Global Warming Potentials in AR4

V. Ramaswamy

NOAA/ Geophysical Fluid Dynamics Laboratory, Princeton University

GWP Definition

- Defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC, 1990).

- A measure of the relative radiative effect of a given substance compared to another, integrated over a chosen time horizon.

- A simple, effective concept, in place since FAR.

Representation

GWP index, based on the time-integrated global mean RF of a pulse emission of 1 kg of some compound (*i*) relative to that of 1 kg of the reference gas CO_2, was developed (IPCC, 1990) and adopted for use in the Kyoto Protocol. The GWP of component *i* is defined by

$$GWP_i \equiv \frac{\int_0^{TH} RF_i(t)\,dt}{\int_0^{TH} RF_r(t)\,dt} = \frac{\int_0^{TH} a_i \cdot [C_i(t)]\,dt}{\int_0^{TH} a_r \cdot [C_r(t)]\,dt}$$

AGWP Gas - i (numerator)

AGWP Ref. Gas (denominator)

where *TH* is the time horizon, RF_i is the global mean RF of component *i*, a_i is the RF per unit mass increase in atmospheric abundance of component *i* (radiative efficiency), $[C_i(t)]$ is the time-dependent abundance of *i*, and the corresponding quantities for the reference gas (*r*) in the denominator. The numerator and denominator are called the absolute global warming potential (AGWP) of *i* and *r* respectively. All GWPs given in this report

GWP
Dependencies and Complexities

Radiative forcing of species:

- spectroscopic details of absorption bands;
- overlap of absorption features amongst species; nonlinear aspects

Lifetimes of species:

- uncertainties in processes and/or measurements and/or modeling;
- dependence on other species e.g., chemistry;

GWP
Dependencies and Complexities

Time horizon choice

- depends on the user emphasis
- shorter horizons if the focus is on short-term effects/ processes e.g., response of continents to a forcing
- shorter horizons if speed of potential climate change is of interest than eventual magnitude
- Longer horizons for long-term change (e.g., slow transfer of heat into the deep oceans, sea-level rise)
- choices used in IPCC ➔ 20, 100, 500 years

GWP Considerations

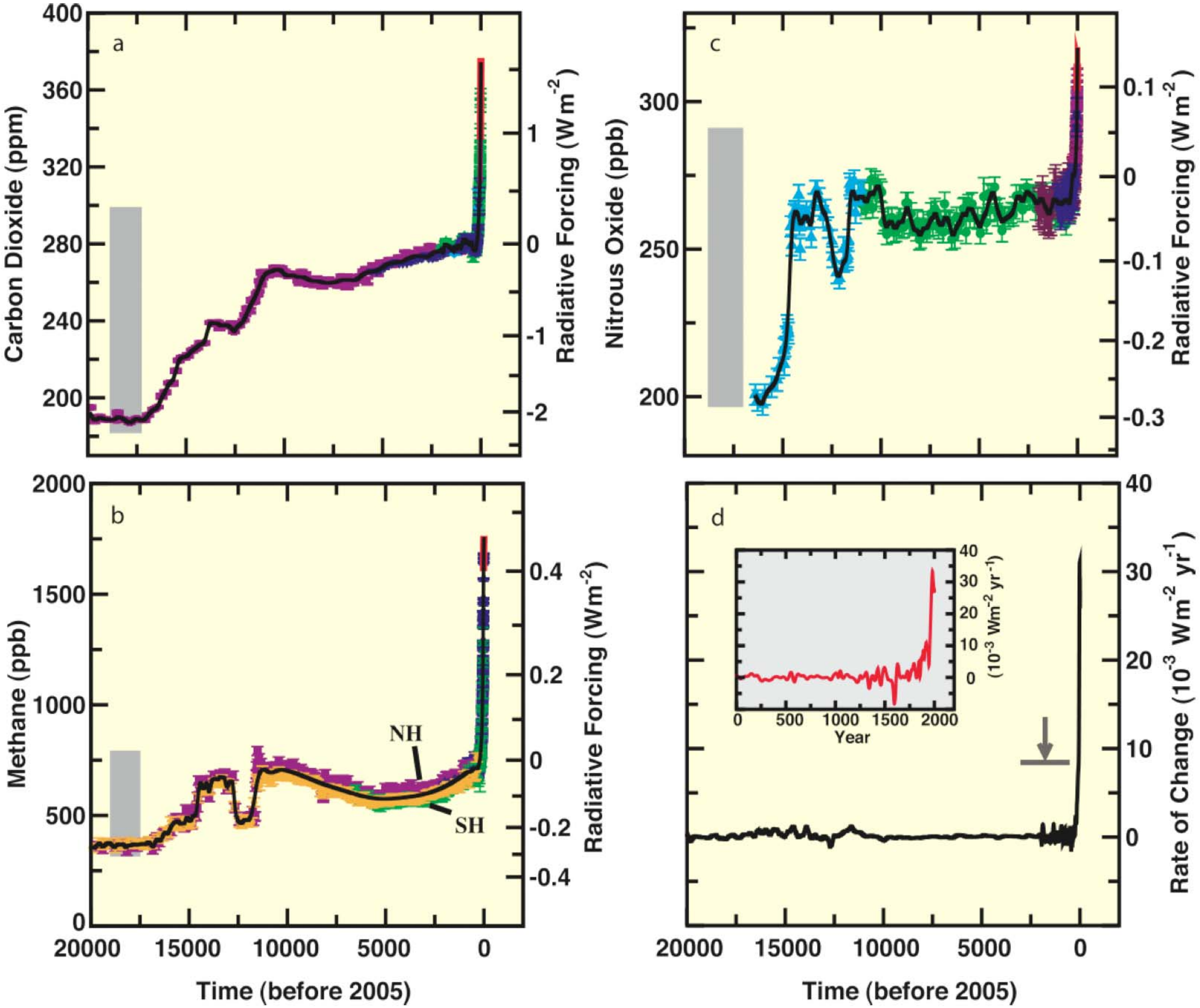
- Reference gas ➔ CO2
  - spectral absorption features well understood;
  - **complex lifetime** (represented by sum of 3 exponential terms)
  - **most significant** in terms of Radiative Forcing

- Carbon Cycle model for lifetimes:
  - **Bern model** (updated version)

- Evaluation of Radiative Forcing per unit mass:
  - small perturbation about **"<u>present-day</u>"** concentration
  - dependence on ***background*** concentration
  - RF per unit mass ***not constant over time***
  - ***different*** CO2 background concentrations (as appropriate for the time) in the different IPCC reports

- Updates in Absorption and Amounts, and Lifetimes based on improved information from laboratory measurements, process studies, modeling

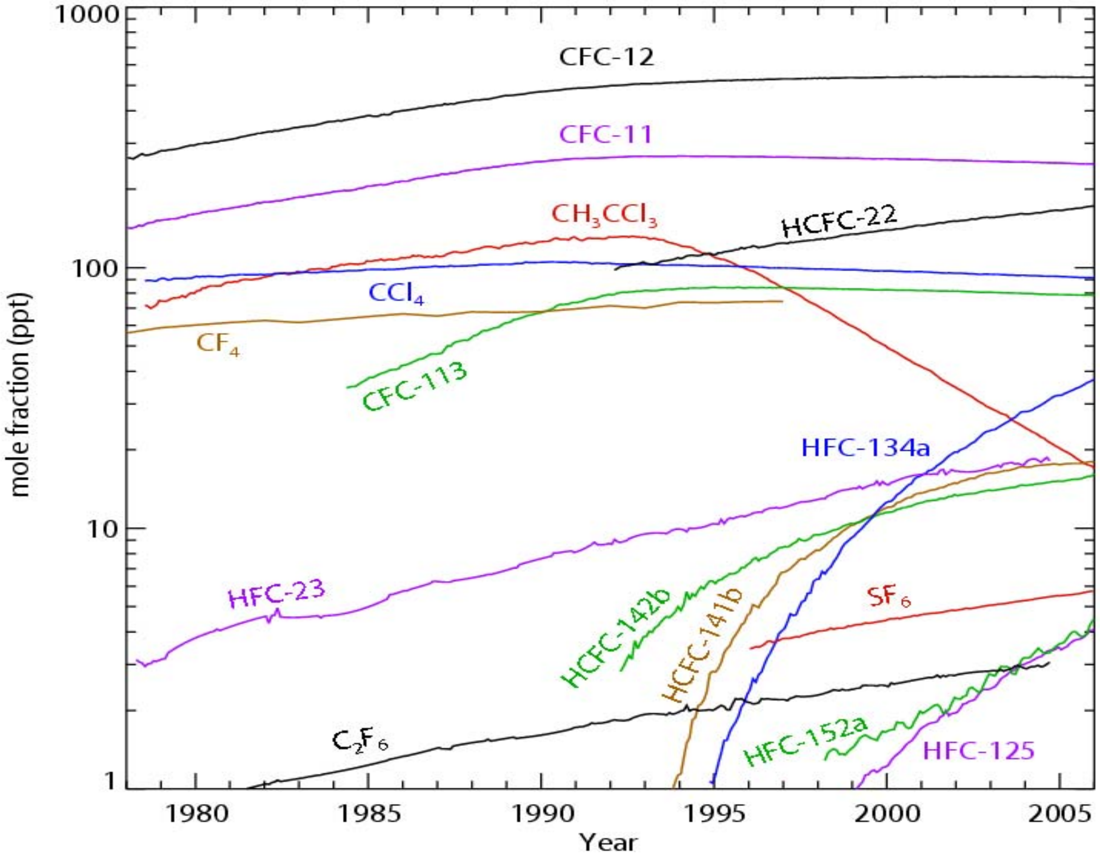
  ➔ *revision in GWP estimates*



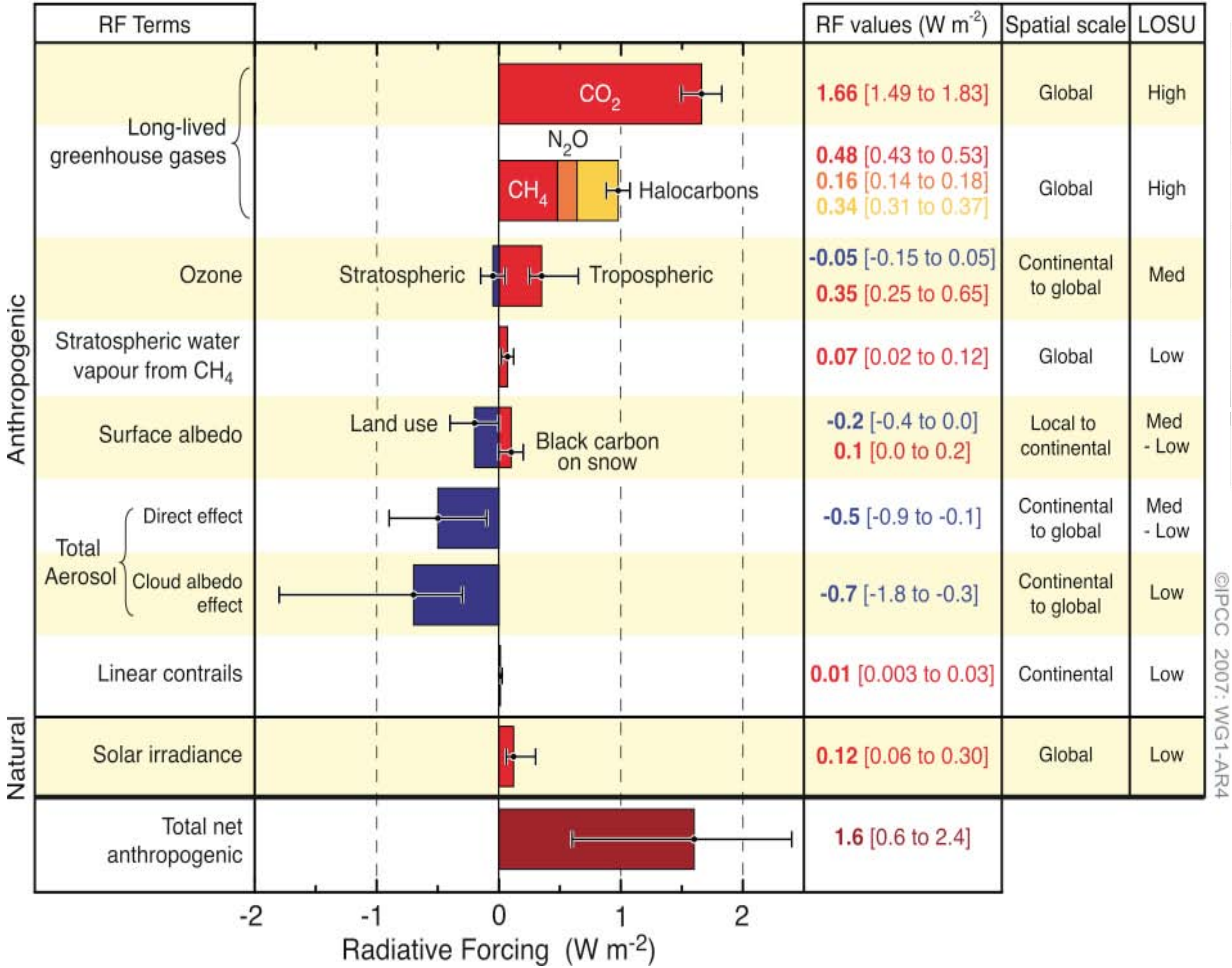
a
Carbon Dioxide (ppm)
Radiative Forcing (W m^{-2})
b
Methane (ppb)
Radiative Forcing (Wm^{-2})
NH
SH
c
Nitrous Oxide (ppb)
Radiative Forcing (W m^{-2})
d
Year
(10^{-3} Wm^{-2} yr^{-1})
Rate of Change (10^{-3} Wm^{-2} yr^{-1})
Time (before 2005)
Time (before 2005)

Figure TS. 2

Temporal evolution of the major
Halocarbons [Figure 2.6]



Some species (CFC-11, CFC-12) flattening or going down because of Protocols
Some species (HCFC-22, SF6) increasing
Overall slight increase in halocarbon radiative forcing since the time of the TAR
Recently evaluated in IPCC/TEAP (2005) report



RF Terms
RF values (W m-2)
Spatial scale
LOSU
Anthropogenic
Long-lived greenhouse gases
CO2
1.66 [1.49 to 1.83]
Global
High
N2O
CH4
Halocarbons
0.48 [0.43 to 0.53]
0.16 [0.14 to 0.18]
0.34 [0.31 to 0.37]
Global
High
Ozone
Stratospheric
Tropospheric
-0.05 [-0.15 to 0.05]
0.35 [0.25 to 0.65]
Continental to global
Med
Stratospheric water vapour from CH4
0.07 [0.02 to 0.12]
Global
Low
Surface albedo
Land use
Black carbon on snow
-0.2 [-0.4 to 0.0]
0.1 [0.0 to 0.2]
Local to continental
Med - Low
Total Aerosol
Direct effect
-0.5 [-0.9 to -0.1]
Continental to global
Med - Low
Cloud albedo effect
-0.7 [-1.8 to -0.3]
Continental to global
Low
Linear contrails
0.01 [0.003 to 0.03]
Continental
Low
Natural
Solar irradiance
0.12 [0.06 to 0.30]
Global
Low
Total net anthropogenic
1.6 [0.6 to 2.4]
-2
-1
0
1
2
Radiative Forcing (W m-2)
©IPCC 2007: WG1-AR4

Table 2.1. *Present-day concentrations and RF for the measured LLGHGs. The changes since 1998 (the time of the TAR estimates) are also shown.*

	Concentrations[b] and their changes[c]		Radiative Forcing[d]	
Species[a]	2005	Change since 1998	2005 (W m^{-2})	Change since 1998 (%)
CO_2	**379 ± 0.65 ppm**	**+13 ppm**	**1.66**	**+13**
CH_4	**1,774 ± 1.8 ppb**	**+11 ppb**	**0.48**	**-**
N_2O	**319 ± 0.12 ppb**	**+5 ppb**	**0.16**	**+11**
	ppt	ppt		
CFC-11	251 ± 0.36	–13	0.063	–5
CFC-12	538 ± 0.18	+4	0.17	+1
CFC-113	79 ± 0.064	–4	0.024	–5
HCFC-22	169 ± 1.0	+38	0.033	+29
HCFC-141b	18 ± 0.068	+9	0.0025	+93
HCFC-142b	15 ± 0.13	+6	0.0031	+57
CH_3CCl_3	19 ± 0.47	–47	0.0011	–72
CCl_4	93 ± 0.17	–7	0.012	–7
HFC-125	3.7 ± 0.10[e]	+2.6[f]	0.0009	+234
HFC-134a	35 ± 0.73	+27	0.0055	+349
HFC-152a	3.9 ± 0.11[e]	+2.4[f]	0.0004	+151
HFC-23	18 ± 0.12[g,h]	+4	0.0033	+29
SF_6	5.6 ± 0.038[i]	+1.5	0.0029	+36
CF_4 (PFC-14)	74 ± 1.6[j]	-	0.0034	-
C_2F_6 (PFC-116)	2.9 ± 0.025[g,h]	+0.5	0.0008	+22
CFCs Total[k]			**0.268**	**–1**
HCFCs Total			**0.039**	**+33**
Montreal Gases			**0.320**	**–1**
Other Kyoto Gases ($HFCs + PFCs + SF_6$)			**0.017**	**+69**
Halocarbons			**0.337**	**+1**
Total LLGHGs			**2.63**	**+9**

Table TS.2. *Lifetimes, radiative efficiencies and direct (except for CH_4) global warming potentials (GWP) relative to CO_2. {Table 2.14}*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon: SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]$1.4x10^{-5}$	1	1	1	1
Methane[c]	CH_4	12[c]	$3.7x10^{-4}$	21	72	25	7.6
Nitrous oxide	N_2O	114	$3.03x10^{-3}$	310	289	298	153

The Tables in the AR4 WG1 Technical Summary and Chapter 2 reflect improved RF estimates and lifetimes.

There is an addendum to this Table that has been prepared by WG1. It includes the gases that were in the TAR table but were missed out in the AR4 document. This addition to the tables will be made available shortly.

GWP revisions

- **CO_2's** RF per unit mass is 8.7% less in AR4
- Improved **RF** expressions (e.g., CO_2, CFCs in TAR; also used in AR4)

- **Methane** values for the 100-year horizon:
  21 [FAR and SAR]; 23 [TAR]; 25 [AR4]

- TAR value incorporated revised CO_2 AGWP
- **Methane** GWP accounts for "indirect" effects
  - increases its own lifetime through OH
  - changes in tropospheric ozone
  - enhances stratospheric H_2O (5% in TAR to 15% in AR4)
  - oxidation to CO_2 not considered (often the case that it is included in national carbon production inventory)

- **N_2O** RF per unit mass is slightly less in AR4

Table TS.2. *Lifetimes, radiative efficiencies and direct (except for CH_4) global warming potentials (GWP) relative to CO_2. {Table 2.14}*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]$1.4x10^{-5}$	1	1	1	1
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200
HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

Indirect GWPs

- **Methane** has 4 potential ways to yield indirect GWPs
- **Carbon monoxide**: via reduced OH levels leading to enhanced concentrations of CH4 and tropospheric ozone

  - dependence on location of emissions
- **Non-methane VOCs**: impacts on tropospheric ozone, CH4 and CO2

  - short lifetimes and nonlinear chemistry → significant uncertainties
- **Nitrogen oxides**: ozone enhancements, CH4 reductions, nitrate aerosol formation

  - nonlinear chemistry,; dependence on location and timing of emission
- **Halocarbons**: ozone depletion

  - no net GWP quoted as CFC warming characteristics and ozone depletion cooling effect are very different from each other.
- **Hydrogen**: main loss through surface deposition, about 25% loss through oxidation by OH; → enhances stratos. H2O, also affects O3; → tropos. effects similar to CO

New alternative metrics for assessing emissions

- AR4 recommends that *Radiative Forcing Index* (RFI) introduced in IPCC (1999) should not be used as an emission metric

  ➔ does not account for the different lifetimes of different forcing agents.

- Revised GWP concept including *efficacy* of forcing agent

  ➔ efficacies are less uncertain than climate sensitivities

  ➔ dependence on location of emissions for the short-lived species.

New alternative metrics for assessing emissions…(continued)

- *Global Temperature Potential*: global-mean surface temperature change at a given future time horizon following an emission of a compound 'x' relative to a reference (say, CO2)

  ➔ advantage, directly related to surface temperature change; do not require simulations with AOGCMs; RF closer to end of horizon has more contribution; need to know response time of climate system

  ➔ some degree of similarity between GTP for sustained emission changes and GWP pulse values

  ➔ problems in addressing short-lived, localized species

  ➔ values not determined yet

AR4 ➔ GWPs remain the recommended metric to compare future climate impacts of emissions of long-lived climate gases

The END

Thank you for your attention !