1, 2013



	a	b	c	d	e
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

AerChemMIP EXPERIMENTS (CMIP6)

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- 30 year runs, fixed SSTs and sea-ice
- Control run with 1850 Pre-industrial emissions/concentrations
- Individual perturbed runs with each aerosol/gas set to present-day (2014) emissions/concentrations
- ERF is calculated as the difference between net TOA radiative flux (perturbed – control)

Experiment ID	CH_4	N_2O	Aerosol Precursors	Ozone Precursors	CFC/ HCFC
piClim-control	1850	1850	1850	1850	1850
piClim-NTCF	1850	1850	2014	2014	1850
piClim-aer	1850	1850	2014	1850	1850
piClim-BC	1850	1850	1850 (non BC) 2014 (BC)	1850	1850
piClim-O3	1850	1850	1850	2014	1850
piClim-CH4	2014	1850	1850	1850	1850
piClim-N2O	1850	2014	1850	1850	1850
piClim-HC	1850	1850	1850	1850	2014
piClim-NOX	1850	1850	1850	1850 (non NO_X) 2014 (NO_X)	1850
piClim-VOC	1850	1850	1850	1850 (non CO/VOC) 2014 (CO/VOC)	1850
piClim-SO2	1850	1850	1850 (non SO2) 2014 (SO2)	1850	1850
piClim-OC	1850	1850	1850 (non OC) 2014 (OC)	1850	1850
piClim-NH3	1850	1850	1850 (non NH3) 2014 (NH3)	1850	1850

ERF FOR AEROSOLS

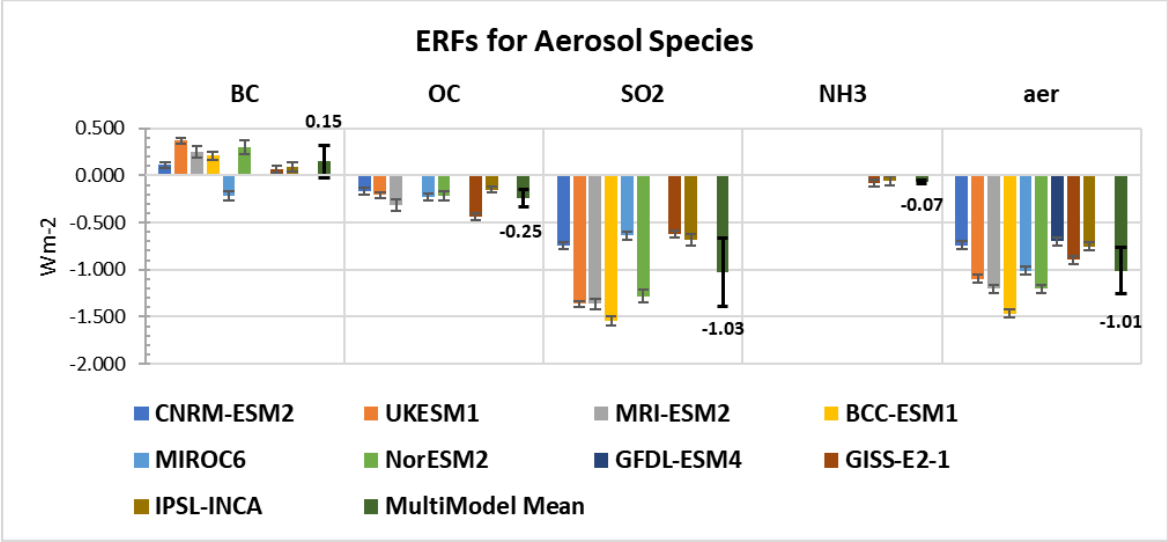
- Multimodel mean ERF from combined aerosols -1.01 Wm $^{-2}$

(-0.63 to -1.47 Wm $^{-2}$)

- Bellouin et al. (2019)

-0.65 to -1.60 W m^{-2}

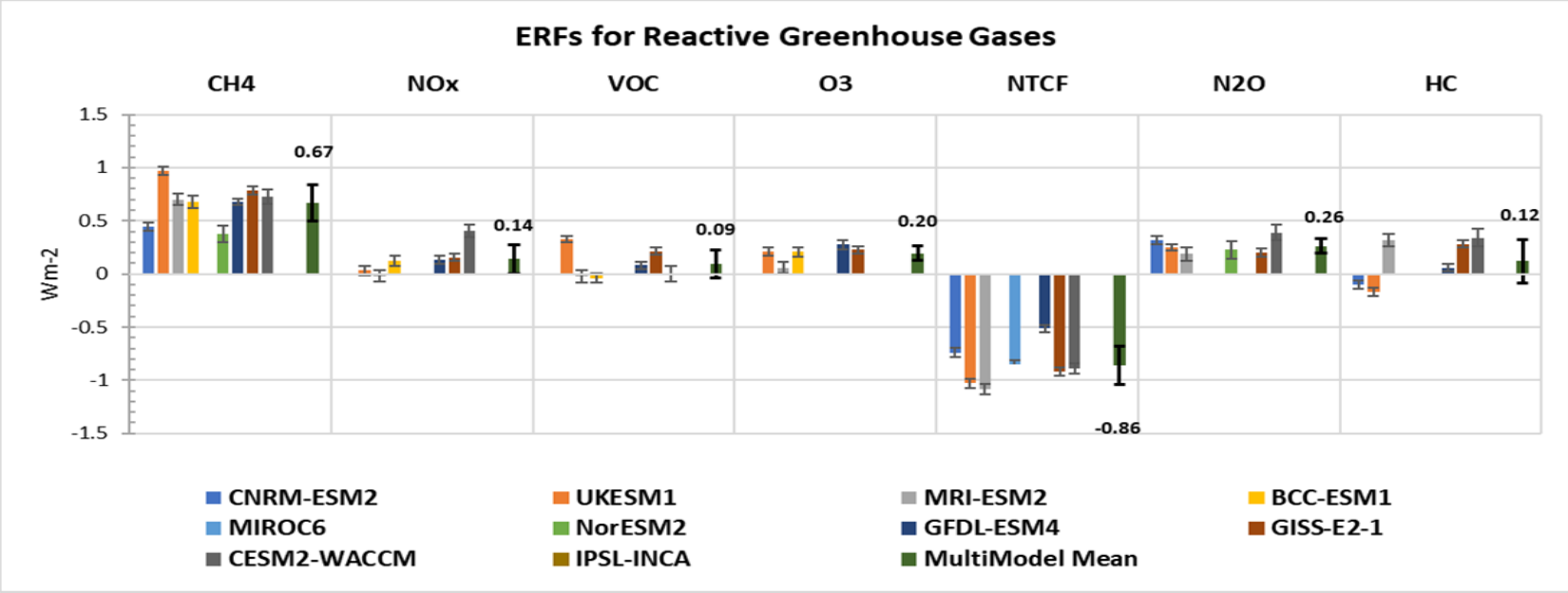
for the overall aerosol ERF



Model differences:
BC shows some variability between models, partly due to whether or not deposition on snow is included, and if ice-nucleation from BC in clouds is included in the models

Differences in ERFs for SO2 are largely due to cloud adjustments (from radiative kernel analysis)

ERF FOR CHEMICALLY REACTIVE GASES



Model differences:

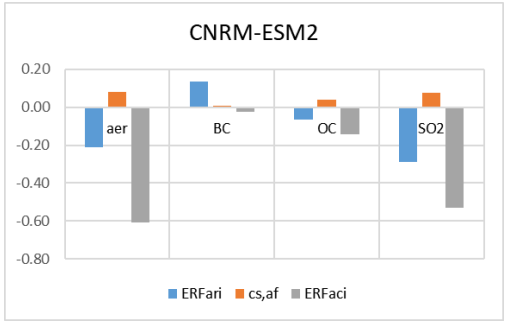
- ESM2-1 has stratospheric ozone chemistry, but prescribed ozone below 560 hPa
- BCC-ESM1 includes only tropospheric chemistry

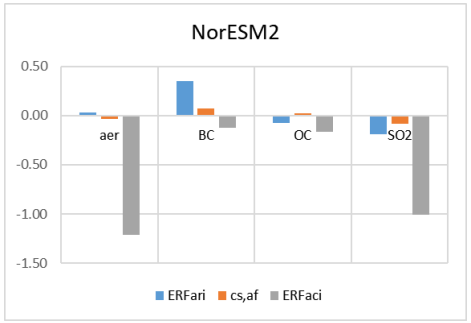
AEROSOL-FREE RADIATION CALLS

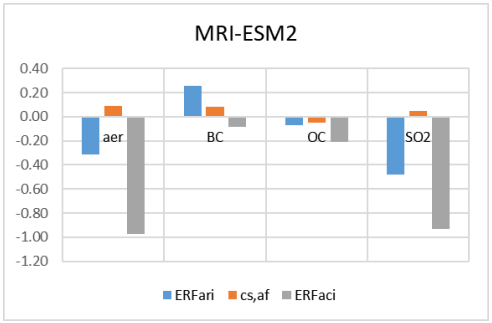
- Decomposing the ERF to the component due to the aerosol-cloud interactions (ERFaci) and the aerosol-radiation interactions (ERFari) is achieved using the method of *(Ghan 2013)*
- We have radiative fluxes calculated for all-sky and clear sky (F and F_{cs}) from the models, to compare the effect of clouds on radiative fluxes
- A second set of calculations of the radiative fluxes can be used to find the radiative fluxes without the scattering and absorption due to aerosols, for both all-sky and clear sky (F_{af}, $F_{cs,af}$) cases – all other effects of aerosols are still present.

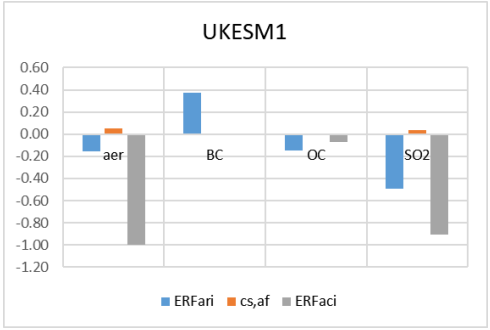
The ERF for each of these cases is calculated, and combined as shown to give the breakdown of the ERF

$$ERF_{ari} = (ERF - ERF_{af})$$
$$ERF_{aci} = (ERF_{af} - ERF_{cs,af})$$
$$ERF_{albedo} = ERF_{cs,af}$$









(Ghan, S. J., Technical Note: Estimating aerosol effects on cloud radiative forcing, Atmos. Chem. Phys., 13, 9971-9974, 2013)

ERFARI

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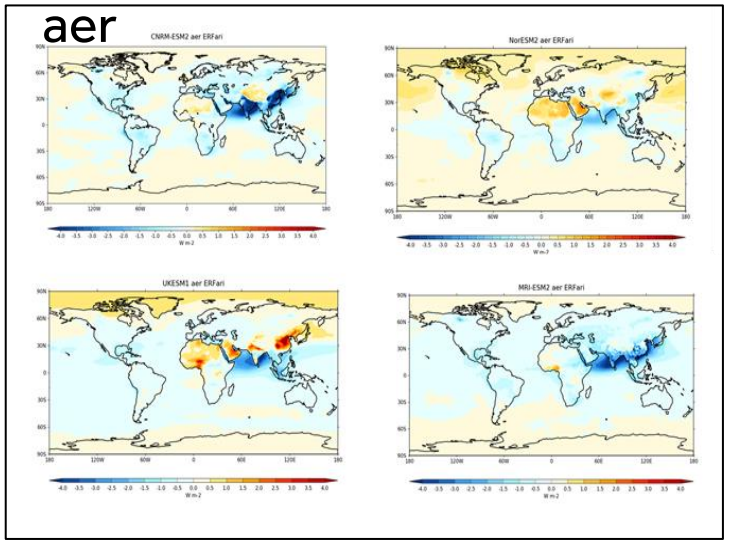
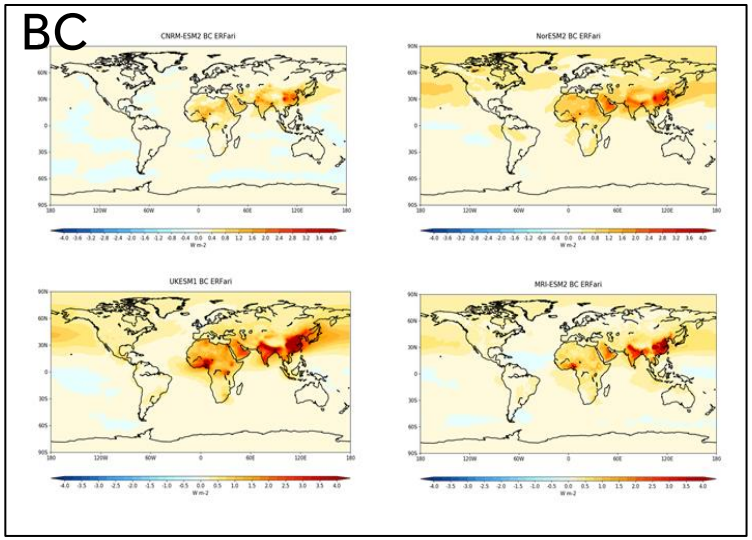
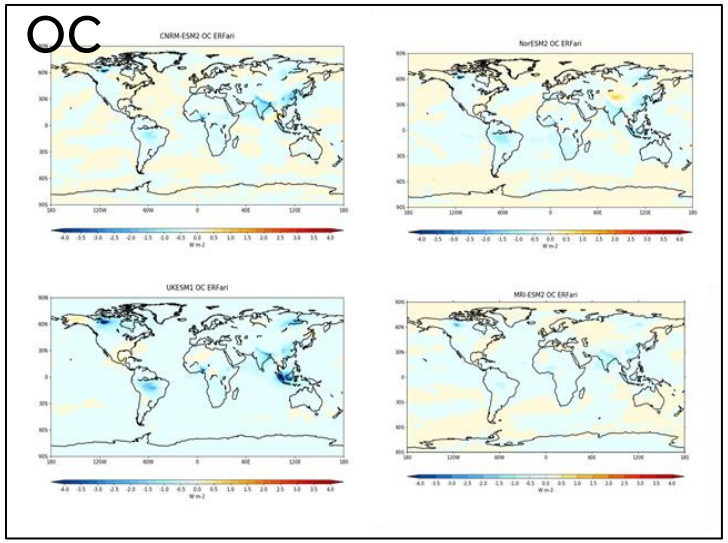
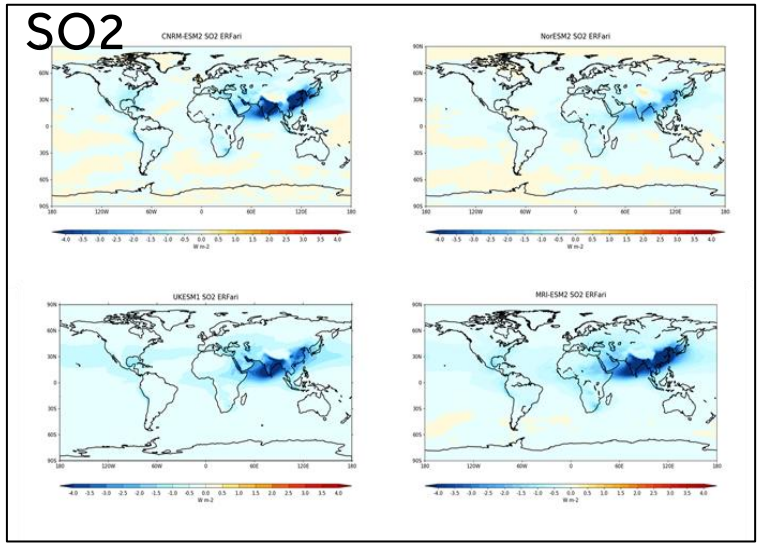


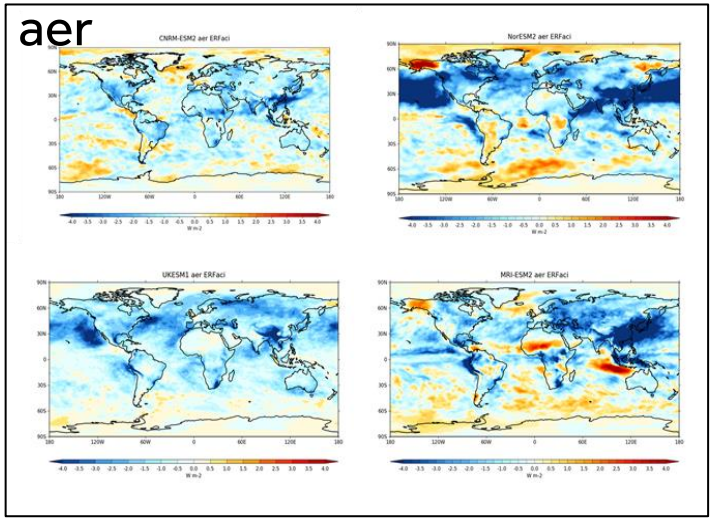


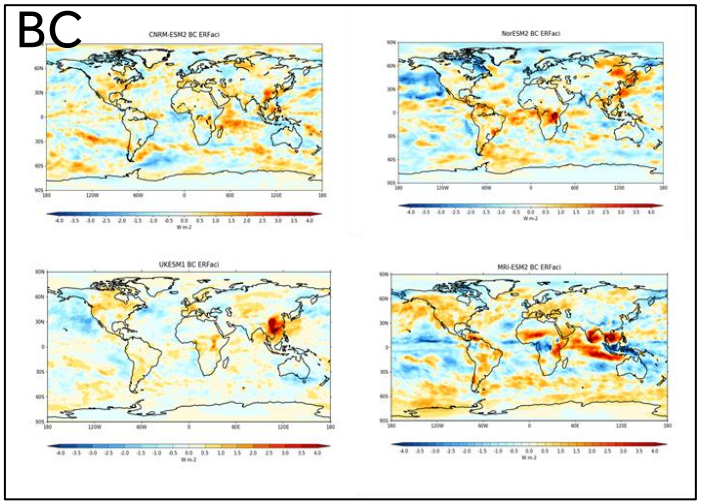


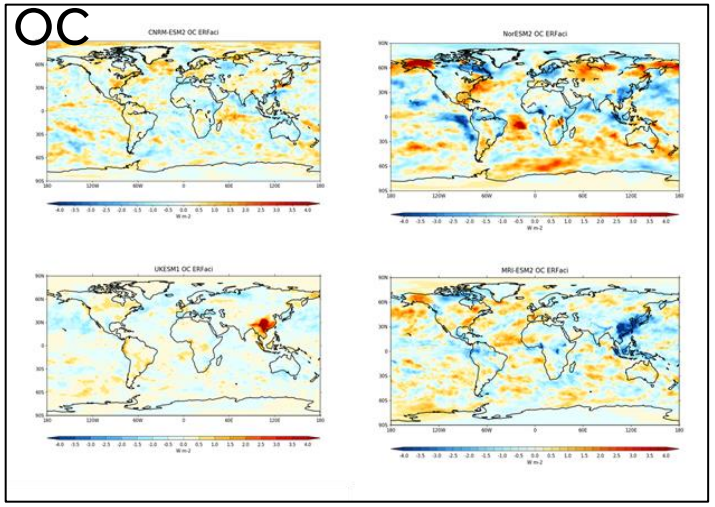


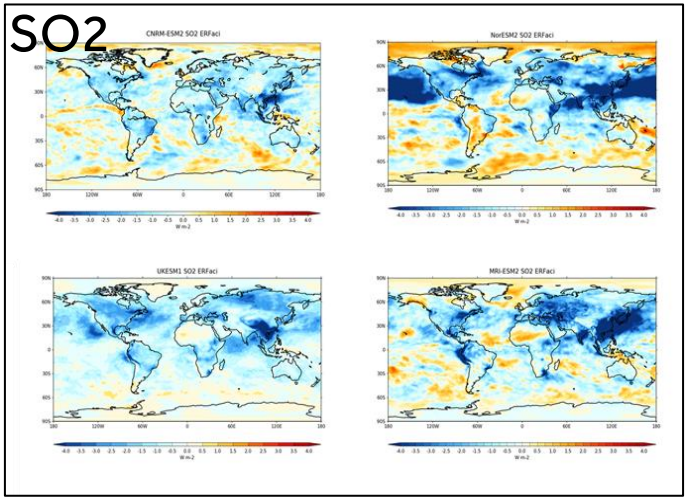
Model comparisons for the ERFari for aerosols: contribution of OC, SO2 and BC to total aerosol ERFari

ERFACI









Model comparisons for the ERFaci for aerosols: contribution of OC, SO2 and BC to total aerosol ERFaci

SUMMARY

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- Multimodel variability in aerosol ERFs:
  - Due to treatment of aerosol-cloud interactions (e.g. ice-nucleation)
  - Inclusion of deposition of BC on snow
  - Characteristics of the aerosols (e.g. non-absorbing OC in UKESM1), SSA, size distributions

- Multimodel variability in reactive gas ERFs:
  - Due to differences in model complexity for chemistry
  - Inclusion of tropospheric and/or stratospheric chemistry

- Use of double-calls with ‘aerosol-free’ radiation calls allows for a cleaner breakdown of ERF due to direct radiative effects vs. aerosol-cloud interactions

Thornhill, G. D., et al: Effective radiative forcing from emissions of reactive gases and aerosols – a multi-model comparison, Atmos. Chem. Phys., 2020, https://doi.org/10.5194/acp-2019-1205