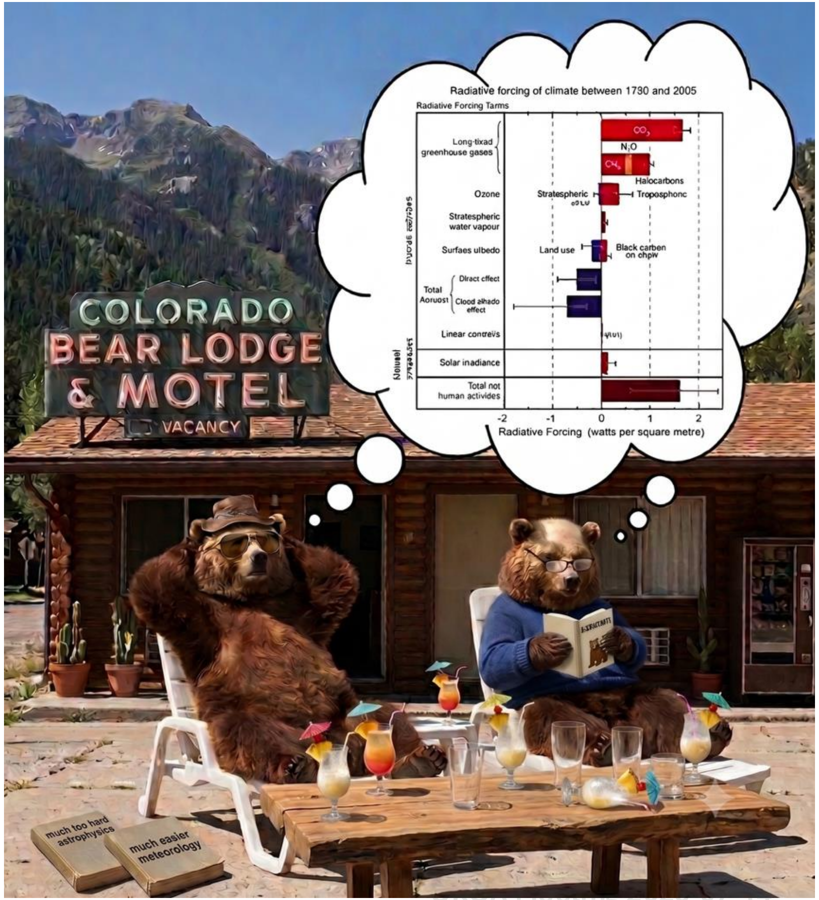
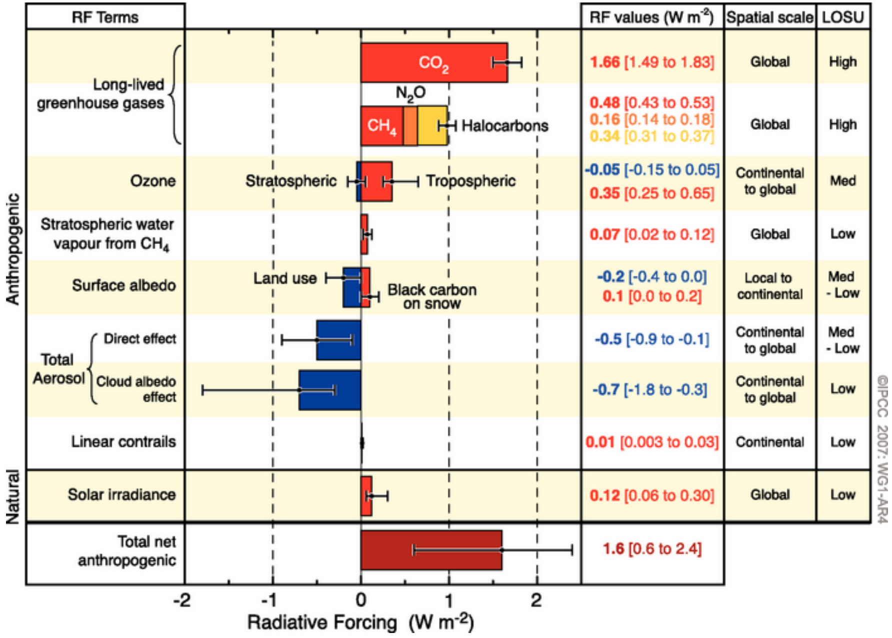
What is AerChemMIP?

- Goal is to quantify the climate and air-quality impacts of aerosols and chemically reactive gases.
- Target species are the near-term climate forcers (NTCFs): methane, tropospheric ozone and aerosols and their precursors, plus nitrous oxide and ozone-depleting halocarbons
- Built on the CMIP6 DECK, the historical simulations and ScenarioMIP futures, so the aerosol and chemistry contributions can be separated out
- Requests specific composition diagnostics to characterise the chemical state, evaluate the models, and understand why they differ
- Successor to the offline ACCMIP effort, now with interactive chemistry inside the coupled climate models



Motivation – as of AR5 (2013)

- NTCFs have driven a historical forcing comparable in magnitude to CO2, but far more spatially inhomogeneous, so the regional response differs from an equivalent well-mixed forcing
- NTCF forcing was the largest single source of uncertainty in total anthropogenic ERF since pre-industrial (IPCC AR5)
- The couplings are complex: methane is a greenhouse gas, an ozone precursor and the dominant OH sink, and feeds stratospheric water vapour; it has more than doubled since 1750 (722 to 1803 ppb)
- Natural systems emit precursors (soil NOx, biogenic VOCs, wildfires, DMS) that respond to climate, needed to be quantified. Earlier efforts (ACCMIP, AeroCom) were offline or decoupled from the CMIP climate runs, so they could not properly characterise the ERFs or the feedbacks
- A coordinated, consistent multi-model set was needed for a clean between-model comparison, to inform IPCC AR6



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The four science questions (‘aims’)

- 1. How have anthropogenic emissions contributed to global radiative forcing and affected regional climate over the historical period?
- 2. How might future policies (climate, air quality, land use) affect the abundances of NTCFs and their climate impacts?
- 3. How do uncertainties in historical NTCF emissions affect radiative-forcing estimates?
- 4. How important are climate feedbacks to natural NTCF emissions, atmospheric composition, and radiative effects?

Each tier and experiment family maps back to one or more of these

AerChemMIP's Approach

- Quantify the effects of interactive aerosols, tropospheric chemistry and stratospheric chemistry; ideally all three, but depending on model capability
- Paired or **counterfactual** runs
  - ERF from atmosphere-only timeslice runs (30 yrs) with identical SSTs but differing composition
  - Climate response from coupled atmosphere-ocean runs with differing composition: the difference in surface temperature and precipitation
  - Diagnose each forcing agent against internal variability from piControl
  - Three ensemble members - NTCF signals are small against internal variability
- Configuration suffixes flag the required complexity: AER (tropospheric aerosol), CHEM-T (tropospheric chemistry), CHEM-S (stratospheric chemistry)
- Baselined on the CMIP6 DECK and historical simulations with matching chemistry and aerosol setup

Experiments, tiers and their uses

- **Four experiment families**
  - Historical, 1850-2014, coupled-ocean and prescribed-SST (hist-piNTCF, hist-piAer, hist-1950HC)
  - Future, 2015-2055, SSP3-7.0 reference vs SSP3-7.0-lowNTCF (strong air-quality controls)
  - Time-slice fixed-SST ERF, the piClim family (piClim-control, piClim-NTCF, piClim-aer, piClim-CH4, down to single species)
  - Natural-emissions runs, doubling a natural flux (dust, sea salt, DMS, fire, lightning NOx, biogenic VOC) to isolate each feedback
- **Three tiers by priority**
  - Tier 1: the minimum needed to answer Q1 and Q2, the overall impact of NTCFs and reactive well-mixed gases
  - Tier 2: separates aerosol from ozone precursors, adding detail to Q1 and Q2
  - Tier 3: individual-species speciation (NOx, VOC, SO2, OC, NH3), supporting Q3; natural-emission runs sit under Q4

Experiments, tiers and their uses

- **Experiment families**
  - Historical attribution experiments
    - **Coupled-ocean and**
    - **Prescribed-SST** (hist-piNTCF, hist-piAer, hist-1950HC)
  - Future(2015-2055)
    - **Coupled ocean** SSP3-7.0 vs SSP3-7.0-lowNTCF (strong air-quality controls)
  - Time-slice PI-PD ERF for single species)
  - Natural-emissions runs, doubling a natural flux (dust, sea salt, DMS, fire, lightning NOx, biogenic VOC) to isolate each feedback

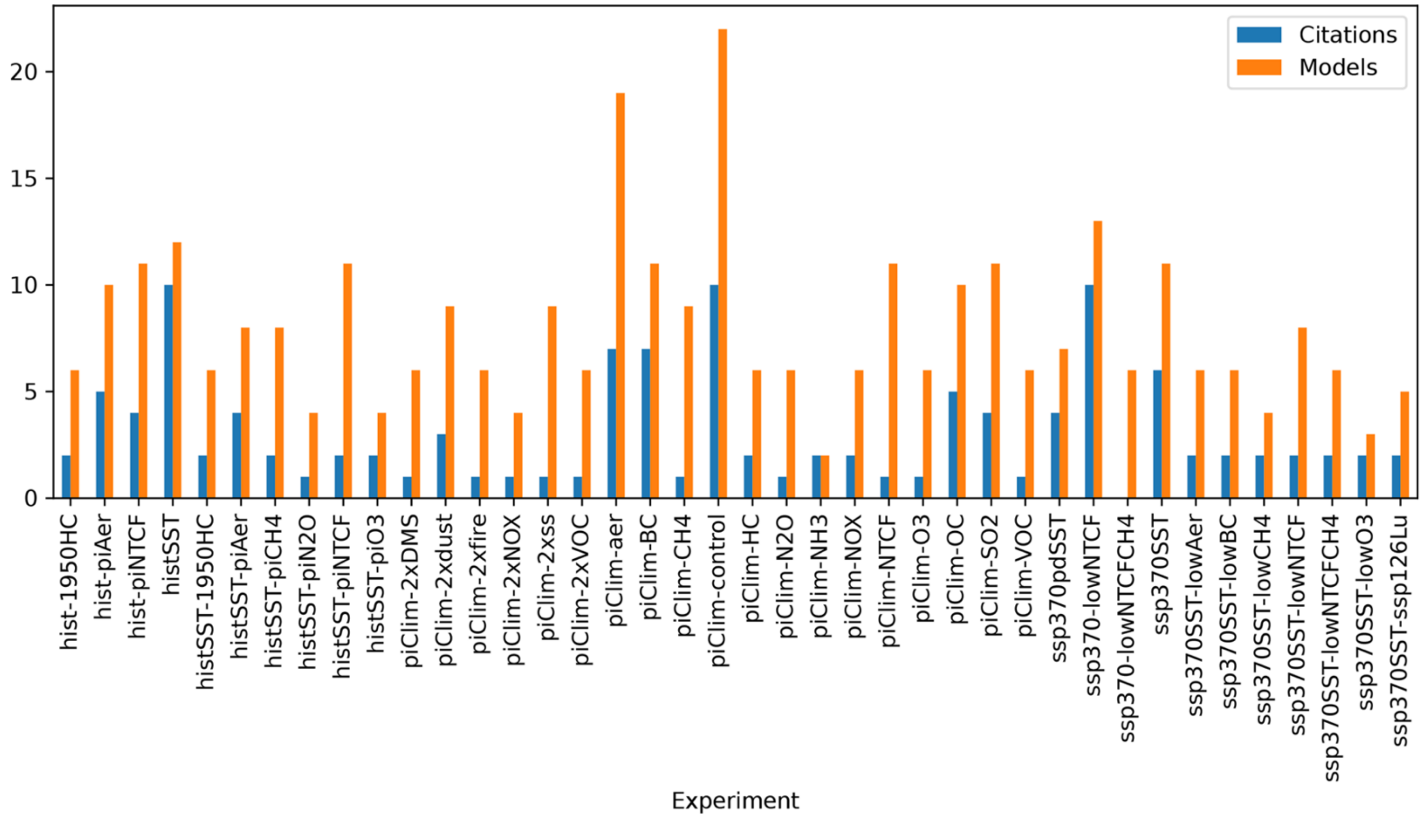
	Coupled A/O - **climate response**		Transient experiment, prescribed SST - **transient ERF**		Idealized timeslice - **PI-PD ERF**	
	hist-	ssp370-	histSST-	ssp370SST-	piClim-	
T1 (A1-A3)	piNTCF 1950HC	ssp370 lowNTCF	histSST piNTCF 1950HC piCH4	ssp370SST lowNTCF	Control NTCF CH4 HC	
T2 (A3, A4)	piAer		piAer piO3 piN2O	lowAer lowBC lowO3 lowCH4 ssp126Lu	aer BC O3 N2O	
T3 (A3)					NOx VOC SO2 OC NH3 2xDMS 2xfire 2xNOx 2xVOC	

Experiments, tiers and their uses

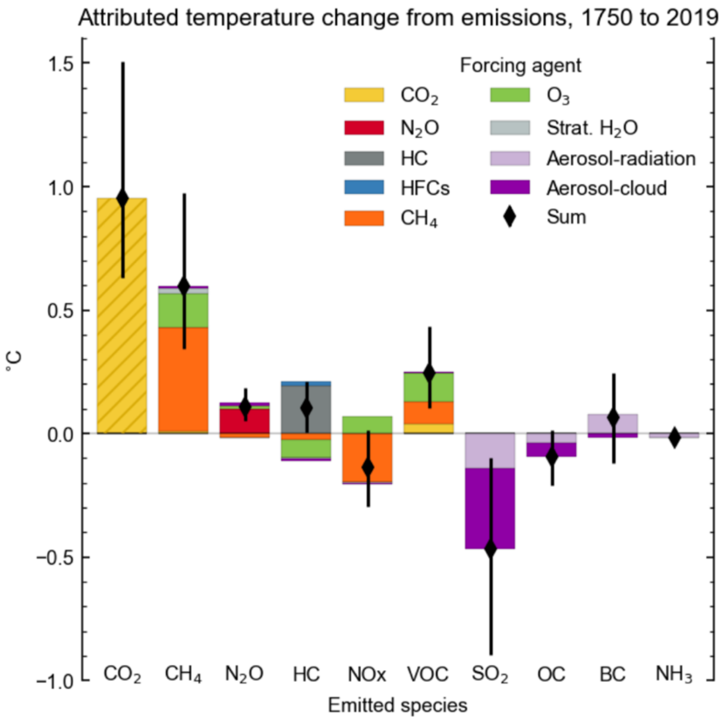
- **Three tiers by priority**
  - Tier 1: the minimum needed to answer Q1 (hist forcing) and Q2 (future policy) = the overall impact of NTCFs and reactive well-mixed gases.
  - Tier 2: separates aerosol from ozone precursors, adding detail to Q1 and Q2
  - Tier 3: individual-species speciation (NOx, VOC, SO2, OC, NH3), supporting Q3; natural-emission expts sit under Q4 (as RF per kg)

	Coupled A/O - **climate response**		Transient experiment, prescribed SST - **transient ERF**		Idealized timeslice - **PI-PD ERF**	
	hist-	ssp370-	histSST-	ssp370SST-	piClim-	
T1 (A1-A3)	piNTCF 1950HC	ssp370 lowNTCF	histSST piNTCF 1950HC piCH4	ssp370SST lowNTCF	Control NTCF CH4 HC	
T2 (A3, A4)	piAer		piAer piO3 piN2O	lowAer lowBC lowO3 lowCH4 ssp126Lu	aer BC O3 N2O	
T3 (A3)					NOx VOC SO2 OC NH3 2xDMS 2xfire 2xNOx 2xVOC	

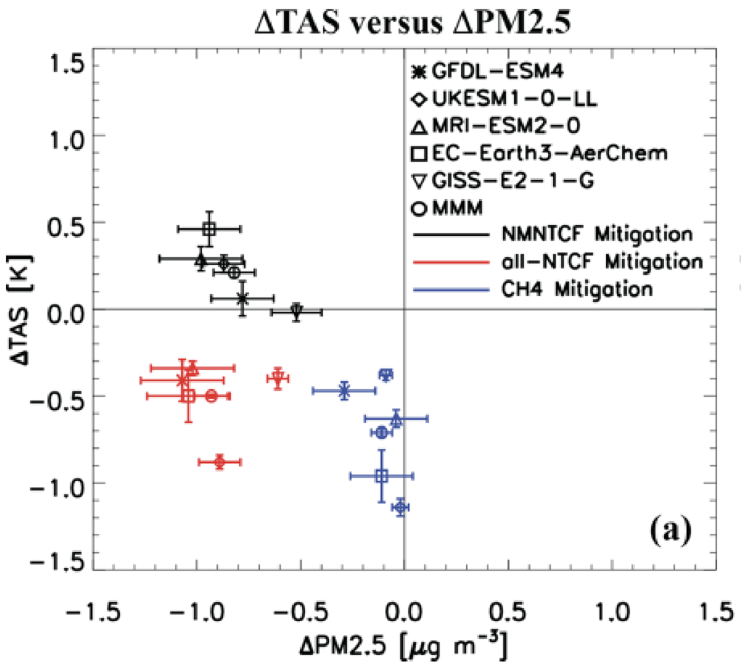
Take up by centres and resulting publications



Successes – examples from literature



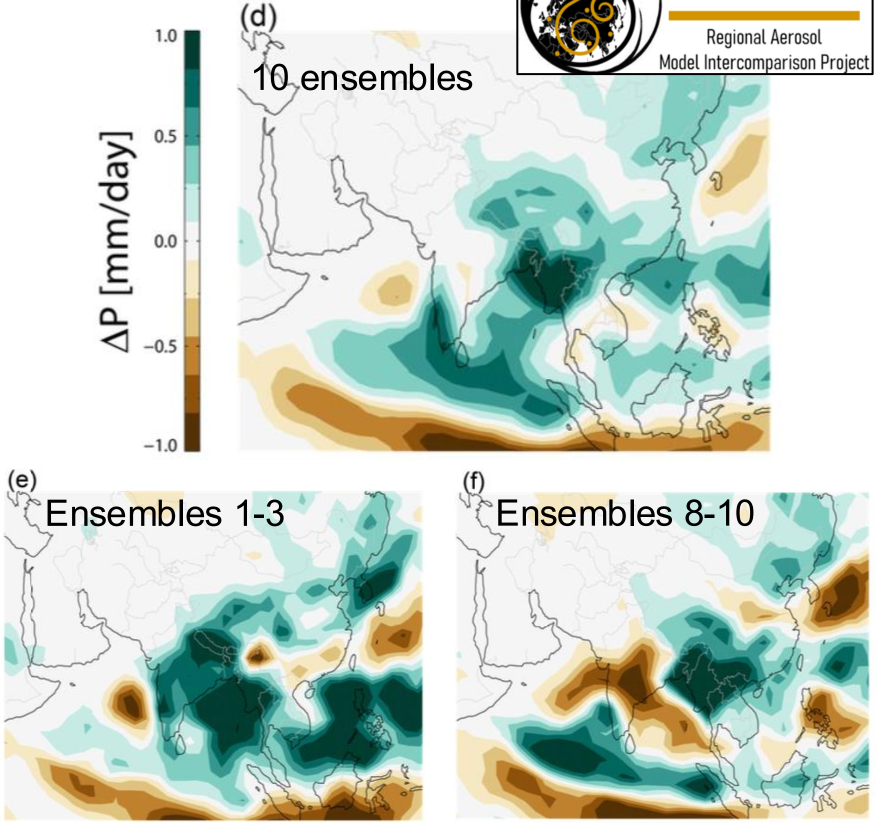
PI-PD ERF



Climate response

Challenges

- **Small signals vs natural variability**
  - Three ensemble members can be challenging
  - Some signals should be treated with caution
- **Consistent diagnostic data**
  - Diagnostics go in sets – O3 and PTP needed to diagnose the tropospheric burden
  - Defining the tropopshere still a challenge!
- **Isolation of climate signal/penalty** – ssp370pdSST
- **PI or PD as base state for ERF** (see Zhang et al., 2026) for more details. ERF of BC is different, also maybe NH3 emissions.
- **Emissions uncertainty** needs further work



Short-lived climate forcers

The Copenhagen Accord for limiting global warming: Criteria, constraints, and available avenues

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Edited by William C. Clark, Harvard University, Cambridge, MA, and approved March 26, 2010 (received for review February 22, 2010)

At last, all the major emitters of greenhouse gases (GHGs) have agreed under the Copenhagen Accord that global average temperature increase should be kept below 2 °C. This study develops the criteria for limiting the warming below 2 °C, identifies the constraints imposed on policy makers, and explores available mitigation avenues. One important criterion is that the radiant energy added by human activities should not exceed 2.5 (range: 1.7–4) watts per square meter (Wm^{-2}) of the Earth's surface. The blanket of man-made GHGs has already added 3 (range: 2.6–3.5) Wm^{-2}. Even if GHG emissions peak in 2015, the radiant energy barrier will be exceeded by 100%, requiring simultaneous pursuit of three avenues: (*i*) reduce the rate of thickening of the blanket by stabilizing CO_2 concentration below 441 ppm during this century (a massive decarbonization of the energy sector is necessary to accomplish this Herculean task), (*ii*) ensure that air pollution laws that reduce the masking effect of cooling aerosols be made radiant energy-neutral by reductions in black carbon and ozone, and (*iii*) thin the blanket by reducing emissions of short-lived GHGs. Methane and hydrofluorocarbons emerge as the prime targets. These actions, even if we are restricted to available technologies for avenues *ii* and *iii*, can reduce the probability of exceeding the 2 °C barrier before 2050 to less than 10%, and before 2100 to less than 50%. With such actions, the four decades we have until 2050 should be exploited to develop and scale-up revolutionary technologies to restrict the warming to less than 1.5 °C.

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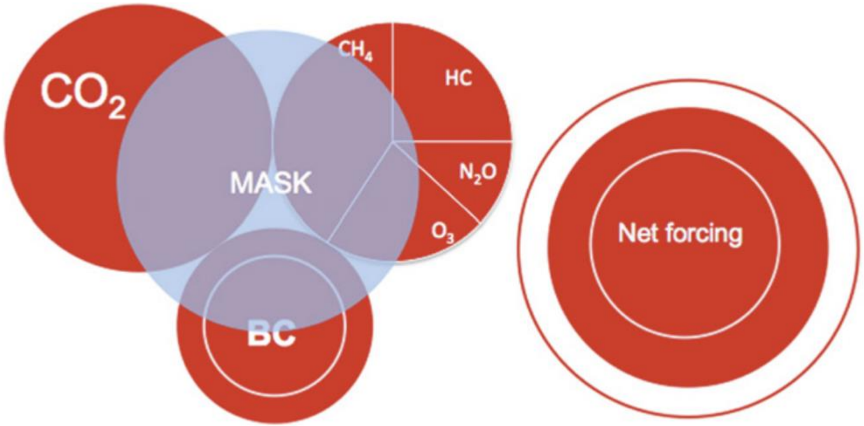
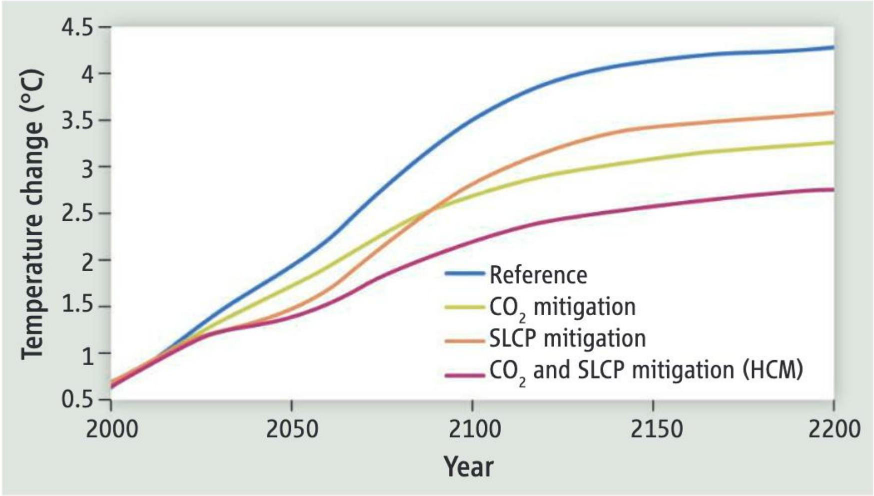
- Ramanathan and Xu, PNAS, 2010

Short-lived climate forcers

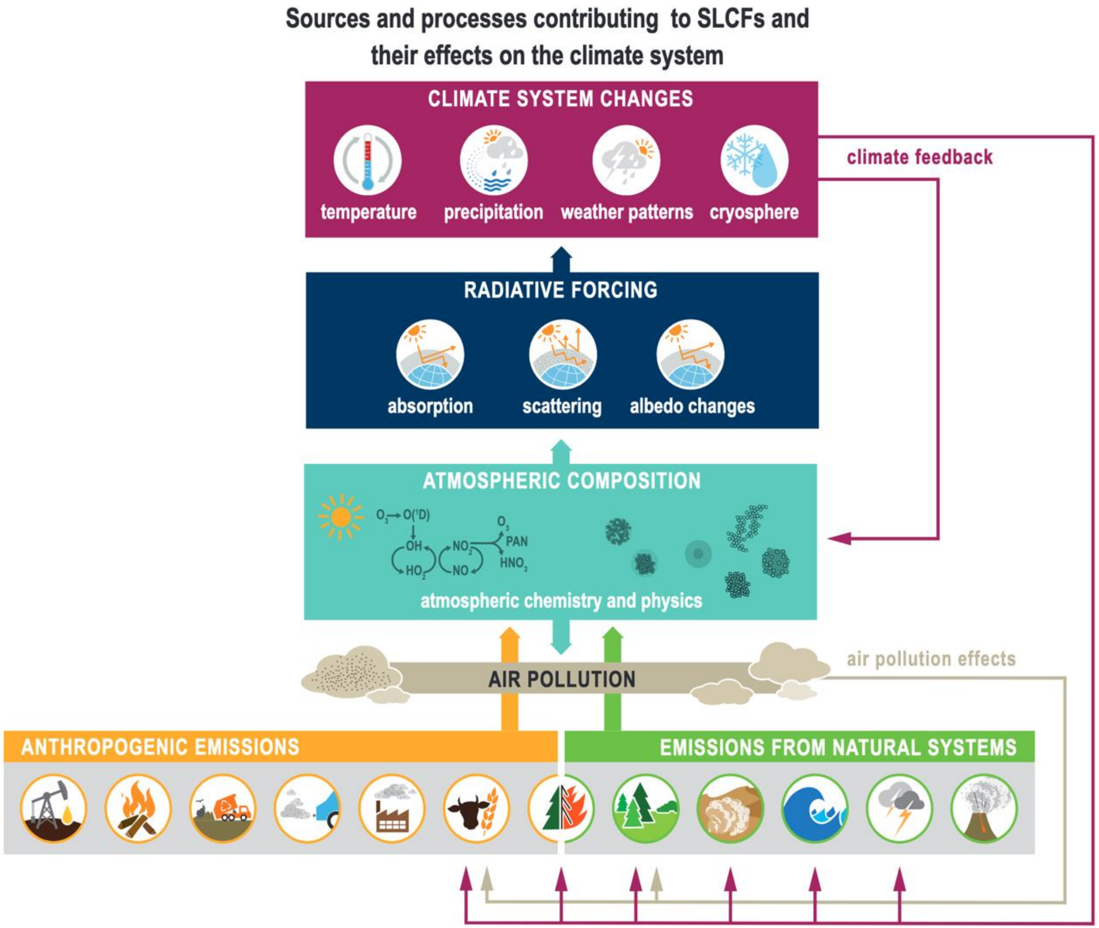


- Ramanathan and Xu, PNAS, 2010



Climate temperature response to reductions in emissions of CO_2, SLCPs, or both. Based on scenarios detailed in the supplemental mate-

Shoemaker et al., Science, 2013



- Szopa et al., AR6 WG1, Ch 6