Global modeling and projection of short-lived climate pollutants

~ Near-term projection with IIASA scenarios ~

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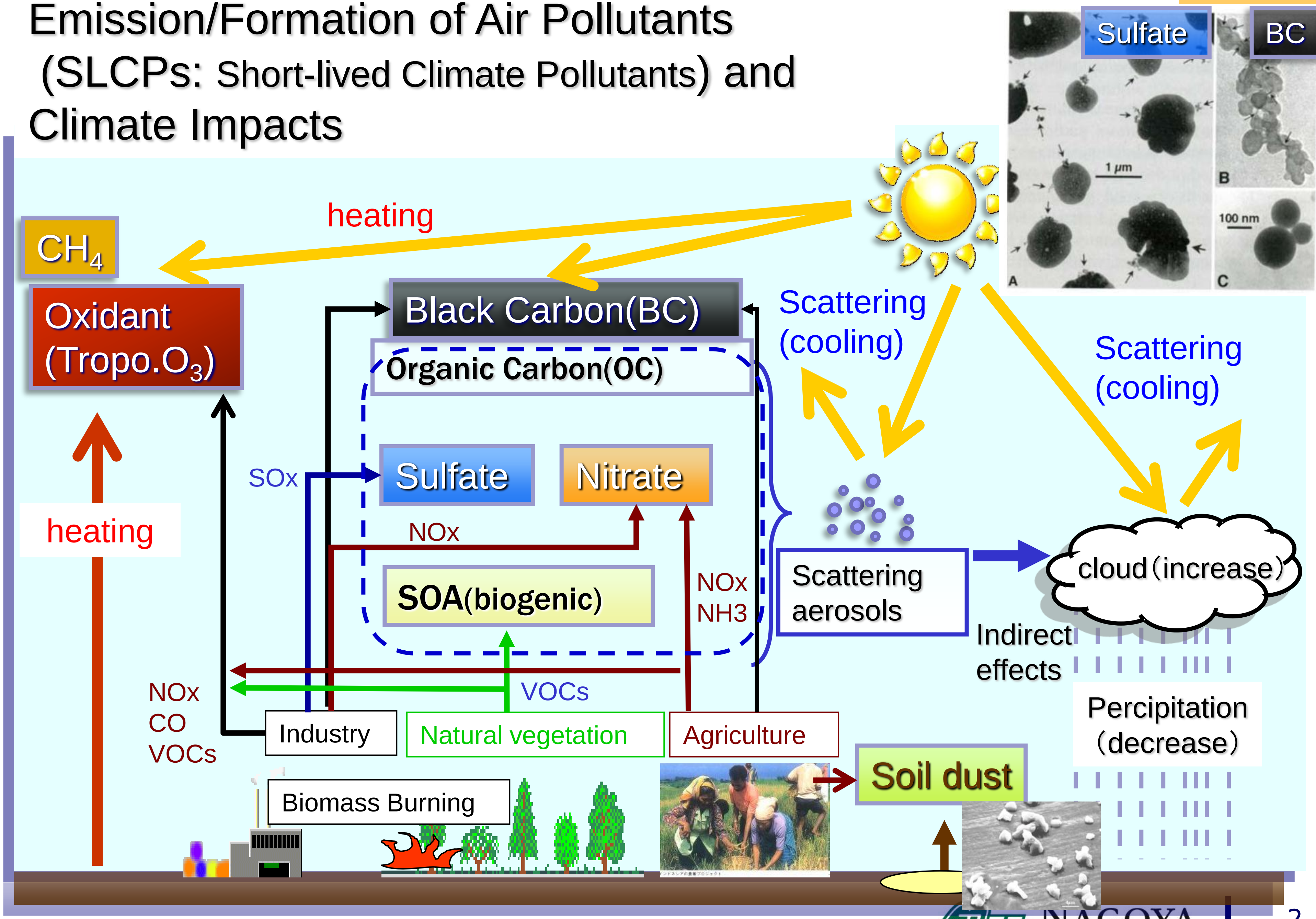
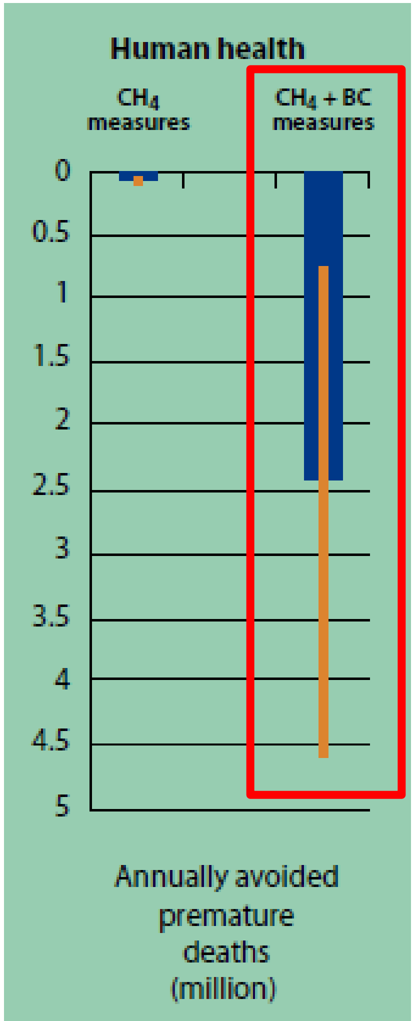
Emission/Formation of Air Pollutants (SLCPs: Short-lived Climate Pollutants) and Climate Impacts

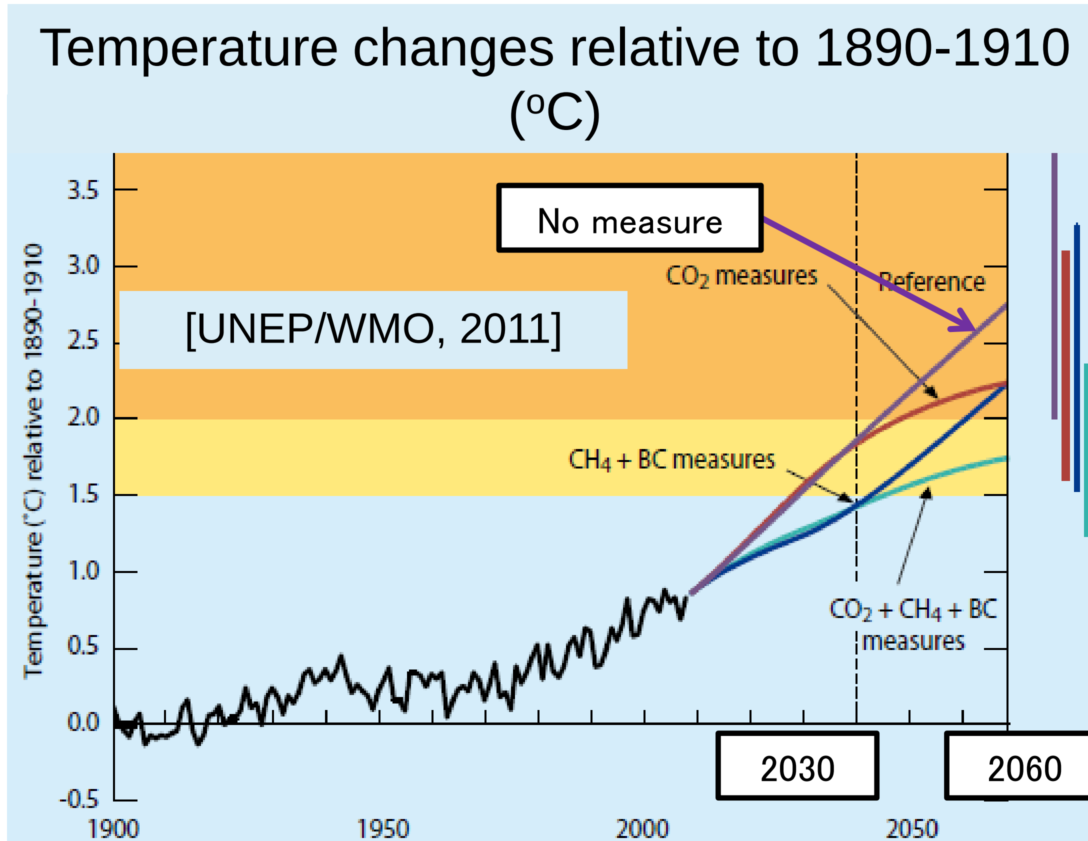


Co-benefits for Near-term Air-Pollution & Warming Issues

- Reduction in O_3/CH_4 and BC is the key to mitigation.
- But reduction in cooling-SLCPs (SO_4^{2-},NO_3^-,OC) may be unfavorable in climate context.



UNEP/WMO, 2011



Shindell et al (2011)

Our ongoing works in the context of co-benefit approach

- Developing/Improving a chemistry-coupled climate model MIROC-ESM-Chem (CHASER-SPRINTARS): focused on interaction between chemistry and aerosols

- Replicating the past changes in global SLCFs distributions using a chemistry-aerosol coupled climate model:
  for O_3, BC/OC, SO_4^{2-}, NO_3^-, & SOA (land-use induced)

- Future Projection of SLCPs and their climate impacts using the RCP and IIASA reference scenarios.

  Near-term future (2030) projection of SLCPs using the IIASA scenarios

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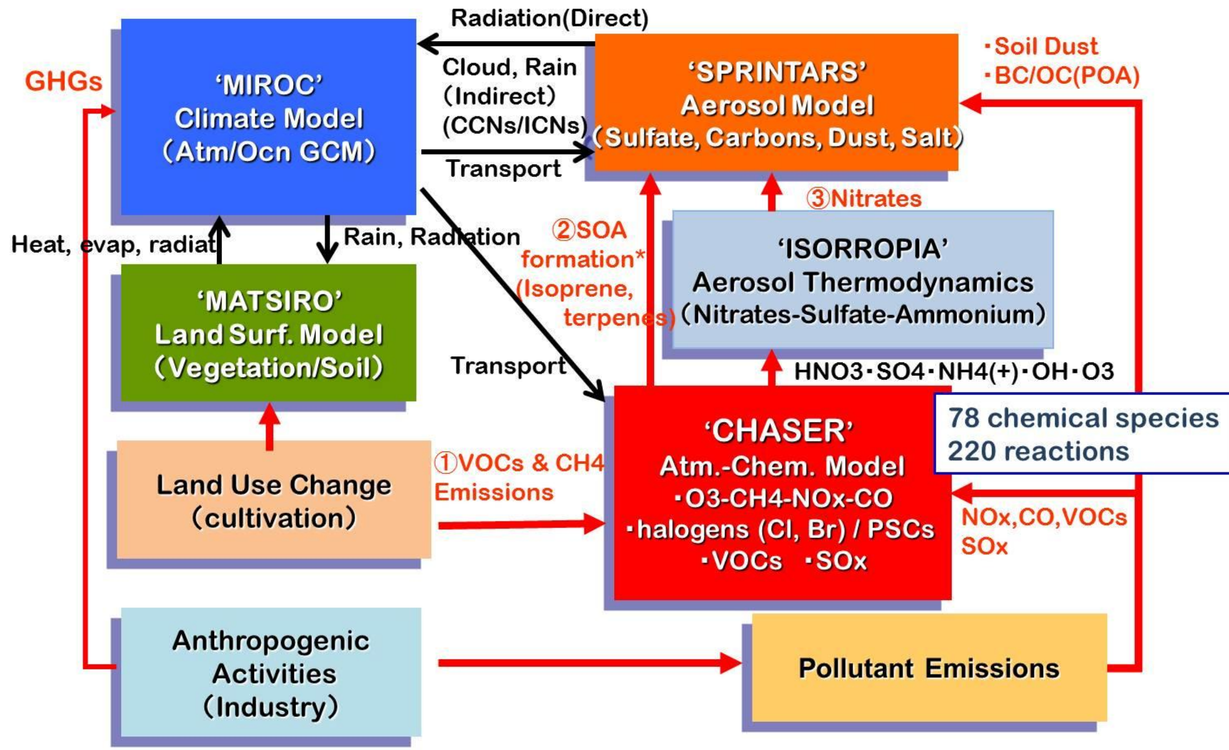
MIROC-ESM-CHEM (MIROC Earth System Model)

Watanabe et al. (2011)

- ✓ Climate Model Core : MIROC-4.5 (t42,L32) developed mainly in AORI/JAMSTEC/NIES/NU/KYU
- ✓ Chemistry : CHASER-V4 (Sudo et al., 2011) ~250 reactions with >70 species
  - Ox-NOx-HOx-CH4-CO chemistry with VOCs (explicit C2s,C3s, and isoprene & terpene)
  - Halogen (ClOx/BrOx) chemistry with PSCs chemistry (Akiyoshi et al. 2004) nudged to HALOE
  - Sulfate&Nitrate (SO_4^{2-}&NO_3^-) and SOA chemistry
  - Sulfate simulation fully coupled with aqus-phase chemistry (cloud pH)
- ✓ Aerosol: SPRINTARS (Takemura et al., 2010)
  - BC/OC, sea-salt, and dust
  - BC aging with SOx/SVOCs
  - Direct & indirect effects (incl. ice nuclei effects)
- ✓ SLCFs Forcing : O_3(T/S), BC/OC, SO_4, NO_3, CH_4
- ✓ Wet Deposition: All calculated in CHASER
- ✓ Natural emissions:
  *BVOCs,LNOx,soil-NOx/NH3, ocean-NH3/VOCs, wet-land-CH4, DMS, etc.
  *basically constant except for lightning NOx, & dust
  *Terpenes/Isoprene emissions = 120, 400 TgC/yr

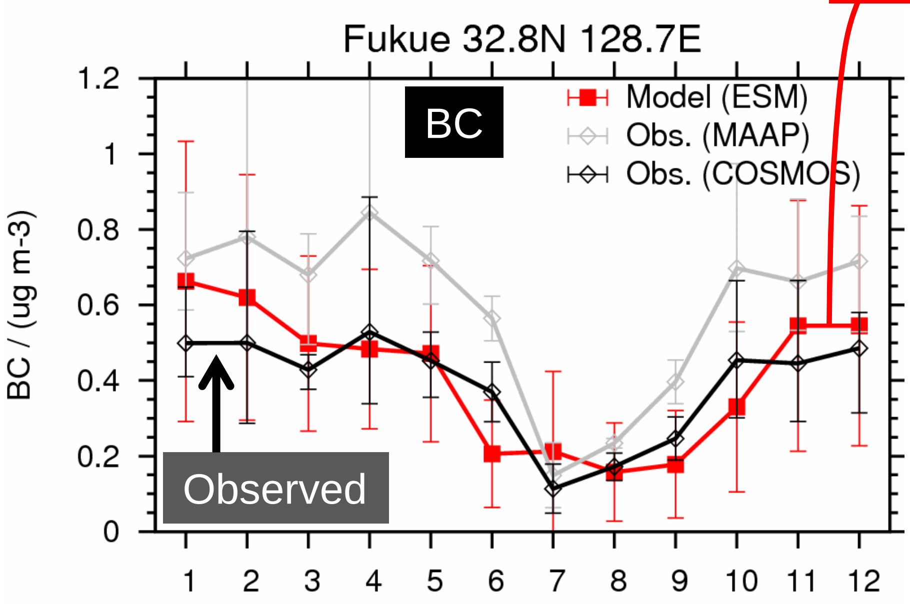
$$[H^+] + [Ca^{2+}] + [NH_4^+] = [HCO_3^-] + [CO_3^{2-}] + [NO_3^-] + [SO_4^{2-}] + [SO_3^{2-}] + [HSO_3^-] + [OH^-]$$

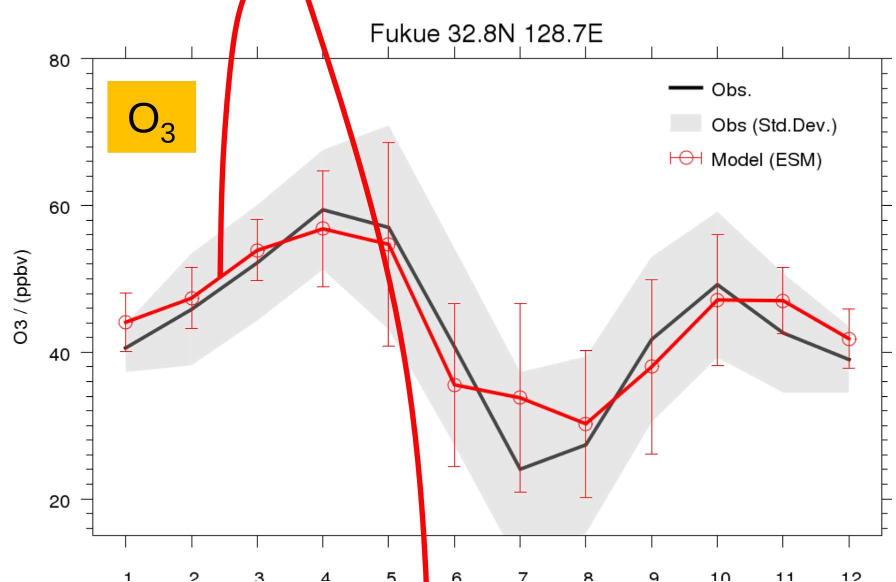


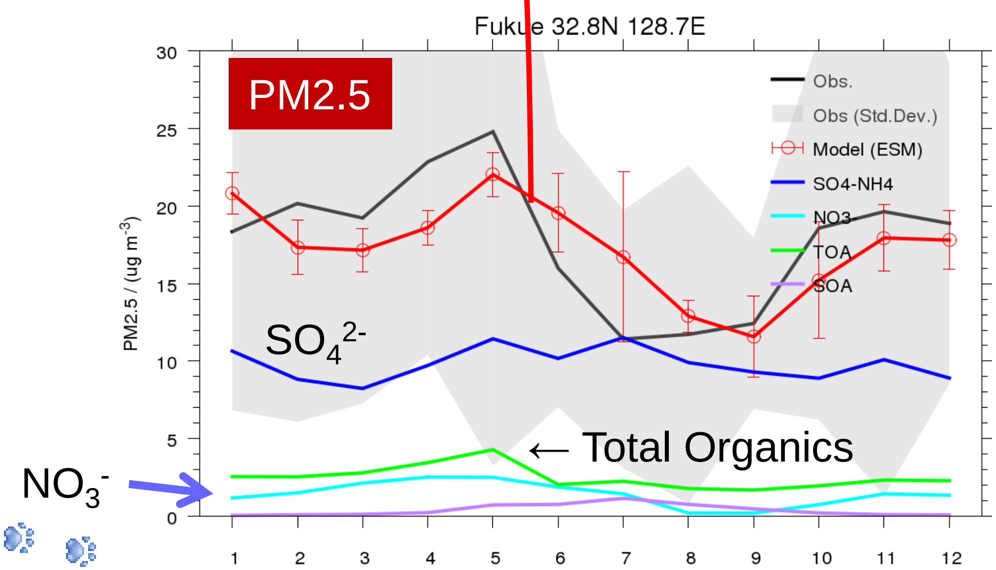
*Based on Griffin et al (2001)

Comparison with BC/O_3 observed at Fukue, Nagasaki, Japan

Modeled (MIROC-ESM-CHEM)





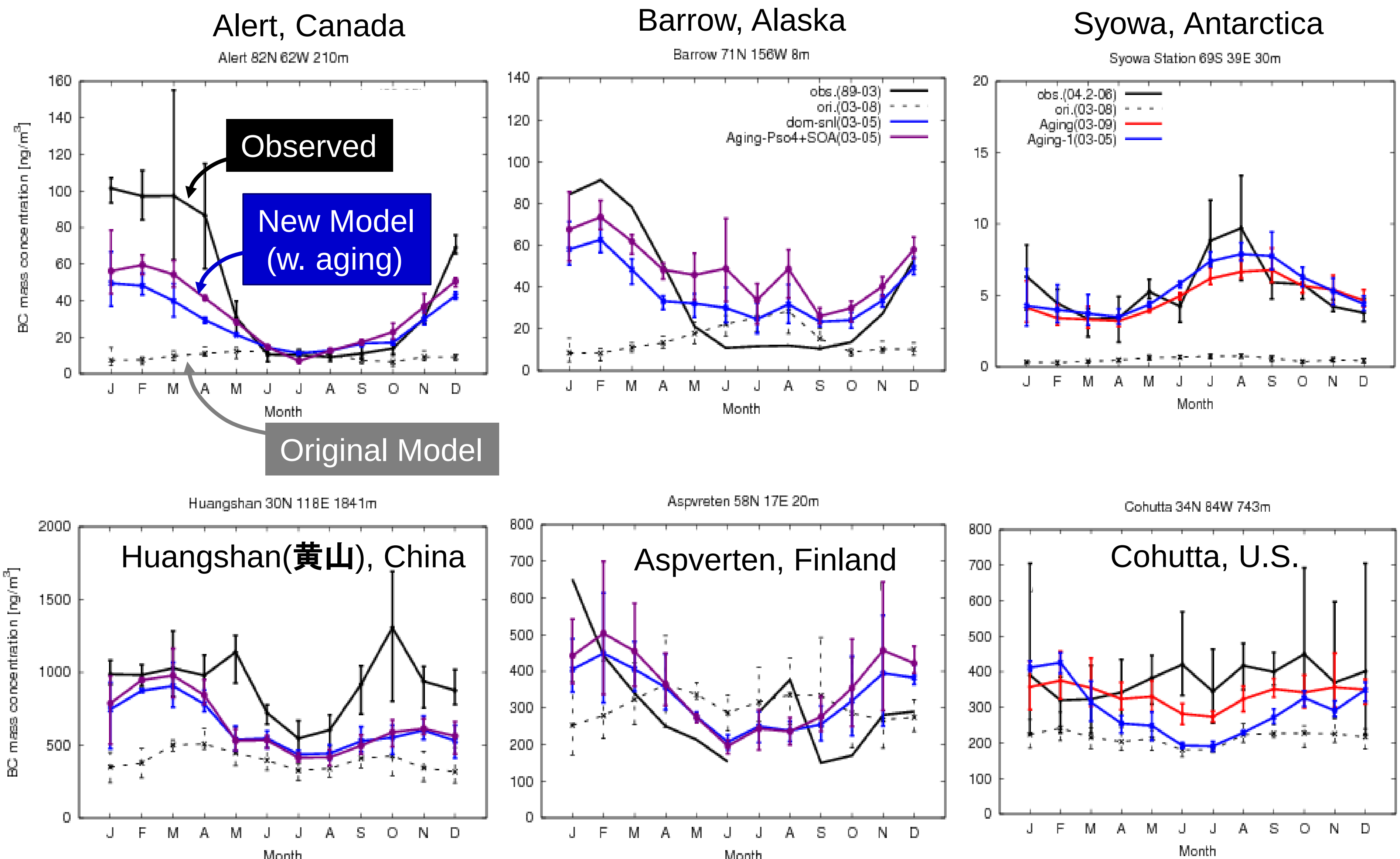


Modelled seasonality/levels are quite consistent with the observation both for O3/BC/$PM_{2.5}$

Observation data are from Kanaya et al. [2012]

Observed and Modelled BC seasonality

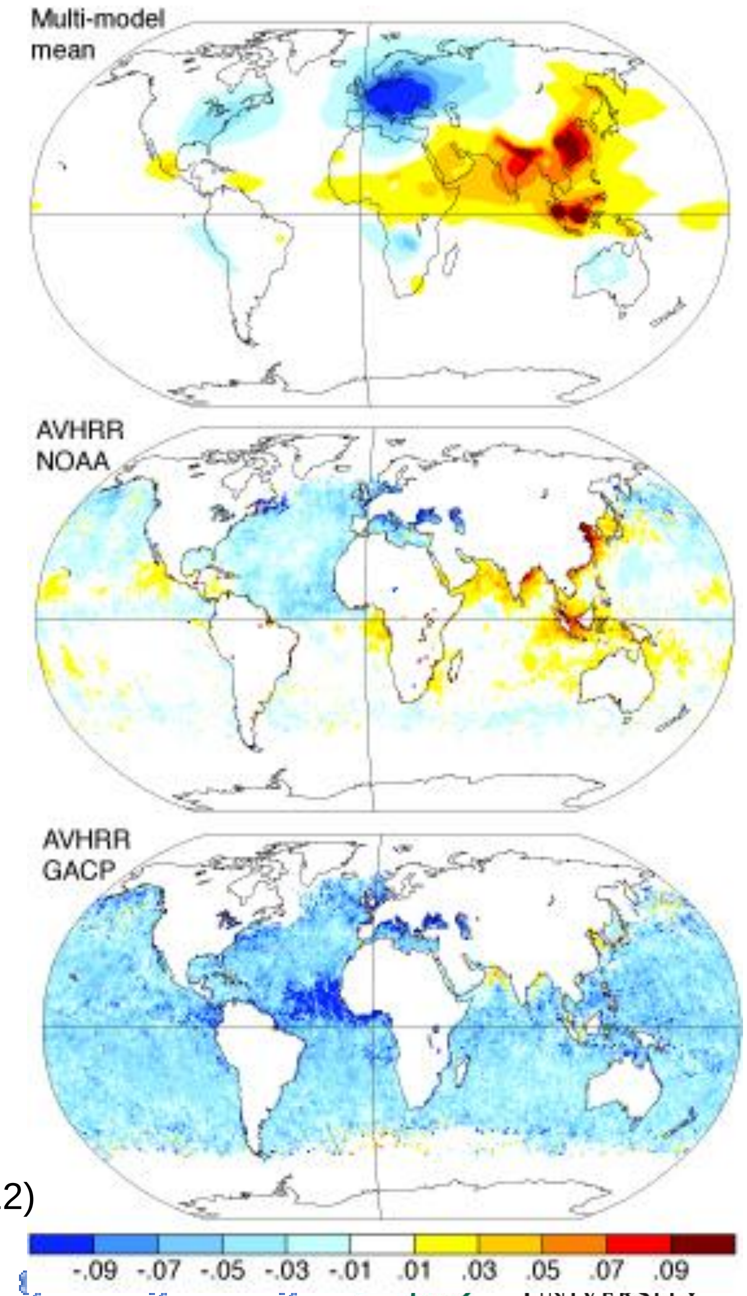
Better simulation than the other IPCC models



IPCC/ACCMIP Multi Model Project

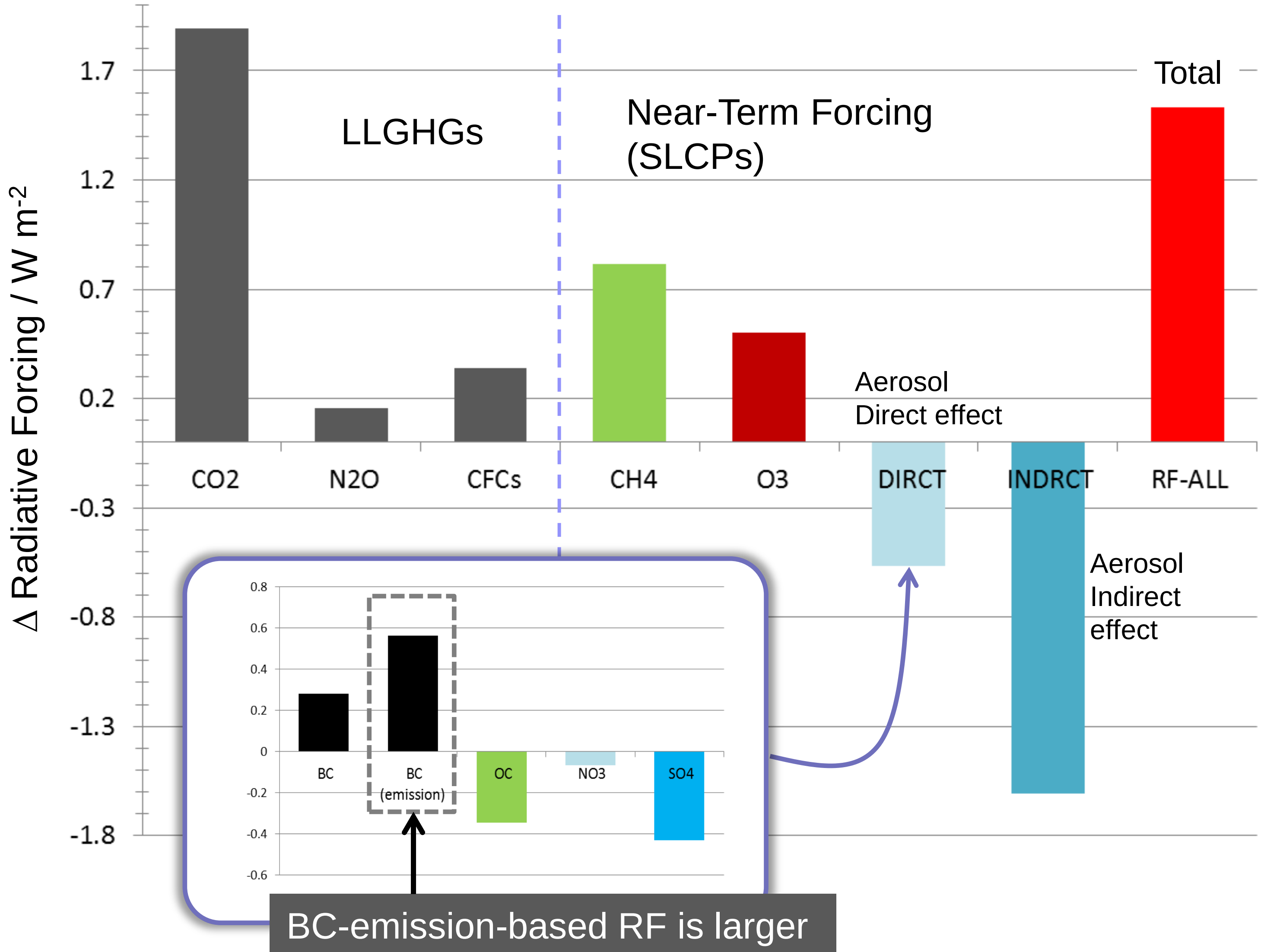
- Chemistry-aerosol models (in the IPCC project) generally well reproduce long-term trends in SLCPs.
- MIROC-ESM-CHEM also does so.

1980-2000 AOD trend



Shindell et al (2012)

Radiative forcing estimated for 1850-2005 (MIROC-ESM-CHEM with IIASA emission for 2005)



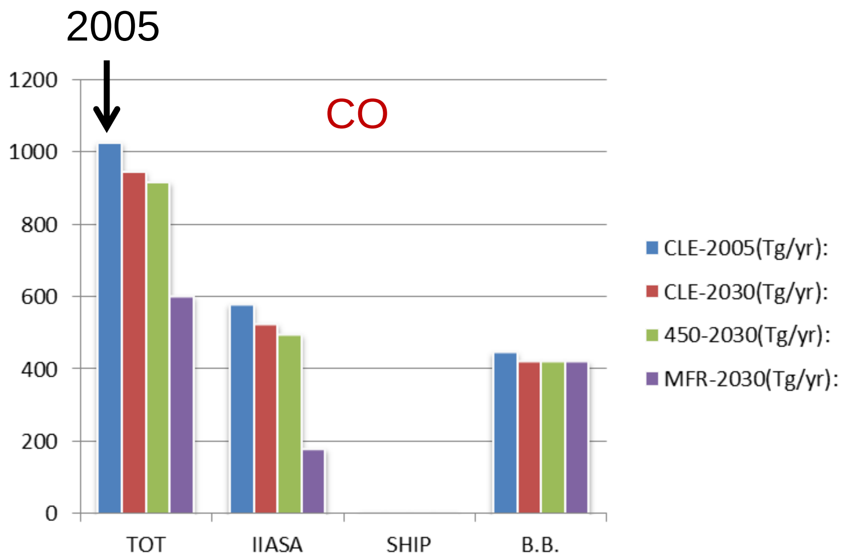
Future projection (for 2030) using the IIASA ref. scenarios

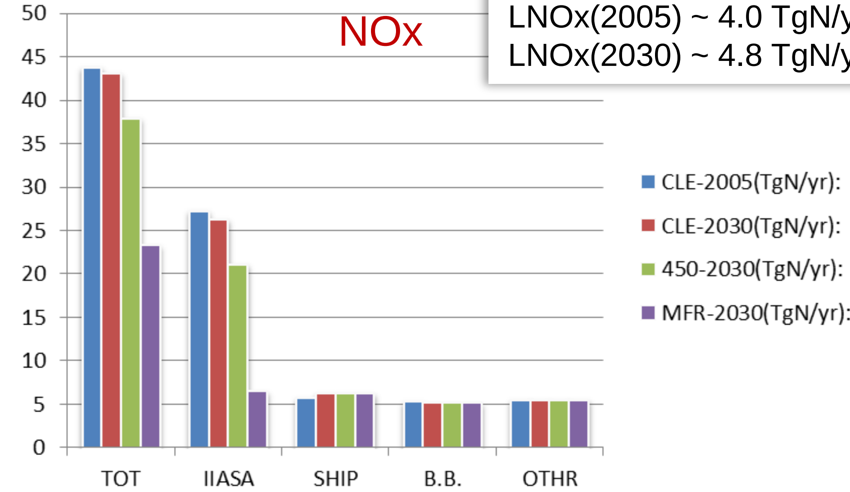
: Evaluate global changes in SLCPs (O_3, CH_4, & aerosols) and their radiative forcing during 2005-2030

Experimental Setup

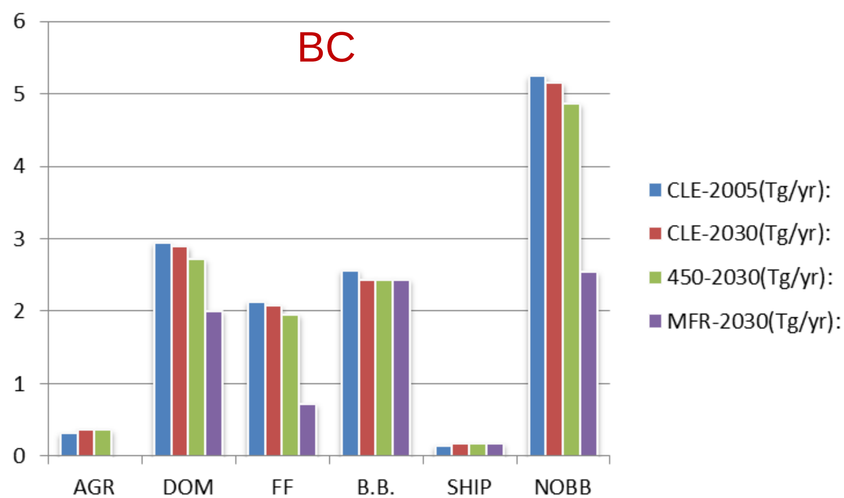
- IIASA emission scenarios for 2030:
  1. CLE (a high-case: current legislation),
  2. 450 (intermediate: 450ppm CO_2 stabilization),
  3. 450C (450 with enhanced Asian reduction)
  4. MFR (a low-case: maximal feasible reduction)
- 7 years time integration for each scenario
- Use last three years for ozone and direct aerosol forcings, last one year for CH_4, and last 6 years for CO_2 and indirect aerosol forcings
- CO_2/N_2O/CFCs change following the 'RCP4.5' scenario
  Strat.O_3 is also changeable due to the CFCs changes
- Ship/Aircraft/B.B. emissions based on RCP8.5
- SST/Sea-ice are prescribed with MIROC-ESM's pre-simulation with RCP4.5

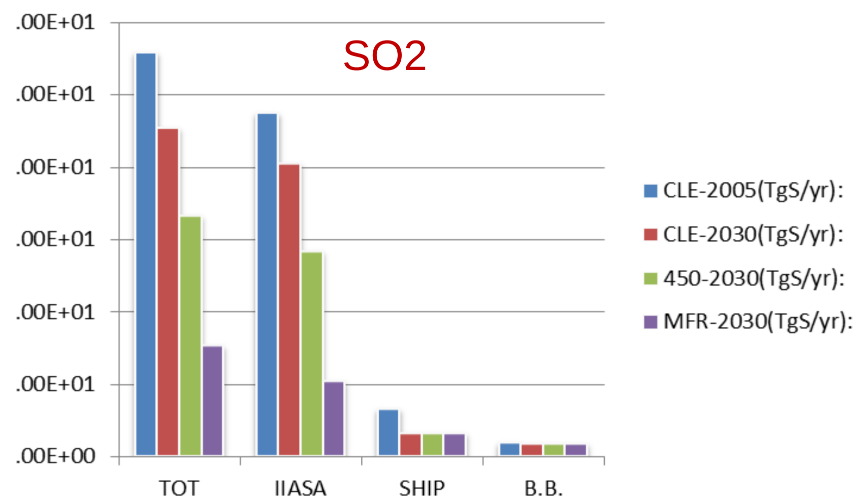
Emission Data (IIASA-ref.)





LNOx(2005) ~ 4.0 TgN/yr
LNOx(2030) ~ 4.8 TgN/yr





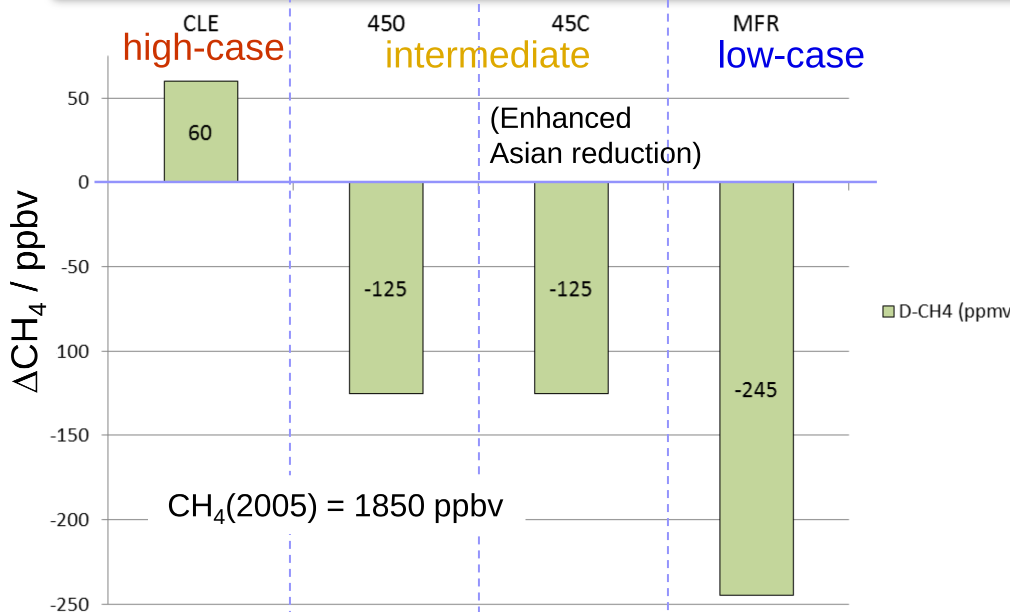
CH_4 in 2030

$$\frac{d[\mathrm{CH_4}]}{dt} = E - k[\mathrm{OH}][\mathrm{CH_4}]$$

- CH_4 decreases by > 100 ppbv except the high-case (+60 ppbv).
- Chemistry (OH abundance) plays an important role (negative impacts) as well as CH_4 emission

Tropospheric OH is determined as a function of (NOx/CO, O_3, H_2O)

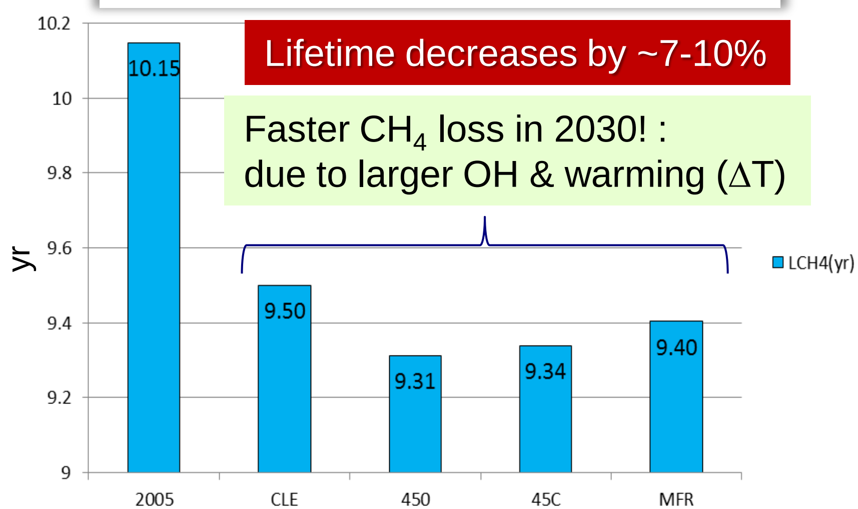
Global mean surface CH_4 changes from 2005



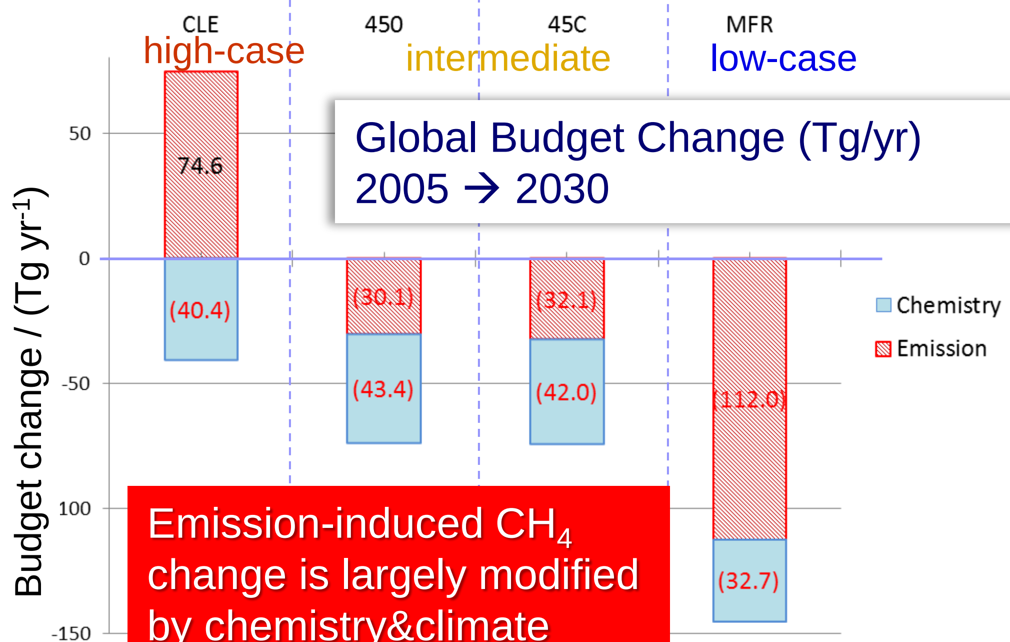
CH_4 Lifetime (yr)

Lifetime decreases by ~7-10%

Faster CH_4 loss in 2030! :
due to larger OH & warming (ΔT)

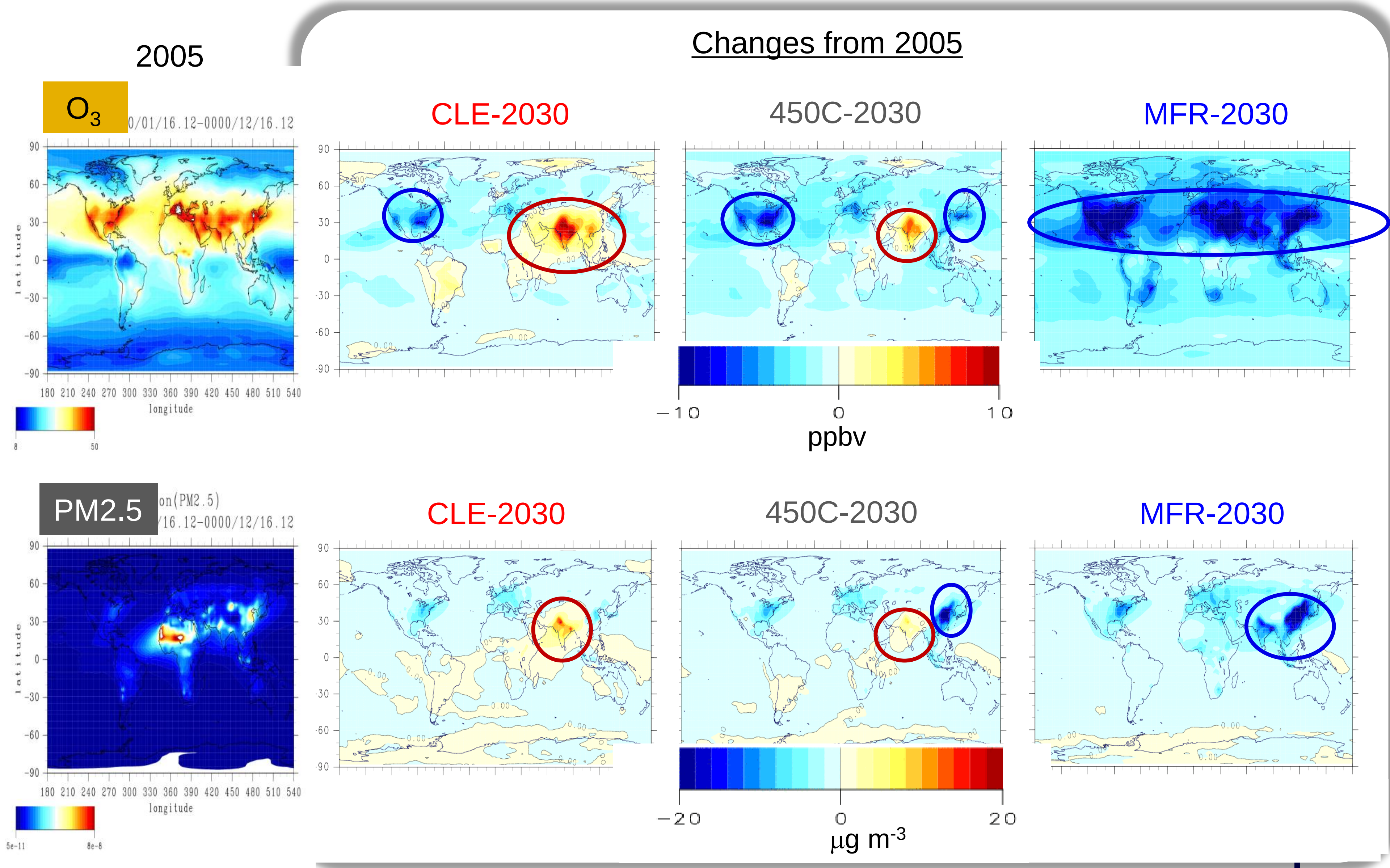


Global Budget Change (Tg/yr)
2005 → 2030

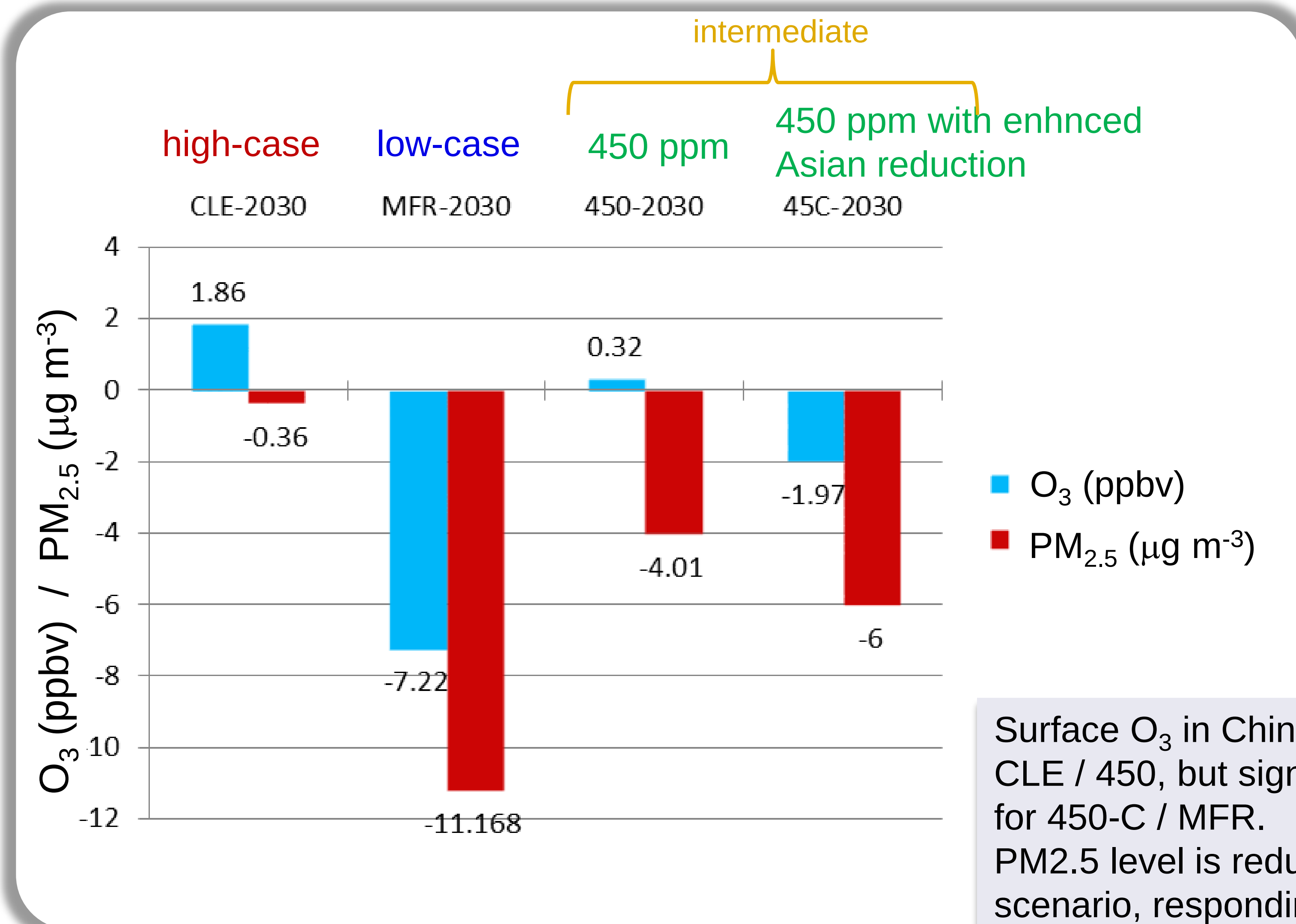


Emission-induced CH_4 change is largely modified by chemistry&climate

Surface O_3 & $PM_{2.5}$（Annual Mean）: 2005 / CLE-2030 / 450C-2030 / MFR-2030



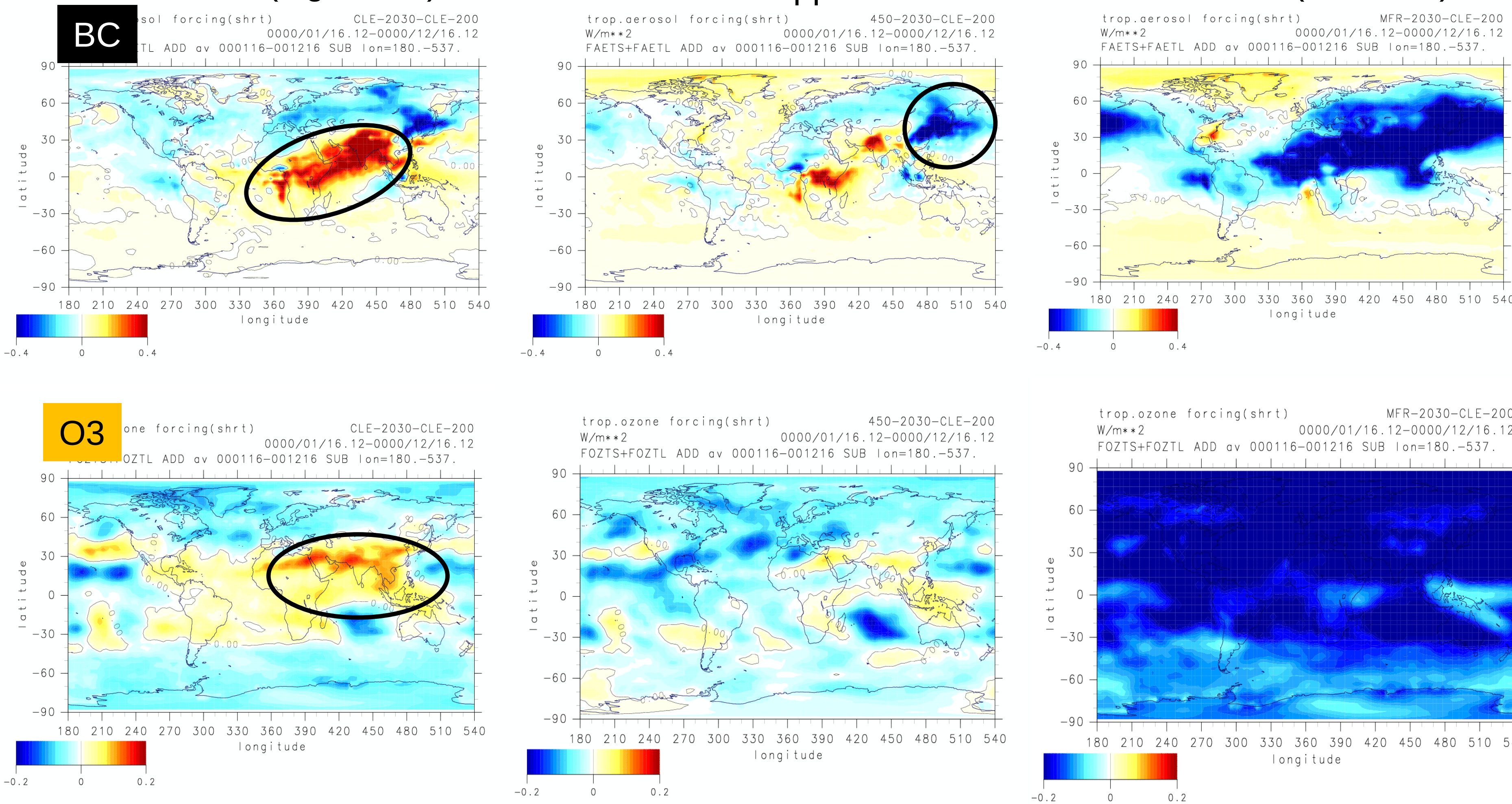
$O_3/PM_{2.5}$ changes in China at 2030 relative to 2005



Surface O_3 in China is increased for CLE / 450, but significantly decreased for 450-C / MFR.
PM2.5 level is reduced in every scenario, responding to the decreased SO_4^{2-} and OC.

Radiative forcing changes during 2005-2030

CLE (high case) | 450ppm | MFR (low case)



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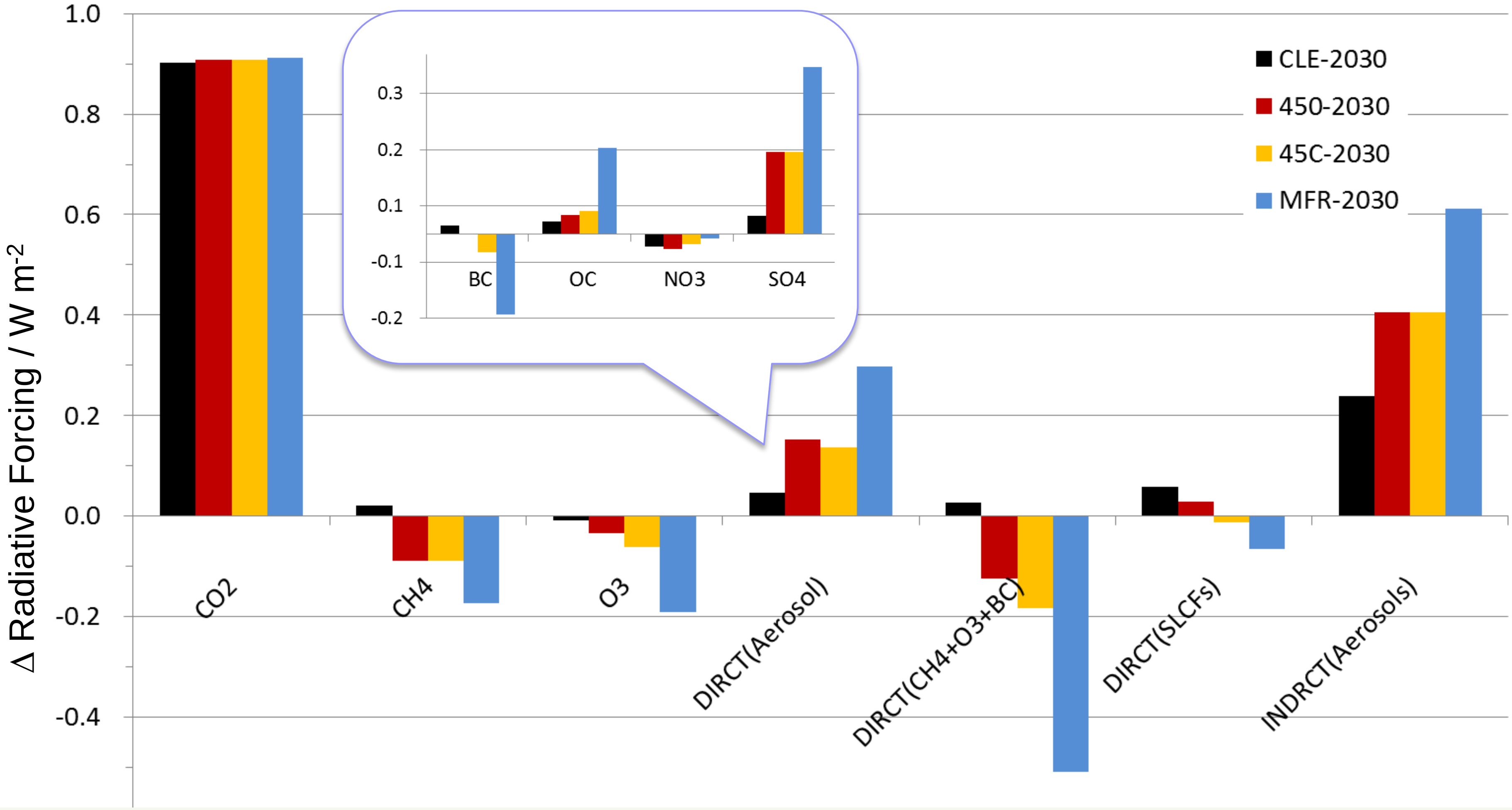
Changes in RF（from 2005 to 2030）
-- Global Mean --

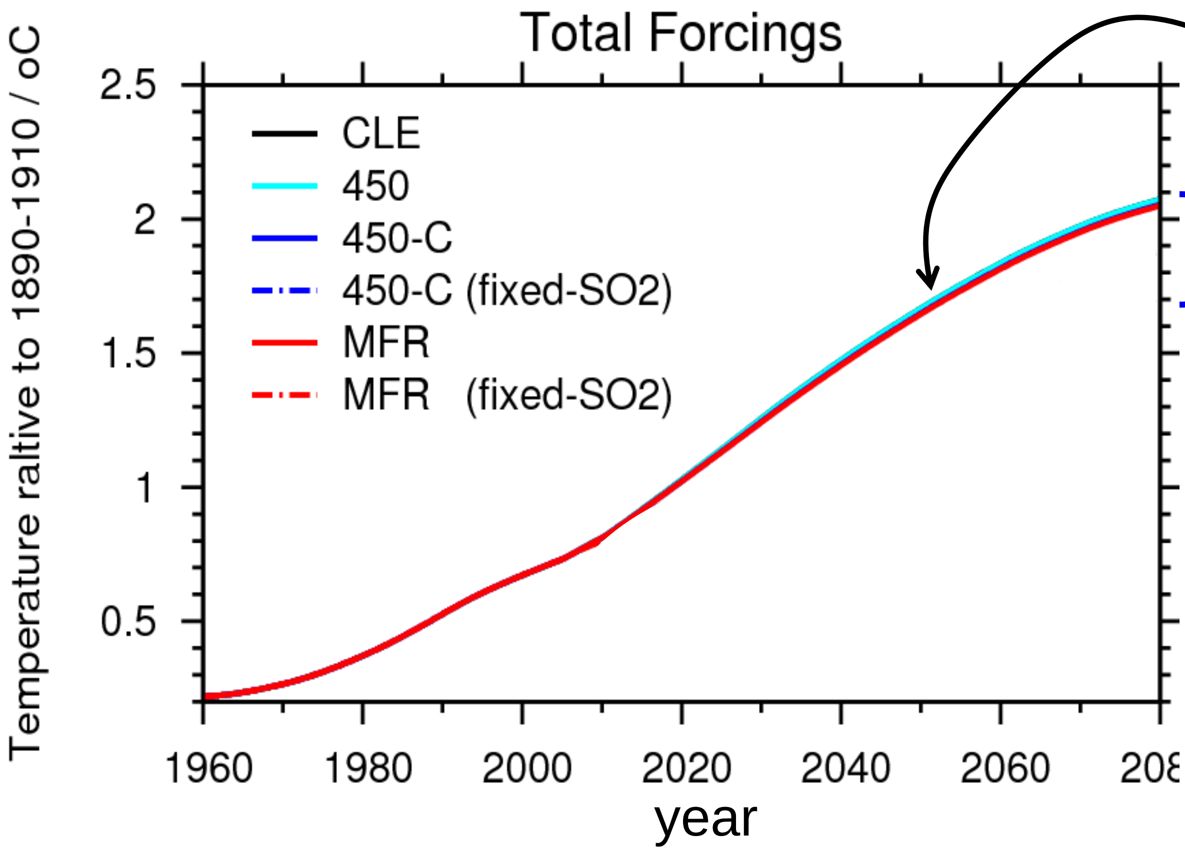


MFR gives a large cooling (~ -0.5 W m^{-2}) due to combined reduction of CH_4, O_3, and BC. However, a very large warming is also predicted in MFR due to decreases in SO_4^{2-}/OC and subsequent indirect effect, which cancel out the direct cooling largely.

Global Mean Temperature projection

Response to 2005-2030 radiative forcings

Surf. ΔT (ºC) from 1890-1910



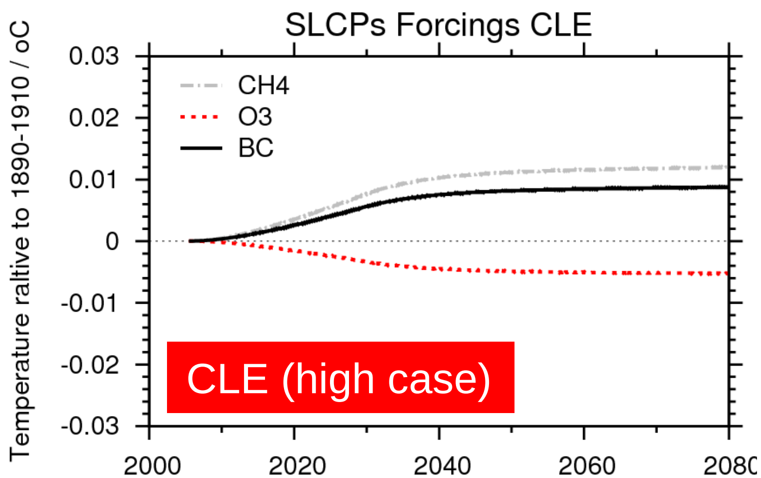
Almost identical ΔT ! regardless of emission scenario

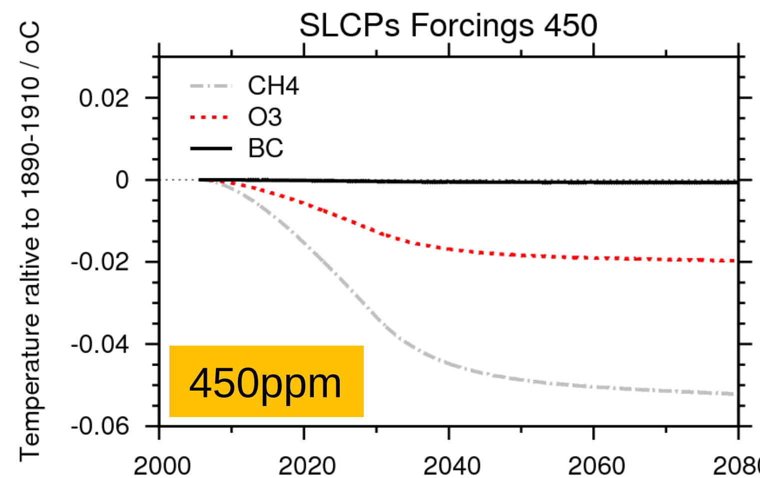
0.45 ºC reduction

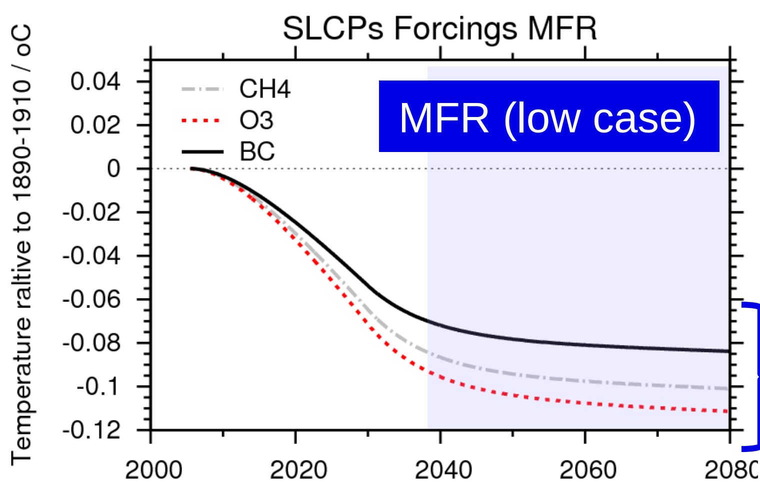
Reduction of SO_2 emission should be avoided ? to achieve a significant warming mitigation.

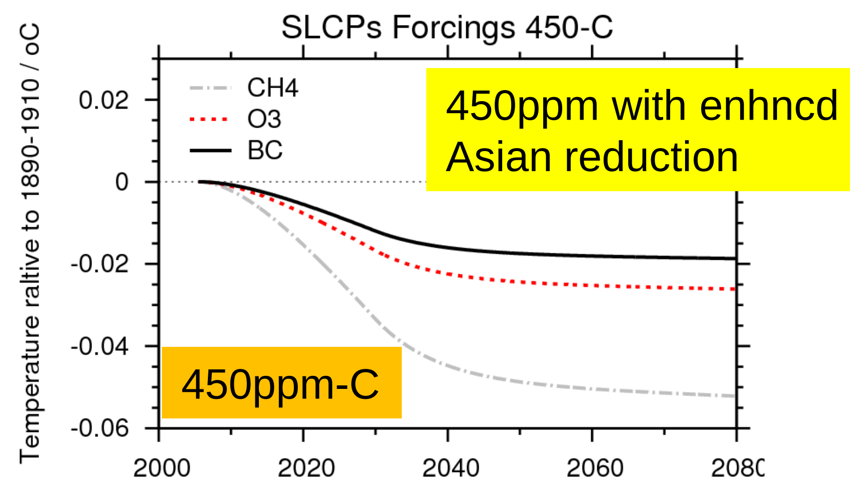
Temperature projection relative to 2005

- heating-SLCPs contributions -









Total (CH_4+O_3+BC): ~ -0.3 °C

Summary

- Near-term future (~2030) projection of SLCPs (NTCP) was performed using a Chemistry-Aerosol coupled climate model (MIROC-CHASER-SPRINTARS) with the four IIASA ref. scenarios (CLE/450/450C/MFR).
- SLCPs changes basically reflect the specified emission scenarios
  - Significant reduction of surface O_3 (5-10 ppbv) and $PM_{2.5}$ (10-20 μg m^{-3}) in E-Asia for the intermediate/low emission cases (450ppm/MFR).
  - But O_3/BC are increased in South Asia for the high/intermediate emission (CLE/450ppm)
- CH_4 change in 2013 largely depends on chemical loss process as well as on emission change:
  - Changes in CH_4 lifetime due to OH changes associated with NO/CO/O_3/H_2O and to temperature.
- Very similar temperature evolutions were obtained for CLE/450/MFR resulting from reduction in heating SLCPs/cooling SLCPs
- Maximal reduction in heating SLCPs (O_3,BC,&CH_4) at 2030, causing negative RF (−0.5 W m^{-2}), can reduce global mean temperature as much as 0.3 °C at 2050.
- Obviously need to consider model ensemble for considering uncertainty.

Thank you …