Radiative forcing from tropospheric and stratospheric ozone 1850-2100

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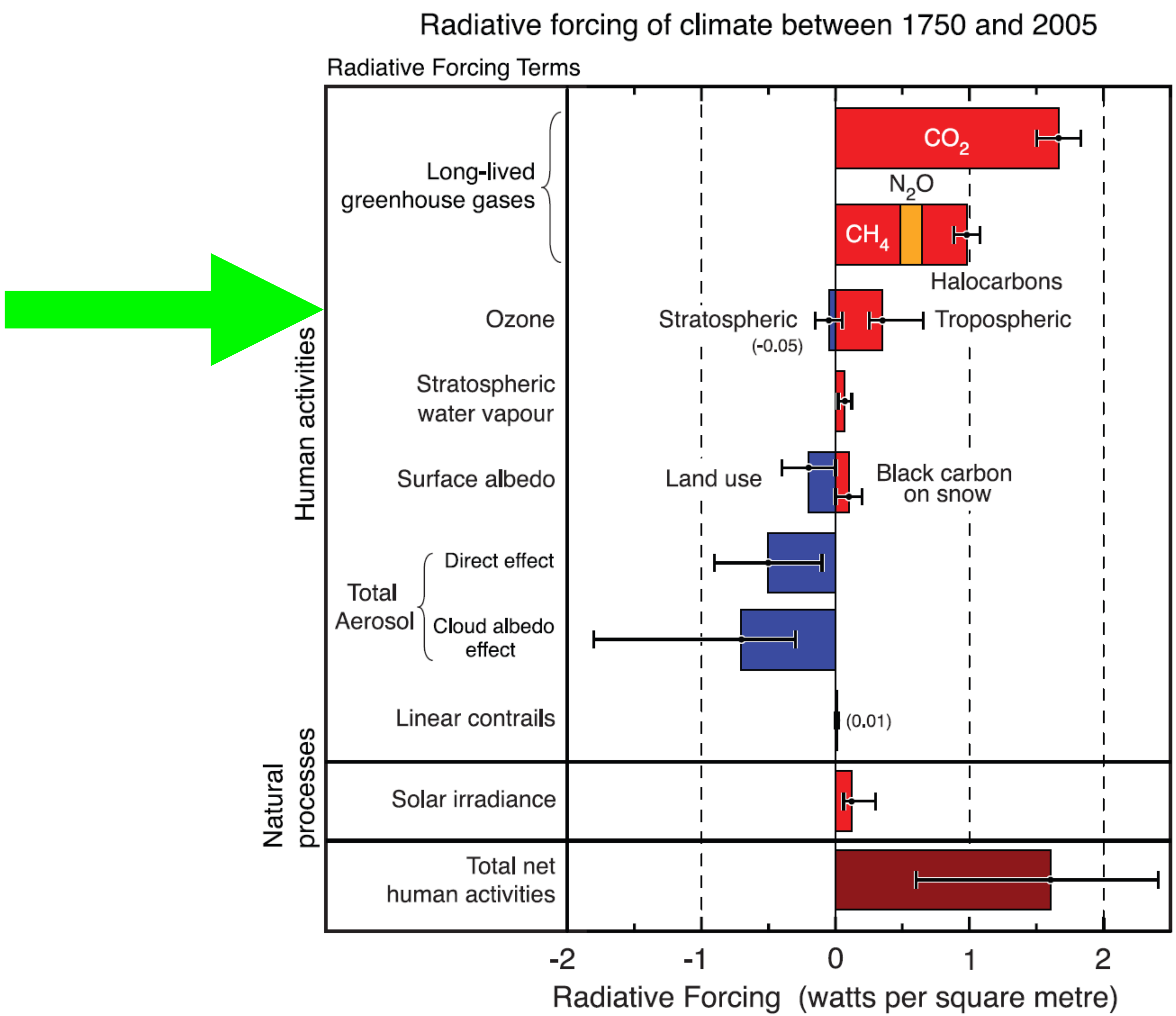
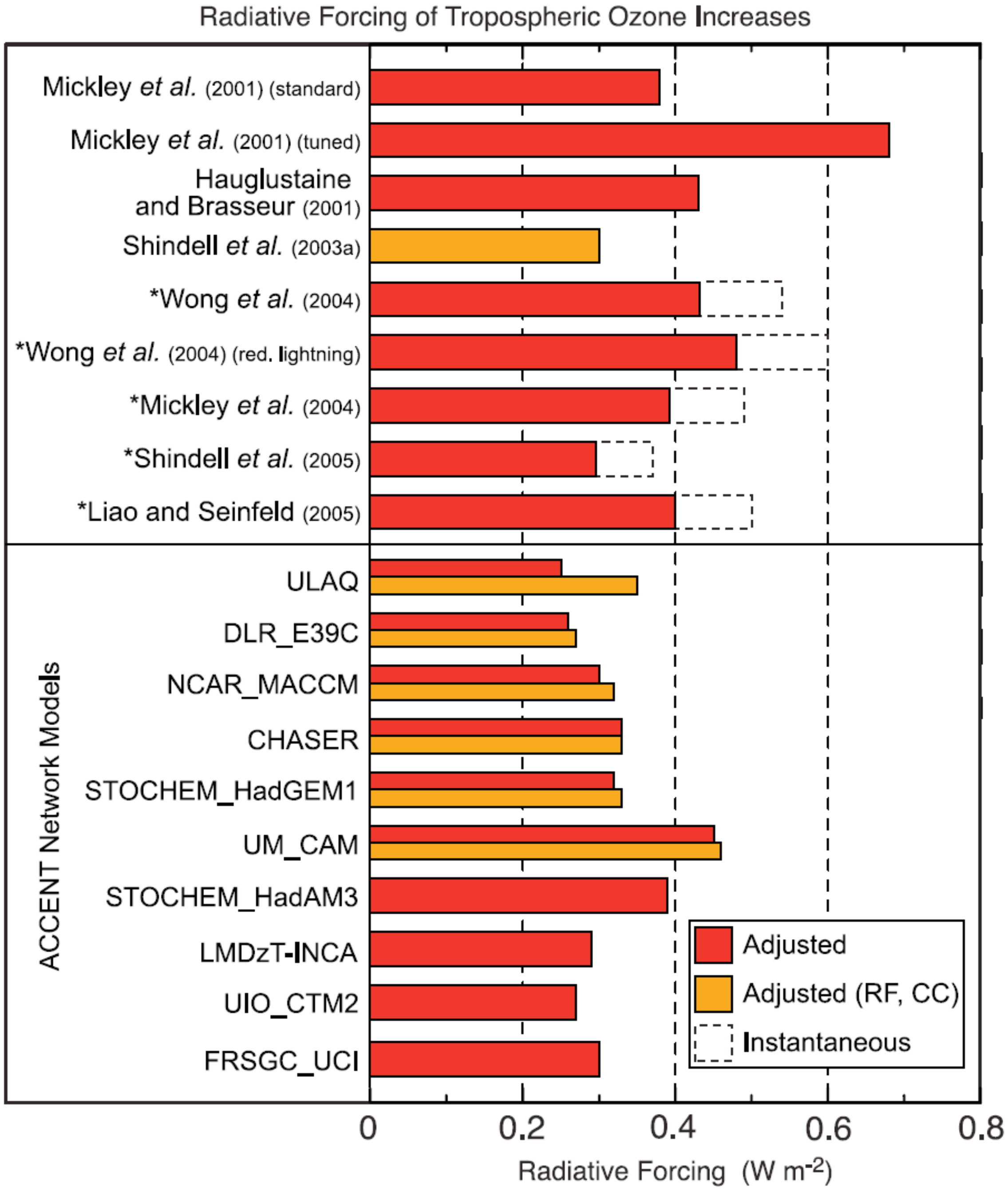


(IPCC AR4, 2007)



Tropospheric O_3 RFs from several studies, including the ACCENT intercomparison (Gauss et al., 2006)

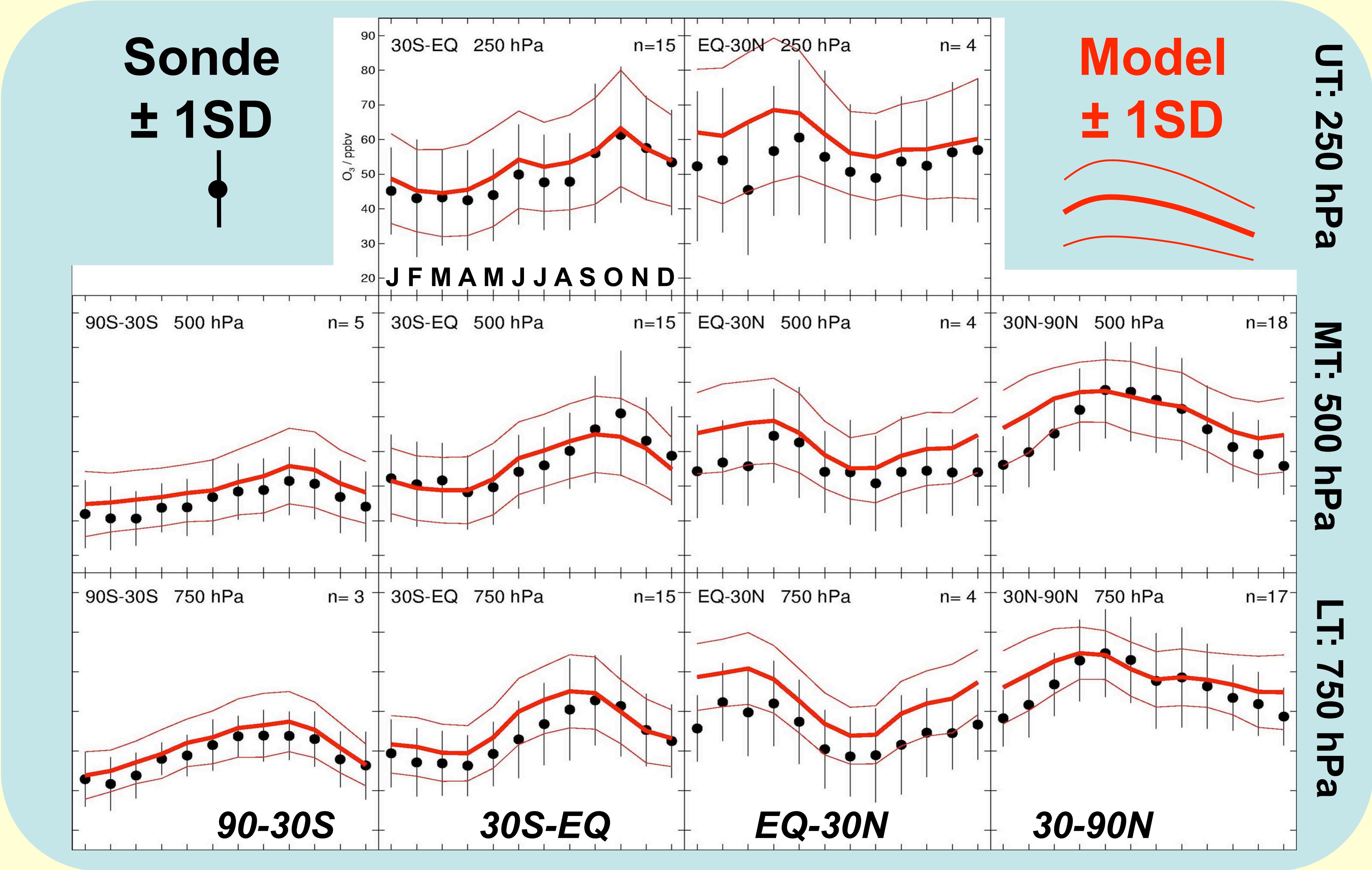
AR4 value: 0.35 W m^{-2}
(range 0.25-0.65 W m^{-2})

Stratospheric O_3 RFs from observationally based studies and models.

AR4 value: -0.05±0.1 W m^{-2}

(IPCC AR4, 2007)

Sonde data from Logan (1999) + SHADOZ data from Thompson et al (2003)



ACCENT intercomparison: Stevenson et al. (2006)

Progress since AR4

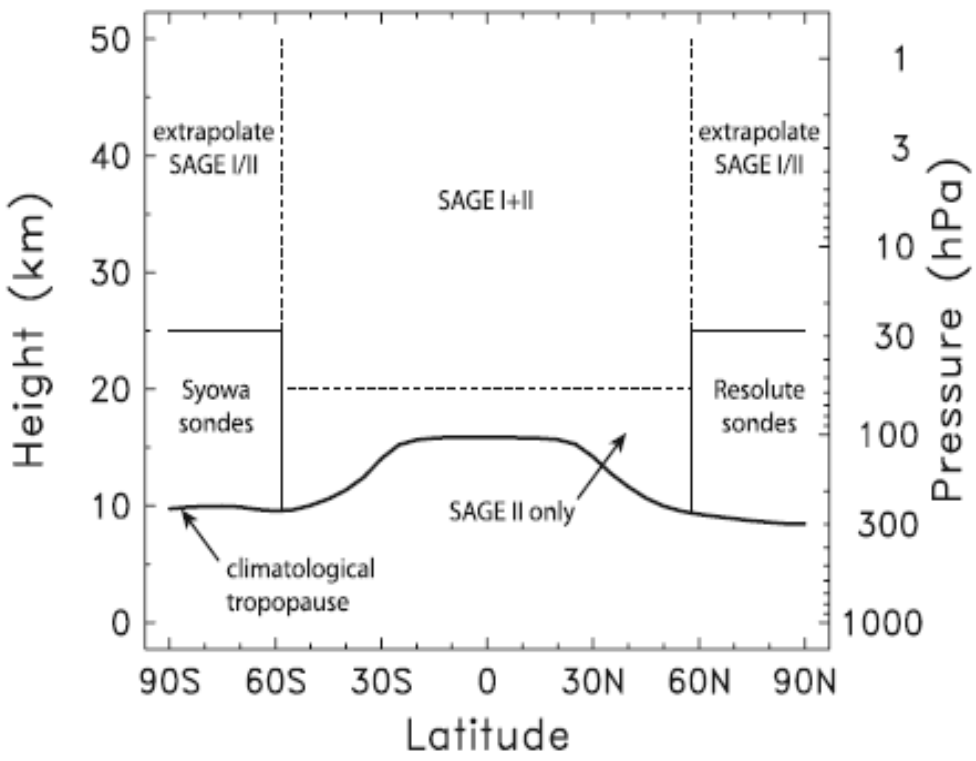
- **Tropospheric RFs rely on model simulations of O_3**
  - **'Present-day' model simulations compare well to observations**
  - **But very little pre-industrial O_3 data**
  - **Model simulations of pre-industrial rely on emissions**
  - **Much of the uncertainty in O_3 RF comes from poorly constrained pre-industrial O_3 levels**
- **New emissions database (Lamarque et al., 2010) created for CMIP5 simulations: historical and merged with future RCP scenarios**
  - **Significant differences in pre-industrial biomass burning emissions**
  - **These emissions used in ACCMIP**
- **New AC&C/SPARC ozone database uses ACCMIP models in the troposphere and uses observations/regressions based on observations for the historical stratosphere, and CCMVal models for the future stratosphere:**
- ***Cionni et al. (2011) 'Ozone database in support of CMIP5 simulations: results and corresponding radiative forcing', Atmos. Chem. Phys. Discuss., 11, 10875-10933***

Construction of the AC&C/SPARC O_3 database: Stratosphere

Historical data (1850-2009)

Stratospheric data (Zonal means):

- **Multiple linear regression analysis of SAGE I+II satellite and polar ozonesonde measurements for the period 1979-2005 *(Randel and Wu, JGR, 2007).***
- **Regression includes terms representing equivalent effective stratospheric chlorine (EESC) and 11-year solar cycle variability.**
- **Extended backwards to 1850 based on the regression fits combined with extended proxy times series of EESC and solar variability.**



Randel and Wu, 2007

Construction of the AC&C/SPARC O_3 database: Stratosphere

Future data (2010-2099)

Stratospheric ozone projections are taken from the future reference simulations (REF-B2) of 13 CCMs that performed this simulation to 2099 in CCMVal-2.
(*SPARC CCMVal, 2010*)

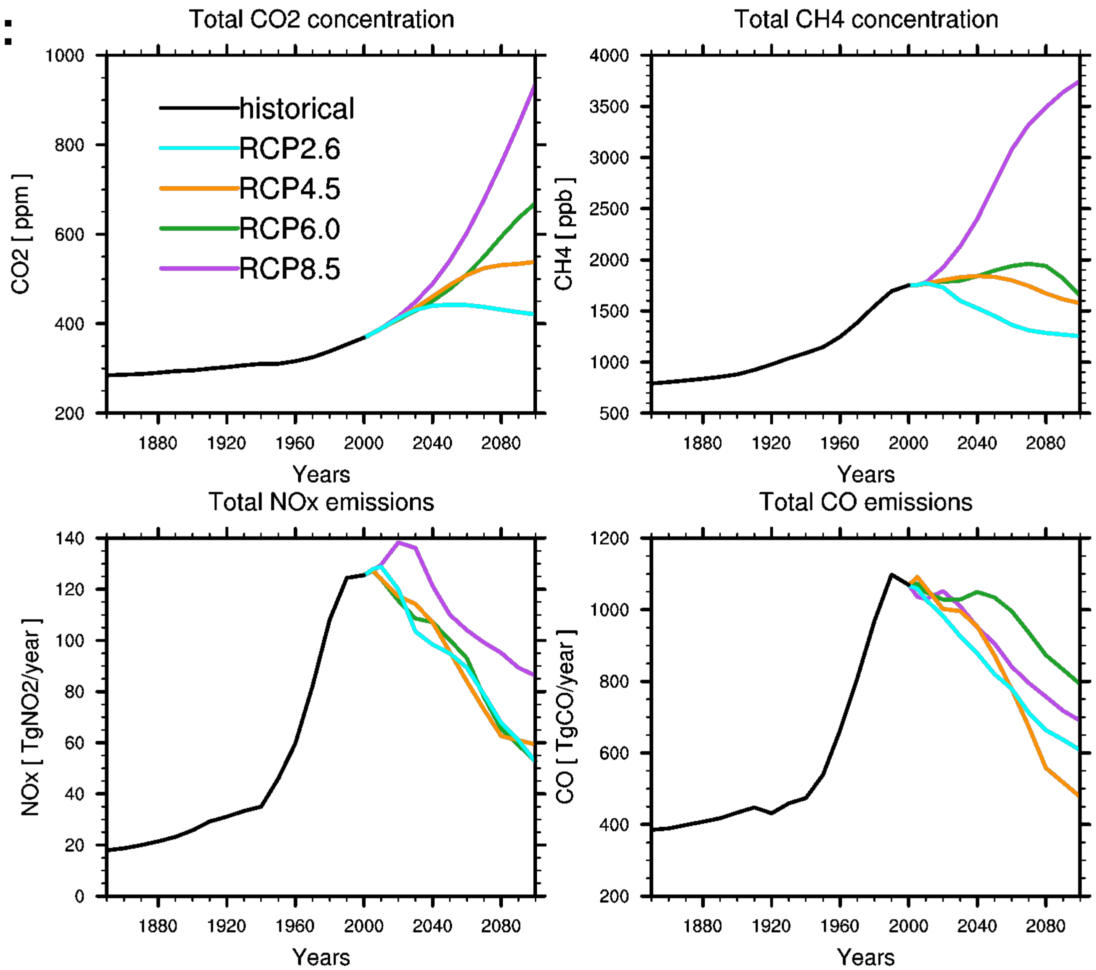
	Model	Group and Location	Horiz. resolution	Vert. Layers / Upper Boundary
1	AMTRAC3	GFDL, USA	2˚ (lat) x 2.5˚(lon)	48 L / 0.002 hPa
2	CAM3.5	NCAR, USA	1.9(lat)x2.5(lon)	26 L / 2.2 hPa
3	CCSRNIES	NIES, University of Tokyo, Japan	T42	34 L / 0.012 hPa
4	CMAM	MSC, Univ. of Toronto, York Univ., Canada	T31	71 L / 0.000637 hPa
5	CNRM-ACM	Meteo-France, France	T42(GCM),T21(CHEM)	60L / 0.07 hPa
6	GEOSCCM	NASA/GSFC, USA	2˚ x 2.5˚	72 L / 0.01hPa
7	LMDZrepro	IPSL, France	2.5˚ x 3.75˚	50 L / 0.07 hPa
8	MRI	MRI, Japan	T42	68 L / 0.01 hPa
9	SOCOL	PMOD/WRC and IAC ETHZ, Switzerland	T30	39 L / 0.01 hPa
10	ULAQ	University of L'Aquila, Italy	10˚ x 22.5˚ (CHEM)	26 L / 0.04 hPa
11	UMSLIMCAT	University of Leeds, UK	2.5˚ x 3.75˚	64 L / 0.01 hPa
12	UMUKCA-UCAM	University of Cambridge, UK	2.5˚ x 3.75˚	64 L / 84 km
13	WACCM (v.3)	NCAR, USA	4˚ x 5˚	66 L / 4.5 x 10^{-6} hPa

Construction of the AC&C/SPARC O_3 database: troposphere

Historical data (1850-2009)

Tropospheric data (3D decadal averages):

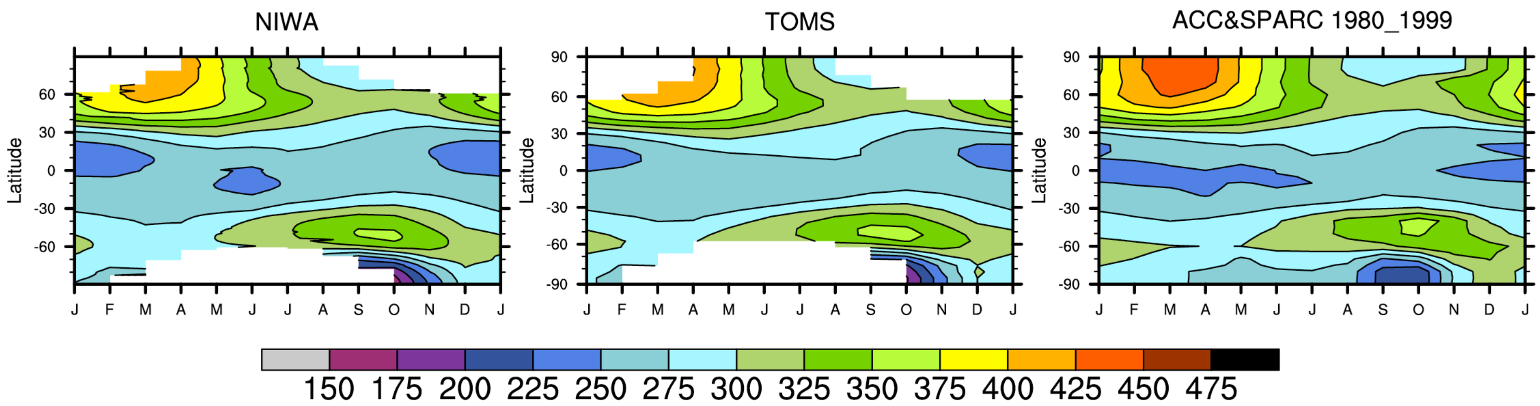
- **Average from the Community Atmosphere Model v3.5 (CAM3.5) and the NASA-GISS PUCCINI model.**
- **Both models simulate tropospheric and stratospheric chemistry with feedback to the radiation and were driven by the recently available historical (1850-2000) emissions described in *Lamarque et al., ACP, 2010*.**



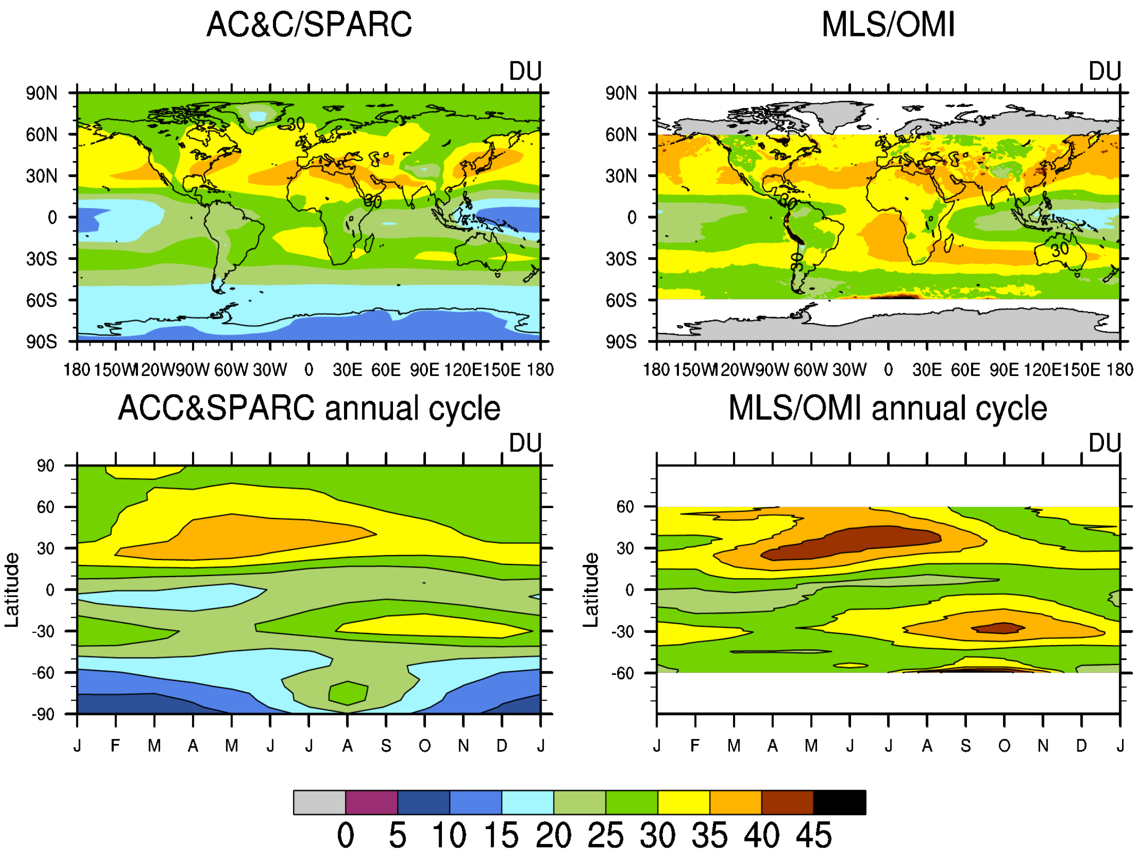
Future data (2010-2099)

- **CAM3.5 only simulations driven by emissions from the 4 RCP scenarios**

Comparison with observations: Total/tropospheric column O_3



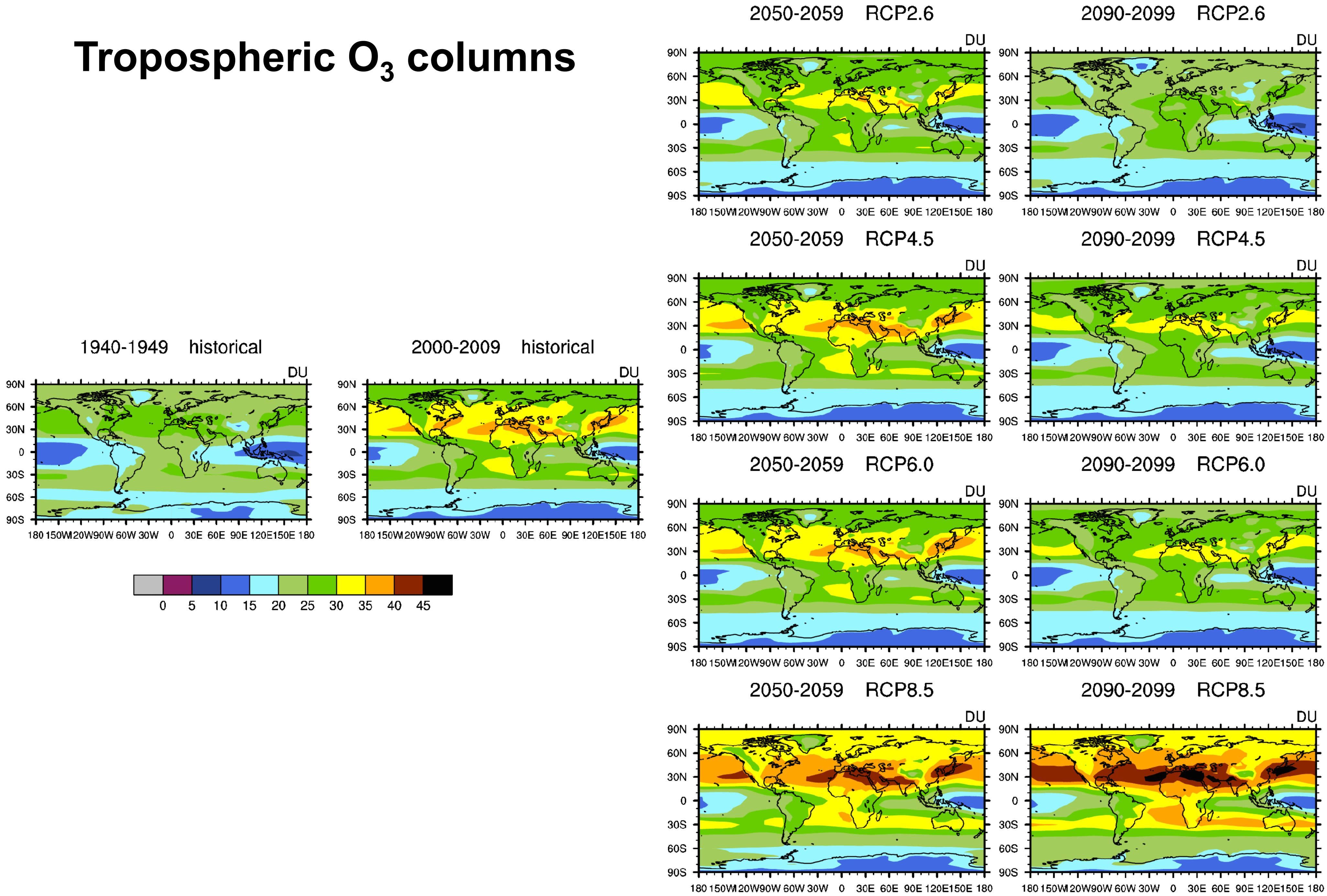
Total column ozone climatologies (1980 to 1999) compared to other observations



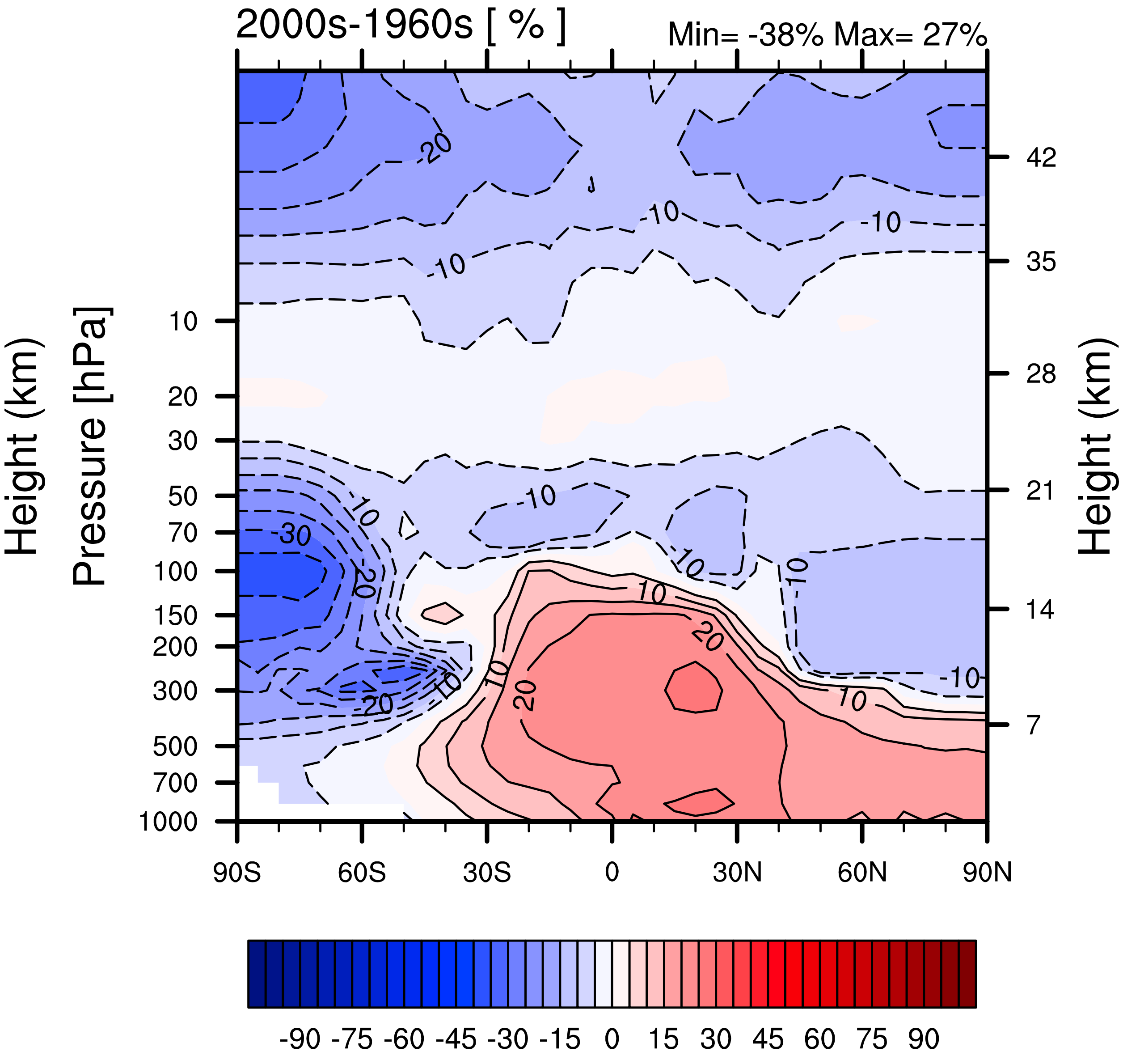
Tropospheric column ozone averaged between 2005 and 2009 compared to the observations

Database lower than satellite tropospheric O_3

Tropospheric O_3 columns



(b) Percentage changes in meridional cross section



% changes
in annual zonal
mean O_3,
2000s-1960s

Definition of radiative forcing (IPCC-TAR):

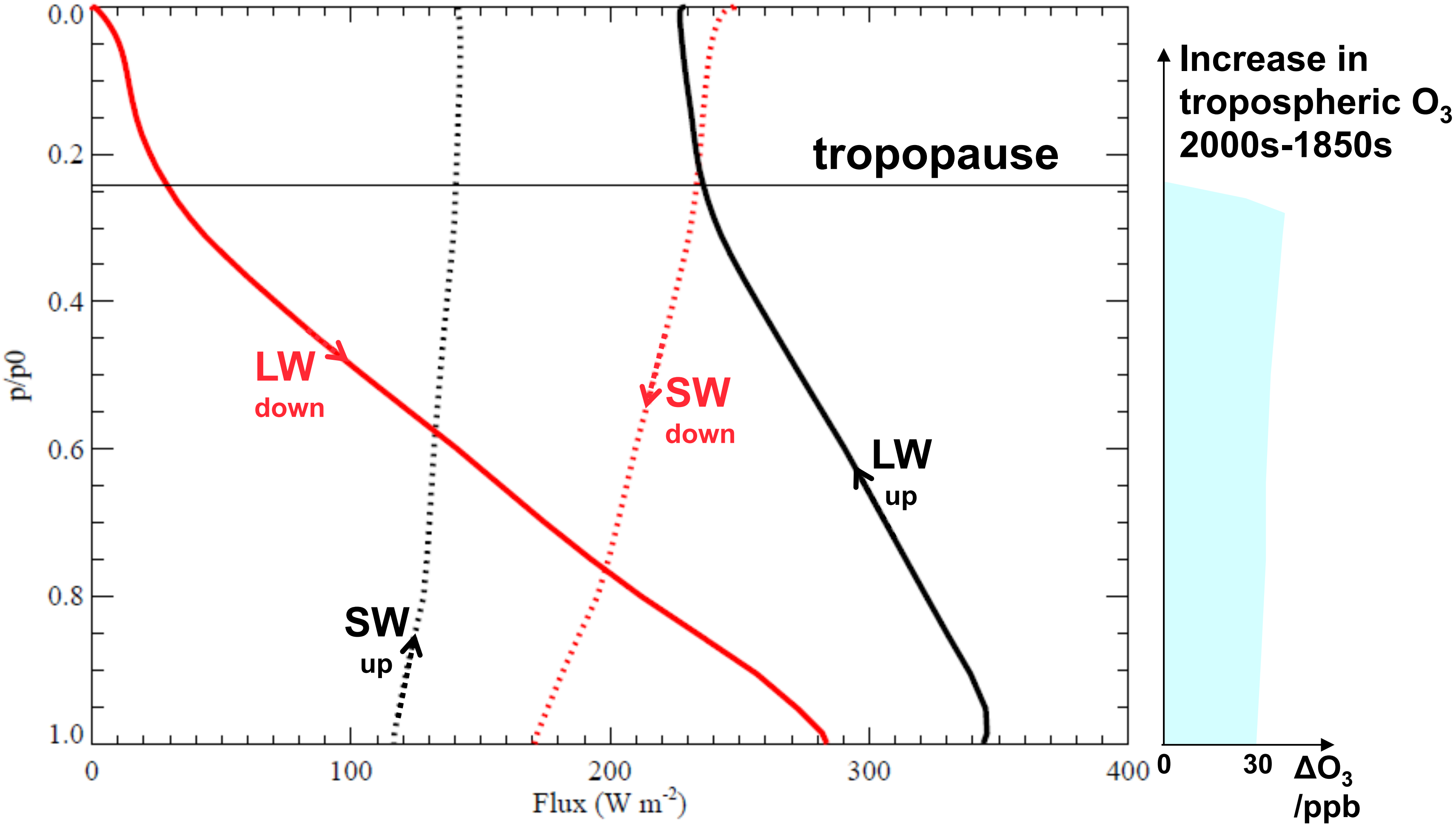
‘The change in the net (down minus up) irradiance (solar plus longwave) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at unperturbed values.’

Radiative Forcing Calculations

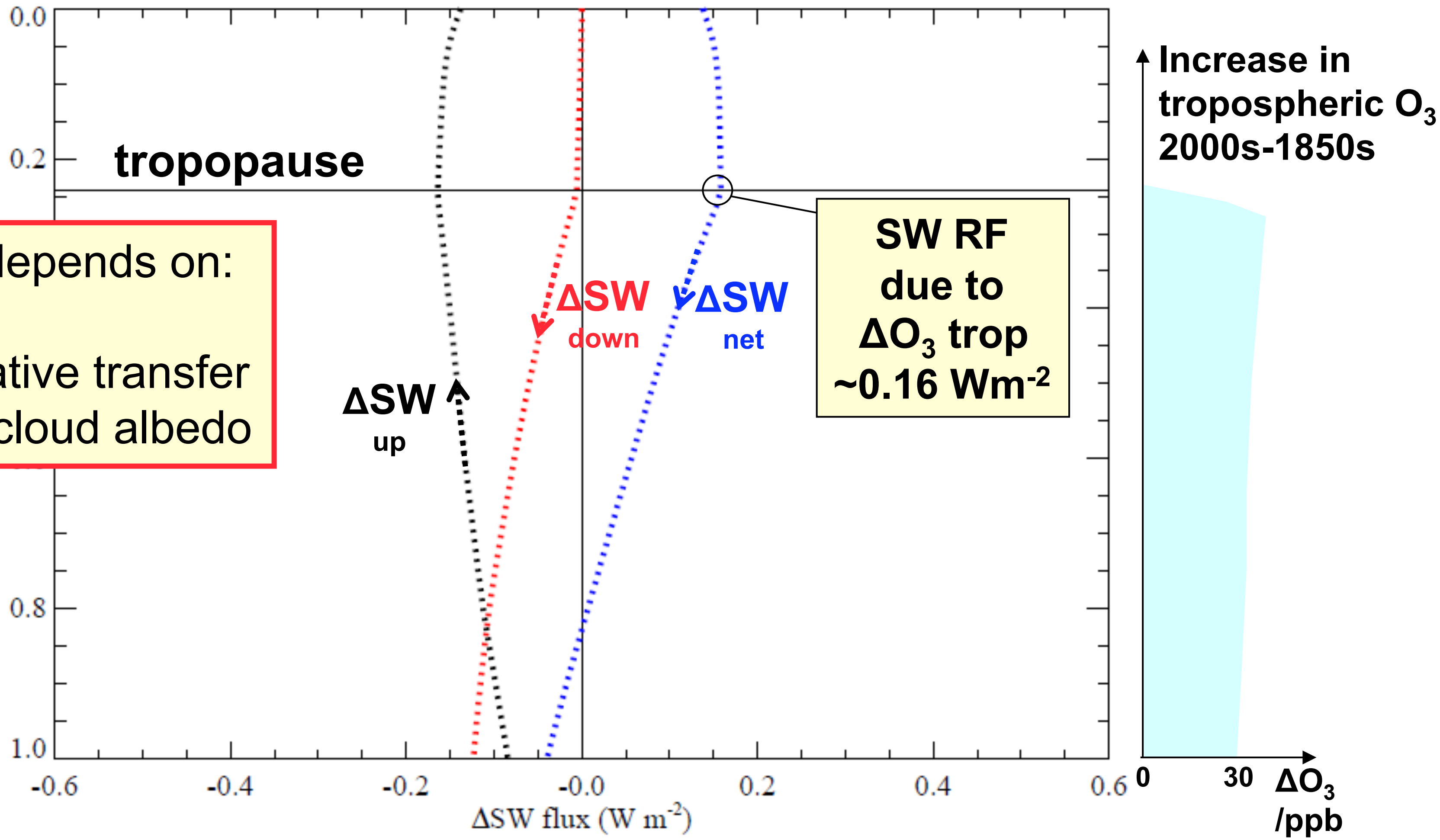
- Offline Edwards & Slingo (1996) code

  Two versions of this code have been used
- Use decadal mean O_3 fields on 5°x 5°grid, 64 vertical levels
- Use background meteorological fields from 64L HadAM3 run
- Include clouds (distributions from HadAM3; some properties from GRAPE)
- Separate trop/strat using climatological tropopause
- Adjust stratospheric temperatures using ‘fixed dynamical heating’ approximation

Baseline SW and LW fluxes for Colorado grid box in October

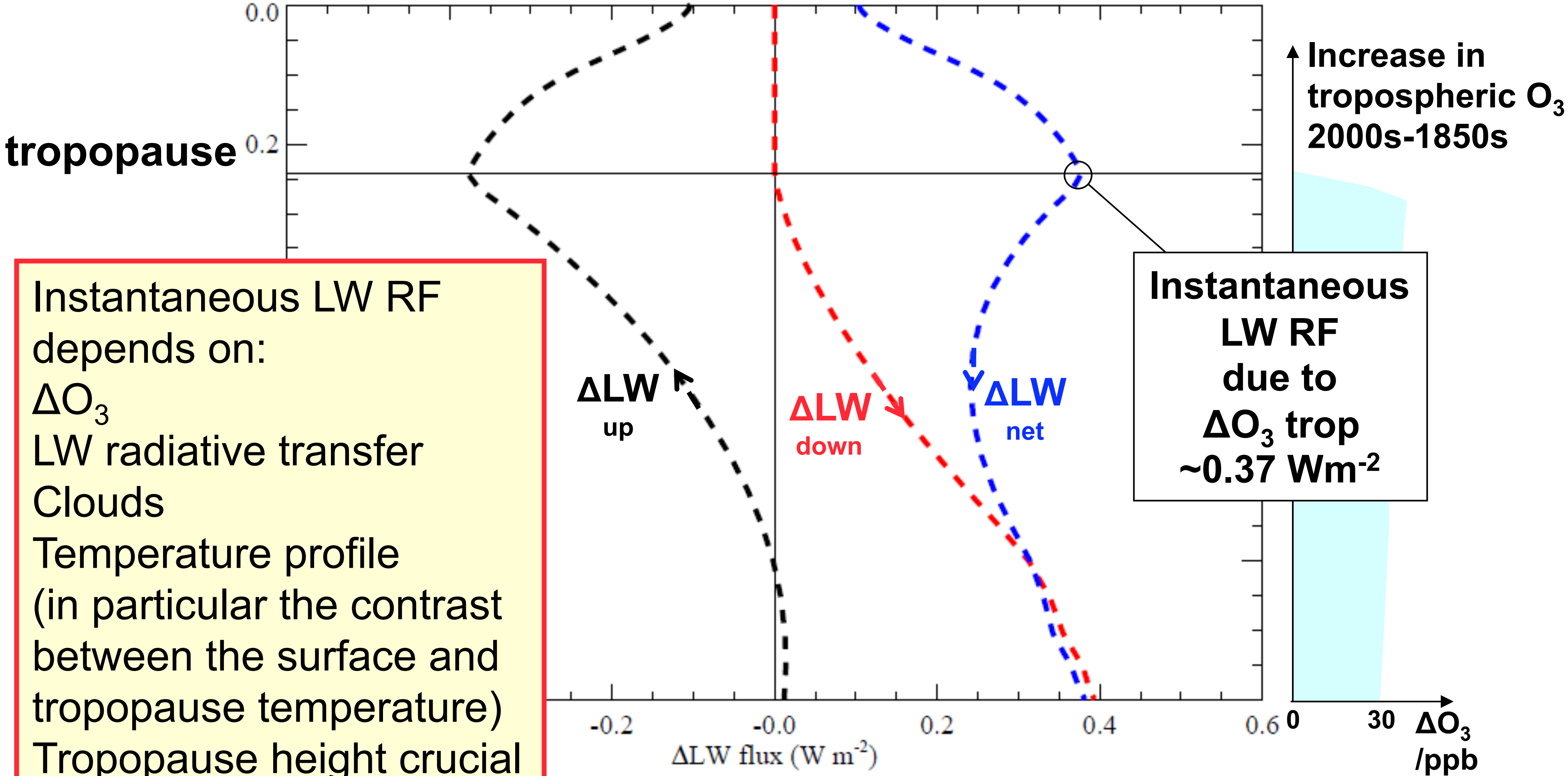


ΔSW fluxes for 2000s-1850s ΔO_3 trop CO, Oct



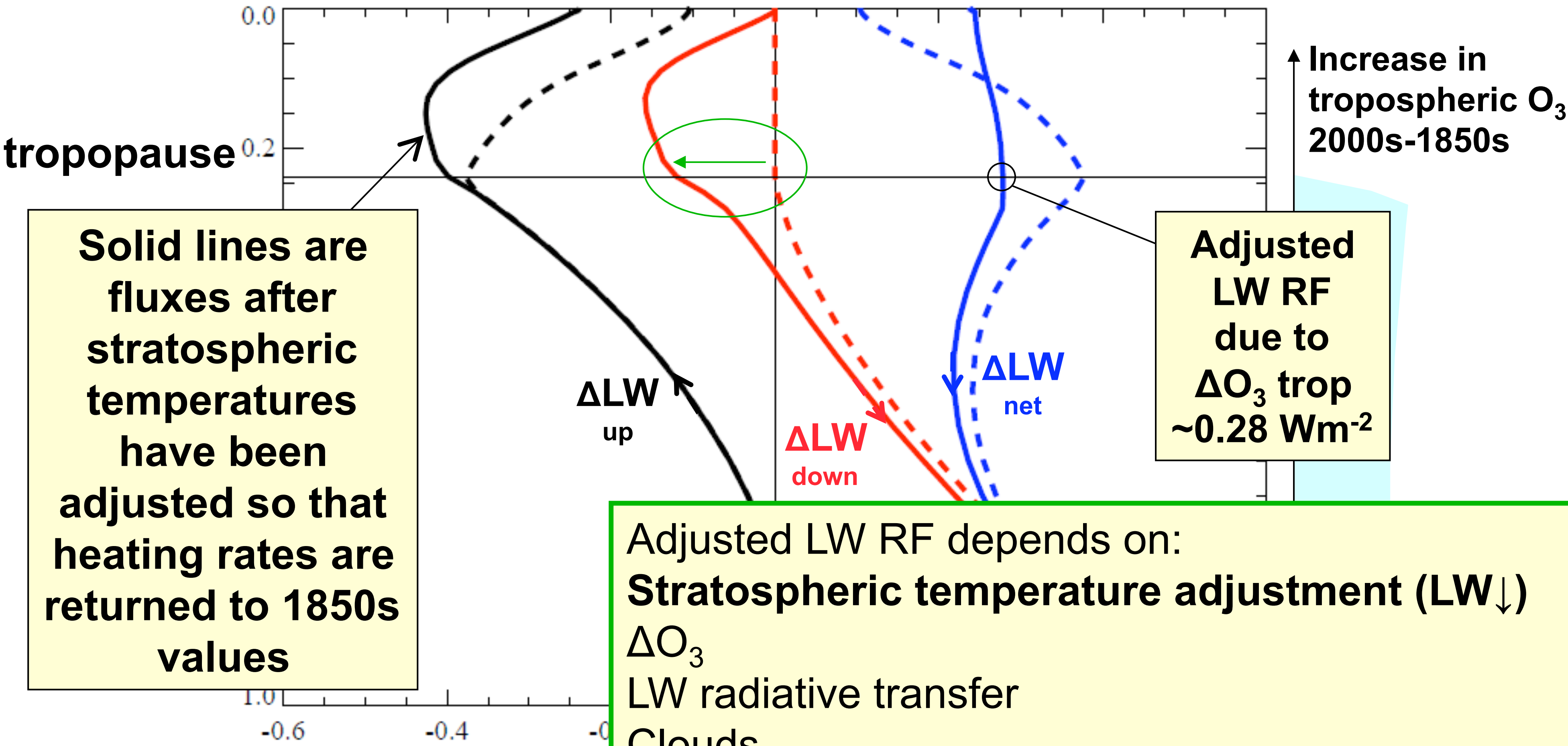
SW RF depends on:
ΔO_3
SW radiative transfer
Surface/cloud albedo

ΔLW instantaneous fluxes for 2000s-1850s ΔO_3 trop CO, Oct



Instantaneous LW RF depends on:
ΔO_3
LW radiative transfer
Clouds
Temperature profile
(in particular the contrast between the surface and tropopause temperature)
Tropopause height crucial

ΔLW adjusted fluxes for 2000s-1850s ΔO_3 trop CO, Oct



Solid lines are fluxes after stratospheric temperatures have been adjusted so that heating rates are returned to 1850s values

Adjusted LW RF due to ΔO_3 trop ~0.28 Wm^{-2}

Adjusted LW RF depends on:

Stratospheric temperature adjustment (LW↓)

ΔO_3

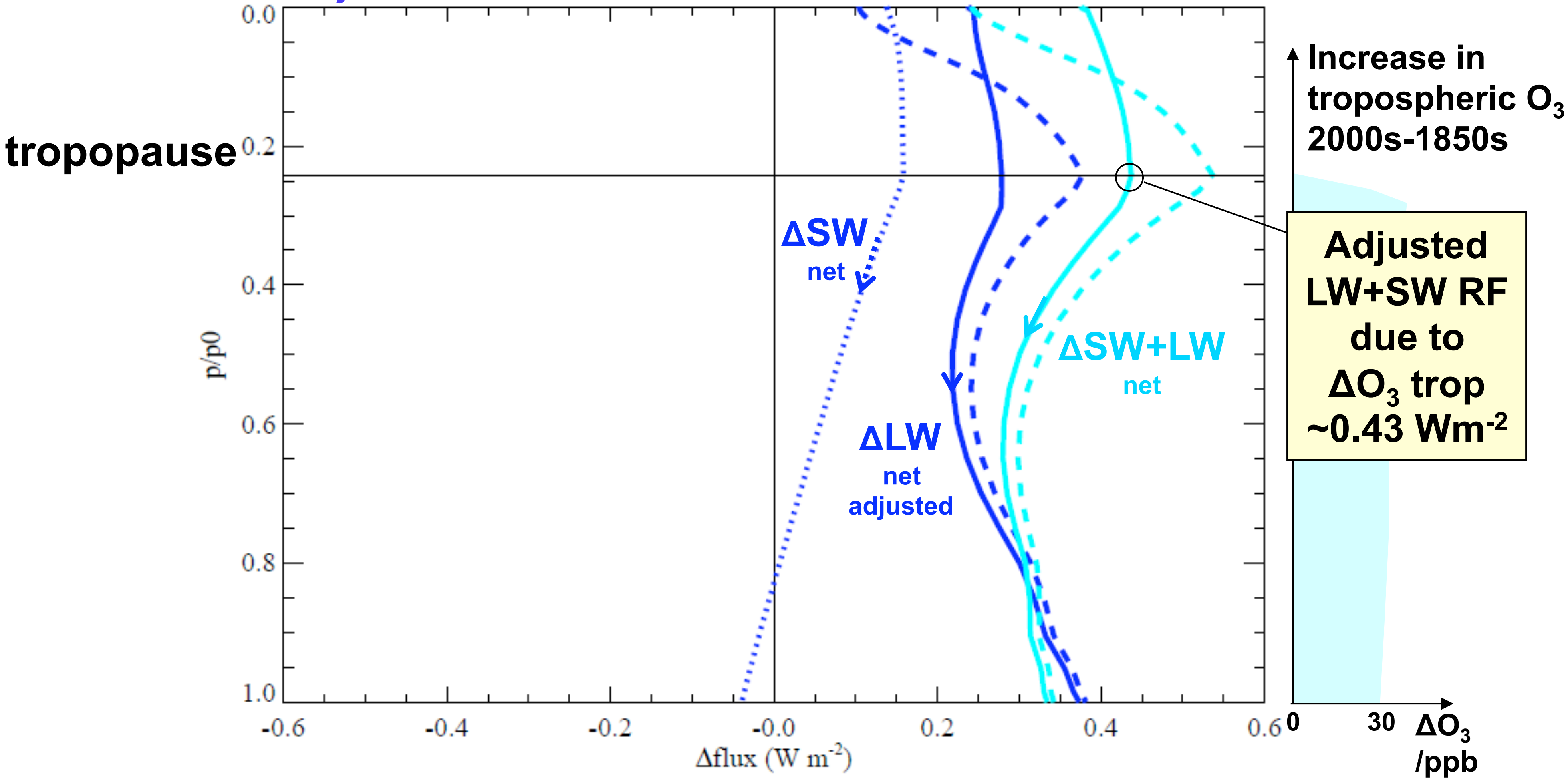
LW radiative transfer

Clouds

Temperature profile

Tropopause height

Total ($LW_{adjusted}$+SW) RF for 2000s-1850s ΔO_3 trop CO, Oct



Results from two versions of the Edwards-Slingo radiation code

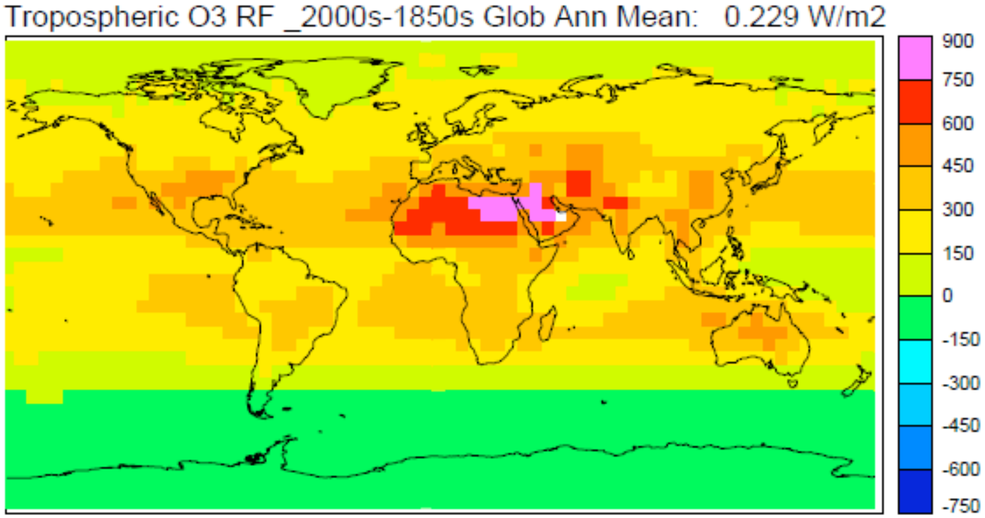
- ‘Old’ version – HadCM3 vintage
    - as used in Cionni et al. (2011) ACPD paper

- ‘New’ version – HadGEM2 vintage
    - Updated ozone absorption cross-sections
    - More detailed treatment of scattering (clouds)
    - More detailed treatment of ocean albedoes
    - Stratospheric temperature adjustment method differs

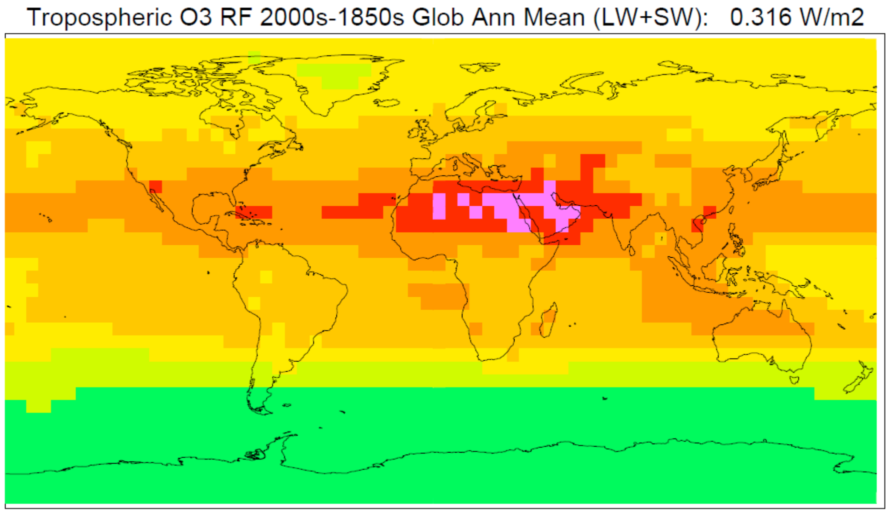
- Different versions produce significantly different O_3 RFs

Radiative forcing results: Tropospheric O_3

Global annual mean forcings (1850s-2000s) at the tropopause, after stratospheric temperature adjustment, taking an area weighted average over all months

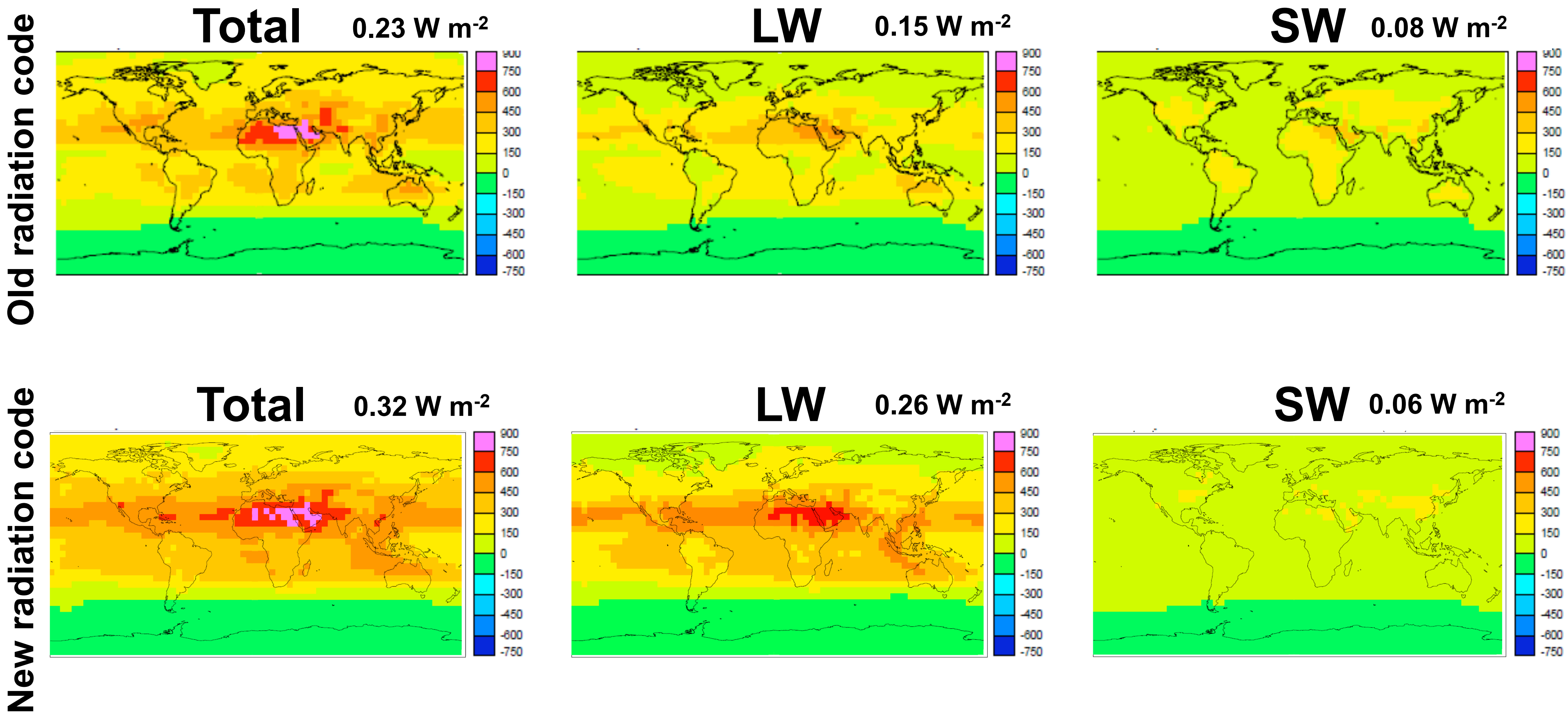


Old radiation code +0.23 W m^{-2}



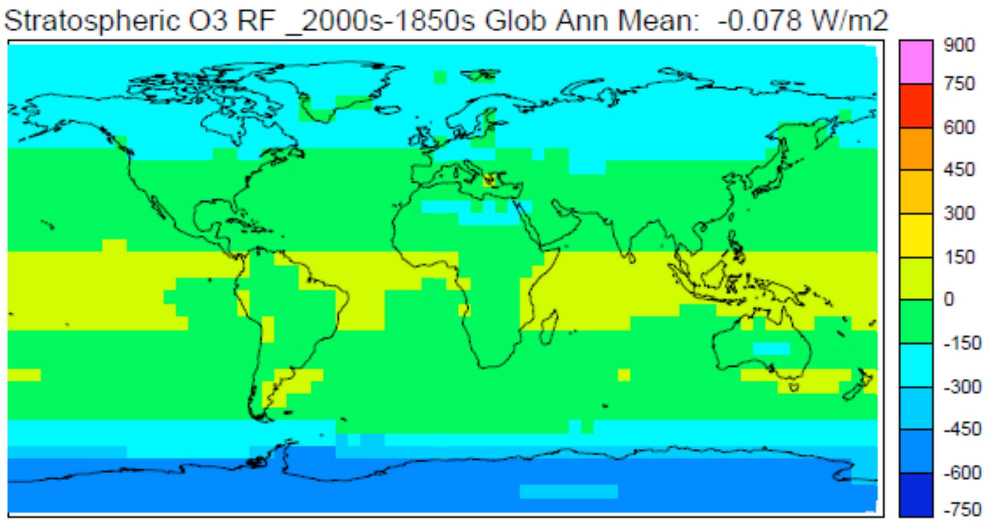
New radiation code +0.32 W m^{-2}

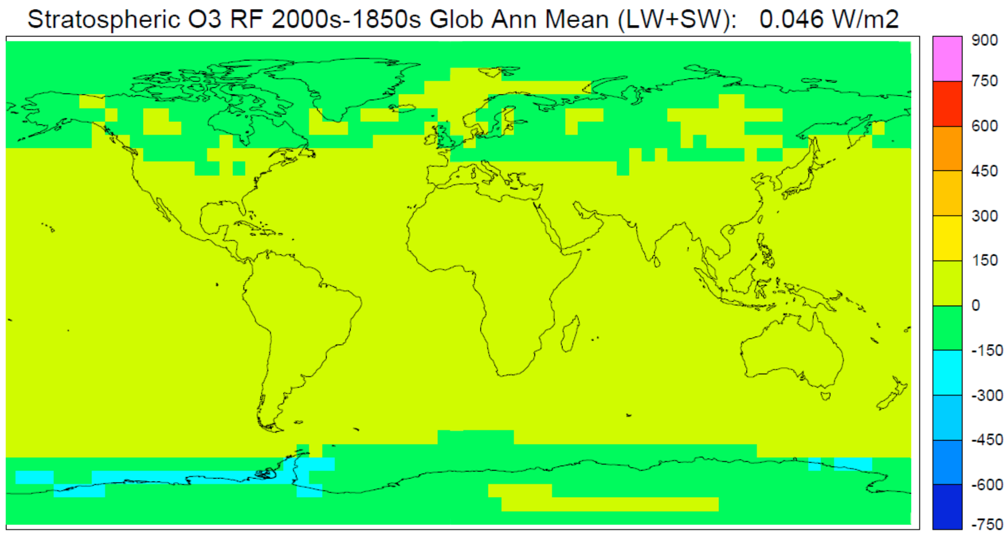
Tropospheric O_3 RF Components



Radiative forcing results: Stratospheric O_3

Global annual mean forcings (1850s-2000s) at the tropopause, after stratospheric temperature adjustment, taking an area weighted average over all months

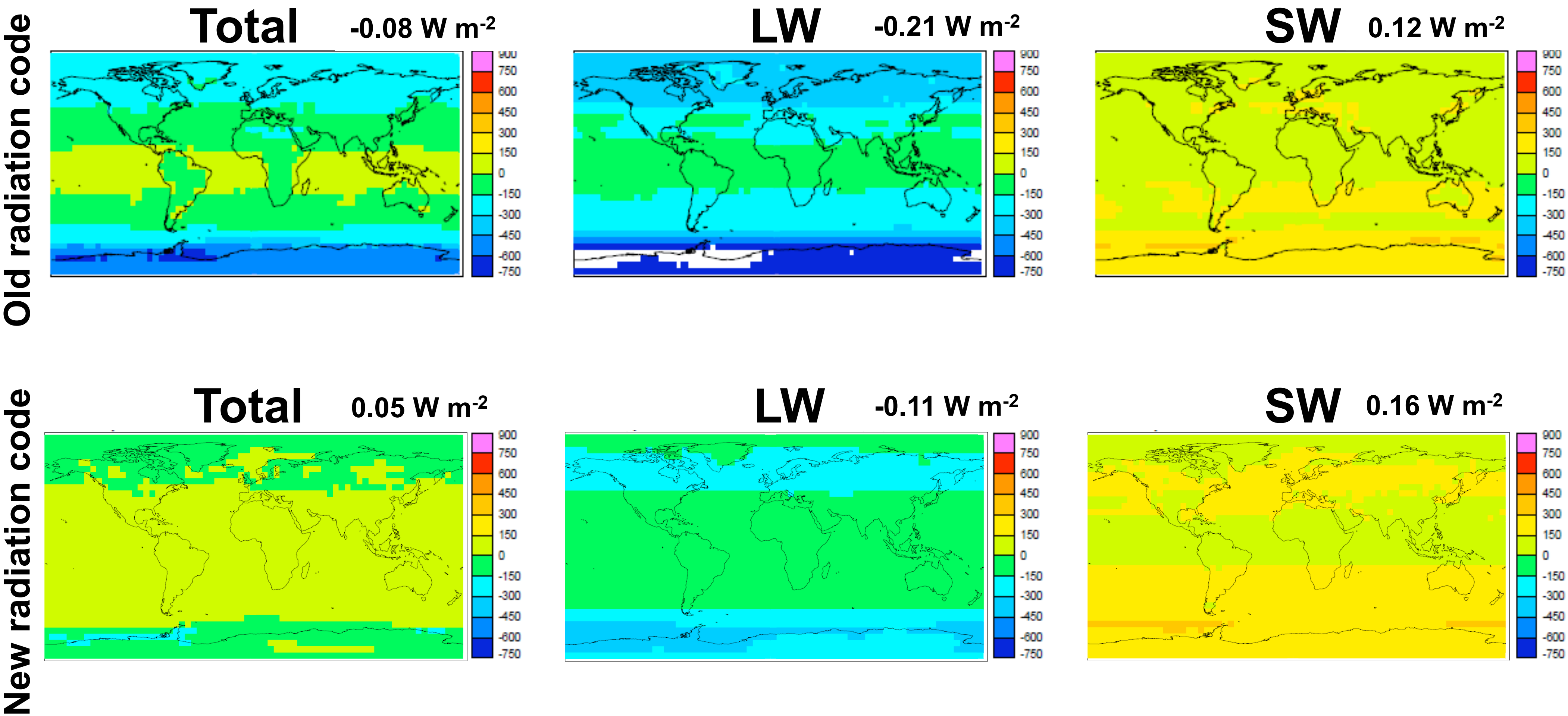




Old radiation code -0.08 W m^{-2}

New radiation code +0.05 W m^{-2}

Stratospheric O_3 RF Components



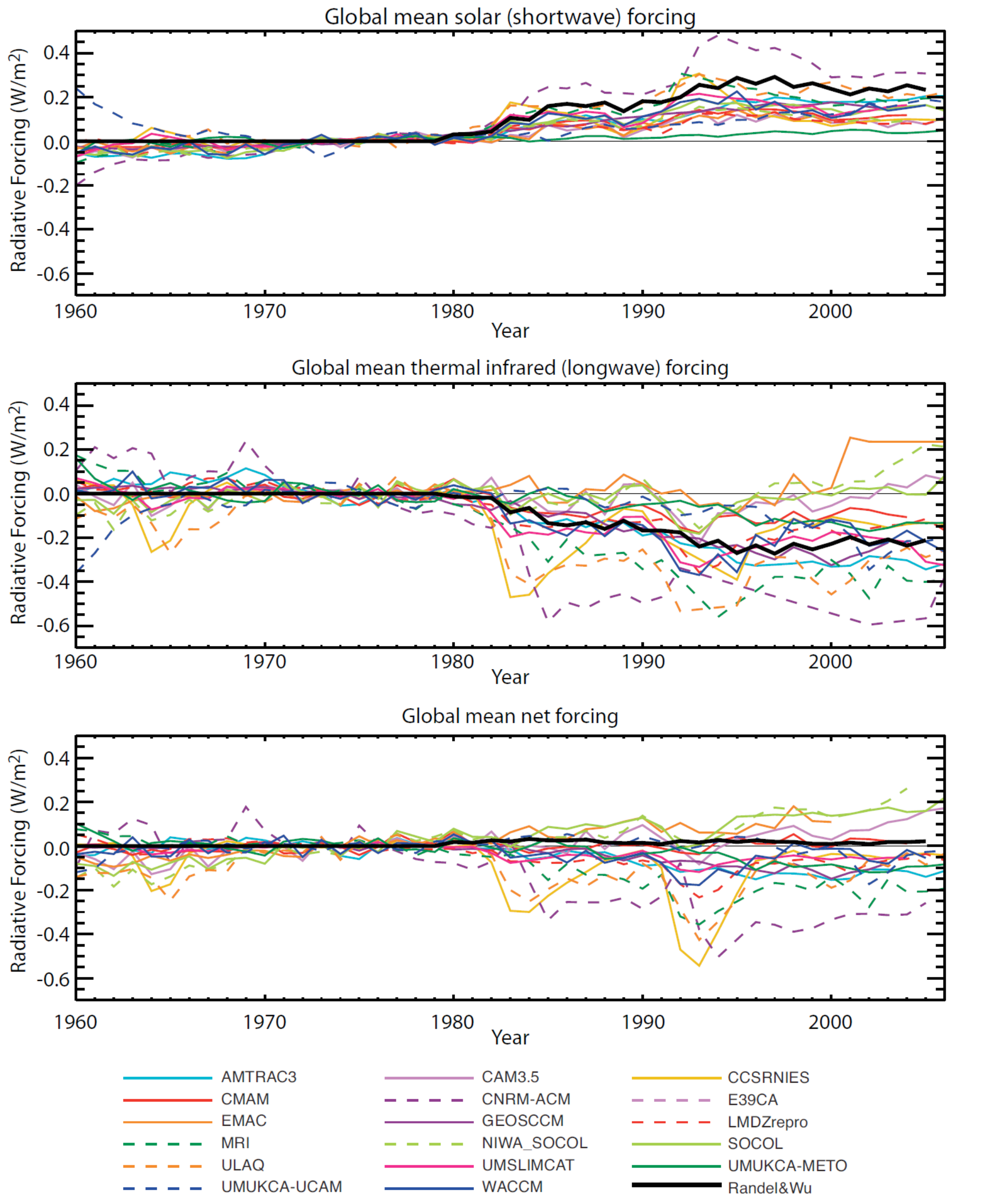


Figure 4-17. Stratospheric ozone global-mean radiative forcing (W/m^2) for shortwave (top), longwave (middle) and net (shortwave plus longwave) compared to the 1970s average, evaluated from the CCMVal REF-B1 scenario ozone fields (colored lines) and from the Randel and Wu (2007) observation-based data set (thick black line). See Table 3-1 in Chapter 3 of this Assessment for a description of the chemistry-climate models shown in the figure. Based on Chapter 10 of SPARC CCMVal (2010).

WMO (2011) Chapter 4 (Forster et al., 2011)

Stratospheric O_3 RFs from 1960-2005

RFs based on observations in black: +0.03 W m^{-2}

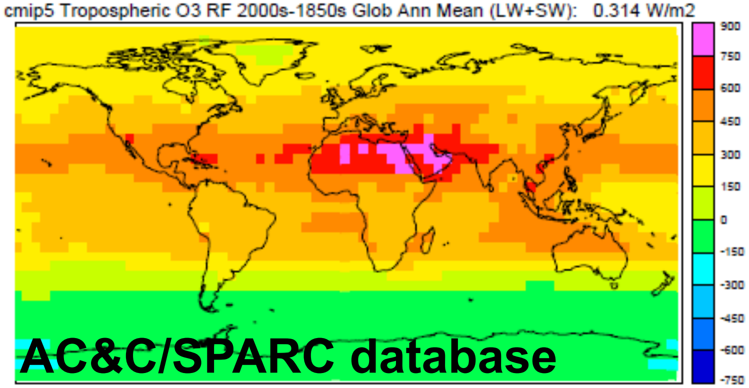
RFs based on models in colour: -0.03 W m^{-2}

WMO chose to retain the IPCC-AR4 assessment value.

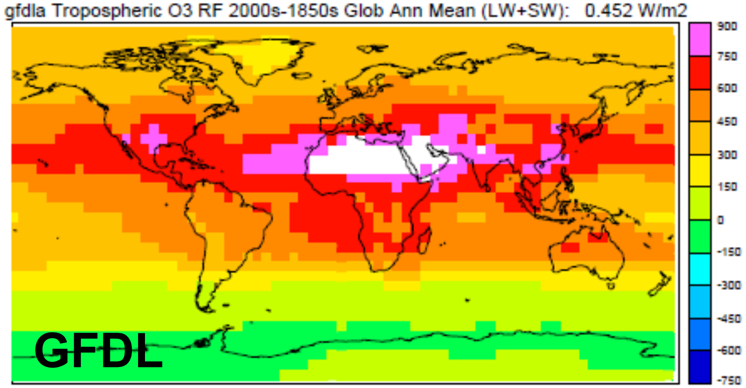
These calculations all use the Edwards-Slingo radiation code, as used here.
Calculations are for clear skies and use the SEFDH <200 hPa.

ACCMIP models tropospheric O_3 RF (1850s-2000s) (preliminary)

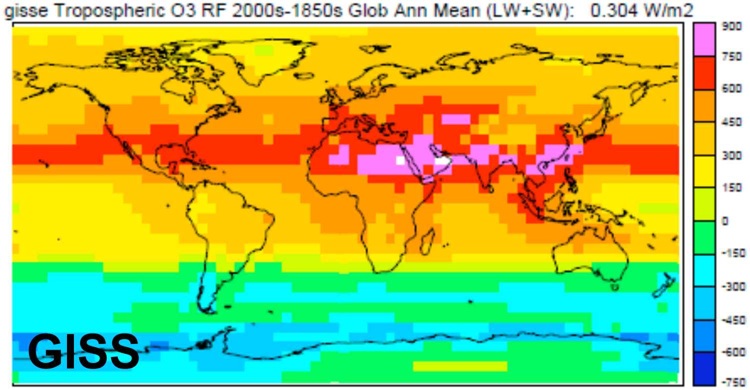
cmip5 Tropospheric O3 RF 2000s-1850s Glob Ann Mean (LW+SW): 0.314 W/m2



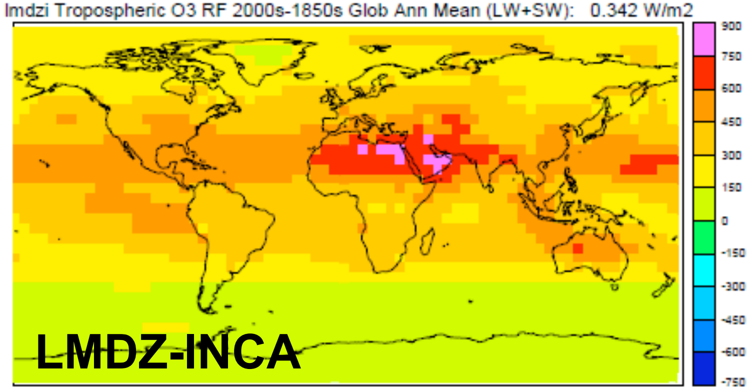
gfdla Tropospheric O3 RF 2000s-1850s Glob Ann Mean (LW+SW): 0.452 W/m2



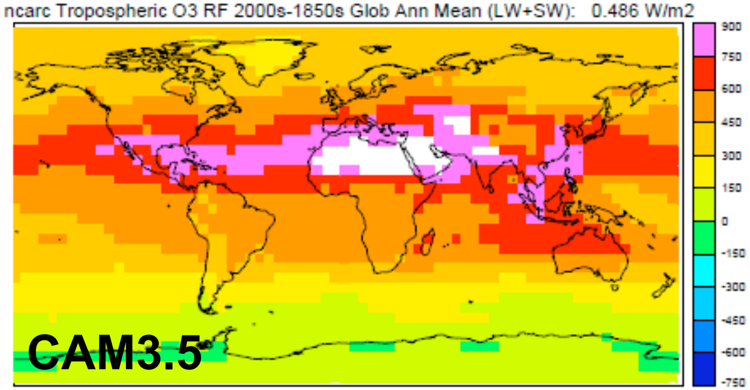
gisse Tropospheric O3 RF 2000s-1850s Glob Ann Mean (LW+SW): 0.304 W/m2



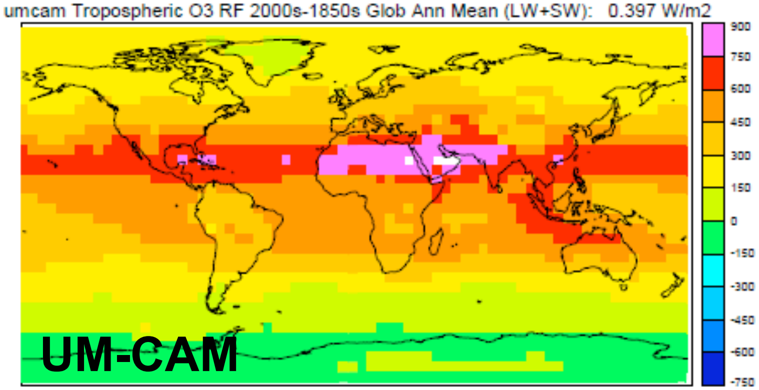
lmdzi Tropospheric O3 RF 2000s-1850s Glob Ann Mean (LW+SW): 0.342 W/m2

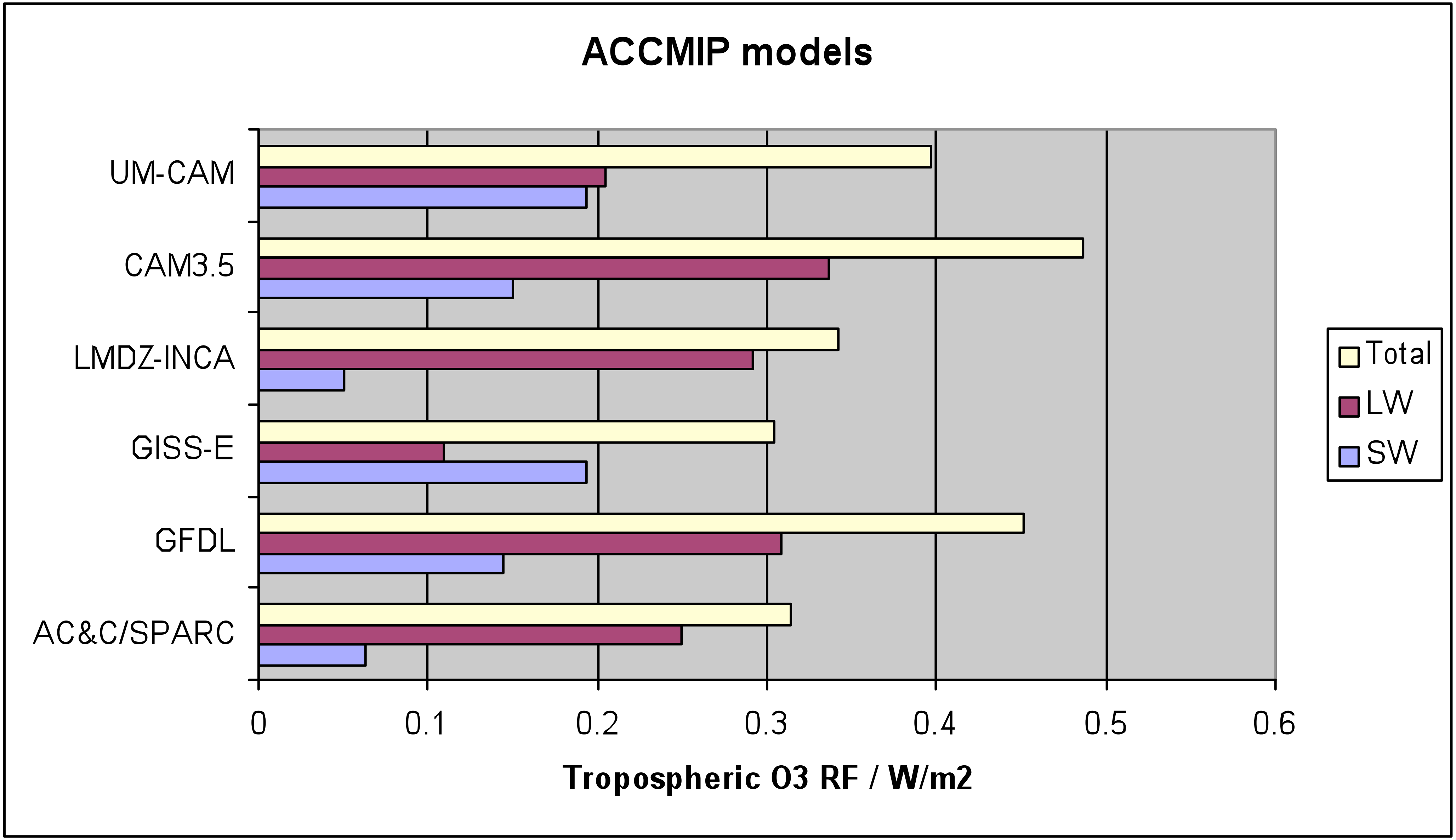


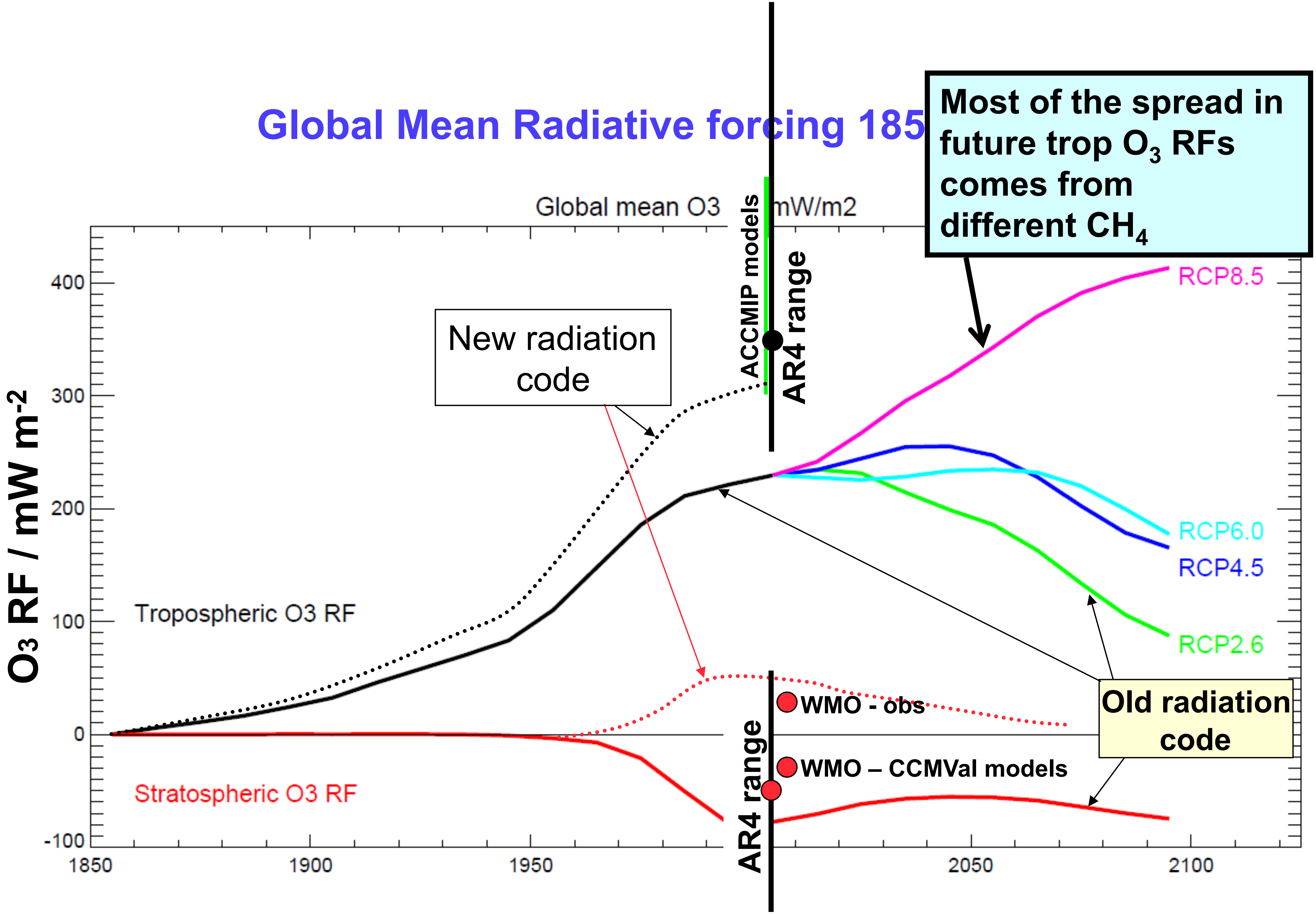
ncarc Tropospheric O3 RF 2000s-1850s Glob Ann Mean (LW+SW): 0.486 W/m2



umcam Tropospheric O3 RF 2000s-1850s Glob Ann Mean (LW+SW): 0.397 W/m2




ACCMIP models
UM-CAM
CAM3.5
LMDZ-INCA
GISS-E
GFDL
AC&C/SPARC
0
0.1
0.2
0.3
0.4
0.5
0.6
Tropospheric O3 RF / W/m2
Total
LW
SW


Global Mean Radiative forcing 185
Most of the spread in future trop O_3 RFs comes from different CH_4
Global mean O3
mW/m2
ACCMIP models
AR4 range
New radiation code
O_3 RF / mW m^{-2}
400
300
200
100
0
-100
1850
1900
1950
2050
2100
Tropospheric O3 RF
Stratospheric O3 RF
RCP8.5
RCP6.0
RCP4.5
RCP2.6
WMO - obs
WMO – CCMVal models
AR4 range
Old radiation code

Conclusions / Actionable Items

Tropospheric O_3 RFs:

- AC&C/SPARC database: 0.23 W m^{-2} (old radiation code)
- AC&C/SPARC database: 0.32 W m^{-2} (new radiation code)
- ACCMIP models (preliminary): 0.3-0.49 W m^{-2}
- Similar to AR4 range

Stratospheric O_3 RFs:

- AC&C/SPARC database: -0.08 W m^{-2} (old radiation code)
- AC&C/SPARC database: +0.05 W m^{-2} (new radiation code)
- WMO/CCMVal report: -0.03 / +0.03 W m^{-2}
- Within AR4 range, but new calculations suggest positive rather than negative

Time evolutions of forcings available

Significant uncertainties due to:

- applied ΔO_3, radiation code, tropopause height, FDH methods

More calculations needed to fully characterise uncertainty range