Source attribution of O_3 radiative forcing using TES observations and GEOS-Chem adjoint sensitivities

IGC5
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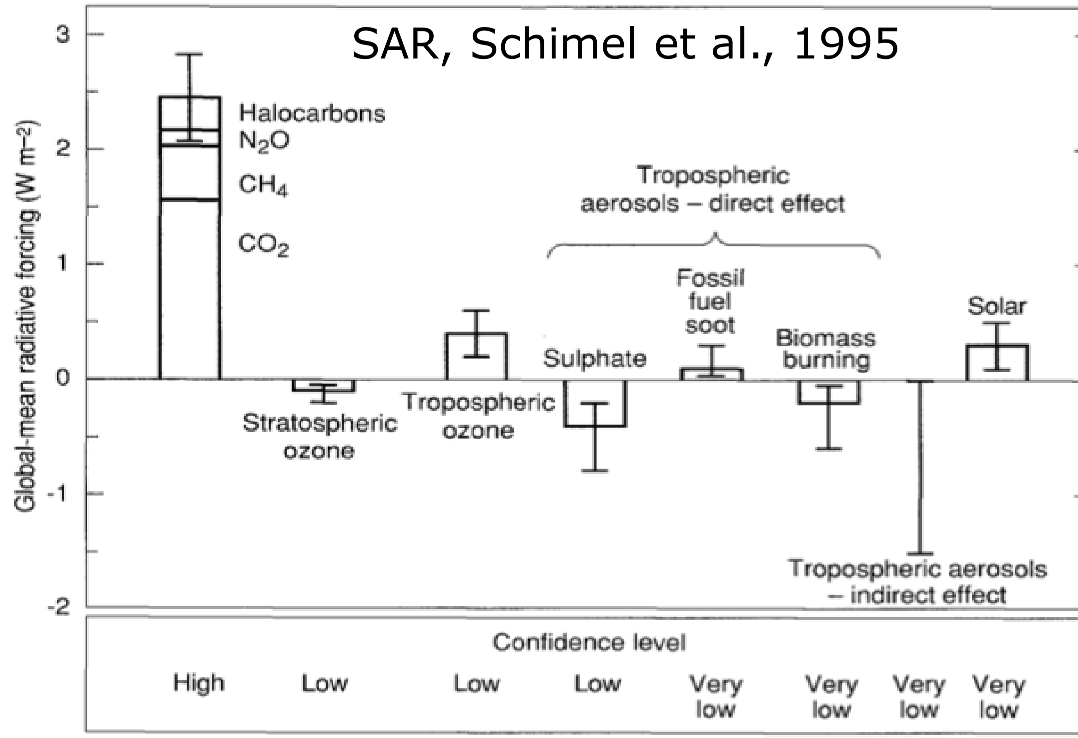
Tropospheric ozone radiative forcing

- 3rd largest GHG contributor to pre-industrial to present radiative forcing

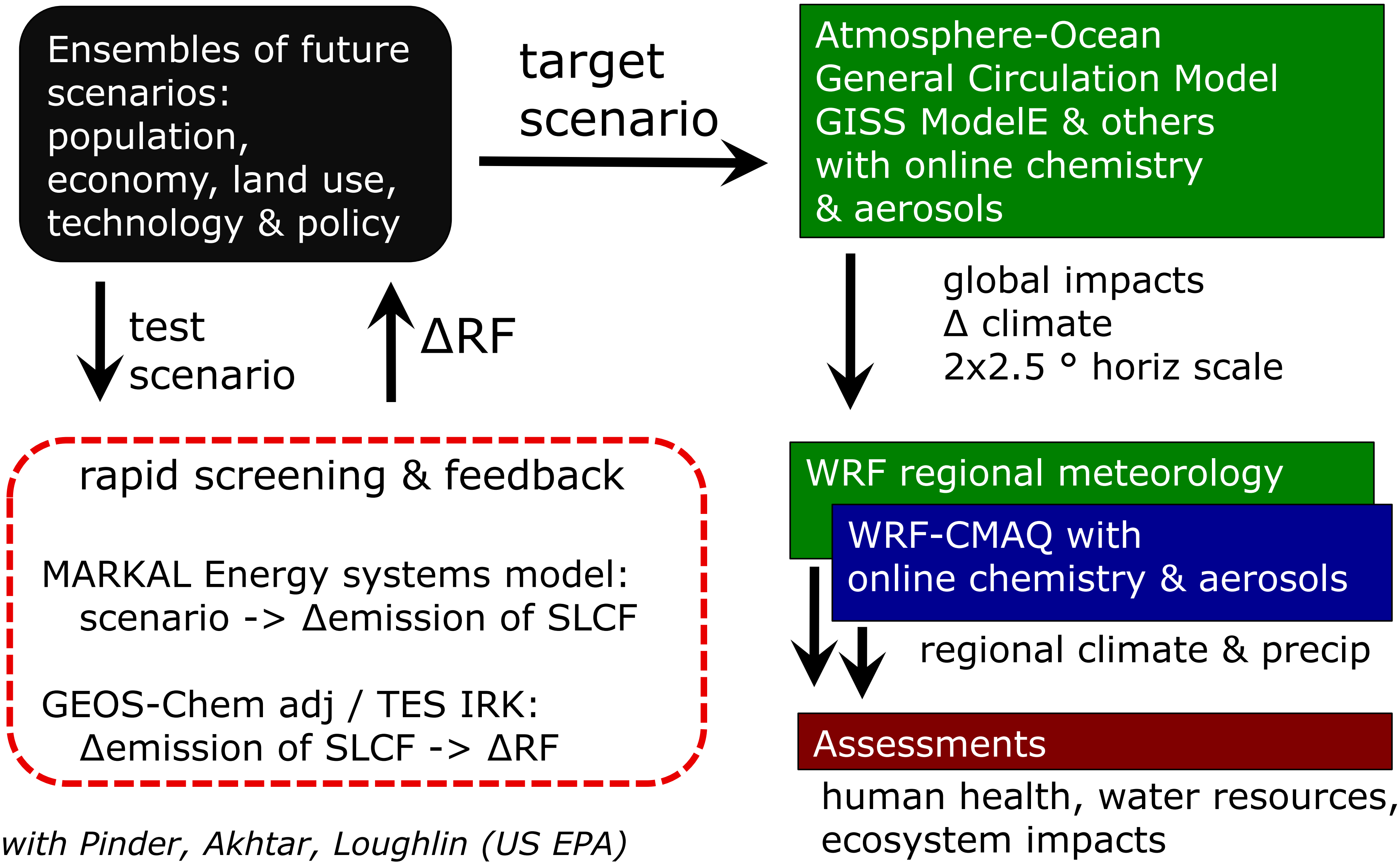


- 0.35 +/- 0.15 W/m^2 since 2nd IPCC report

- Model based

- Moving towards more specific refinements of SLCFs: Unger et al., 2008; Shindell et al., 2008; Fuglestvedt et al., 2008; Kloster et al., 2008

Systems for modeling air quality & climate change

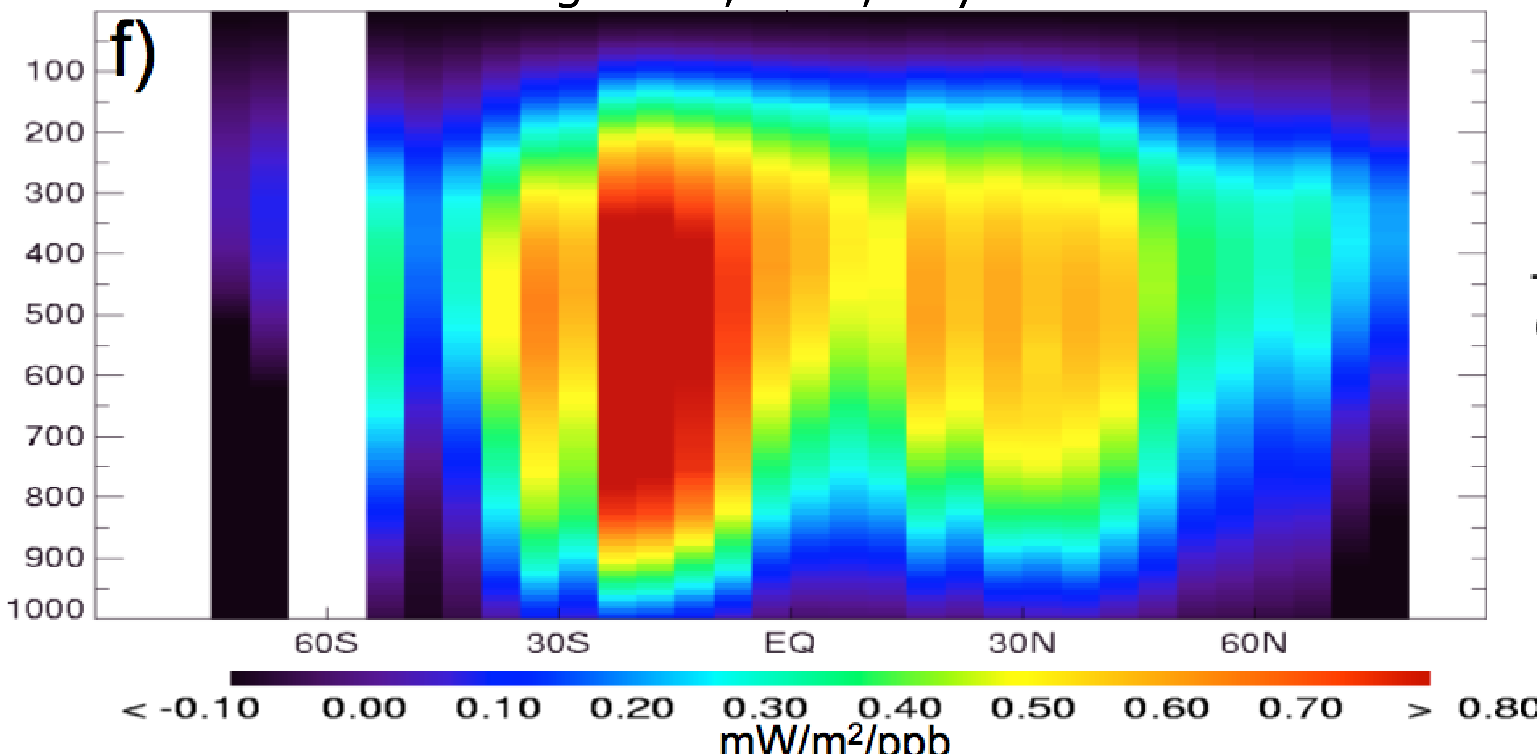


with Pinder, Akhtar, Loughlin (US EPA)

O_3 radiative effect observed from TES

All-sky tropospheric Instantaneous Radiative Kernel, IRK, is change in OLR per change in O_3 [ppb]

Aug 2006, land, daytime



$$\frac{\partial OLR}{\partial O_3(z)}$$

Worden et al., (2008; 2011), Aghedo et al., 2011

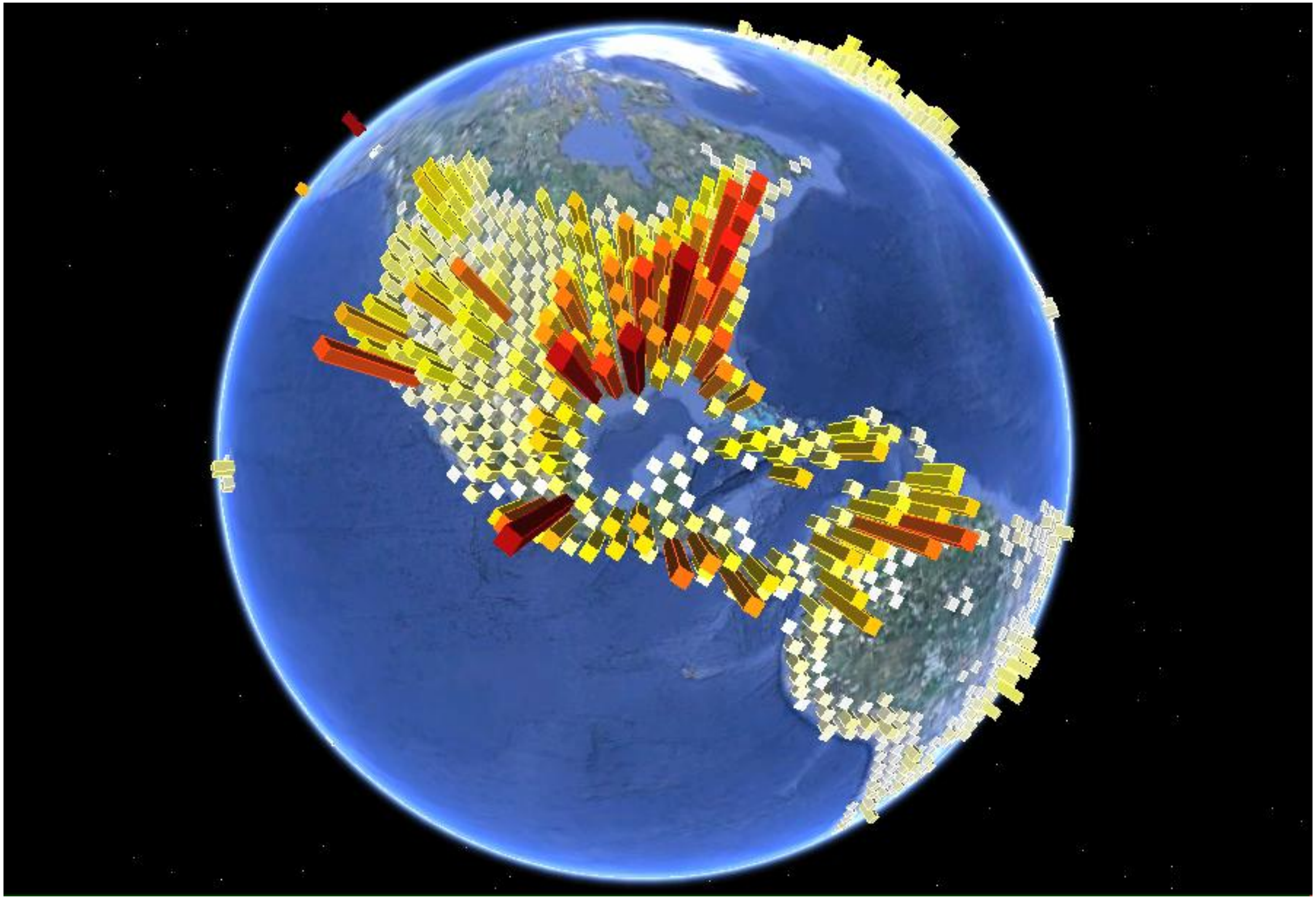
Merging TES and GEOS-Chem sensitivities

GEOS-Chem adjoint:
- sensitivity of model response w.r.t. emissions
- broken down by sector-species *i* and location *x*,*y*: $E_i(x,y)$

Combine GEOS-Chem adjoint sensitivities with TES IRKs:

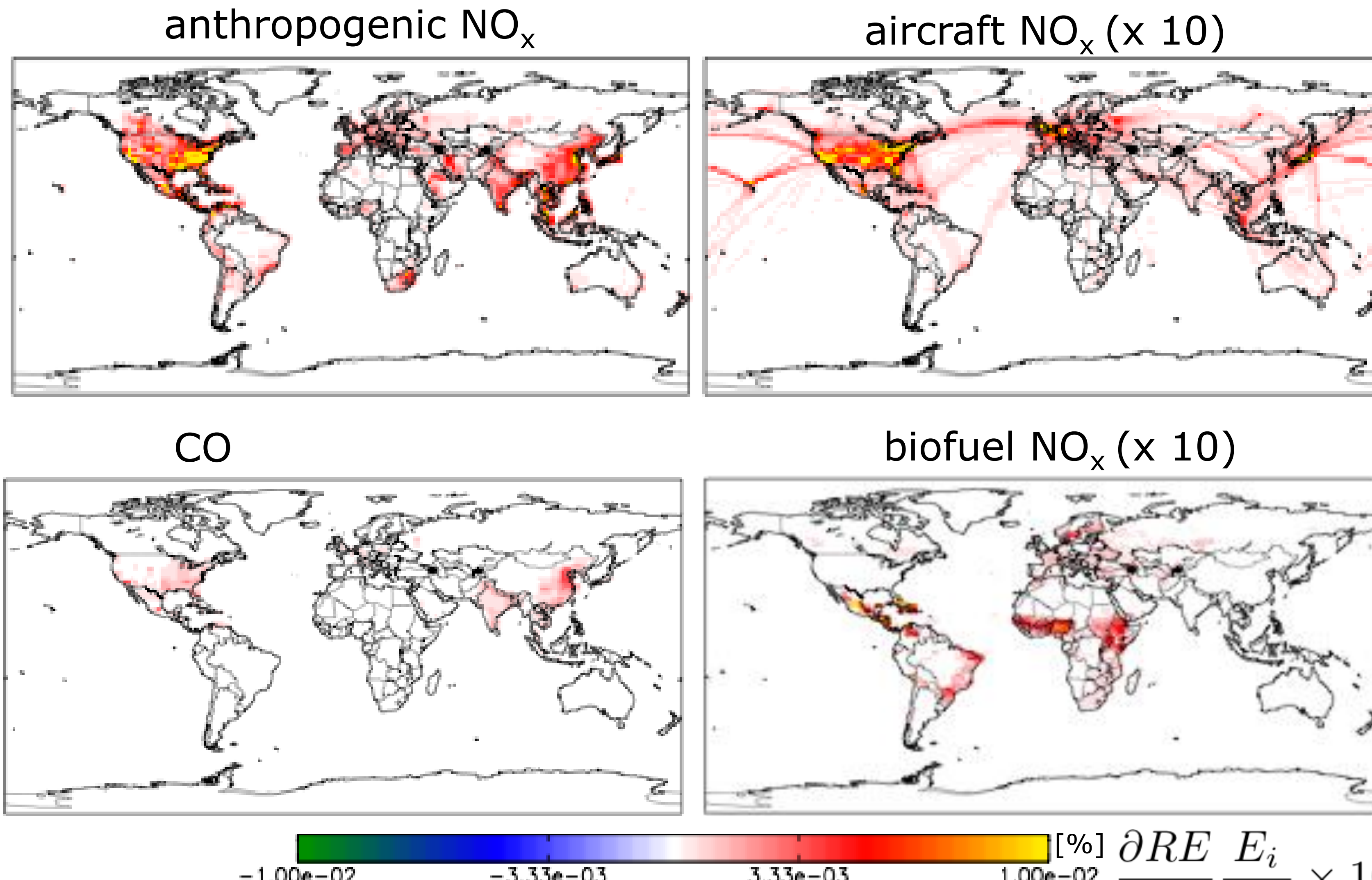
$$\frac{\partial \text{radiative effect}}{\partial E_i(x,y)} = \boxed{\frac{\partial \mathrm{O}_3(x,y,z)}{\partial E_i(x,y)}} \times \boxed{\frac{\text{radiative effect}}{\partial \mathrm{O}_3(x,y,z)}}$$

The ultimate radiative forcing bar chart



Trop O_3 radiative forcing from anthropogenic NO_x emissions

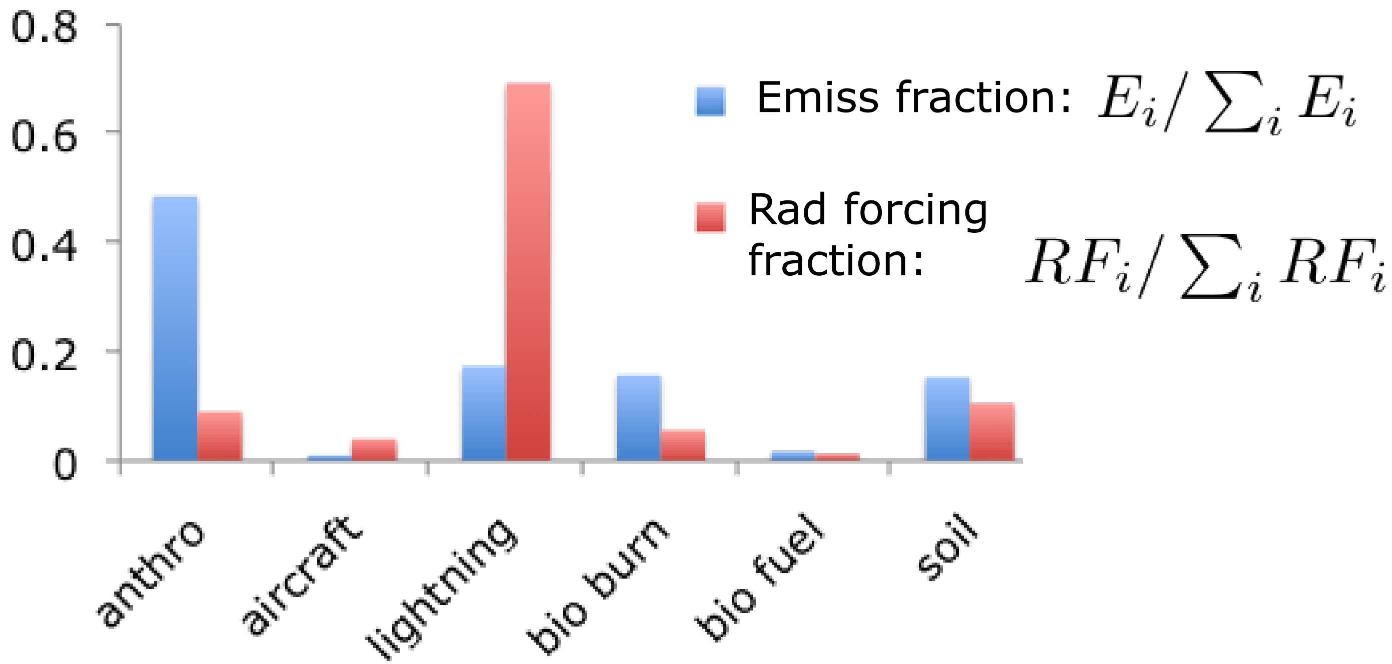
Ozone radiative forcings



$$\frac{\partial RE}{\partial E_i}\frac{E_i}{RE} \times 100\%$$

Radiative forcing efficiencies

Consider RF of different NO_x sectors compared to their contribution to total NO_x emissions:

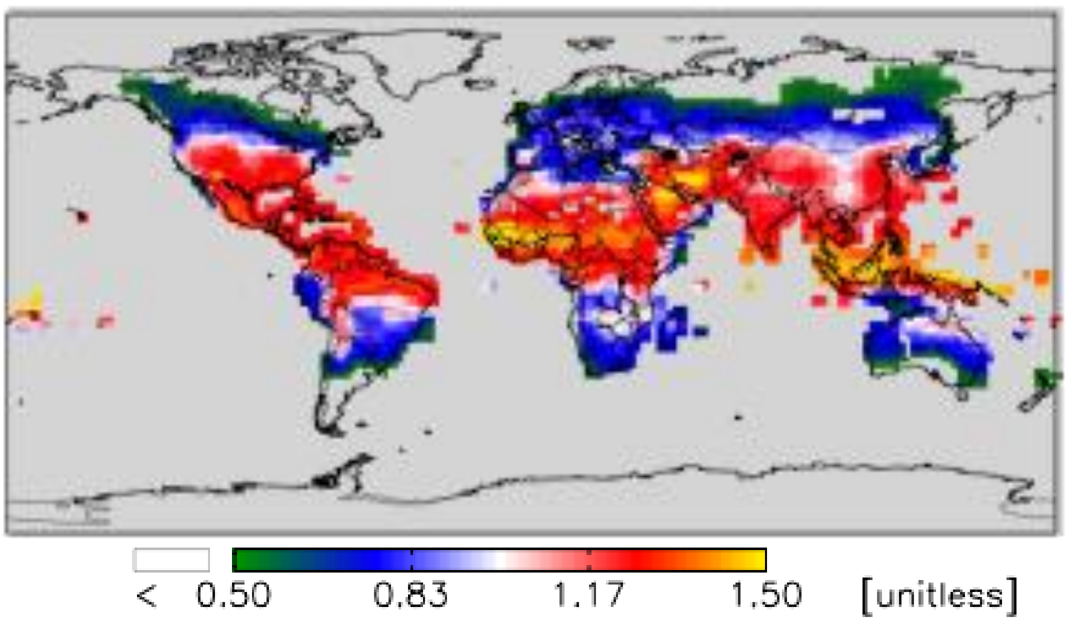


Radiative effect efficiencies

Combine O_3 sensitivities with RE sensitivities to map efficiency

$$r_{eff} = \frac{\text{radiative effect sensitivity}}{\text{ozone column sensitivity}}$$

Results show amount by which anthropogenic NO_x influences O_3 that is radiatively important:



Aug, 2006

Final Remarks

Need to consider additional months, seasons:

- TES IRK's being calculated as we speak

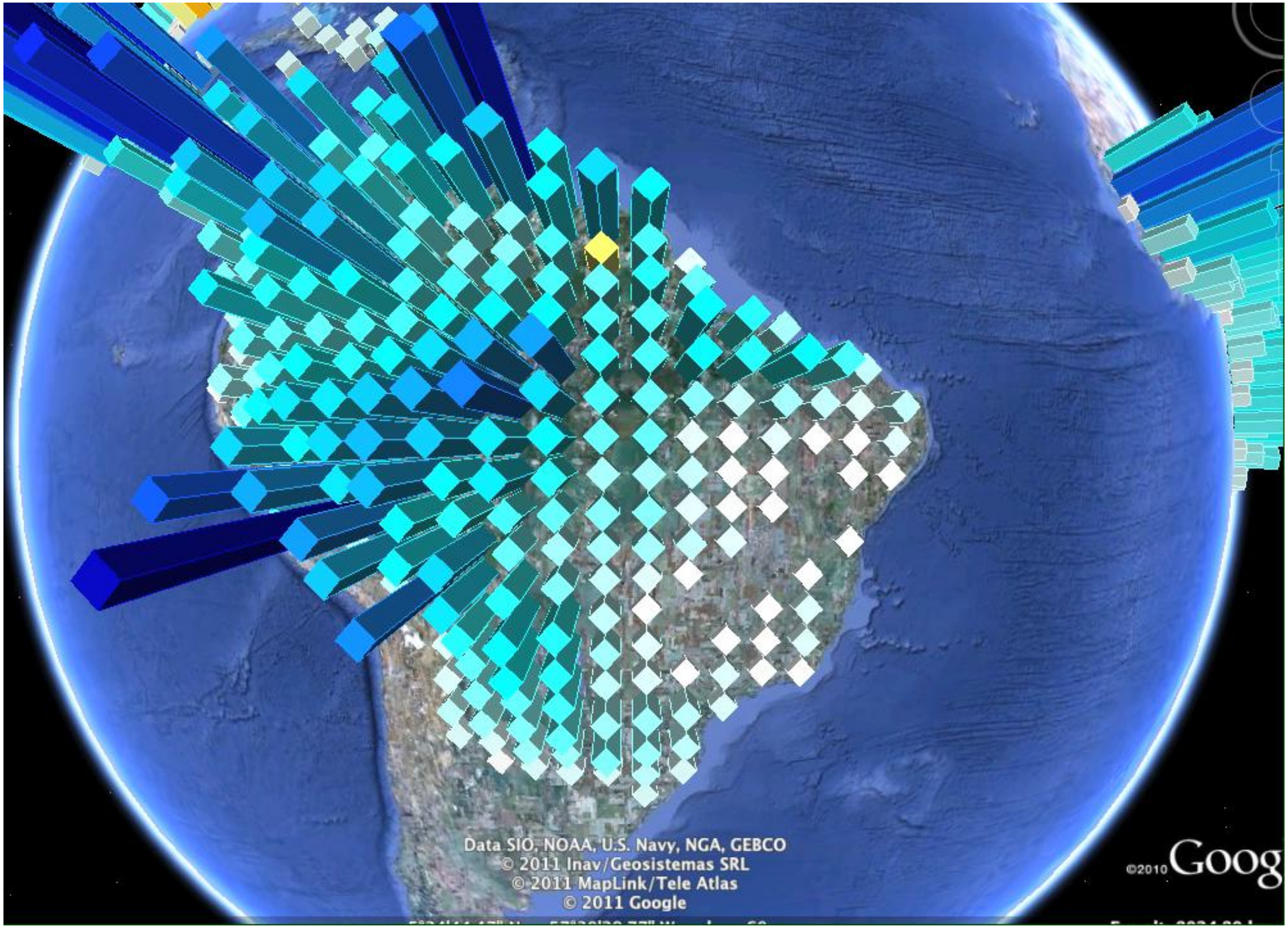
Need to consider other impacts of NO_x emissions:

$$RF(NO_x) = \frac{\partial RE(O_3)}{\partial NO_x} + \frac{\partial RE(CH_4)}{\partial NO_x} + \frac{\partial RE(PM)}{\partial NOx} + \ldots$$

Not all forcing is equivalent (e.g., Shindell & Faluvegi, 2009)

the end

Ozone radiative effects from isoprene



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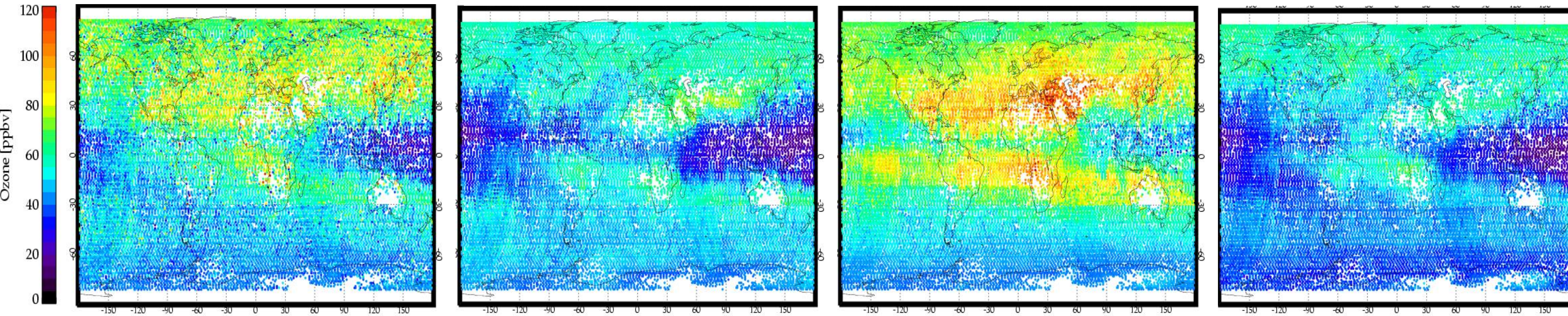
Radiative forcing of tropospheric O_3: uncertainty

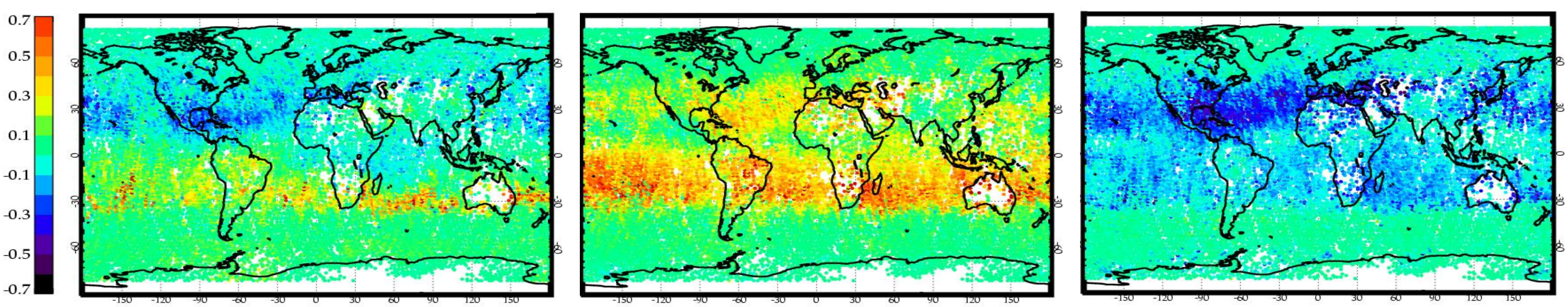
Variability in model estimated O3 at 511 hPa:

TES **AM2-Chem** **ECHAM5-MOZ** **GISS**



leads to large biases in OLR relative to TES

AM2-Chem **ECHAM5-MOZ** **GISS**

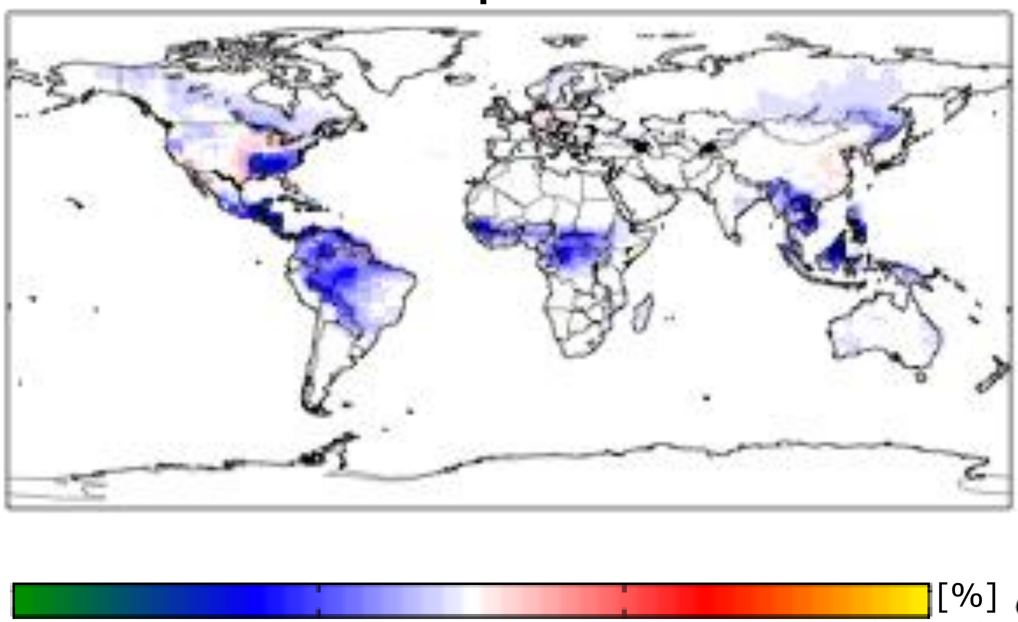


(Aghedo et al., 2011)

Ozone radiative forcings

Contribution from natural VOCs:

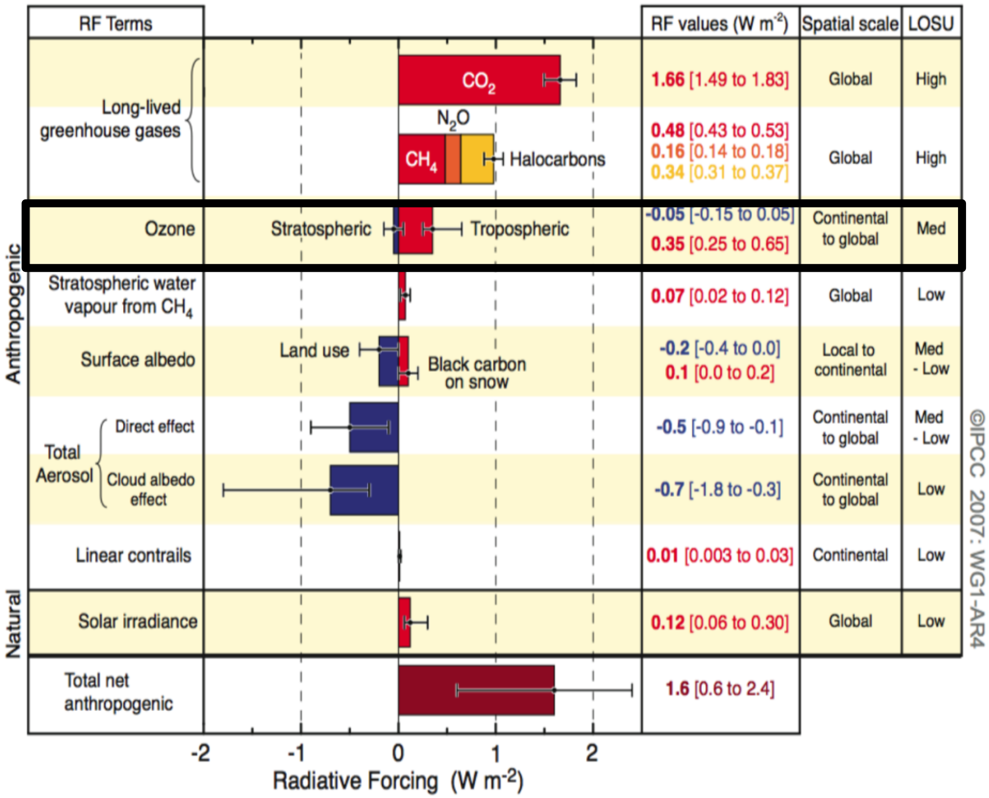
Isoprene



$$\frac{\partial RE}{\partial E_i}\frac{E_i}{RE}\times 100\%$$

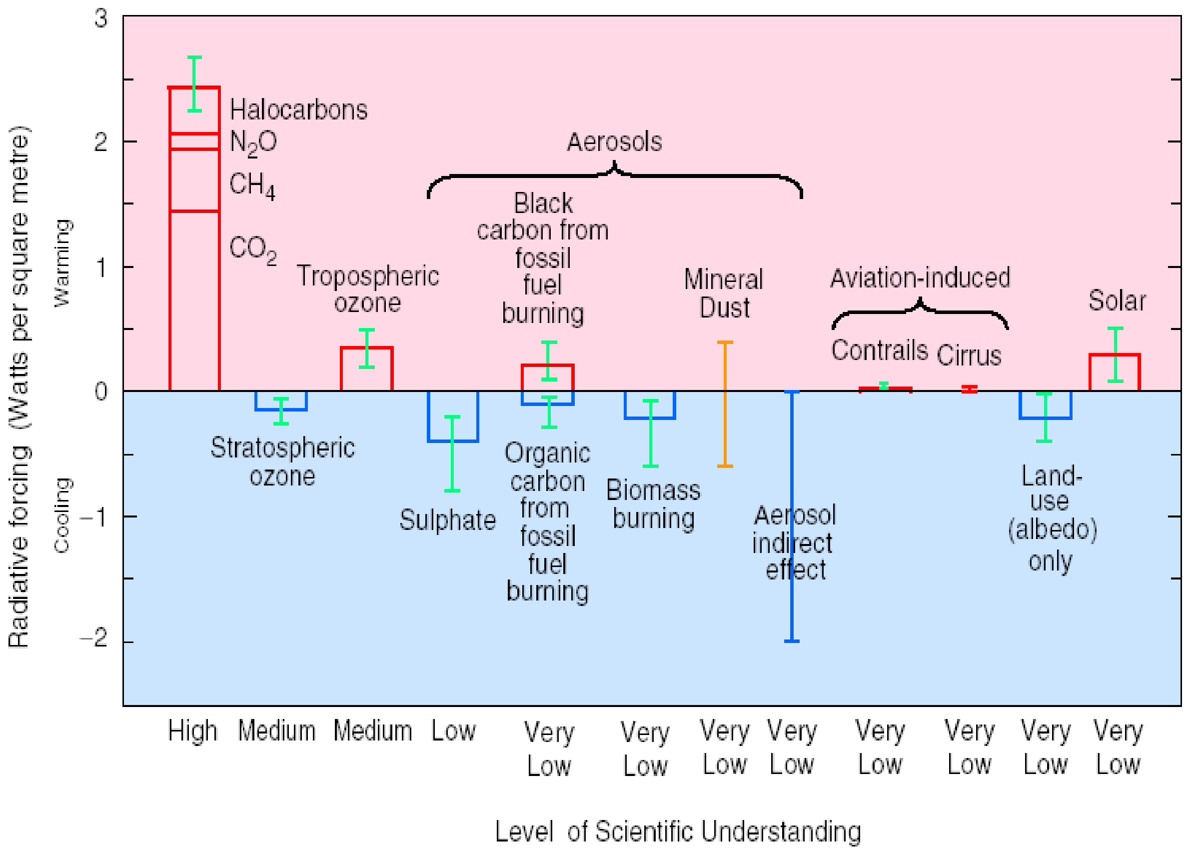
An IPCC retrospective on radiative forcing of tropospheric ozone

AR4, Forster et al., 2007



An IPCC retrospective on radiative forcing of tropospheric ozone

TAR, Ramaswamy, 2001



An IPCC retrospective on radiative forcing of tropospheric ozone

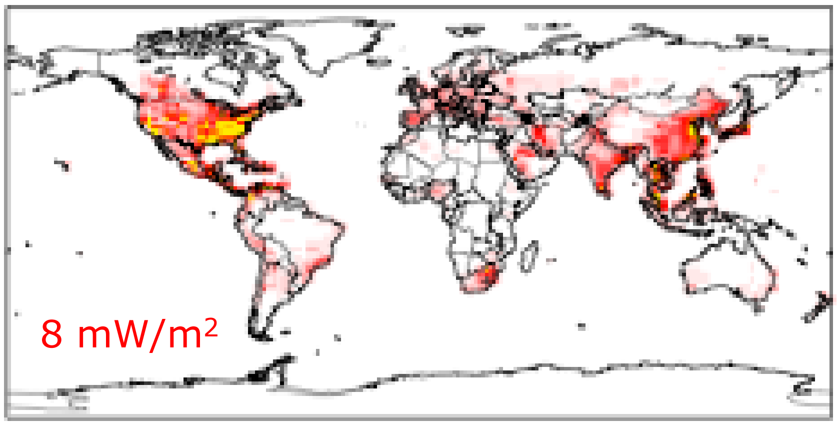
FAR, Shine et al., 1990

Table 2.1: Direct radiative effects and indirect trace gas chemical-climate interactions (based on Wuebbles et al., 1989)

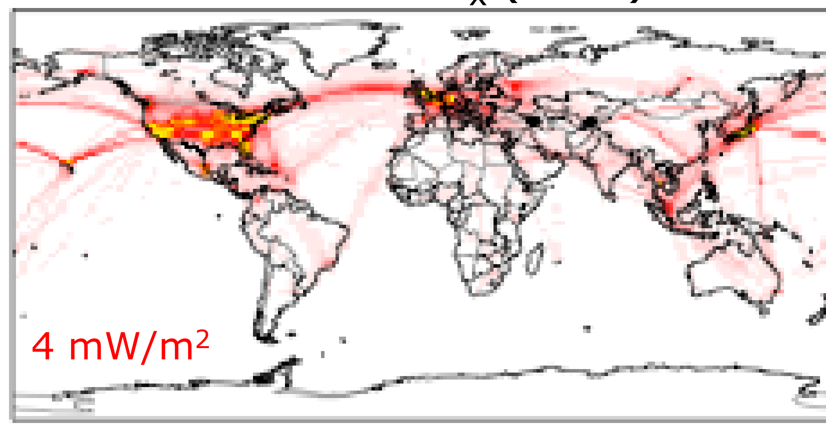
Gas	Greenhouse Gas	Is its tropospheric concentration affected by chemistry?	Effects on tropospheric chemistry? *	Effects on * stratospheric chemistry?
CO_2	Yes	No	No	Yes, affects O_3 (see text)
CH_4	Yes	Yes, reacts with OH	Yes, affects OH, O_3 and CO_2	Yes, affects O_3 and H_2O
CO	Yes, but weak	Yes, reacts with OH	Yes, affects OH, O_3 and CO_2	Not significantly
N_2O	Yes	No	No	Yes, affects O_3
NOx	Yes	Yes, reacts with OH	Yes, affects OH and O_3	Yes, affects O_3
CFC-11	Yes	No	No	Yes, affects O_3
CFC-12	Yes	No	No	Yes, affects O_3
CFC-113	Yes	No	No	Yes, affects O_3
HCFC-22	Yes	Yes, reacts with OH	No	Yes, affects O_3
CH_3CCl_3	Yes	Yes, reacts with OH	No	Yes, affects O_3
CF_2ClBr	Yes	Yes, photolysis	No	Yes, affects O_3
CF_3Br	Yes	No	No	Yes, affects O_3
SO_2	Yes, but weak	Yes, reacts with OH	Yes, increases aerosols	Yes, increases aerosols
CH_3SCH_3	Yes, but weak	Yes, reacts with OH	Source of SO_2	Not significantly
CS_2	Yes, but weak	Yes, reacts with OH	Source of COS	Yes, increases aerosols
COS	Yes, but weak	Yes, reacts with OH	Not significant	Yes, increases aerosols
O_3	Yes	Yes	Yes	Yes

Ozone radiative forcings

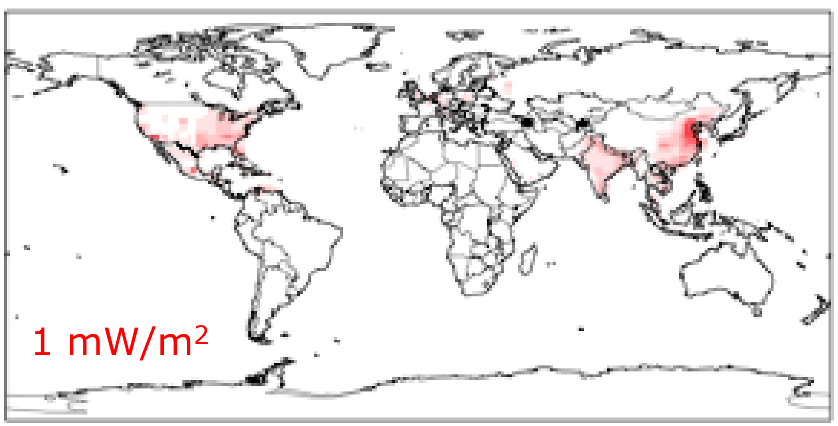
anthropogenic NO_x



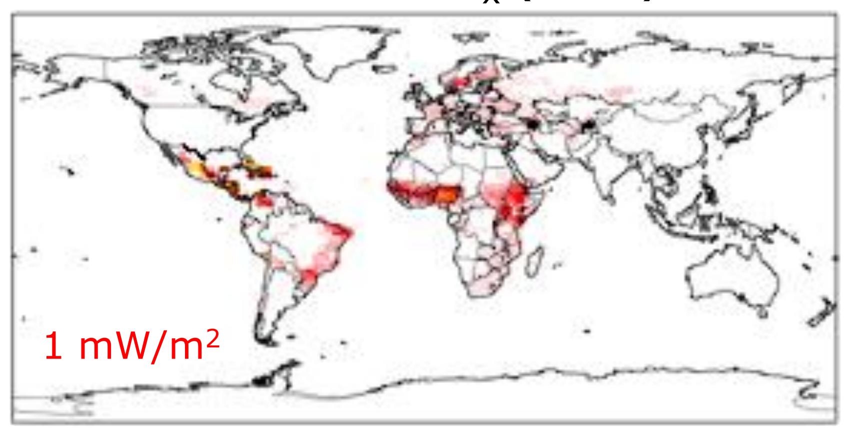
aircraft NO_x (x 10)

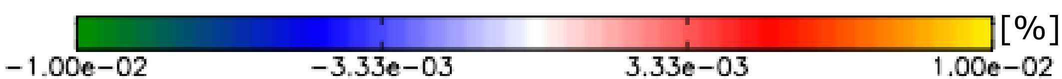


CO



biofuel NO_x (x 10)





$$\frac{\partial RE}{\partial E_i}\frac{E_i}{RE} \times 100\%$$

note: #'s low, just one month