EARTH SYSTEM SCIENCE: Weather and Climate

Greenhouse and Trace Gases

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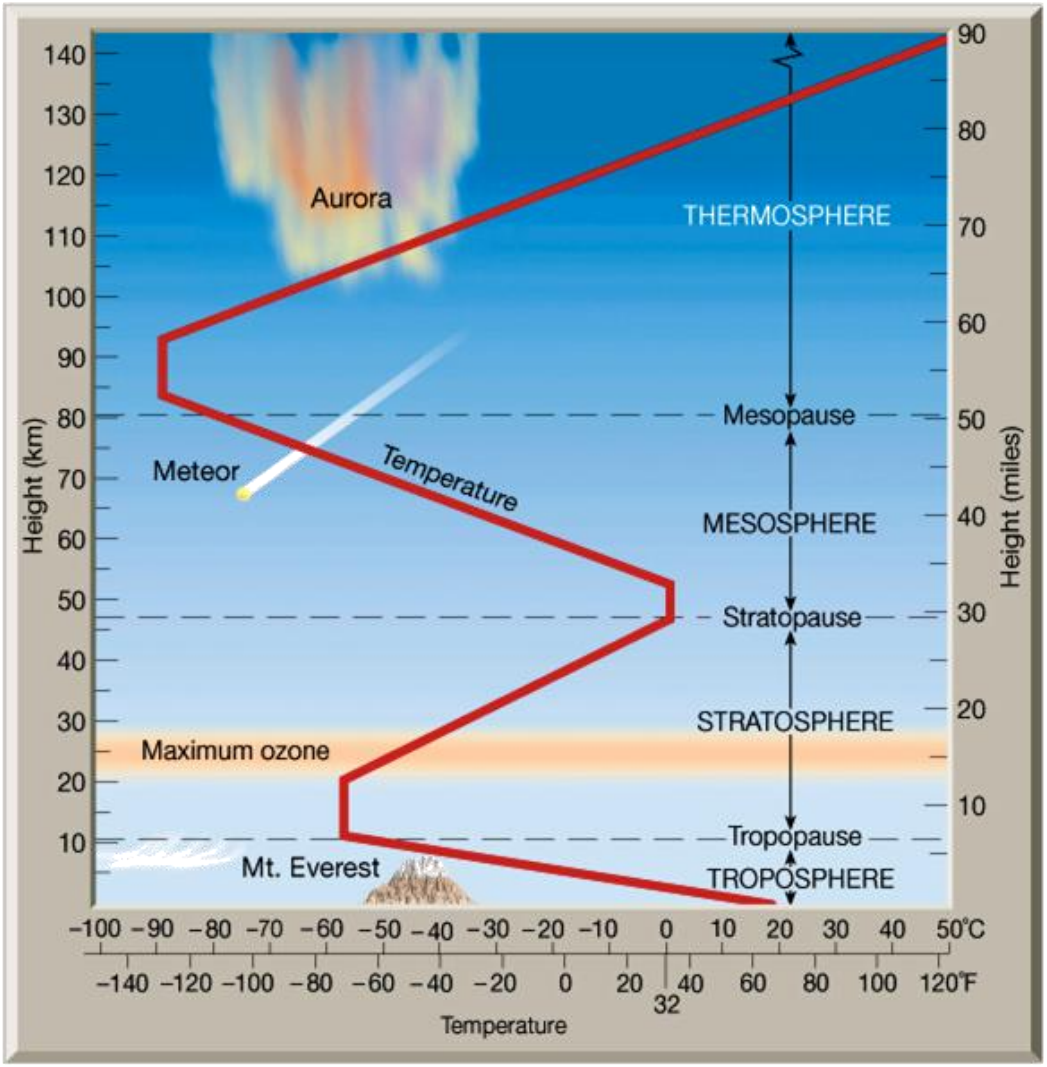
Composition of the atmosphere
(remote areas)

Άζωτο	N_2	78,1 %	}	99 %
Οξυγόνο	O_2	20,9 %	}	
Αργόν	Ar	0,93 %		
Διοξ. Άνθρακα	CO_2	0,035 %		
Νέον	Ne	0,0018 %		
Ήλιον	He	0,0005 %		
Μεθάνιο	CH_4	0,00017 %		
Κρυπτόν	Kr	0,00011 %		
Υδρογόνο	H_2	0,00005 %		
Όζον	O_3	1-4 10-6 %		
Νερό	H_2O	1 %		Έδαφος
		10^{-7} %		Τροπόπαυση

Vertical distribution of atmosphere



- **Composition**

Omoiosphere (0-100 km)

Heterosphere (>100 km)

Thermosphere (100-400 km)

Exosphere (>400 km)

- **Tempereature**

Troposphere (0-12±4 km)

Stratosphere (Tropopause -50 km)

Mesosphere (Startopause-80 km)

- Other criteria

Ionosphere (70-300 km)

Magnetosphere (1000 km-10 R_Γ)

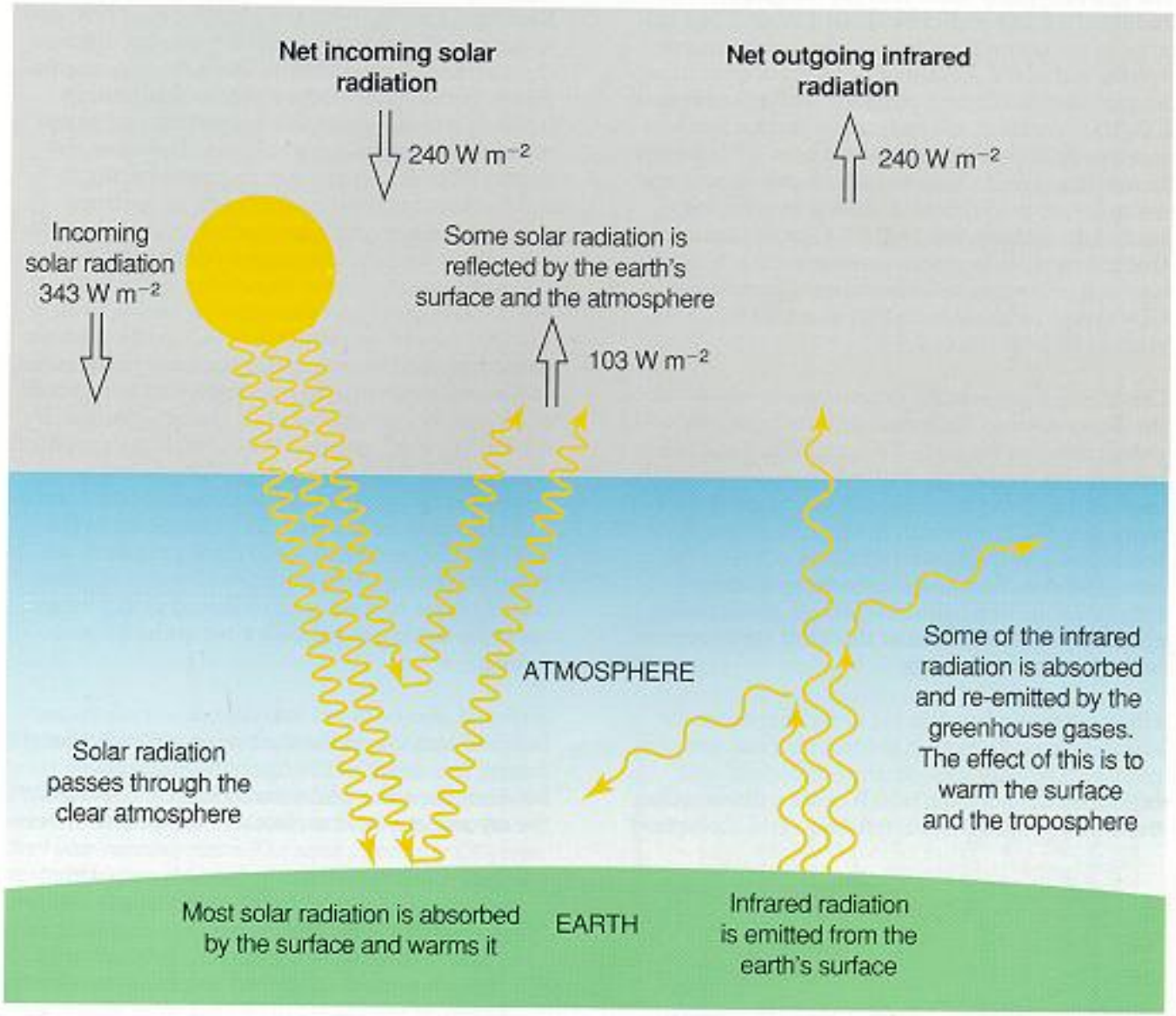
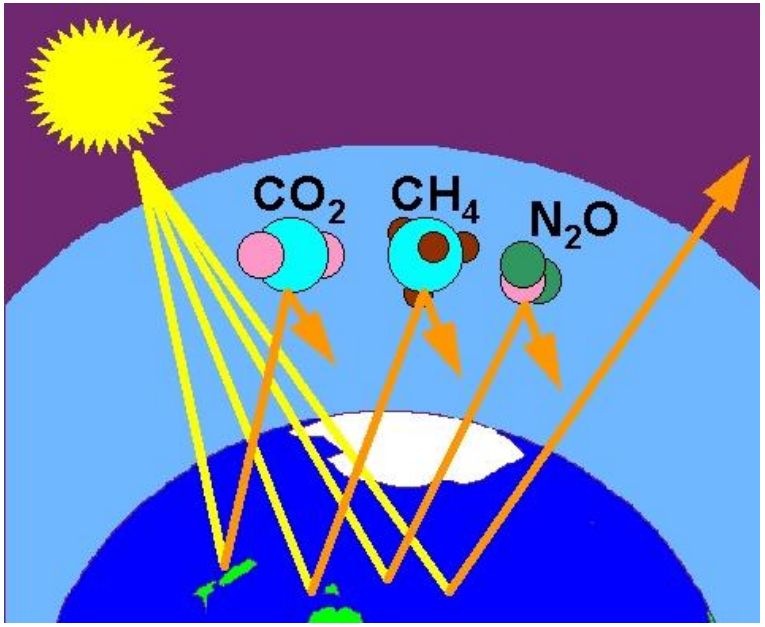


Figure 1. *A simplified diagram illustrating the global long-term radiative balance of the atmosphere. Net input of solar radiation (240 W m^{-2}) must be balanced by net output of infrared radiation. About a third (103 W m^{-2}) of incoming solar radiation is reflected and the remainder is mostly absorbed by the surface. Outgoing infrared radiation is absorbed by greenhouse gases and by clouds keeping the surface about 33 °C warmer than it would otherwise be.*

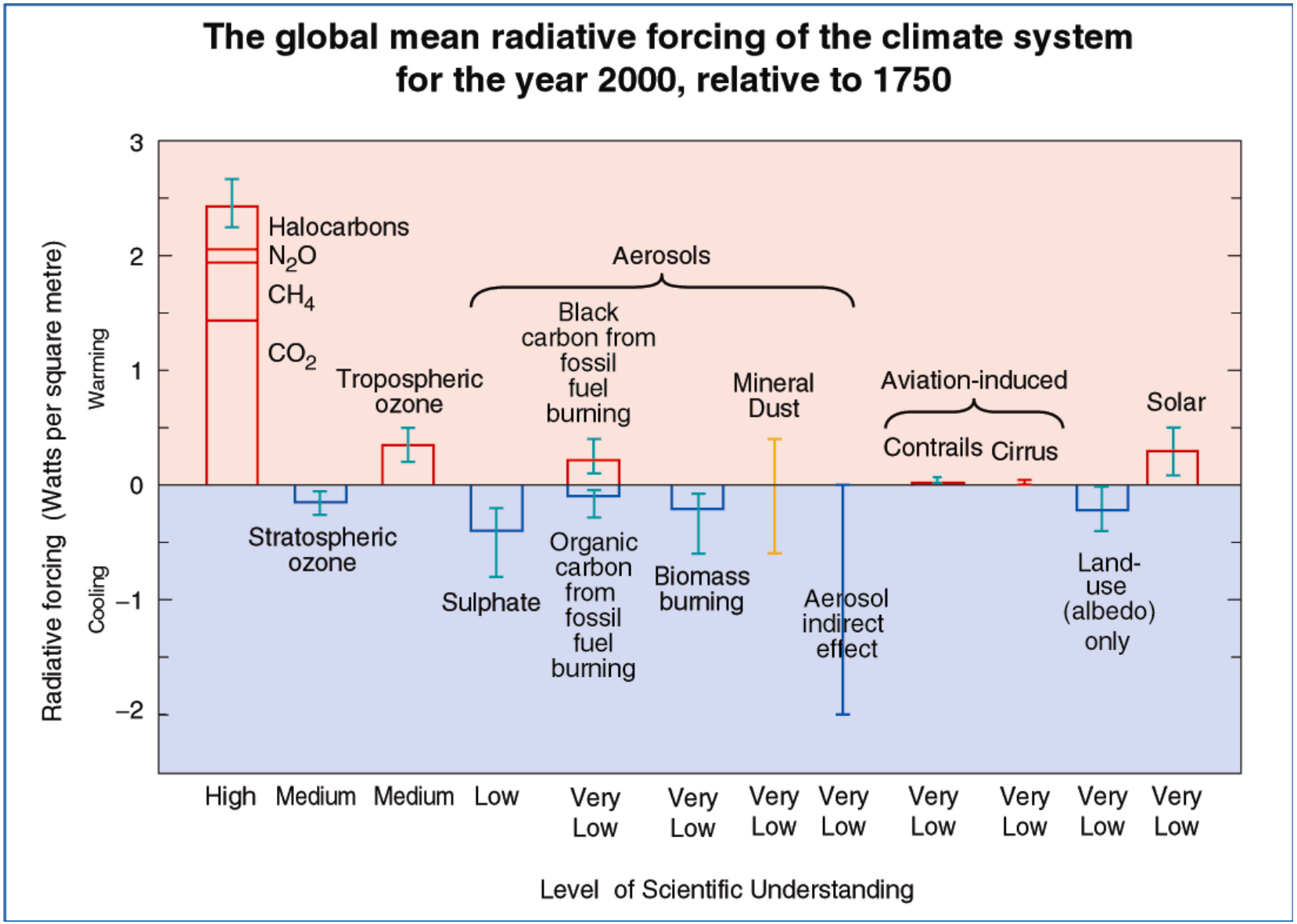
Greenhouse gases

Infrared radiation emitted from the Earth is absorbed in the atmosphere by just a few gases – the greenhouse gases.

Warming of the atmosphere by naturally occurring greenhouse gases makes the surface of the Earth about 33^{o}C (59^{o}F) warmer.



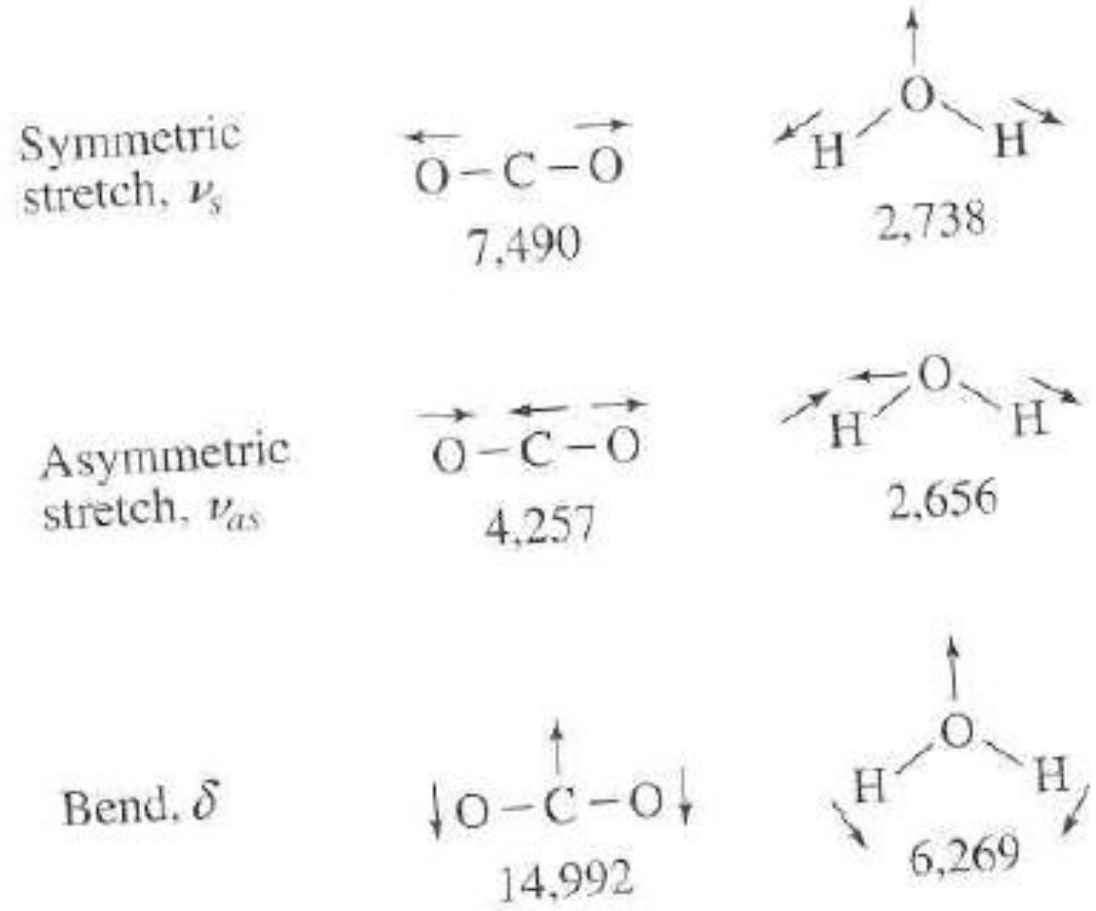
However - The amount of key gases has risen dramatically since the Industrial revolution.



http://www.ipcc.ch

Greenhouse gases (GHG)

Gases which behave as electrical dipole e.g. CO_2, H_2O, N_2O, CH_4, CFCs, O_3



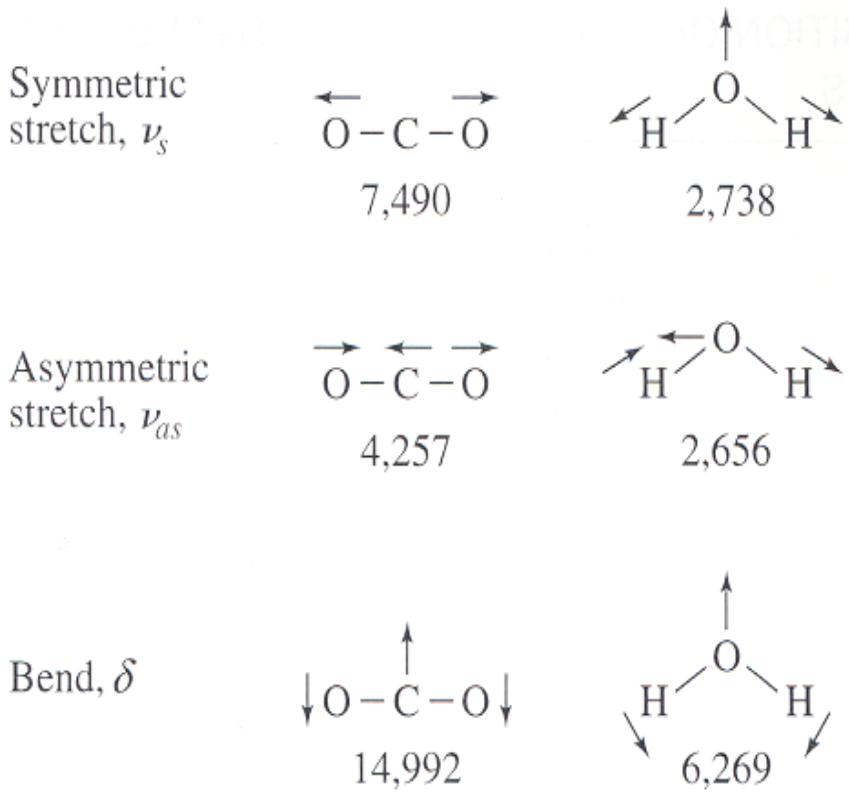


Figure 6.12 Molecular vibrations of CO_2 and H_2O in units of wavelengths (nm).

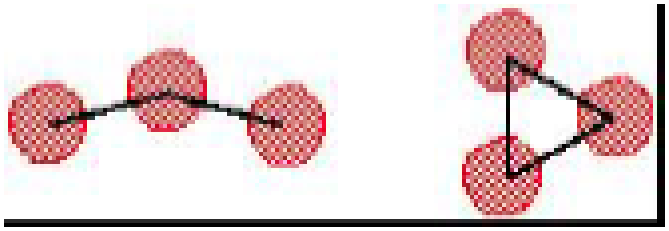
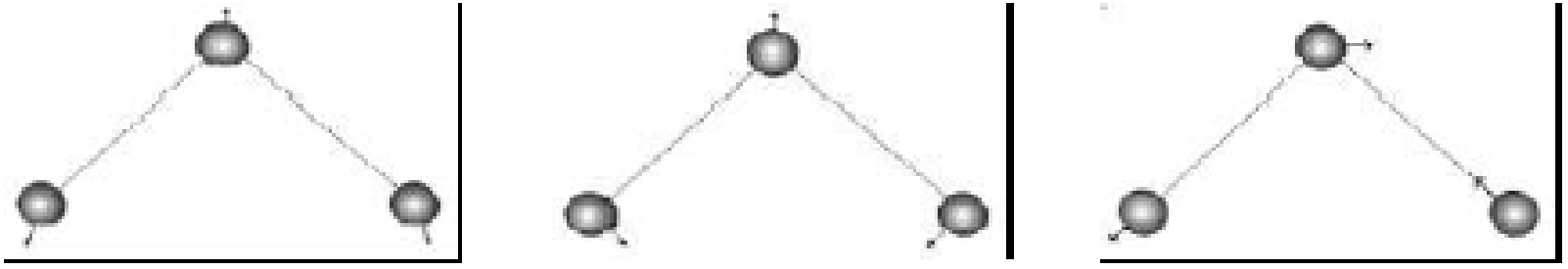


Figure 1. Two forms of possible ozone molecule.

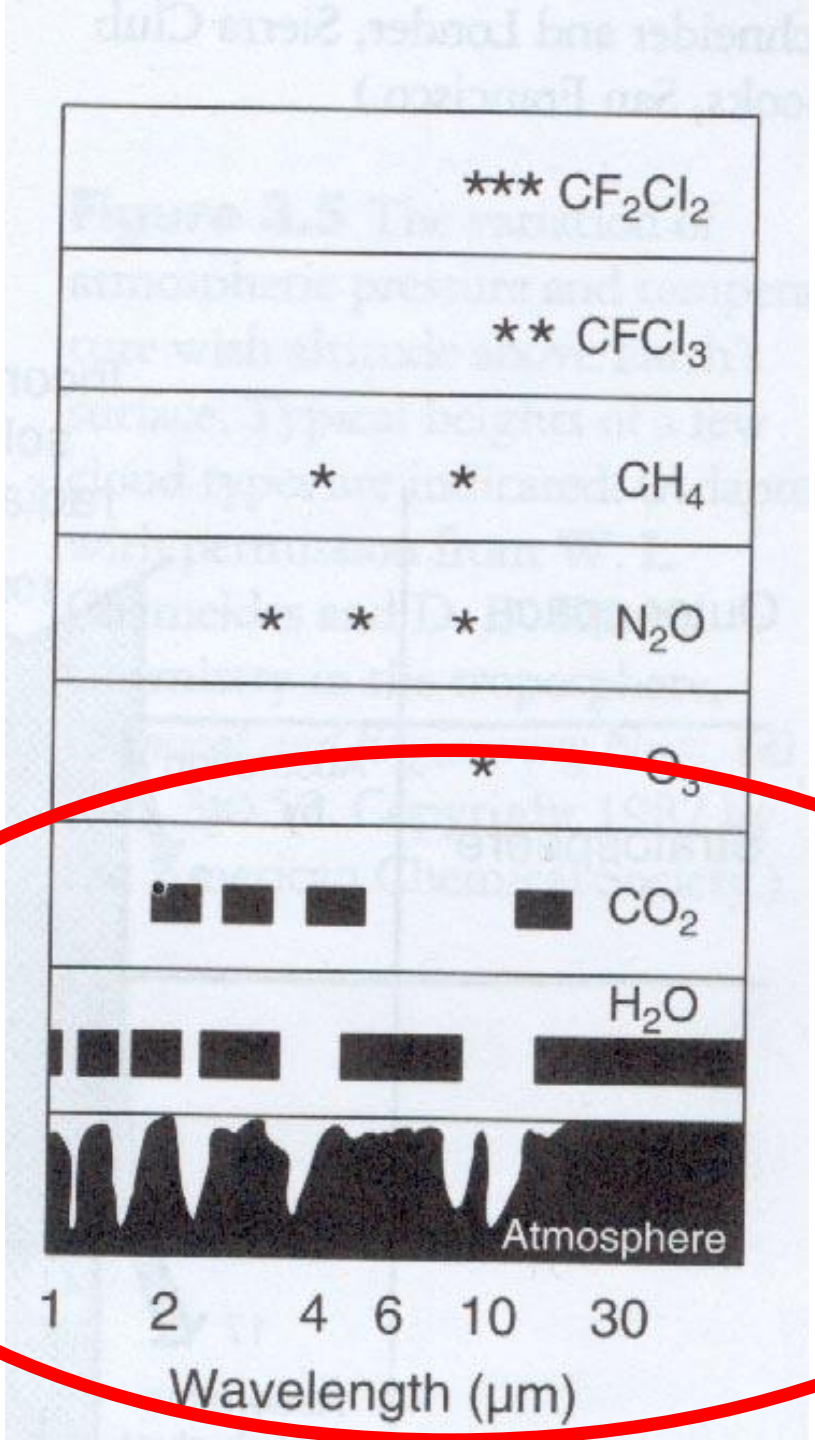
O_3

The actual molecule is non-linear with a bond angle of 116° (Figure 2) [6].

Figure 2. Four resonance structures of the ozone molecule. Adopted from [6].

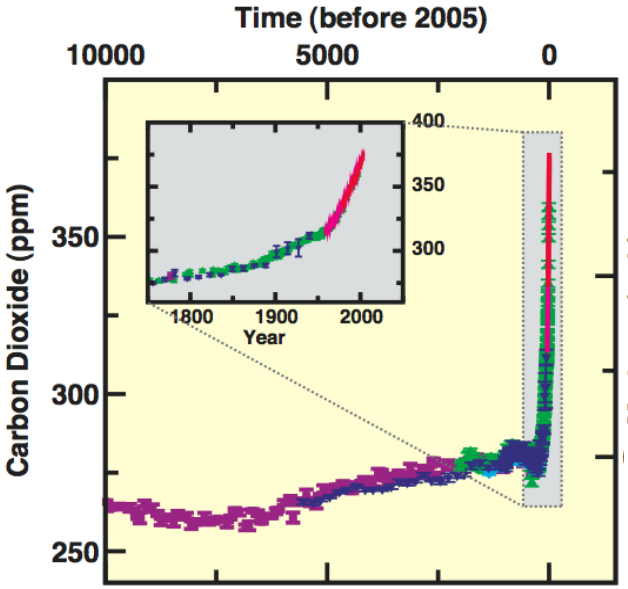


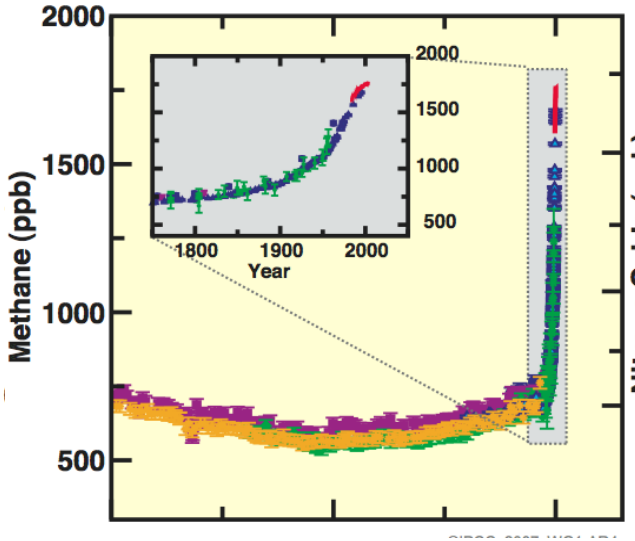
'Stretching' symmetric vibration q1 'Bending' vibration q2 'Stretching' asymmetric vibration q3

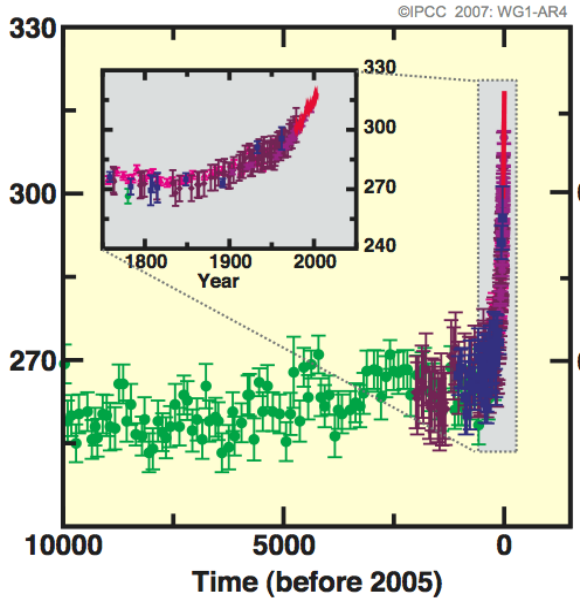

*** CF_2Cl_2
** $CFCl_3$
* * CH_4
* * * N_2O
* O_3
CO_2
H_2O
Atmosphere
1 2 4 6 10 30
Wavelength (μm)

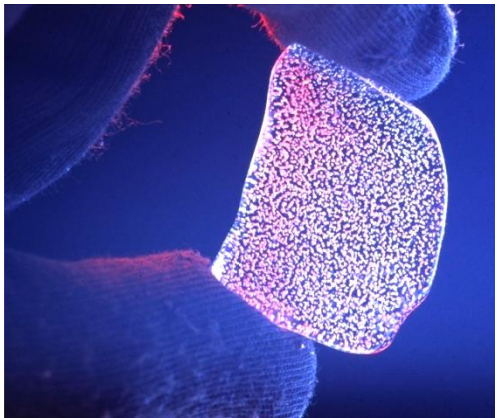
Industrial revolution and the atmosphere

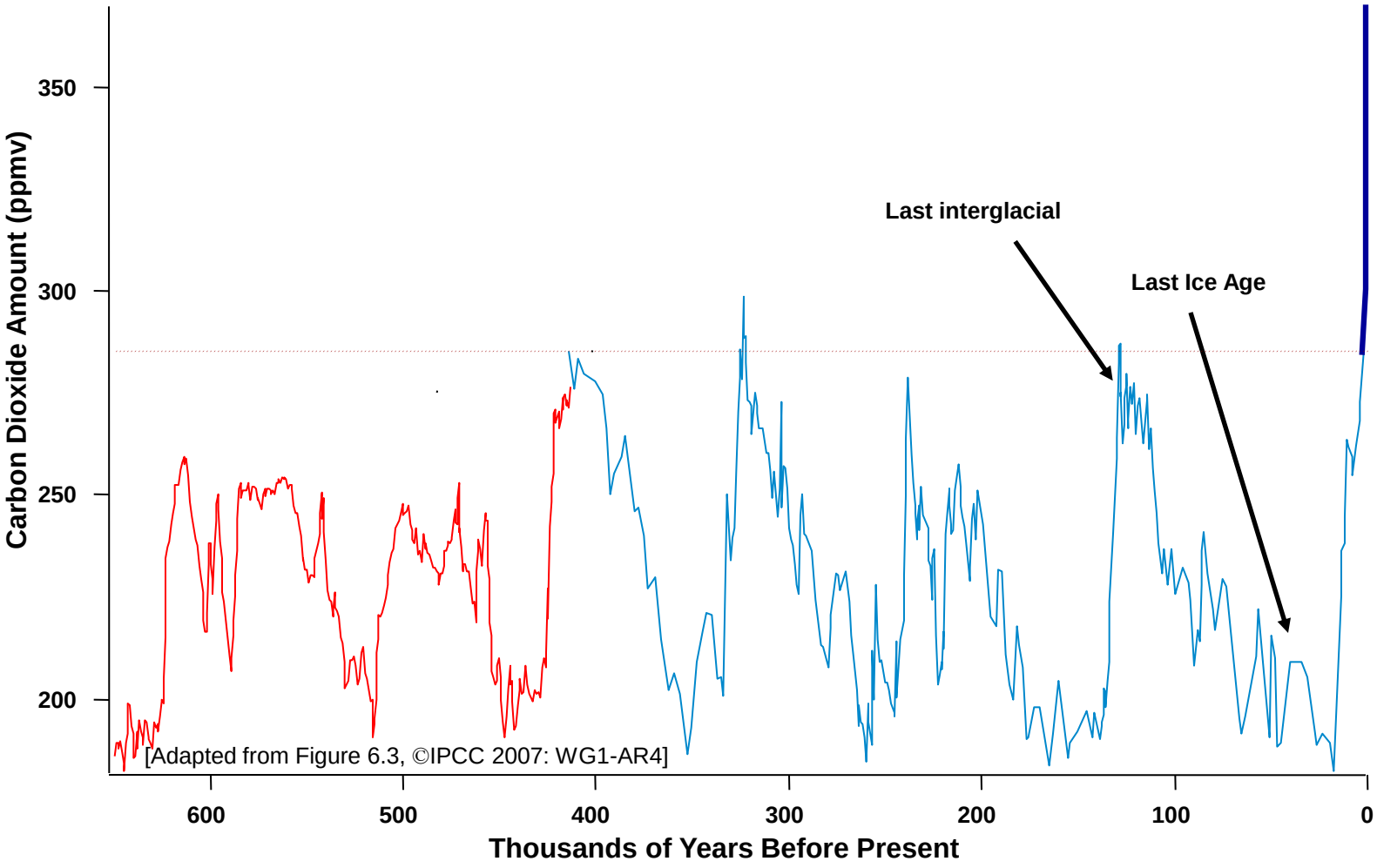
The current concentrations of greenhouse gases, and their rates of change, are unprecedented









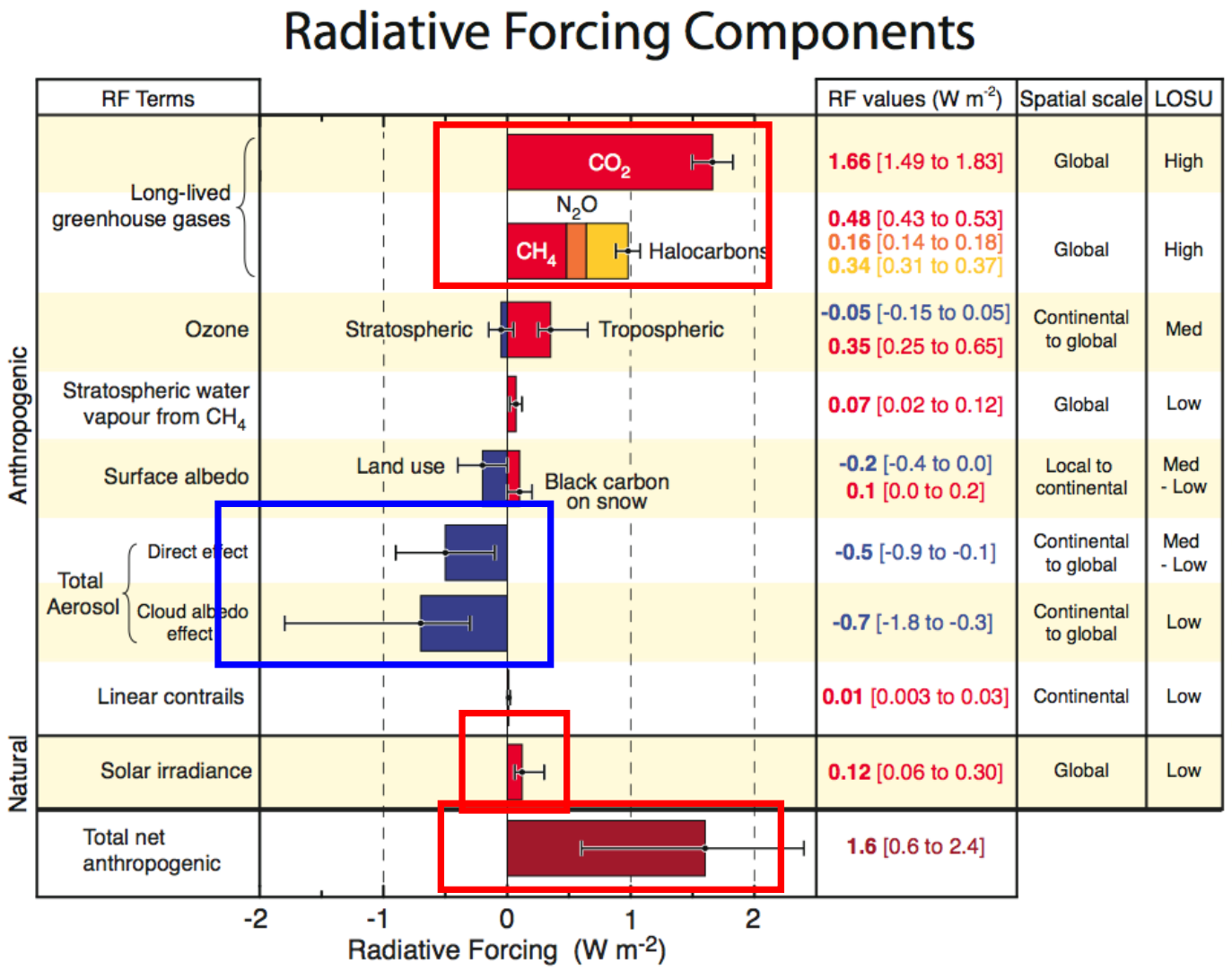


Ice ages are not random. They are 'forced' (by earth's orbital clock…. changes in the sunlight received).

Humans are 'forcing' the system in a new way. CO_2 increases due to fossil fuel burning are the dominant cause of global warming.

CO_2 has not been this high in more than half a million years.

Human and Natural Drivers of Climate Change

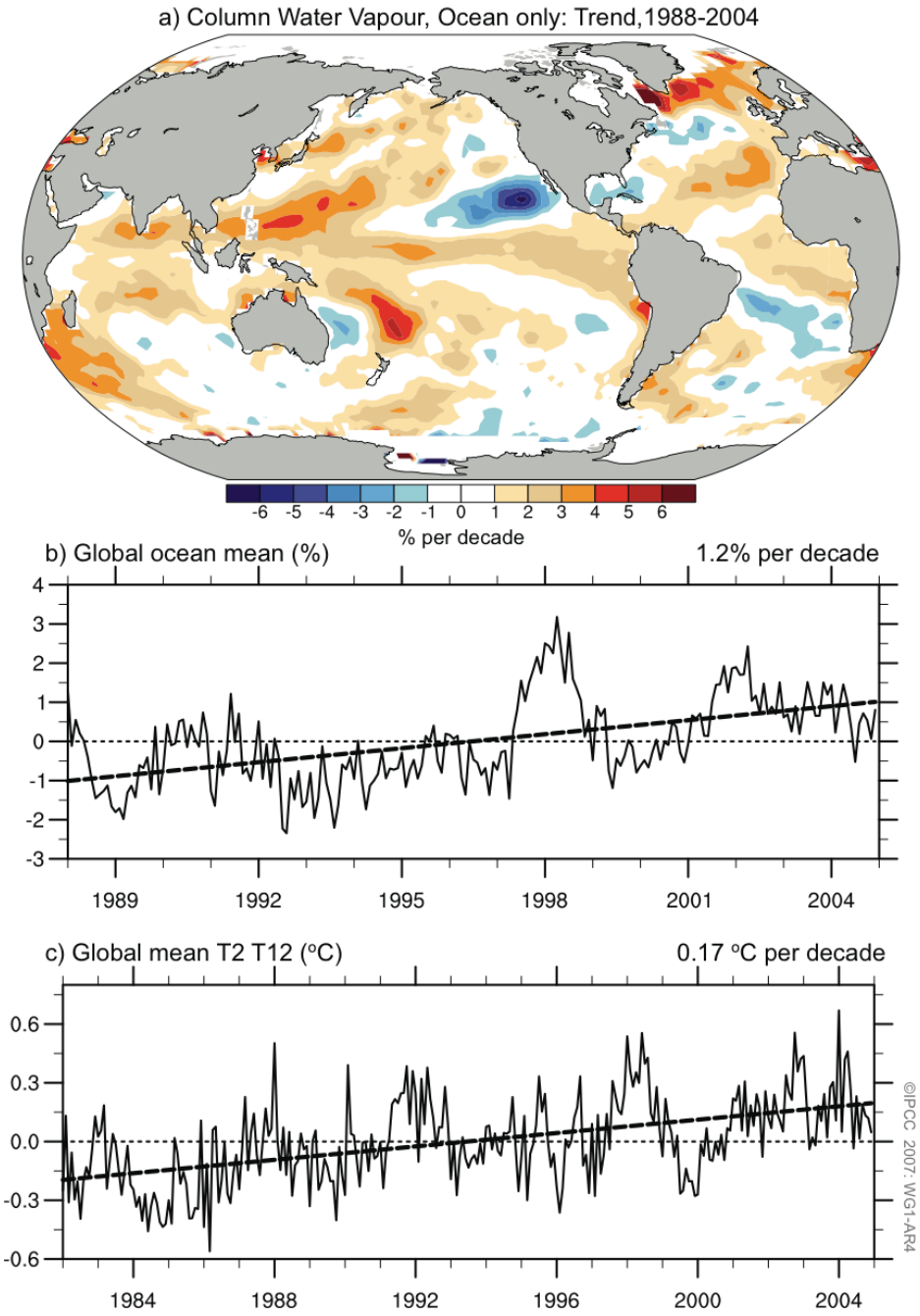


Water Vapor Feedback

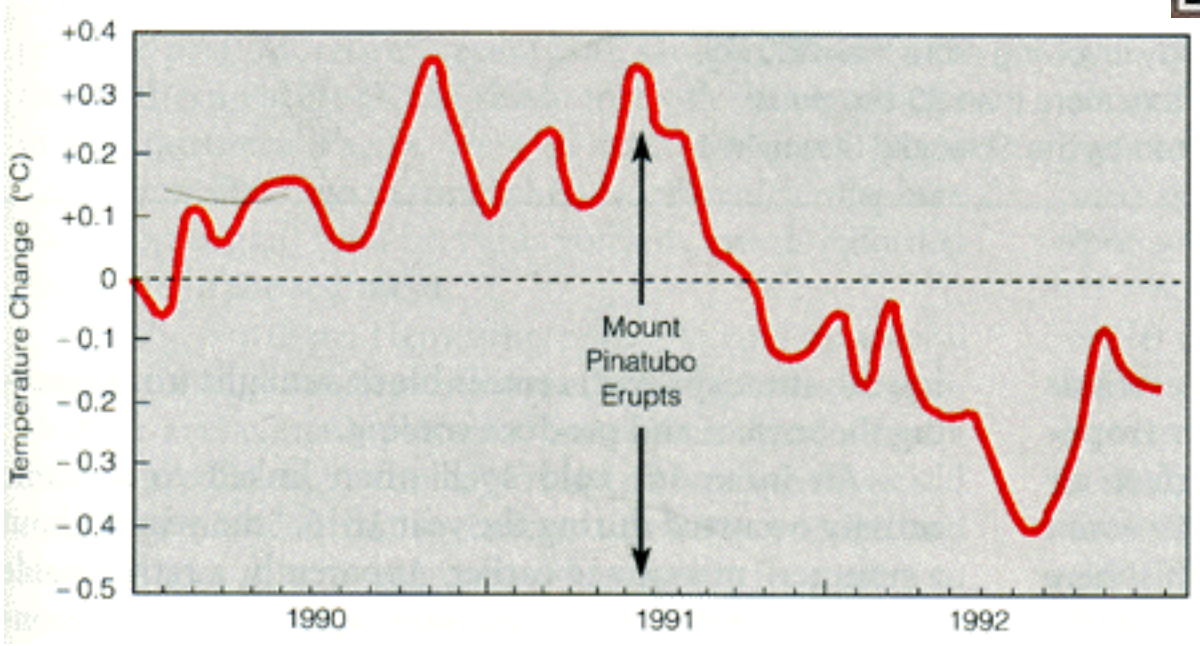
Water vapor responds to changes in climate, but it doesn't drive changes in climate. It's a major feedback that amplifies global climate change (by about 50%)……

New in IPCC (2007):

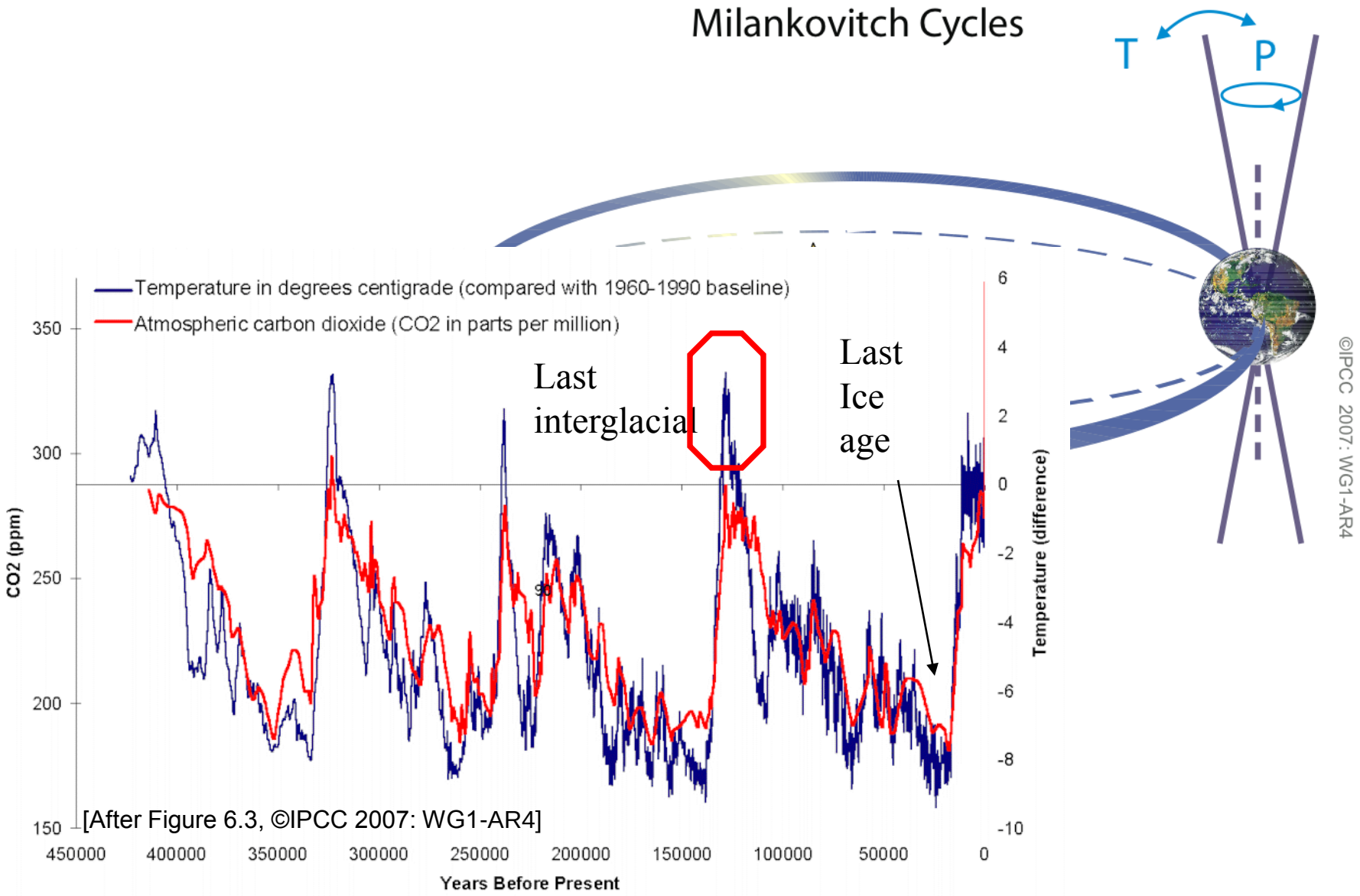
Observed trends that



Explosive Volcanic Eruptions: Proof of Fast-Response Climate Change Due to Forcing



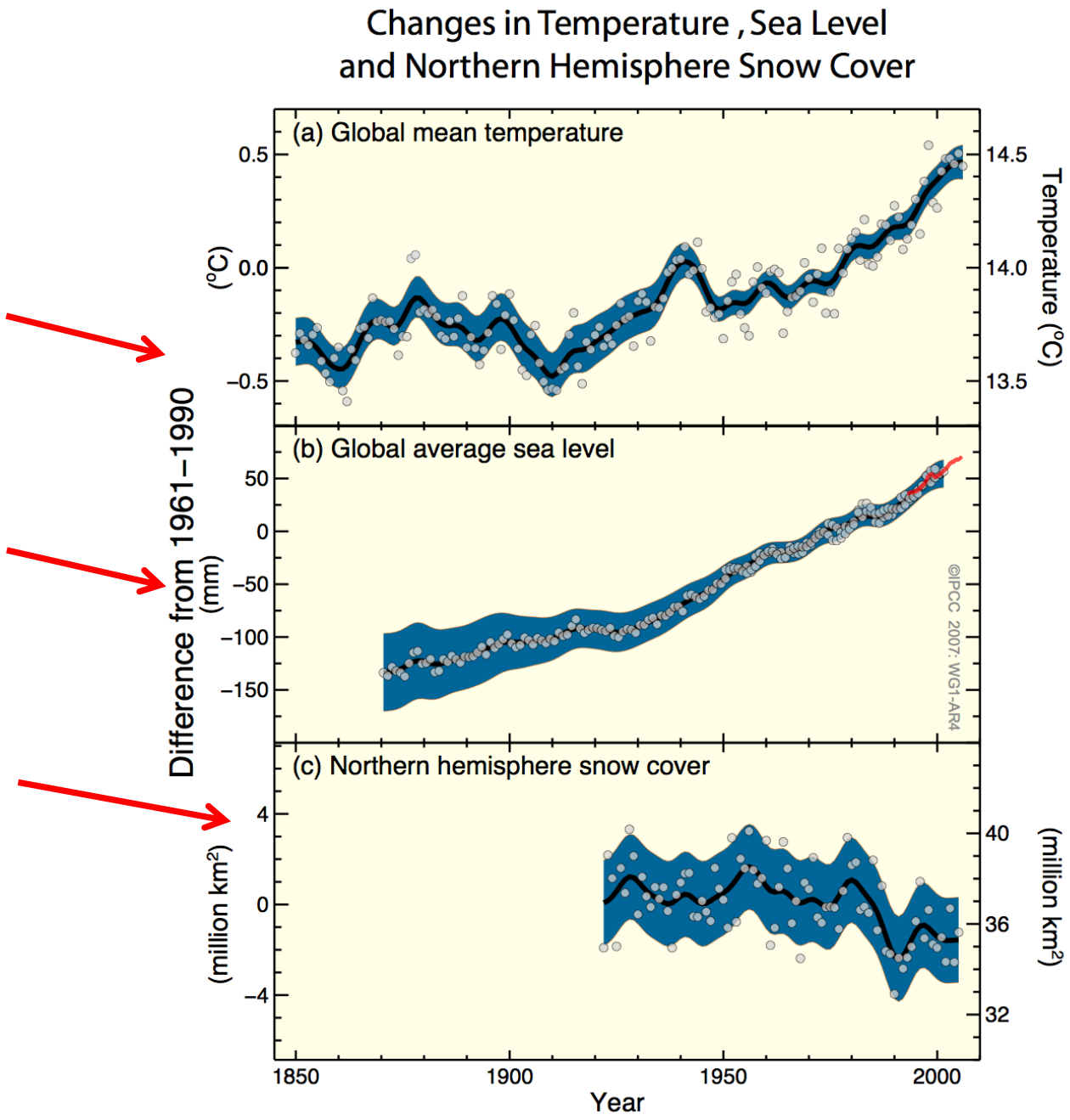
Ice Age Forcing and Response



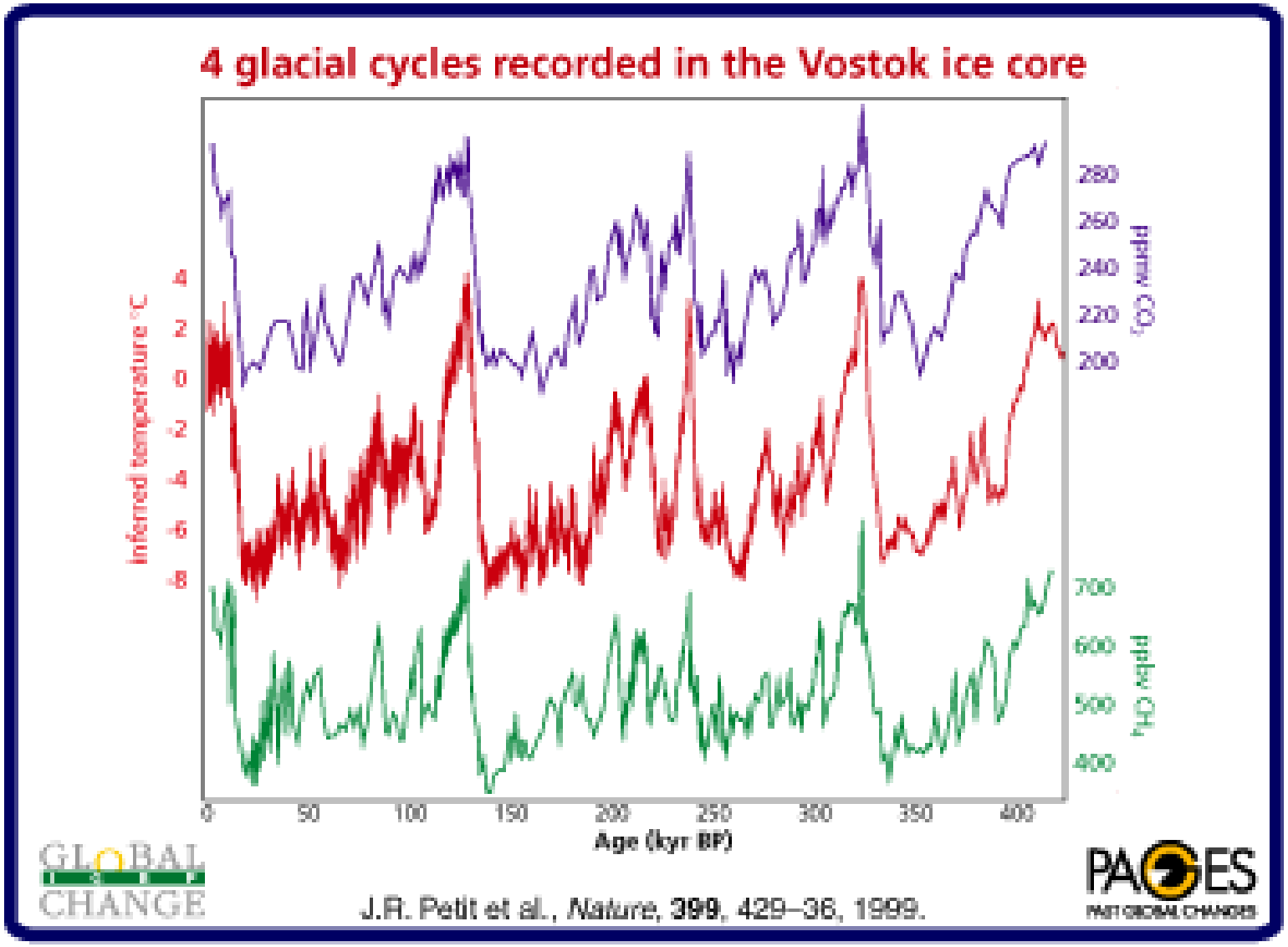
[After Figure 6.3, ©IPCC 2007: WG1-AR4]

Warming is Unequivocal

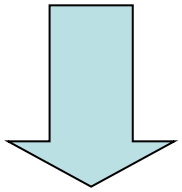
Rising atmospheric temperature



Vostoc 4 glacials

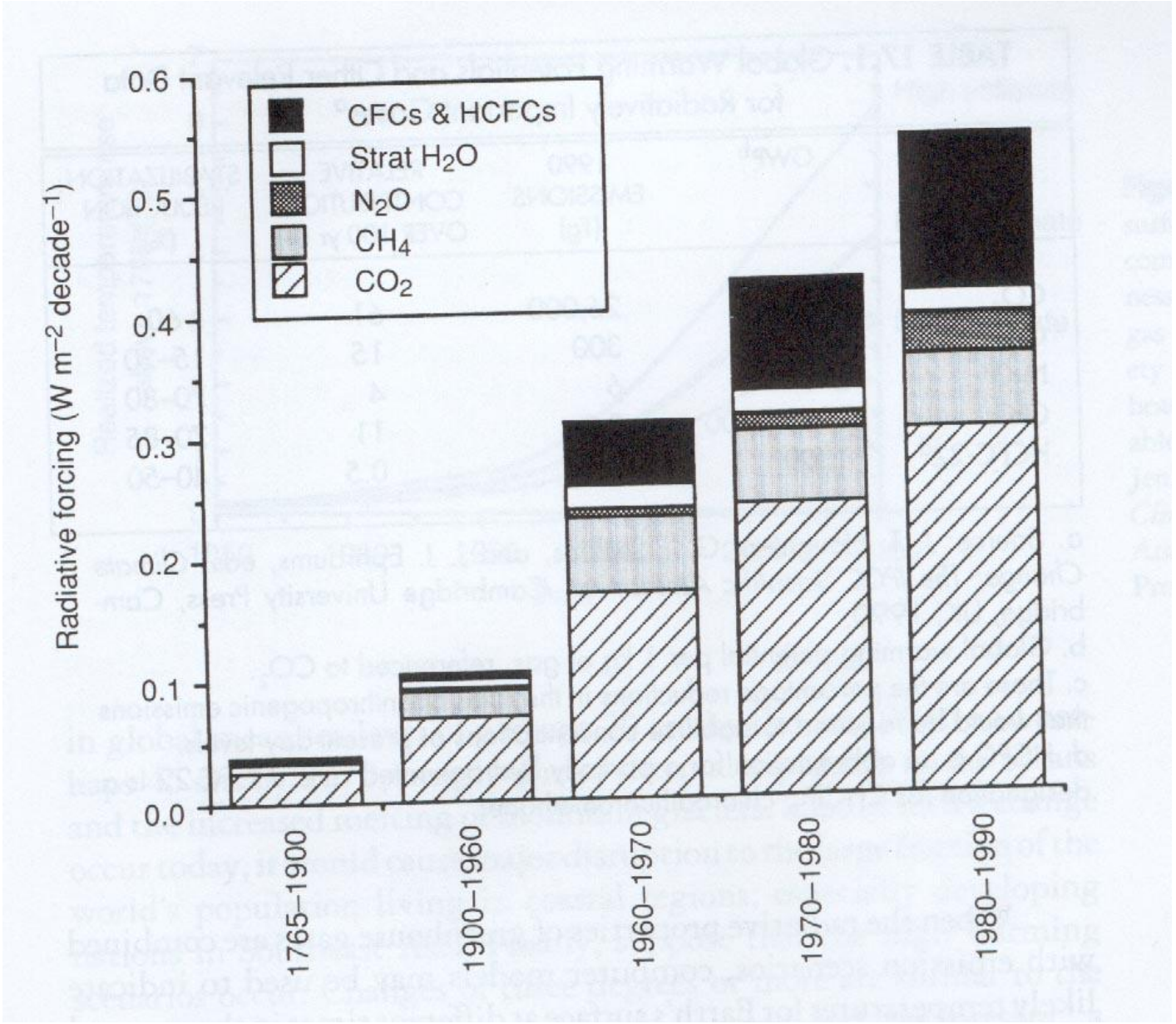


Changes in atmospheric composition (4 greenhouse gases)



	CO_2	CH_4	N_2O	CFCs
Προβιομηχανικές συγκεντρώσεις (έτος ~1750)	280 ppmv	800 ppbv	280 ppbv	0
Συγκεντρώσεις (έτος 1988)	351 ppmv	1700 ppbv	310 ppbv	CFC11: 0,26 ppbv CFC12: 0,44 ppbv
Σύγχρονη αύξηση (1980 - 1988) ανά χρόνο	0,48%	17 ppbv	0,3% - 0,4%	CFC11: 0,05 ppbv CFC12: 0,05 ppbv

Radiative forcing induced by greenhouse gases



% contribution of greenhouse gases (GHG) to radiative forcing

	1975-1990	1980-1990
CO_2	61%	50%
CH_4	15%	10%
CFCs	12%	16%
$N_2O + NO_x$	9%	14%

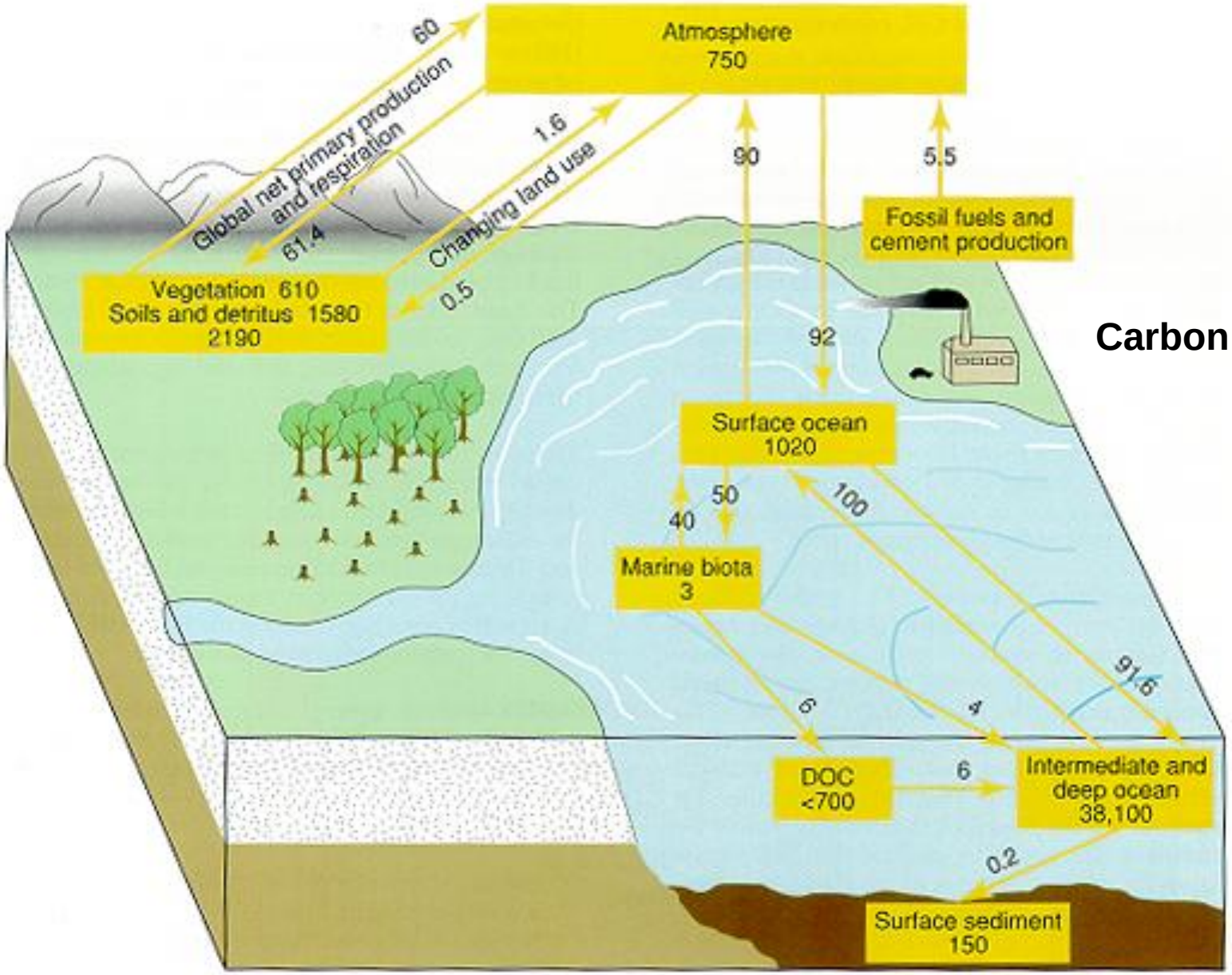
Contribution of each GHG is not equal :

$$CO_2 = f(\log C)$$

$$CH_4, N_2O = f(\sqrt{C})$$

$$CFCs = k.c.$$

CO_2 budget in the environment (Gt-C = 10^{15} gC)



Carbon cycle

Figure 4. *The global carbon cycle. The numbers in boxes indicate the size in GtC of each reservoir. On each arrow is indicated the magnitude of the flux in GtC/yr. (DOC = dissolved organic carbon).*

Table 1. Carbon pools in the major reservoirs on Earth.

Pools	Quantity (Gt)
Atmosphere	720
Oceans	38,400
Total inorganic	37,400
Surface layer	670
Deep layer	36,730
Total organic	1,000
Lithosphere	
Sedimentary carbonates	>60,000,000
Kerogens	15,000,000
Terrestrial biosphere (total)	2,000
Living biomass	600–1,000
Dead biomass	1,200
Aquatic biosphere	1–2
Fossil fuels	4,130
Coal	3,510
Oil	230
Gas	140
Other (peat)	250

Energy consumption in US 1850-2000

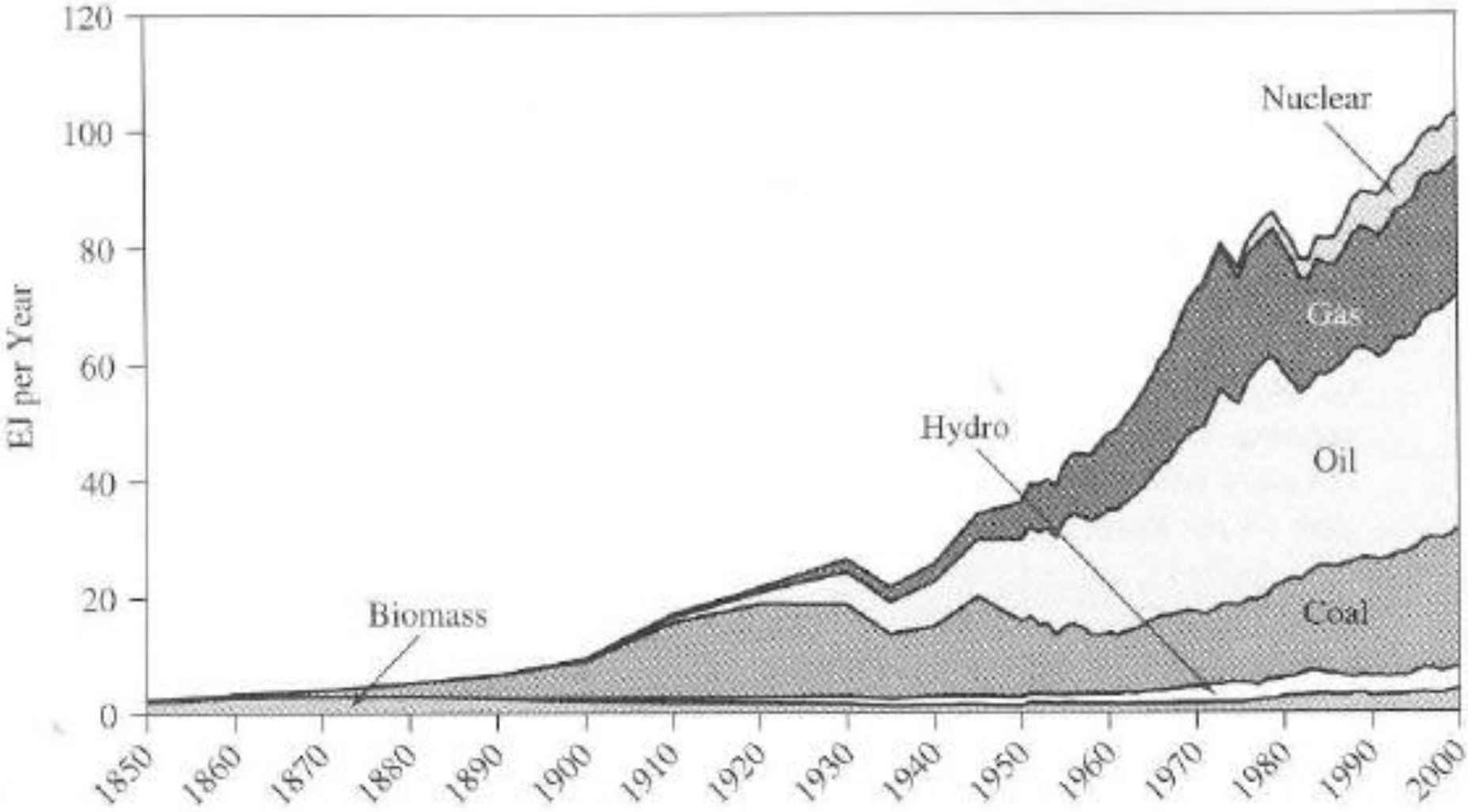
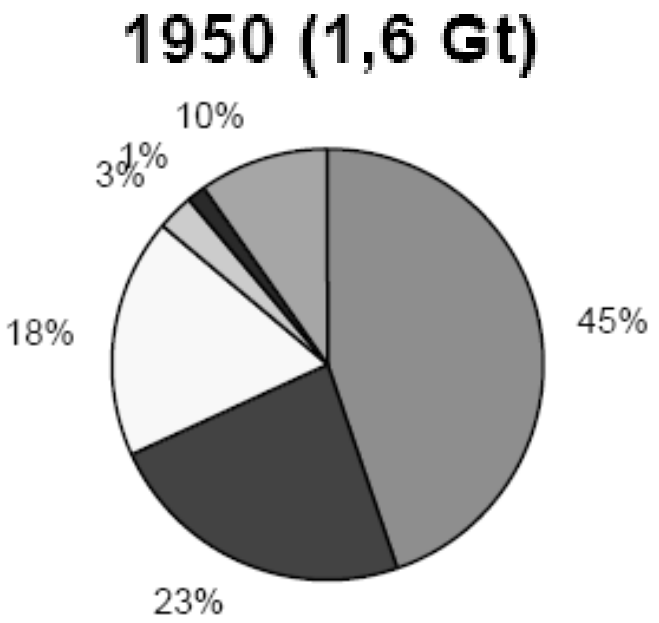
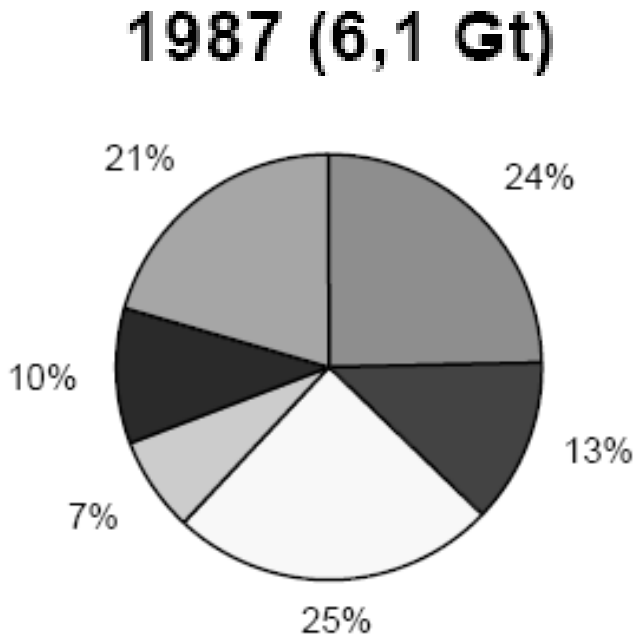


Figure 1.5 Historical trends in U.S. energy consumption, 1850–2000. *Source:* Energy Information Agency, U.S. Department of Energy, *Annual Energy Outlook 2000*, energy consumption by source, Washington, DC.

CO_2 Emissions

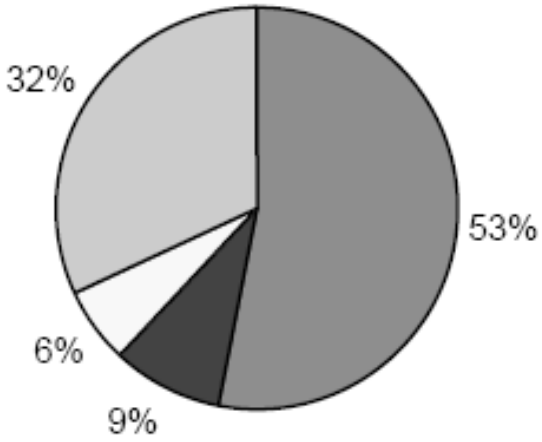




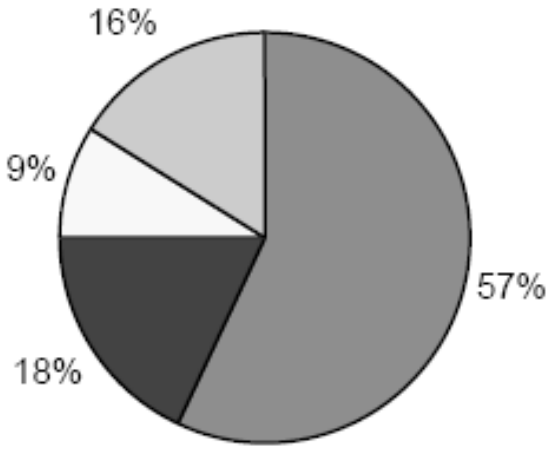
	1950	1987
Β. ΑΜΕΡΙΚΗ	44,7%	24,8%
Δ. ΕΥΡΩΠΗ	23,4%	12,5%
Α. ΕΥΡΩΠΗ	18%	24,7%
ΙΑΠΩΝΙΑ + ΑΥΣΤΡΑΛΙΑ	2,8%	7,2%
ΚΙΝΑ	1,4%	10,3%
ΧΩΡΕΣ ΥΠΟ ΑΝΑΠΤΥΞΗ	9,7%	20,5%

Κατανομή του πληθυσμού της γης

1950 (2.6 δισ.)

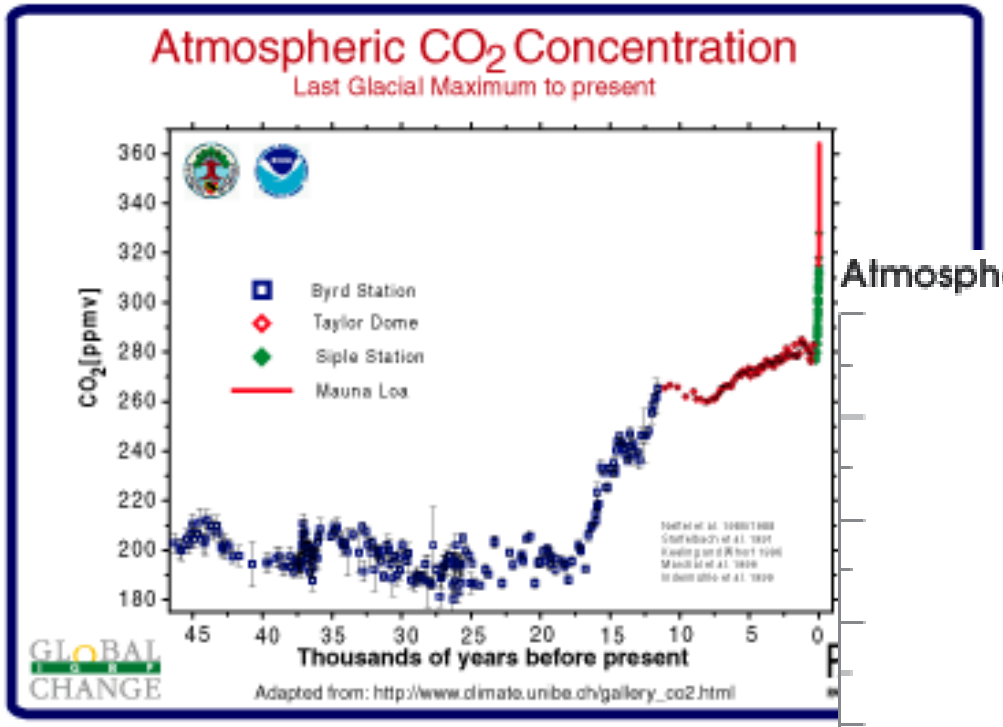


2025 (8.6 δισ.)

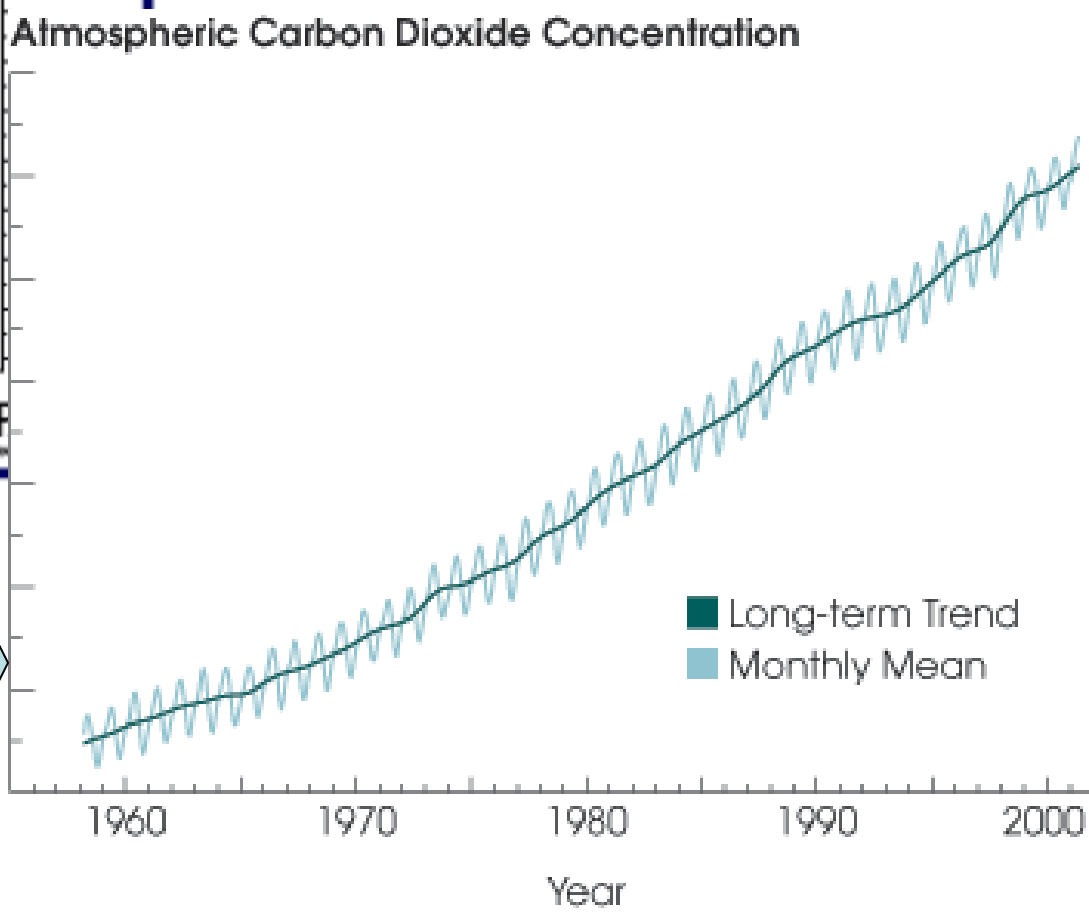


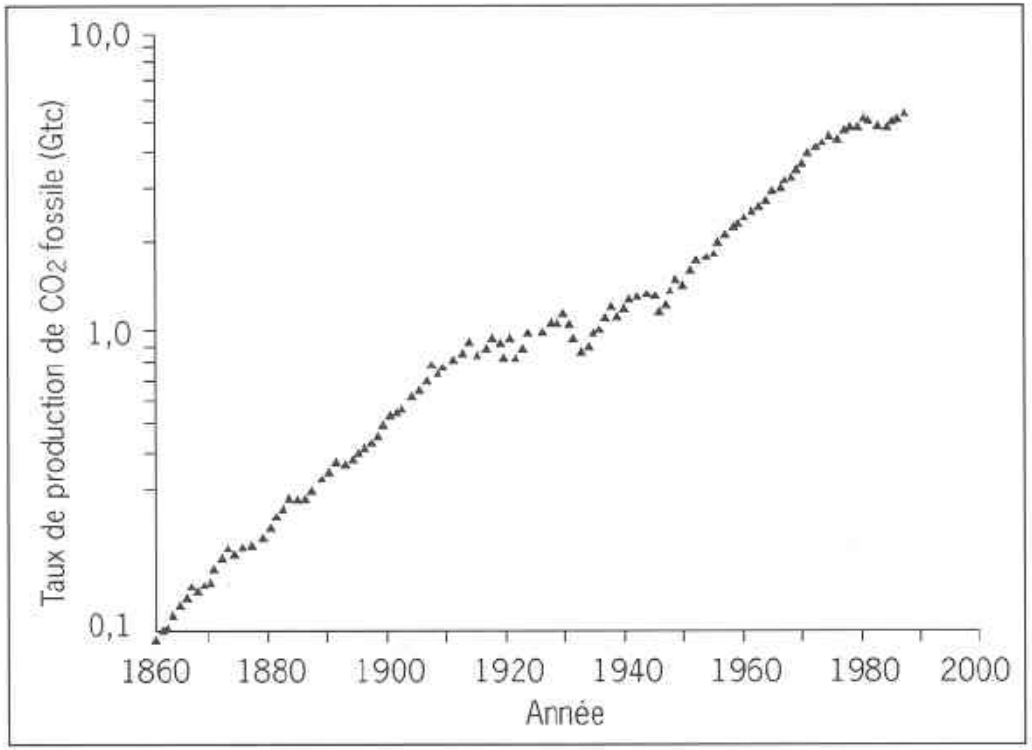
	1950	2025
ΑΣΙΑ	53%	57%
ΑΦΡΙΚΗ	9%	18%
Ν. ΑΜΕΡΙΚΗ	6%	9%
ΑΝΕΠΤ. ΧΩΡΕΣ	32%	16%

Atmospheric CO_2 trends

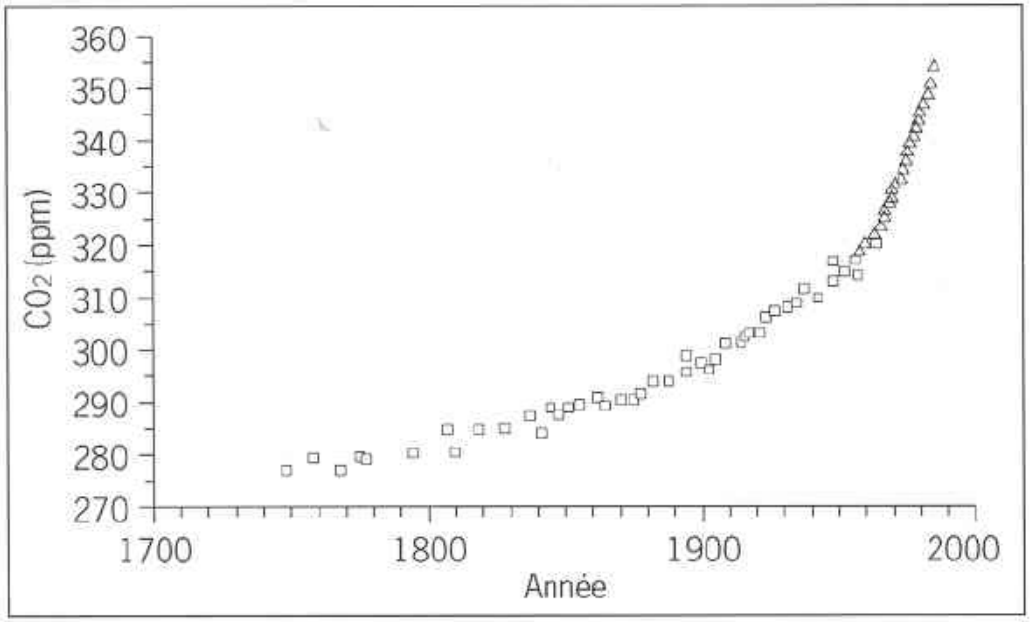


Seasonal variability



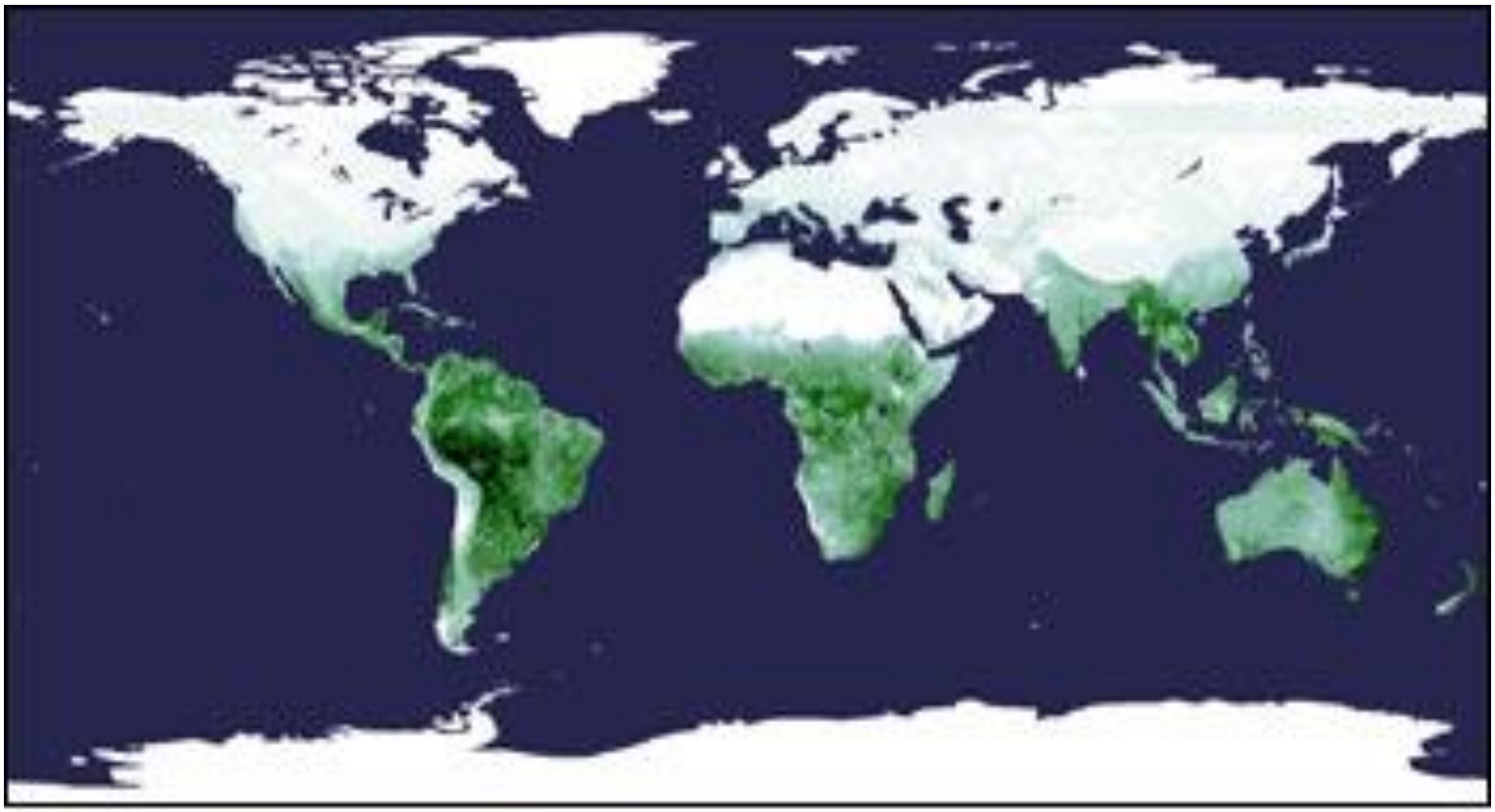


Increase in CO_2 emissions from fossil fuel



Increase in atmospheric CO_2

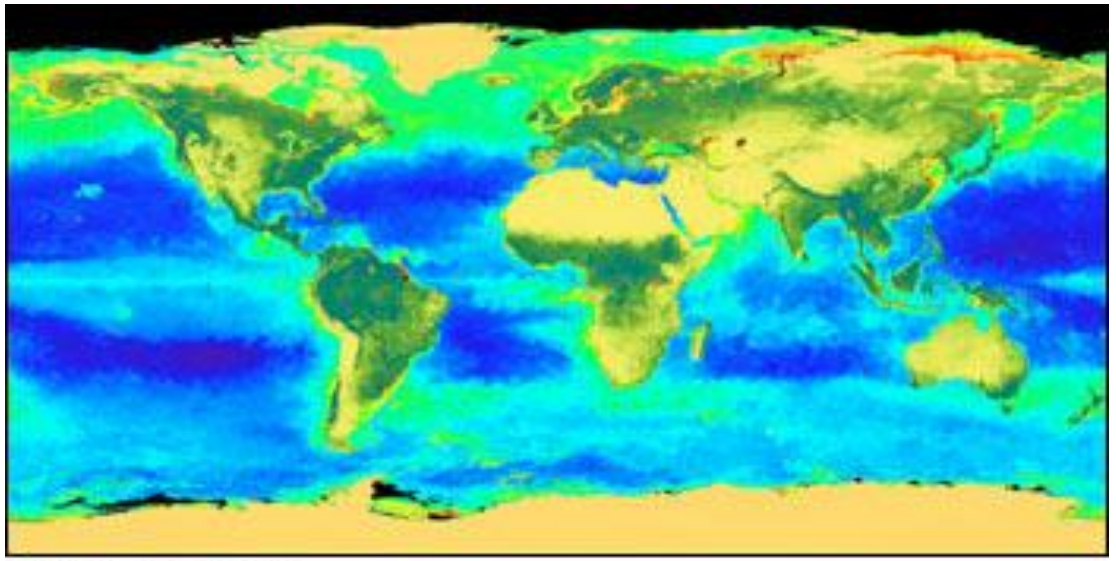
Photosynthetic activity



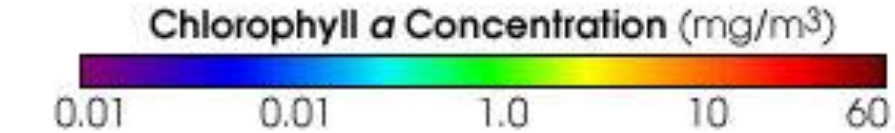
Photosynthetic Activity (Dec. 18–25, 2000)

low high

Chl-a



September 2000



Global biosphere