EARTH SYSTEM SCIENCE:
Weather and Climate

Greenhouse and Trace Gases

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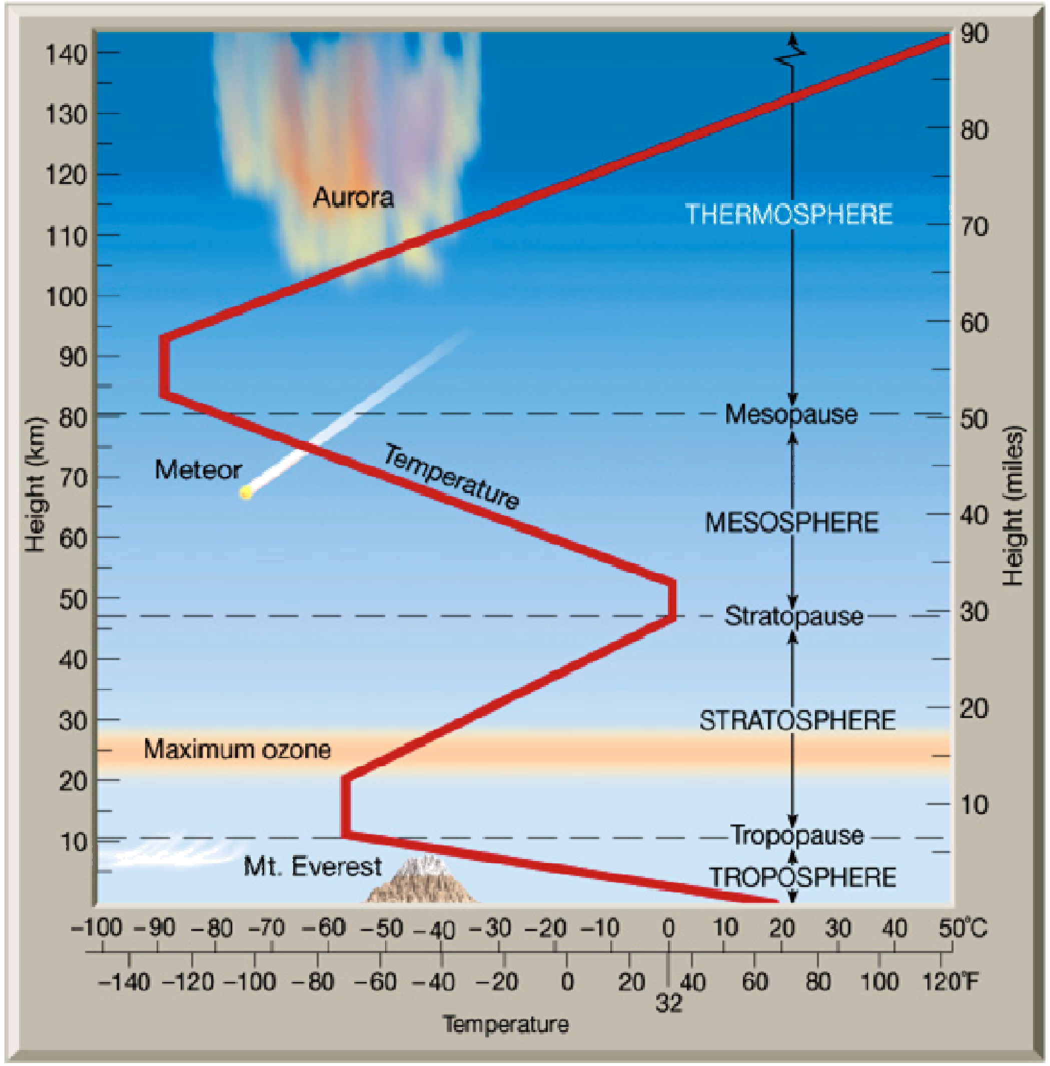
Composition of the atmosphere
(remote areas)

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})

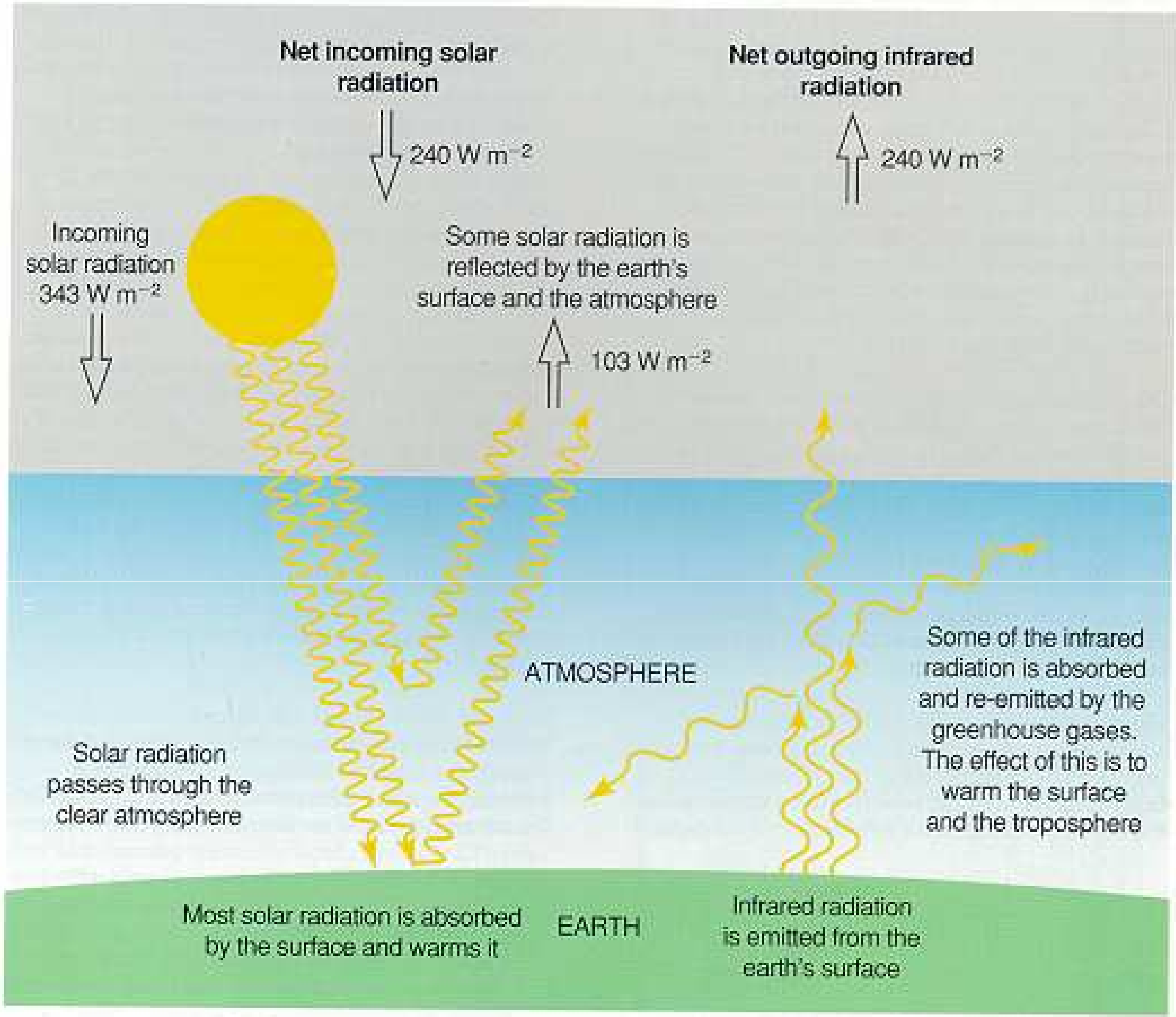
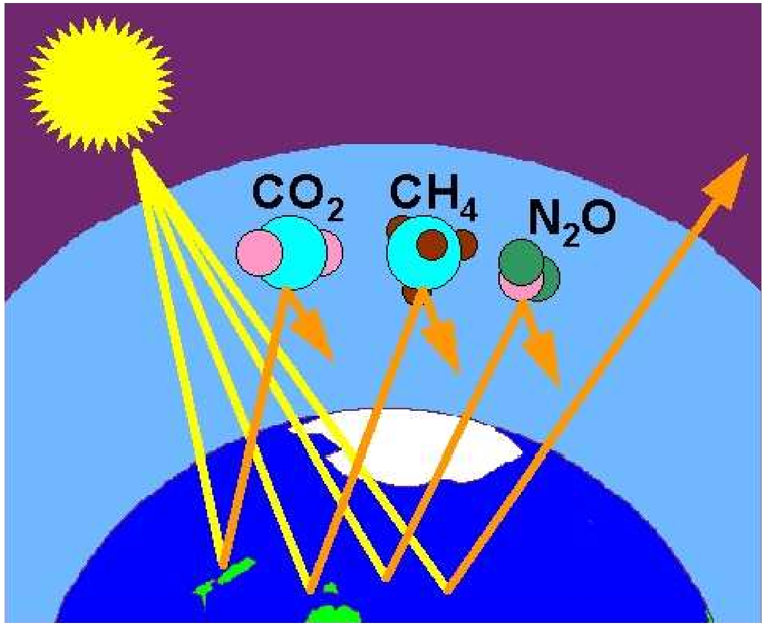


Figure 1. *A simplified diagram illustrating the global long-term radiative balance of the atmosphere. Net input of solar radiation (240 W m^{-2}) must be balanced by net output of infrared radiation. About a third (103 W m^{-2}) of incoming solar radiation is reflected and the remainder is mostly absorbed 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.*

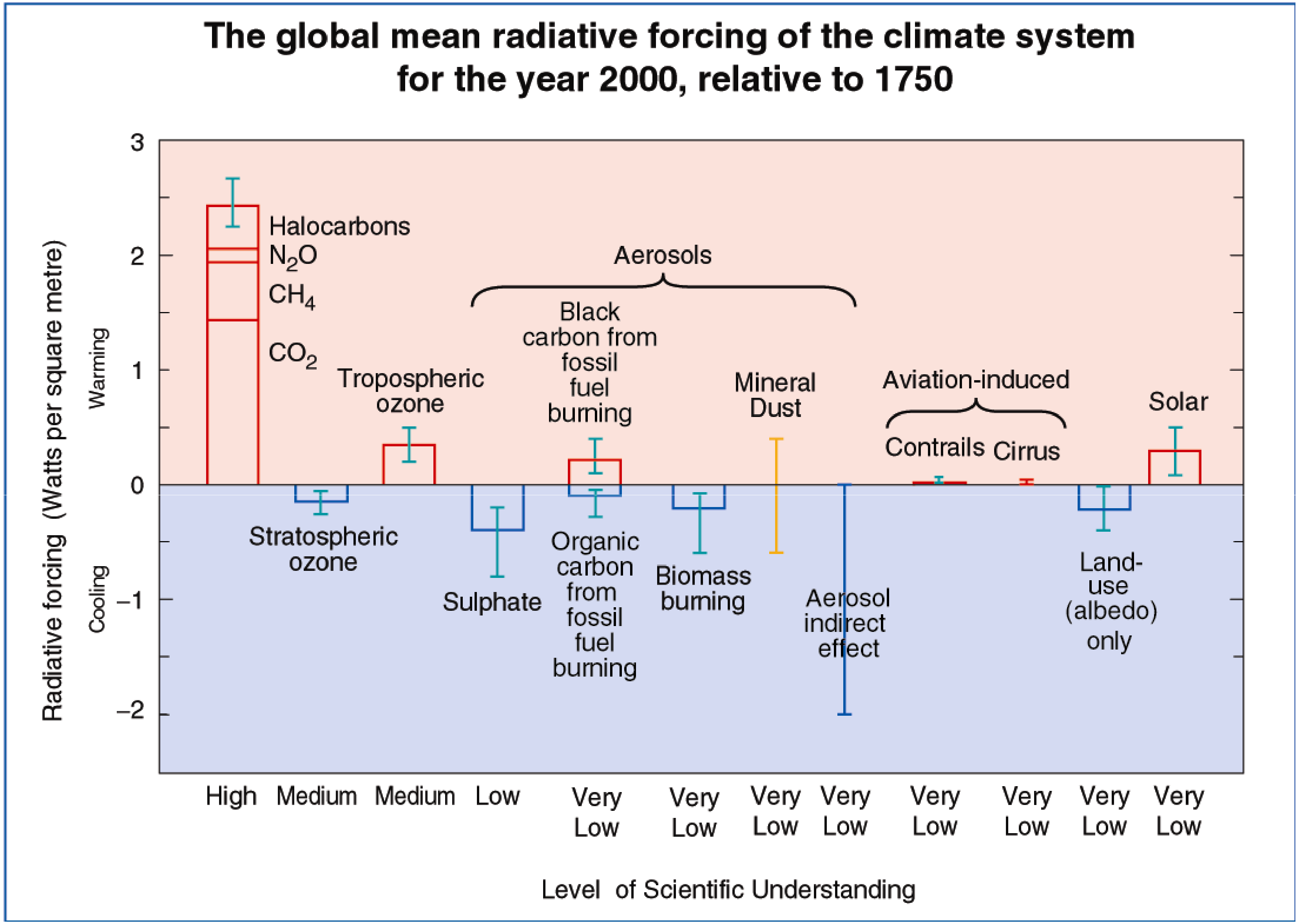
Greenhouse gases

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°C (59°F) warmer.



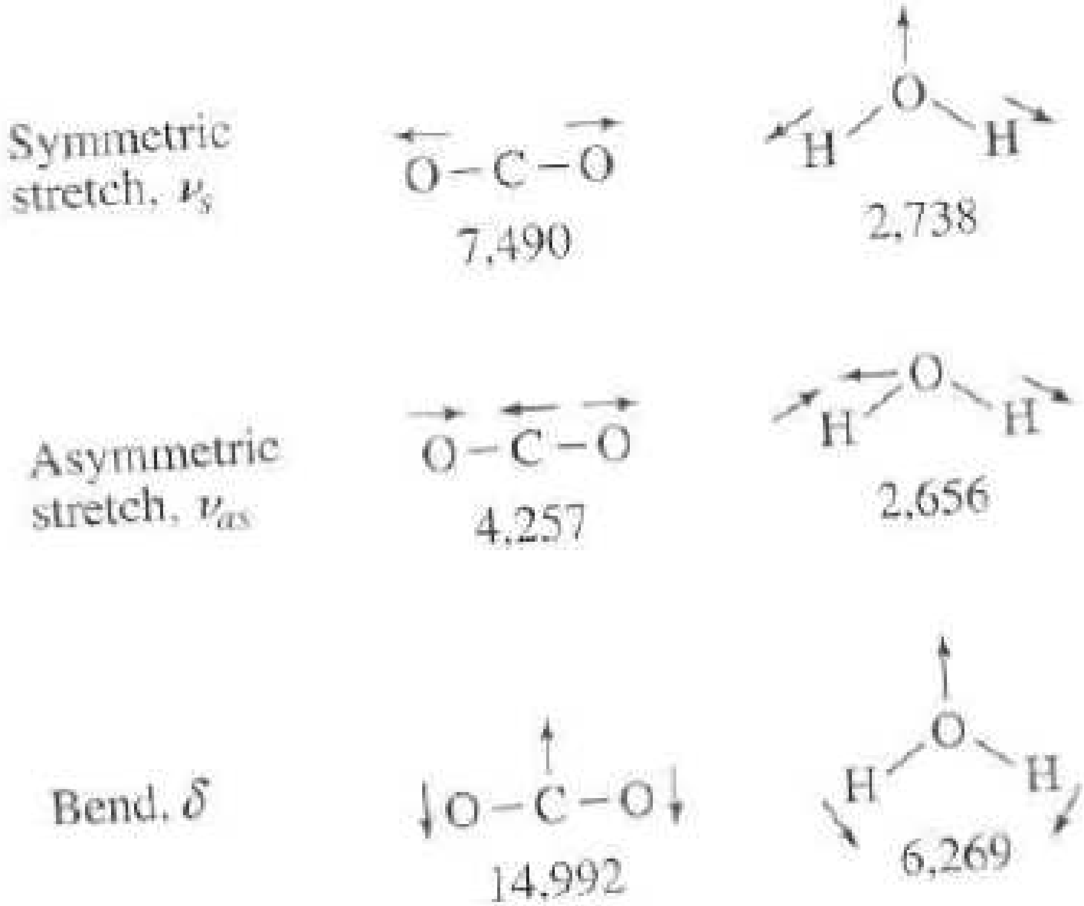
However - The amount of key gases has risen dramatically since the Industrial revolution.



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



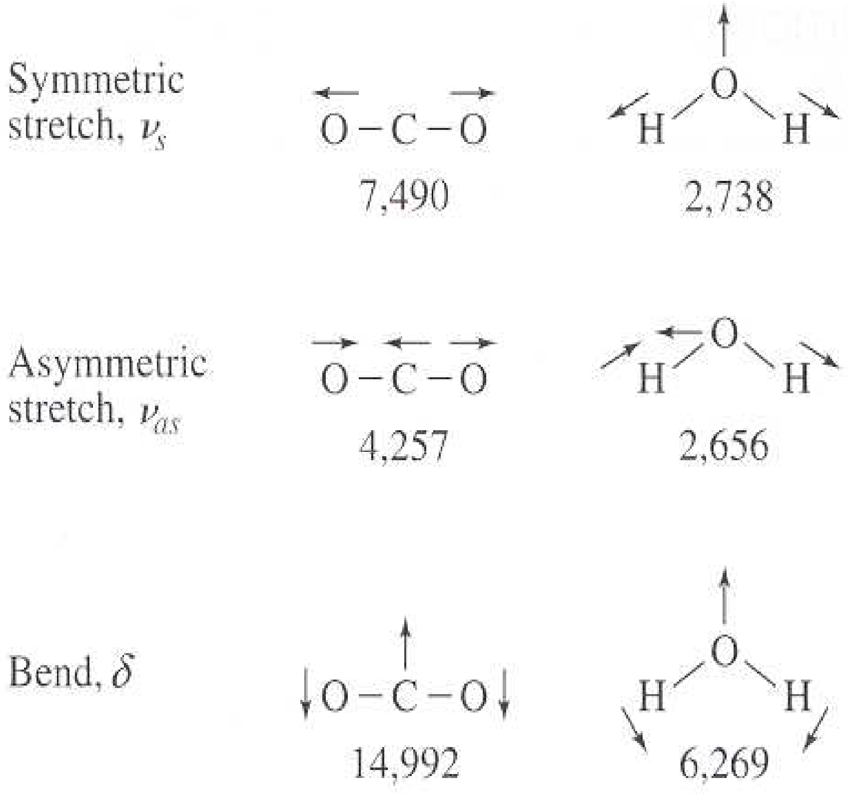


Figure 6.12 Molecular vibrations of CO_2 and H_2O in units of wavelengths (nm).

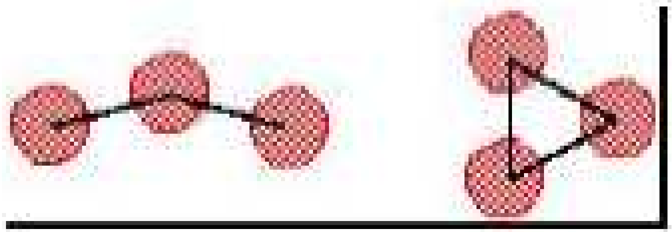
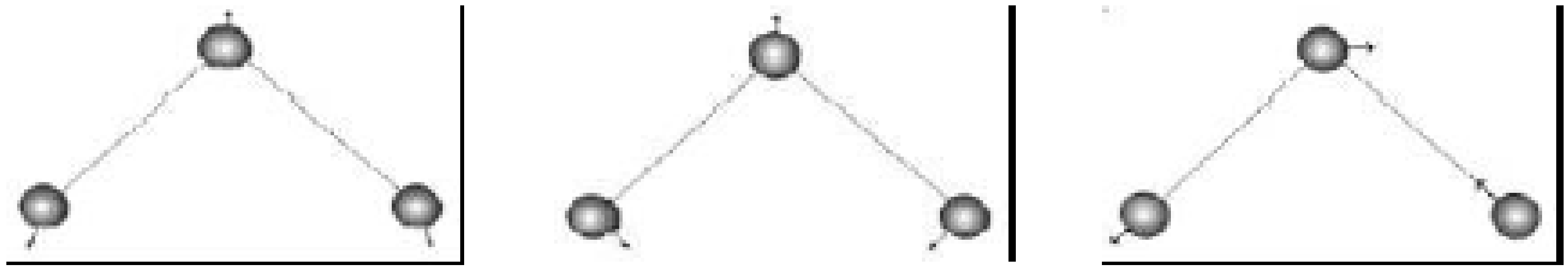


Figure 1. Two forms of possible ozone molecule.

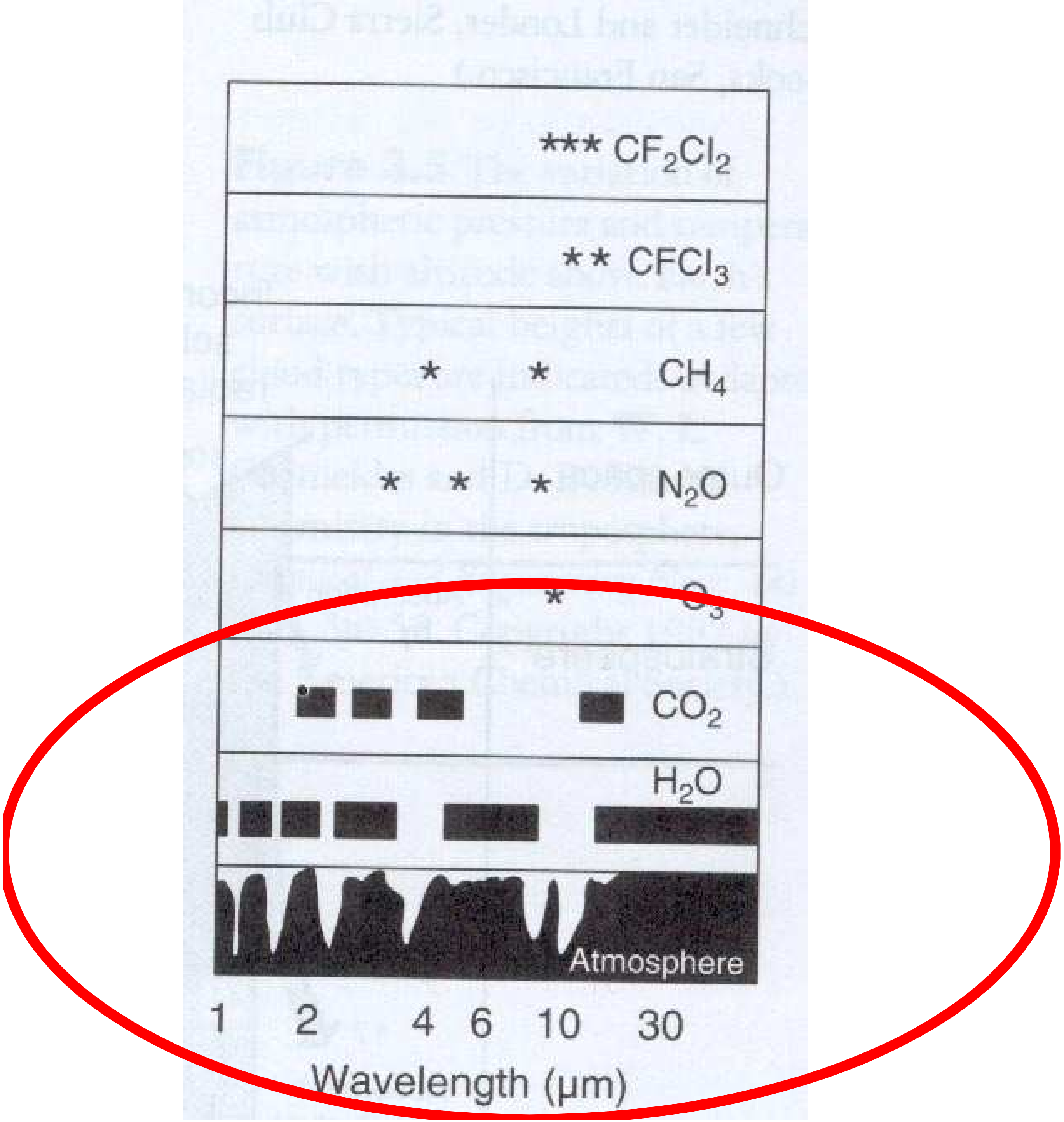
O_3

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].

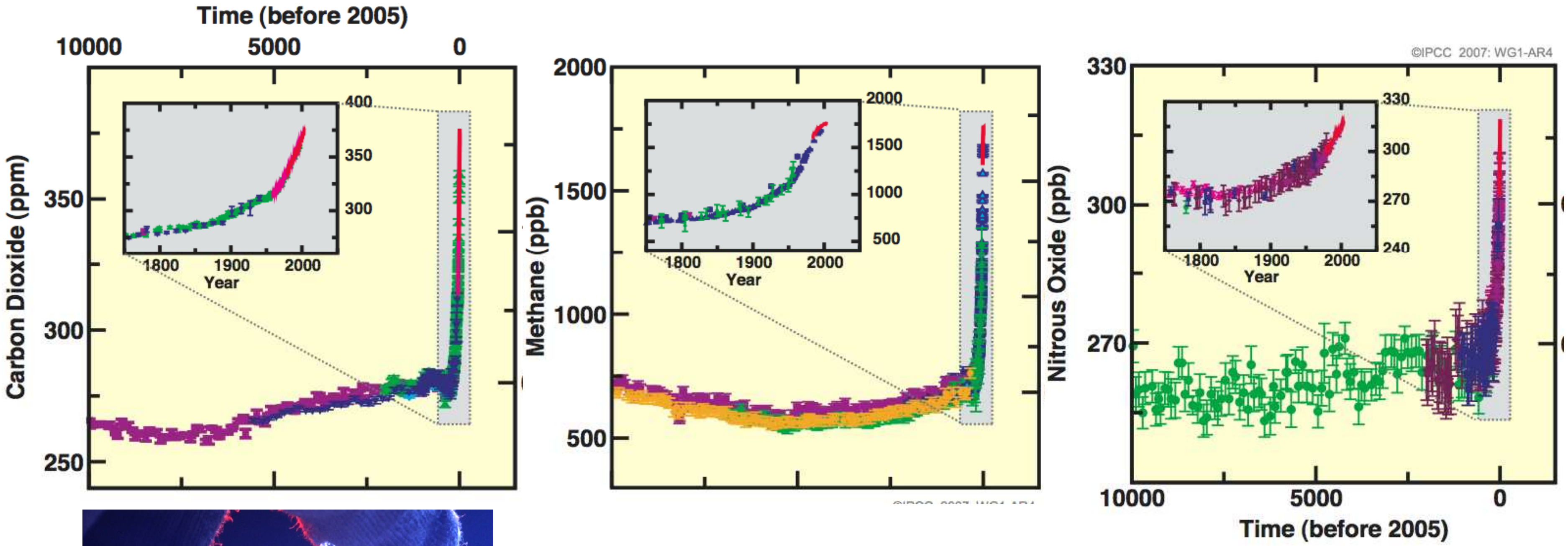


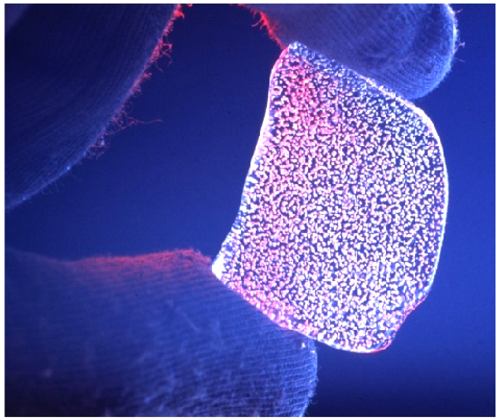
'Stretching' symmetric vibration q1 'Bending' vibration q2 'Stretching' asymmetric vibration q3

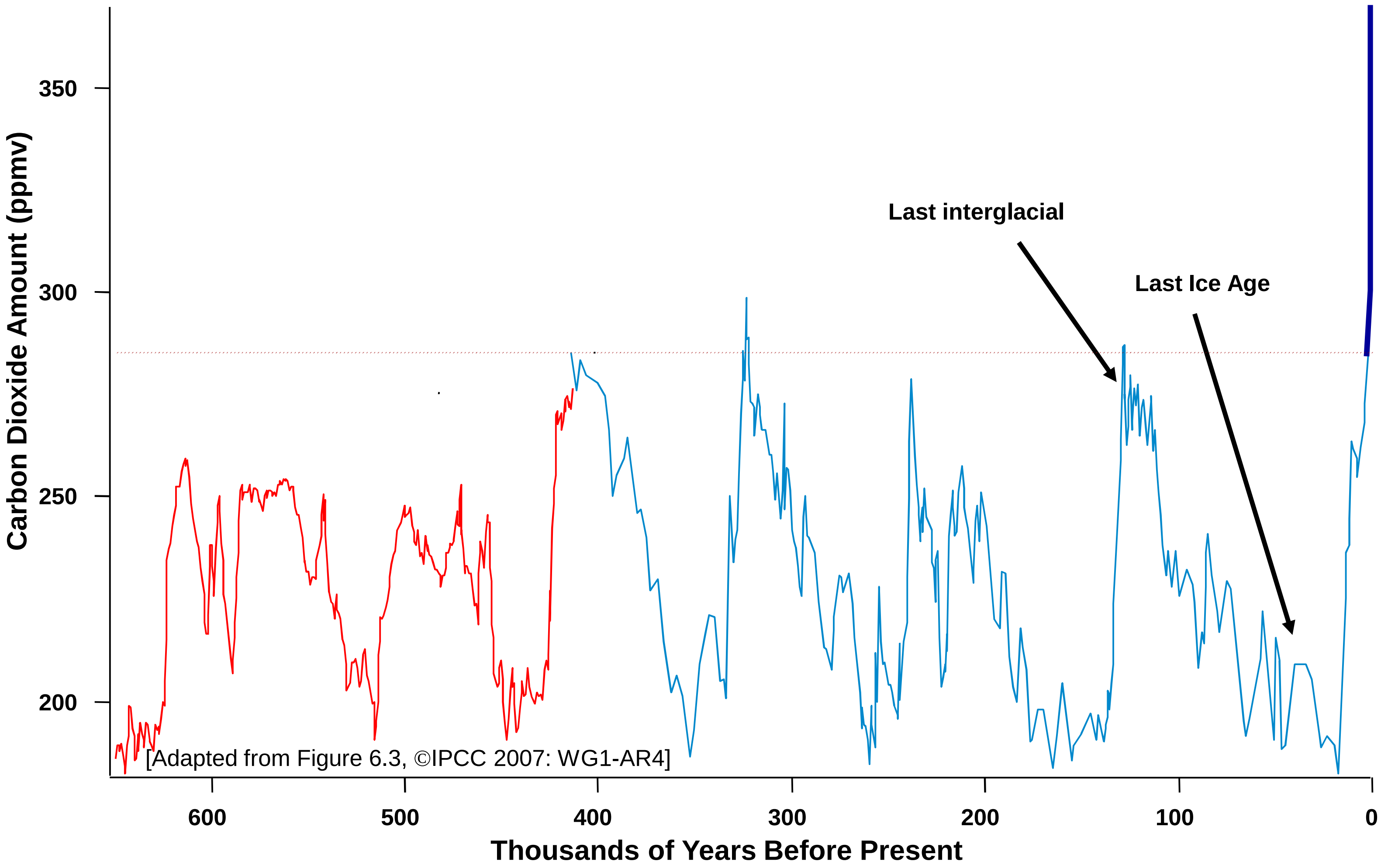

*** CF_2Cl_2
** $CFCl_3$
* * CH_4
* * * N_2O
* O_3
CO_2
H_2O
Atmosphere
1 2 4 6 10 30
Wavelength (μm)

Industrial revolution and the atmosphere

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





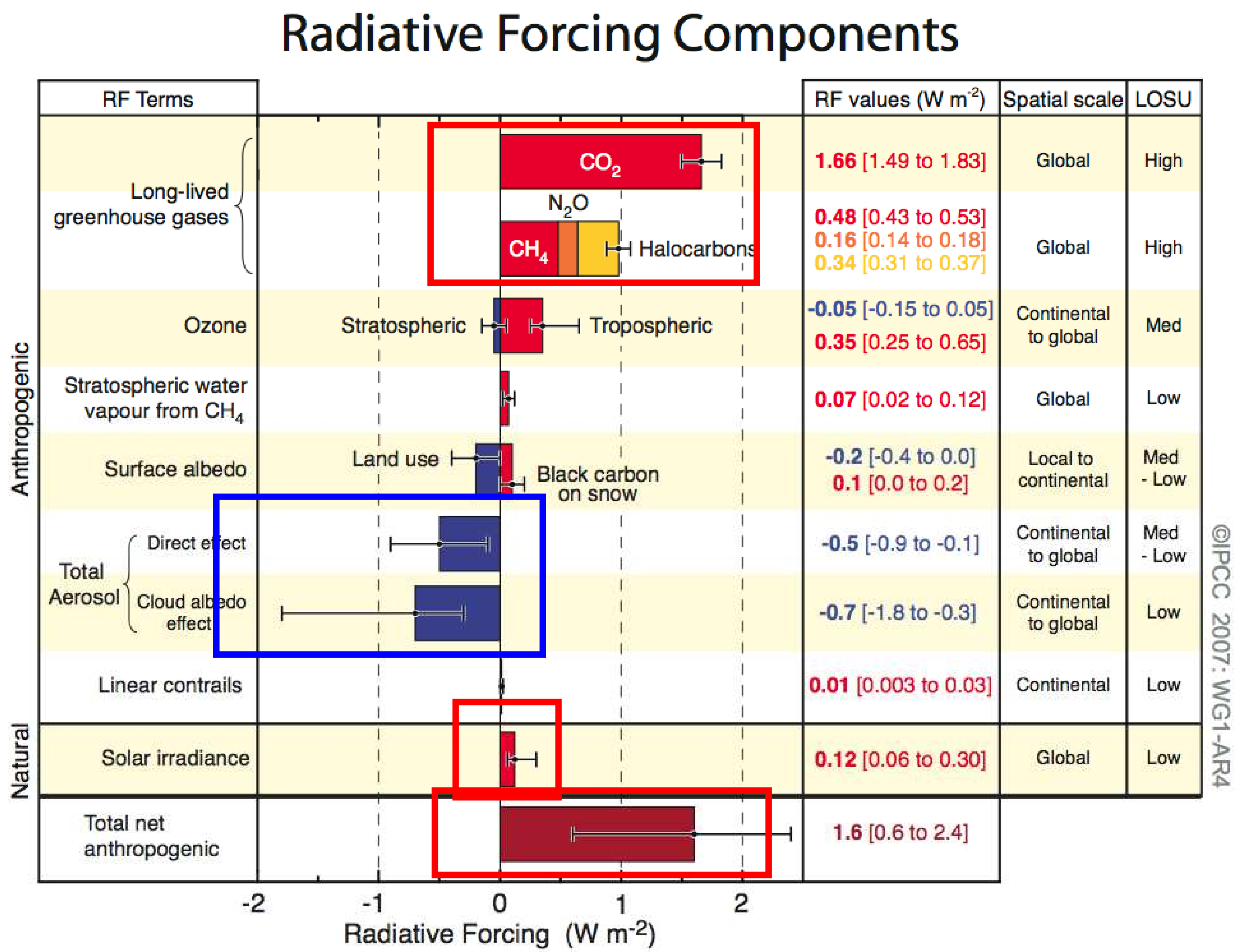


Ice ages are not random. They are 'forced' (by earth's orbital clock…. changes in the sunlight received).

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

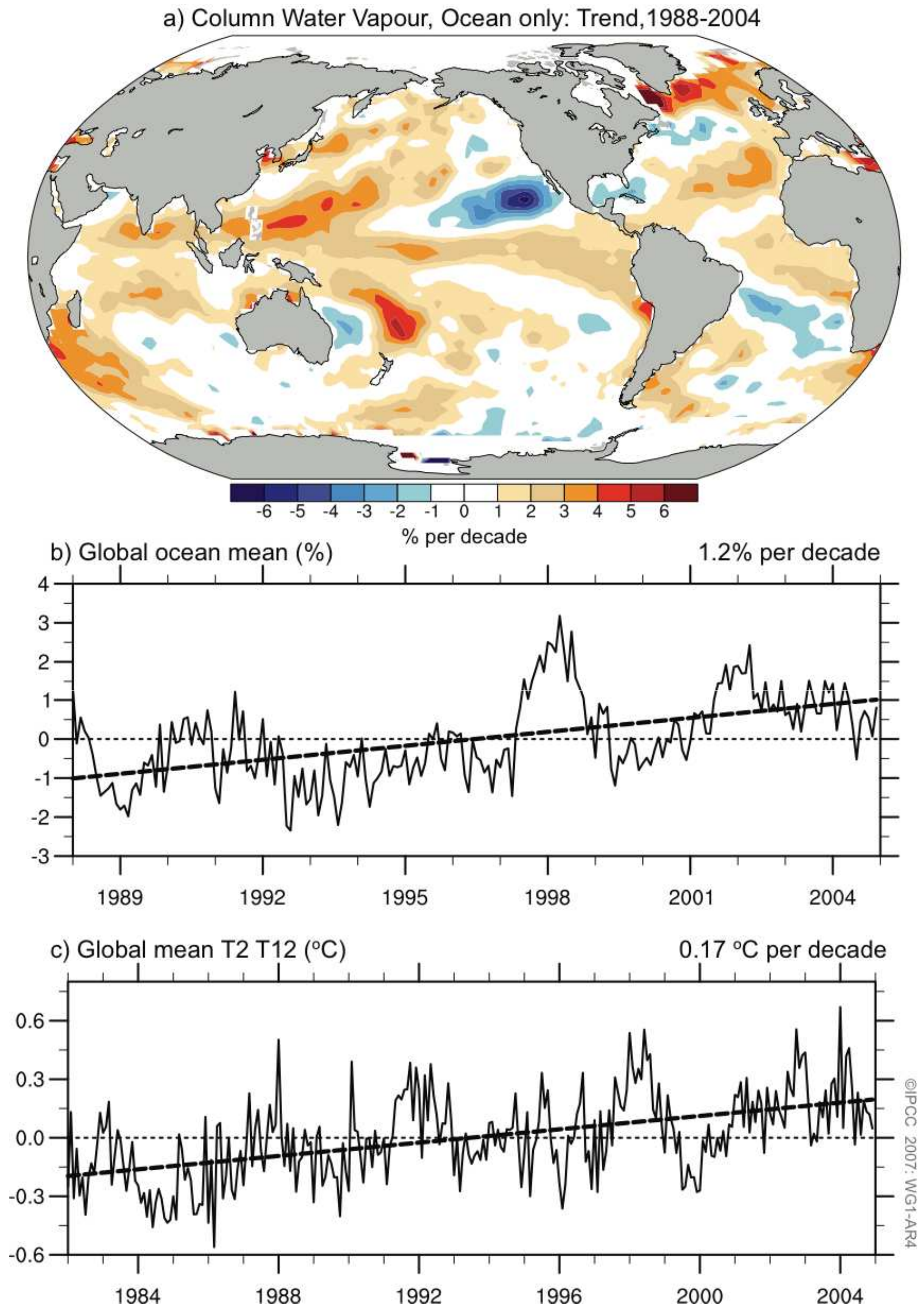


Water Vapor Feedback

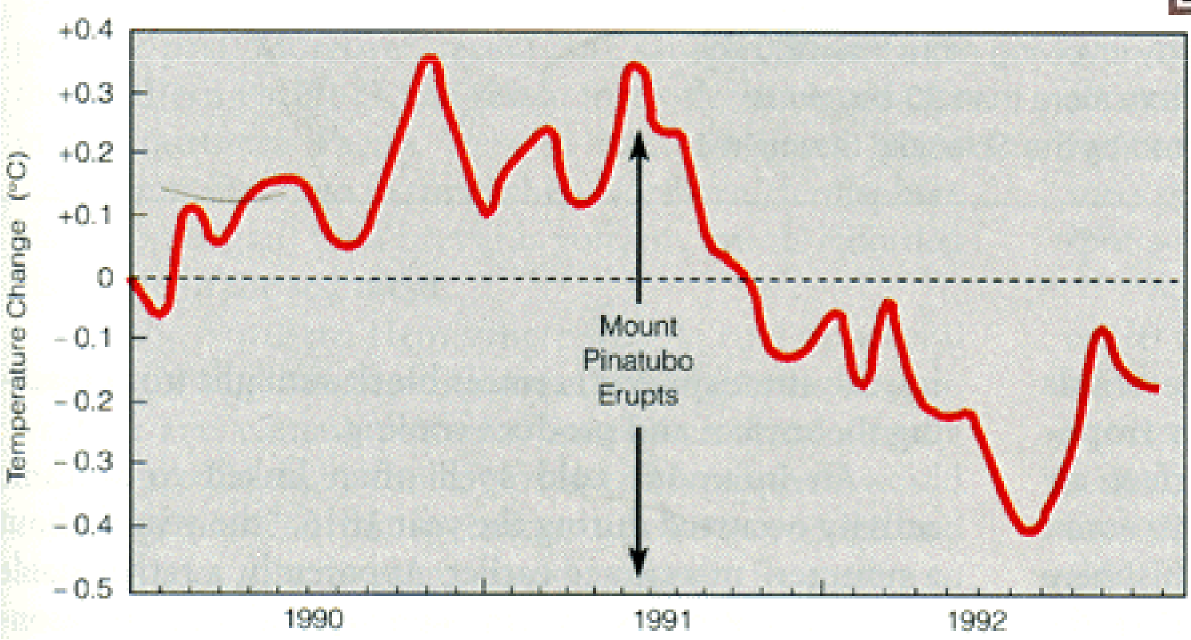
Water vapor responds to changes in climate, but it doesn't drive changes in climate. It's a major feedback that amplifies global climate change (by about 50%)……

New in IPCC (2007):

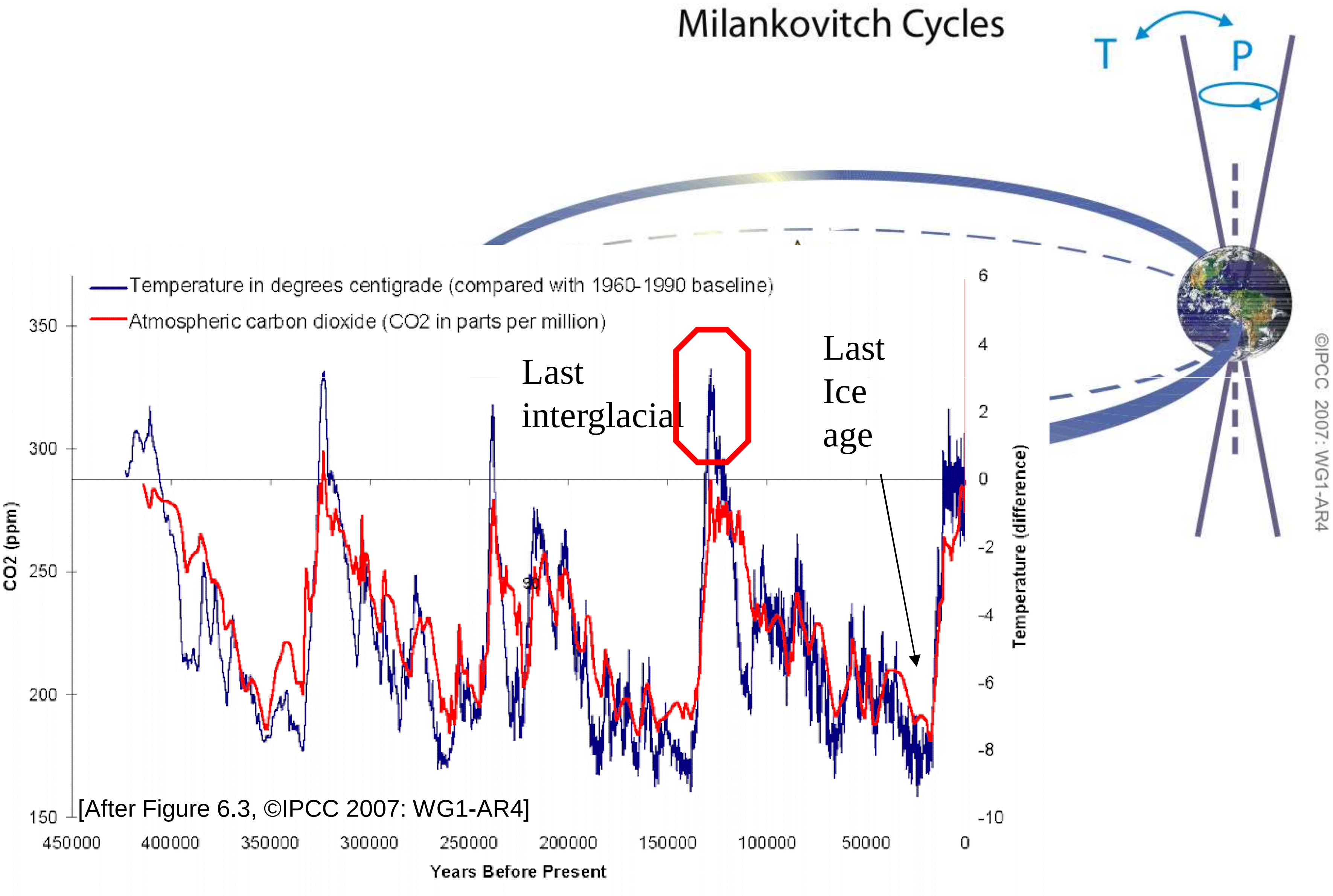
Observed trends that



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



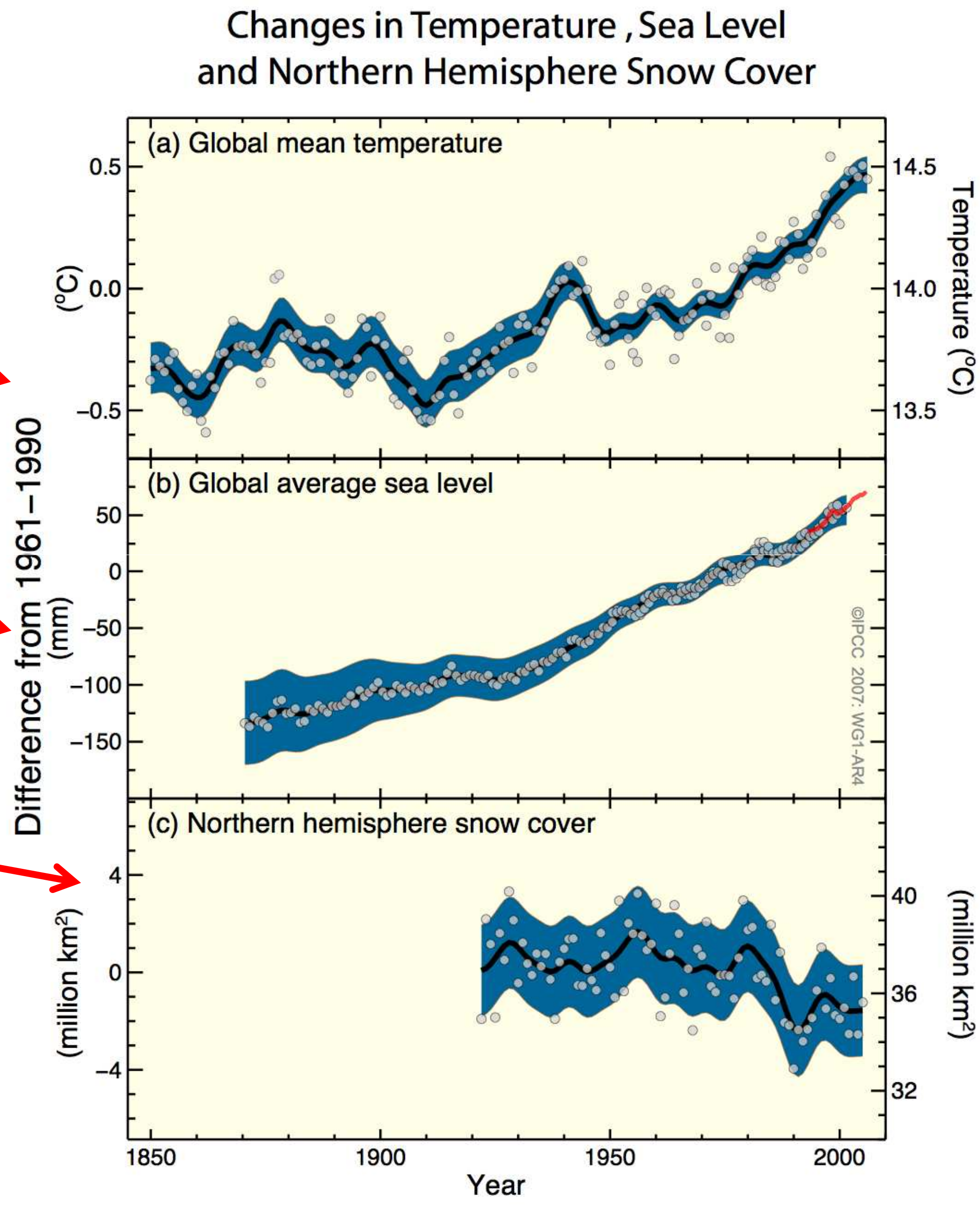
Ice Age Forcing and Response



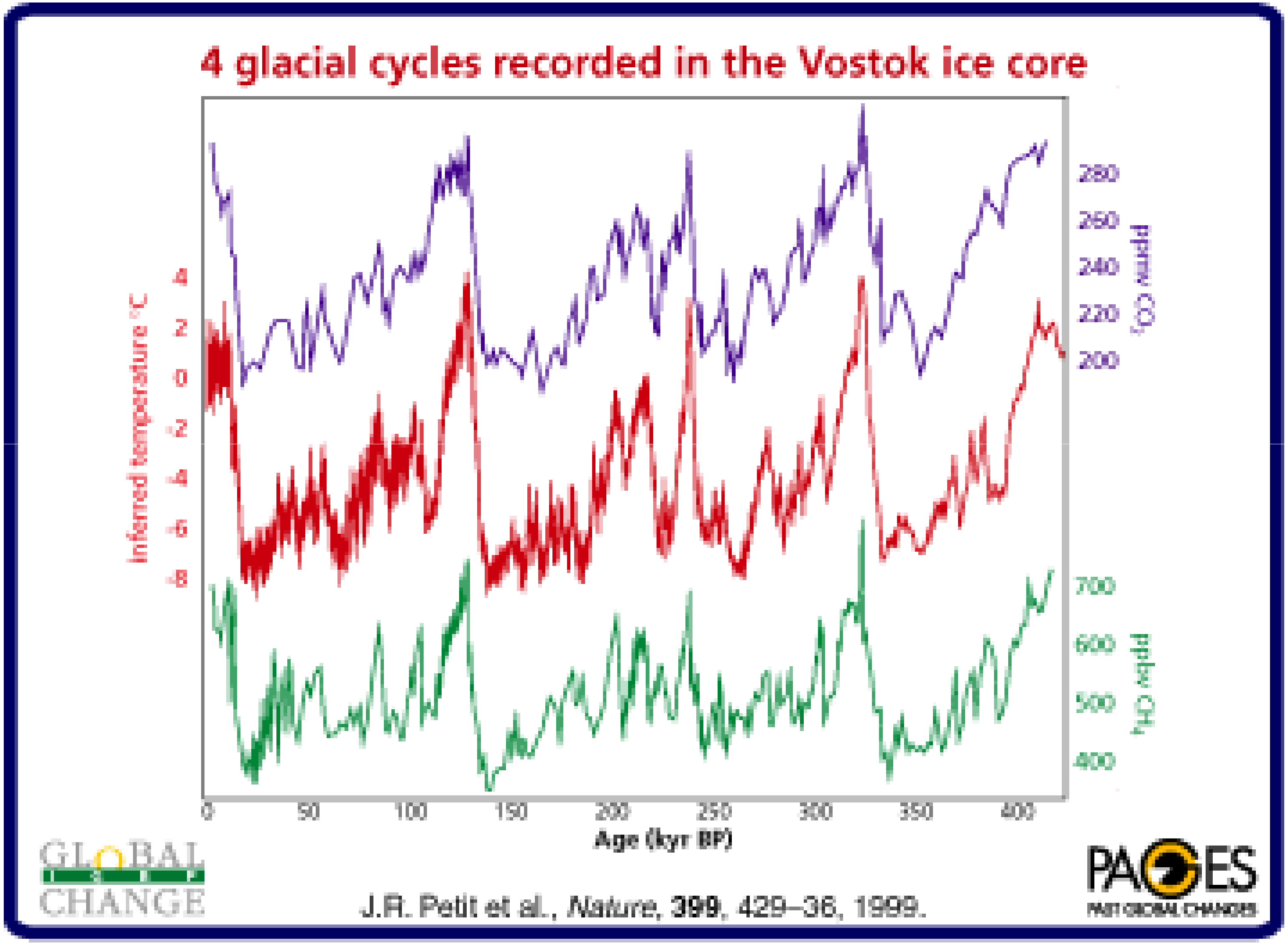
Warming is Unequivocal

Rising atmospheric

temperature



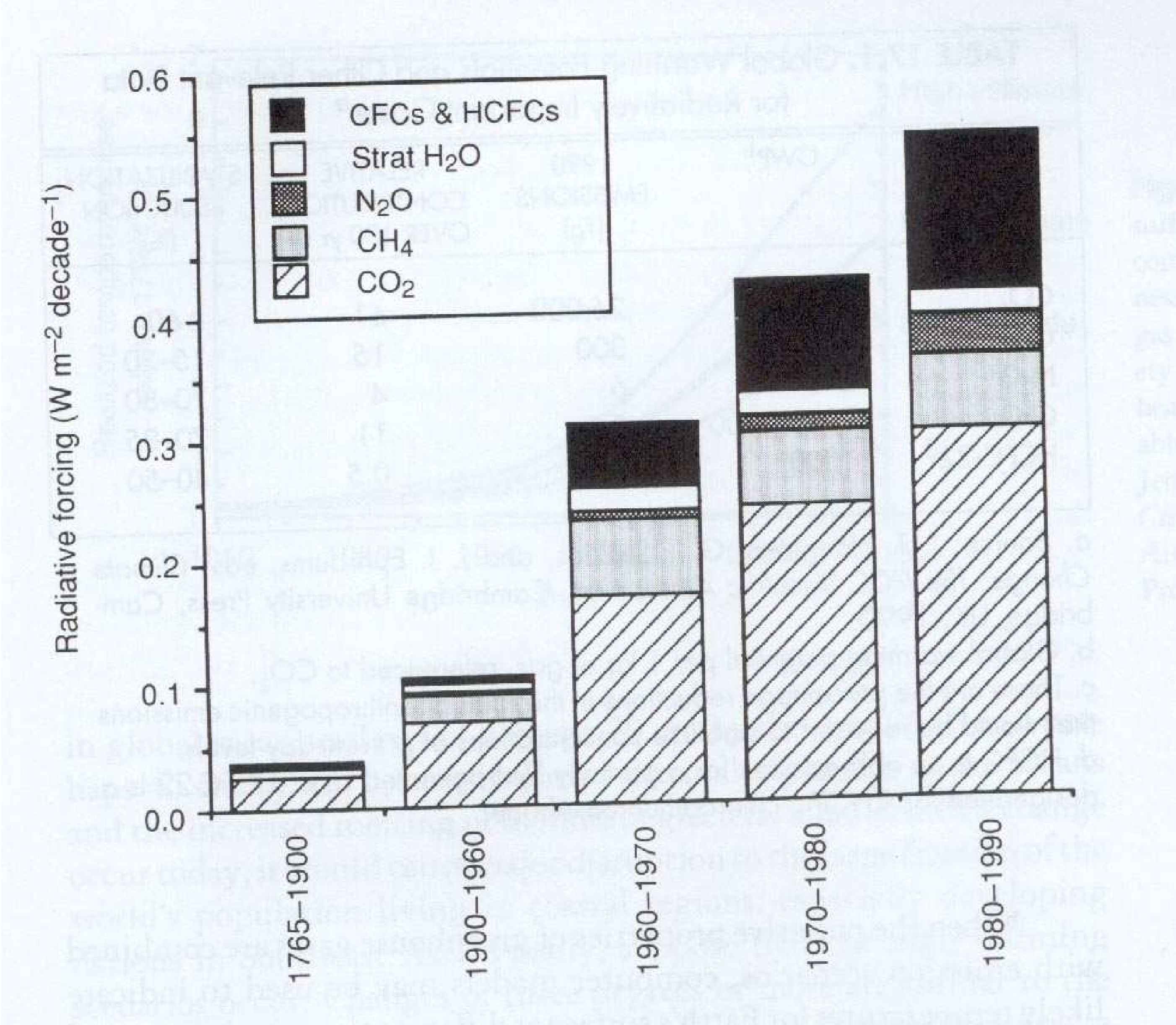
Vostoc 4 glacials



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%

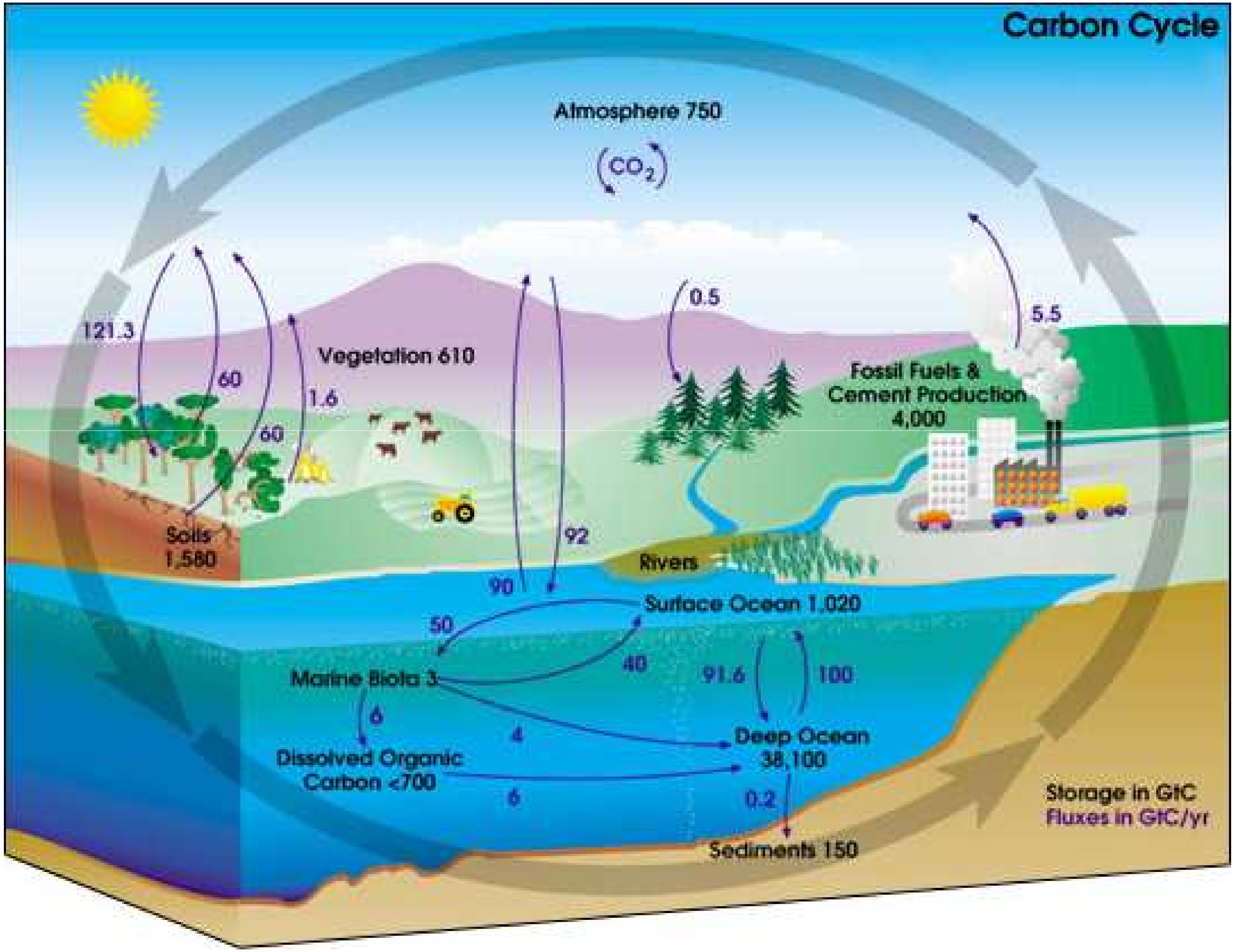
Contribution of each GHG is not equal :

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

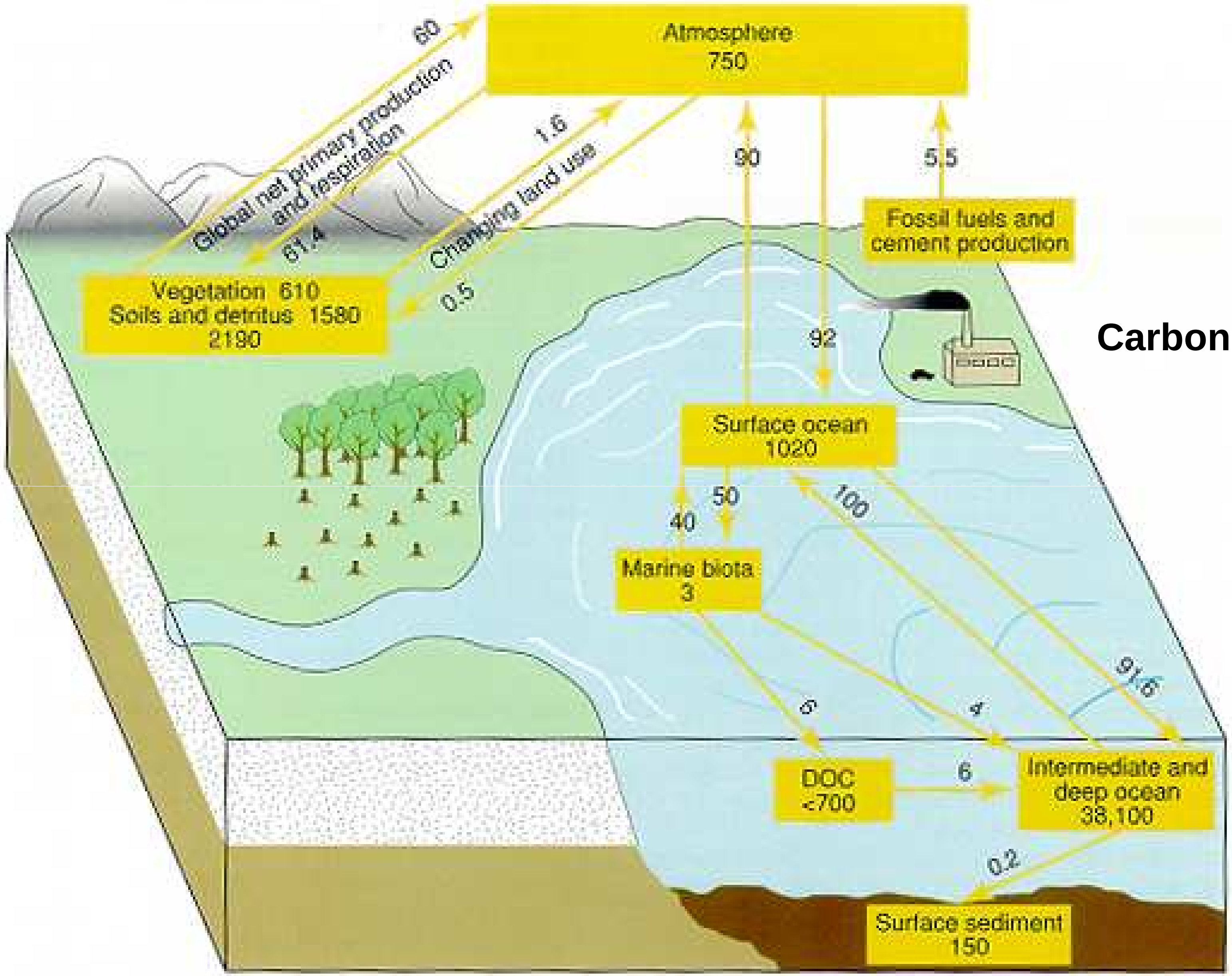
$$CH_4, N_2O = f(\sqrt{C}\ )$$

$$CFCs = k.c.$$

Carbon cycle



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

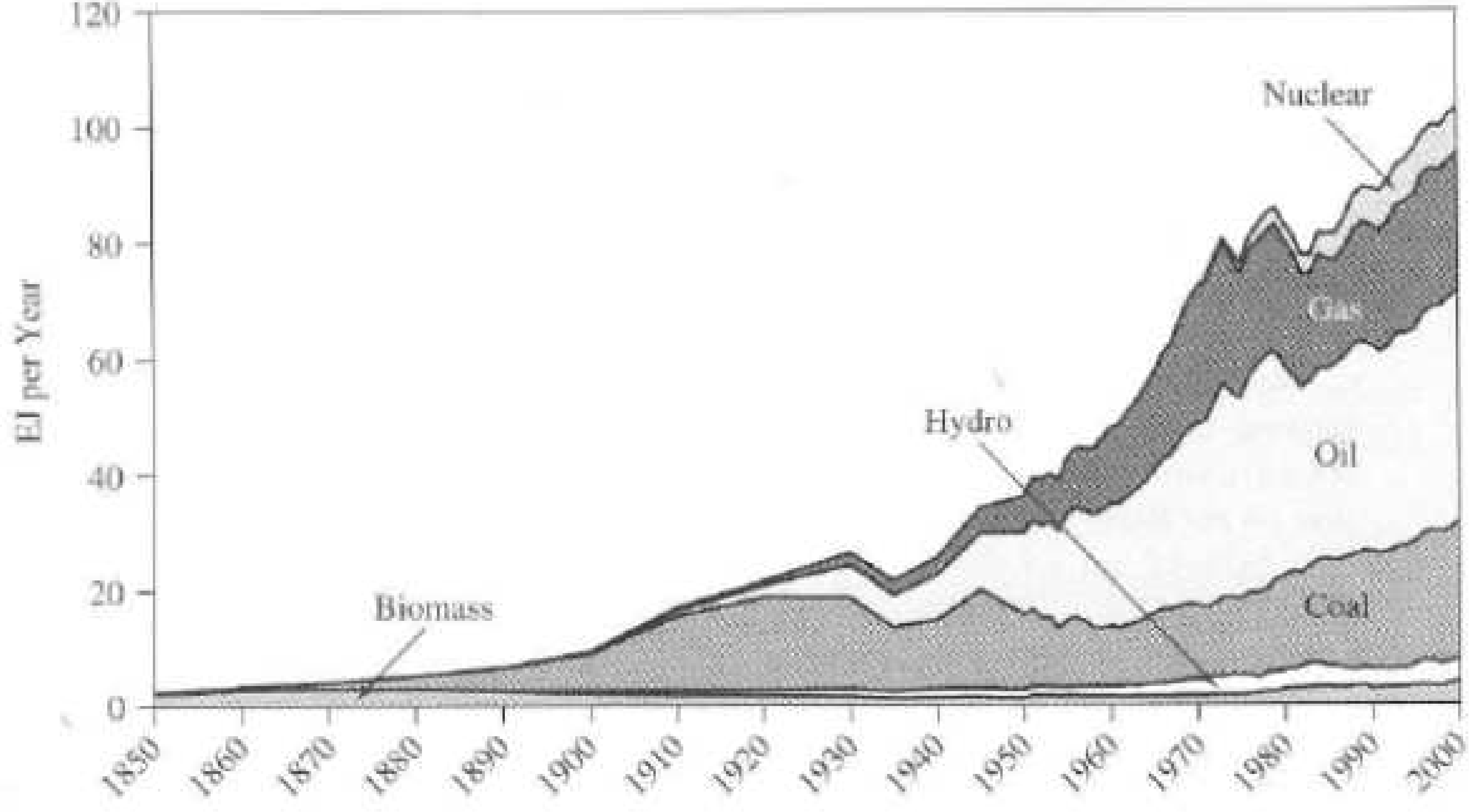
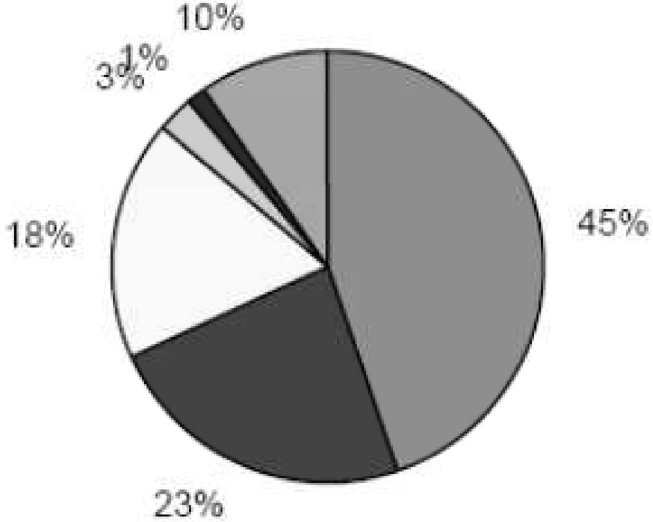


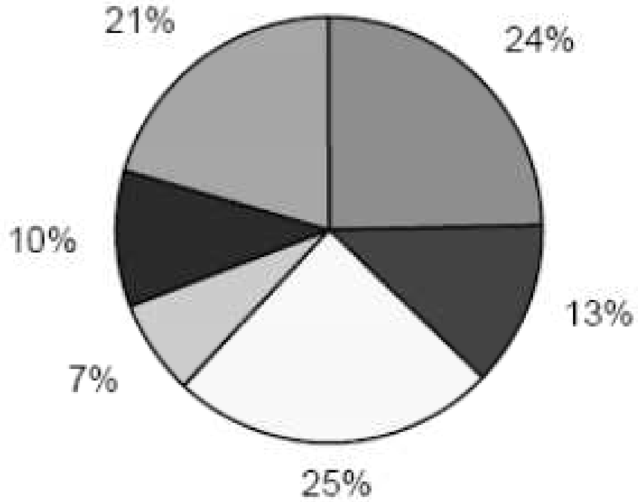
Figure 1.5 Historical trends in U.S. energy consumption, 1850–2000. *Source:* Energy Information Agency, U.S. Department of Energy, *Annual Energy Outlook 2000*, energy consumption by source, Washington, DC.

CO_2 Emissions

1950 (1,6 Gt)

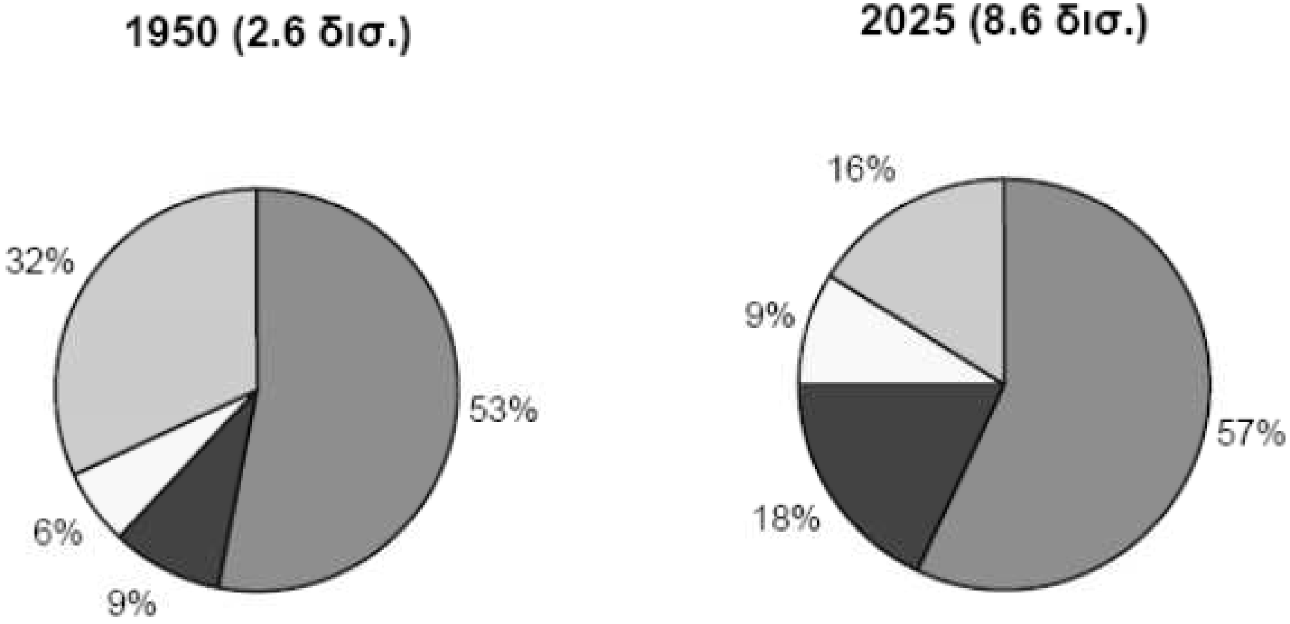


1987 (6,1 Gt)



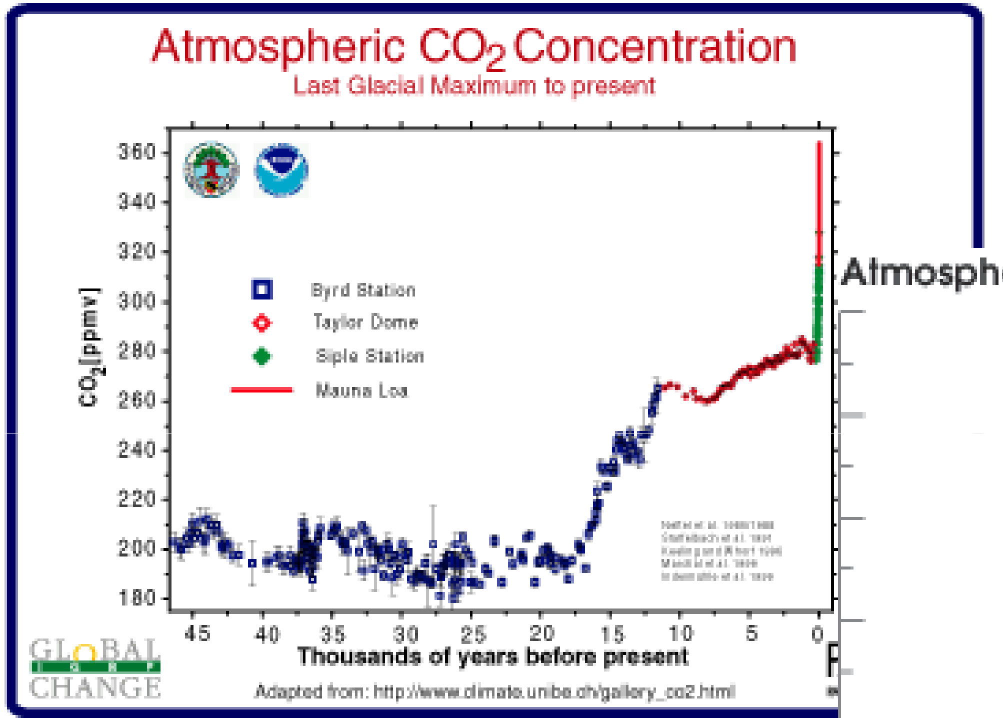
	1950	1987
Β. ΑΜΕΡΙΚΗ	44,7%	24,8%
Δ. ΕΥΡΩΠΗ	23,4%	12,5%
Α. ΕΥΡΩΠΗ	18%	24,7%
ΙΑΠΩΝΙΑ + ΑΥΣΤΡΑΛΙΑ	2,8%	7,2%
ΚΙΝΑ	1,4%	10,3%
ΧΩΡΕΣ ΥΠΟ ΑΝΑΠΤΥΞΗ	9,7%	20,5%

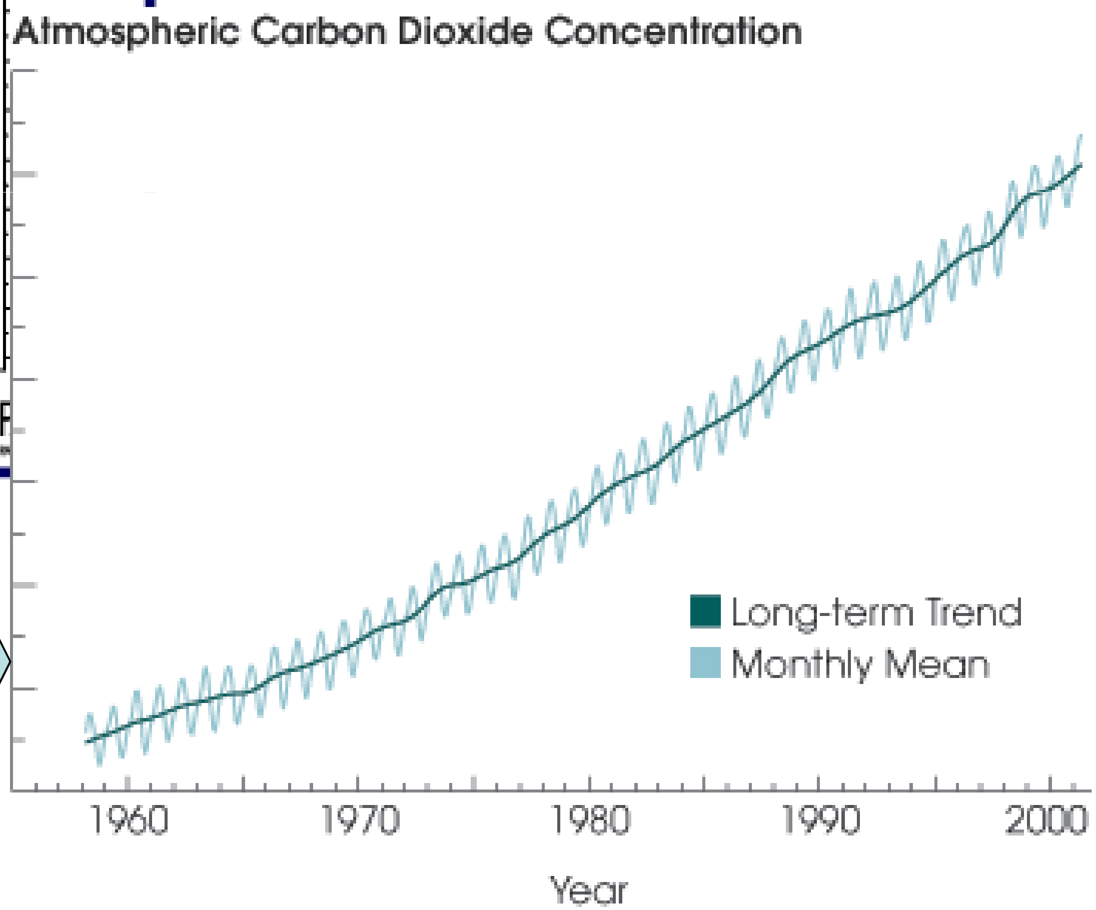
Κατανομή του πληθυσμού της γης



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

Atmospheric CO_2 trends





Seasonal variability

Carbon dioxide is exchanged between atmosphere, oceans and terrestrial Biosphere and in geological time scales between sediments and rocks

- CO_2 exchange between atmosphere/oceans

- CO_2 exchange between surface waters and long term storage in the deep ocean

- CO_2 emissions or sinks from land-use change

- Plant photosynthesis and CO_2 transport to soil

Sources and sinks of atmospheric CO_2 in GTC/yr (IPCC 94)

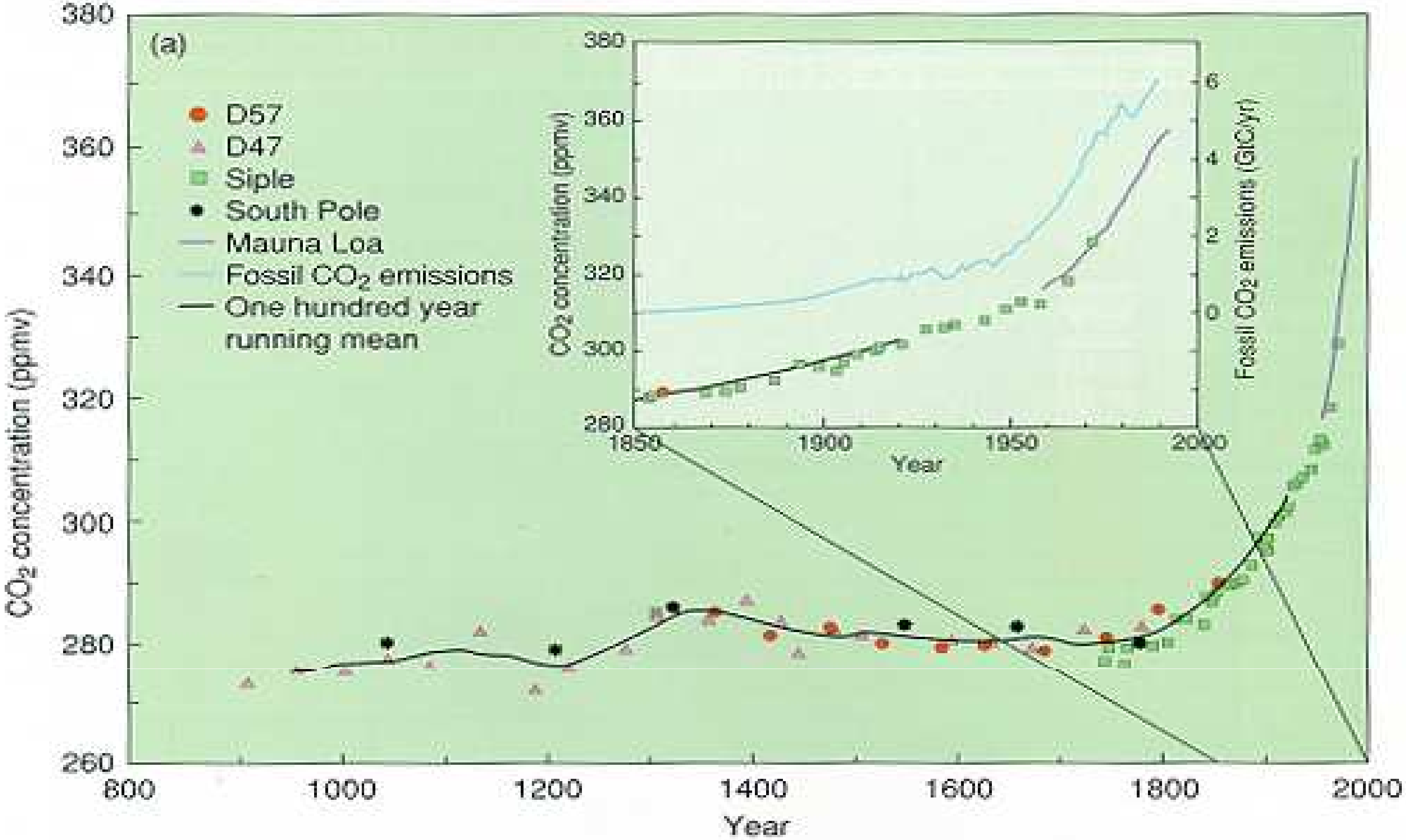
Sources CO_2

Fossil fuel and cement production :	5.5 (0.5)
Land use change in tropical areas :	1.6 (1.0)
Total human driven sources:	7.1 (1.5)

Carbon storage

Atmosphere (Increase in CO2 levels) :	3.2 (0.2)
Oceanic storage:	2.0 (0.8)
Lange change use (Northern-hemisphere) :	0.5 (0.5)
Total storage	5.7 (1.5)

Deficit in budget: **Land based/continental sinks**	1.4 (1.5)



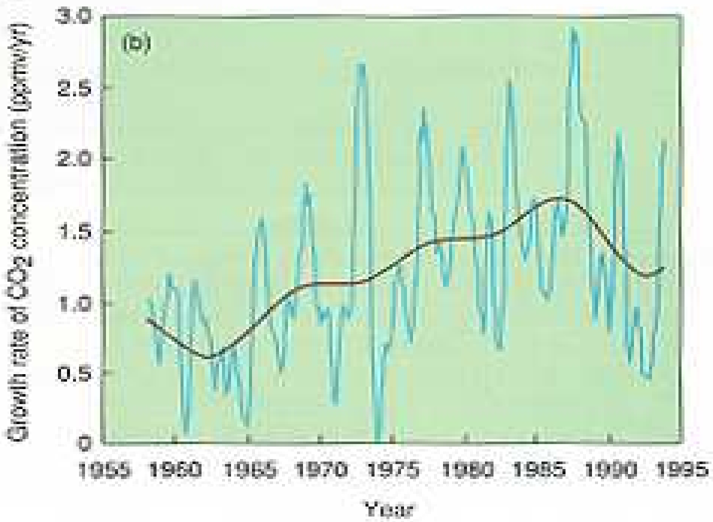


Figure 2. *(a) CO_2 concentrations over the past 1000 years from ice-core records (D47, D57, Siple and South Pole) and (since 1958) from the Mauna Loa, Hawaii measurement site. The smooth curve is based on a hundred year running mean. The rapid increase in CO_2 concentration since the onset of industrialisation is evident and has followed closely the increase in CO_2 emissions from fossil fuels (see inset of period from 1850 onwards). (b) Growth rate of CO_2 concentration since 1958 in ppmv/yr at the Mauna Loa station showing the high growth rates of the late 1980s, the decrease in growth rates of the early 1990s, and the recent increase. The smooth curve shows the same data but filtered to suppress any variations on time-scales less than approximately 10 years.*

CO_2 fertilisation : Increase of CO_2 in the atmosphere ($2CO_2$) result in +20-40% increase of photosynthesis

Nitrogen fertilization: Increase in N application results in increase of C storage

Climatic effects: photosynthesis and respiration can be influenced by natural climate variability

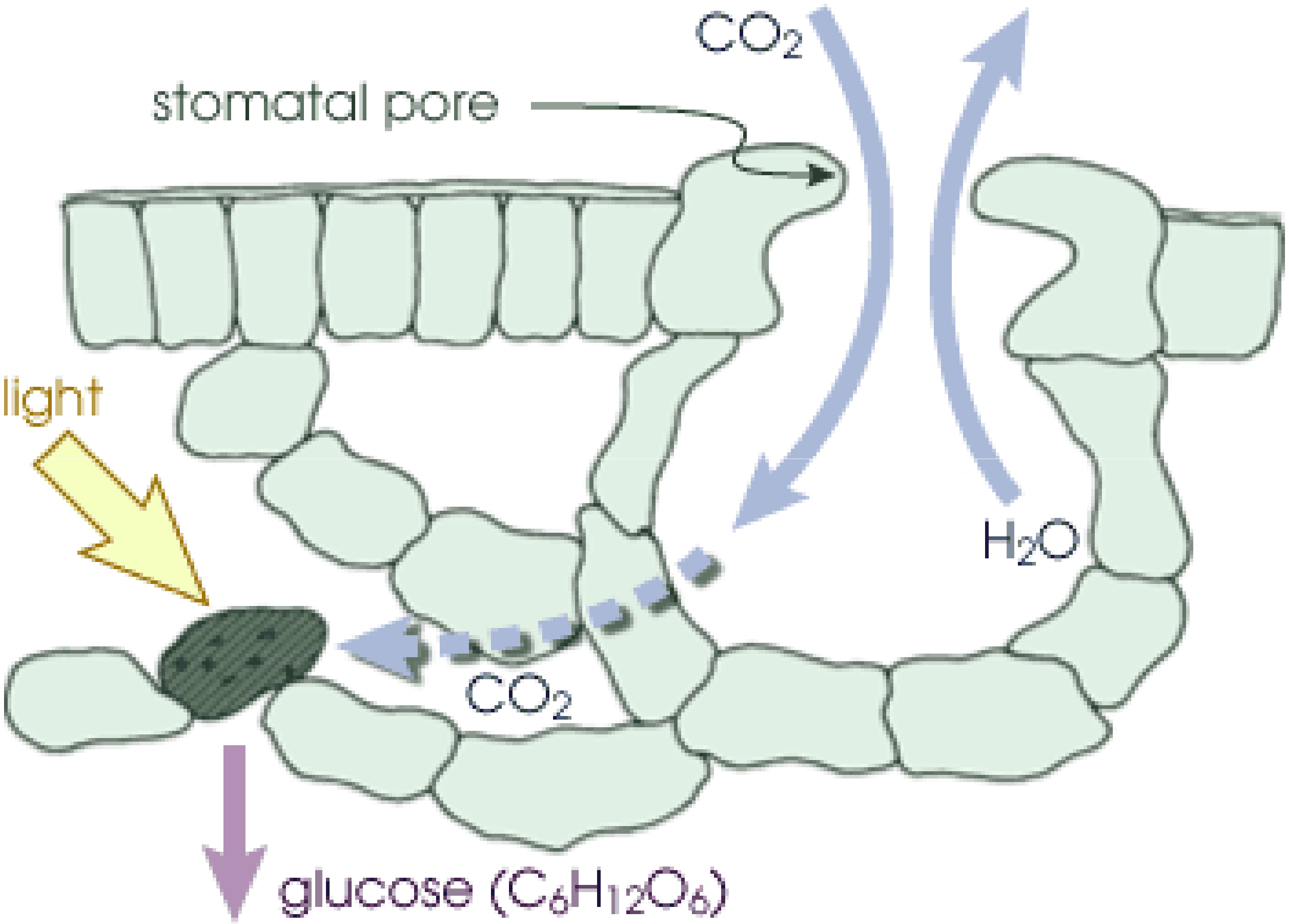
Atmospheric CO_2 variability depends on:

- Human activities
- Biogeochemical cycles
- Climatic effects
- Feedbacks of C cycle

CO2 regulation (temporary scale)

- Oceans (1000 yr)
  - Oceans capacity is limited and depend on cations availability from rocks erosion
  - Rate of anthropogenic CO_2 emissions is much higher compared to cations availability, thus saturation of oceans in CO_2 absorption is expected.
- Plants (9 yr)

photosynthesis



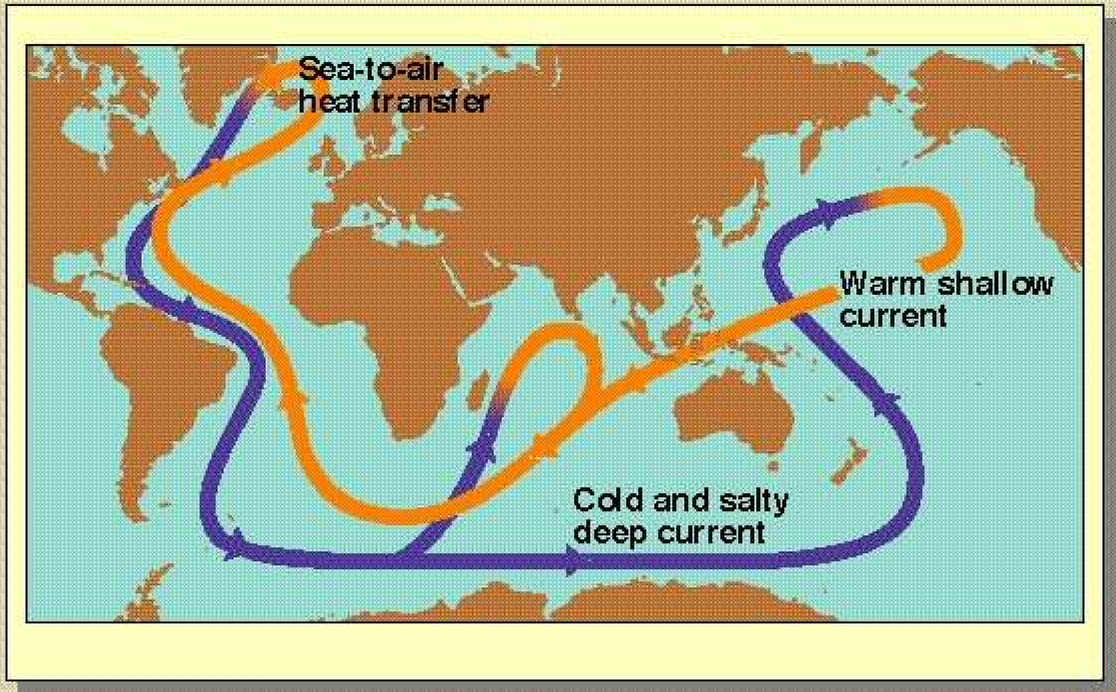
Factors controlling C level in seawater :

✓ Αντλία διαλυτότητας (solubility pump)

✓ Βιολογική αντλίας (biological pump)

- **Solubility pump: CO_2 more soluble in cold/saline waters**
- Increase in atmospheric CO_2 results in global warming ➔ water column stratification ➔ decrease of CO_2 transport to deep waters
- **Biological pump: Photosynthesis of phytoplankton** ➔ ➔ 150-200 ppmv lower atmospheric CO_2

The Oceanic "Conveyor Belt"



Carbonate chemistry in the ocean

Average Ocean pH:

(1) The surface ocean is saturated with respect to $CaCO_3$;
(2) Observed seawater Ca^{2+} concentration is 0.01 M;
(3) The present-day atmospheric CO_2 concentration is 365 ppmv.
Relevant chemical equilibria:

$$CO_2(g) \Leftrightarrow CO_2 \bullet H_2O \quad K_H = 3\times10^{-2}\,M\ atm^{-1}$$

$$CO_2 \bullet H_2O \Leftrightarrow HCO_3^{-} + H^{+} \quad K_1 = 9\times10^{-7}\,M$$

$$HCO_3^{-} \Leftrightarrow CO_3^{2-} + H^{+} \quad K_2 = 7\times10^{-10}\,M$$

$$CaCO_3(s) \Leftrightarrow Ca^{2+} + CO_3^{2-} \quad K_s = 9\times10^{-7}\,M^2$$

→ Calculate the pH of the surface ocean.

Speciation of total dissolved CO_2 (aq) in water

$$CO_2(g) \Leftrightarrow CO_2 \bullet H_2O \quad K_H = 3\times10^{-2} M\ atm^{-1}$$

$$CO_2 \bullet H_2O \Leftrightarrow HCO_3^- + H^+ \quad K_1 = 9\times10^{-7} M$$

$$HCO_3^- \Leftrightarrow CO_3^{2-} + H^+ \quad K_2 = 7\times10^{-10} M$$

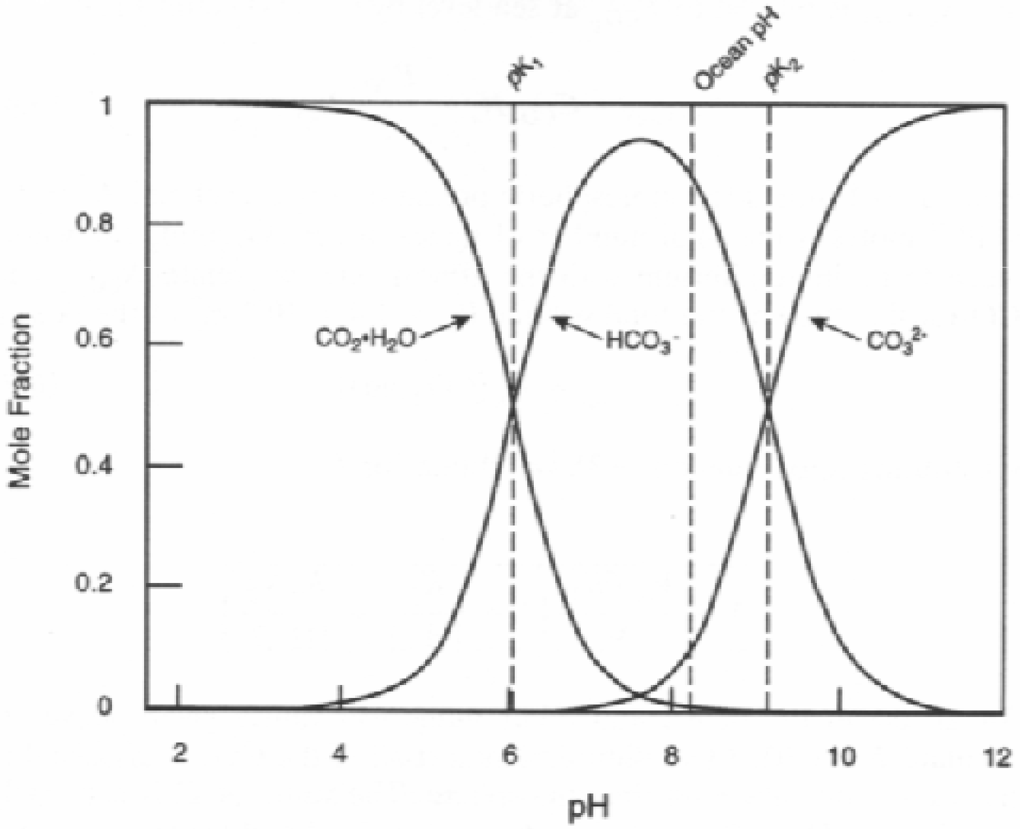


Fig. 6-7 Speciation of total carbonate CO_2(aq) in seawater versus pH.

Most of CO_2 dissolved in the ocean is in the form of bicarbonate (HCO_3^-).

Partitioning of CO_2 between atmosphere and ocean

$$F = \frac{N_{CO2(g)}}{N_{CO2(g)} + N_{CO2(aq)}}$$

$$N_{CO2}(g) = C_{CO2} N_a = \frac{P_{CO2}}{P} N_a$$

$$[CO_2(aq)] = [CO_2 \bullet H_2O] + [HCO_3^{\;-}] + [CO_3^{\;2-}]$$
$$= K_H P_{CO2} \left(1 + \frac{K_1}{[H^+]} + \frac{K_1 K_2}{[H^+]^2}\right)$$

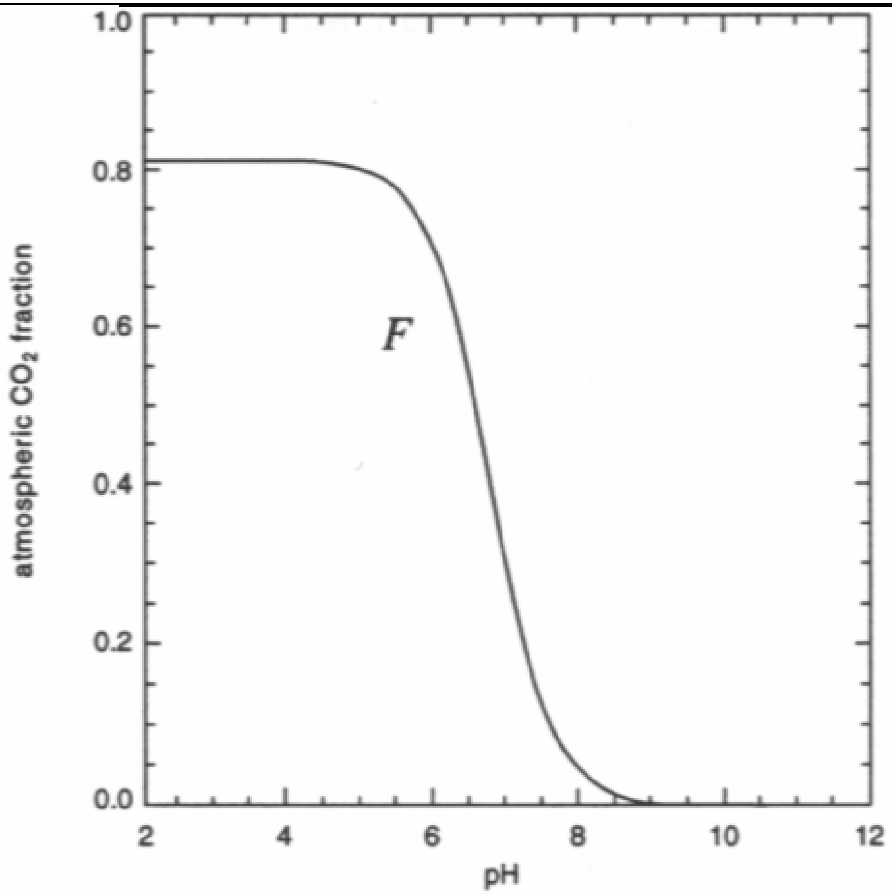


Fig. 6-8 pH dependence of the atmospheric fraction F of CO_2 at equilibrium in the atmosphere-ocean system (equation (6.8)).

For an ocean pH of 8.2, F=0.03.

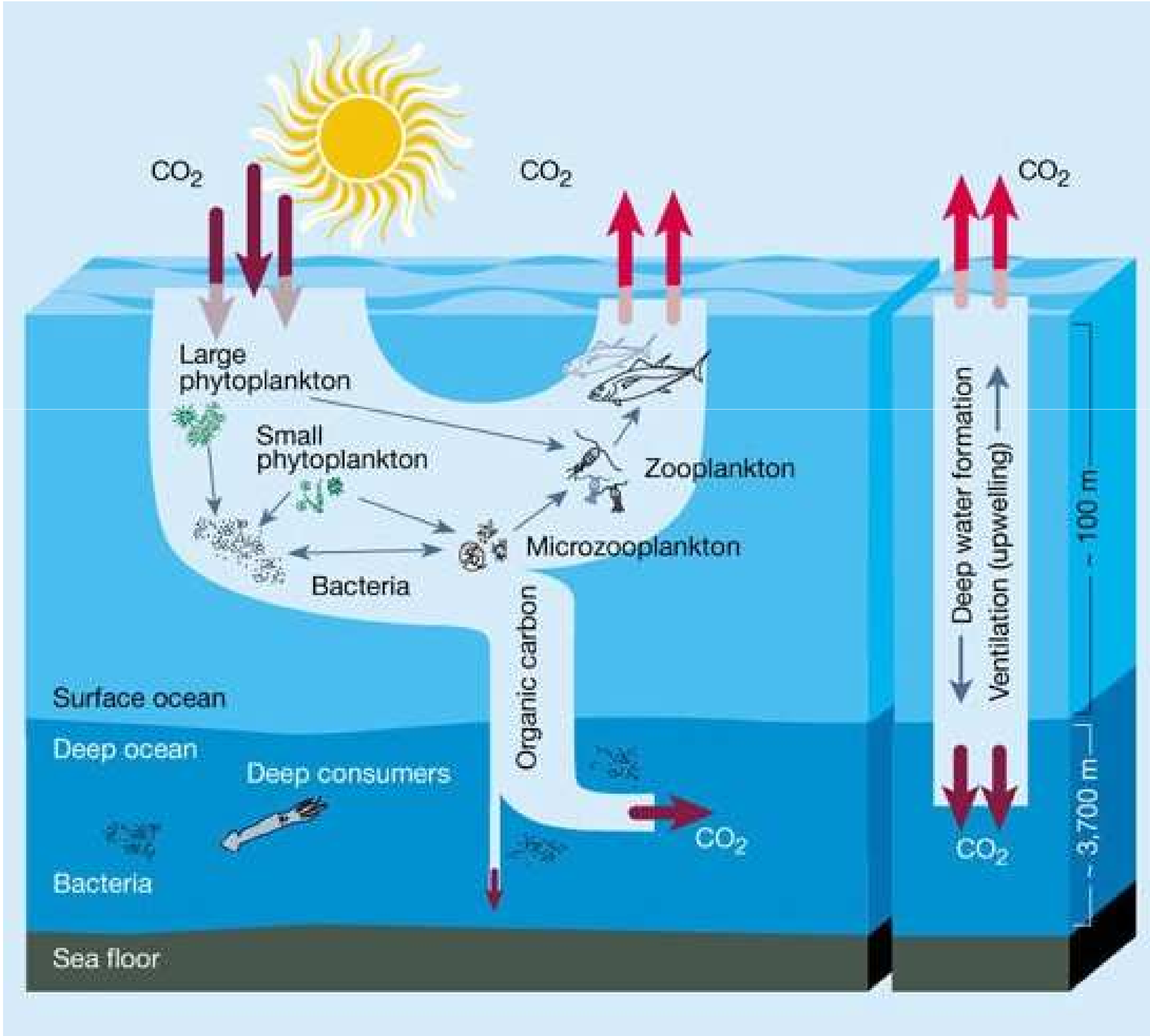
Almost all of the CO_2 is dissolved in the ocean; only 3% in the atmosphere.

F is sensitive to pH.

Uptake of CO_2 by the ocean: biological pump

- 90% → CO_2 (aq)
- 10% deposition via dead plankton

- Brings 7 PgC/yr towards the deep ocean compared to the 40 PgC/yr due to deep water formation



Uptake of CO_2 by the terrestrial biosphere

Processes in the cycling of CO_2 between the atmosphere and the biosphere:

- Photosynthesis
- Respiration
- Microbial decay

<u>Net primary productivity (NPP)</u>: the yearly average rate of photosynthesis minus the rate of respiration by all plants in an ecosystem.

NPP can be determined by:

- Long-term measurement of the CO_2 flux to the ecosystem from a tower.
- Monitoring the growth of vegetation in a selected plot.

NPP of an ecosystem depends on:

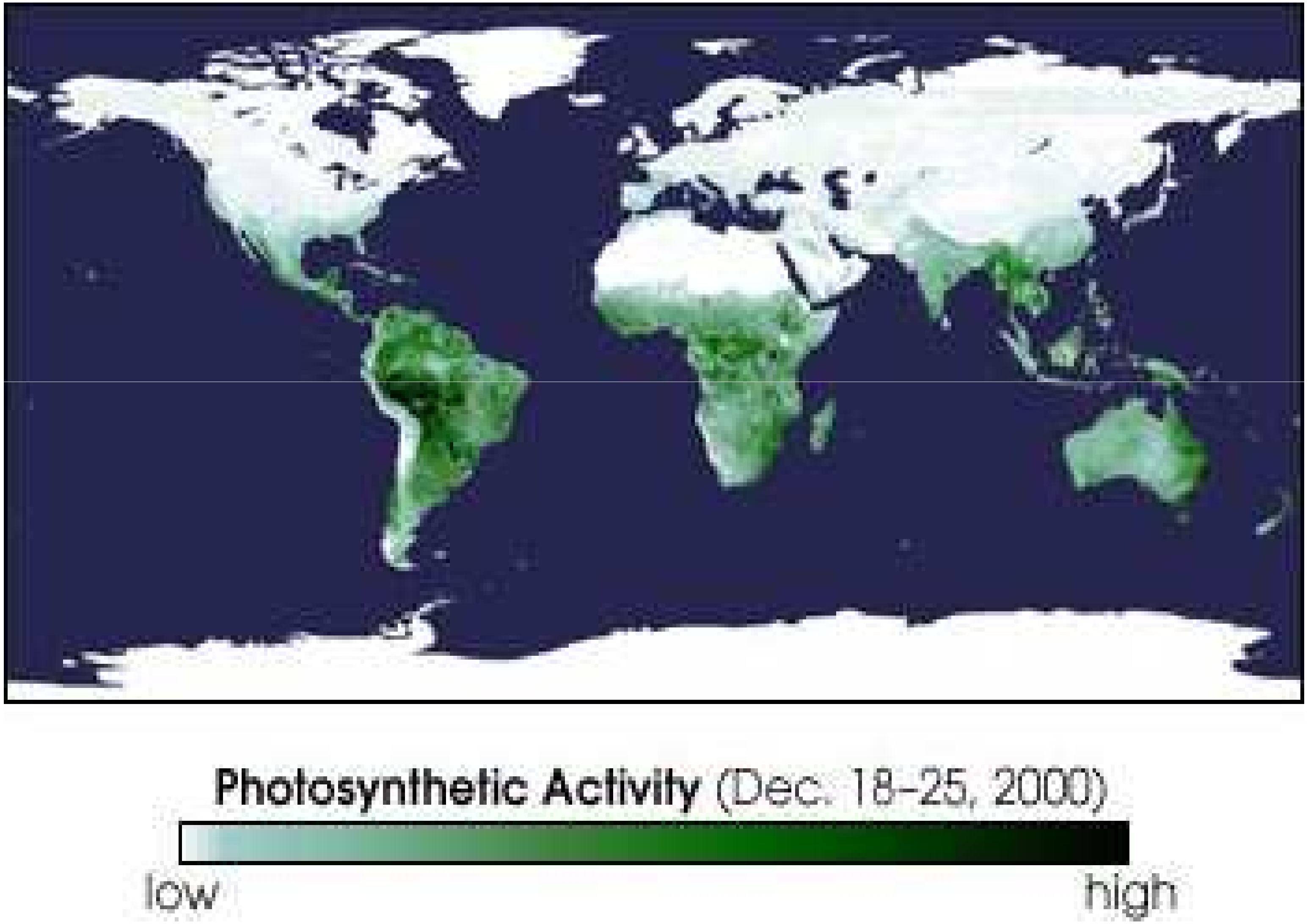
- Ecosystem type
- Solar radiation
- Temperature
- Water availability

The global terrestrial NPP is ~ 60 Pg C/yr.

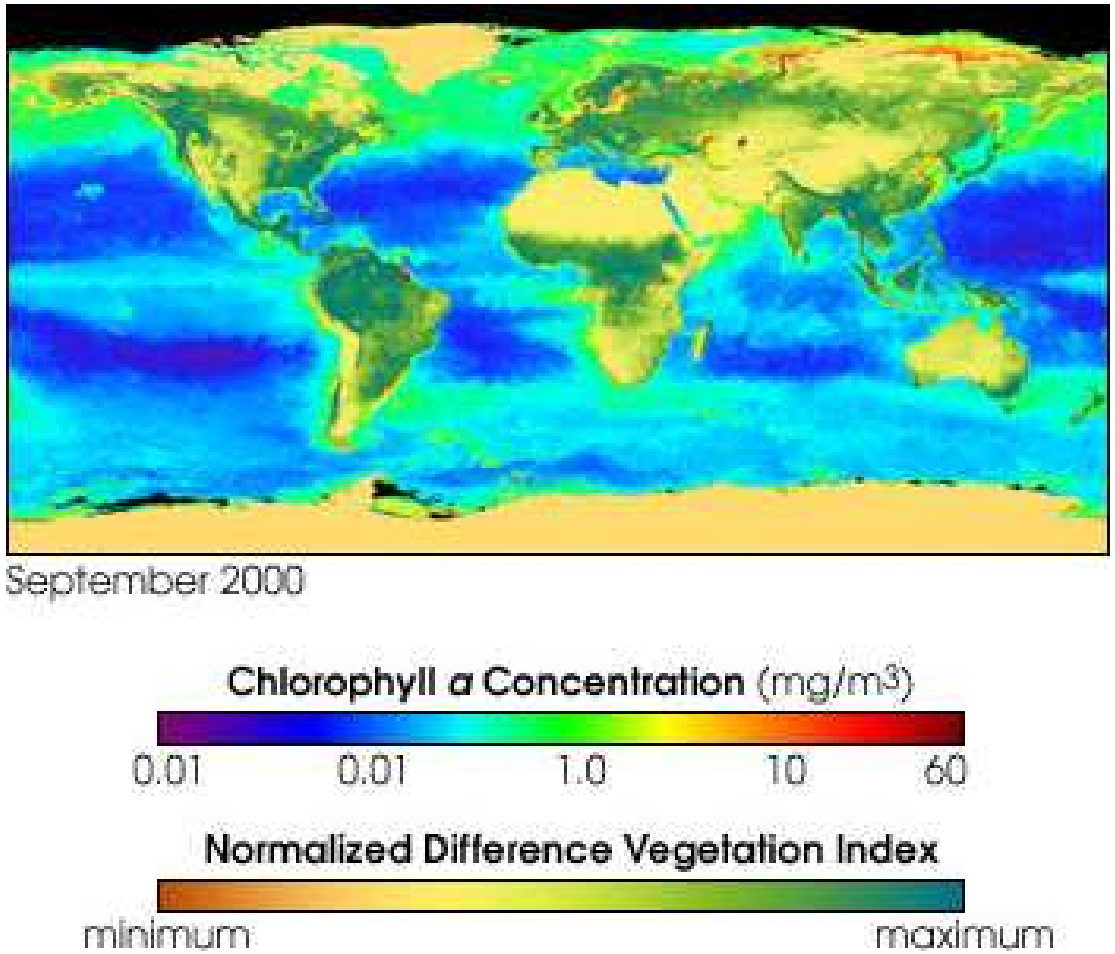
The lifetime of CO2 against net uptake by terrestrial plants is: 9 yr. (Atmospheric CO_2 responds, on a time scale of a decade, to changes in NPP or in decay rates.)

http://teaching.ust.hk/~chem541/Geochemical_cycles_II.doc

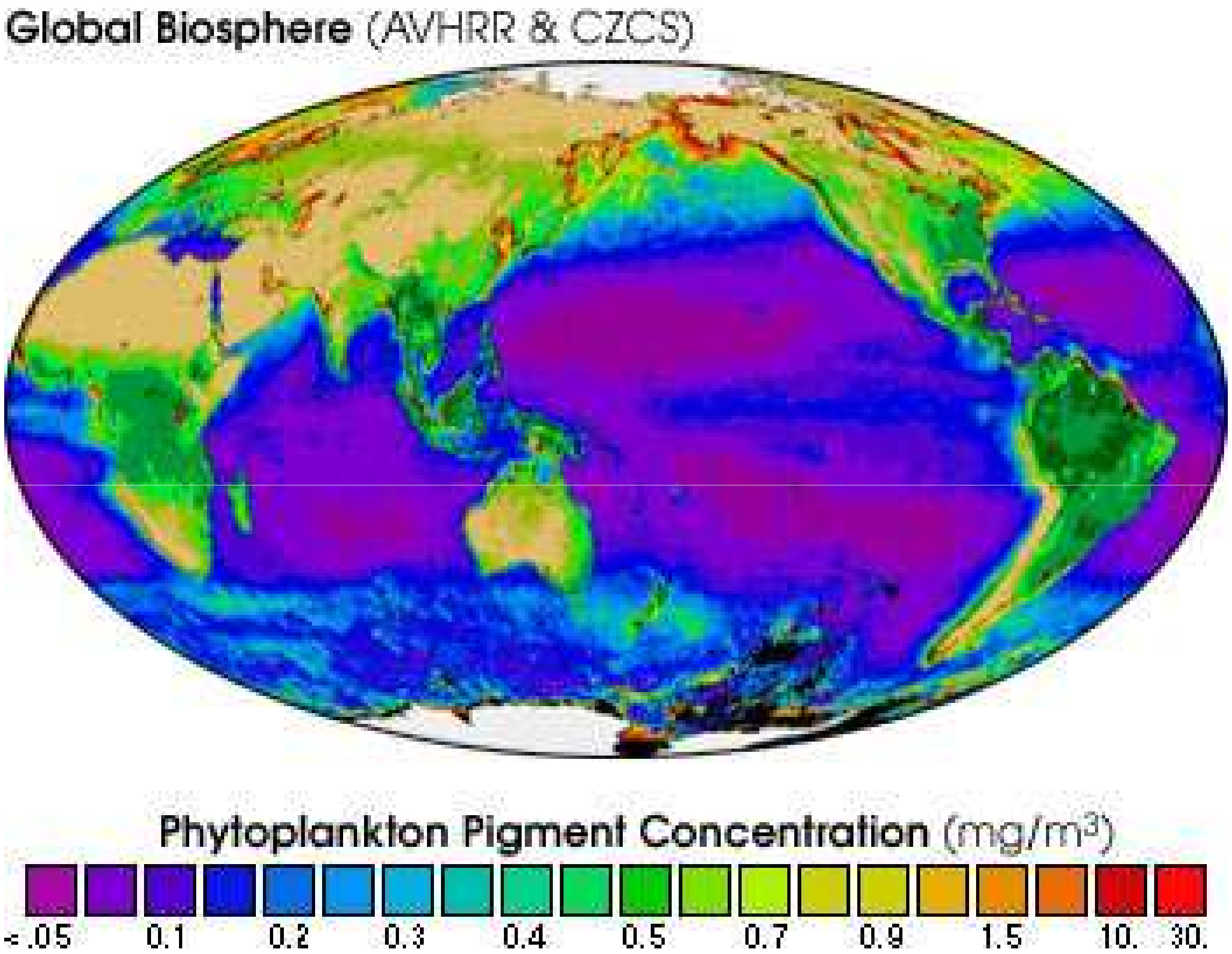
Photosynthetic activity



Chl-a


September 2000
Chlorophyll a Concentration (mg/m3)
0.01
0.01
1.0
10
60
Normalized Difference Vegetation Index
minimum
maximum

Global biosphere



Μπορούμε να ξεχωρίσουμε τις ανθρωπογενείς διαταραχές από την φυσική μεταβλητικότητα των βιογεωχημικών κύκλων και του κλίματος?

Ποια είναι η ευαισθησία του κλίματος της γης στις αλλαγές του ατμοσφαιρικού CO_2 ?

The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System

P. Falkowski,1*† R. J. Scholes,2* E. Boyle,3‡ J. Canadell,4‡ D. Canfield,5‡ J. Elser,6‡ N. Gruber,7‡ K. Hibbard,8‡ P. Ho¨gberg,9‡ S. Linder,10‡ F. T. Mackenzie,11‡ B. Moore III,8‡ T. Pedersen,12‡ Y. Rosenthal,1‡ S. Seitzinger,1‡ V. Smetacek,13‡ W. Steffen14‡

Science, 13 Oct. 2000, 291-296

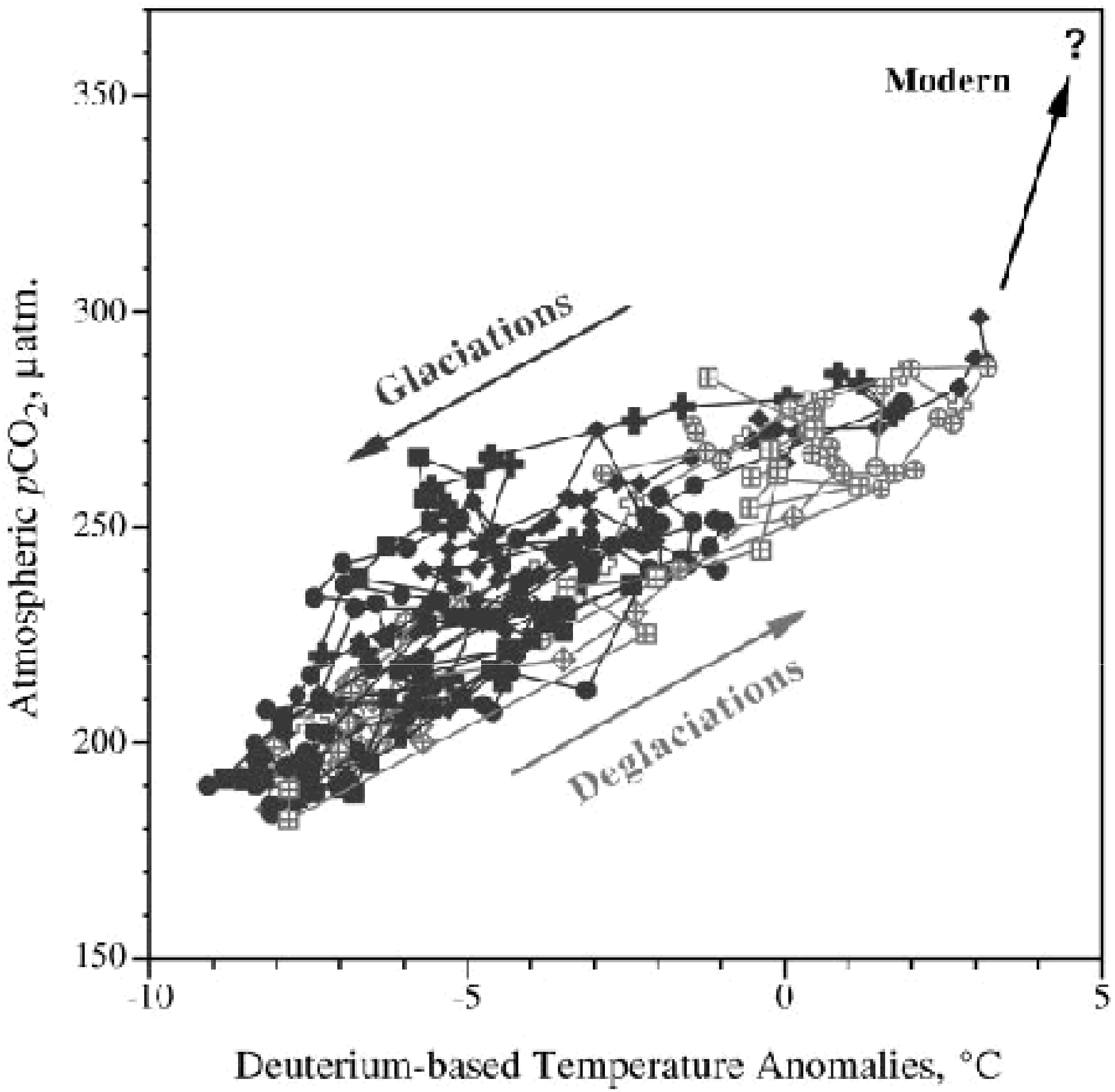
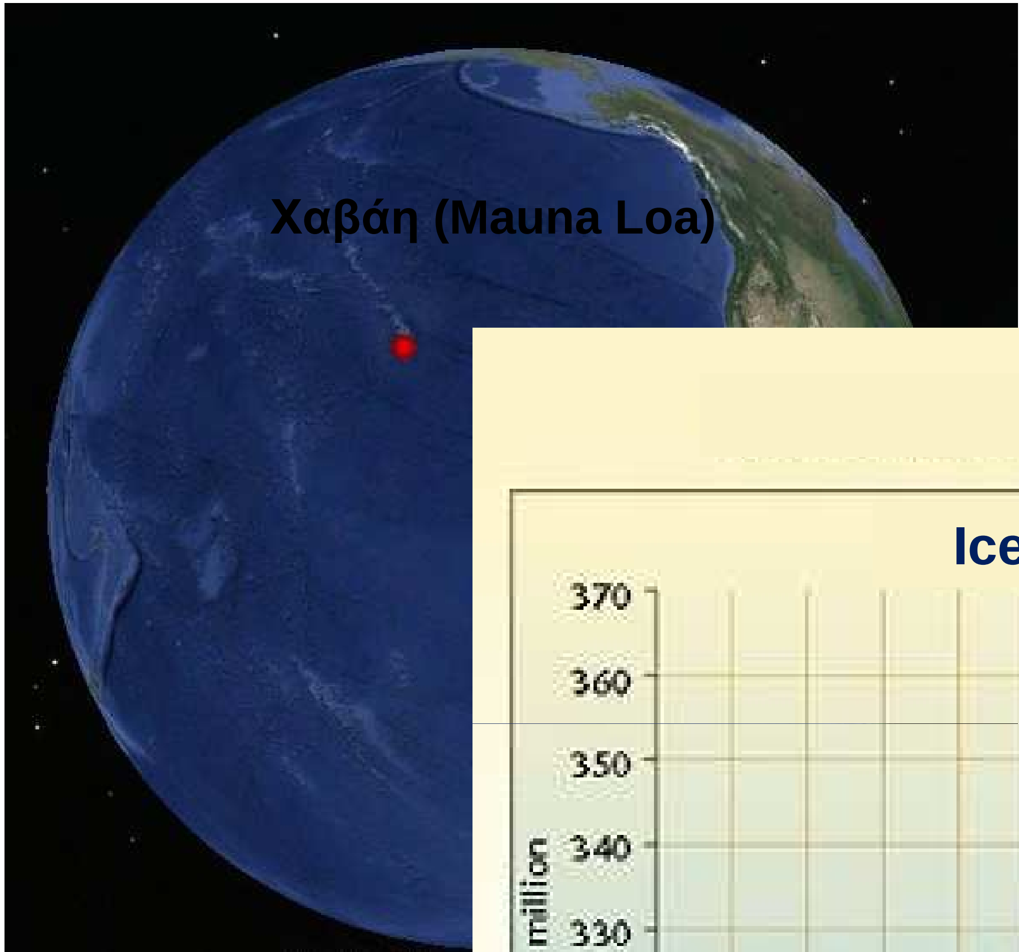
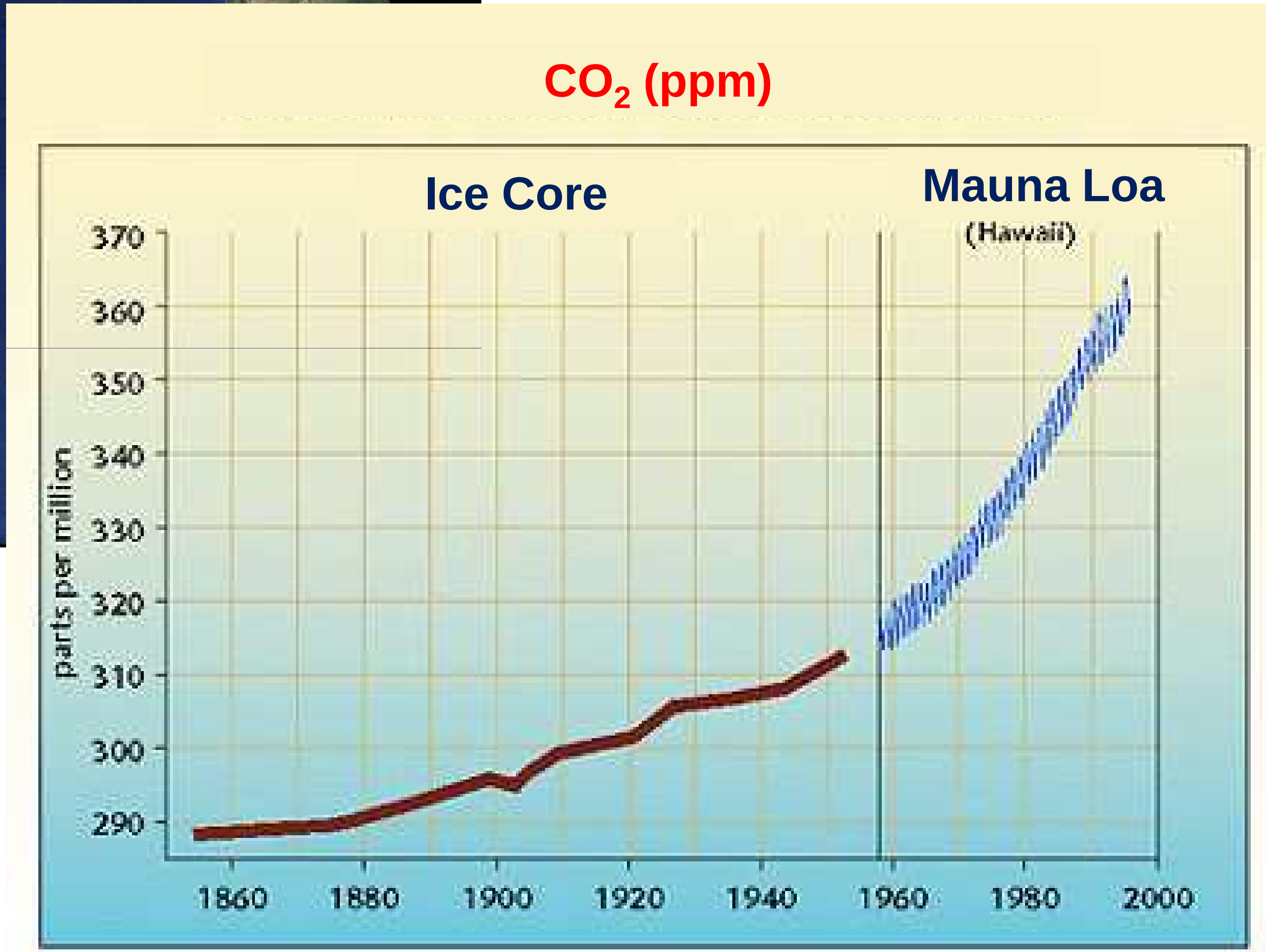
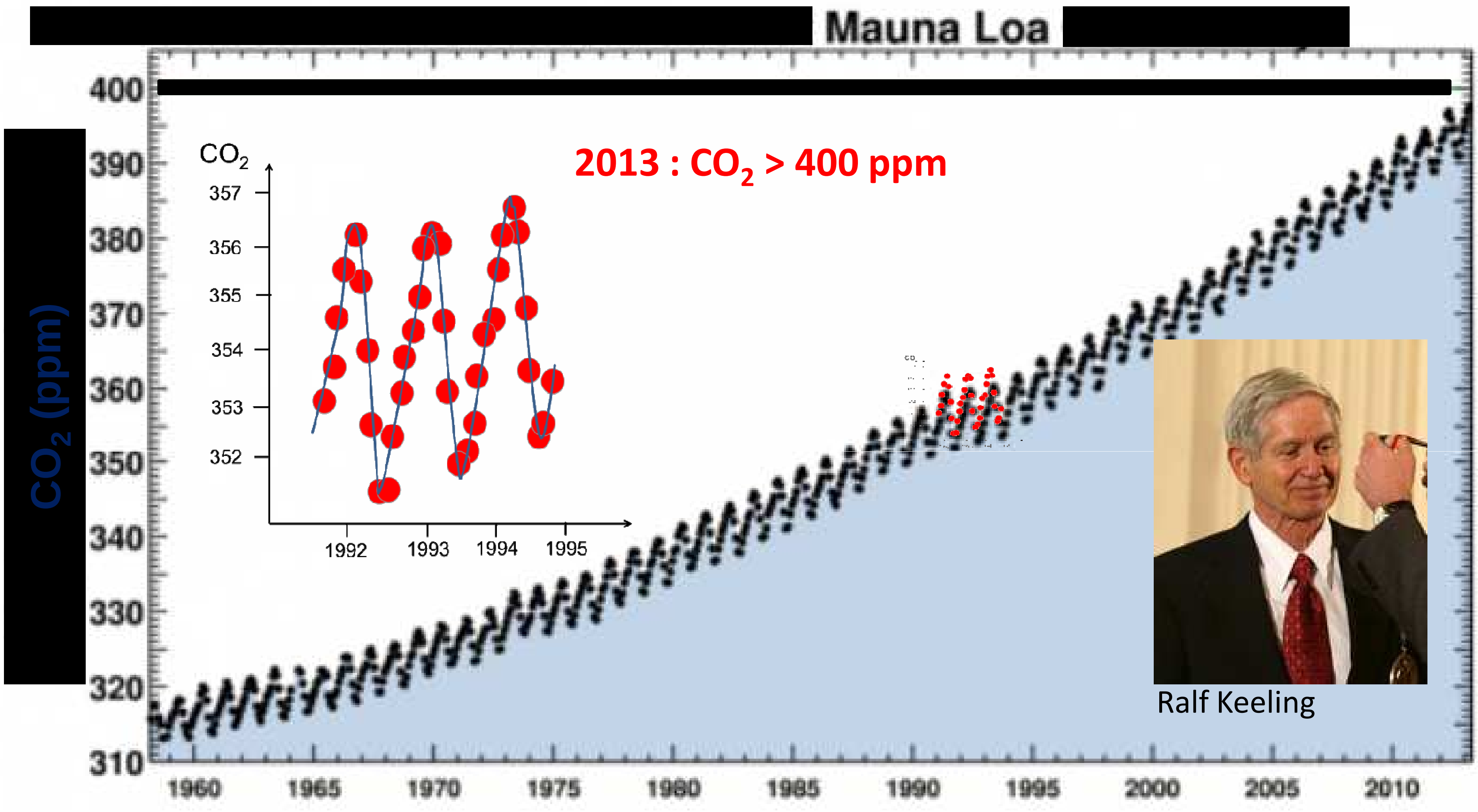


Fig. 1. A correlation between atmospheric partial pressure of CO_2 (pCO_2) and isotopic (δ_D) temperature anomalies as recorded in the Vostok ice core. The figure shows that climate variations in the past 420,000 years operated within a relatively constrained domain. Data are from (*8*).


Χαβάη (Mauna Loa)


CO2 (ppm)
Ice Core
Mauna Loa
(Hawaii)
parts per million
370
360
350
340
330
320
310
300
290
1860
1880
1900
1920
1940
1960
1980
2000

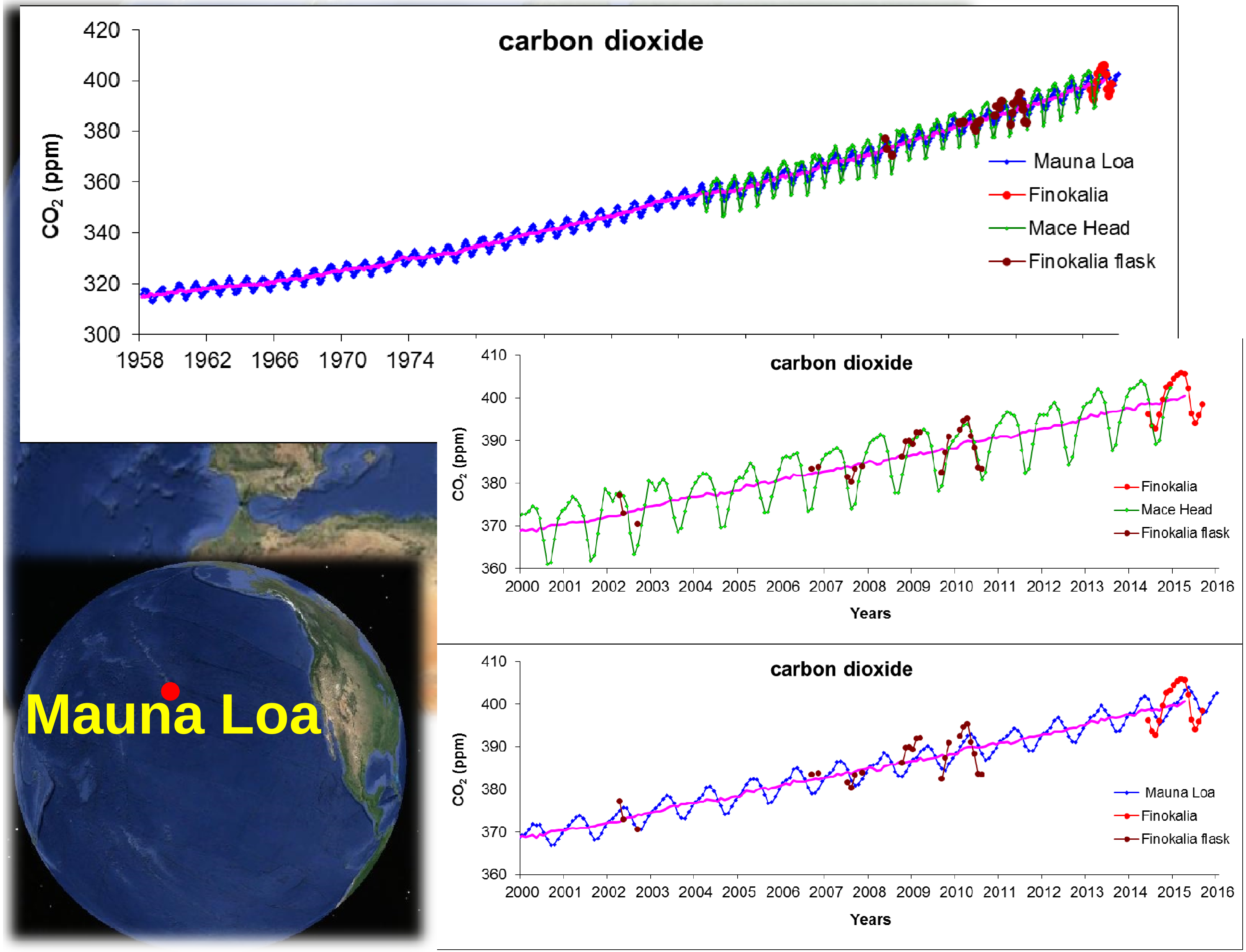
Carbon-dioxide



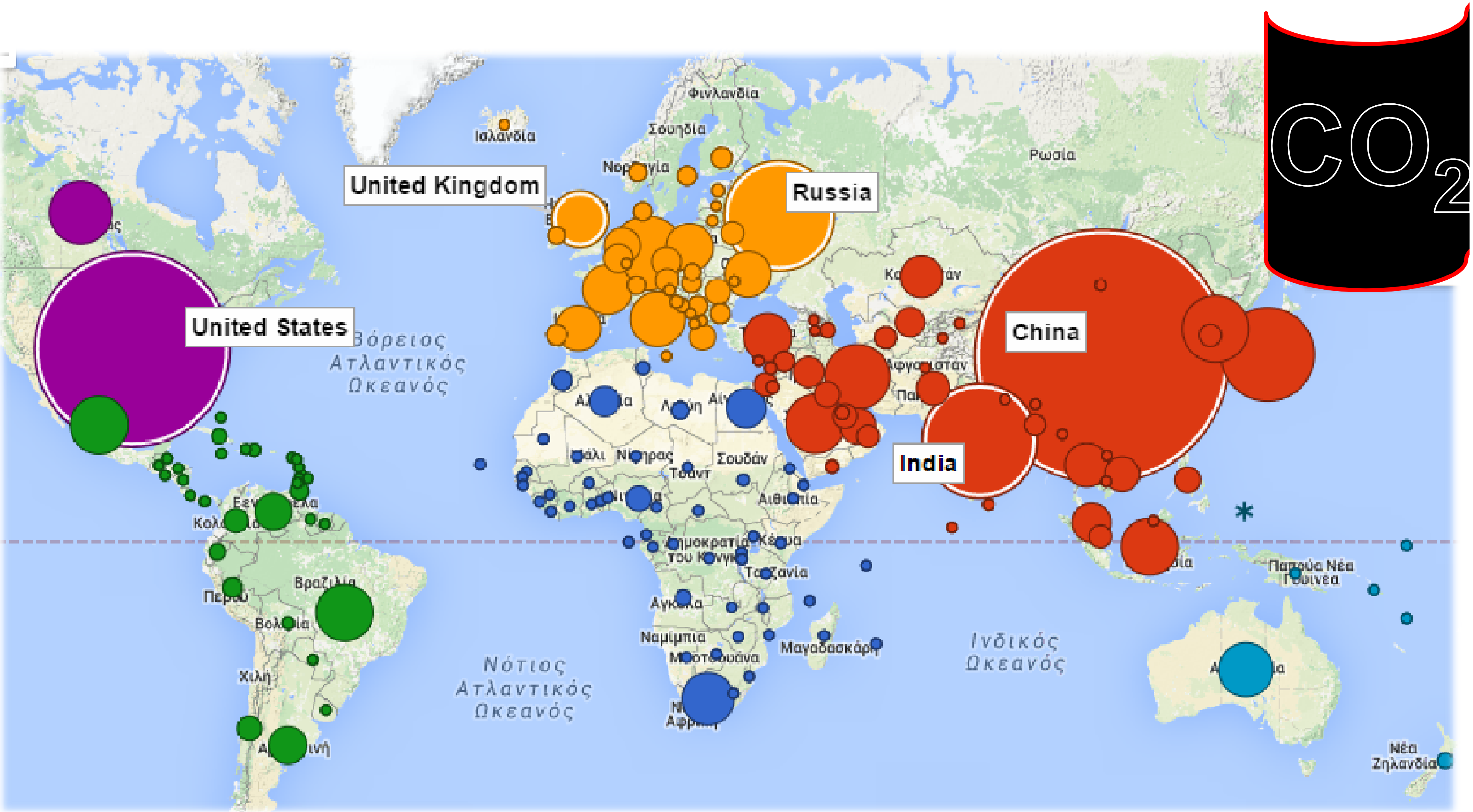
ICOS ATC
(Integrated Carbon Observation System)

Σταθμός Φινοκαλιάς

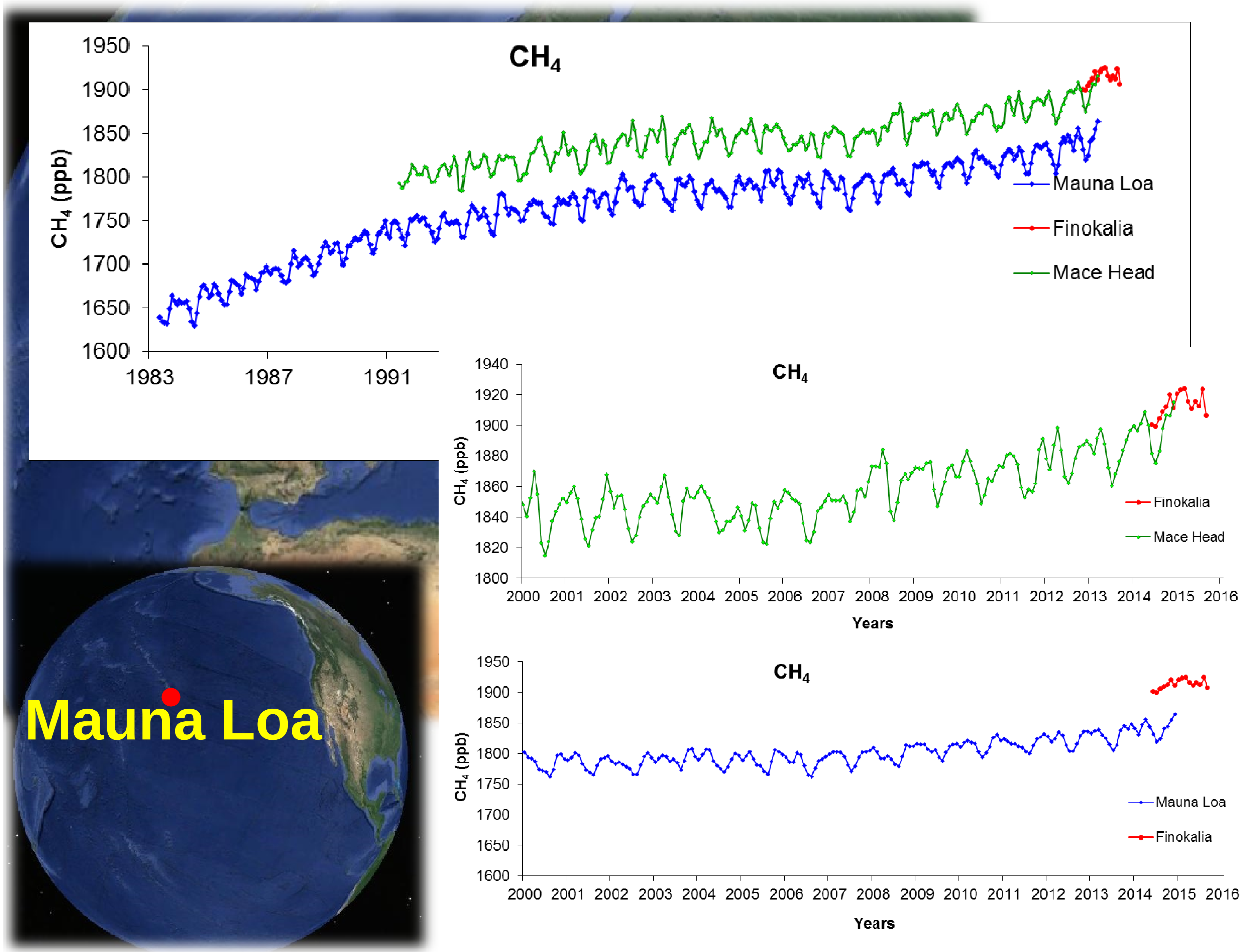
Σταθμός Φινοκαλιάς



carbon dioxide
CO2 (ppm)
420
400
380
360
340
320
300
1958
1962
1966
1970
1974
Mauna Loa
Finokalia
Mace Head
Finokalia flask
Mauna Loa
carbon dioxide
CO2 (ppm)
410
400
390
380
370
360
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
Years
Finokalia
Mace Head
Finokalia flask
carbon dioxide
CO2 (ppm)
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
Years
Mauna Loa
Finokalia
Finokalia flask



CO_2
United Kingdom
Russia
United States
China
India
Φινλανδία
Σουηδία
Ισλανδία
Ρωσία
Βόρειος Ατλαντικός Ωκεανός
Σουδάν
Αιθιοπία
Τανζανία
Ναμίμπια
Βραζιλία
Χιλή
Νότιος Ατλαντικός Ωκεανός
Ινδικός Ωκεανός
Νέα Ζηλανδία


CH4
CH4 (ppb)
1950
1900
1850
1800
1750
1700
1650
1600
1983
1987
1991
Mauna Loa
Finokalia
Mace Head
CH4
CH4 (ppb)
1940
1920
1900
1880
1860
1840
1820
1800
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
Years
Finokalia
Mace Head
CH4
CH4 (ppb)
1950
1900
1850
1800
1750
1700
1650
1600
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
Years
Mauna Loa
Finokalia
Mauna Loa

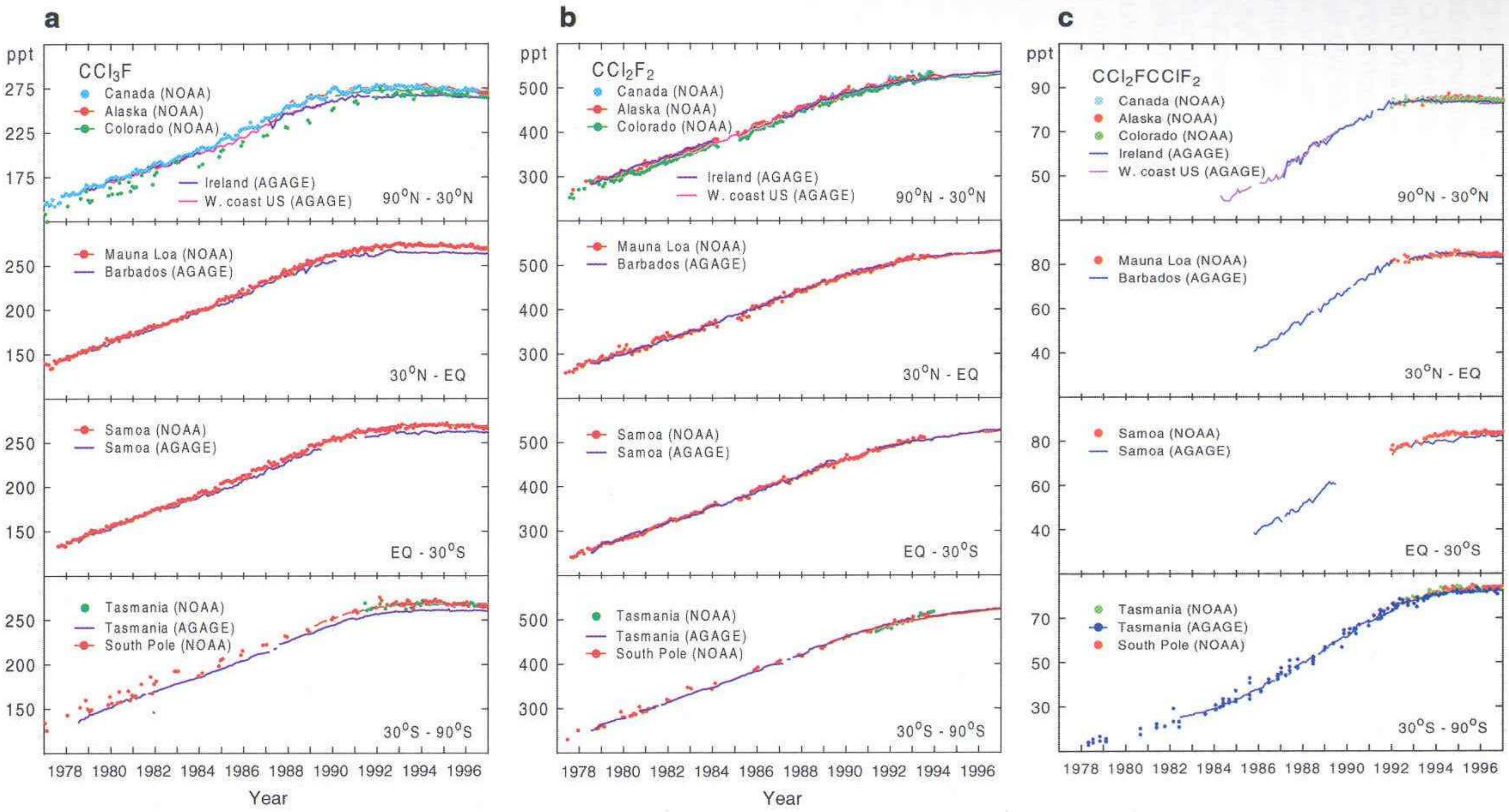
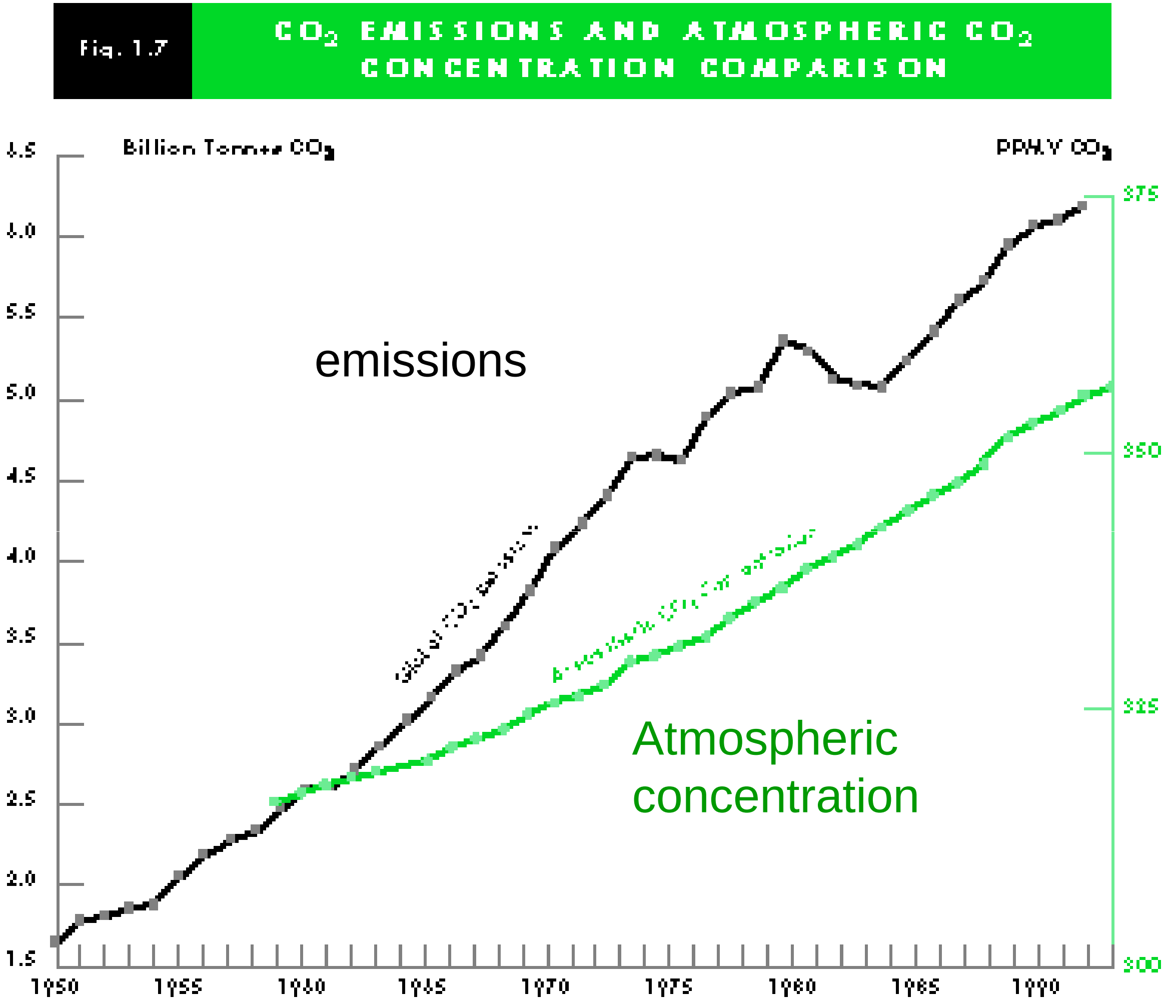


Figure 1-1. Monthly mean background data (in situ and flask) for CCl_3F, CCl_2F_2, and CCl_2FCClF_2 from the ALE/GAGE/AGAGE (Prinn *et al.*, 1998) and NOAA/CMDL (Elkins *et al.*, 1998) global networks.

CO2 emission vs atmospheric concentration



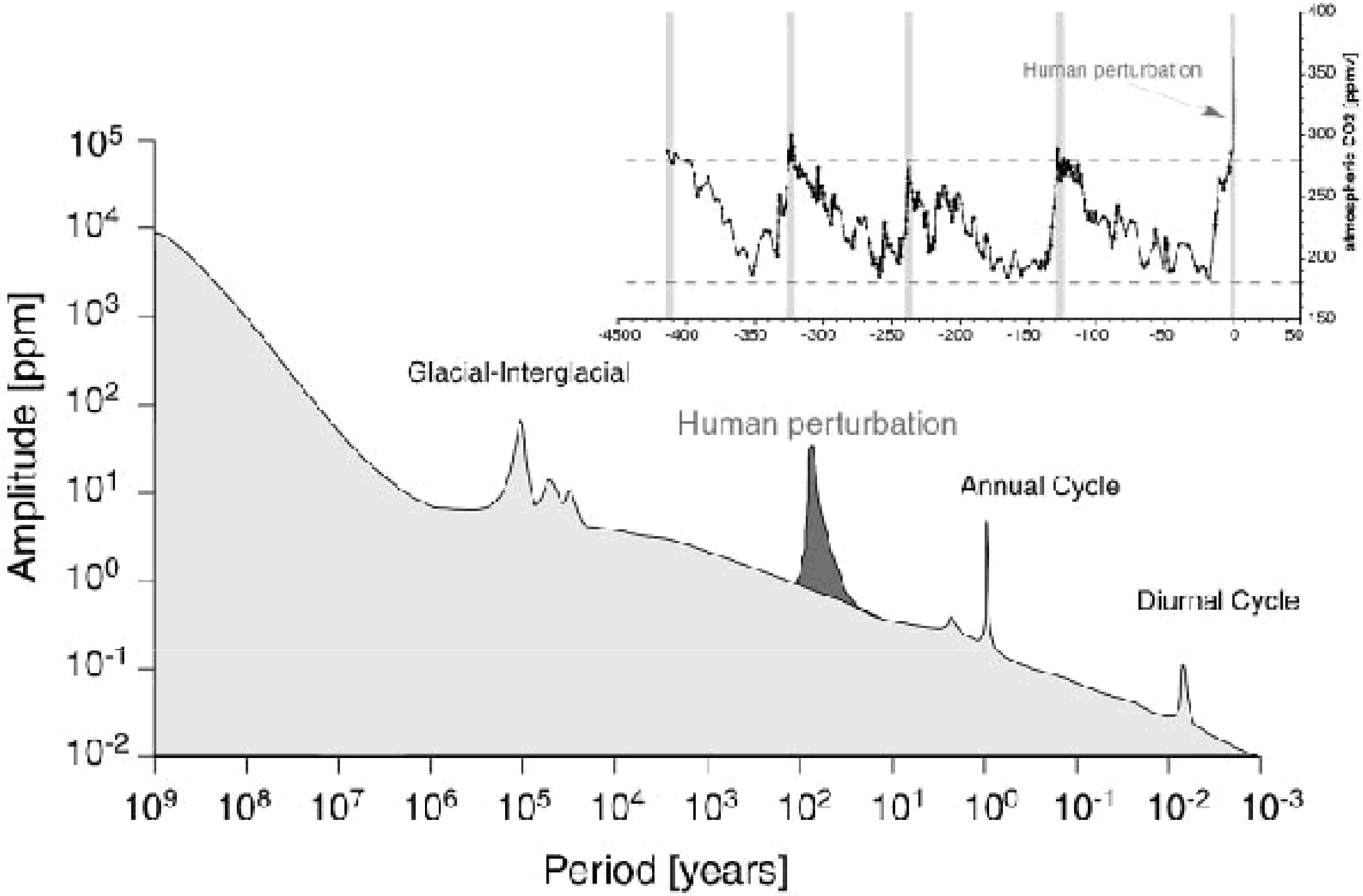
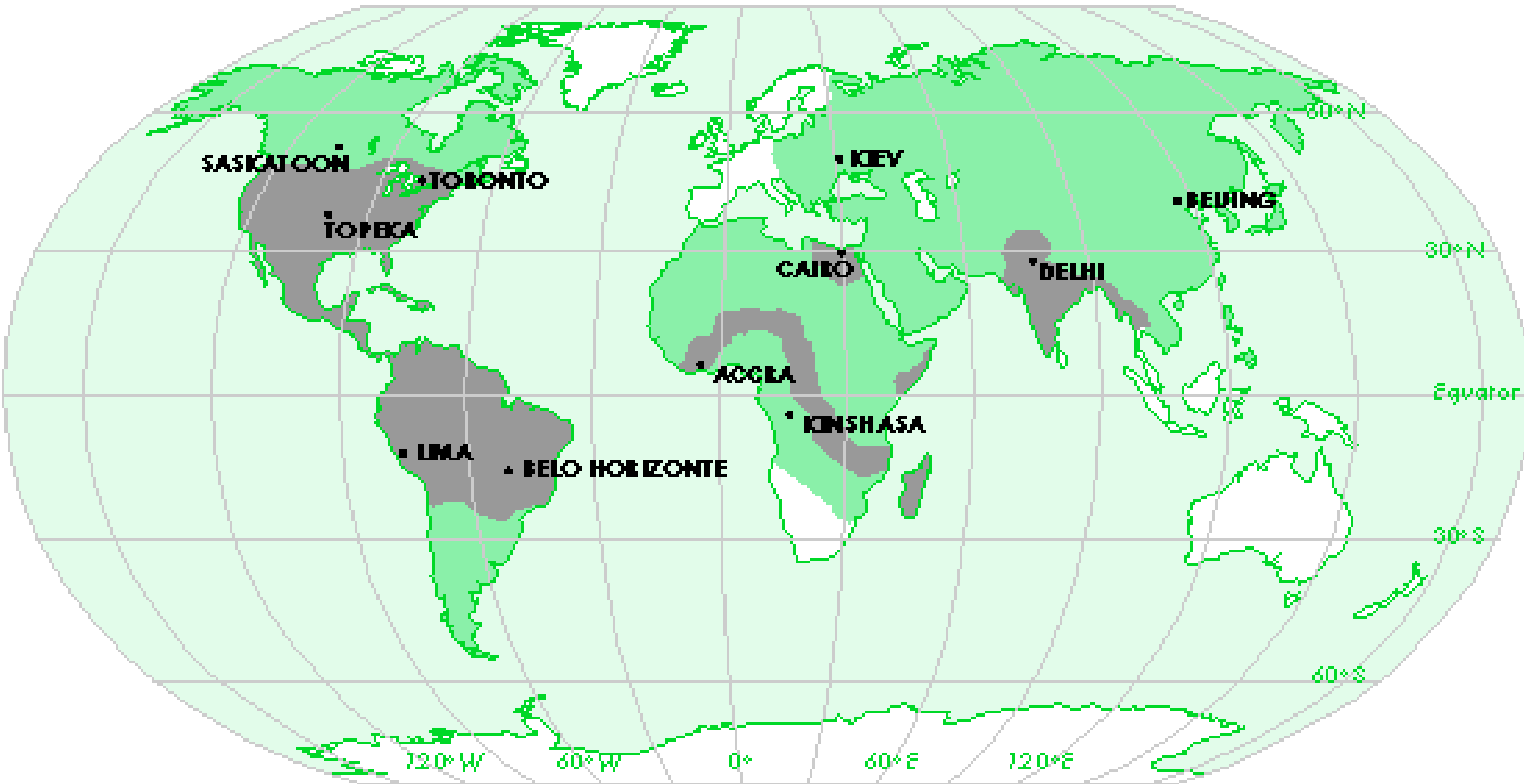


Fig. 2. Schematic variance spectrum for CO_2 over the course of Earth's history. Note the impact of human perturbations on the decade-to-century scale. (**Inset**) Changes in atmospheric CO_2 over the past 420,000 years as recorded in the Vostok ice, showing that both the rapid rate of change and the increase in CO_2 concentration since the Industrial Revolution are unprecedented in recent geological history.

$CO_2 x2$

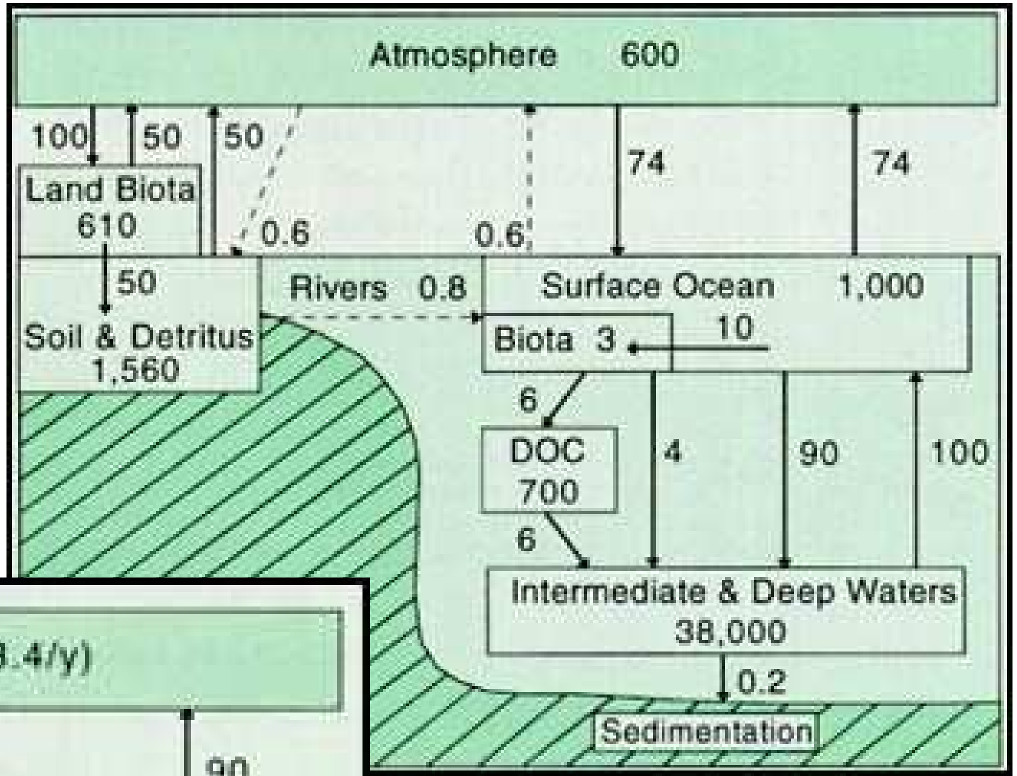
Fig. 2.1 **CHANGE IN GRAIN YIELD BASED ON A DOUBLING OF CO_2 (555 PPMV)**



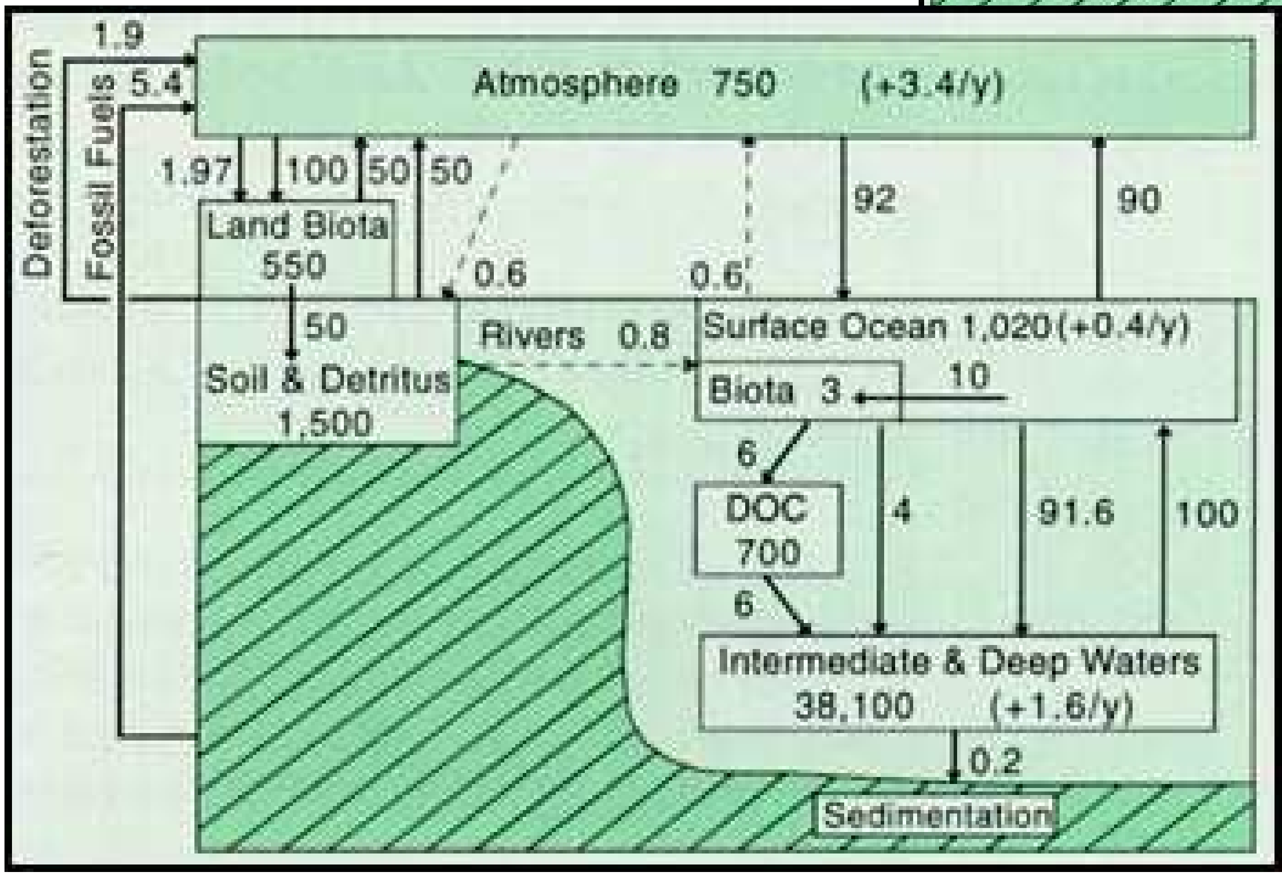
Between 0 – 20% reduction

More than 20% loss in grain yields

Pre-Industrial period



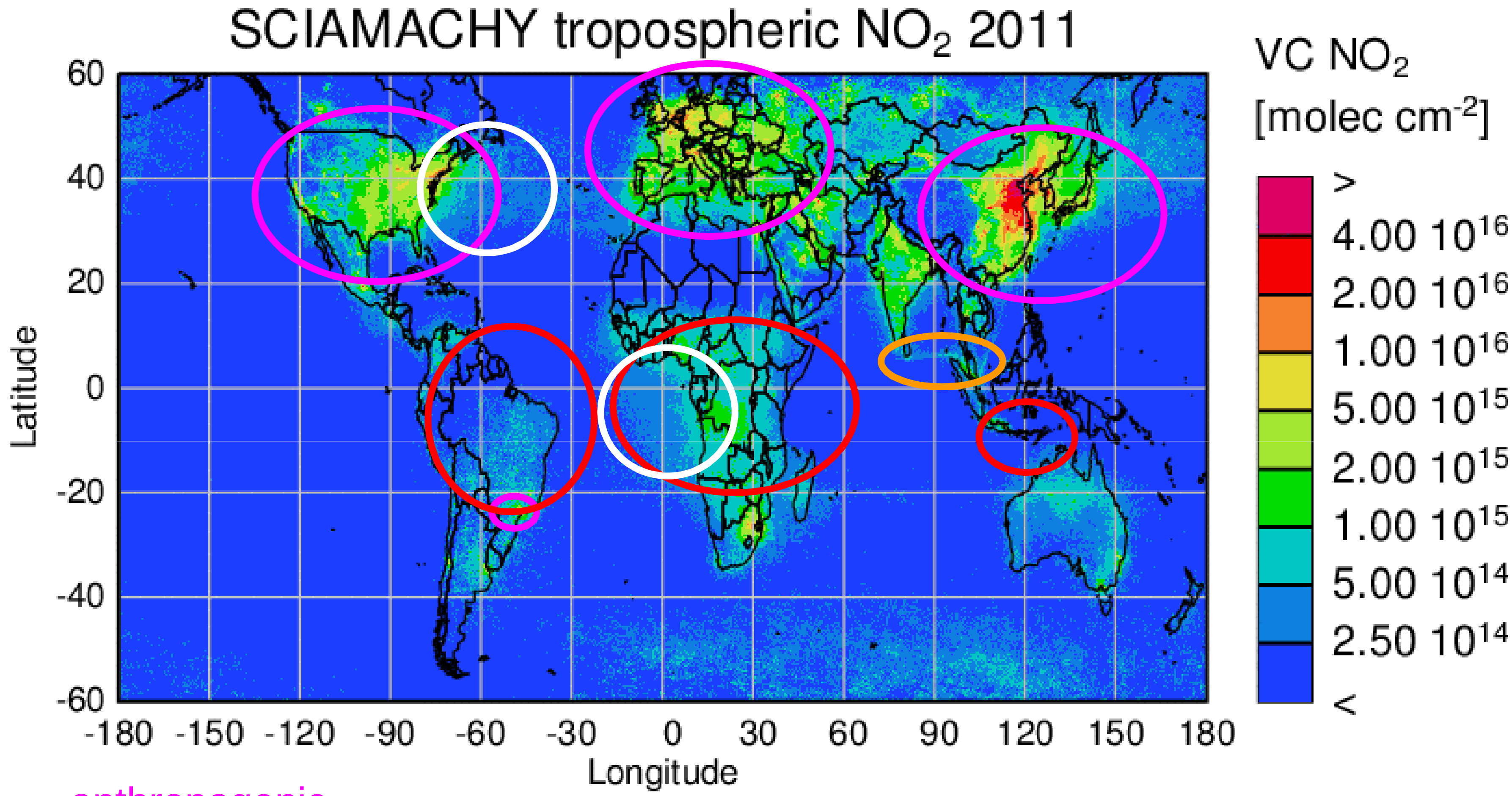
Industrial period



Tropospheric NO_2.

Nitrogen Dioxide

Tropopsheric NO_2 and Sources?



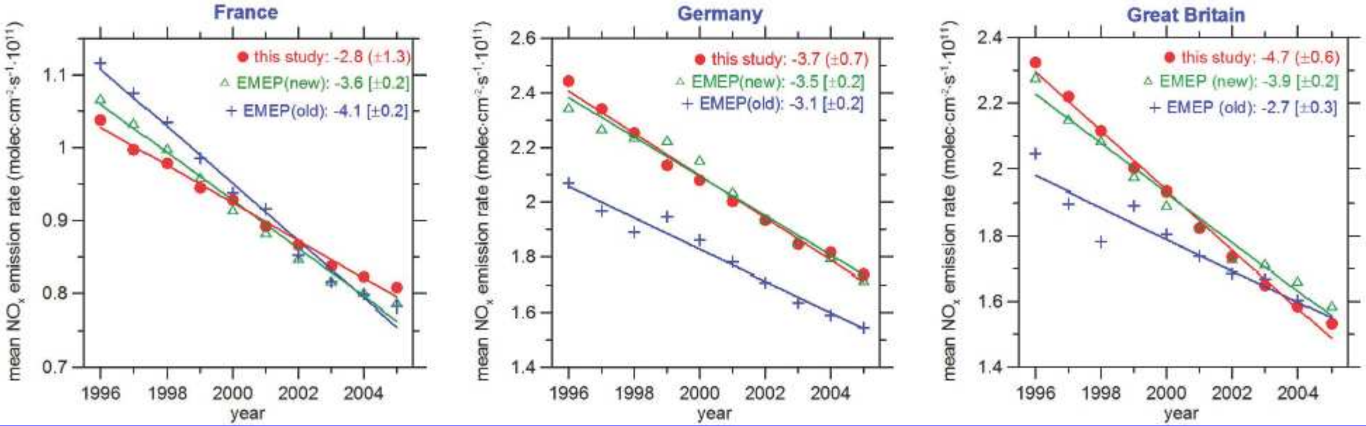
anthropogenic pollution

biomass burning

ships

transport

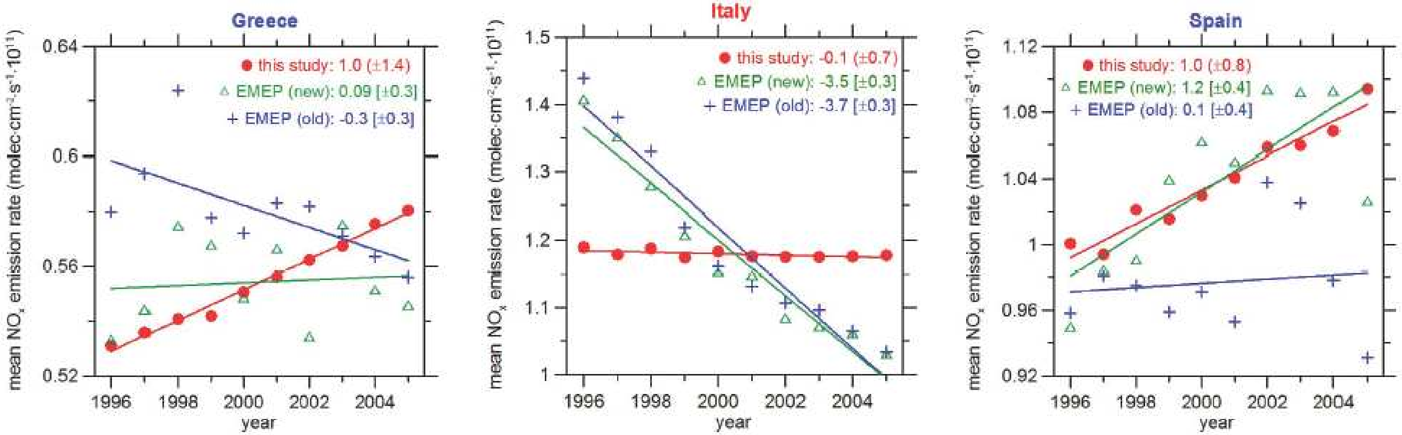
NO_2 Change in Europe



GOME and SCIAMACHY data over Europe + CHIMERE

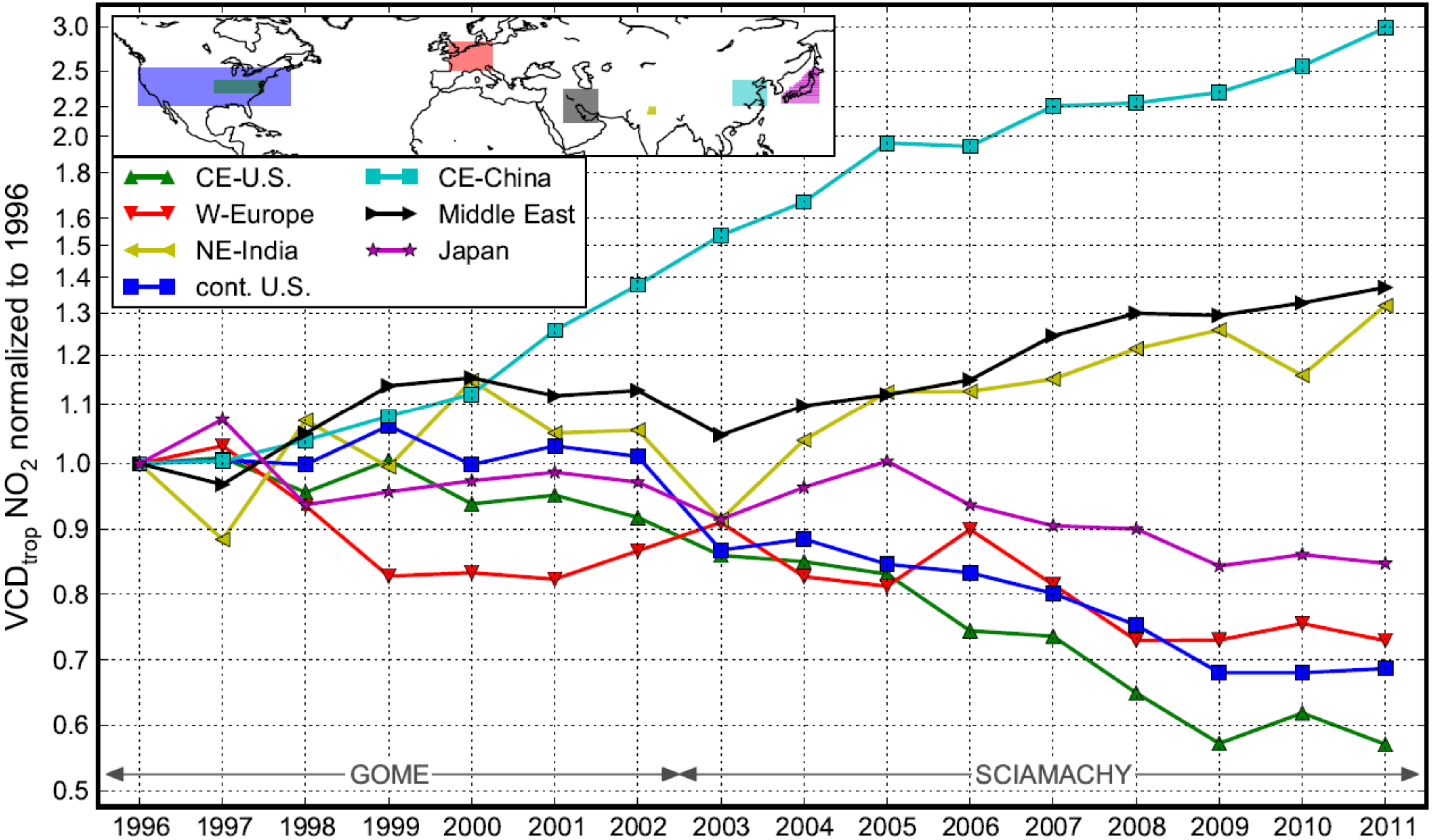
Comparison to two versions of EMEP emissions

Excellent agreement with latest EMEP in NE, disagreement in SE.



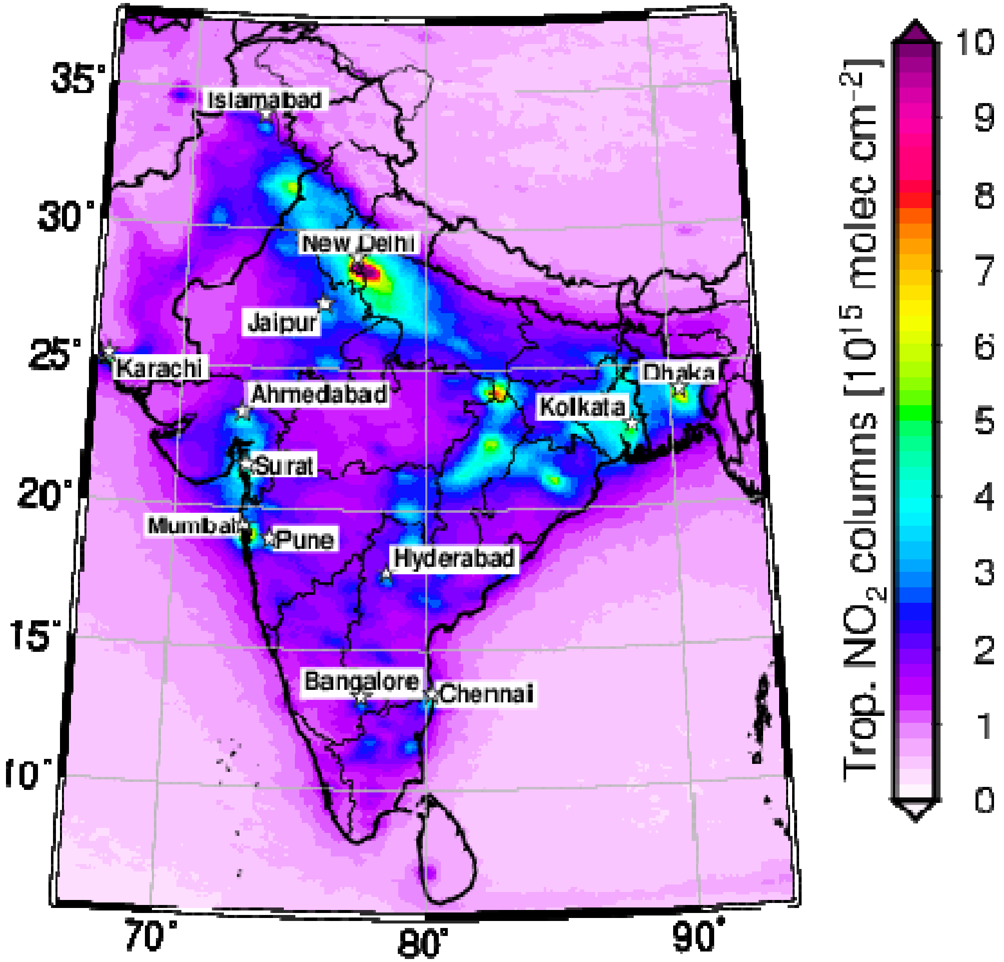
Konovalov, I.et al., Satellite measurement based estimates of decadal changes in European nitrogen oxides emissions, Atmos. Chem. Phys. Discuss., 8, 2013-2059, 2008

NO_2 Changes over Regions Hilboll et al., 2012/2013

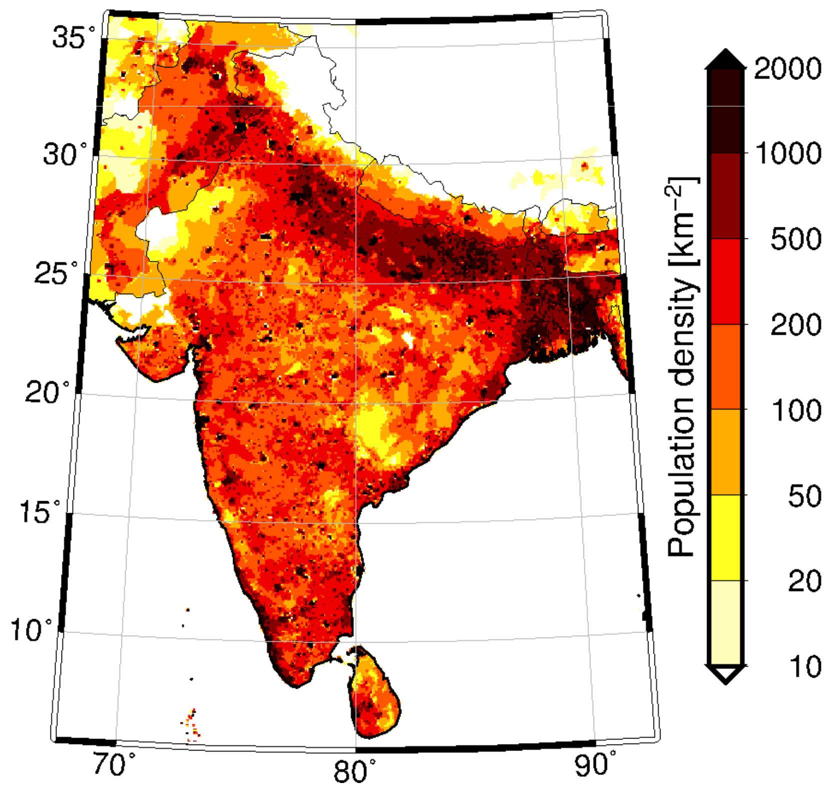


Hilboll, A., Richter, A., and Burrows, J. P.: Long-term changes of tropospheric NO2 over megacities derived from multiple satellite instruments, Atmos. Chem. Phys., 13, 4145-4169, doi:10.5194/acp-13-4145-2013, 2013.

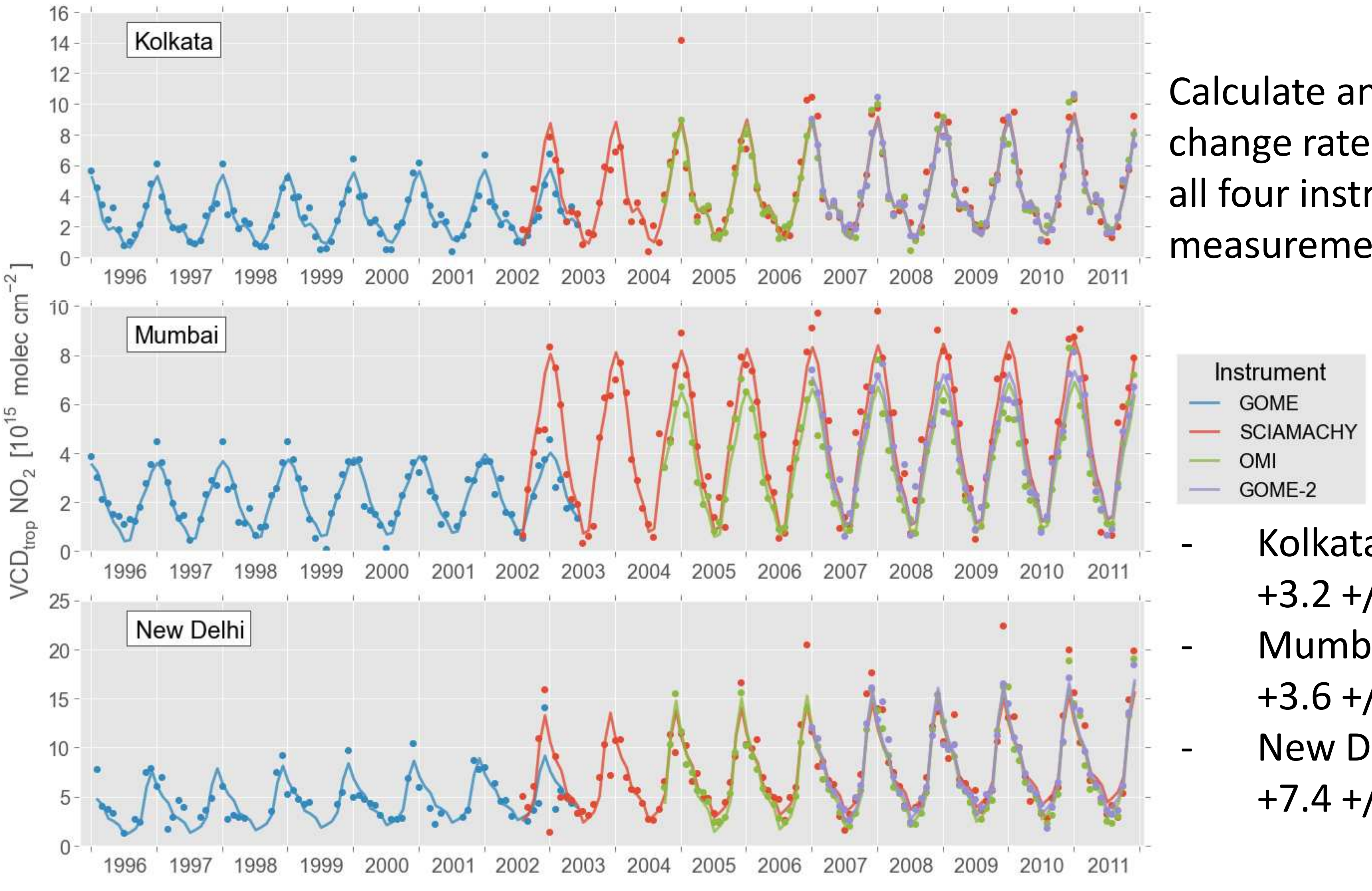
Tropospheric NO_2 column over Indian Subcontinent observed from space: SCIAMACHY (2003-2011)



Centres of Population are clearly visible



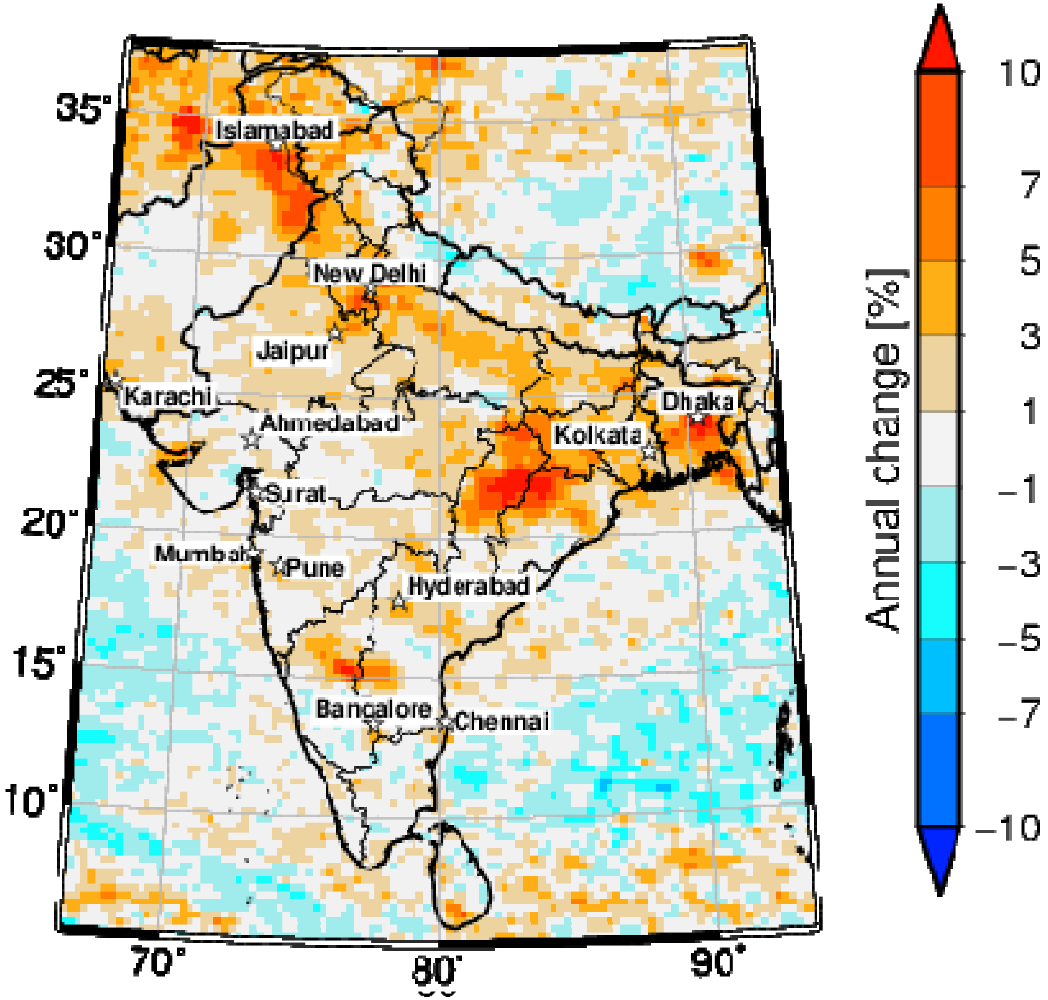
Calculation of annual change rates



Calculate annual change rates from all four instruments' measurements:

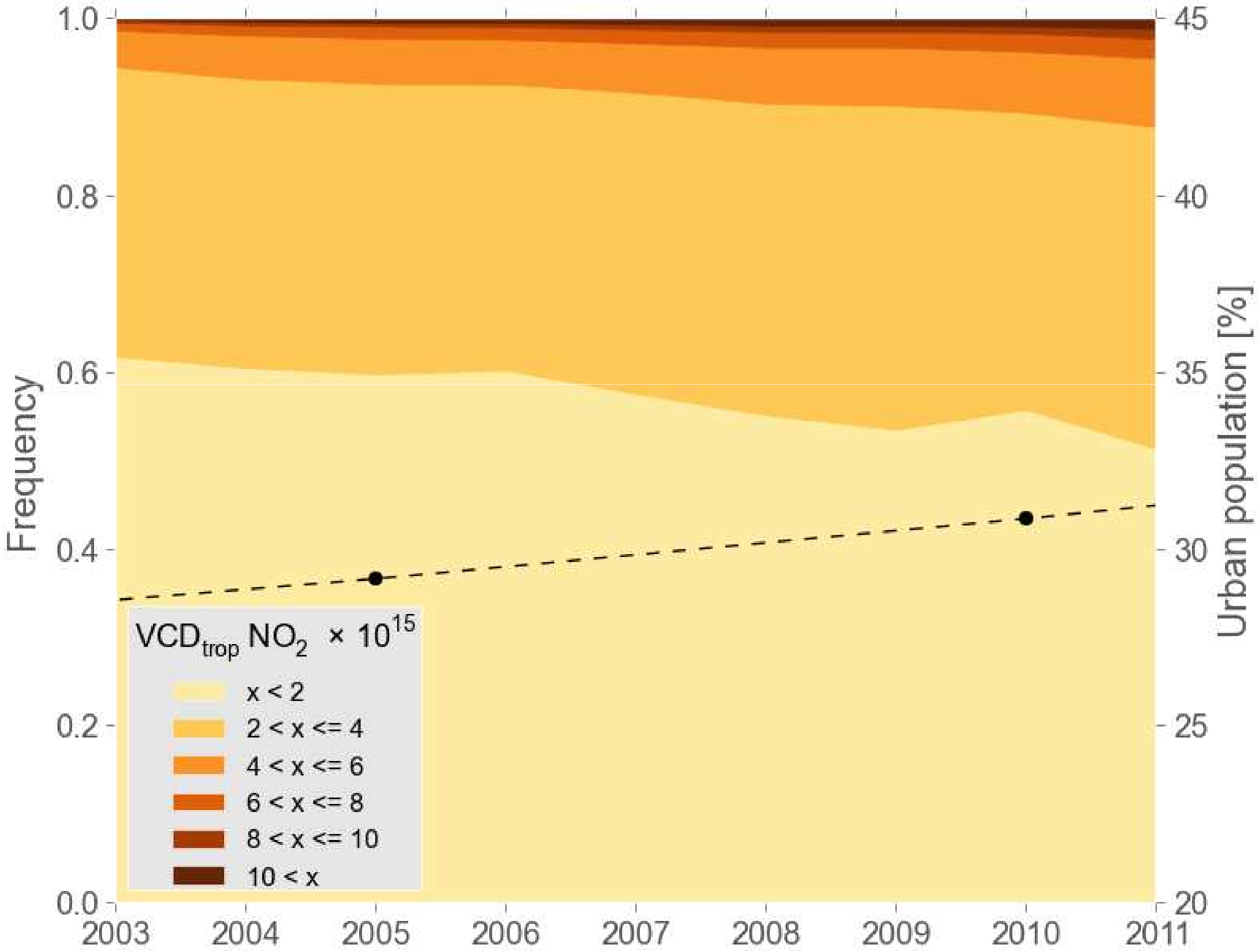
- Kolkata: +3.2 +/- 1.0 %
- Mumbai: +3.6 +/- 1.1 %
- New Delhi: +7.4 +/- 1.7%

Tropospheric NO_2 over India/ South Asia strongly increasing in populated regions



- Tropopsheric NO_2 strongly increases in major centres of population
- Attributed to fossil fuel, domestic heating and cooking and related
- Strongest relative increase is in Odisha and Chhattisgarh
- Attributed to heavy industry + electricity

The area of regions with high NO_2 pollution are growing

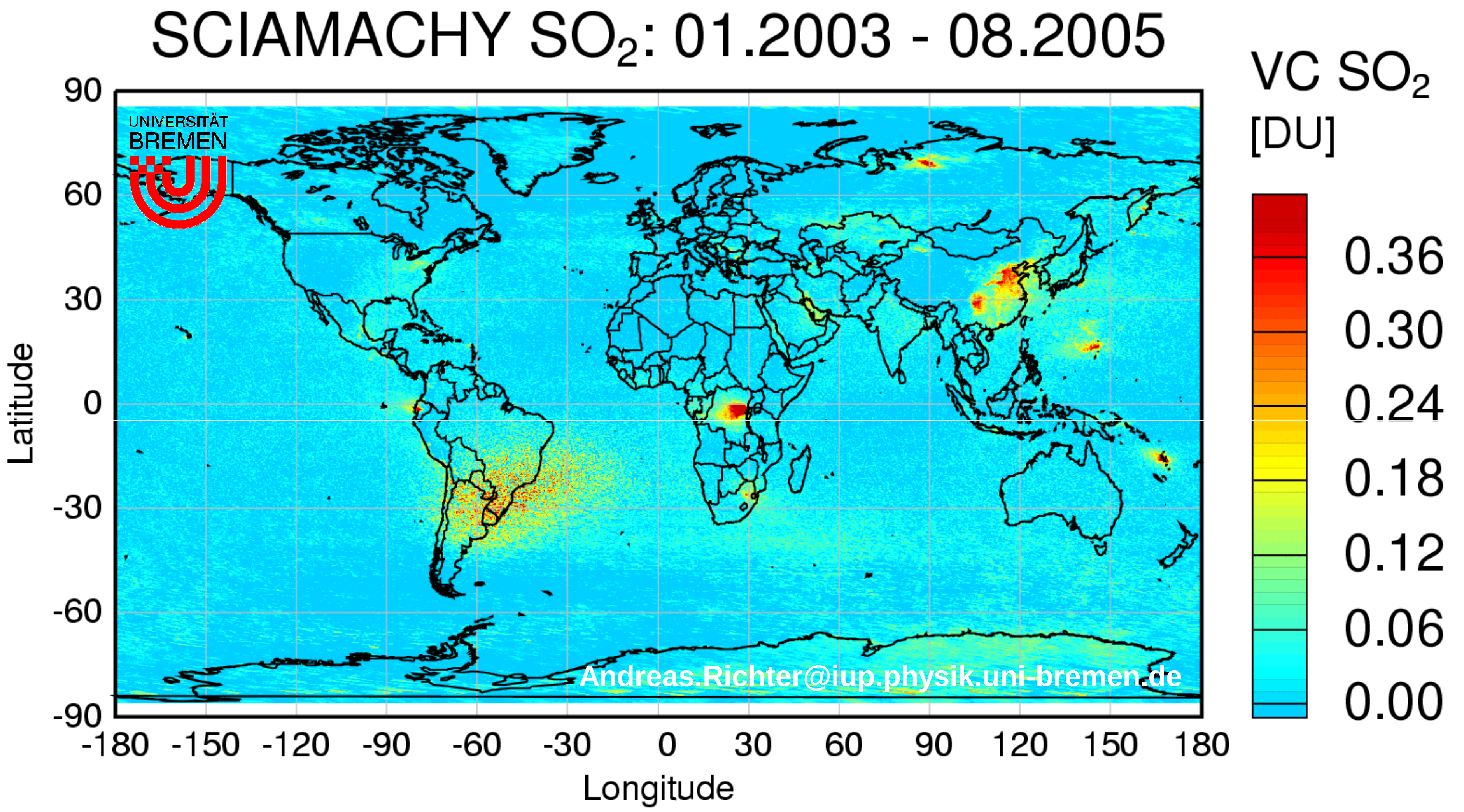


- Percentage of area with higher NO_2 pollution is increasing
- The area of pristine i.e. low NO_2 decreases
- Attributed to emissions resulting from urbanization trend and population increase

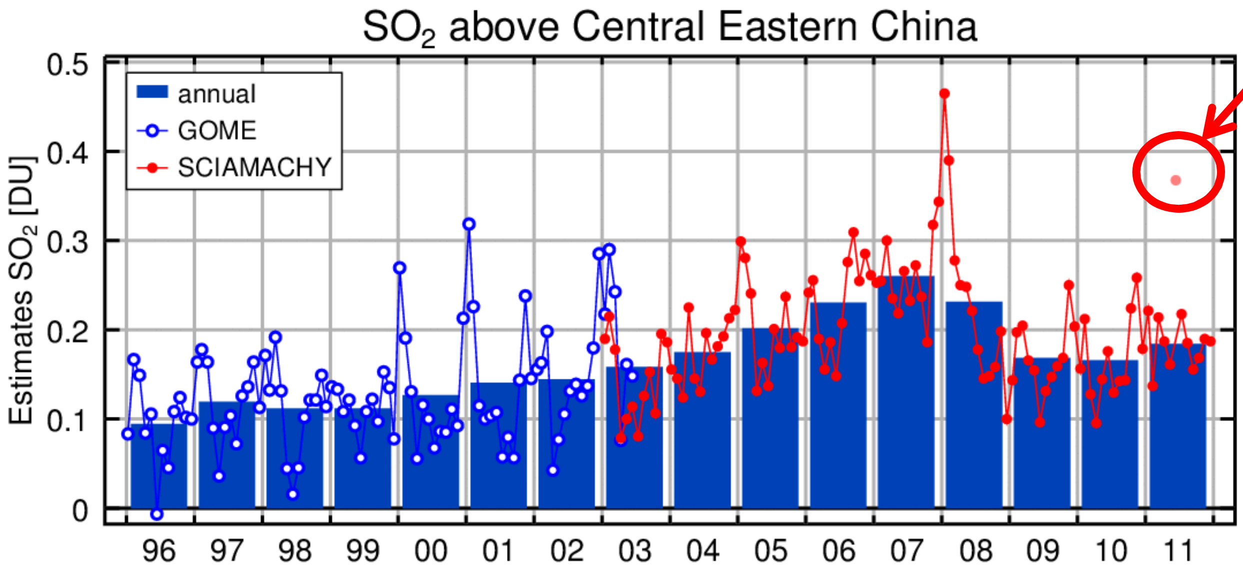
Tropospheric SO_2

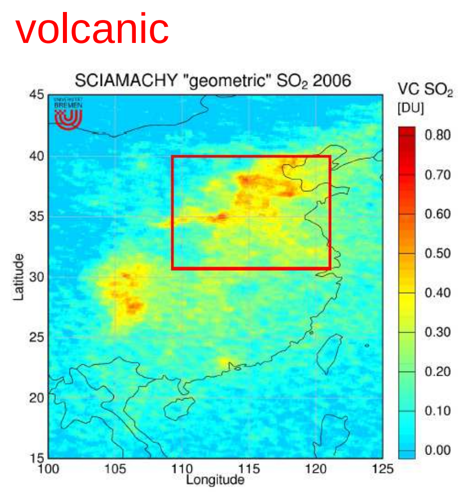
Sulphur
Dioxide

SCIAMACHY SO_2 Columns



GOME and SCIAMACHY SO_2 over Central East China

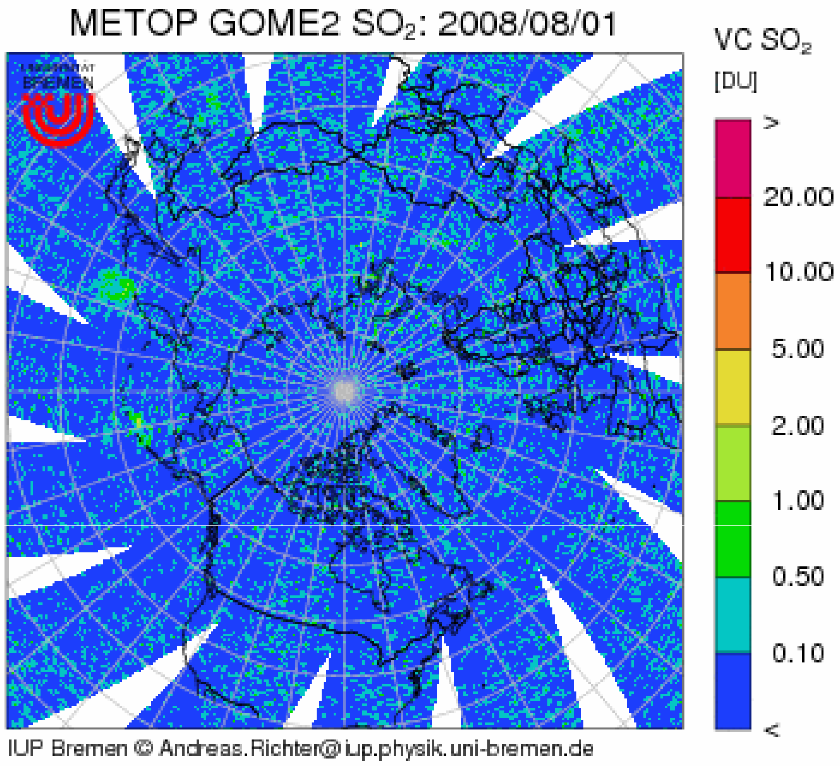




- SO_2 mainly emitted from coal fired power plants – lignite and less from anthracite
- Large increase in SO_2 loading observed from 2000 to 2007
- Turnover in 2007
- Decrease to 2003 / 2004 levels but may be increasing again?

Decrease explained by legislation requiring flue-gas desulphurization of power plants
Not all power plants have been equipped other sources are also increasing

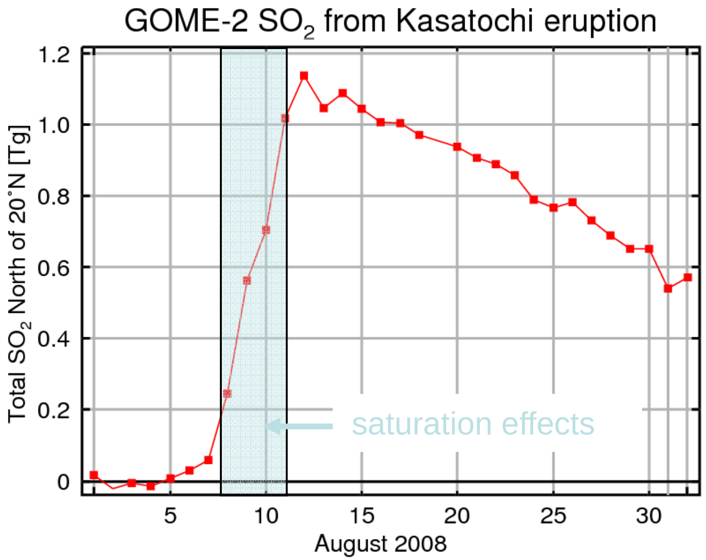
Kasatochi eruption as seen in GOME-2 SO_2



- After some smaller SO_2 emissions, large eruption on August 8, 2008
- SO_2 rapidly distributes over the NH
- GOME-2 integrated SO_2 column indicates more than 1 Tg total SO_2 emission

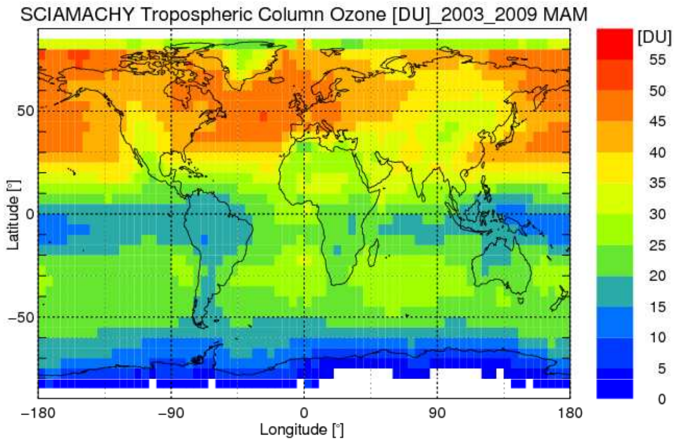
Kasatochi volcano

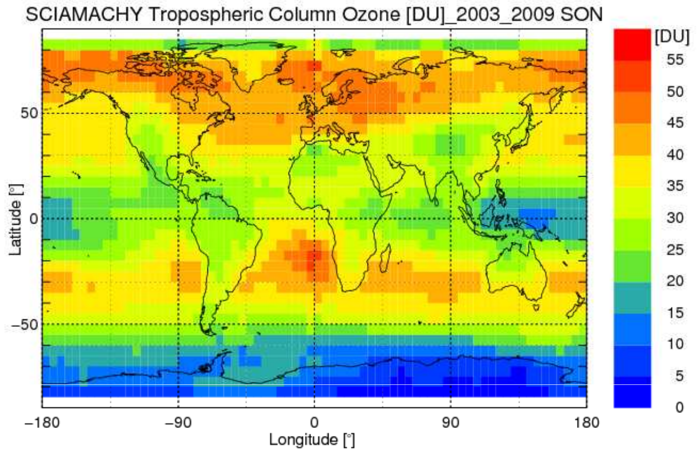
Altitude: 314 m
Latitude: 52.16° N
Longitude: 175.51° W

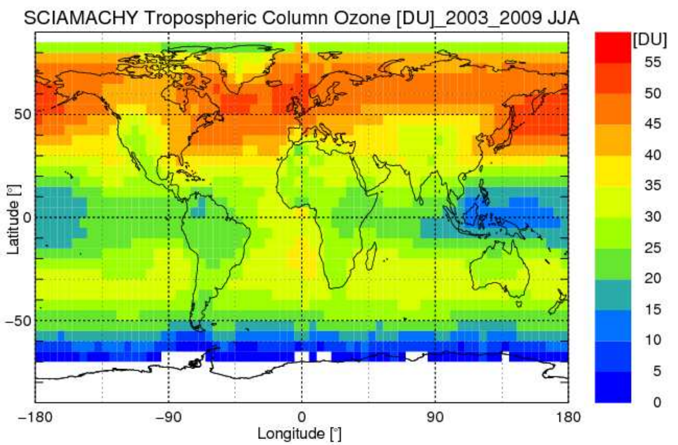


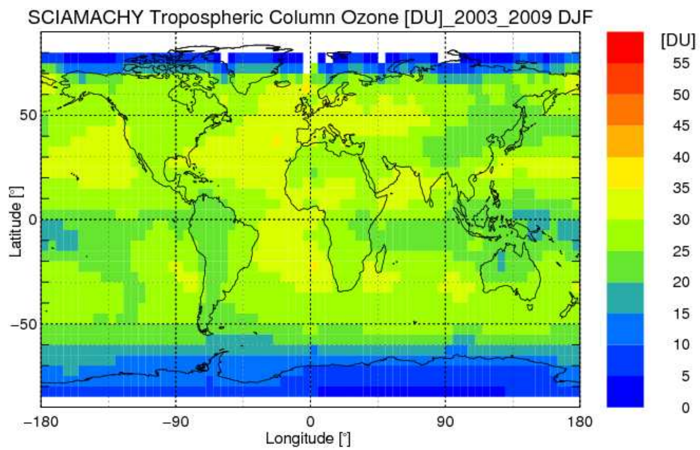
Tropospheric O_3

SCIAMACHY Tropospheric O_3: Total (Nadir) – Summed Profile above Tropopause (Limb)







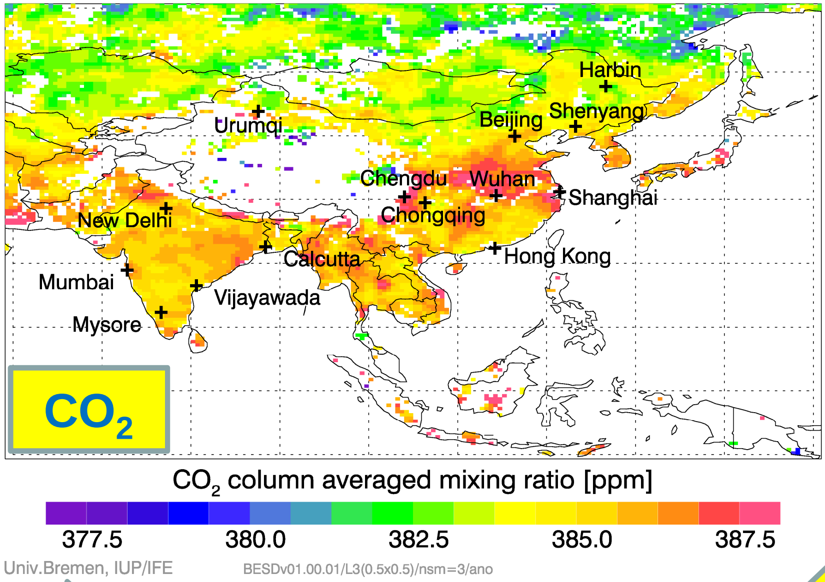


Total Dry Column Mole fraction CO_2 and CH_4

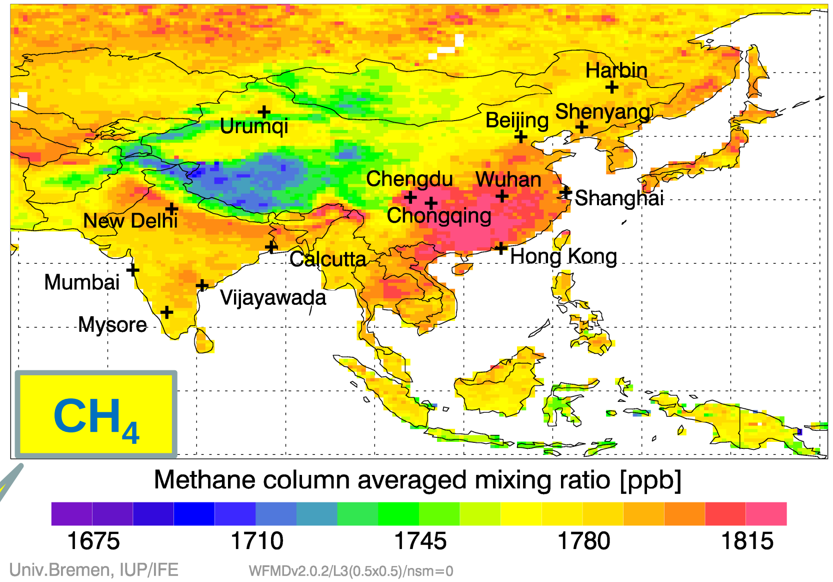
Carbon dioxide and methane

SCIAMACHY „Carbon gases“ CO_2, CH_4, CO

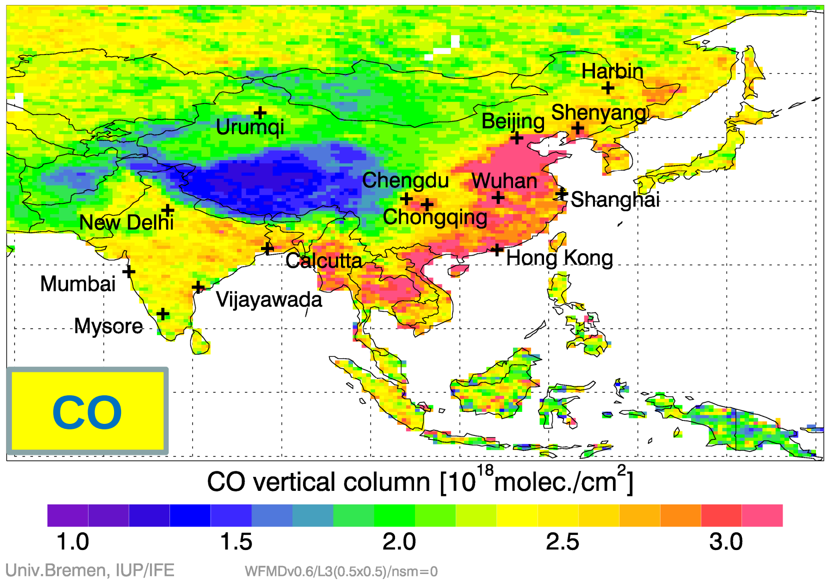
Carbon Dioxide SCIAMACHY/BESD 2006-2011



Methane SCIAMACHY/WFMD 2003-2005



Carbon monoxide SCIAMACHY/WFMD 2004

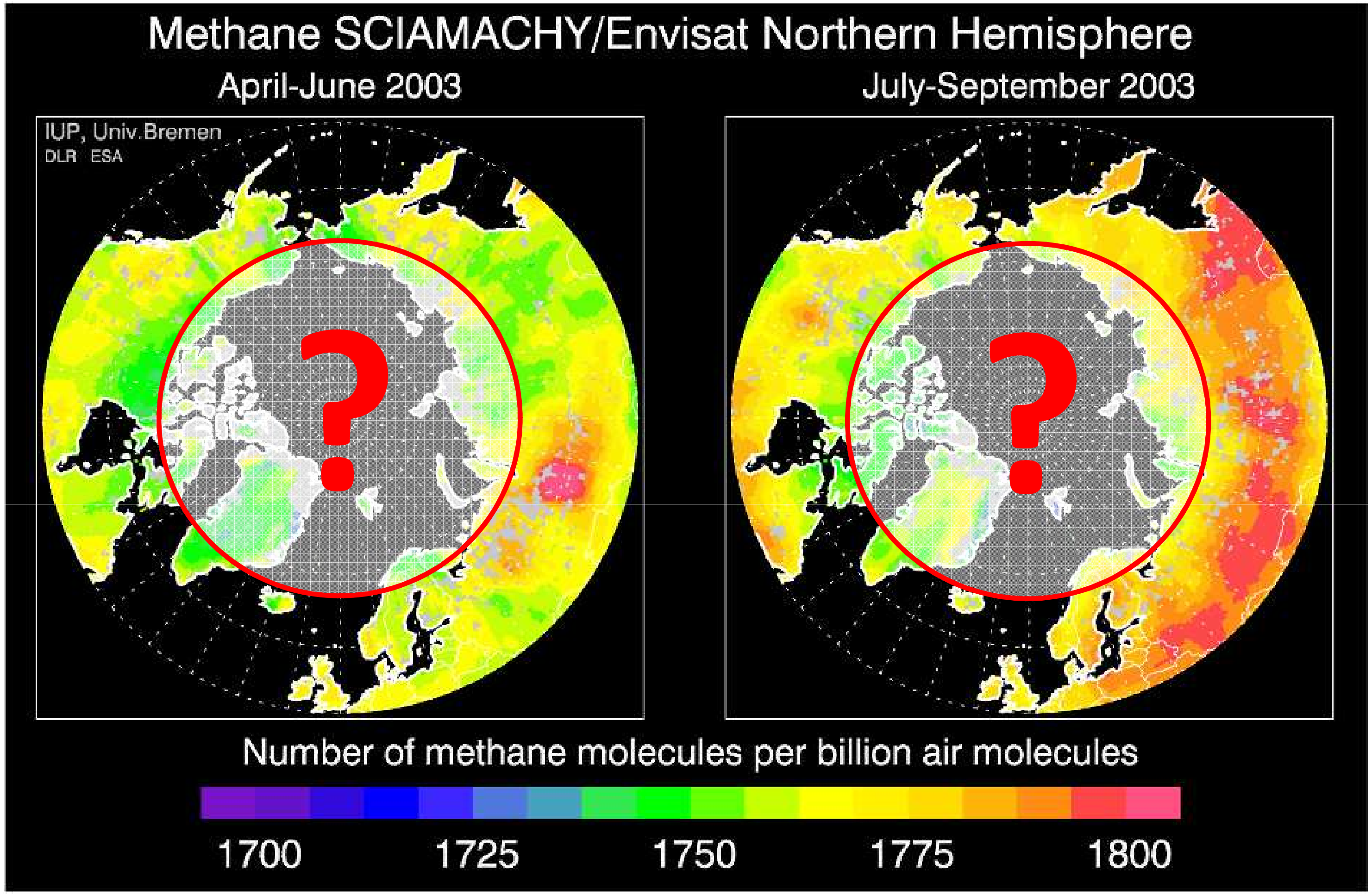


Natural uptake and release, anthropogenic emissions

Anthropogenic and natural emissions (rice, wetlands, …)

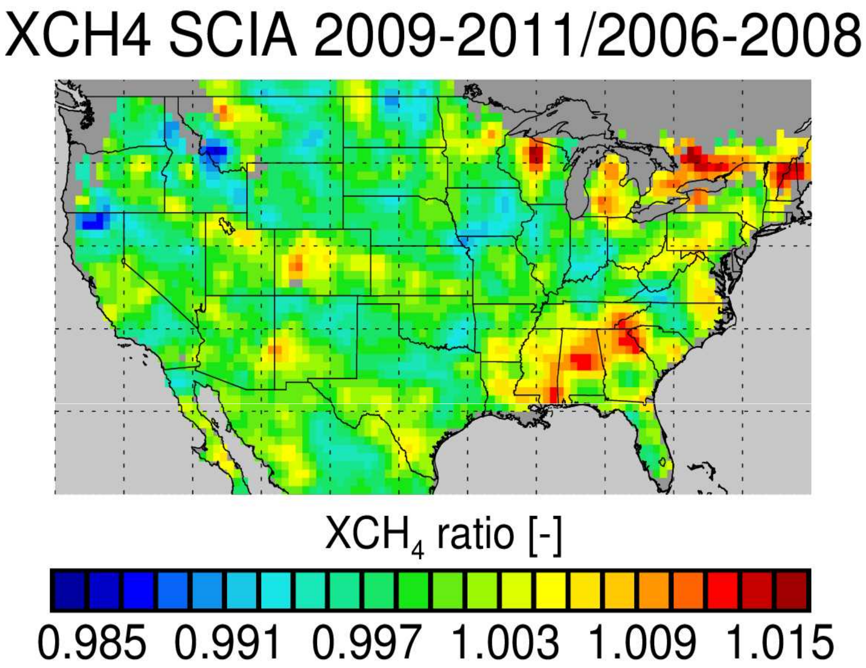
Anthropogenic and biomass burning emissions

Methane @ high latitudes

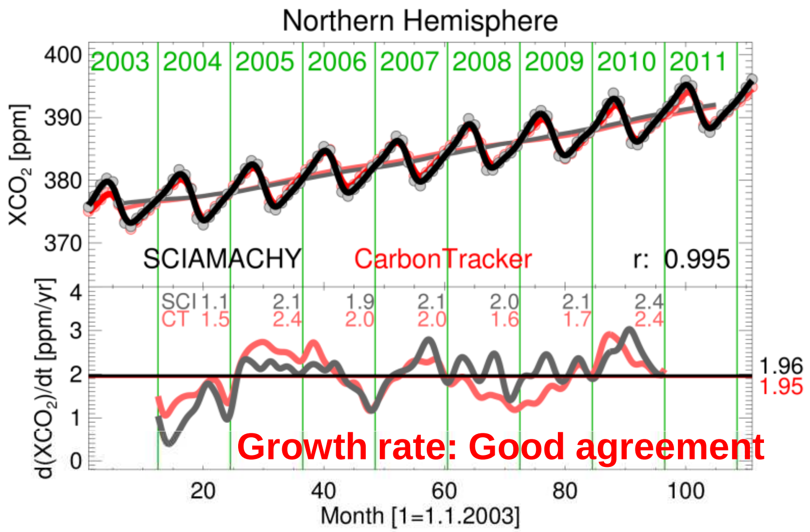


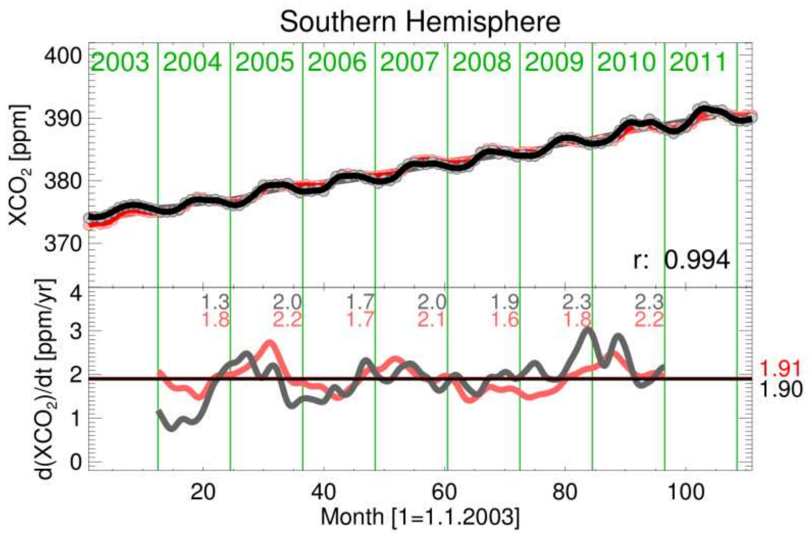
Future observation of methane in vulnerable high latitude regions including Arctic sea and shelf areas. Very difficult with SCIAMACHY & GOSAT. Not possible with OCO.

Shale Gas increase an other changes in CH_4 from 2003-2008 and 2009 to 2011

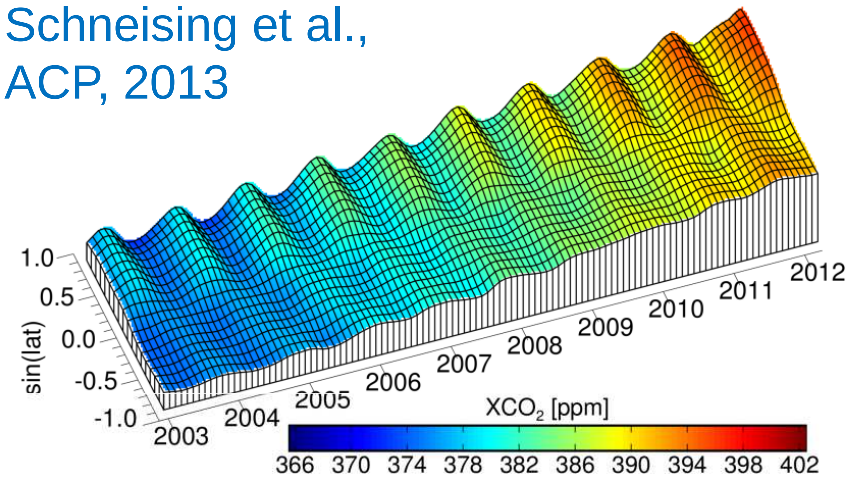


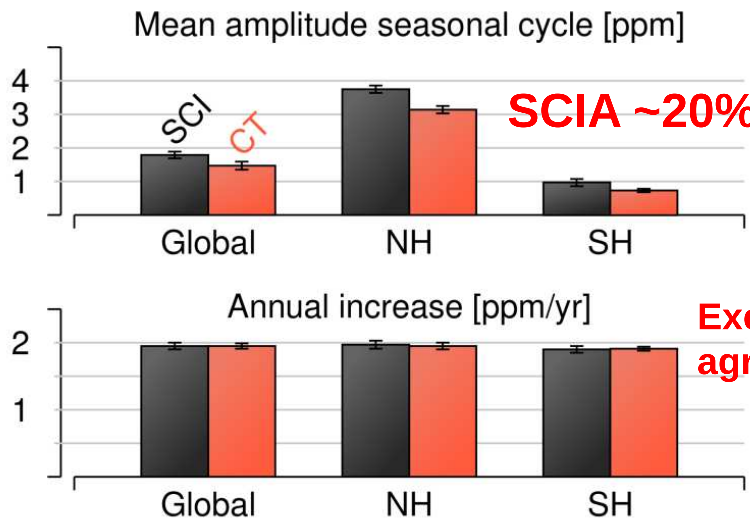
Model comparison: SCIAMACHY/WFMD XCO_2 versus NOAA's CarbonTracker





Schneising et al., ACP, 2013





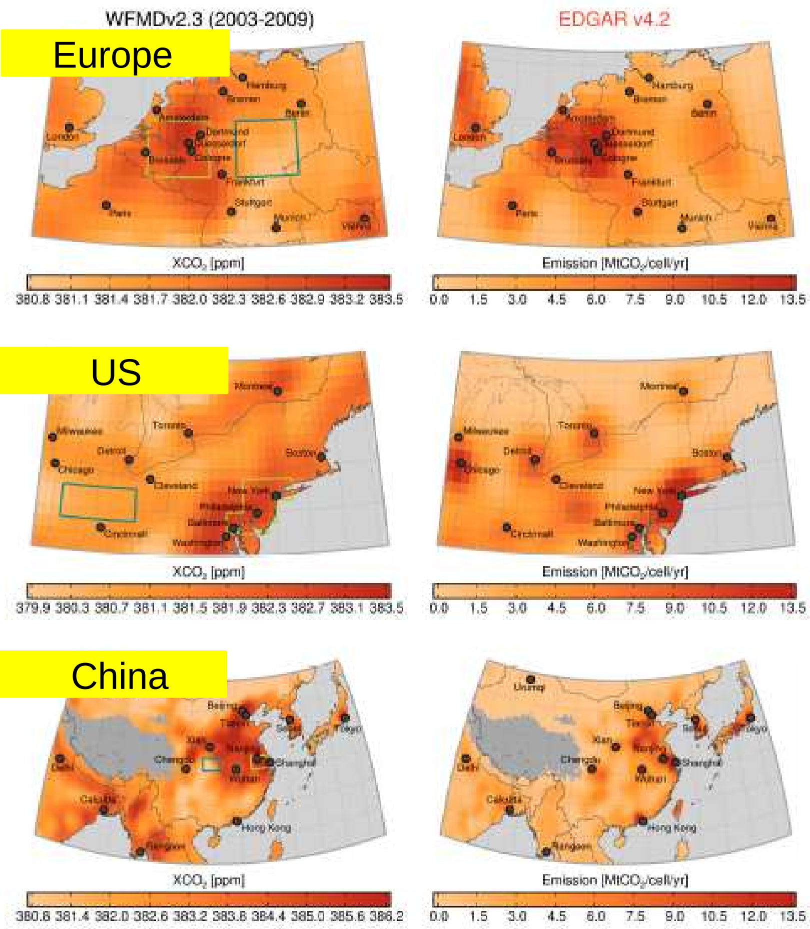
SCIA ~20%larger

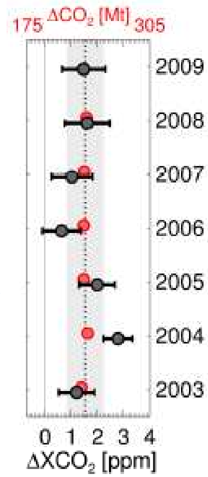
Exellent agreement

Carbon Cycle Applications: CO_2 over major anthropogenic source regions

Schneising et al., 2013

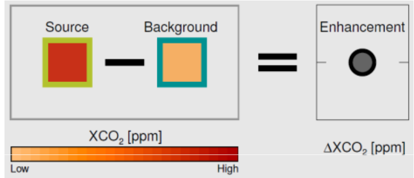
SCIAMACHY XCO_2 | EDGAR CO_2 emissions

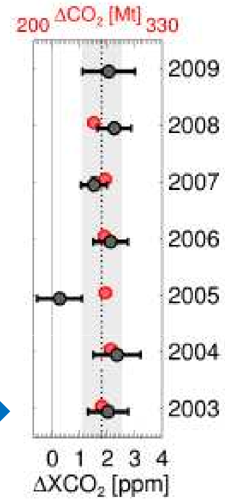


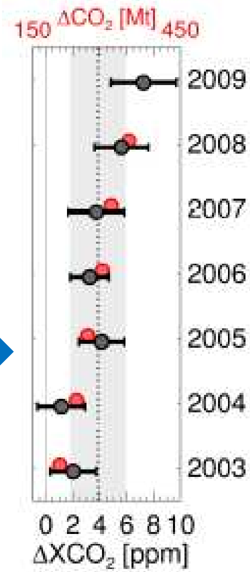


SCIAMACHY
EDGAR

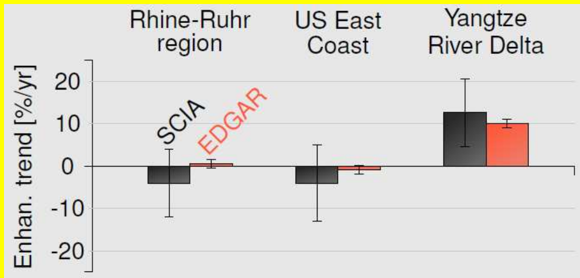
Regional enhancement =
Source - Background







Trend [$\%CO_2/yr$]



EDGAR emissions consistent with SCIAMACHY

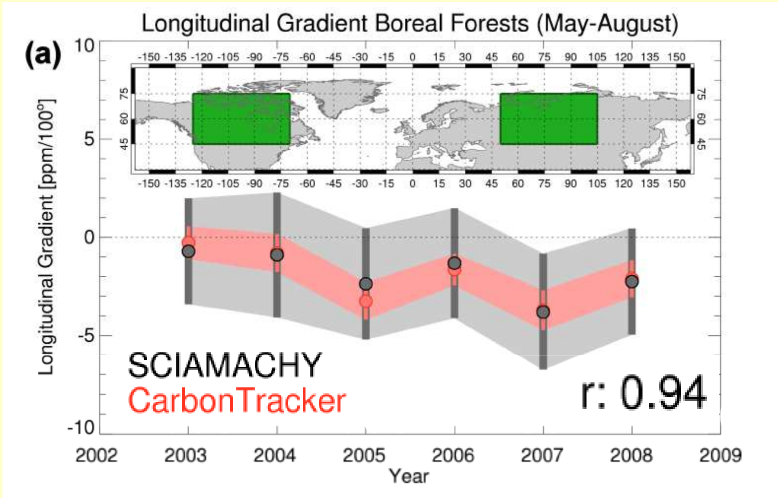
Carbon sink issues: Boreal forest carbon uptake?

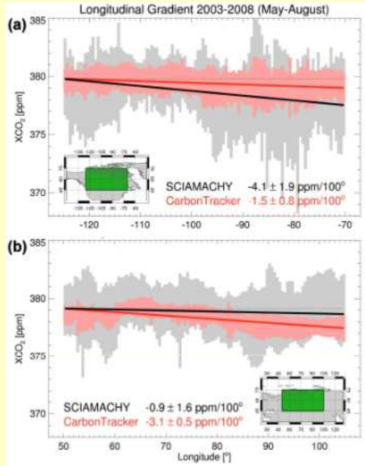
Approach: Analysis of XCO_2 **longitudinal gradients** (along wind) during growing season:

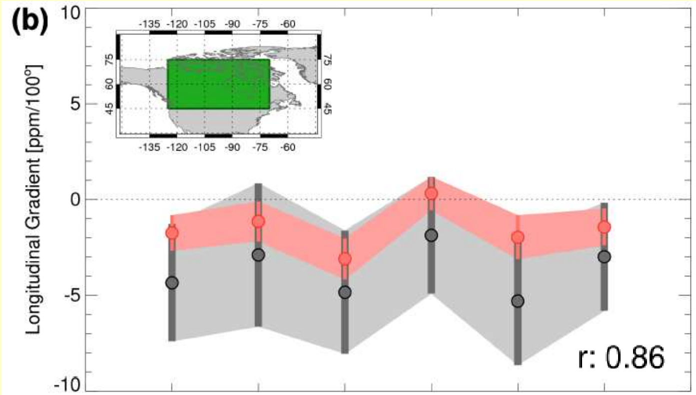
Schneising et al., ACP, 2011

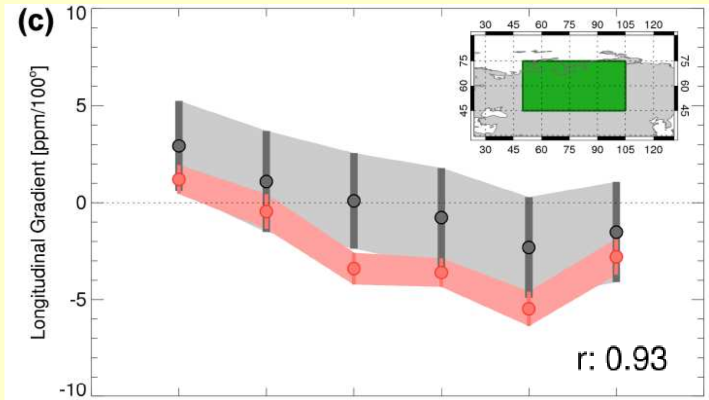
Overall:
Excellent agreement !

SCIAMACHY vs CarbonTracker





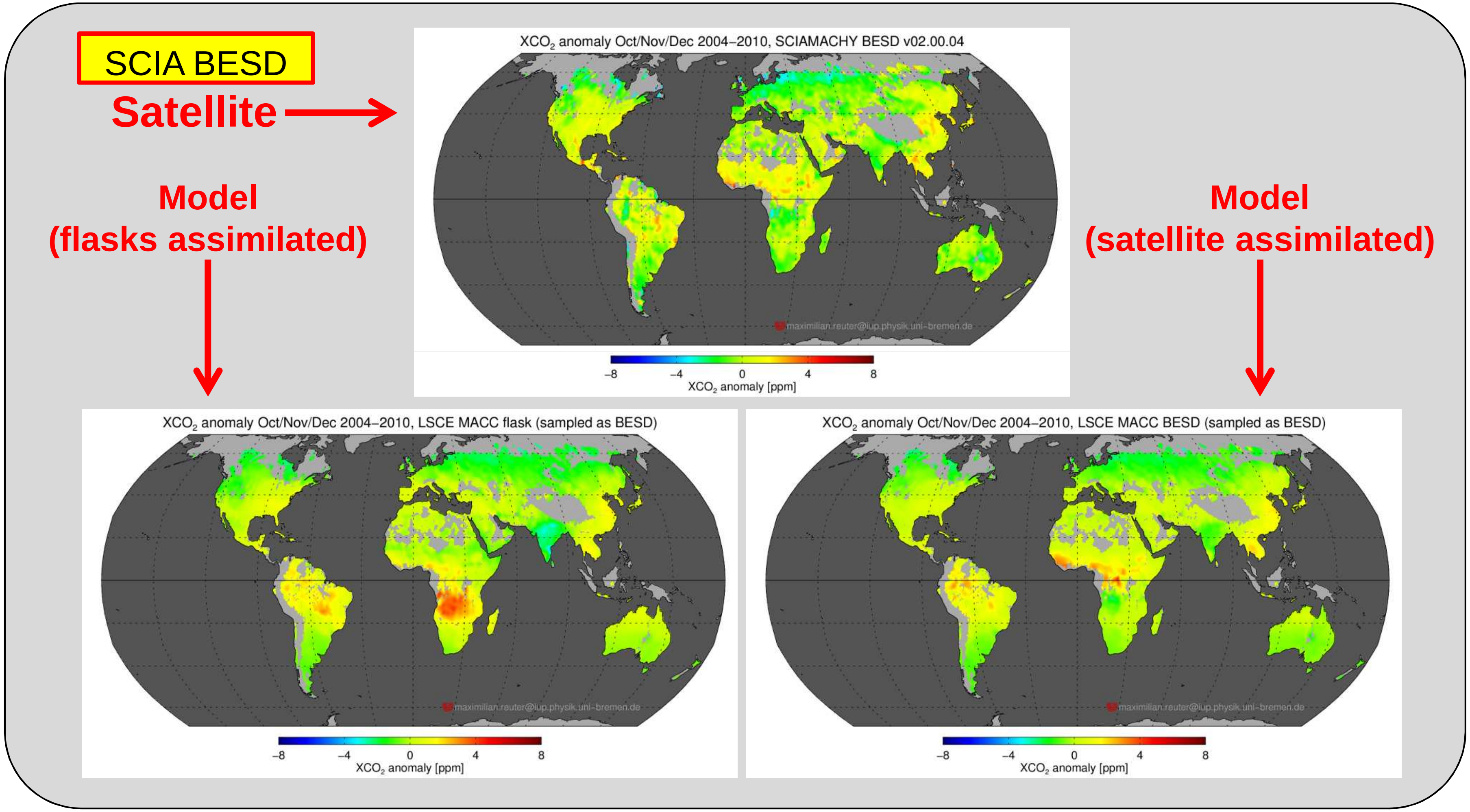




Canada: Stronger uptake !?

Siberia: Weaker uptake !?

SCIAMACHY/BESD XCO_2: Initial CO_2 flux inversion



LSCE/MACC Courtesy: F. Chevallier, LSCE