Earth2Class Workshops for Teachers

State of Carbon Cycle in 2009 in the Eve of the Copenhagen International Climate Conference: Challenge to the Humanity

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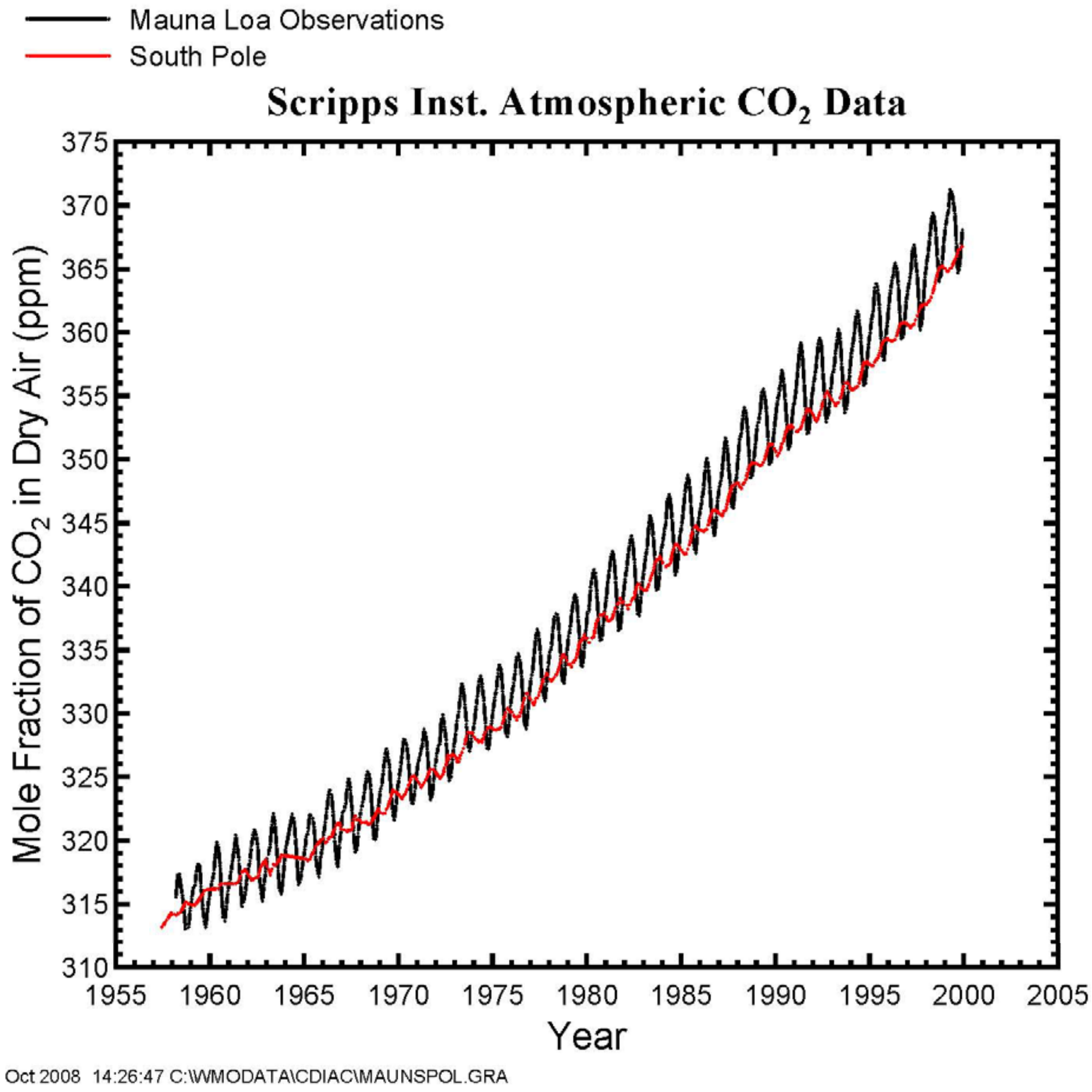
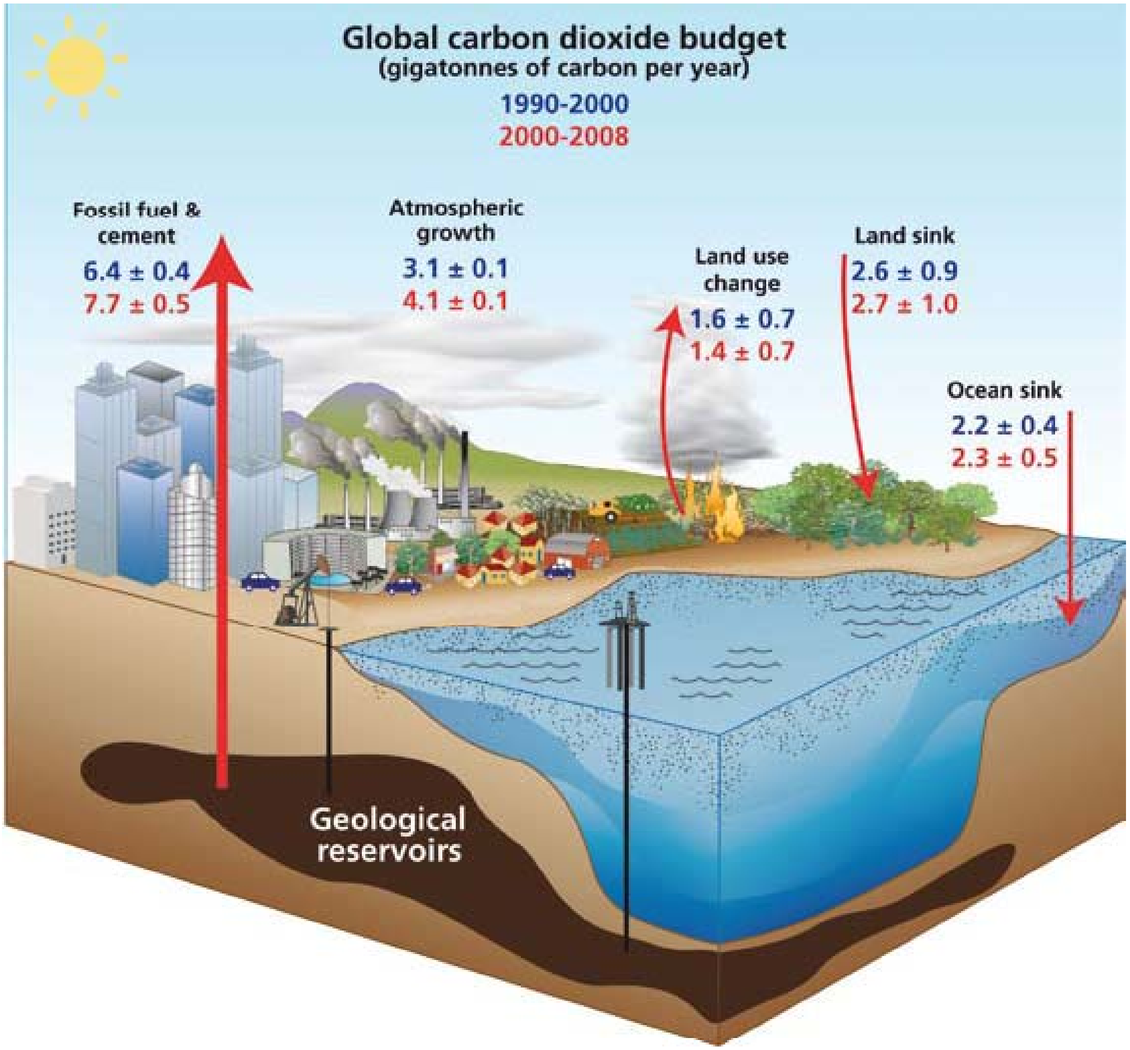
November 21, 2009

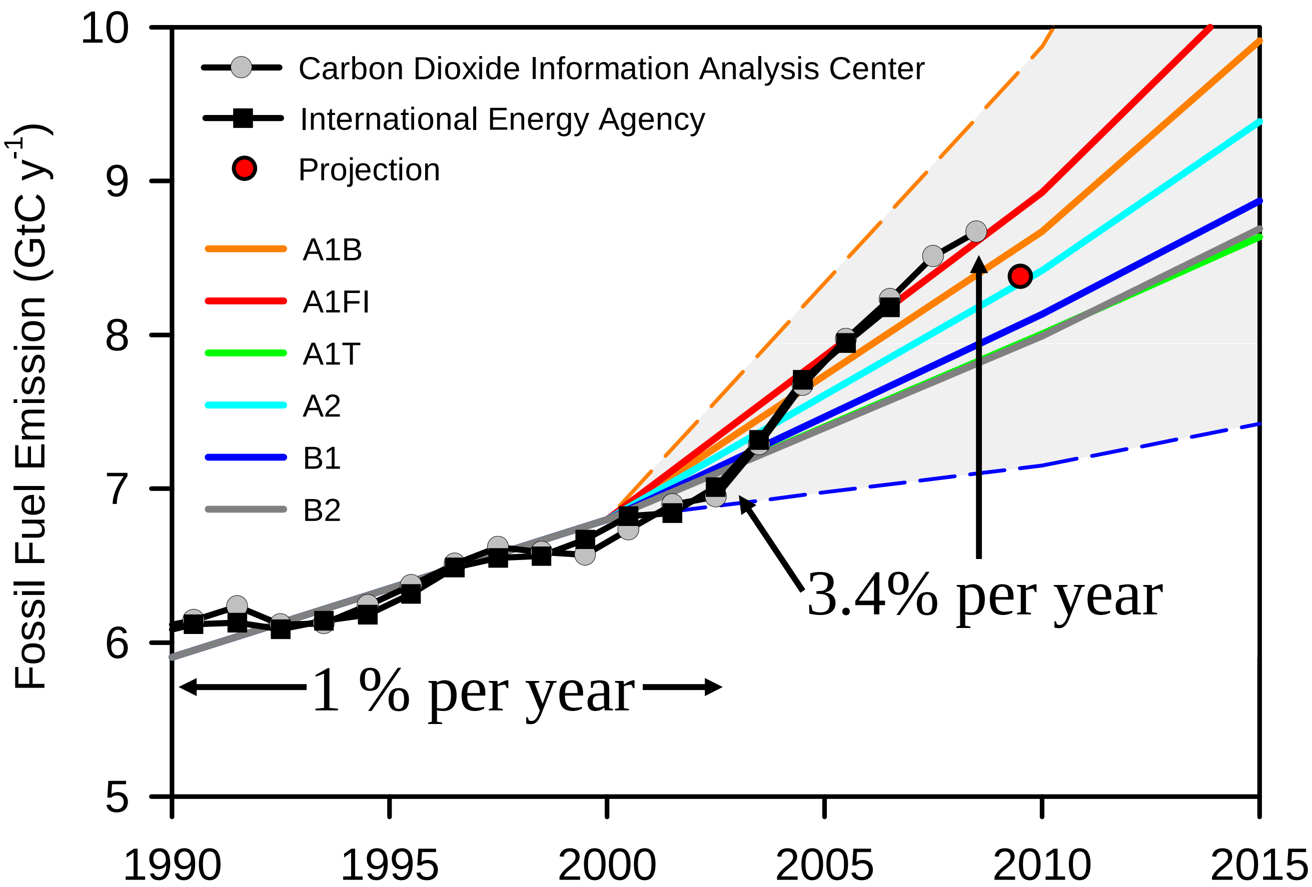
Air CO2 at Mauna Loa and South Pole, 1957-2000



Global Carbon Cycle



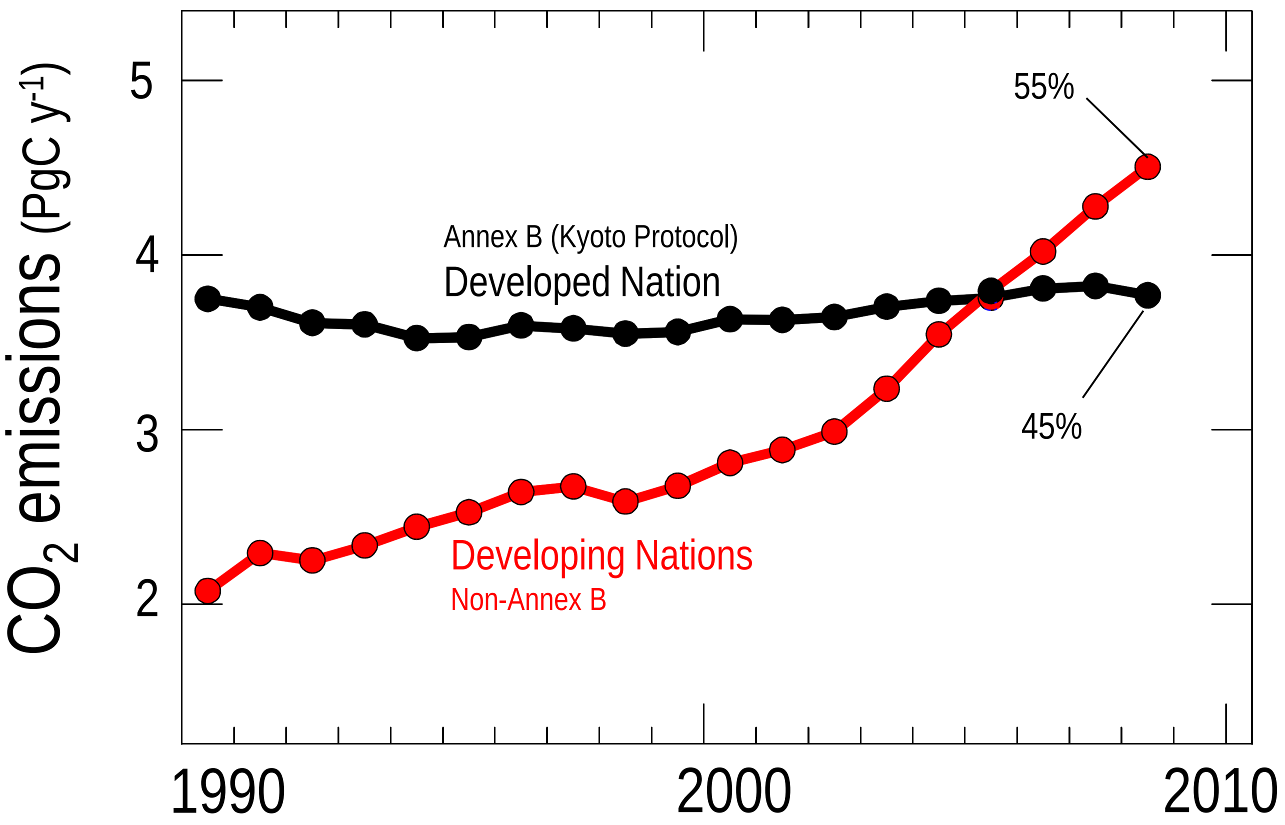
Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Projection 2009
Emissions: -2.8%
GDP: -1.1%
C intensity: -1.7%

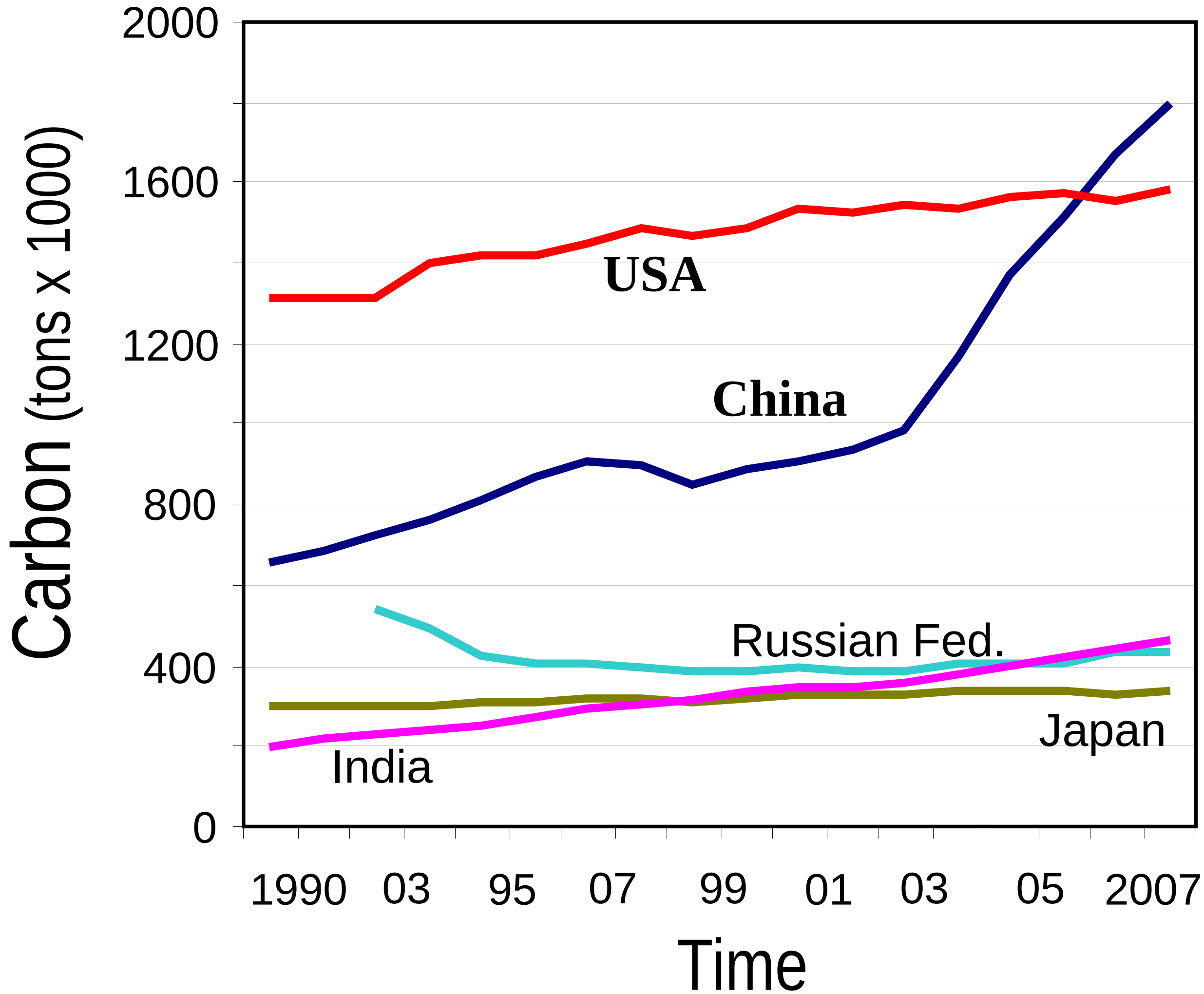
Raupach et al. 2007, PNAS, updated; Le Quéré et al. 2009, Nature-geoscience; International Monetary Fund 2009

Annual Emission Rate of Carbon to the Atmosphere



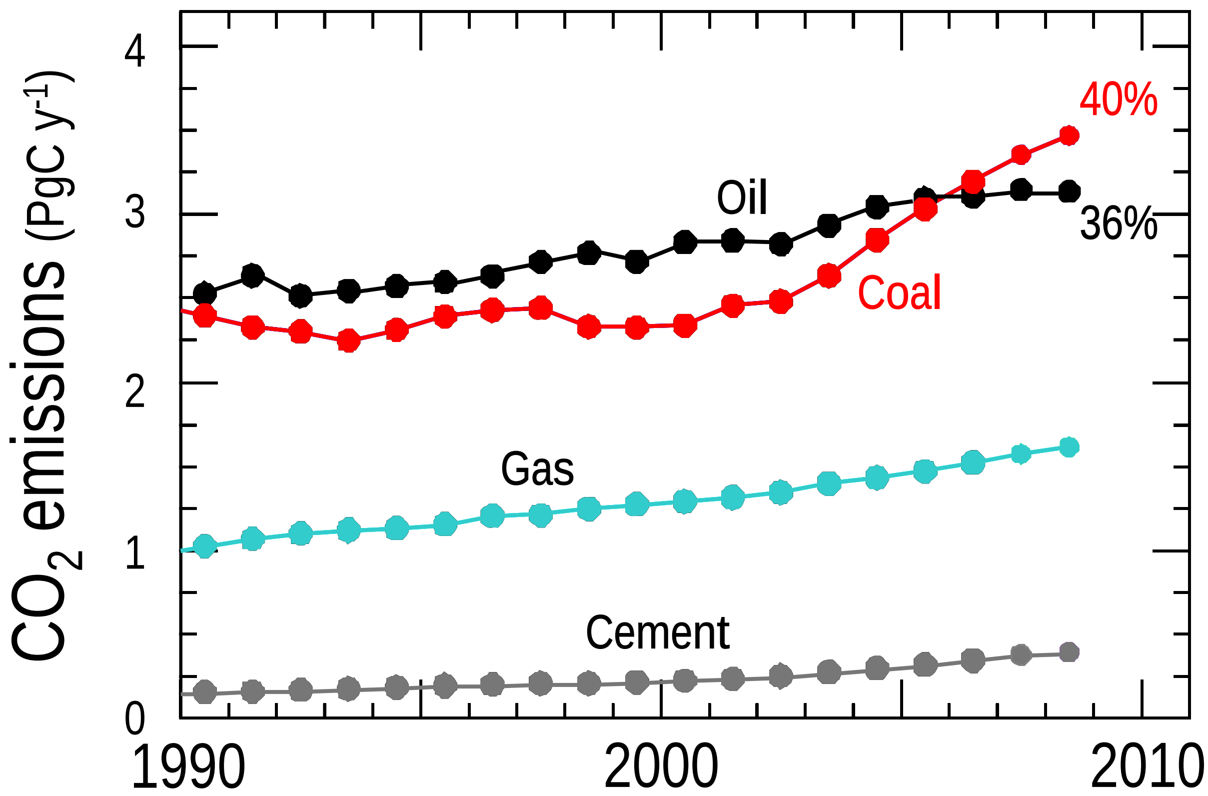
Le Quéré et al. 2009, Nature-geoscience; CDIAC 2009

Fossil Fuel Emissions: Top Emitters (>4% of Total)



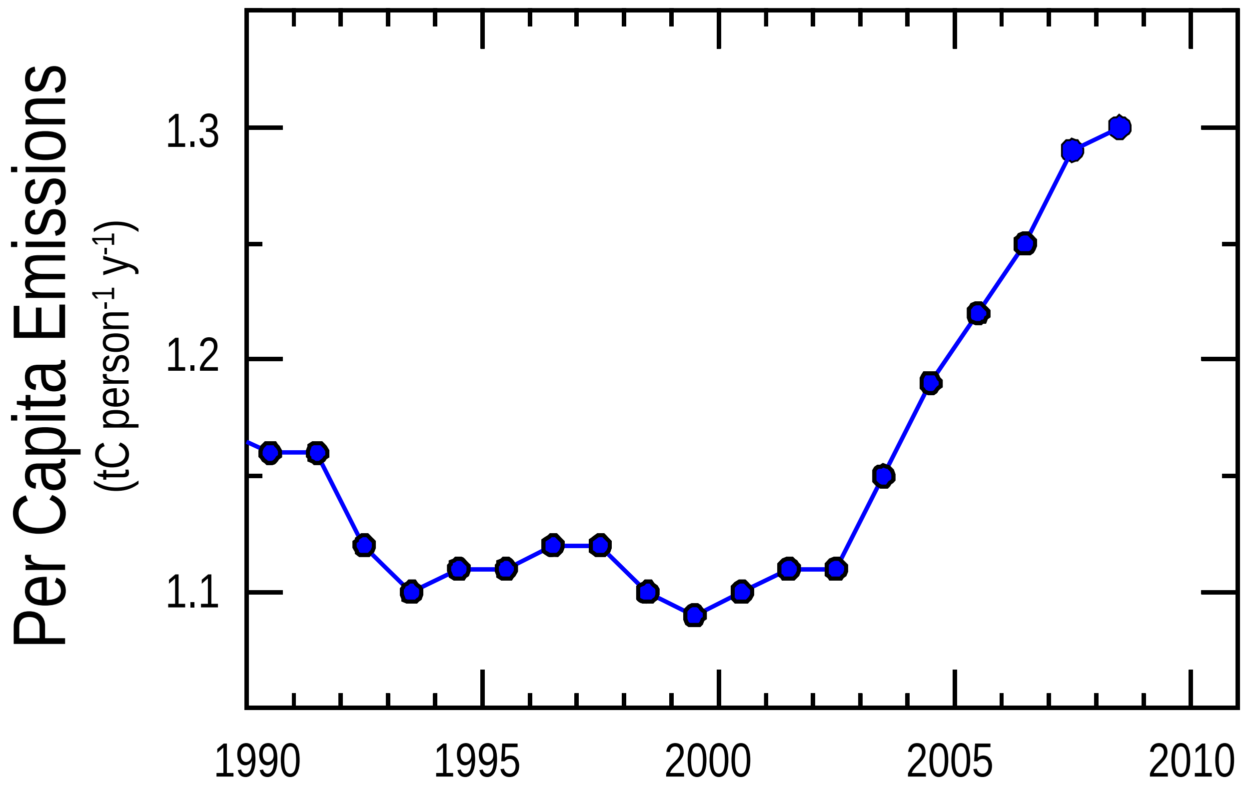
Global Carbon Project 2009; Data: Gregg Marland, CDIAC 2009

Components of FF Emissions



Le Quéré et al. 2009, Nature-geoscience

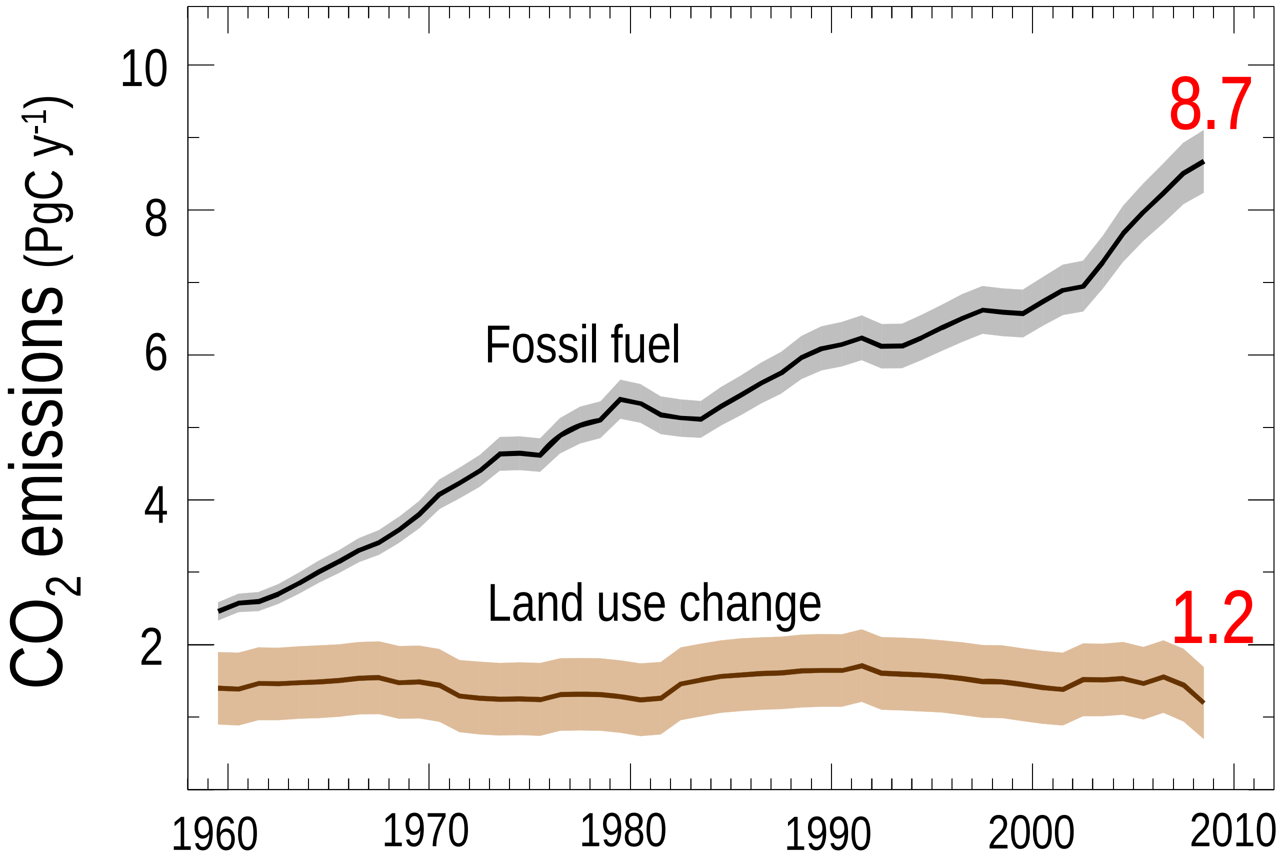
Per Capita CO_2 Emissions



Develop countries continue to lead with the highest emission per capita

Le Quéré et al. 2009, Nature-geoscience; CDIAC 2009

Total Anthropogenic Carbon Emissions

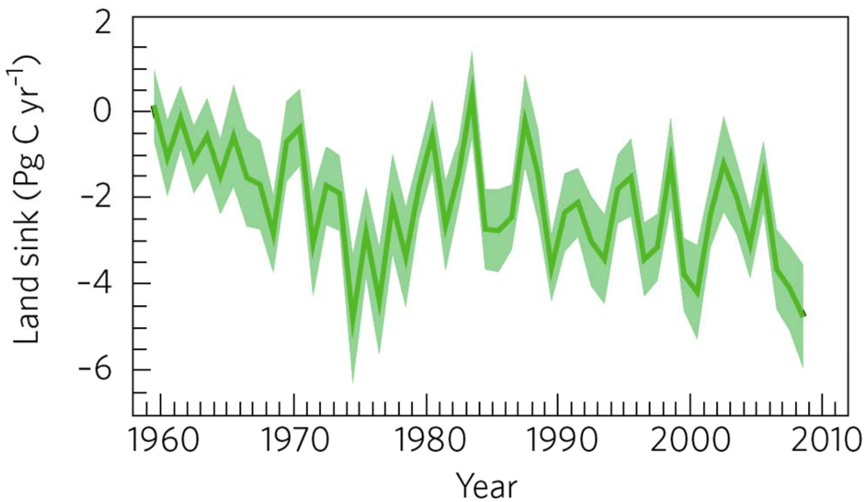


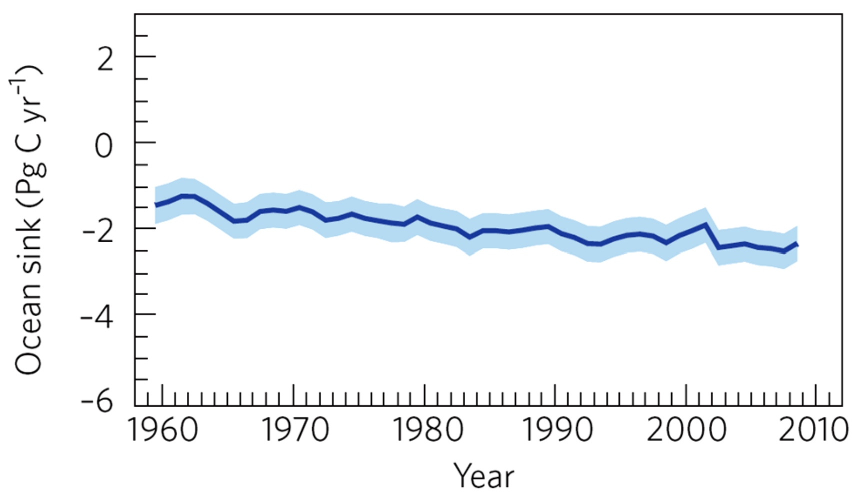
9.9 PgC

12% of total anthropogenic emissions

Le Quéré et al. 2009, Nature-geoscience; Data: CDIAC, FAO, Woods Hole Research Center 2009

Modeled Carbon Sink Rates for Land Biosphere and Oceans

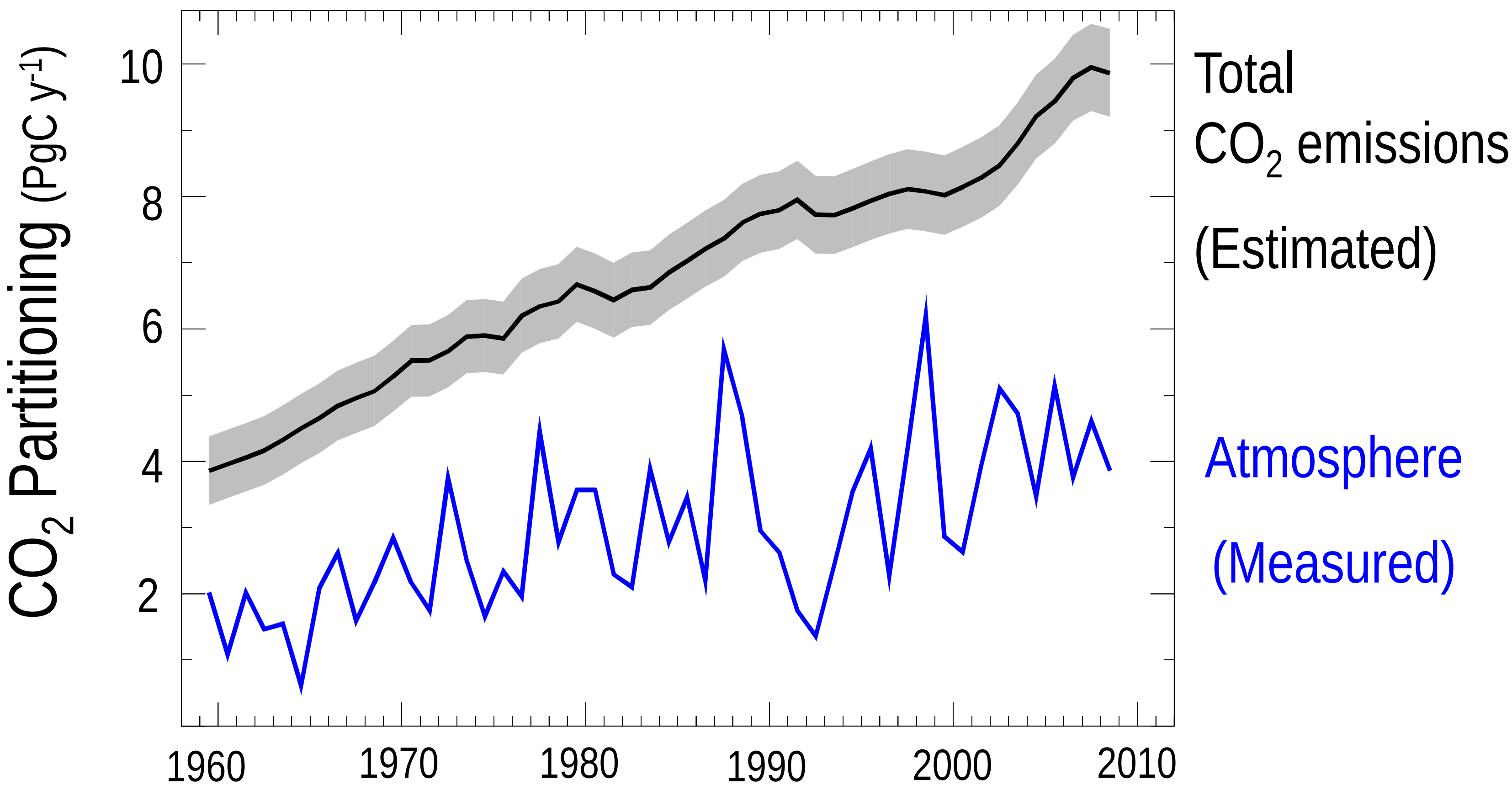




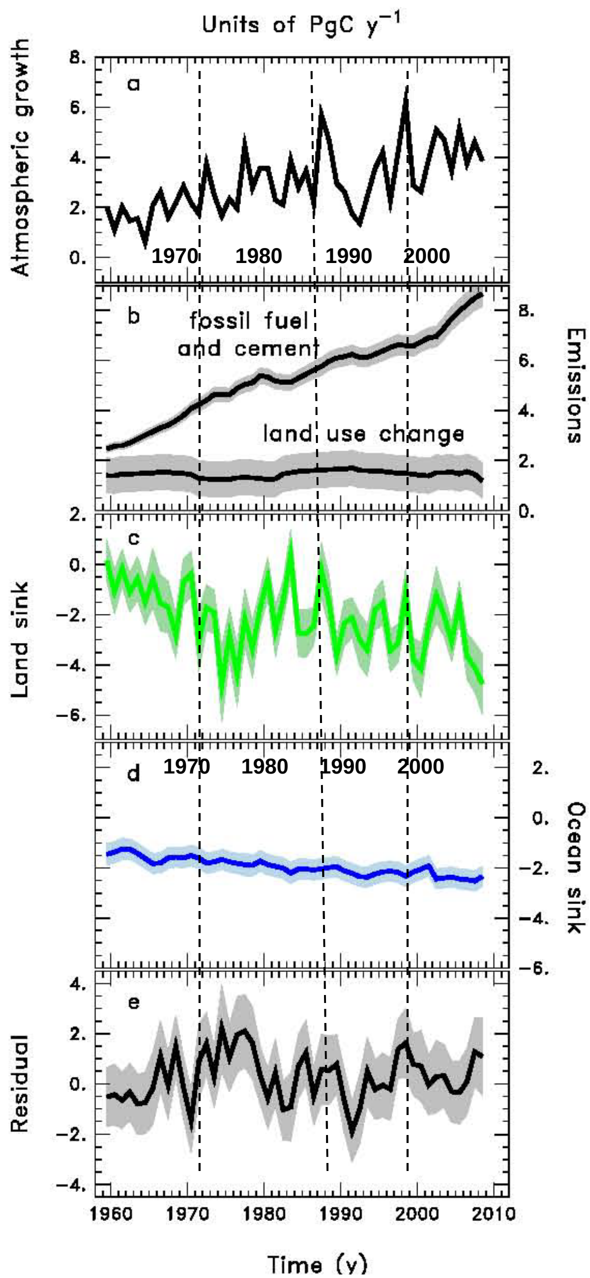
Le Quéré et al. 2009, Nature-geoscience

Carbon Accumulation Rates in the Atmosphere

Evolution of the fraction of total emissions that remain in the atmosphere



Data: NOAA, CDIAC; Le Quéré et al. 2009, Nature-geoscience



CO_2 EMISSIONS, SEA AND LAND UPTAKE

All units are in Pg-C per year
(1 Peta-gram = 10^{15} grams
= 1 Giga tons)

Balance in recent years:

Industrial emissions ~ 8.5 Pg-C/yr
Land use change ~ 1.5 Pg-C/yr
TOTAL EMISSIONS ~ 10.0 Pg-C/yr

Atmospheric growth 4.5 Pg-C/yr
Land biota uptake ~ 4 Pg-C/yr
Ocean uptake ~ 2 Pg-C/yr
RESERVOIRS ~10.5 Pg-C/yr

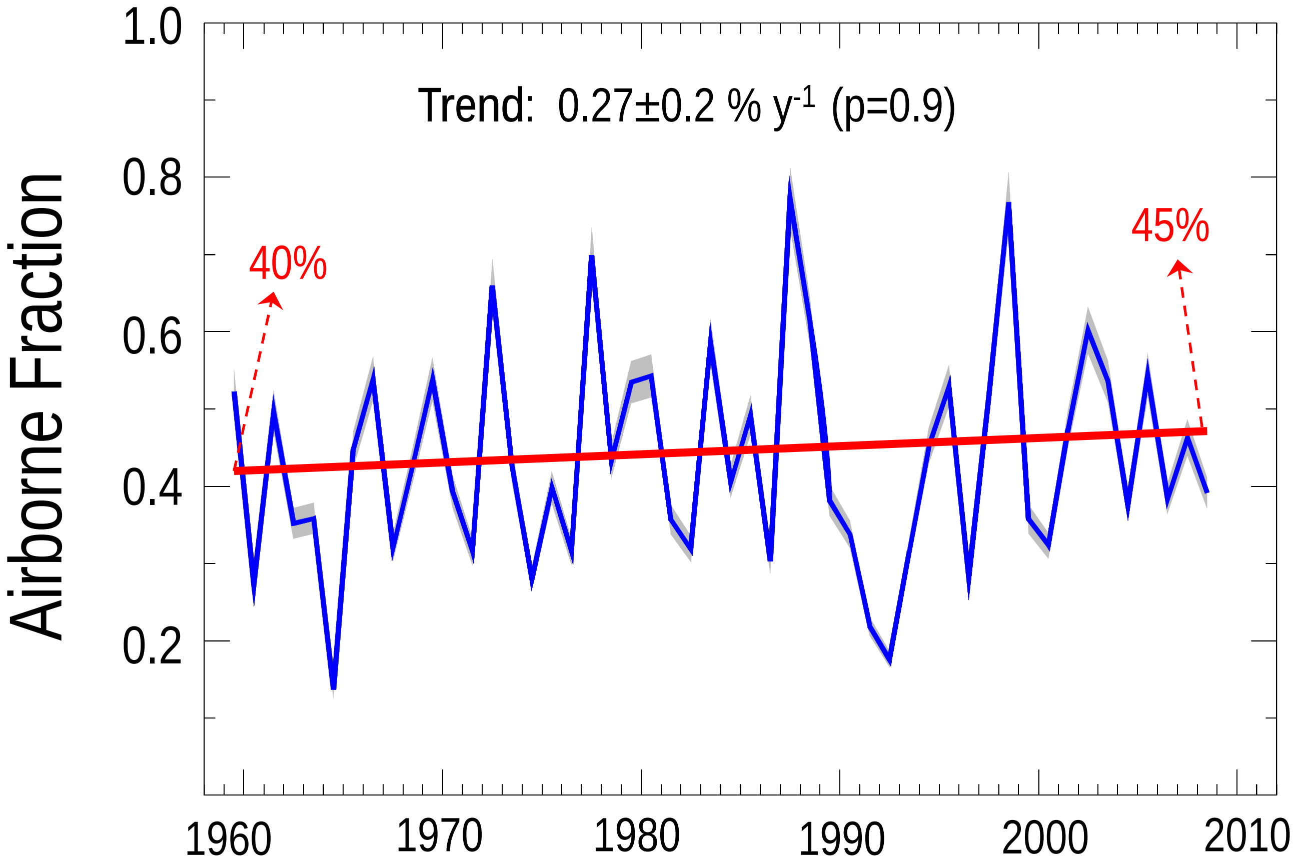
RESIDUALS = (TOTAL EMISSIONS) -(ATM.) – (LAND) – (OCEAN) = ~ 0 on the average, but vary from +3 to –3 Pg-C/yr from year to year.

Le Quere et al. (2009) Nature GS.

Airborne Fraction of Anthropogenic Carbon Emissions

Fraction of total CO_2 emissions that remains in the atmosphere

(Amount of Carbon Increase each year)/(Annual Total Anthropogenic Emission)



Are the natural carbon sinks weakening?

Le Quéré et al. 2009, Nature-geoscience; Canadell et al. 2007, PNAS; Raupach et al. 2008, Biogeosciences

Sea-Air CO_2 Exchange and CO_2 partial pressure

CO_2 in seawater = $\{[CO_2]aq + [H_2CO_3]\} + [HCO_3^-] + [CO_3^=]$

0.5 – 1 % **97%** **2.5%**

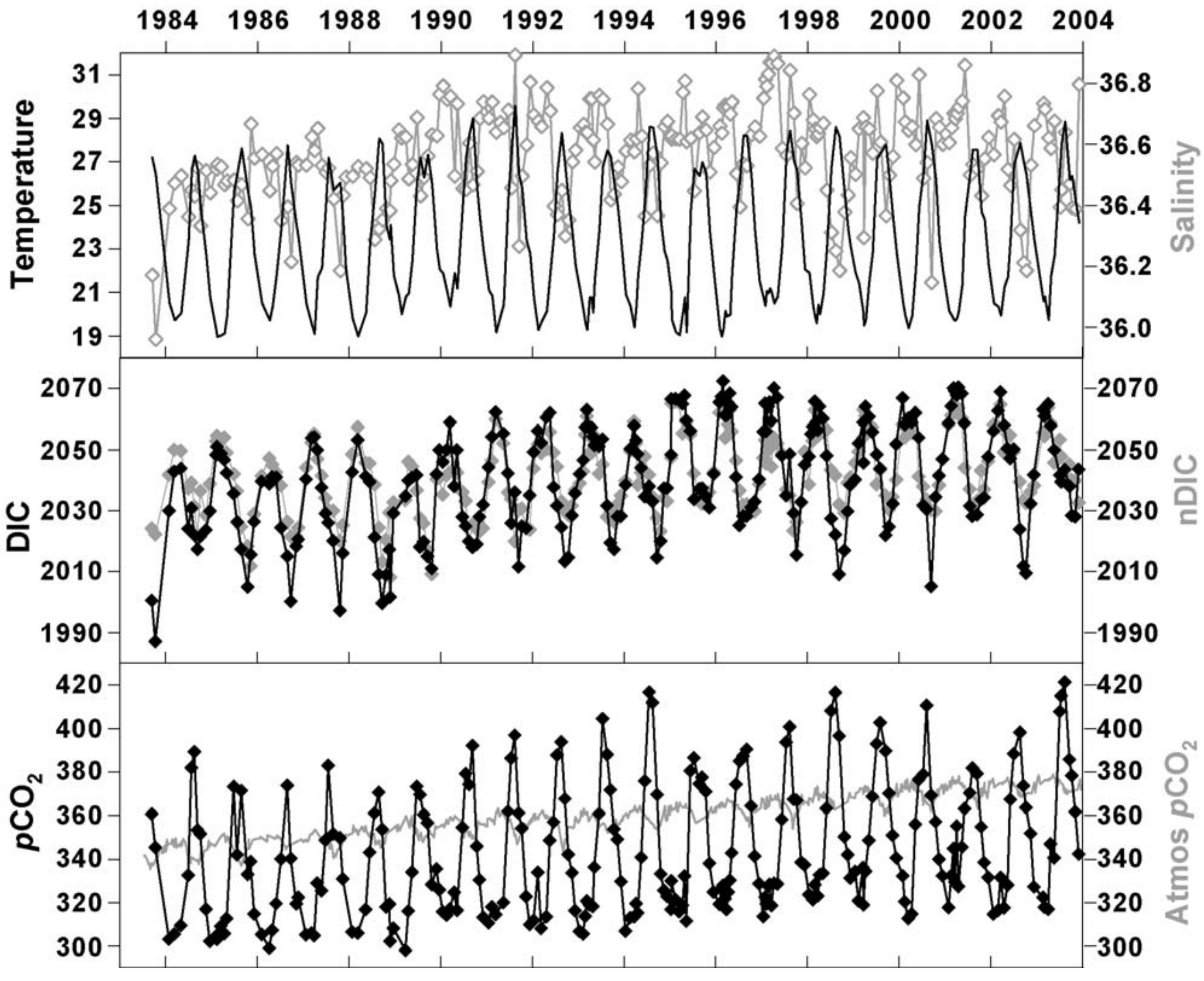
Sea exchanges CO_2 molecules with air only through $[CO_2]$aq. Since $[CO_2]$aq cannot be distinguished from $[H_2CO_3]$, they are commonly considered together.

Partial pressure of CO_2 (pCO_2) in seawater is a measure of the exchangeable CO_2 molecules, and may be considered as "vapor" pressure of CO_2.

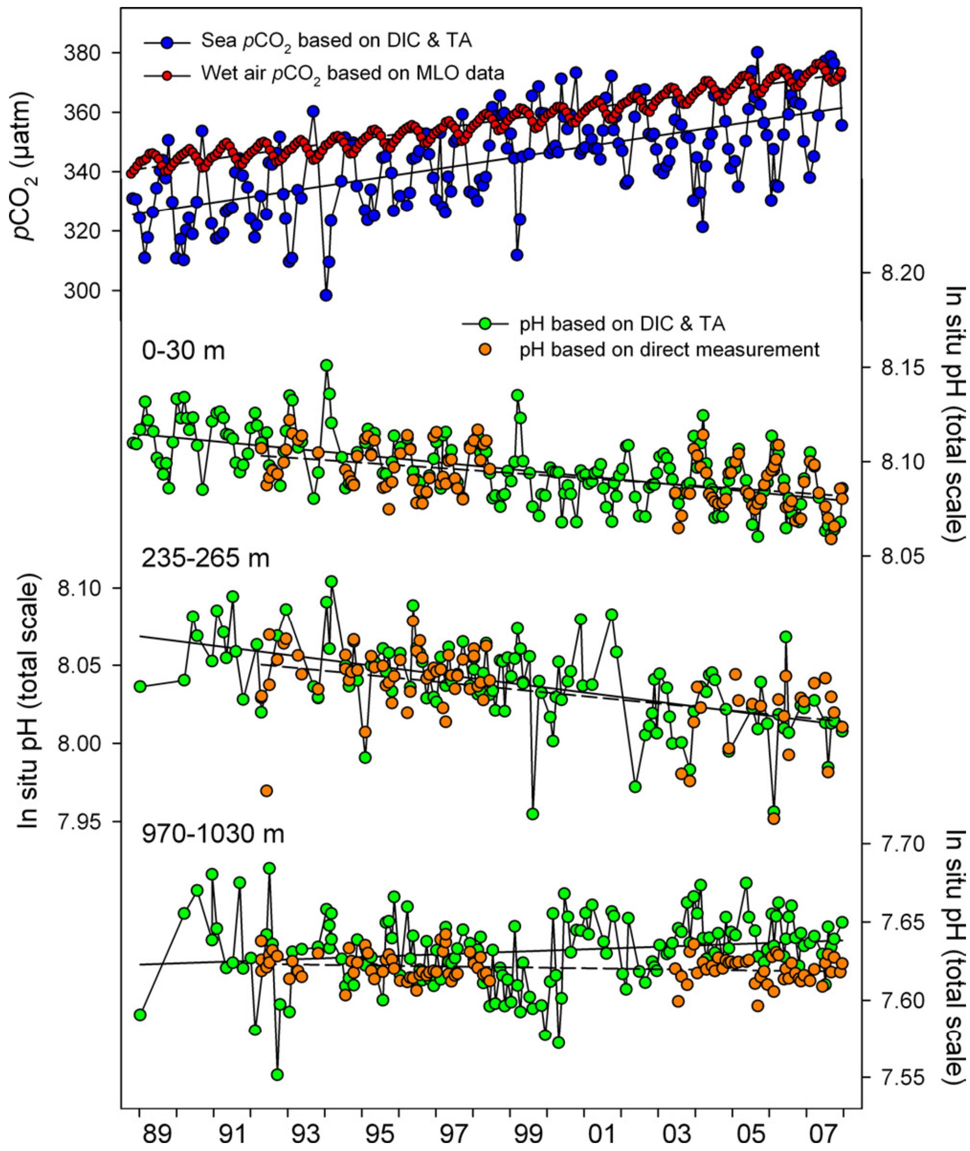
When pCO_2 in seawater is greater than that in the overlying air, CO_2 escapes from seawater to air. When pCO_2 in seawater is smaller than that in the overlying air, CO_2 in air is absorbed by seawater. pCO_2 in seawater is sensitively affected by temperature, photosynthesis and calcification.

BERMUDA TIME SERIES (N. R. BATES, JGR, 2007)

1984-2004 MEAN RATE = 1.80±0.013 μatm/yr for ocean, 1.80 μatm/yr for air



1989-2007 HAWAII TIME SERIES (HOT), Dore et al. PNAS, 2009

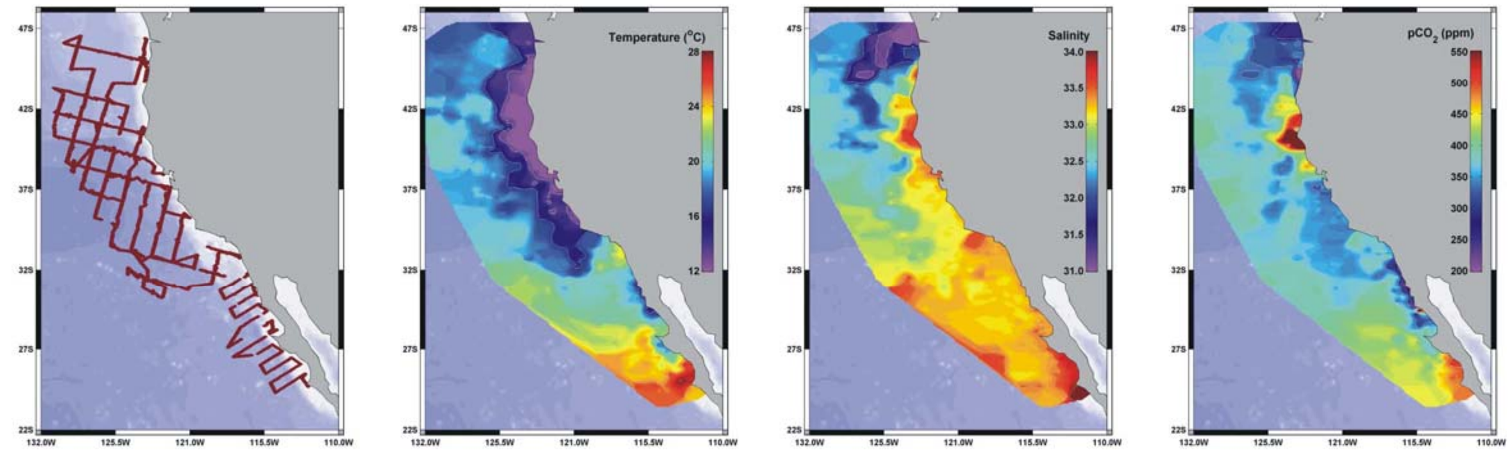


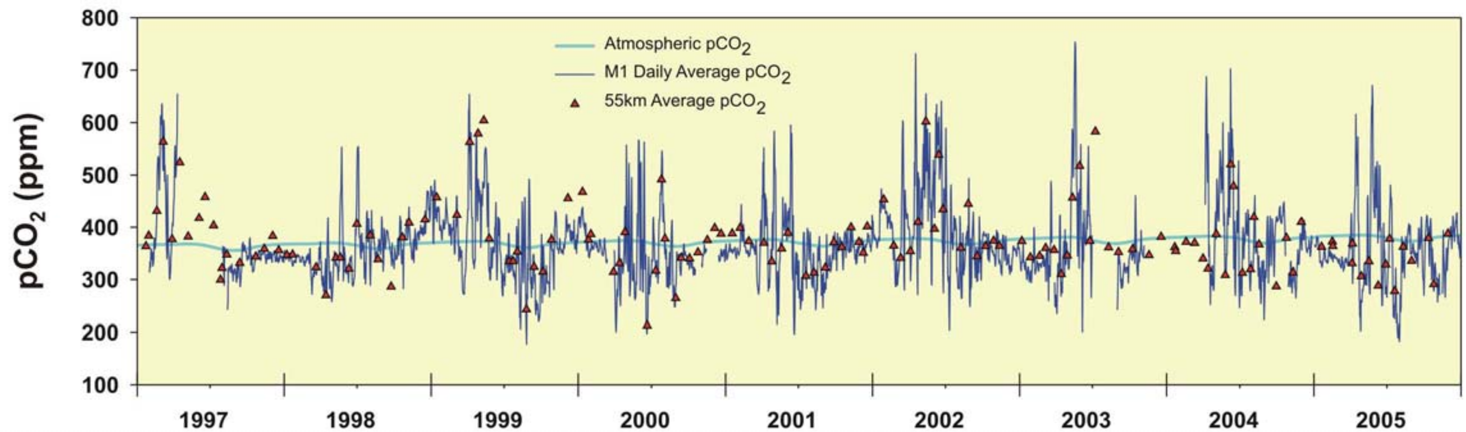
Air pCO_2 change rate = 1.68 ± 0.03 µatm/yr

Ocean pCO_2 change rate = 1.88 ± 0.16 µatm/yr

Ocean pH change rate = -0.0019 ± 0.0002 /yr

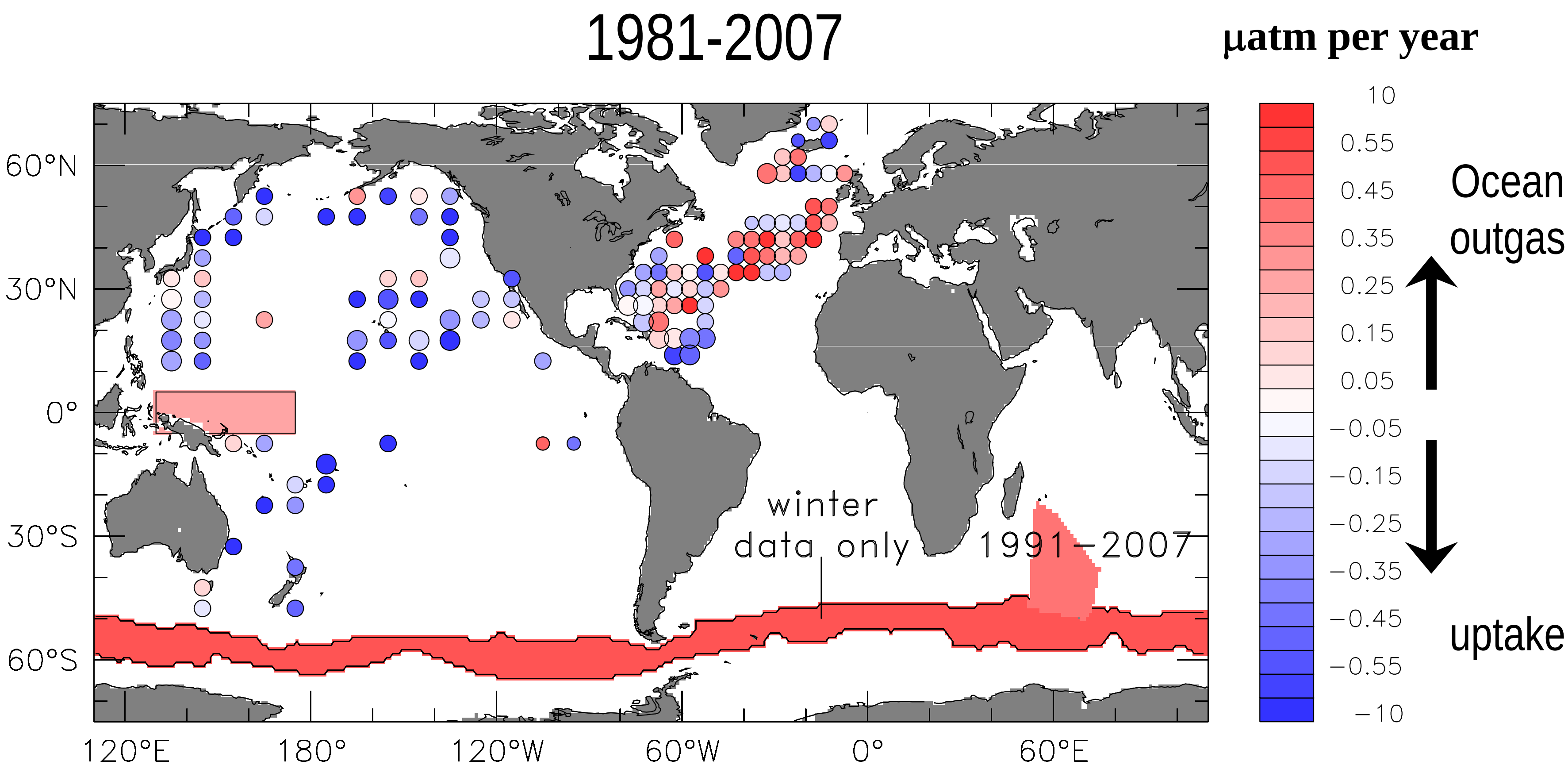
DISTRIBUTION OF SURFACE WATER PCO_2, TEMPERATURE AND SALINITY IN THE U.S. WEST COAST, JUNE-AUGUST, 2002; AND 1997-2005 TIME SERIES OF SURFACE WATER PCO2 IN THE MONTREY BAY (F. CHAVEZ, MBARI)





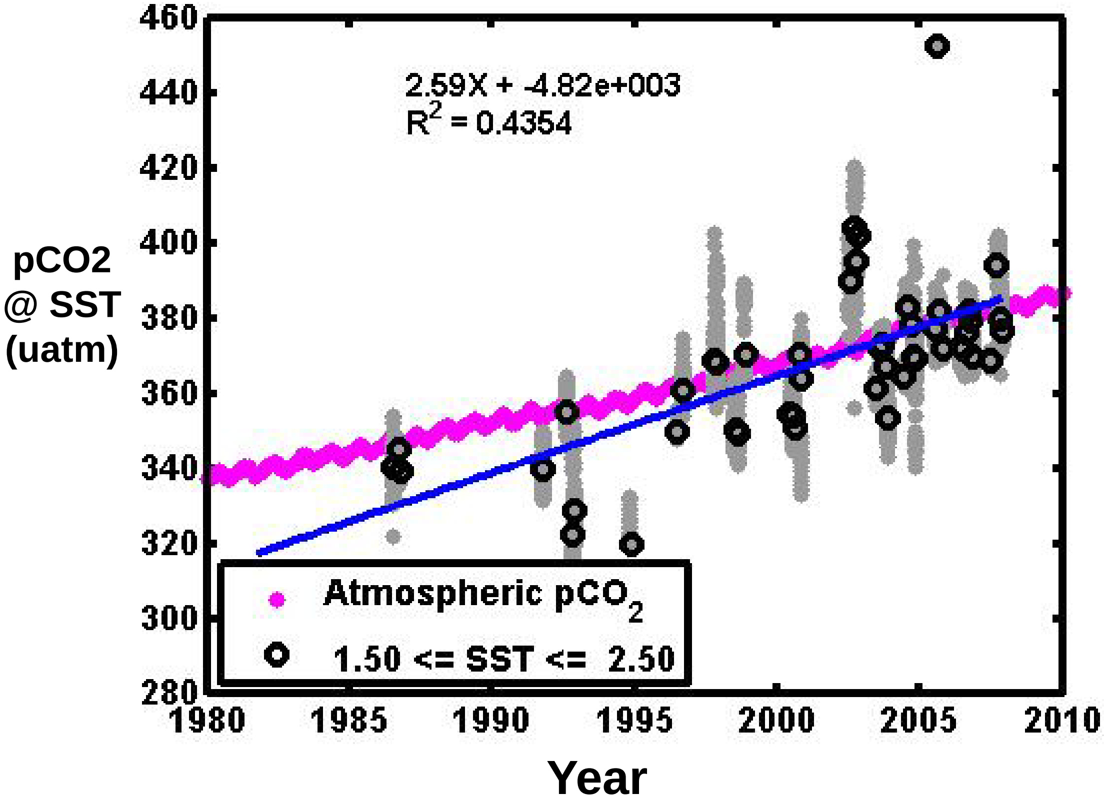
Observed Rate of Change in the Sea-Air pCO2 Difference

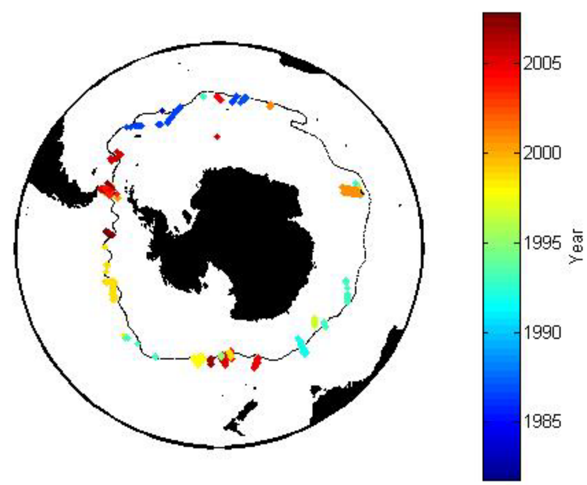
Zero = Ocean pCO2 increase rate is same as the atmospheric pCO2
Red = Ocean pCO2 increase rate is faster than the atmospheric pCO2
Blue = Ocean pCO2 increase rate is slower than the atmospheric pCO2



Le Quéré et al. 2009, Nature-geoscience

CHANGE IN WINTER TIME SURFACE WATER pCO_2
IN THE ICE-FREE ZONE (POOZ) OF THE SOUTHERN OCEAN
1.50°C < SST < 2.50°C; Day of year, 172 to 326 (late June – mid-Nov)





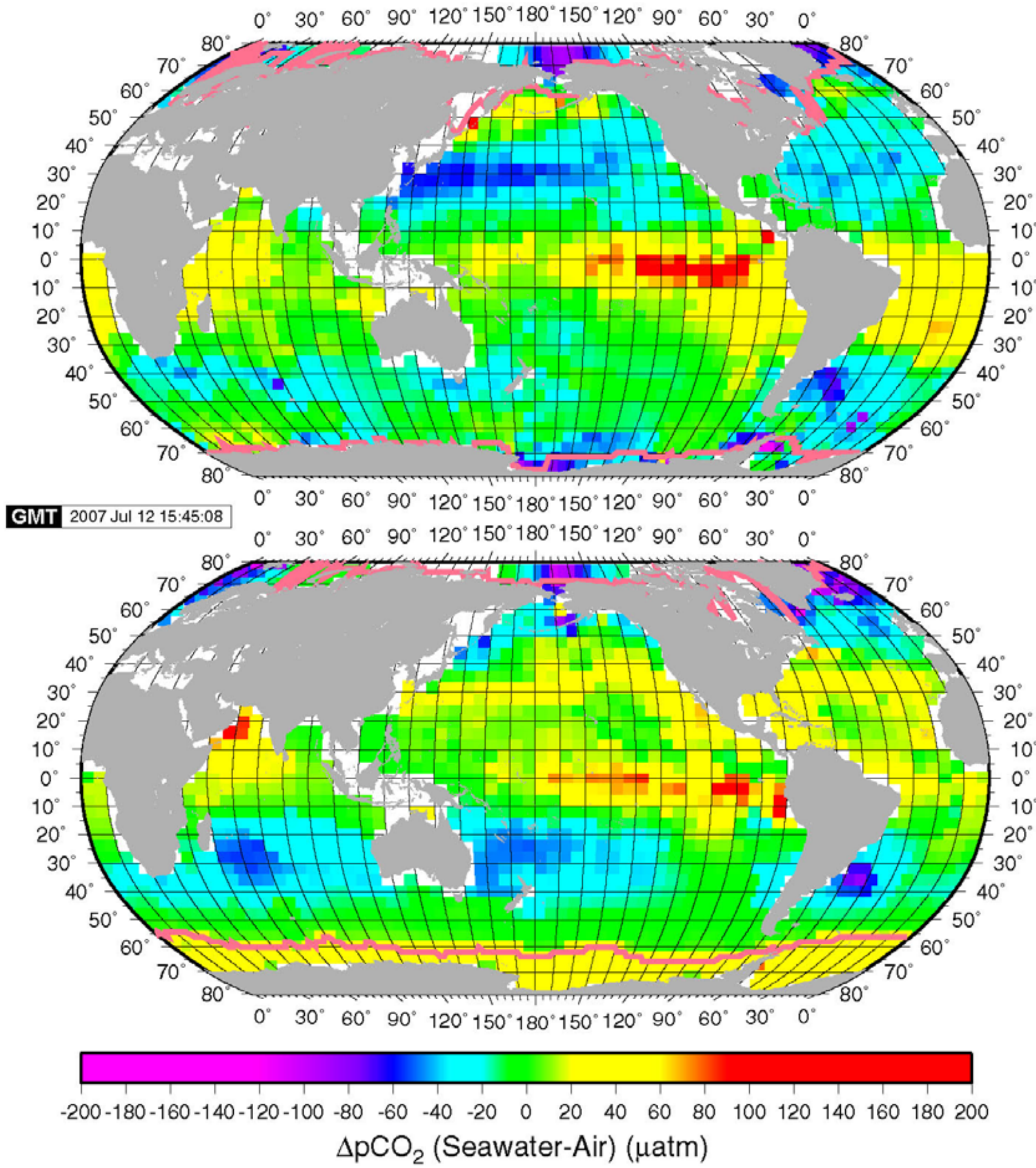
SUMMARY AND CONCLUSIONS

1) The anthropogenic emissions of CO_2 are rapidly increasing at the fastest rate anticipated by IPCC (3.4% per year) as a result of increases in "per capita carbon production rates" and human population. 2008 is an exception due to the economic recession.
2) While the carbon emissions from the Developed Countries increased only modestly, those from Developing Countries (China and India) increased very rapidly. The Developing Countries exported manufactured goods as they increased "Carbon emissions".
3) The carbon cycle in the modern world is broadly understood in the decadal scale, but not in the annual scale satisfactorily.
4) The ocean CO_2 sinks may be weakening for the past decades, while the land biota sink appears to be holding steady.
5) Unless the CO_2 emissions are reduced substantially, the atmospheric CO_2 concentrations would double the pre-industrial level by 2030. The presumed "tipping point" for the global warming of 4°F may be exceeded then.

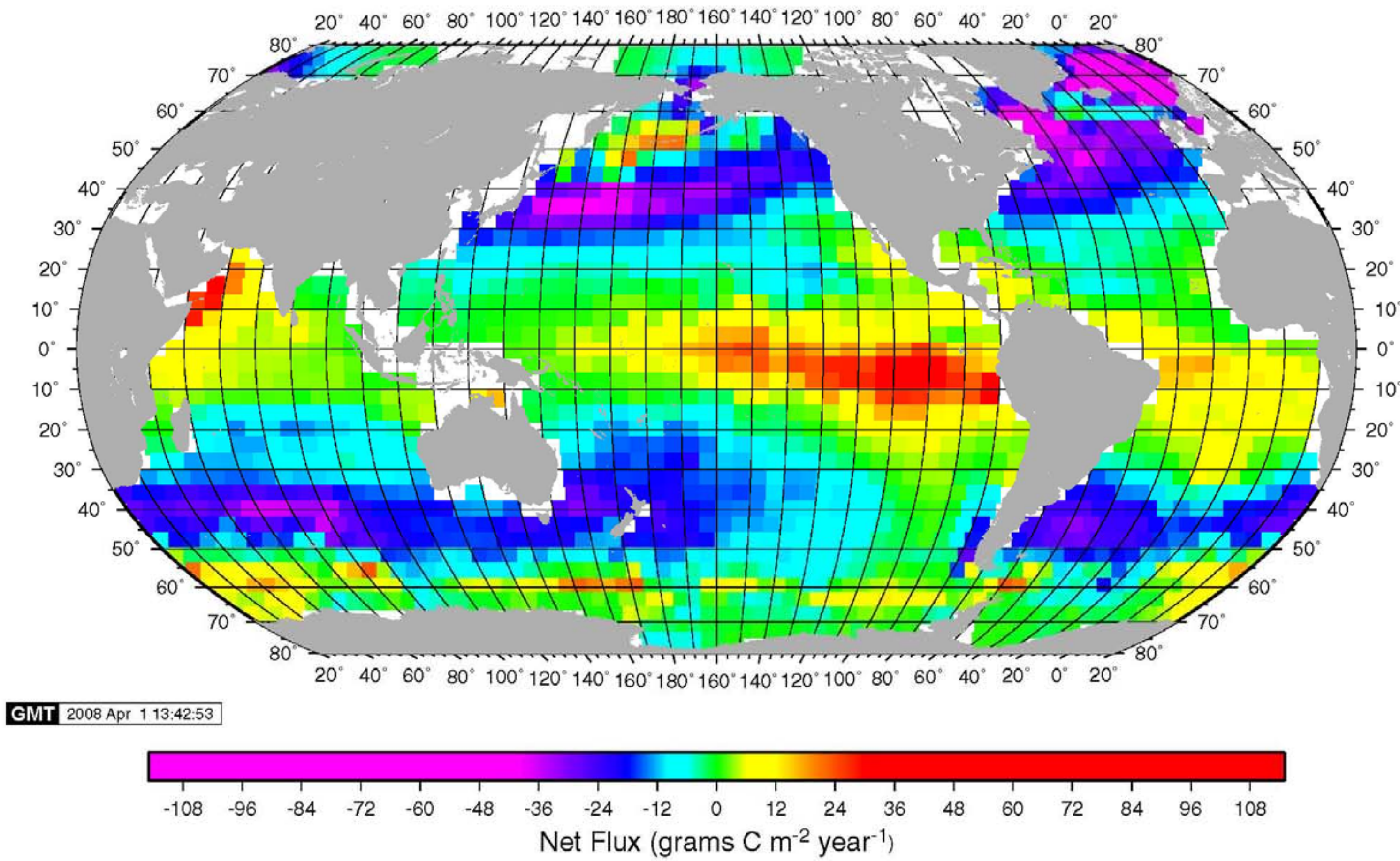
CLIMATOLOGICAL MEAN SEA-AIR pCO_2 DIFFERENCES

FEBRUARY, 2000

AUGUST, 2000



Mean Annual Air-Sea Flux for 2000 (NCEP II Wind, 3,040K, Γ=.26)



Takahashi et al. (Deep Sea Res., 2009)

ATMOSPHERIC CO2 – MARINE PHOTOSYNTHESIS - CALCIFIERS

$CaCO_3$ + CO_2 + H_2O = Ca^{++} + $2\ HCO_3^-$

SHELLS — AIR/SEA — OCEAN — DISSOLVED

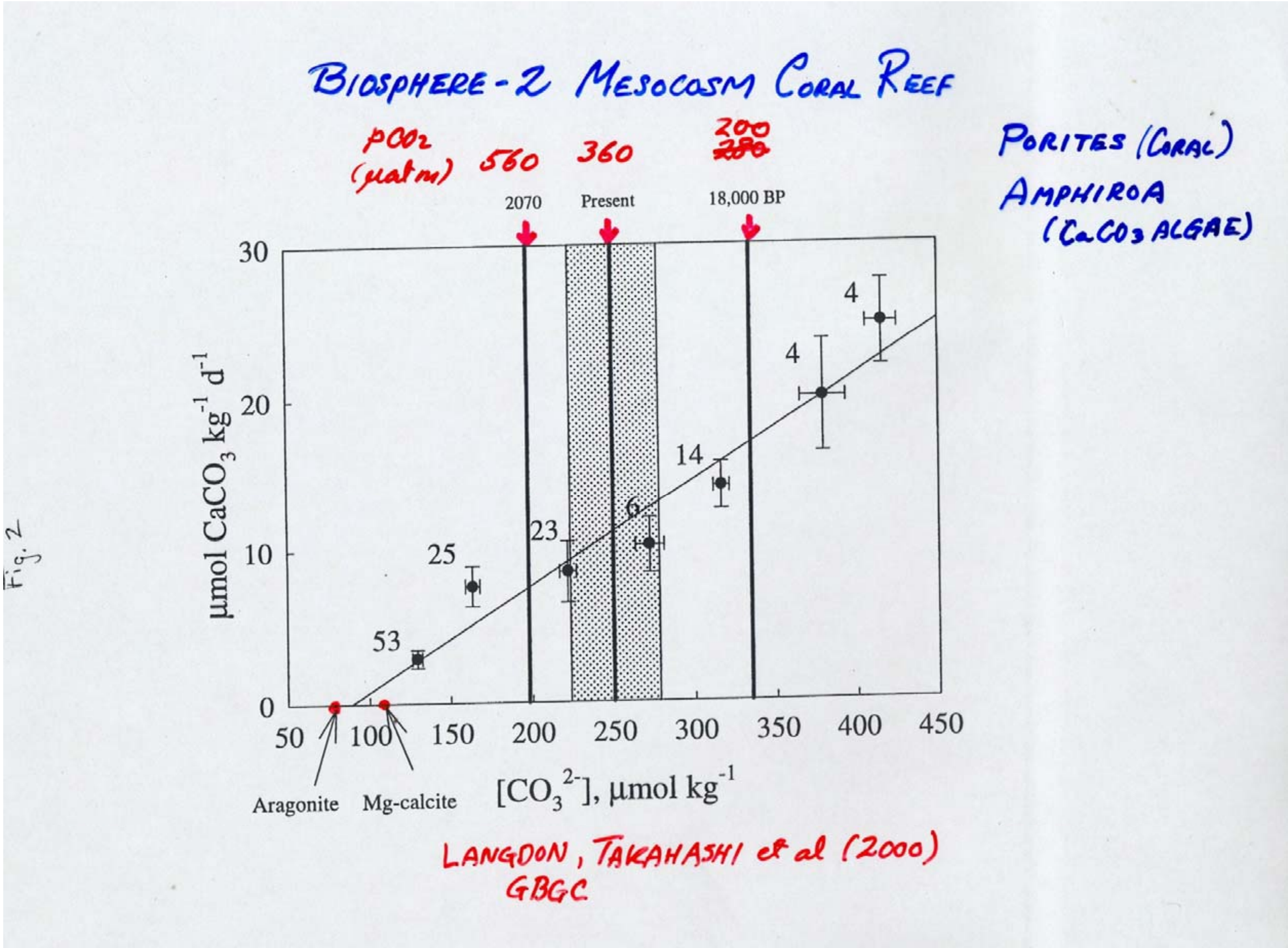
FORAMINIFERA
COCCOLITHS
CORALS

Increase in atmospheric CO_2 causes dissolution of $CaCO_3$.
(The reaction goes to right)

Increase in the photosynthetic utilization of CO_2 encourages
The growth of $CaCO_3$. (The reaction goes to left.)

Precipitation of $CaCO_3$ causes seawater to lose CO_2 to air.
(The reaction goes to left.)

pCO2 and Coral Growth Rate



Volume of Liquid CO2 Emissions and Sequestration Capacity

Global CO2 Emissions ~ 6 Gigatons-C/yr

(1 Gigaton = 1 billion tons = 10^{15} grams)

Volume as liquid CO2 ~ 30 ft x 50 miles x 50 miles

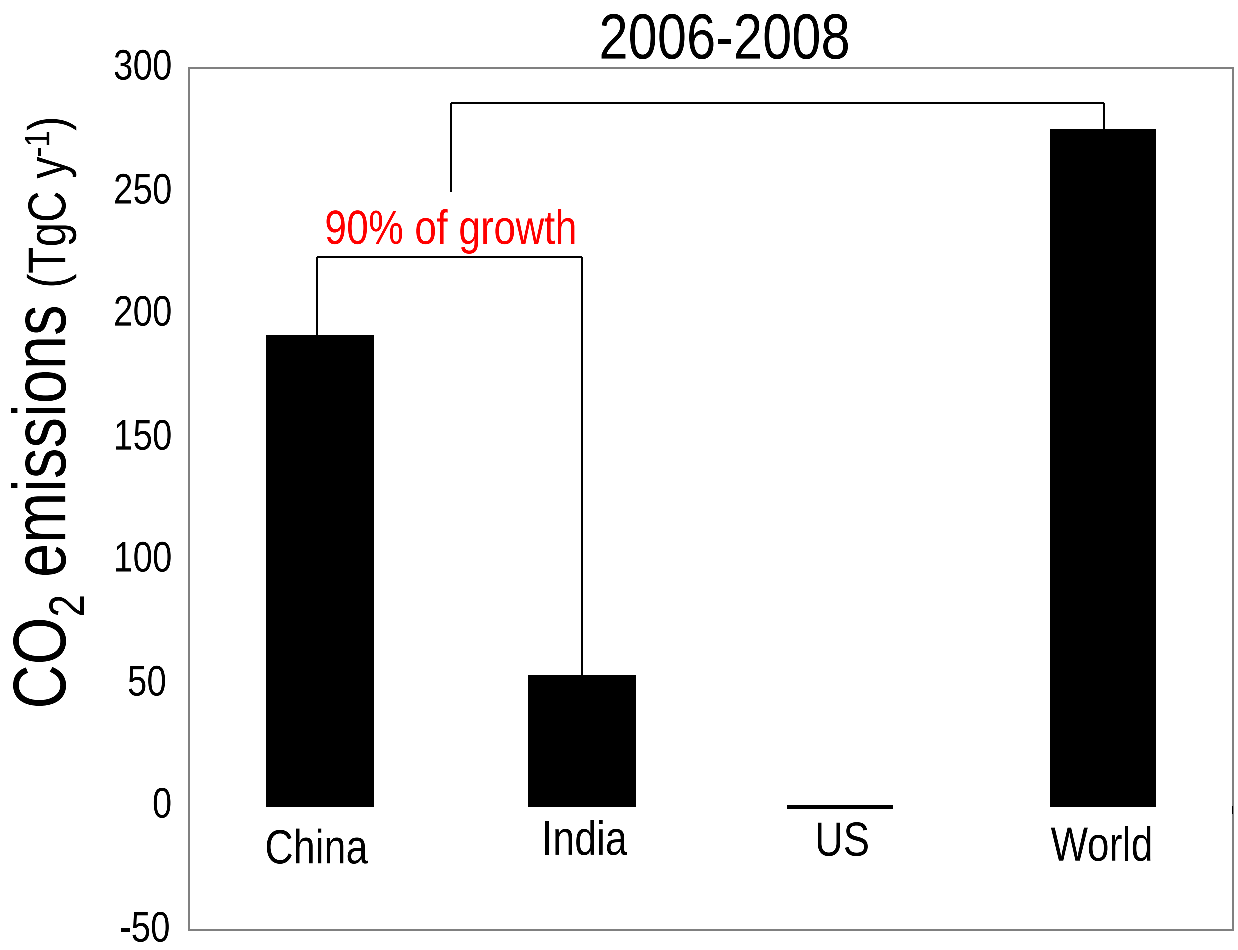
U. S. Emissions ~1.3 Gigatons-C/yr

Volume as liquid CO2 ~ 30 ft x 10 miles x 10 miles

(3600 x Giant Stadium)

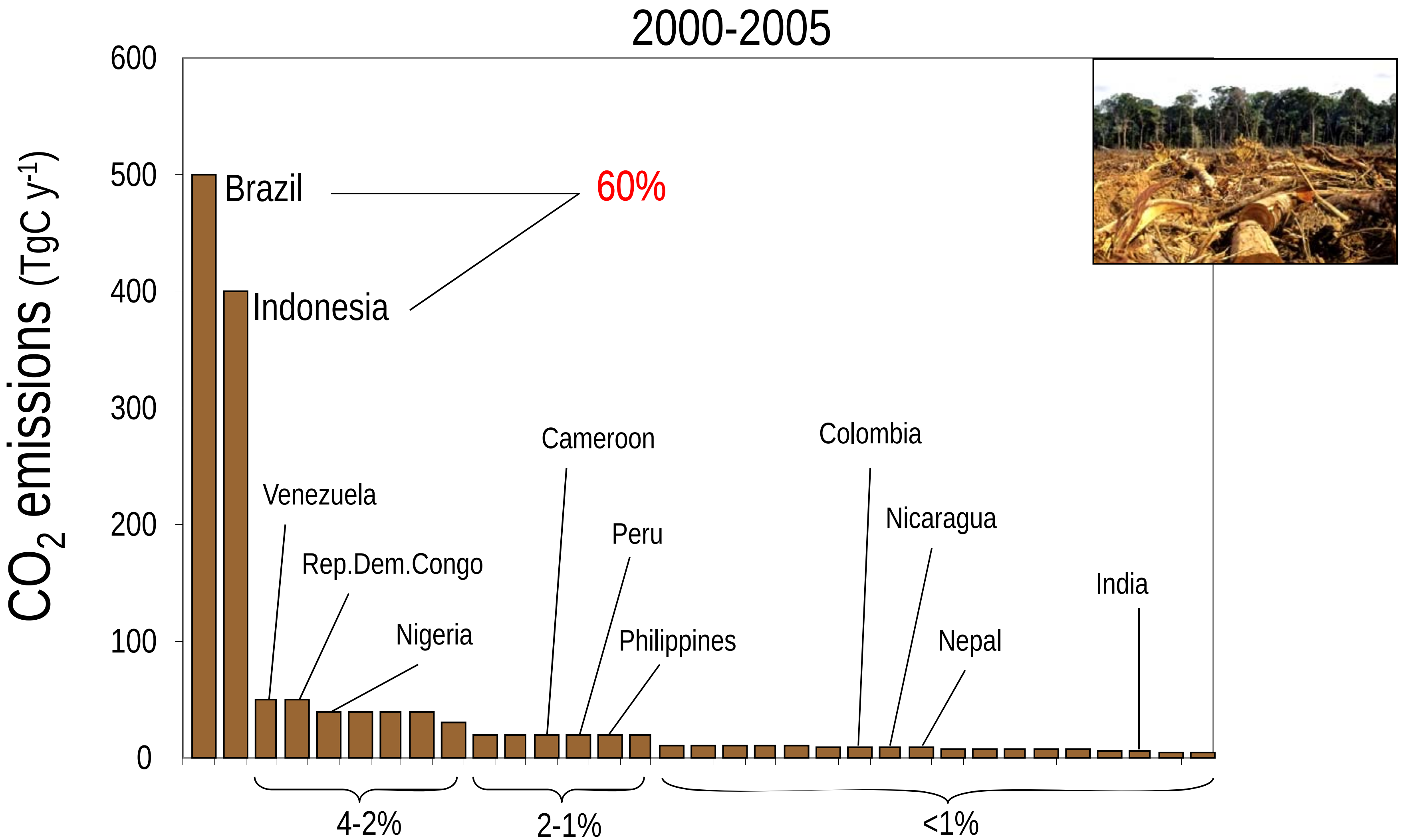
Depleted gas reservoirs	0.5 – 170 Gigaton-C
“Depleted” oil reservoirs	3 – 80 Gigatons-C
Land aquifers	50 – 14,000 Gigatons-C
Juan de Fuca Ridge	250 Gigaton-C
Deep ocean rocks	Very large ?

Growth Rate of Emissions from Coal Burning, 2006 to 2008



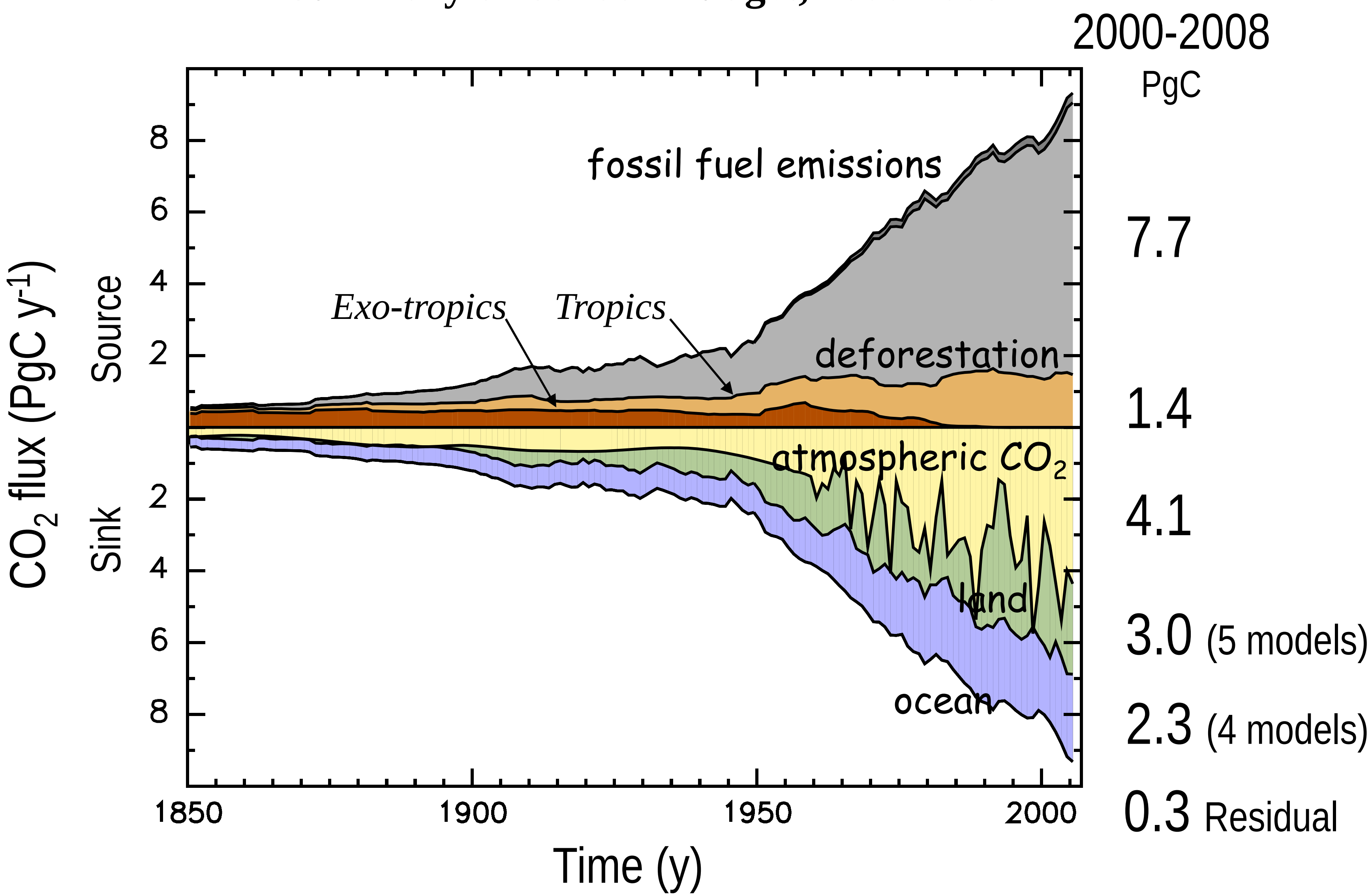
CDIAC 2009; Global Carbon Project 2009

Net CO_2 Emissions from LUC in Tropical Countries



RA Houghton 2009, unpublished; Based on FAO land use change statistics

Summary of Carbon Budget, 2000-2008



Global Carbon Project 2009; Le Quéré et al. 2009, Nature-geoscience