California Environmental Protection Agency
AIR RESOURCES BOARD

*Board Meeting 26 June 2008*

# Climate Change Impacts of the Non-Kyoto Greenhouse Gases and Aerosols

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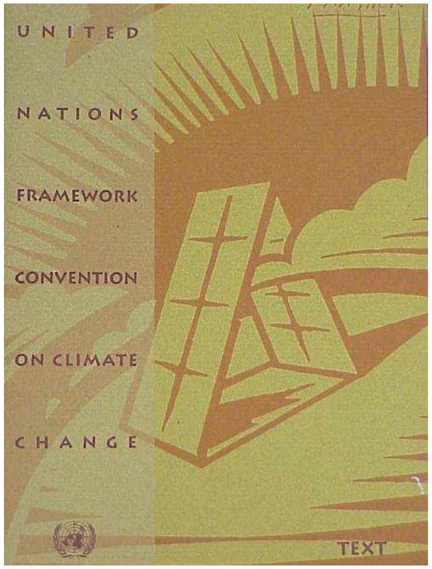
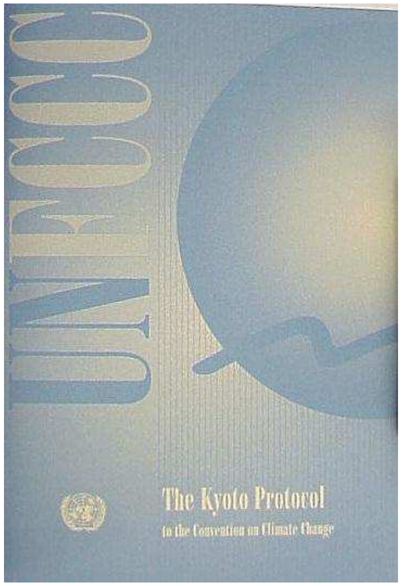
# *Conventions / Protocols governing Climate Change*

**1992 United Nations Framework Convention on Climate Change**

*adopted in 1992 and entered into force in 1994*

*(188 ratification – 28 Jan 2003)*



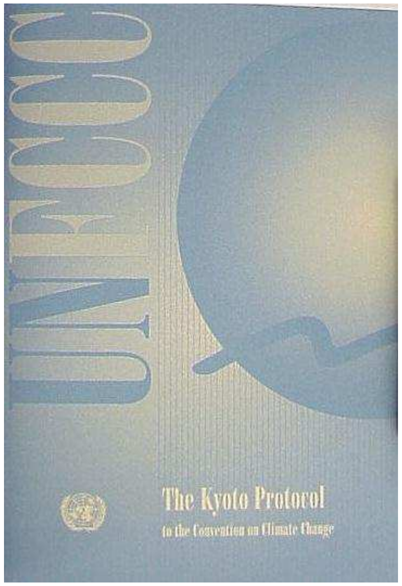




**1997 Kyoto Protocol**

*ratified 2004, in force 16 Feb 2005*

# Greenhouse Gases included in the Kyoto Protocol

## *Annex A*




**<u>Greenhouse gases</u>**

Carbon dioxide ($CO_2$)

Methane ($CH_4$)

Nitrous oxide ($N_2O$)

Hydrofluorocarbons (HFCs)

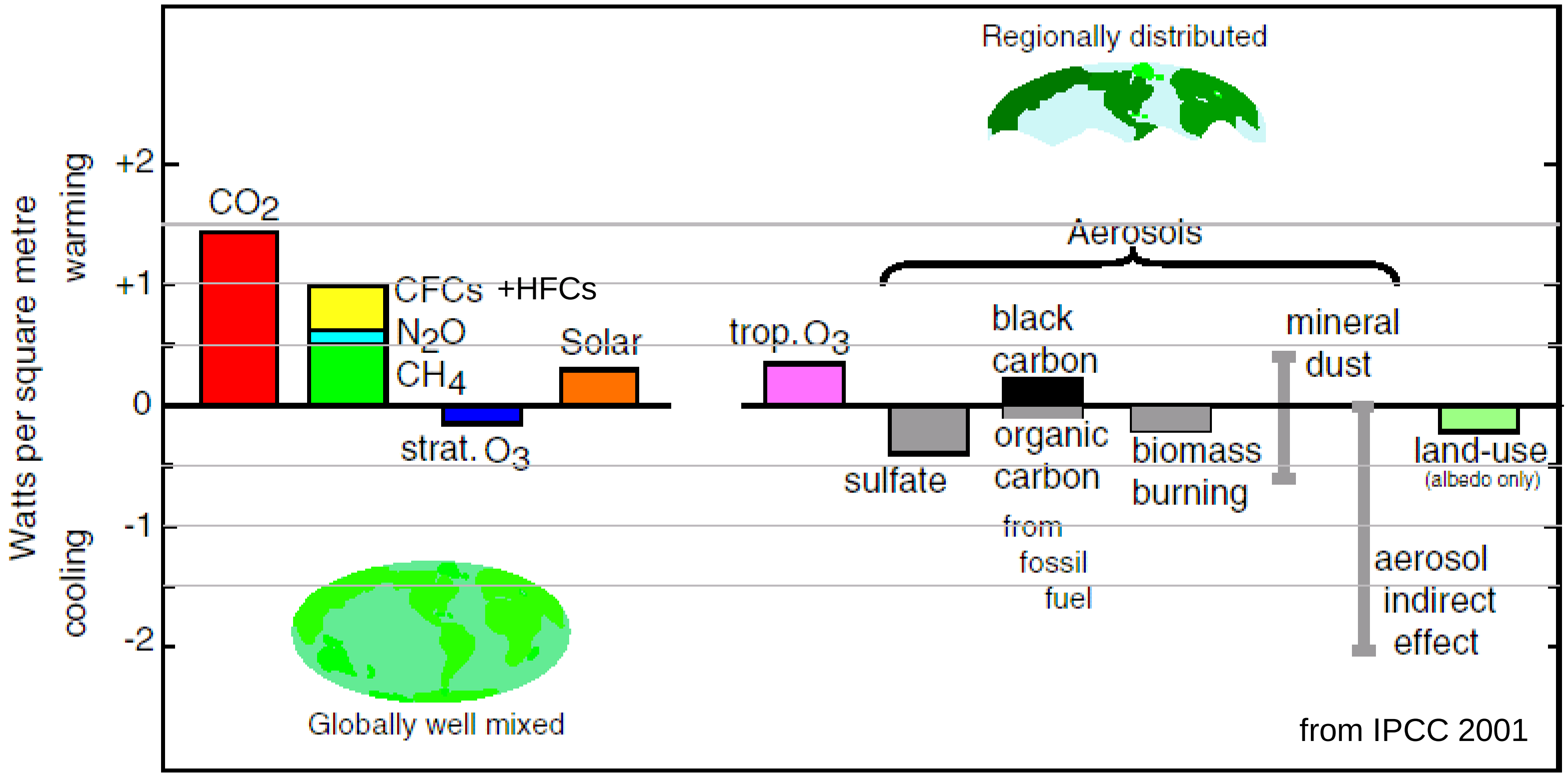
Perfluorocarbons (PFCs)

Sulphur hexafluoride ($SF_6$)

**<u>Sectors/source categories</u>**

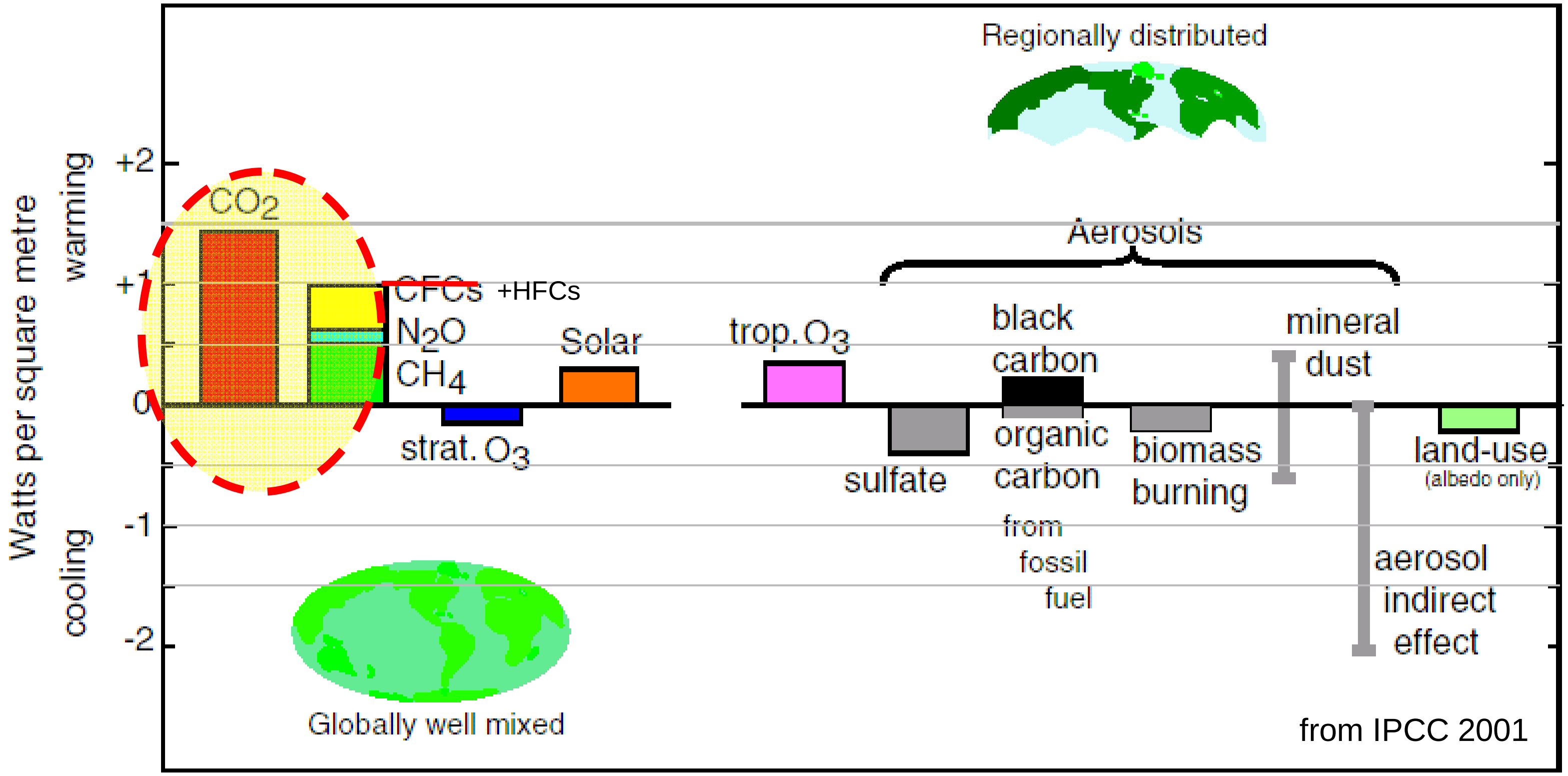
Energy, Fuel combustion, Energy industries, Manufacturing industries and construction, Transport, Other sectors,
Fugitive emissions from fuels, Solid fuels, Oil and natural gas,
Mineral products, Chemical industry, Metal production,
Production of halocarbons and sulphur hexafluoride
Consumption of halocarbons and sulphur hexafluoride
Agriculture, Enteric fermentation, Manure management
Rice cultivation, Agricultural soils, Prescribed burning of savannas
Field burning of agricultural residues, Waste, Wastewater handling, Other

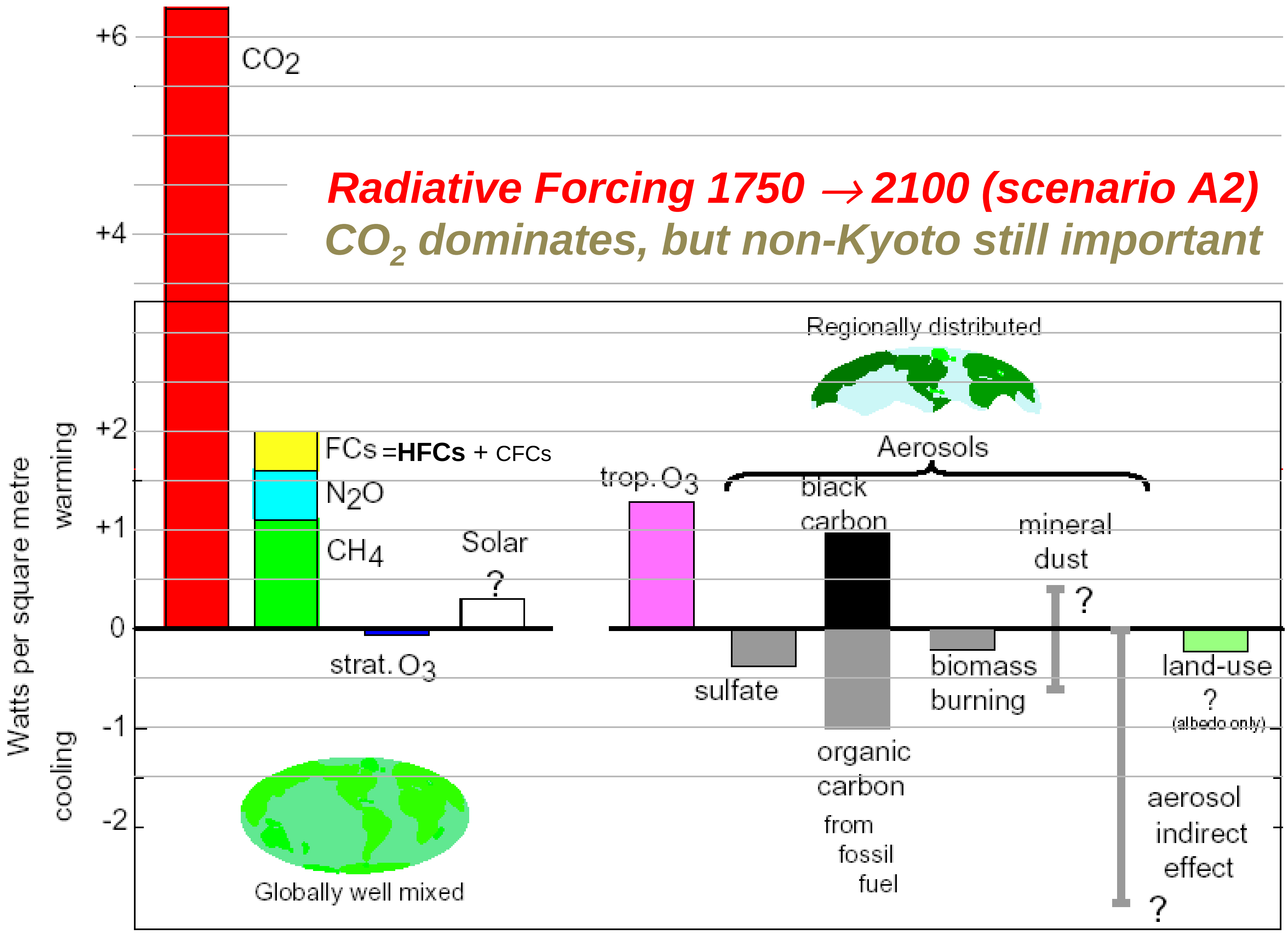
# *Radiative Forcing 1750 → 2000*
## *from IPCC TAR 2001, the recent 2007 AR4 is similar*



## *Radiative Forcing 1750 → 2000*

## *Kyoto Greenhouses are only a part of climate forcing*






from IPCC 2001

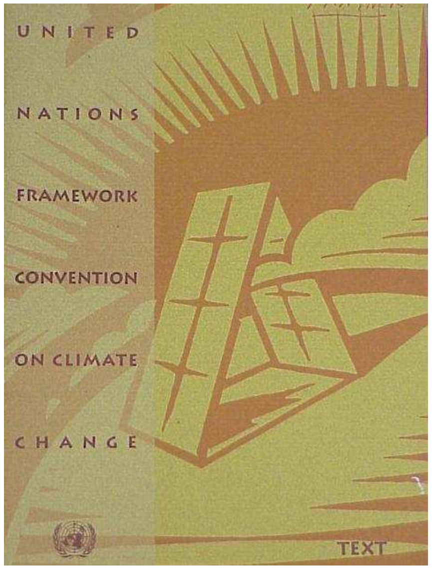
# Kyoto Greenhouse Gas Emissions

1990-2002, million metric tons $CO_2$-equivalent*

| Kyoto gas | Global | Annex-Ir | EU-15 | USA | CA |
|---|---|---|---|---|---|
| FF $CO_2$ | 22811 | 11447 | 3308 | 5423 | **337** |
| LUCF $CO_2$ | +7891 | -1314 | -233 | -915 | **-21** |
| $CH_4$ | 5866 | 1378 | 400 | 629 | **31** |
| $N_2O$ | 3254 | 970 | 367 | 420 | **30** |
| PFCs | 92 | 44 | 9 | 15 | **2.3** |
| HFCs | 155 | 123 | 40 | 69 | **8.6** |
| $SF_6$ | 62 | 50 | 12 | 28 | **2.5** |

* Using 1996 IPCC SAR 100-yr GWP.

The Framework Convention is a bit broader
in recognizing what forces climate change




**UN FCCC ARTICLE 1**

"Source" means any process or activity which releases a greenhouse gas, *an aerosol or a precursor of a greenhouse gas* into the atmosphere.

**UN FCCC ARTICLE 3.3**

... policies and measures should ... *cover all relevant sources, sinks and reservoirs of greenhouse gases* …

## Greenhouse Gases and Aerosols not in Kyoto

CFCs & HCFCs *(Ozone Depleting Substances, under the Montreal Protocol)*

Tropospheric Ozone Precursors (NOx, CO, VOC, $CH_4$*)

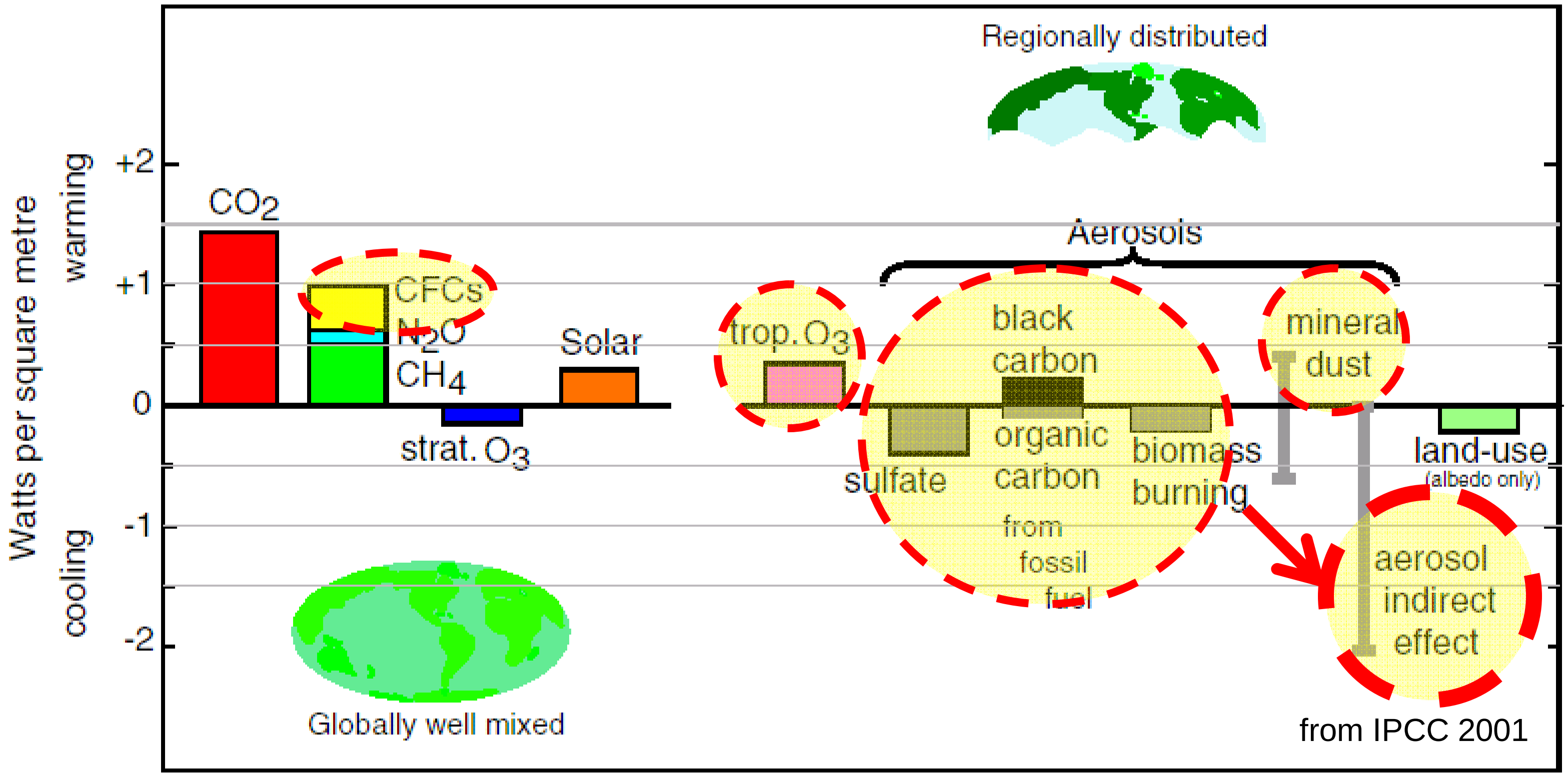
Black (Elemental) Carbon Aerosols

Organic Carbon Aerosols

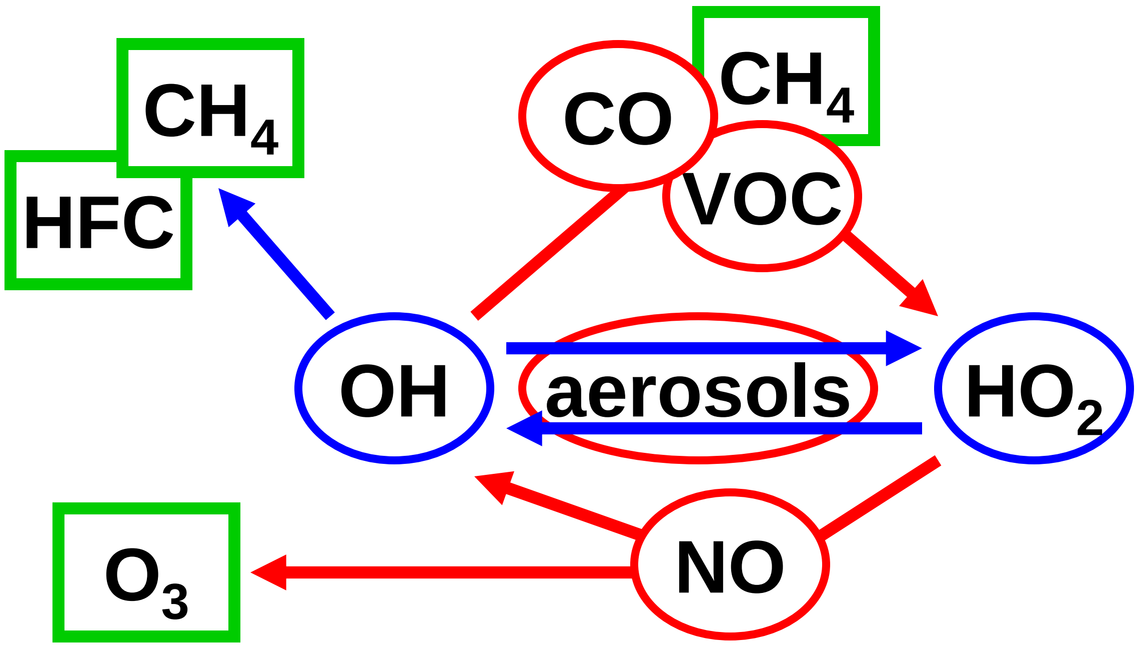
Sulfate & Nitrate Aerosols

Dust (land-use change, agriculture, construction)

## *Radiative Forcing 1750 → 2000*
## *Non-Kyoto forcings are large !*



*How do **criteria pollutants** interact with **greenhouse gases ?***

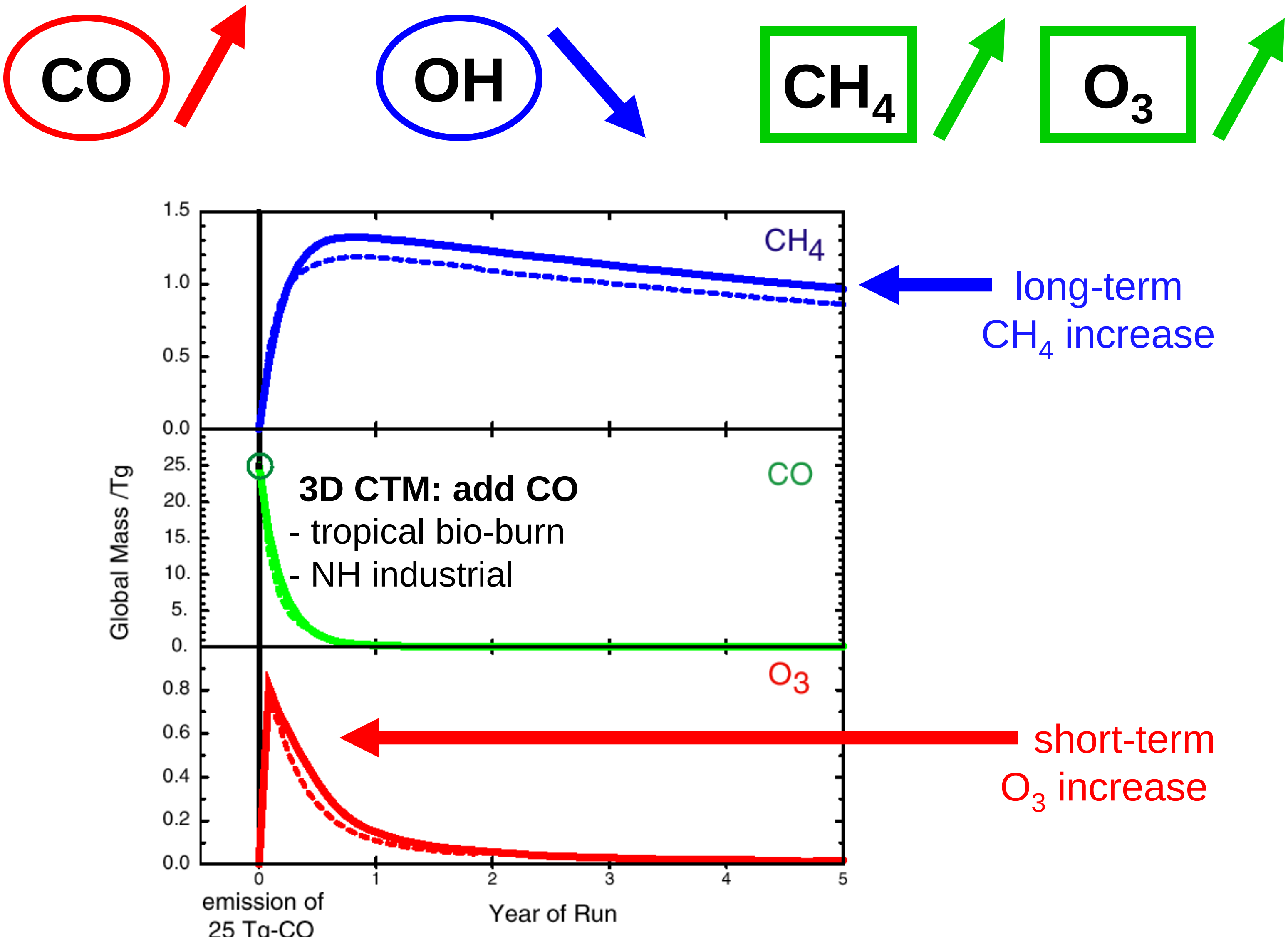



CO, VOC, $NO_X$ *(=NO+$NO_2$)*, aerosols & $CH_4$ control

**Tropospheric Chemistry (OH, $HO_2$)**

which is the sink for $CH_4$ & HFCs; the source for $O_3$

## *CO becomes an indirect greenhouse gas*



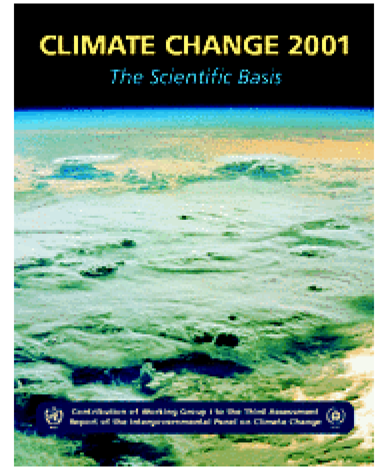
CO indirect, 2001

**Executive Summary**

*Two important new findings since the IPCC WGI Second Assessment Report (IPCC, 1996) (hereafter SAR) demonstrate the importance of atmospheric chemistry in controlling greenhouse gases:*

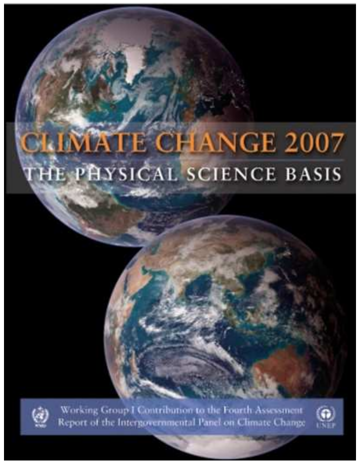
Currently, tropospheric ozone ($O_3$) is the third most important greenhouse gas after carbon dioxide ($CO_2$) and methane ($CH_4$). It is a product of photochemistry, and its future abundance is controlled primarily by emissions of $CH_4$, carbon monoxide (CO), nitrogen oxides ($NO_x$), and volatile organic compounds (VOC). There is now greater confidence in the model assessment of the increase in tropospheric $O_3$ since the pre-industrial period, which amounts to 30% when globally averaged, as well as the response to future emissions. For scenarios in which the $CH_4$ abundance doubles and anthropogenic CO and $NO_x$ emissions triple, the tropospheric $O_3$ abundance is predicted to increase by an additional 50% above today's abundance.

CO is identified as an important indirect greenhouse gas. An addition of CO to the atmosphere perturbs the OH-$CH_4$-$O_3$ chemistry. Model calculations indicate that the emission of 100 Mt of CO stimulates an atmospheric chemistry perturbation that is equivalent to direct emission of about 5 Mt of $CH_4$.



# CO indirect GWP

***2007***




### *2.10.3.2 Carbon Monoxide*

The indirect effects of CO occur through reduced OH levels (leading to enhanced concentrations of $CH_4$) and enhancement of ozone. The TAR gave a range of 1.0 to 3.0 for the 100-year GWP. Since the TAR, Collins et al. (2002) and Berntsen et al. (2005) have calculated GWPs for CO emissions that range between 1.6 and 2.0, depending on the location of the emissions. Berntsen et al. (2005) found that emissions of CO from Asia had a 25% higher GWP compared to European emissions. Averaging over the TAR values and the new estimates give a mean of 1.9 for the 100-year GWP for CO.

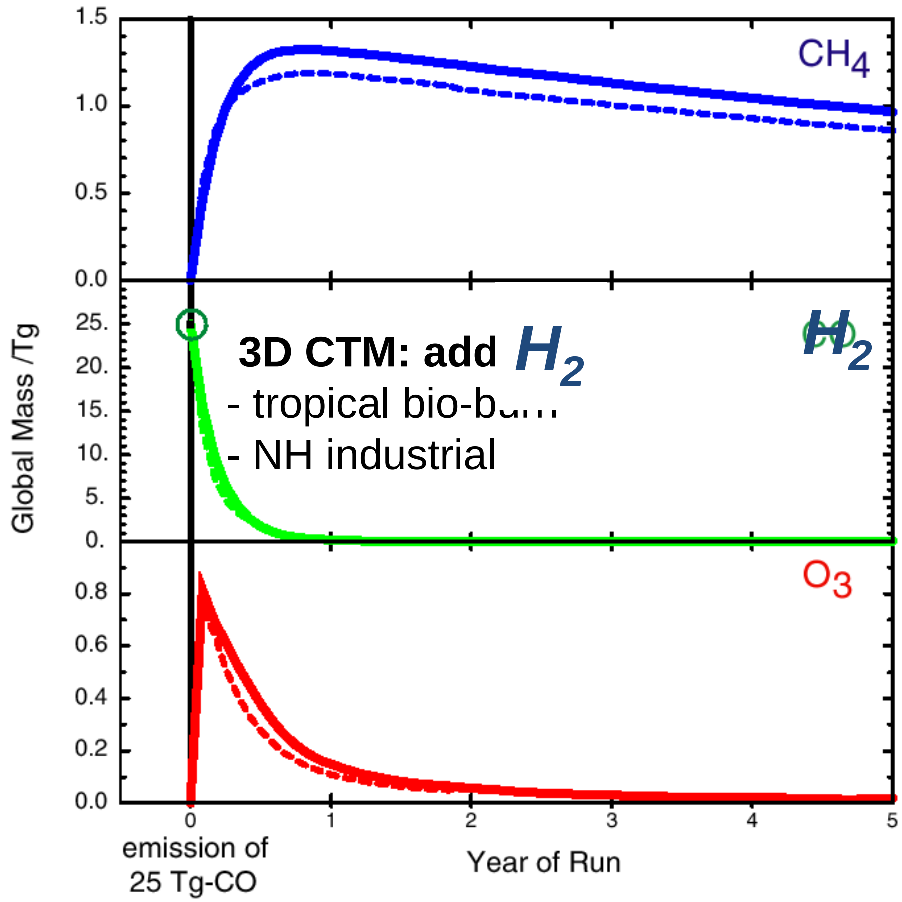
# CO and VOCs are easier:

## both indirect impacts ($CH_4$ and $O_3$) are same sign

| Organic Compound/Study | $GWP^{CH_4}$ | $GWP^{O_3}$ | GWP |
|---|---|---|---|
| Ethane ($C_2H_6$) | 2.9 | 2.6 | 5.5 |
| Propane ($C_3H_8$) | 2.7 | 0.6 | 3.3 |
| Butane ($C_4H_{10}$) | 2.3 | 1.7 | 4.0 |
| Ethylene ($C_2H_4$) | 1.5 | 2.2 | 3.7 |
| Propylene ($C_3H_6$) | –2.0 | 3.8 | 1.8 |
| Toluene ($C_7H_8$) | 0.2 | 2.5 | 2.7 |
| Isoprene ($C_5H_8$) | 1.1 | 1.6 | 2.7 |
| Methanol ($CH_3OH$) | 1.6 | 1.2 | 2.8 |
| Acetaldehyde ($CH_3CHO$) | –0.4 | 1.7 | 1.3 |
| Acetone ($CH_3COCH_3$) | 0.3 | 0.2 | 0.5 |
| | **+** | **+** | |

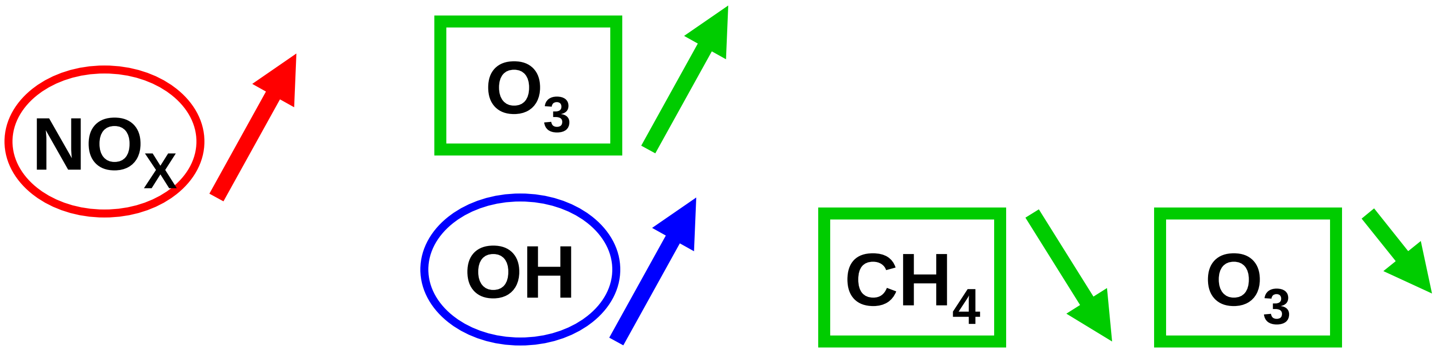
## $H_2$ is likewise an indirect greenhouse gas *(Prather, 2003)*

$H_2$ ↑ OH ↓ $\boxed{CH_4}$ ↑ $\boxed{O_3}$ ↑




**$H_2$ GWP ~ 6 - 9**

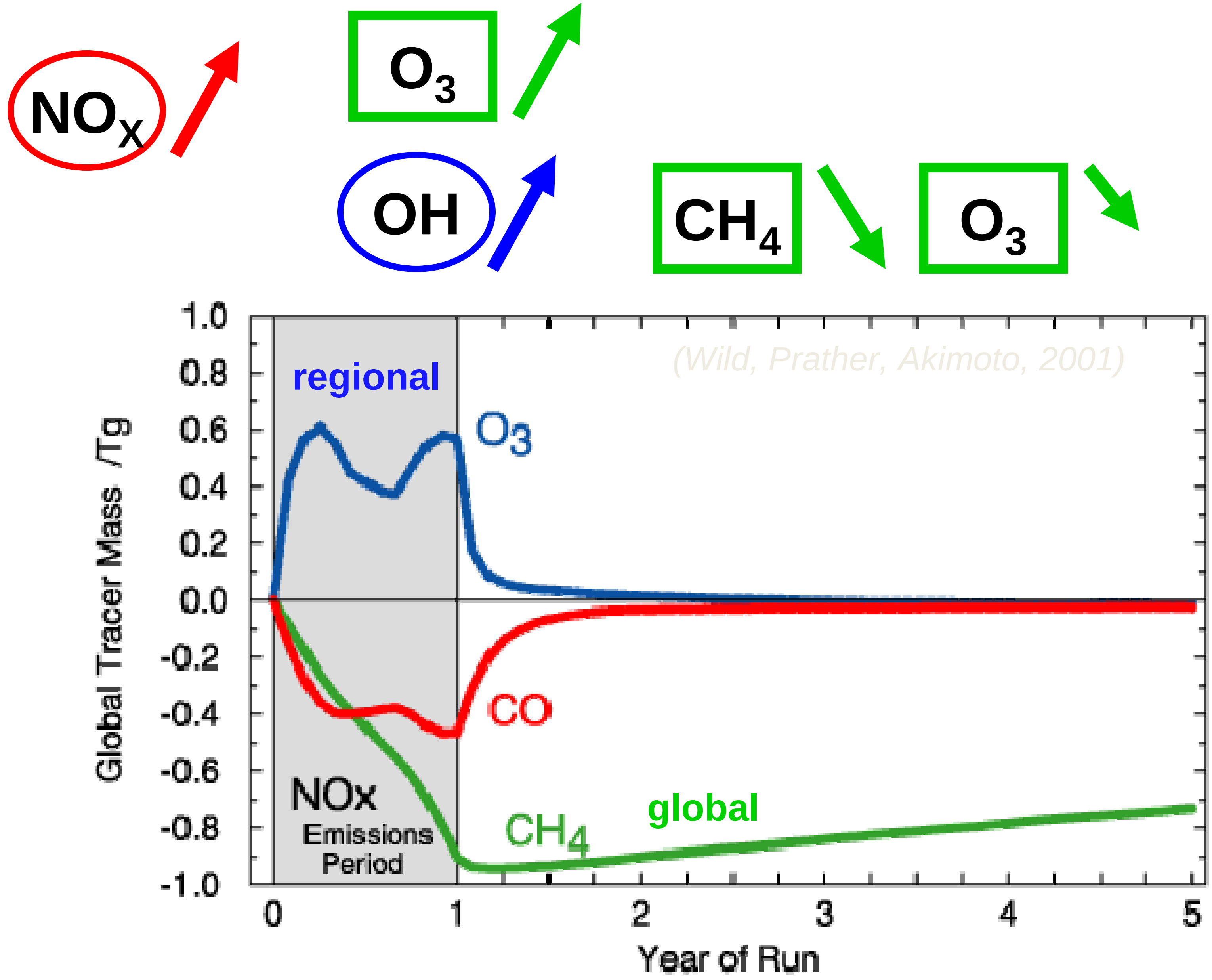
## *NOx identified as an indirect greenhouse gas*



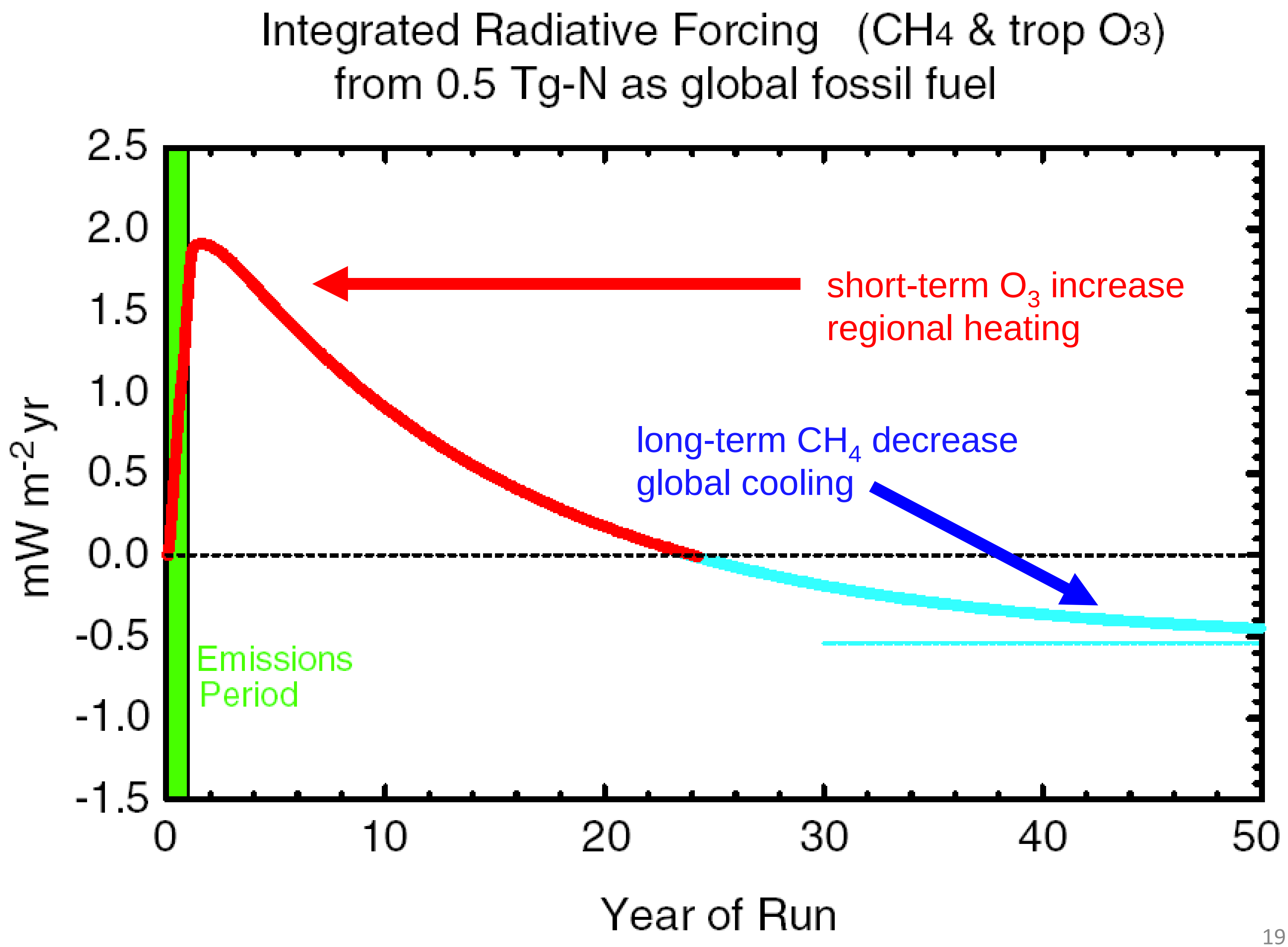

NOx proposed as indirect greenhouse gas
(Shine, Derwent, et al, 1st IPCC Assessment Report)

Rejected as too far ahead of its time
(1992 IPCC Interim Report)

Post SAR, explicit in 1999 IPCC Aviation Assessment,
NOx is indirect greenhouse gas.



NOx
O3
OH
CH4
O3
(Wild, Prather, Akimoto, 2001)
regional
global
O3
CO
CH4
NOx Emissions Period
Global Tracer Mass /Tg
Year of Run
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
1
2
3
4
5



Integrated Radiative Forcing (CH4 & trop O3)
from 0.5 Tg-N as global fossil fuel
mW m-2 yr
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
10
20
30
40
50
Year of Run
short-term O3 increase
regional heating
long-term CH4 decrease
global cooling
Emissions
Period

# NOx is harder:

indirect impacts ($CH_4$ and $O_3$) have opposite sign

depend greatly on location & season

| Organic Compound/Study | $GWP^{CH_4}$ | $GWP^{O_3}$ | GWP |
|---|---|---|---|
| Derwent et al. NH surface $NO_x$[a,b] | –24 | 11 | –12 |
| Derwent et al. SH surface $NO_x$[a,b] | –64 | 33 | –31 |
| Wild et al., industrial $NO_x$ | –44 | 32 | –12 |
| Berntsen et al., surface $NO_x$ Asia | –31 to –42[c] | 55 to 70[c] | 25 to 29[c] |
| Berntsen et al., surface $NO_x$ Europe | –8.6 to –11[c] | 8.1 to 12.7 | –2.7 to +4.1[c] |
| Derwent et al., Aircraft $NO_x$[a,b] | –145 | 246 | 100 |
| Wild et al., Aircraft $NO_x$ | –210 | 340 | 130 |
| Stevenson et al. Aircraft $NO_x$ | –159 | 155 | –3 |

| | − | + | |

Aerosols are even more difficult:

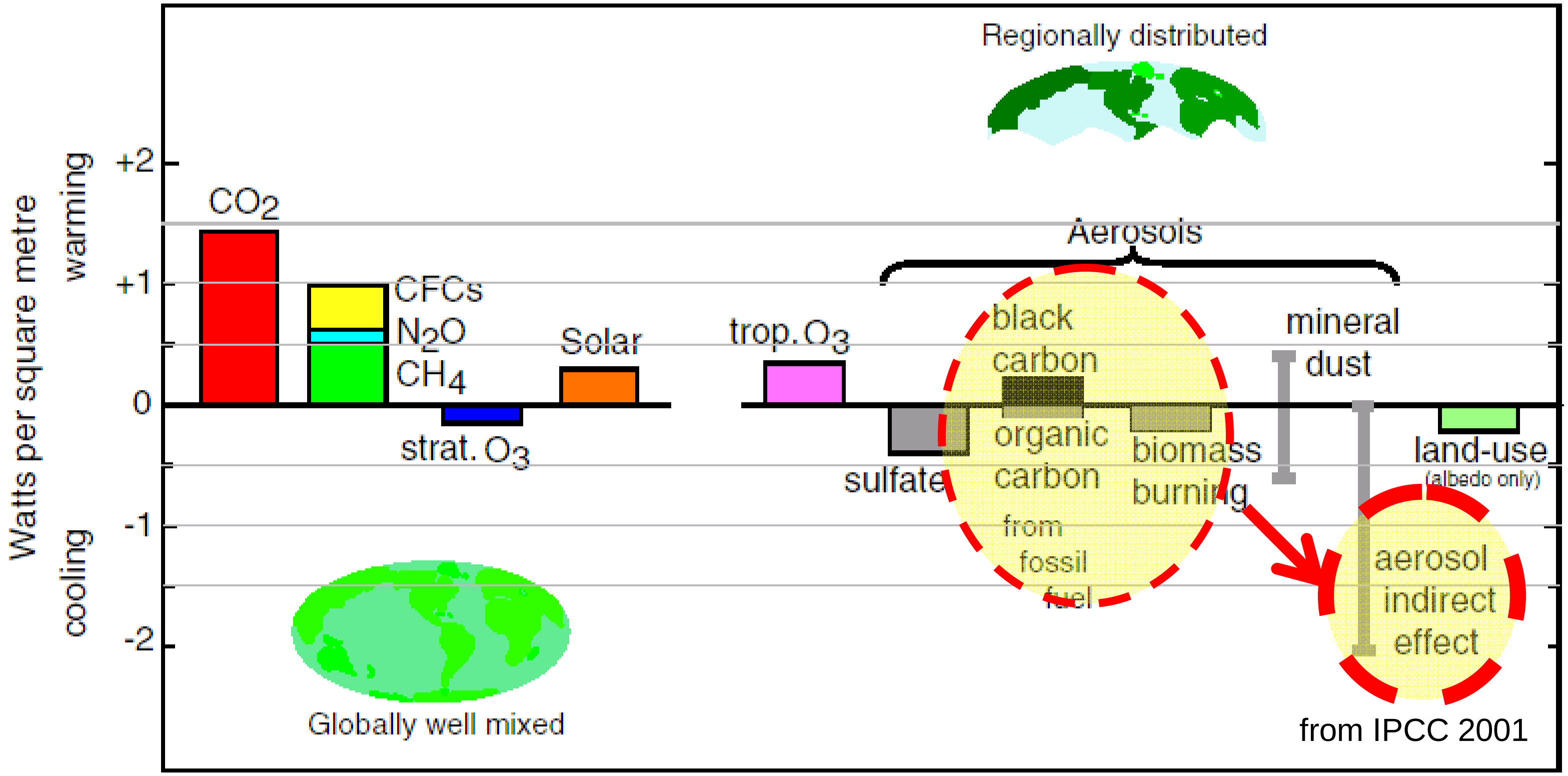
*IPCC does not give GWPs for aerosols!*

*Even more time-space variable than NOx.*

*Black Carbon (BC) is never emitted alone, and is accompanied by organic carbon & “other” stuff.*

*Aerosols from fossil fuel and biomass burning (BC + OC) have both heating & cooling*

## *Radiative Forcing 1750 → 2000*



BC aerosol is even more difficult:

*It is not clear that published GWPs for BC aerosols truly represent the full consequence of PM control.*

*Recent individual publications tend to represent scientific advocacy/viewpoints, not yet assessed*

**Black Carbon May be Second-Most Significant Global Warming Pollutant After Carbon Dioxide; Alters Pictur of Diesel Engine Benefits**

5 November 2007

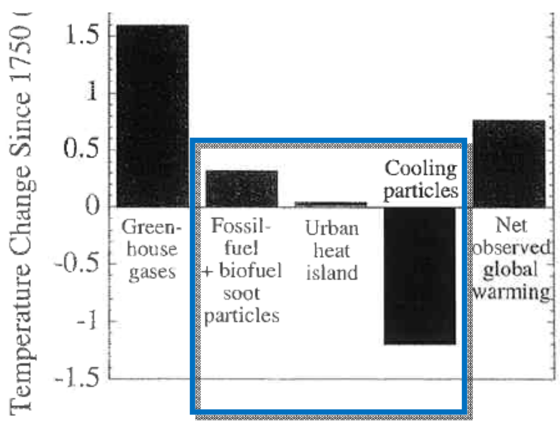
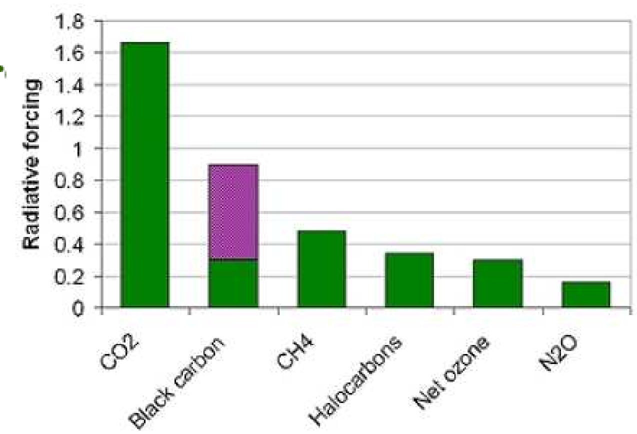



Figure 1. Warming Effect of Various Air Pollutants




*Green bars indicate IPCC estimates; purple segment indicates findings of recent research. Units are radiative forcings, a measure of influence on global energy exchange, expressed in watts per square meter.*

Source: EarthTrends, 2008 using data from IPCC, 2007

# ODS emissions may be simpler:

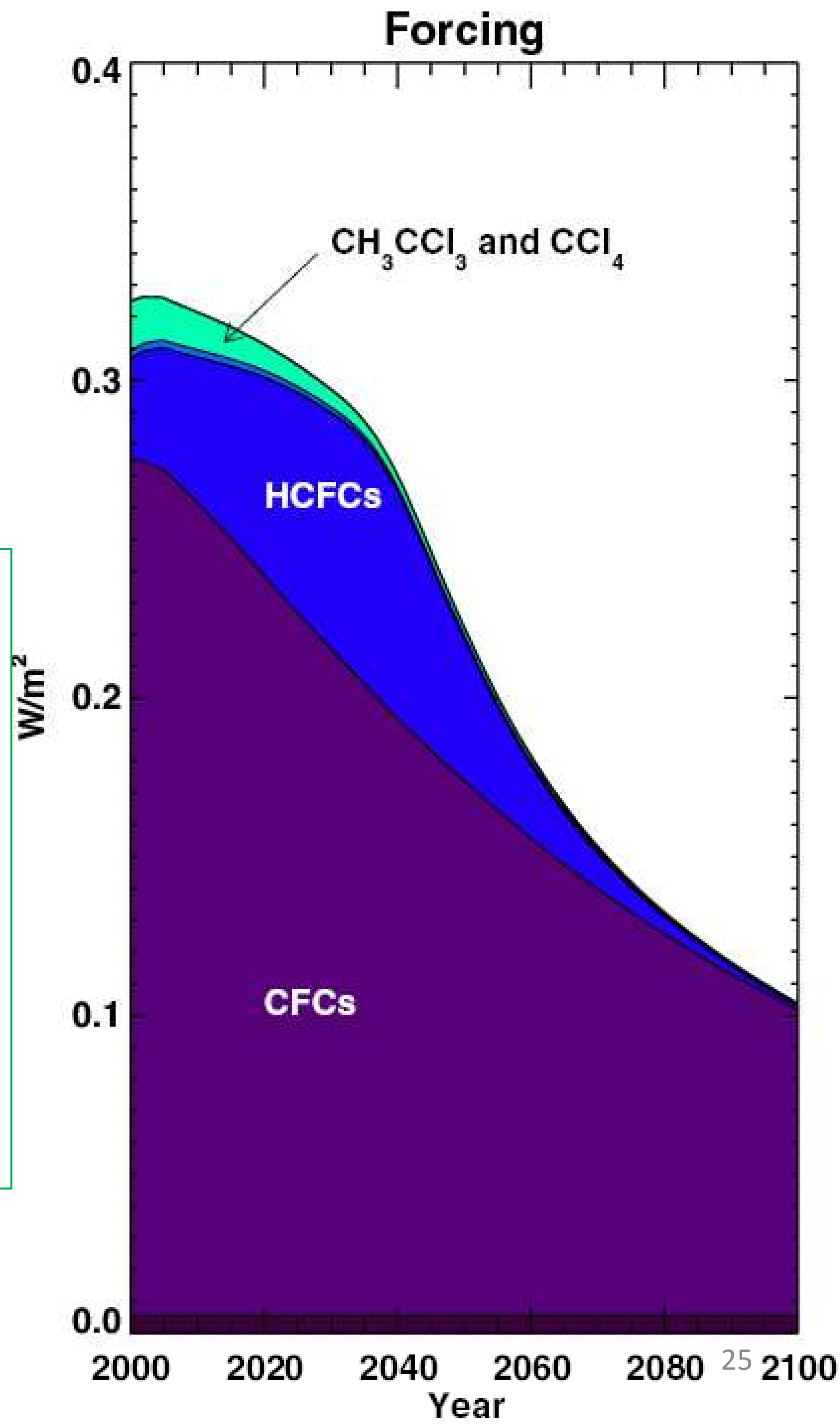
*Although phased-out, CFCs & other ODS continue to be emitted.*

| Chemical | Use |
|---|---|
| CFC-11 | Pre-1994 central A/C, refrigerators |
| CFC-12 | A/C in pre-1994 motor vehicles |
| Halons | Pre-1994 fire suppression systems |
| HCFC-141b | Pre-2003 insulation foam in buildings and appliances |
| HCFC-22 | Pre-2010 window units, central A/C, commercial refrig. |
| HCFC-142b | Pre-2010 foam insulation |
| HCFC-225 | Pre-2015 solvents |
| HCFC-123 | Pre-2015 central A/C and fire suppression equipment |

# ODS emissions continue to drive radiative forcing

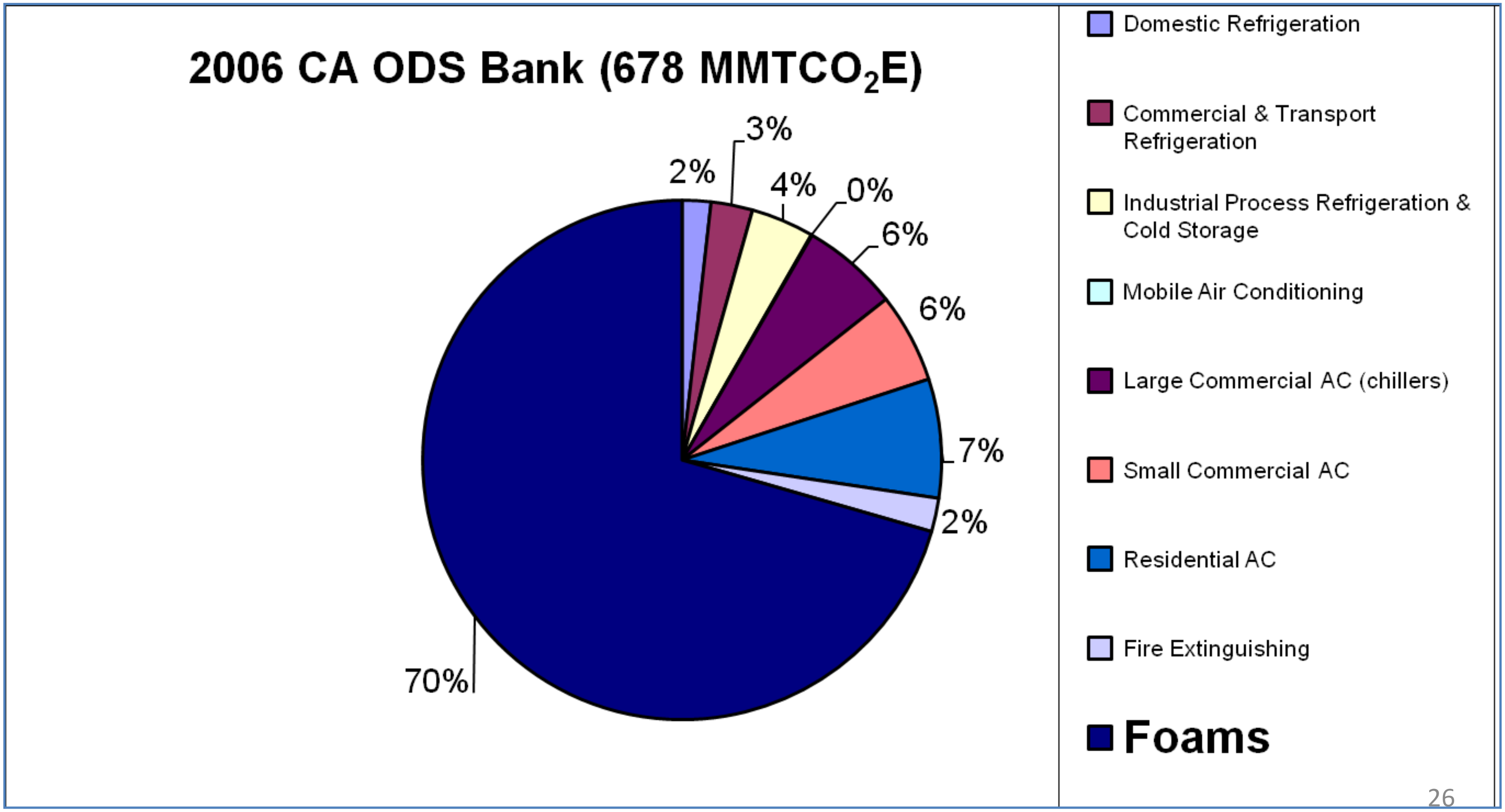
worldwide banks:

| Species | WMO (2003) 2002 Bank | IPCC/TEAP (2005) 2002 Bank | This Assessment 2002 Bank |
|---|---|---|---|
| CFC-11 | 594 | 1,687 | 1,654 |
| CFC-12 | 0 | 711 | 711 |
| CFC-113 | 7 | 0 | 5 |
| HCFC-22 | 1,317 | 1,531 | 1,531 |
| HCFC-141b | 753 | 836 | 674 |
| HCFC-142b | 210 | 224 | 224 |
| Halon-1211 | 72 | 125 | 125 |
| Halon-1301 | 58 | 42 | 42 |



ODS emissions may be simpler:

*California CFCs are emitted from existing banks, such as insulating foams.*



# Non-Kyoto Climate Forcers in California

## Preliminary Calculations

| Climate Forcer | 100-year Global Warming Potential[a] | MMT[b] (2005) | $MMTCO_2E$ | 2005-2020 Change[c] |
|---|---|---|---|---|
| **CO** | 1.0 – 3.0 | 4.56 | **5 – 15** | -36% |
| **VOC=ROG** | 1.1 – 6.2 | 0.81 | **1 – 5** | -18% |
| **$NO_X$** | Zero to 20 | 1.07 | **0 – 20??** | -32% |
| **Diesel PM** | 500 – 1,200?? | 0.029 | **15 to 35 minus indirect RF??** | -85%[d] |
| **Other PM** | unknown | -- | **likely negative** | -- |
| **CFC, HCFC** | 100 – 10,000 | 0.014 | **~40** | -50%[e] |

[a] Fossil fuel soot GWP range from Hansen et al. (2007) and Jacobson (2005), all others from IPCC
[b] CFC and HCFC estimate from USEPA Vintaging model, all others from CARB emission inventory
[c] $CO_2$ etc.: AB 32 target. CO, ROG, $NO_X$: CARB emission inventory for rules already adopted.
[d] Diesel PM: 2000 to 2020 Diesel Risk Reduction Plan target.
[e] The reduction is based on phase out schedule of the CFCs/HCFCs and does not consider ongoing or planned reduction measures.

# Conclusions: How much can California do with non-Kyoto greenhouse gases and aerosols ?

Preliminary Calculations

| Climate Forcer | **$MMTCO_2E$** | 2005-2020 Change [a] |
|---|---|---|
| Kyoto ($CO_2$, $CH_4$, $N_2O$, HFC, PFC, $SF_6$) | **~500** | -15% |
| Ozone (CO, VOC, $NO_X$) | **zero to 40** | -30% |
| Diesel PM | **~25 minus indirect cloud effects ??** | -85% [b] |
| Other PM | **negative** | -- |
| Montreal (CFC, HCFC) | **~40** | -50% [c] |

[a] $CO_2$ etc.: AB 32 target. CO, ROG, $NO_X$: CARB emission inventory for rules already adopted.
[b] Diesel PM: 2000 to 2020 Diesel Risk Reduction Plan target.
[c] The reduction is based on phase out schedule of the CFCs/HCFCs and does not consider ongoing or planned reduction measures.