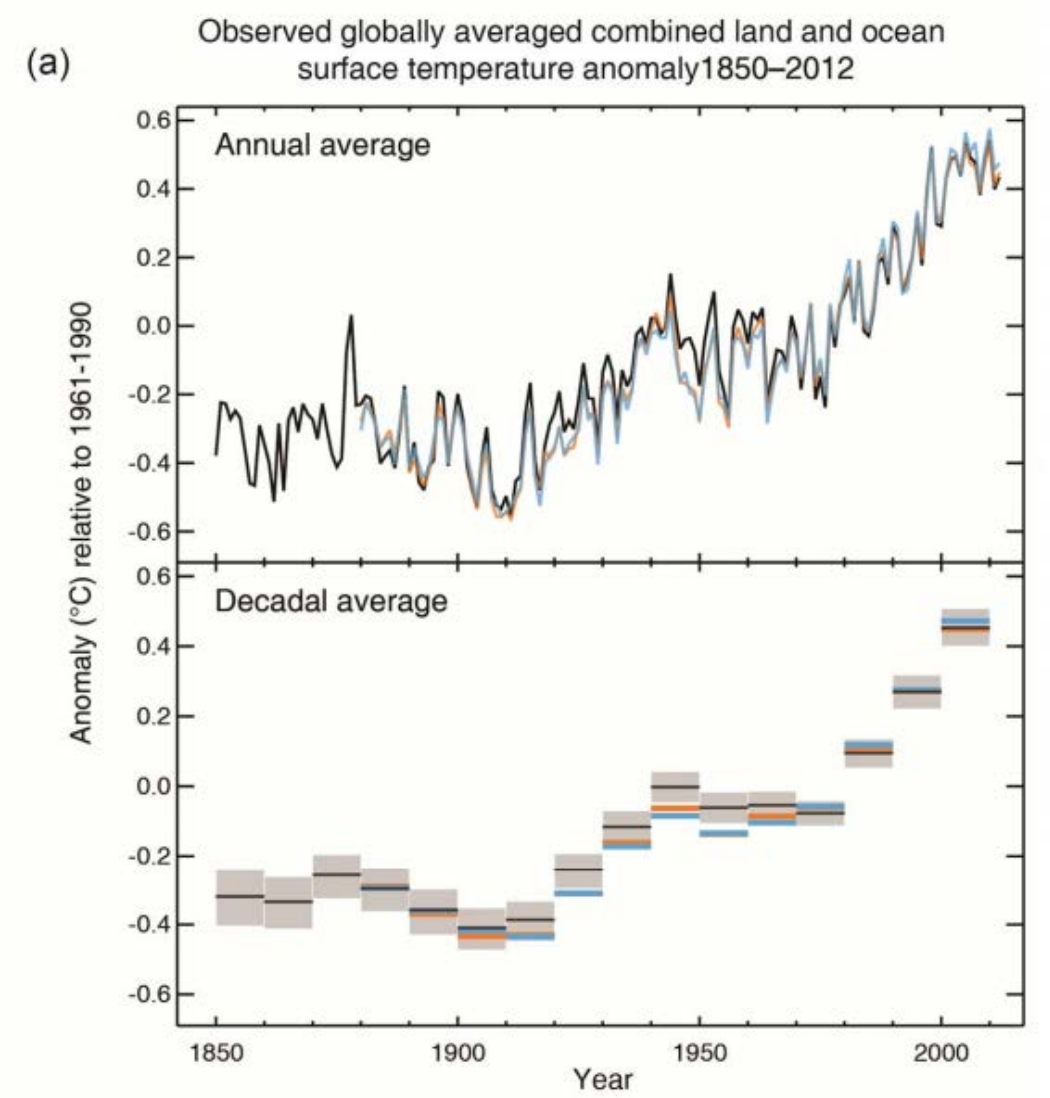
Radiative Forcing

Simple concept, complex in practice

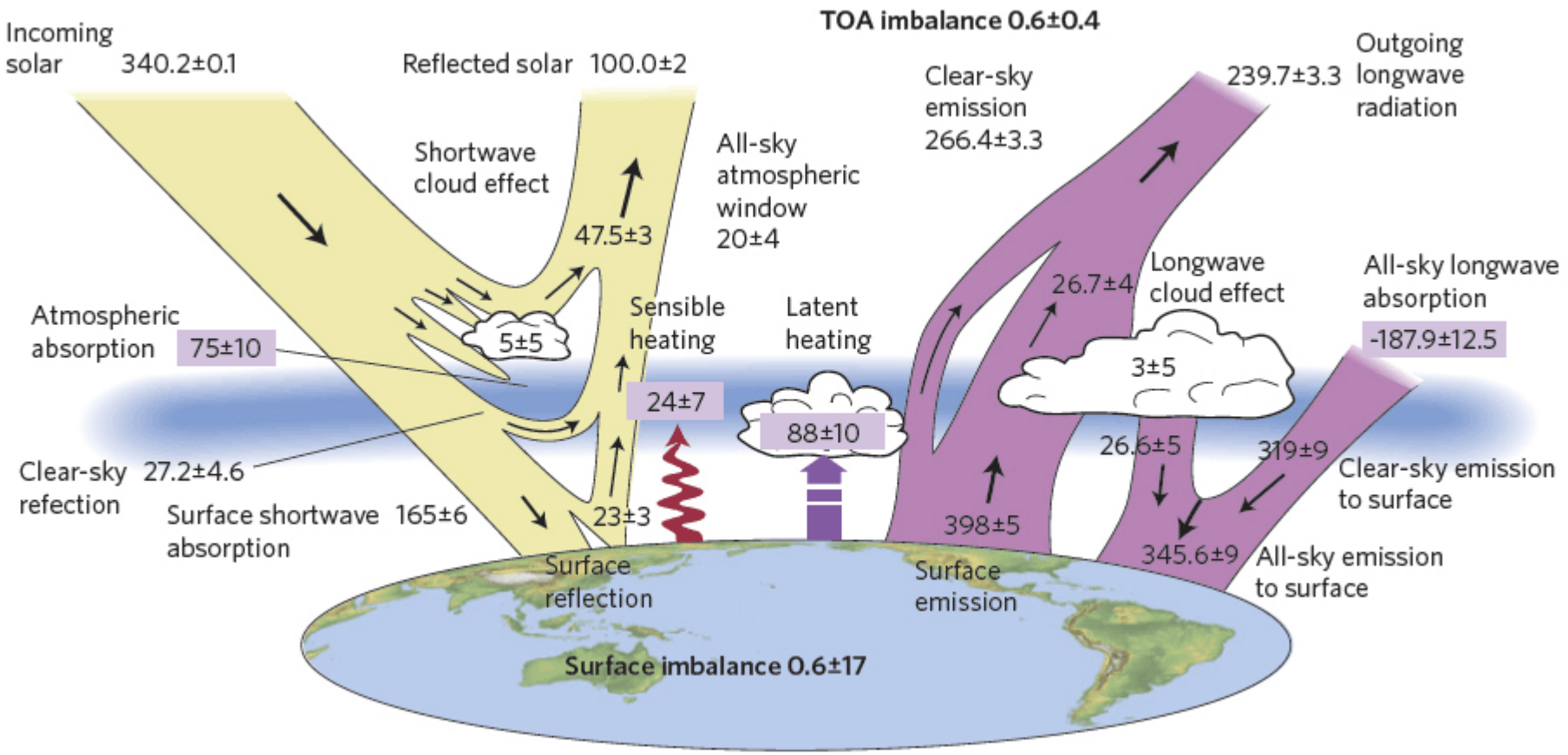
Bjørn H. Samset and Gunnar Myhre,
CICERO

b.h.samset@cicero.oslo.no

- What is «radiative forcing»?
- Complexities: Forcing – adjustments – response
- RF in AeroCom, and its usage
- Towards a common, operational definition of «RF» for model intercomparison projects



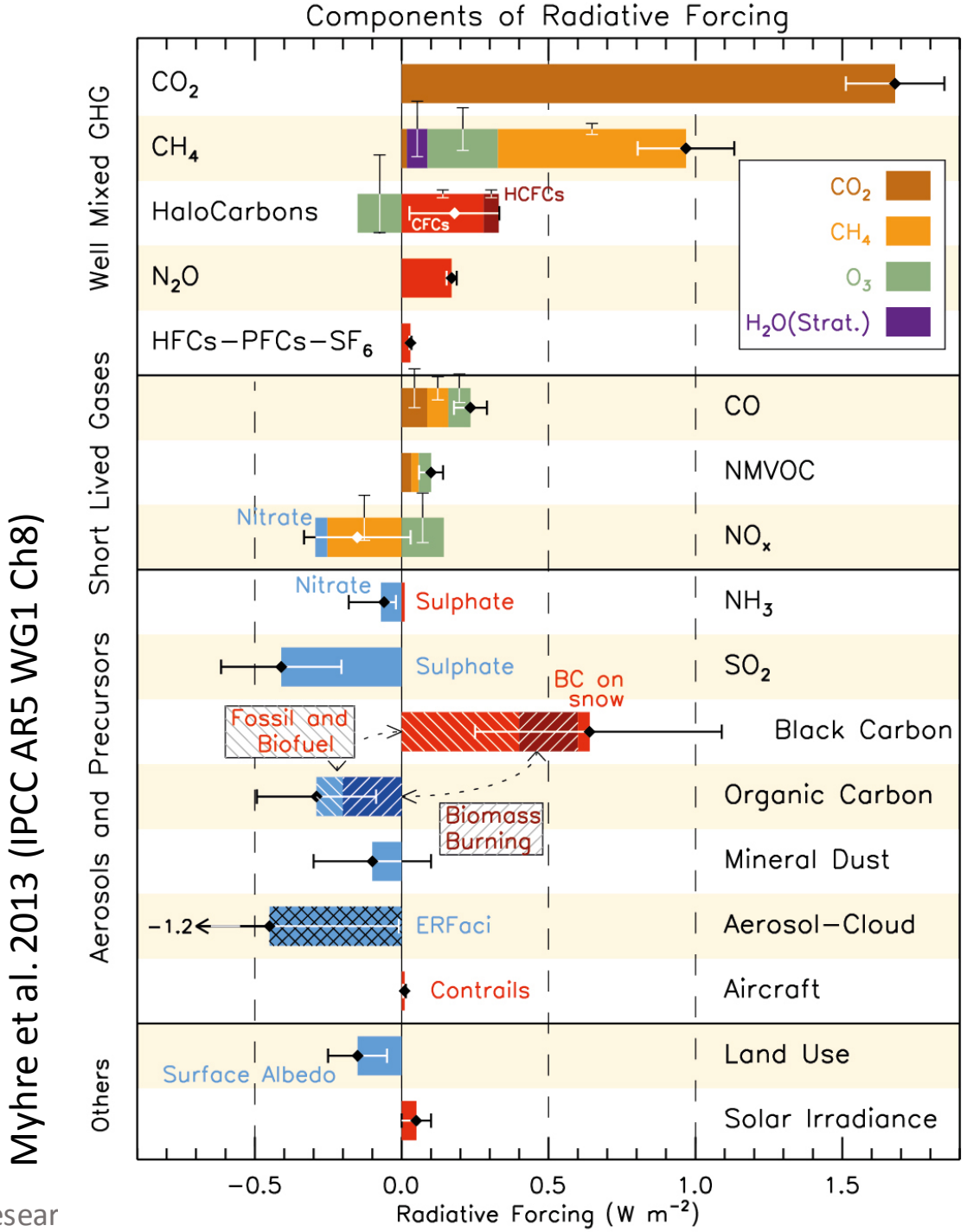
What combination of changes to the global climate system caused this?



Radiative forcing:
The change in net energy flux into the climate system due to some change, evaluated at the tropopause.

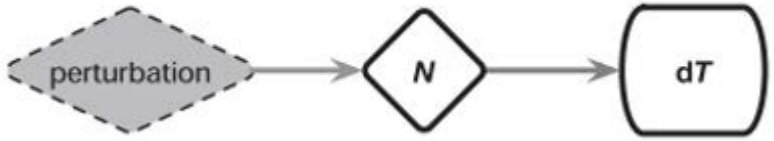
Extremely useful concept: Allows us to compare the climate impacts of different drivers (CO2, aerosols, land use change, …).

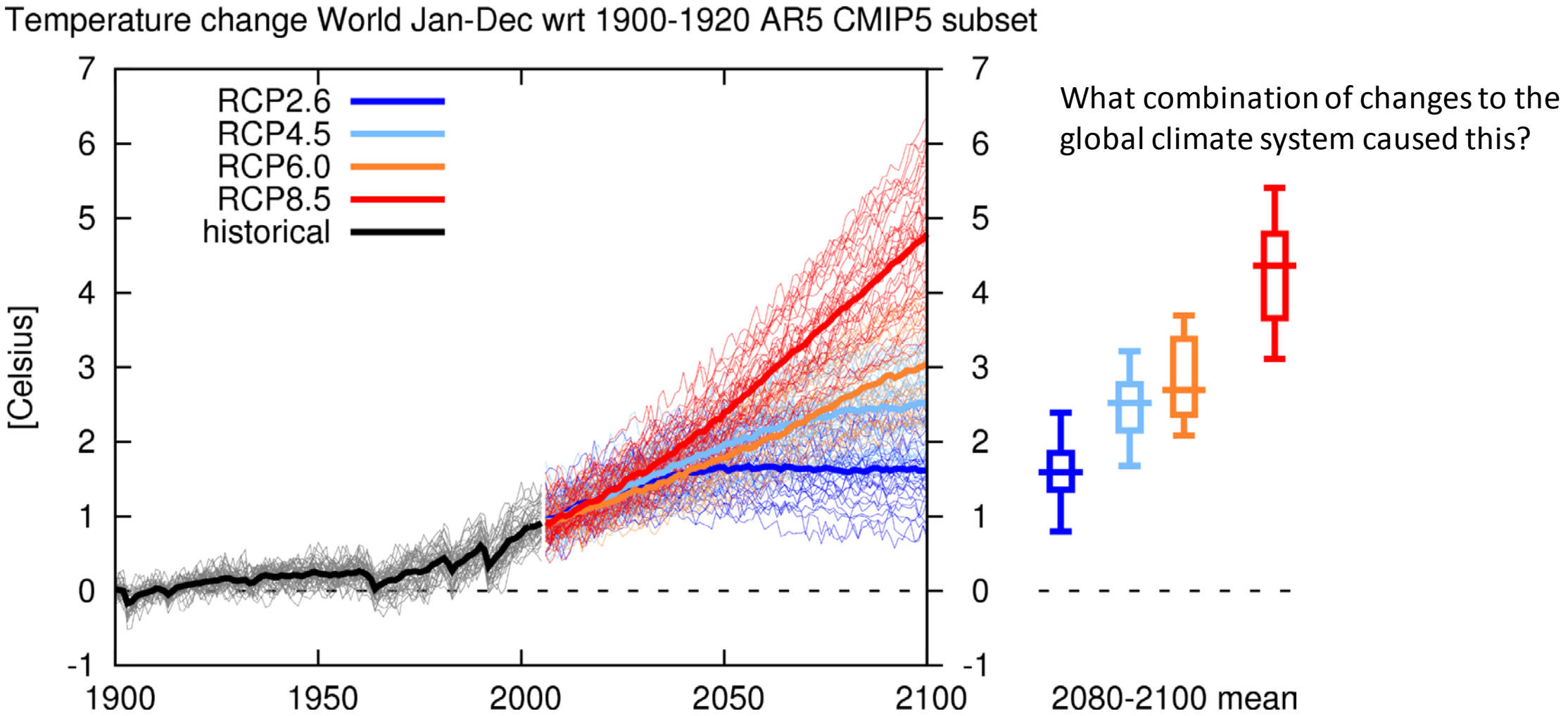
In principle.



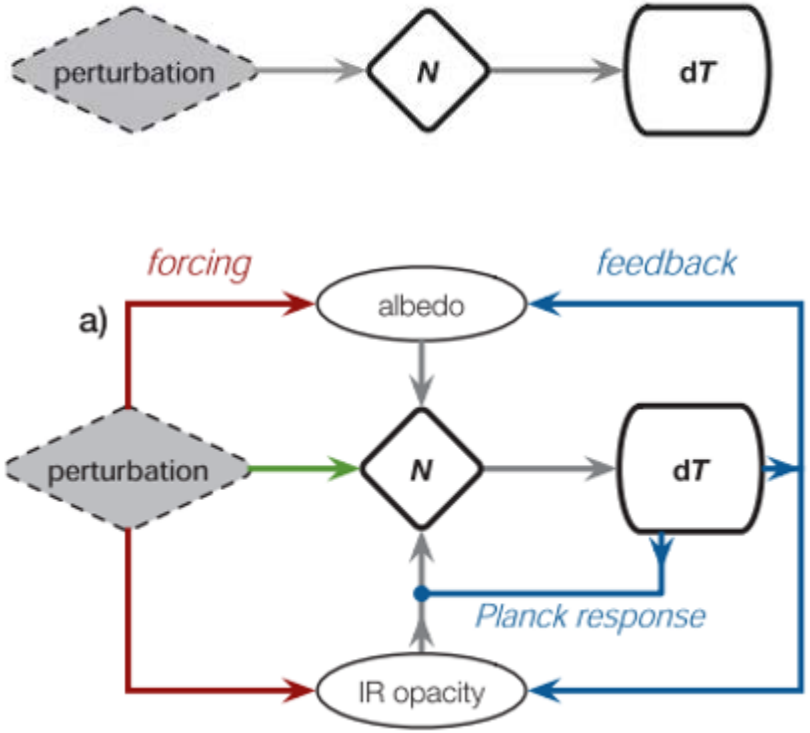
Myhre et al. 2013 (IPCC AR5 WG1 Ch8)

$$RF_{CO_2} = 5.35 \times \log {}^{C}/_{C_0}$$




Temperature change World Jan-Dec wrt 1900-1920 AR5 CMIP5 subset
RCP2.6
RCP4.5
RCP6.0
RCP8.5
historical
[Celsius]
7
6
5
4
3
2
1
0
-1
1900
1950
2000
2050
2100
What combination of changes to the global climate system caused this?
2080-2100 mean

The forcing – adjustment - response framework

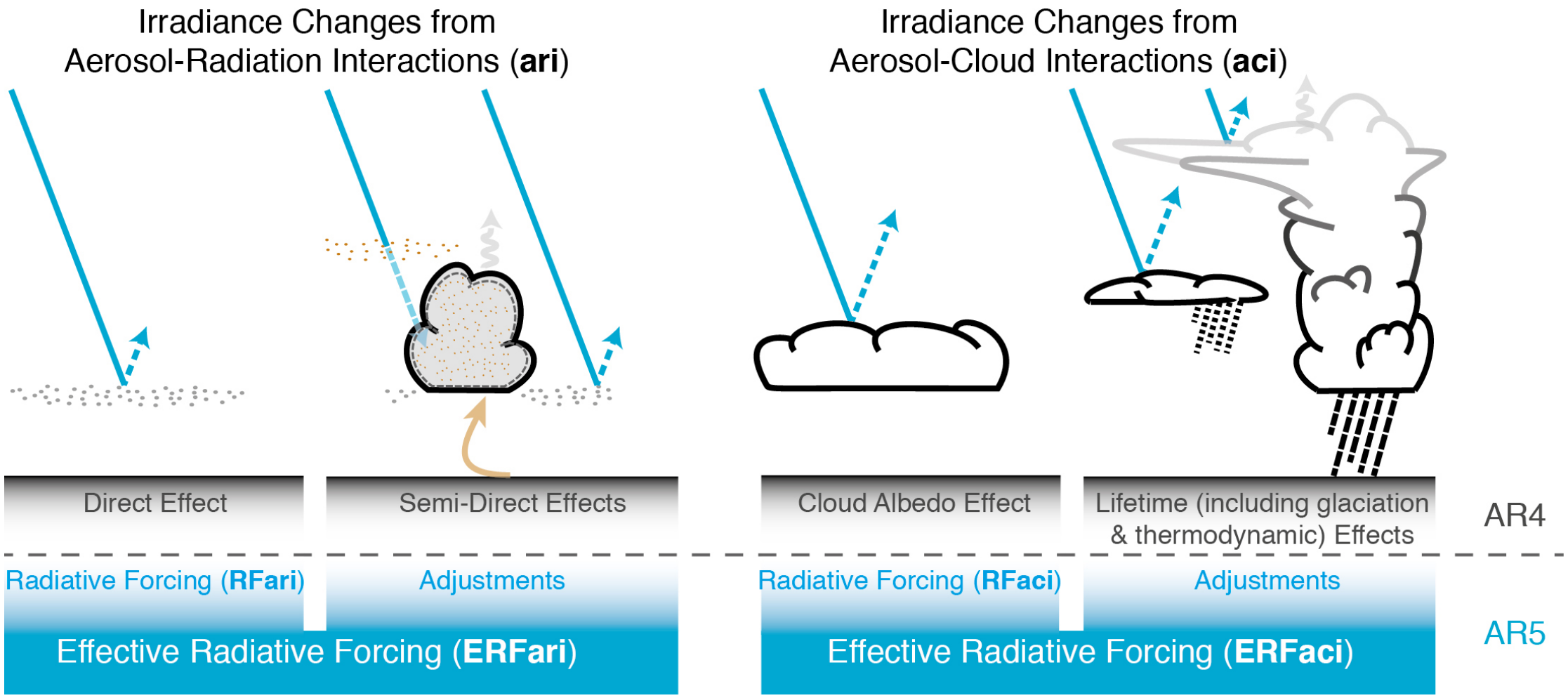


IRF: Instantaneous Radiative Forcing, no adjustments

ERF: Effective Radiative Forcing, after rapid adjustments

Initial forcing, then a set of (primarily rapid) adjustments, then a set of (primalily slow, surface temperature change driven) responses.

Sherwood et al., BAMS, 2015


Irradiance Changes from
Aerosol-Radiation Interactions (ari)
Irradiance Changes from
Aerosol-Cloud Interactions (aci)
Direct Effect
Semi-Direct Effects
Cloud Albedo Effect
Lifetime (including glaciation & thermodynamic) Effects
AR4
Radiative Forcing (RFari)
Adjustments
Radiative Forcing (RFaci)
Adjustments
AR5
Effective Radiative Forcing (ERFari)
Effective Radiative Forcing (ERFaci)

Radiative Forcing in AeroCom I and II

Key AeroCom question: What is the modeled radiative forcing of anthropogenic aerosols over the industrial era, and what is the inter-model variability in this calculation?

| Bjørn H. Samset | Research Director, CICERO | b.h.samset@cicero.oslo.no | @bjornhs |

RF, the AeroCom way:

- Two one-year model runs: One with present day aerosol emissions (CTRL), one with preindustrial emissions (PRE)
- Emissions: Common to all models
- Meteorology: Common year, either read in from reanalysis or with nudged winds

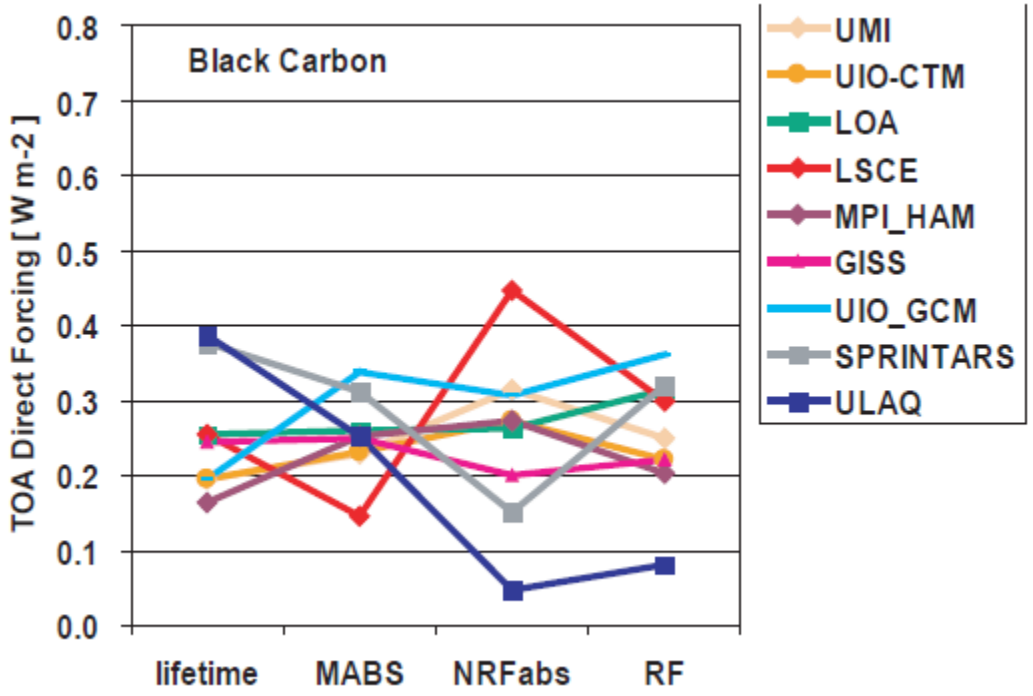
- RF: Difference in global mean outgoing TOA shortwave radiative flux between CTRL and PRE

- To isolate the RF of one species, perform additional CTRL run with that species at preindustrial emissions

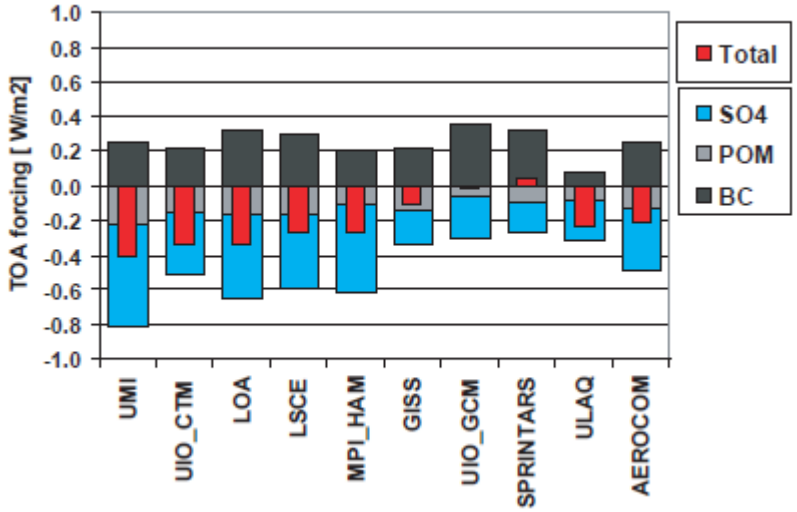
- No indirect effects, nudged winds -> no (or very few) adjustments -> IRF_{SW}

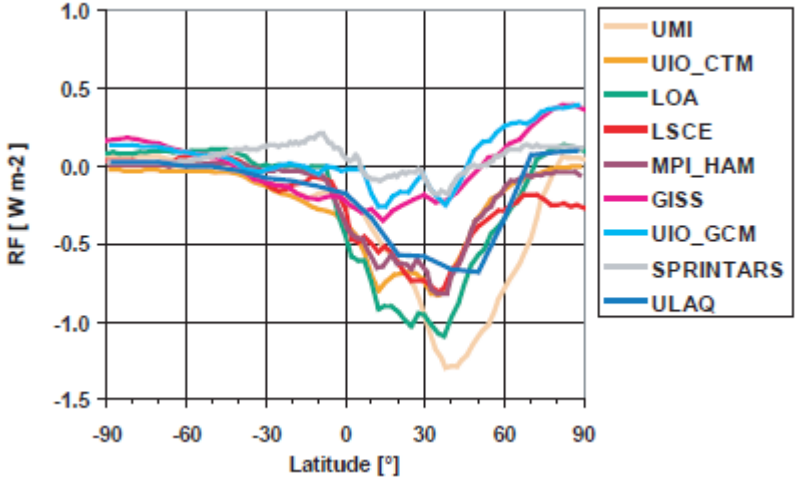
- Allows comparison of optical properties, radiative transfer, aerosol transport, lifetime etc.

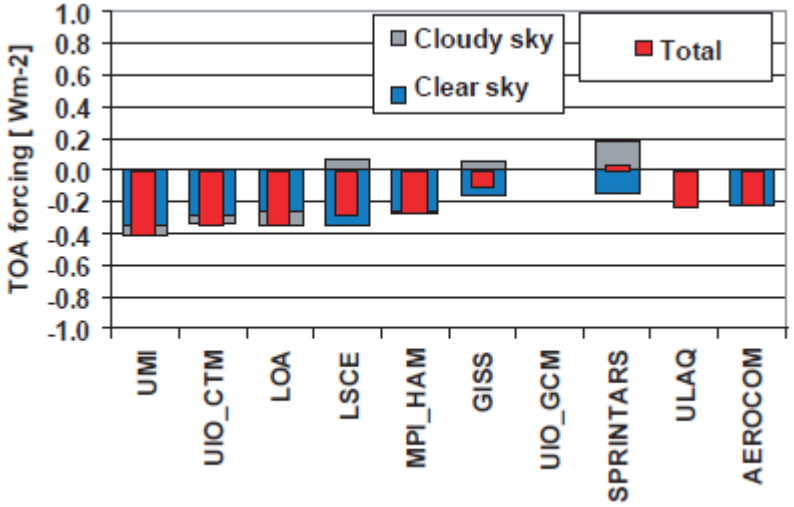
Schulz et al., ACP, 2006

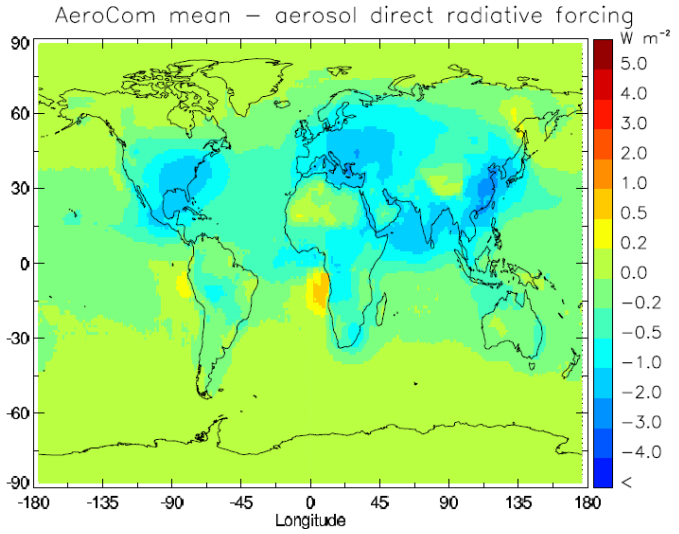


AeroCom Phase I, Schulz et al., ACP, 2006

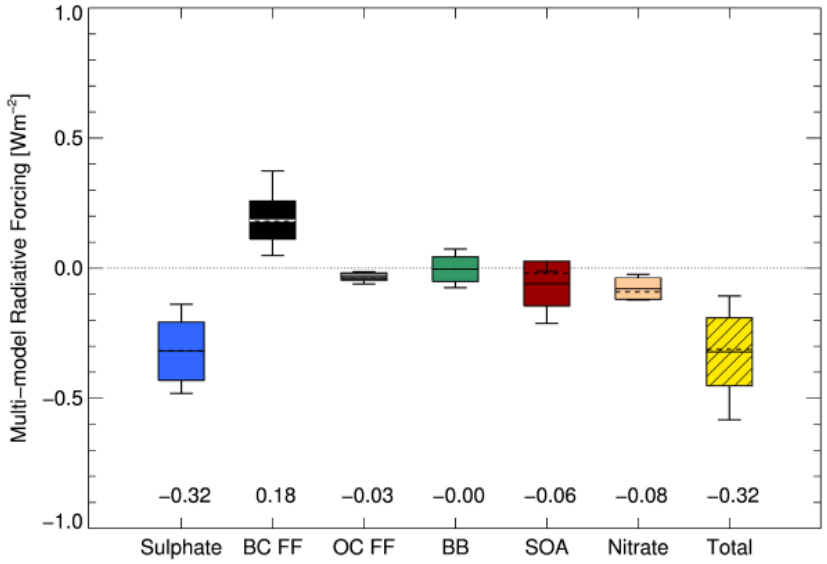


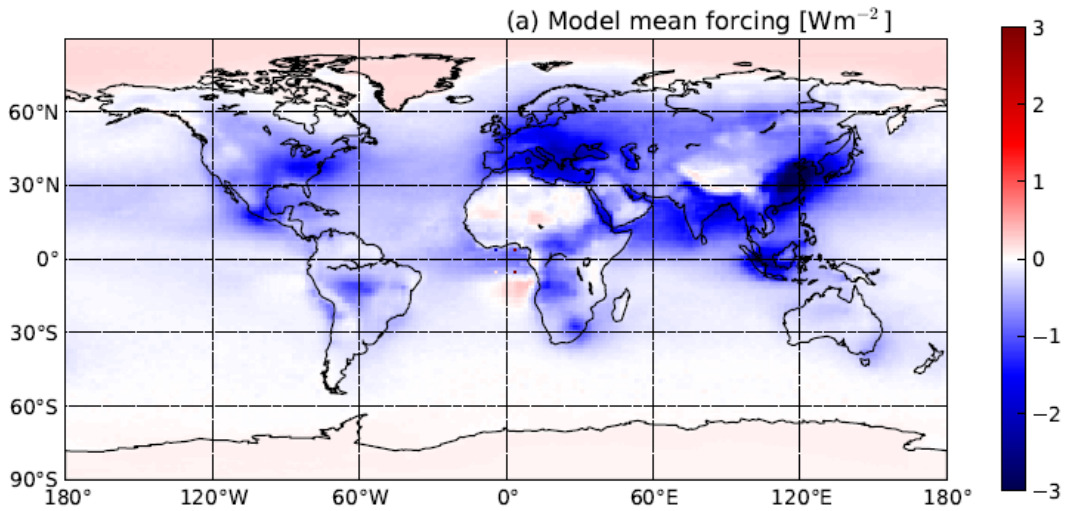


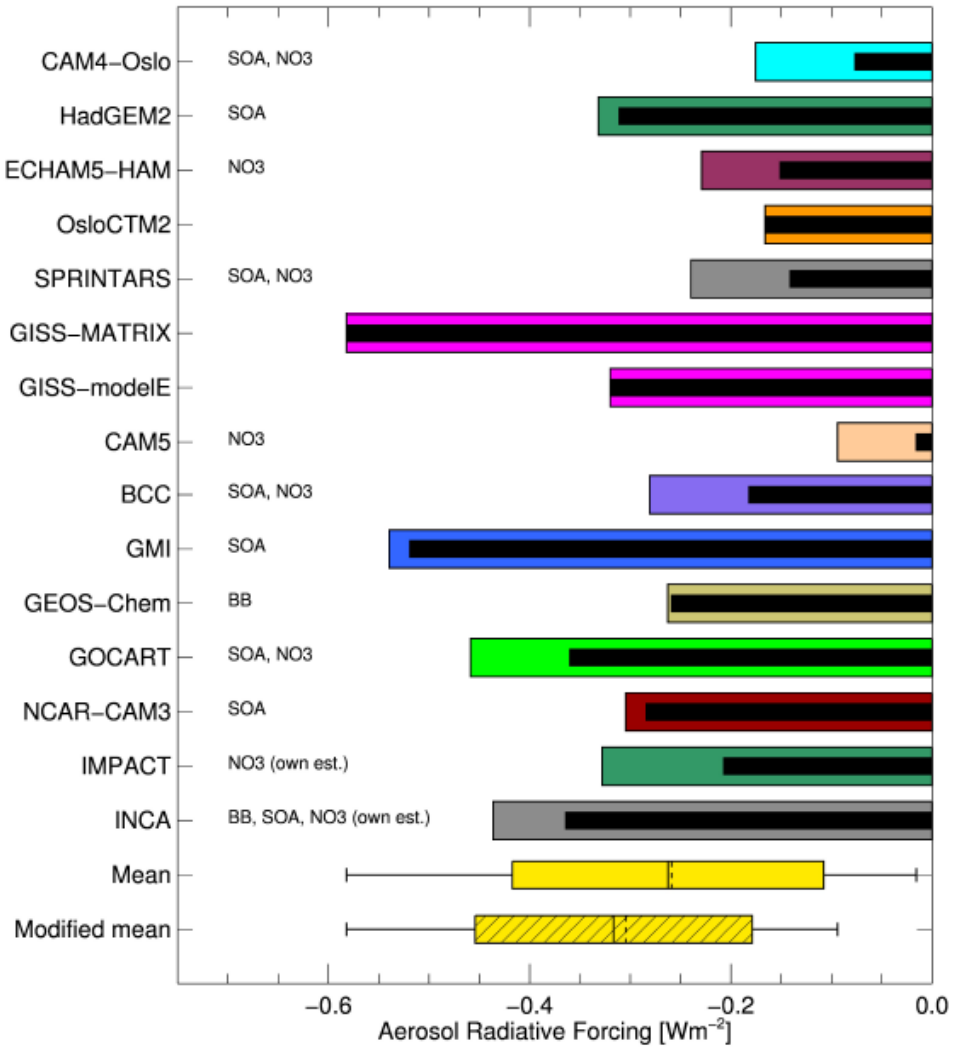




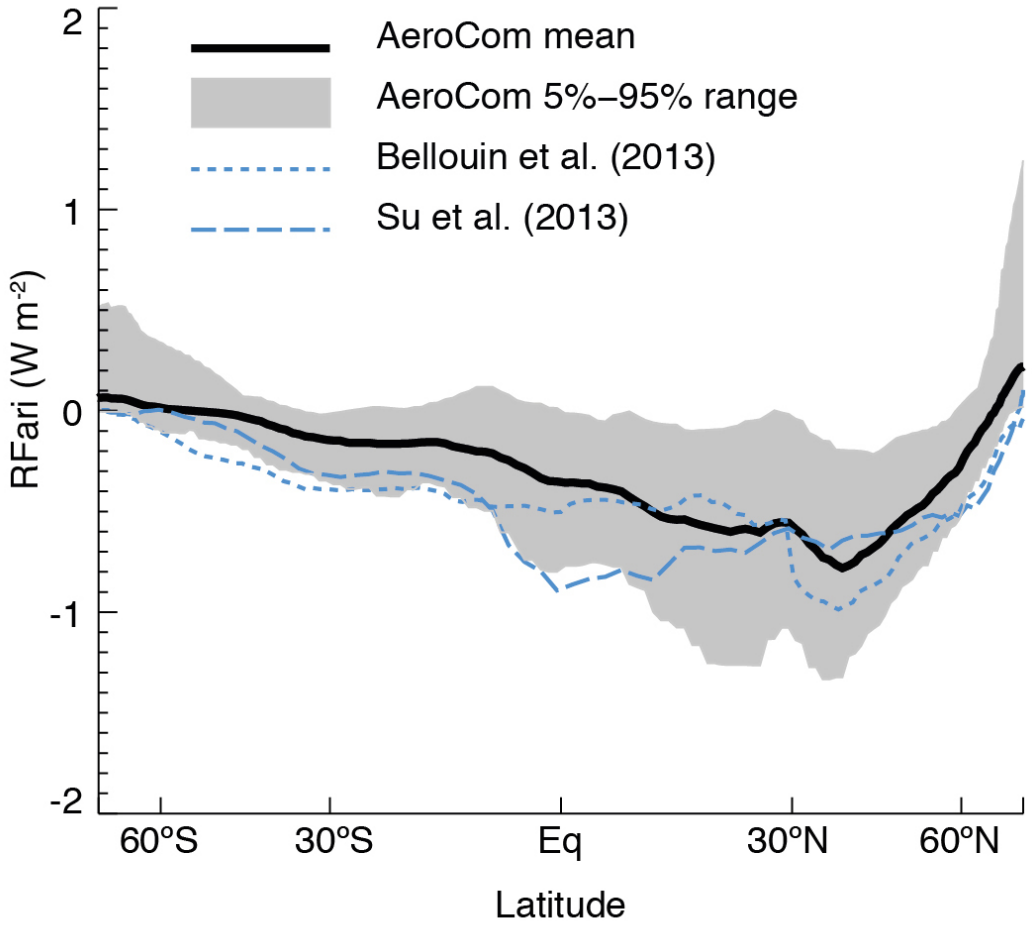
AeroCom Phase II, Myhre et al., ACP, 2013

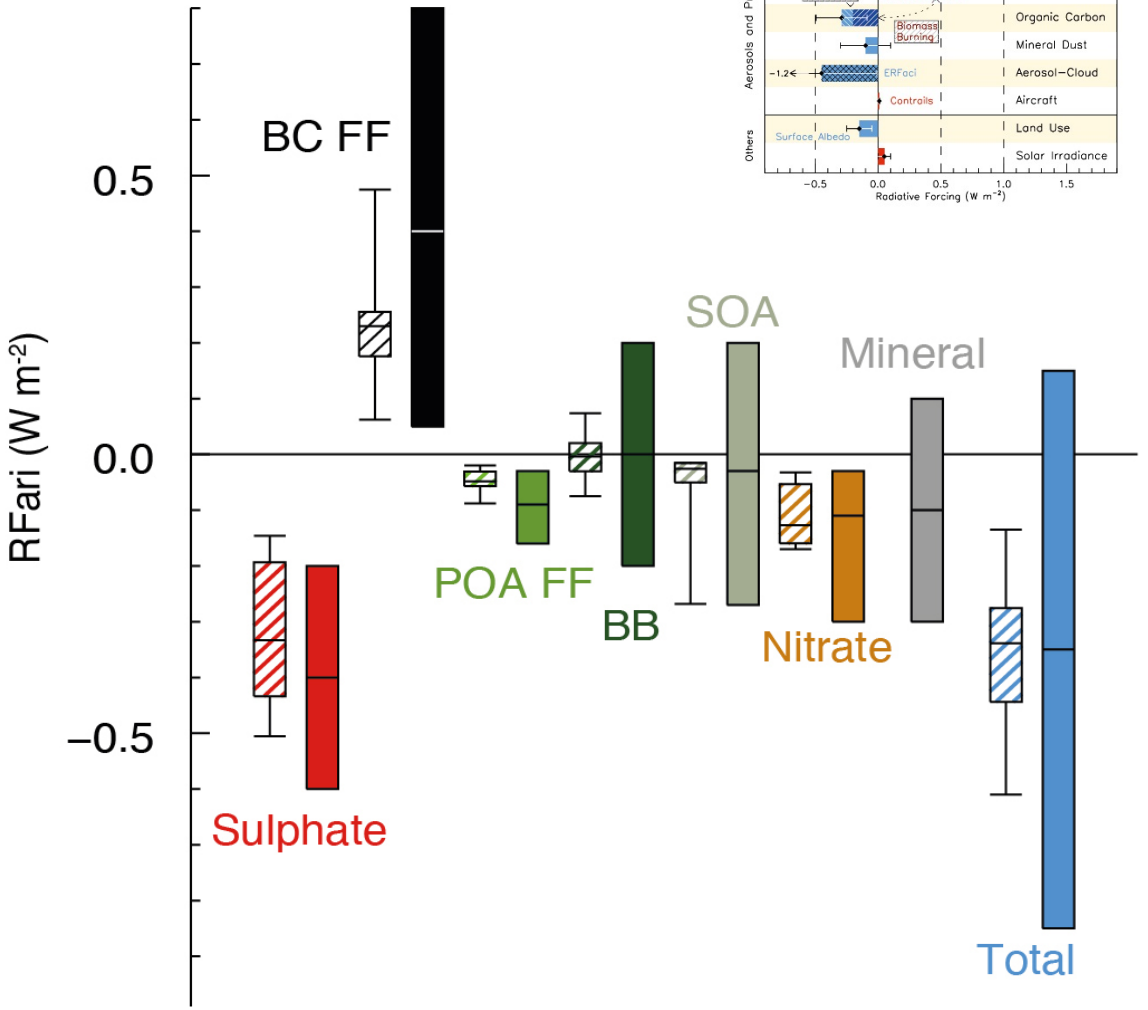


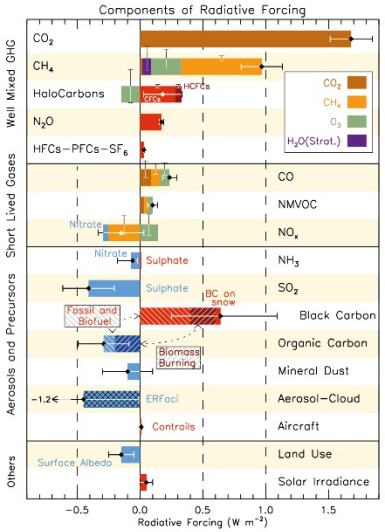




AeroCom Phase II in IPCC AR5



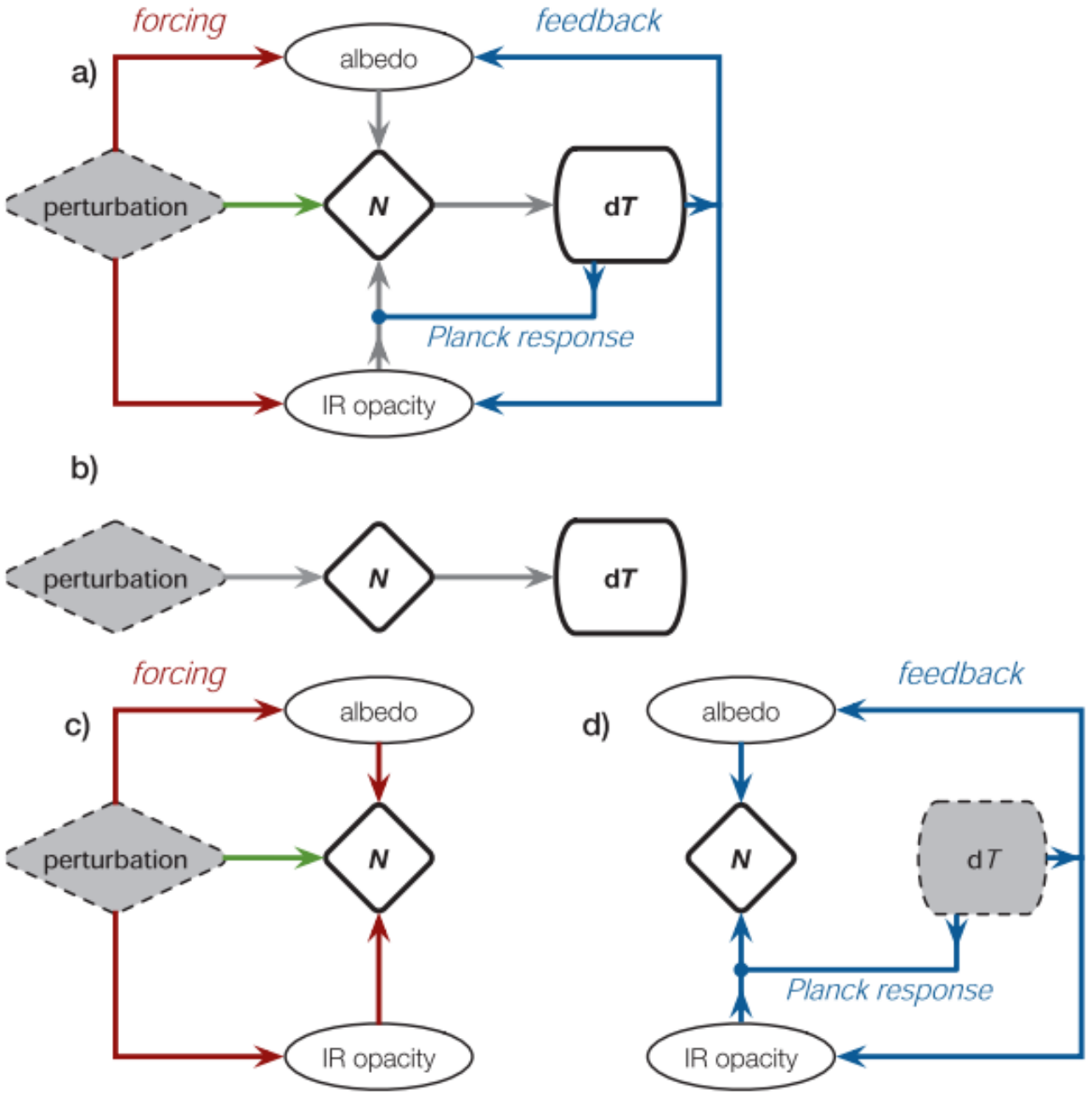




| Bjørn H. Samset | Research Director, CICERO | b.h.samset@cicero.oslo.no | @bjornhs |

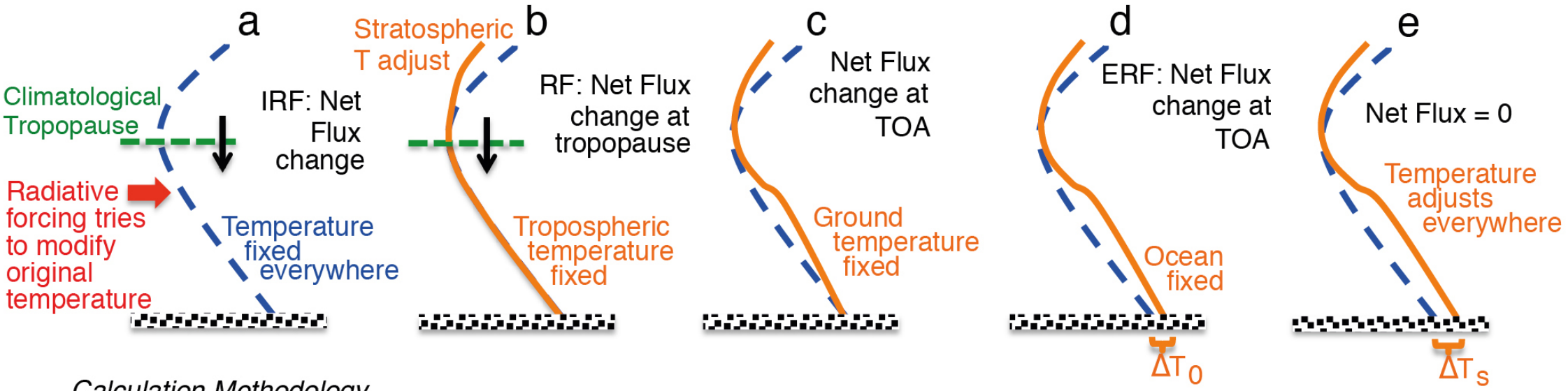
…but: How do we diagnose (E)RF in coupled climate models?

«RF» is not well-defined operationally



Sherwood et al., BAMS, 2015

RF ERF_reg ERF_fsst



Calculation Methodology

Online or offline pair of radiative transfer calculations within one simulation

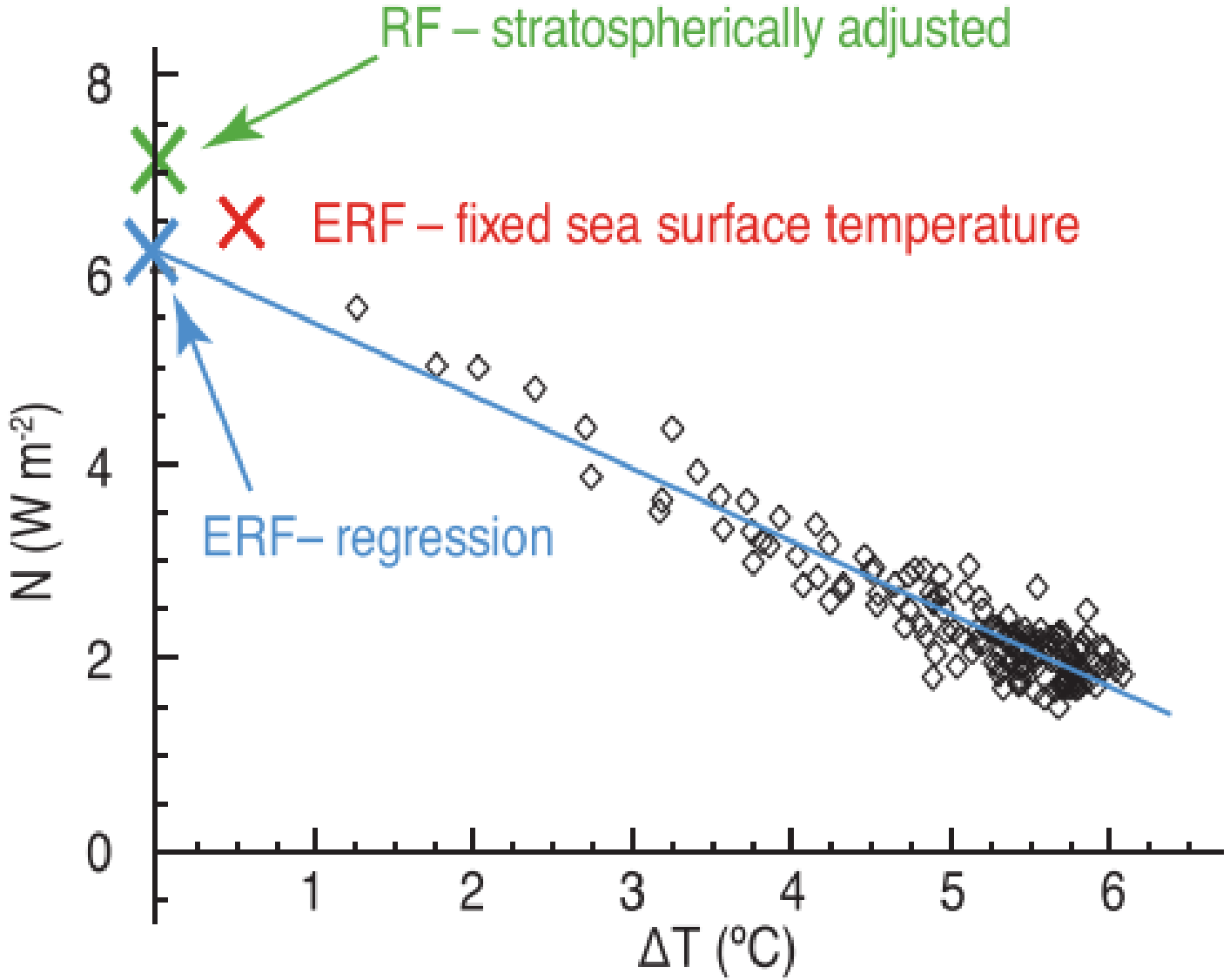
Difference between two offline radiative transfer calculations with prescribed surface and tropospheric conditions allowing stratospheric temperature to adjust

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

Myhre et al. 2013 (IPCC AR5 WG1 Ch8)



Sherwood et al., 2014, BAMS

Recommendations for diagnosing effective radiative forcing from climate models for CMIP6

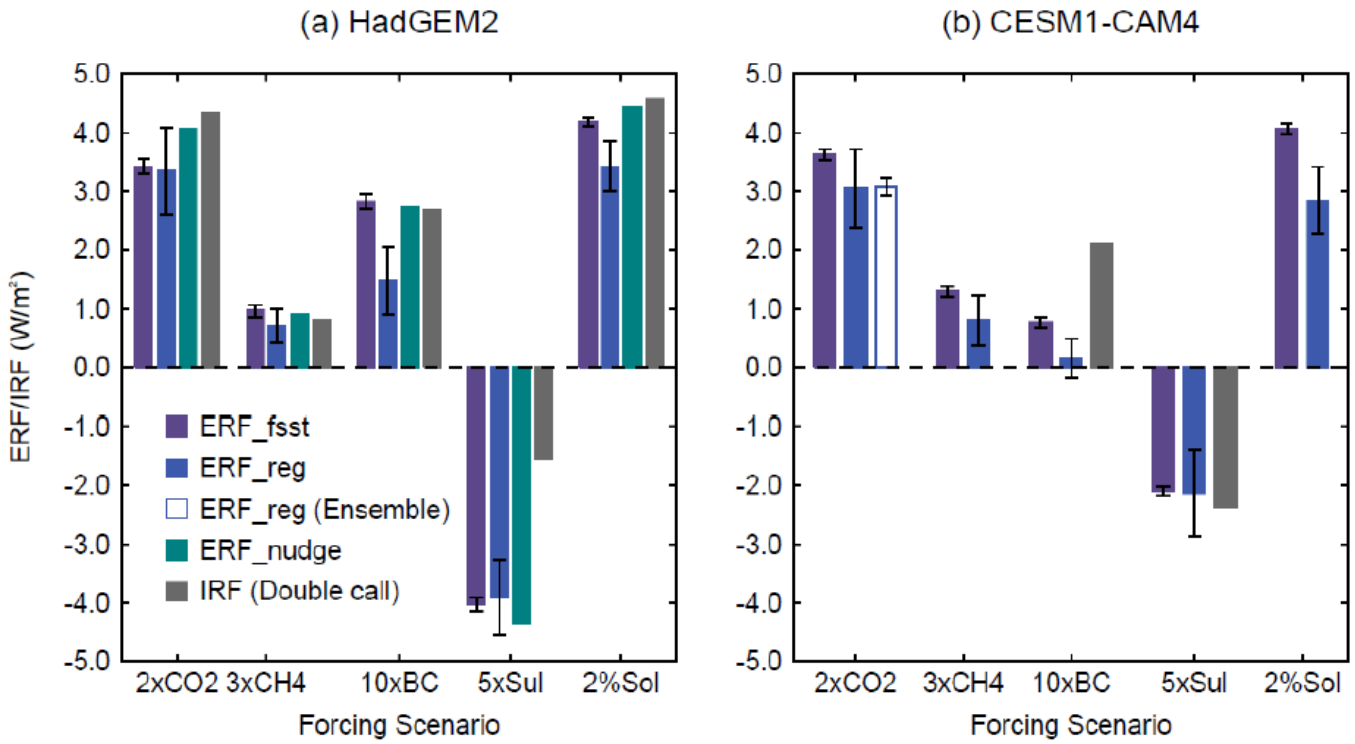
Piers M. Forster, Thomas Richardson, Amanda C. Maycock, Christopher J. Smith: University of Leeds, UK

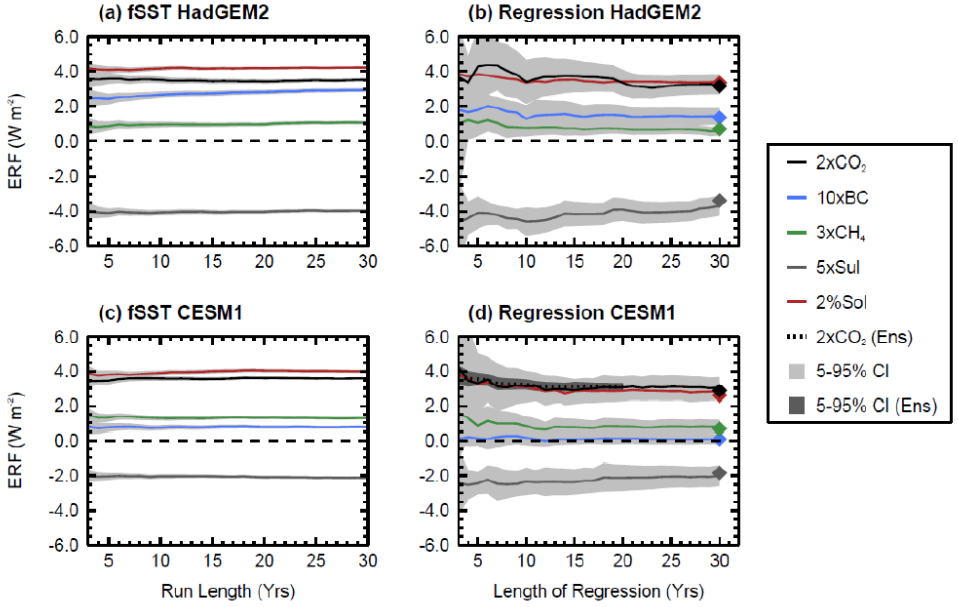
Bjorn H. Samset, Gunnar Myhre: CICERO, Oslo, Norway

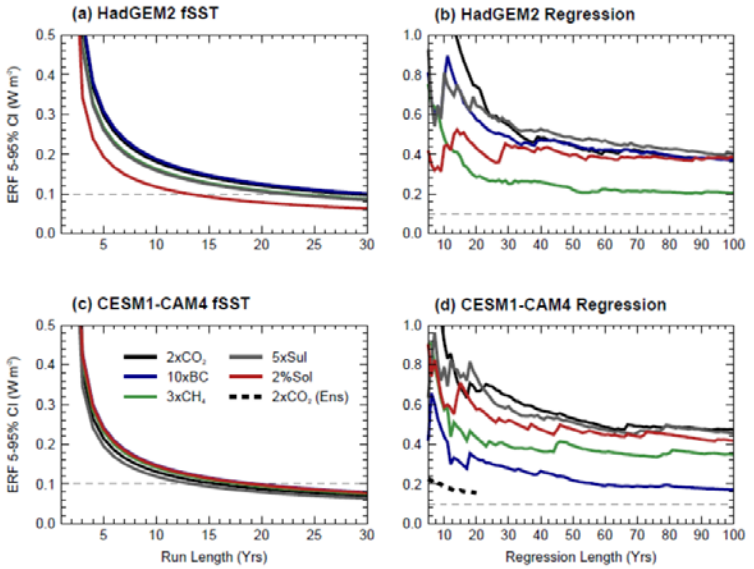
Timothy Andrews Met Office, U.K.

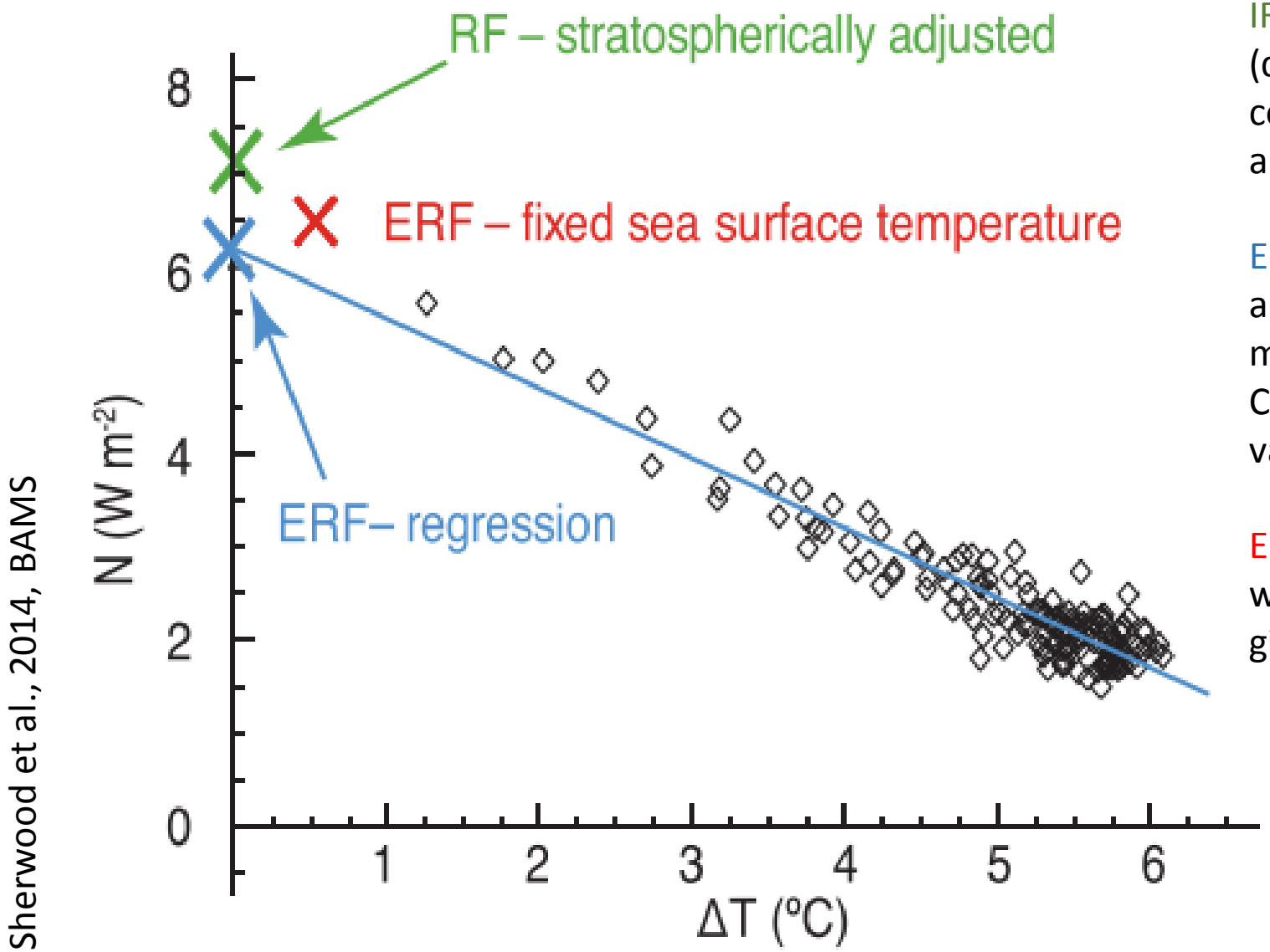
Robert Pincus, University of Colorado, U.S.A.

Michael Schulz, Norwegian Meteorological Institute, Norway









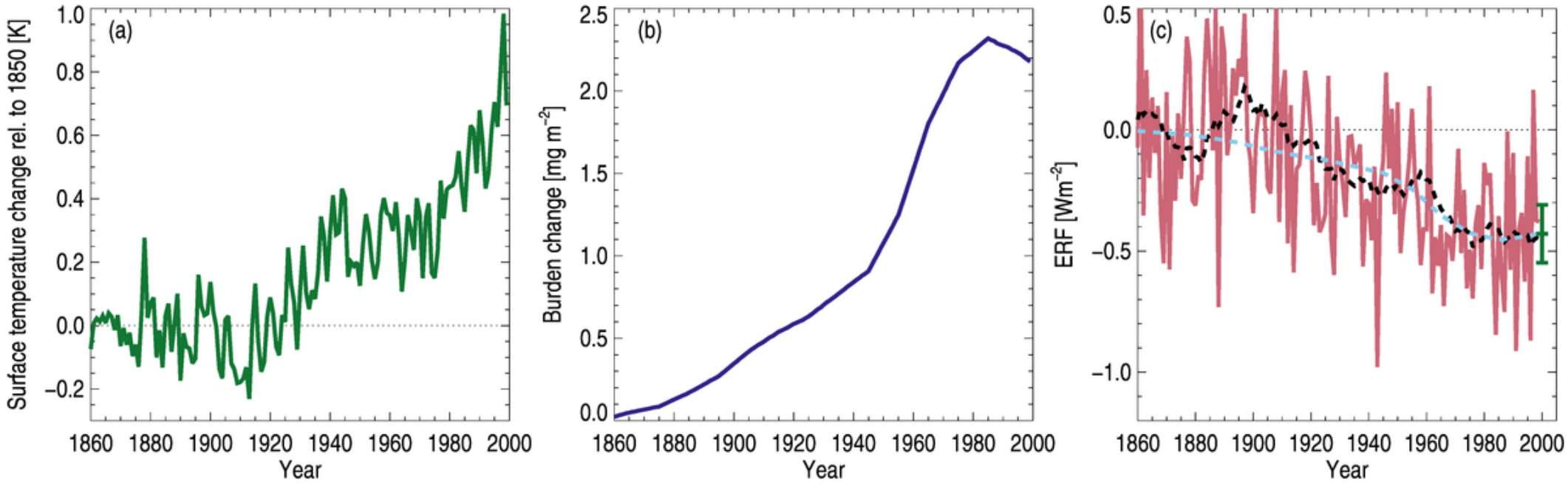
Sherwood et al., 2014, BAMS

IRF: Less inter-model variation. Reqires extra code (double call). No adjustments included, but combined with ERF estimate, allows separation of adjustments.

ERF_reg: Has exactly the definition we want for adjustments and responses. Requires long runs, multiple ensembles for weaker forcings.
Can't be used for transient evolutions. Interannual variability adds noise.

ERF_fsst: Best error characteristics. Regionally well sampled. Quick to run/test. Land response gives some temperature change.

ERF_trans: AMIP + time slices

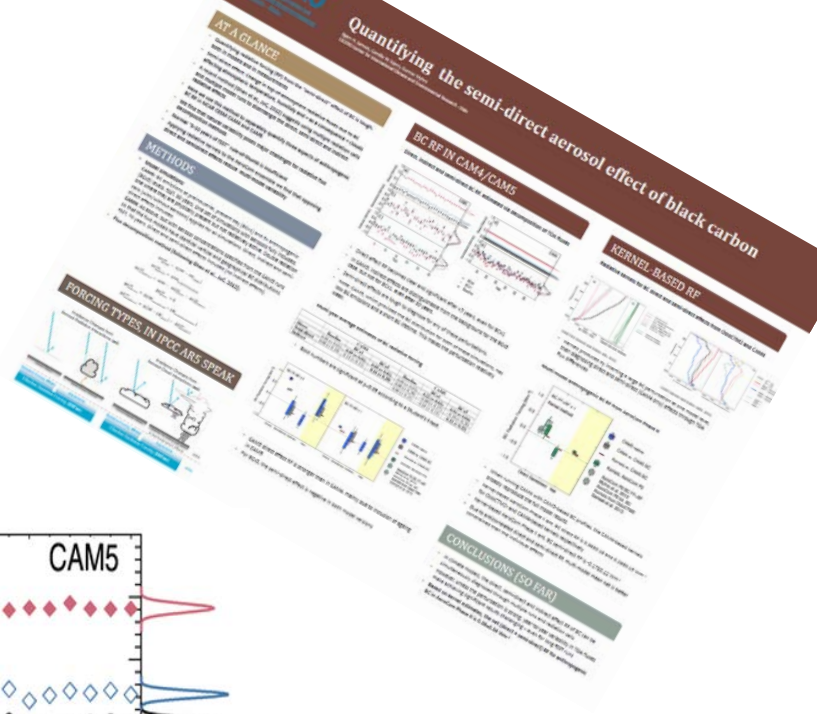


Recommendation from Forster et al.
(JGRA, in revision)

If our ambition is to estimate ERF to within 0.1 Wm^{-2} globally, the ERF_fSST approach meets this goal with 30 years of model integration. To obtain similar error characteristics from the ERF_reg approach would require more than 45 ensemble members of 20-year coupled model integrations, making ERF_fSST a far more computationally efficient method.

We recommend adopting an ERF_fSST approach for ERF estimates going forward, using a fixed SST and sea ice seasonally-varying climatology based on the model's own preindustrial climatology. This method is currently proposed by RFMIP for both its time-slice simulations and for historic and future scenarios. AerChemMIP also currently proposes a fixed preindustrial climatology for its time-slice experiments. The free running integrations are suitable for diagnosing ERF to within a 5% to 95% confidence interval of 0.1 W m^{-2} for a 30 year simulation. If better accuracy is needed nudging approaches may provide a useful way forward but are hard to implement and have not yet been sufficiently tested in a range of models.

Disentangling the direct, indirect and semi-direct aerosol effects (i.e. forcing and cloud-mediated adjustments) via multiple radiation calls?



$$RF^{SW}_{direct} = \Delta(SW - SW_{clean})$$

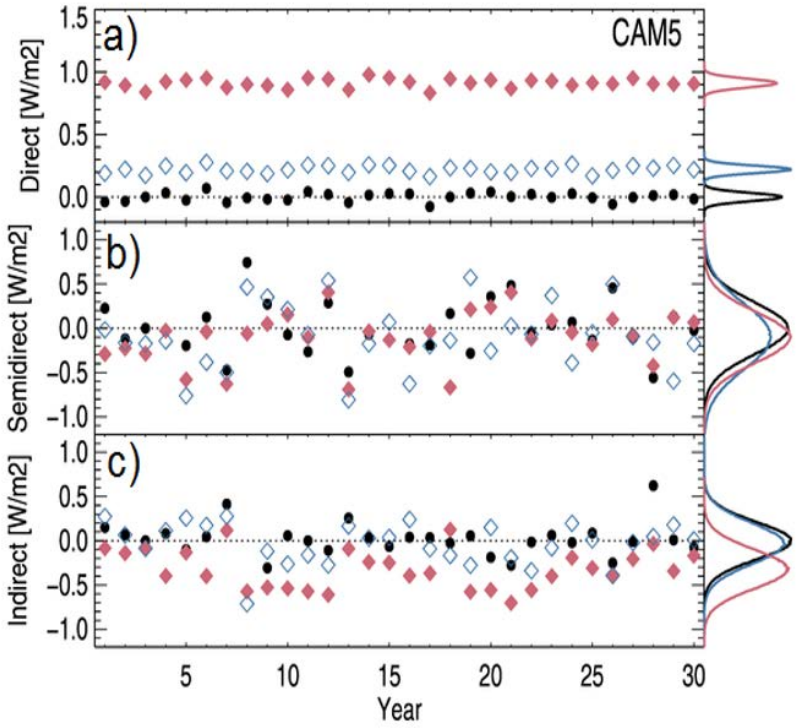
$$RF^{SW}_{indirect} = \Delta SW_{noanthrad,clean}$$

$$RF^{SW}_{semidirect} = \Delta SW - RF^{SW}_{DIRECT} - RF^{SW}_{INDIRECT}$$

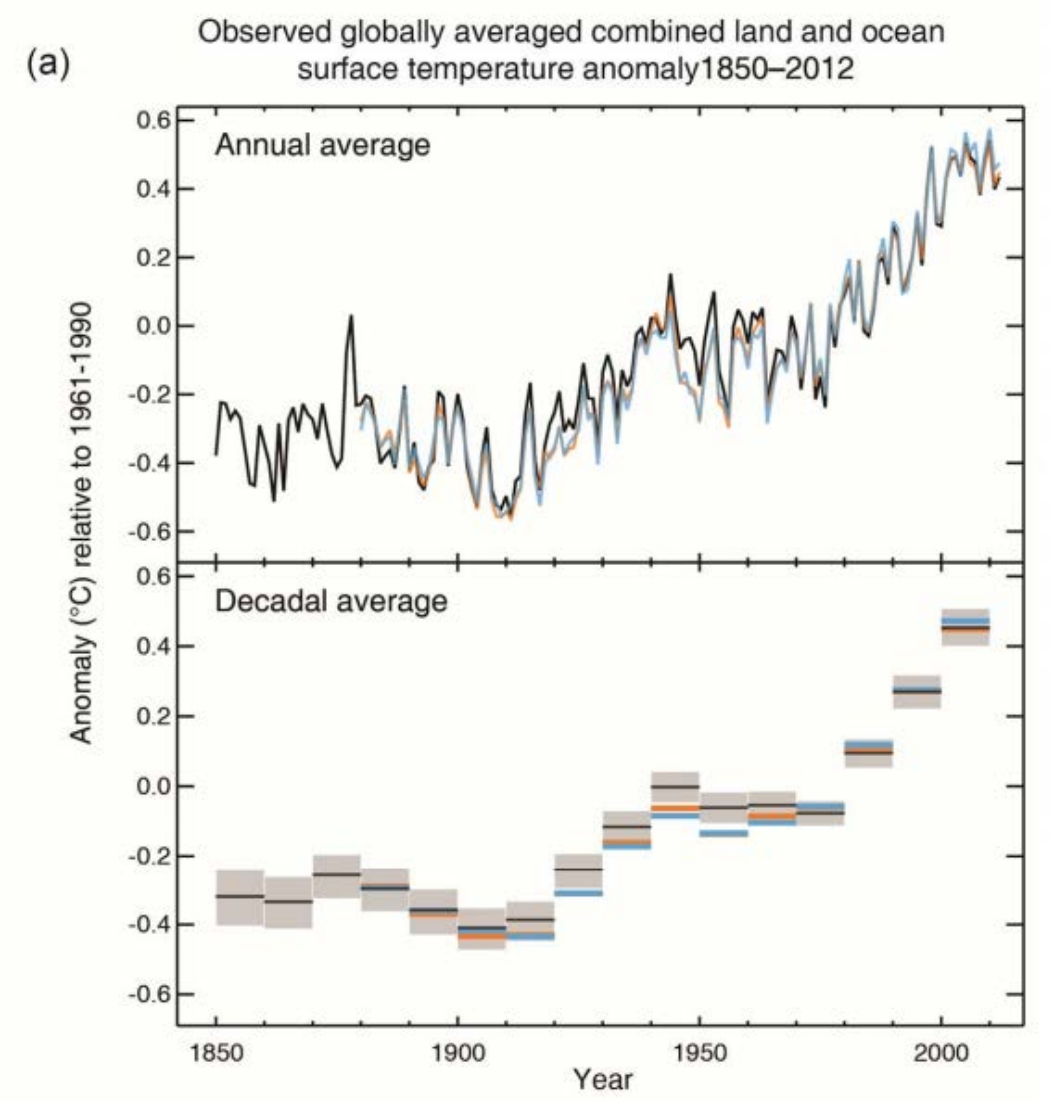
$$RF^{LW}_{direct} \approx 0$$

$$RF^{LW}_{indirect} = \Delta(LW_{noanthrad} - LW_{noanthrad,clear})$$

$$RF^{LW}_{semidirect} = \Delta(LW - LW_{clear}) - RF^{LW}_{INDIRECT}$$



Ghan et al., JoC, 2012; Ghan, ACP, 2013



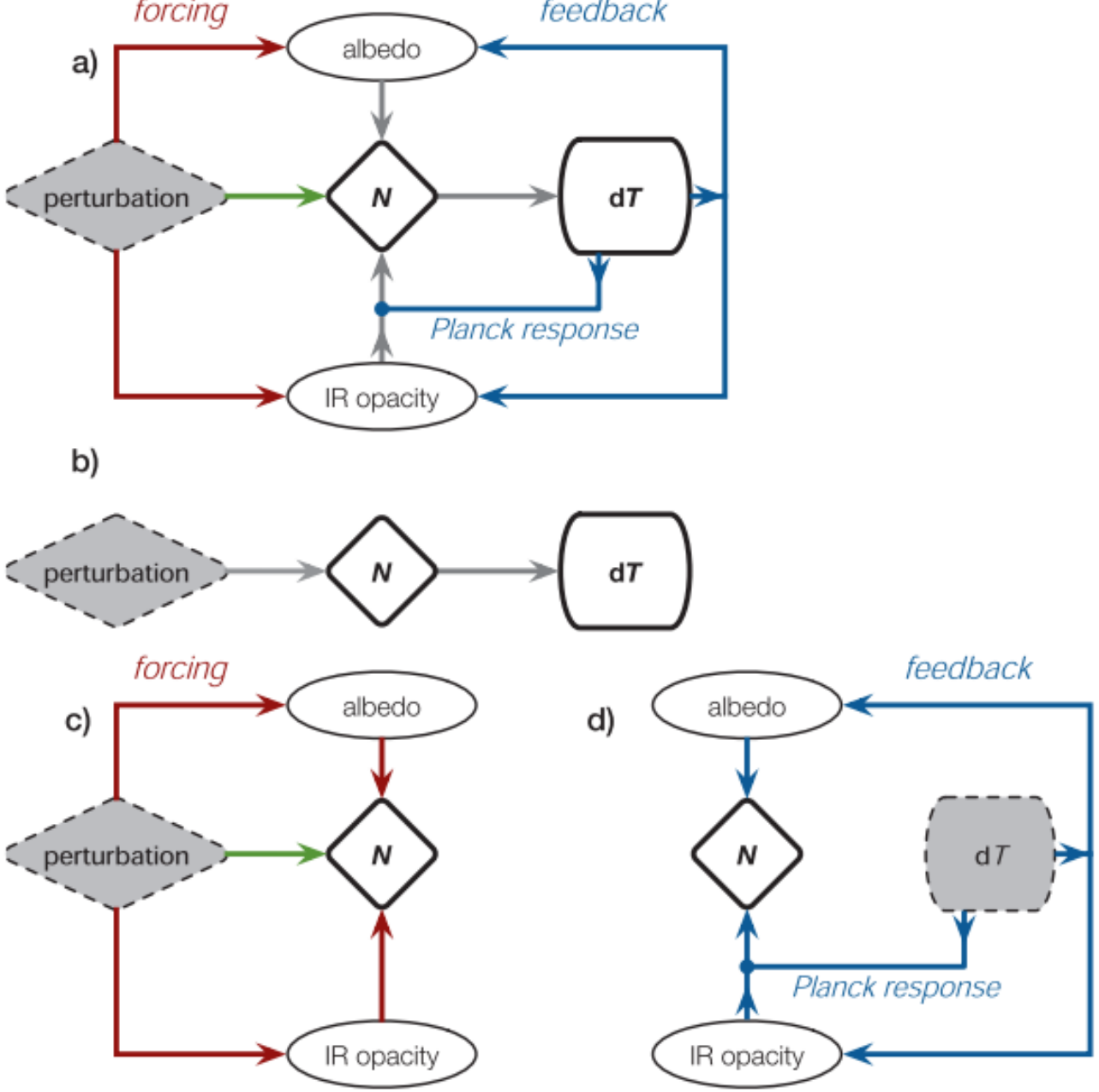
Conclusions

What combination of changes to the global climate system caused this?

A set of climate perturbations causing instantaneous radiative forcing, a complex web of subsequent (rapid) adjustments, followed by (generally slower) responses driven by the change in surface temperature.

To diagnose all this in climate models, we need both IRF and ERF estimates, but most of all we need to agree on an operational definition and record the required diagnostics.

Conclusions


forcing
feedback
a)
albedo
perturbation
N
dT
Planck response
IR opacity
b)
perturbation
N
dT
forcing
c)
albedo
perturbation
N
IR opacity
feedback
d)
albedo
N
dT
Planck response
IR opacity

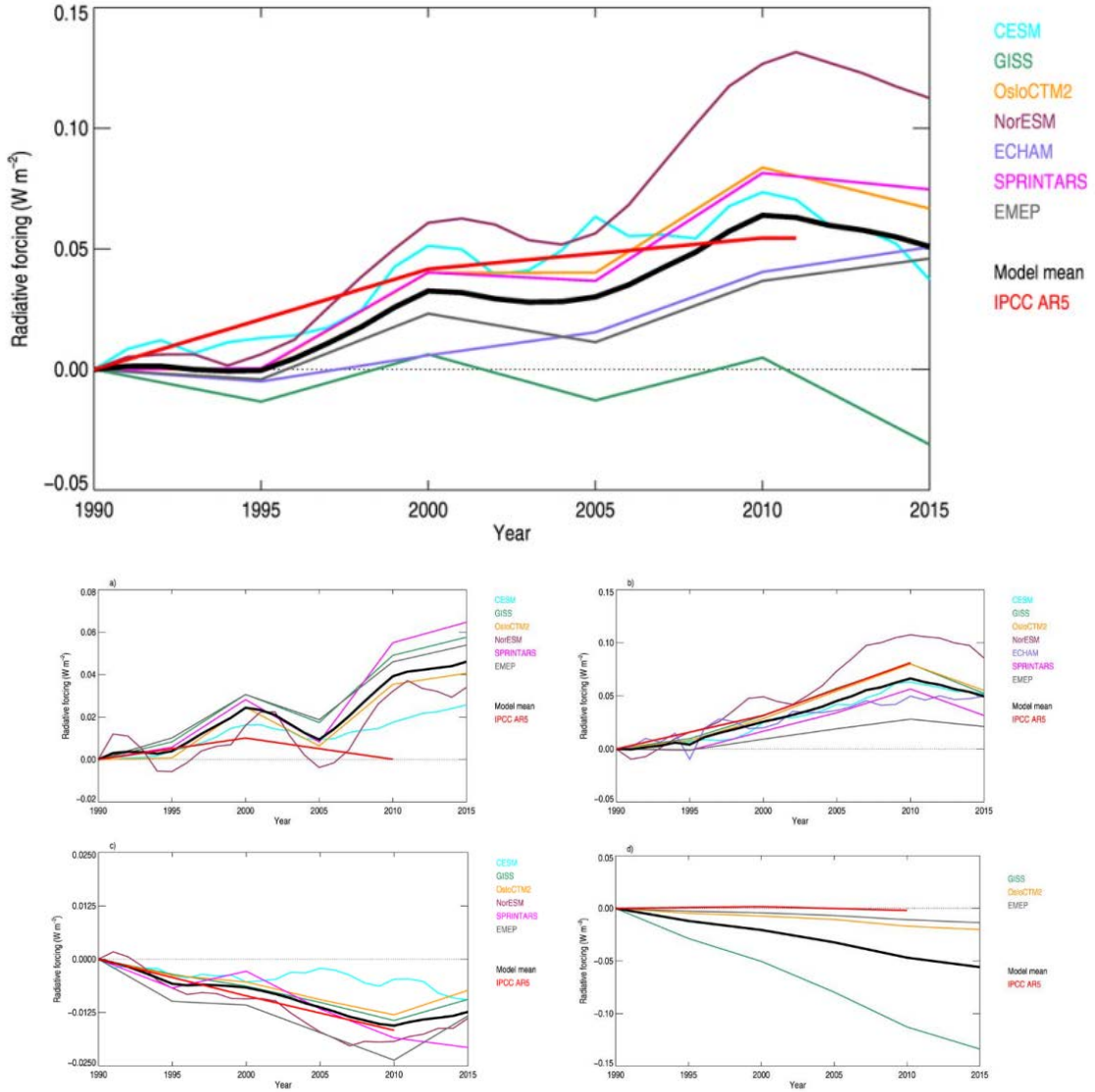


Figure 3: Radiative forcing (W m^{-2}) of the direct aerosol effect by aerosol component (sulphate, a; BC, b; OA, c; nitrate, d) over the period 1990-2015.

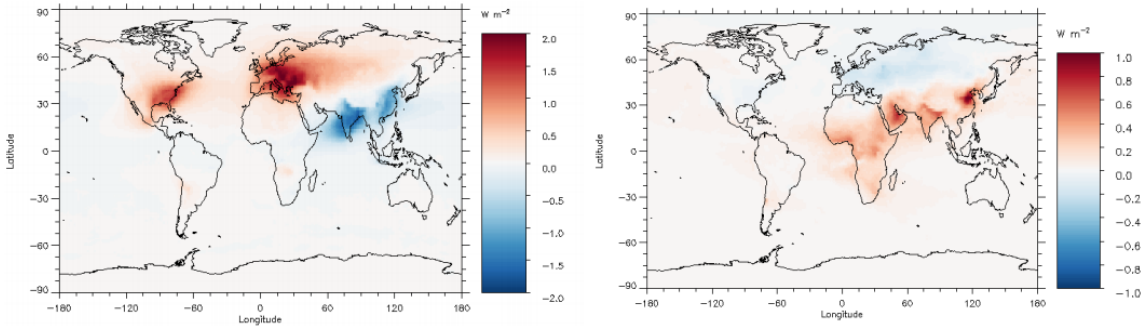


Figure 4: Geographical distribution of the 1990-2015 radiative forcing (W m^{-2}) of the multi-model mean direct aerosol effect sulphate (left) and BC (right) as driven by emission changes.

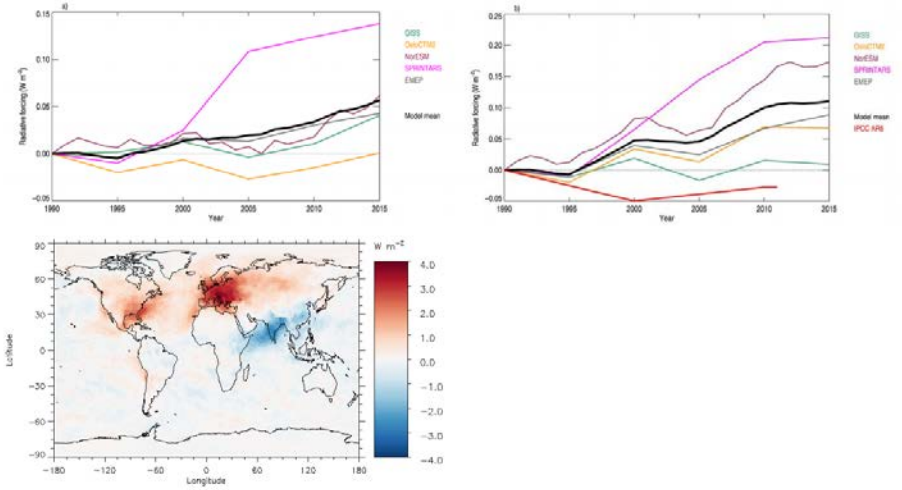
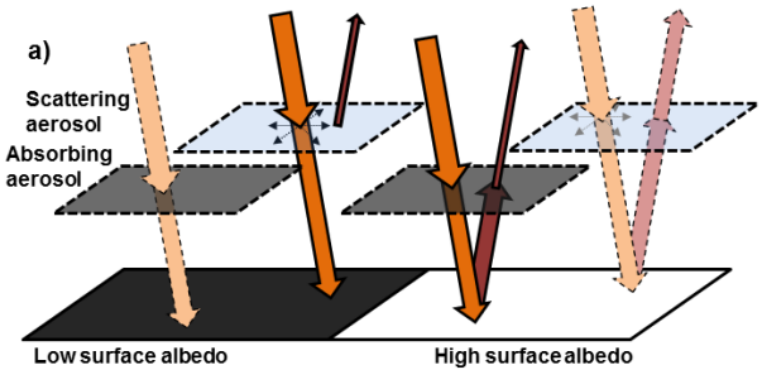
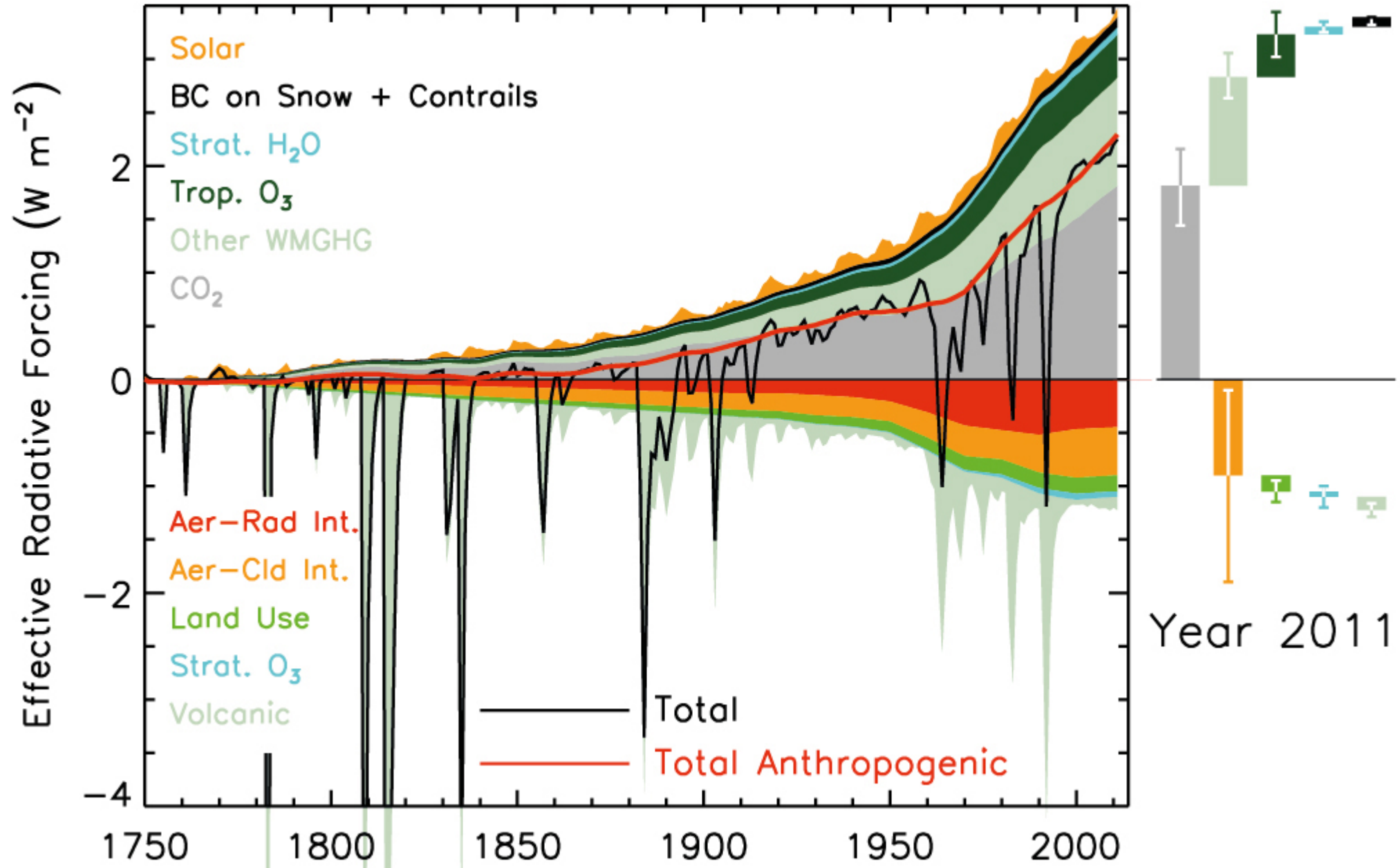


Figure 5: Radiative forcing (W m^{-2}) over the period 1990-2015 of the aerosol-cloud interaction for a subset of the models (a) and total aerosol effect (b). The lower panel shows the geographical distribution of radiative forcing (W m^{-2}) of the multi-model mean total aerosol effect.

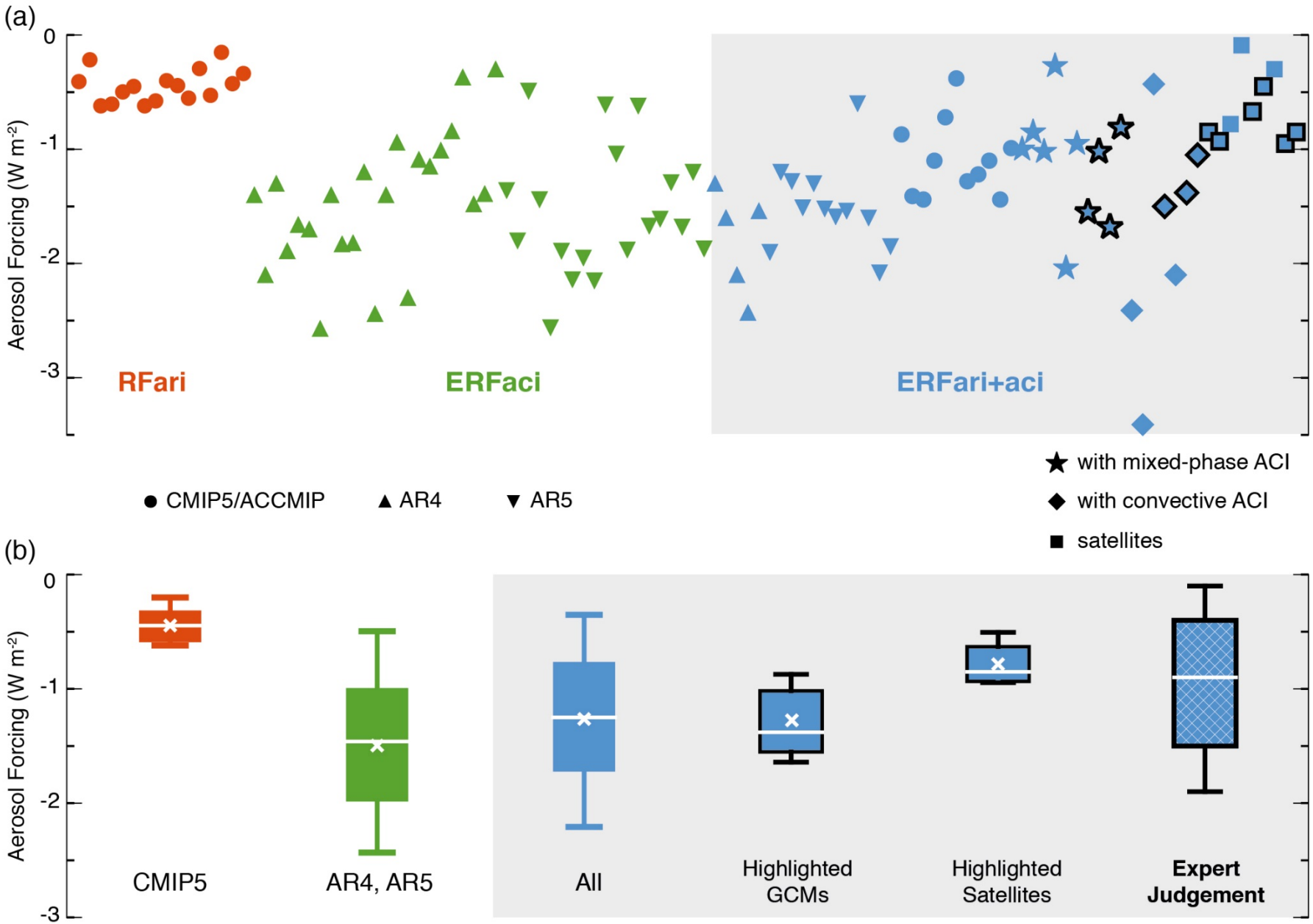
Parameters affecting the RF of the direct radiative effect (RFari) of black carbon



- RF def (energy balance plot)
- AR5: RF summary, time series, ERFari/aci def
- + RF TOA, surf, atm
- RF in AeroCom (TOA flux difference, nudged winds, same met) Ph1 and 2
- Example: What goes into RF of BC? Opt. Prop., ageing, hygr growth, location, altitude, abs vs scattering, … Albedo-dependence…
- AeroCom results, usage in AR5
- IPCC/Sherwood ill av greg-metode etc.
- RF in coupled simulations: Forster et al. Greg, fSST, double call
- Decoupling: Semidir (poster tease), multi-calls
- Aerosol RF over recent years (acpd)
- RF is not climate impact. ERF er nærmere.



Myhre et al. 2013 (IPCC AR5 WG1 Ch8)


(a)
Aerosol Forcing (W m-2)
0
-1
-2
-3
RFari
ERFaci
ERFari+aci
● CMIP5/ACCMIP
▲ AR4
▼ AR5
★ with mixed-phase ACI
◆ with convective ACI
■ satellites
(b)
Aerosol Forcing (W m-2)
0
-1
-2
-3
CMIP5
AR4, AR5
All
Highlighted GCMs
Highlighted Satellites
Expert Judgement