Long-term consequences of continued carbon dioxide emission to the atmosphere

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As given at ICDC7 on 26 Sep 2005; corrected to 30 Sep 2005

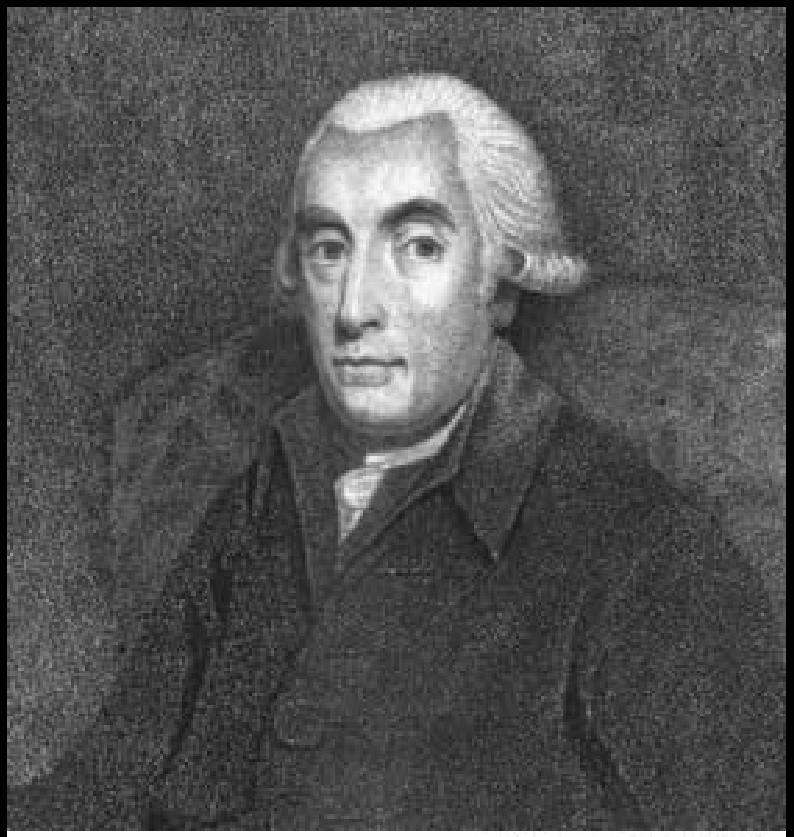
Carbon

from Latin *carbo* meaning charcoal

Photo: Chip Yee Enterprise, Malaysia

Carbon dioxide

Identified by Joseph Black in 1754


Library of Congress

In 1756, described

- Produced by combustion, respiration, fermentation
- Behaves like an acid
- Component of carbonate minerals

Greenhouse effect

Described by Joseph Fourier in 1824

"The transparency of the waters and the air augments the degree of heat acquired, because the chaleur lumineuse [shortwave radiation] *penetrates easily into the interior of the mass, and the chaleur obscure* [longwave radiation] *leaves with more difficulty."*

Translation: W.M. Connelley; Image source unknown

In 1827, Fourier described

- Concept of global energy balance
- Atmosphere and ocean transport of heat from equator to poles
- Atmosphere transparent to solar radiation (*chaleur lumineuse*)
- Long-wave radiation to space (*chaleur obscure*) increases with surface temperature
- Atmosphere inhibits transmission
- of long-wave radiation to space

Image source unknown

Land-use change and climate

- Climate effects of land-surface change
  - *"The movements of the air and the waters, the extent of the seas, the elevation and the form of the surface, the effects of human industry and all the accidental changes to the terrestrial surface modify the temperatures in each climate."*
    Fourier (1827)

Land-use change and climate

- Climate effects of land-surface change

NATURE · VOL 359 · 22 OCTOBER 1992

Effects of boreal forest vegetation on global climate

Gordon B. Bonan*, David Pollard & Starley L. Thompson

National Center for Atmospheric Research, PO Box 3000, Boulder, Colorado 80307-3000, USA

NATURE | VOL 408 | 9 NOVEMBER 2000 | www.nature.com

Offset of the potential carbon sink from boreal forestation by decreases in surface albedo

Richard A. Betts

Hadley Centre for Climate Prediction and Research, The Met Office, Bracknell, Berkshire RG12 2SY, UK

Climate Dynamics (2000) 16:93–105

T. N. Chase · R. A. Pielke Sr. · T. G. F. Kittel
R. R. Nemani · S. W. Running

Simulated impacts of historical land cover changes on global climate in northern winter

GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 2, PAGES 291-294, JANUARY 15, 2001

Land use Changes and Northern Hemisphere Cooling

B. Govindasamy, P. B. Duffy and K. Caldeira

Climate and Carbon Cycle Modeling group Atmospheric Science Division Lawrence Livermore National Laboratory Livermore, CA

The long-term global carbon cycle

- Jacques Joseph Ebelman (1845)
  - *"I see in volcanic phenomena the principal cause that restores carbon dioxide to the atmosphere that is removed by the decomposition of rocks."*
  - *"One can admit that the roots of [vegetation] can produce or accelerate the weathering of silicates with which they are in contact.*
  - *"The terrestrially-derived carbonates end up by being deposited or they are taken up by marine animals, molluscs and zoophytes."*

Translation: Berner and Maasch

The long-term global carbon cycle

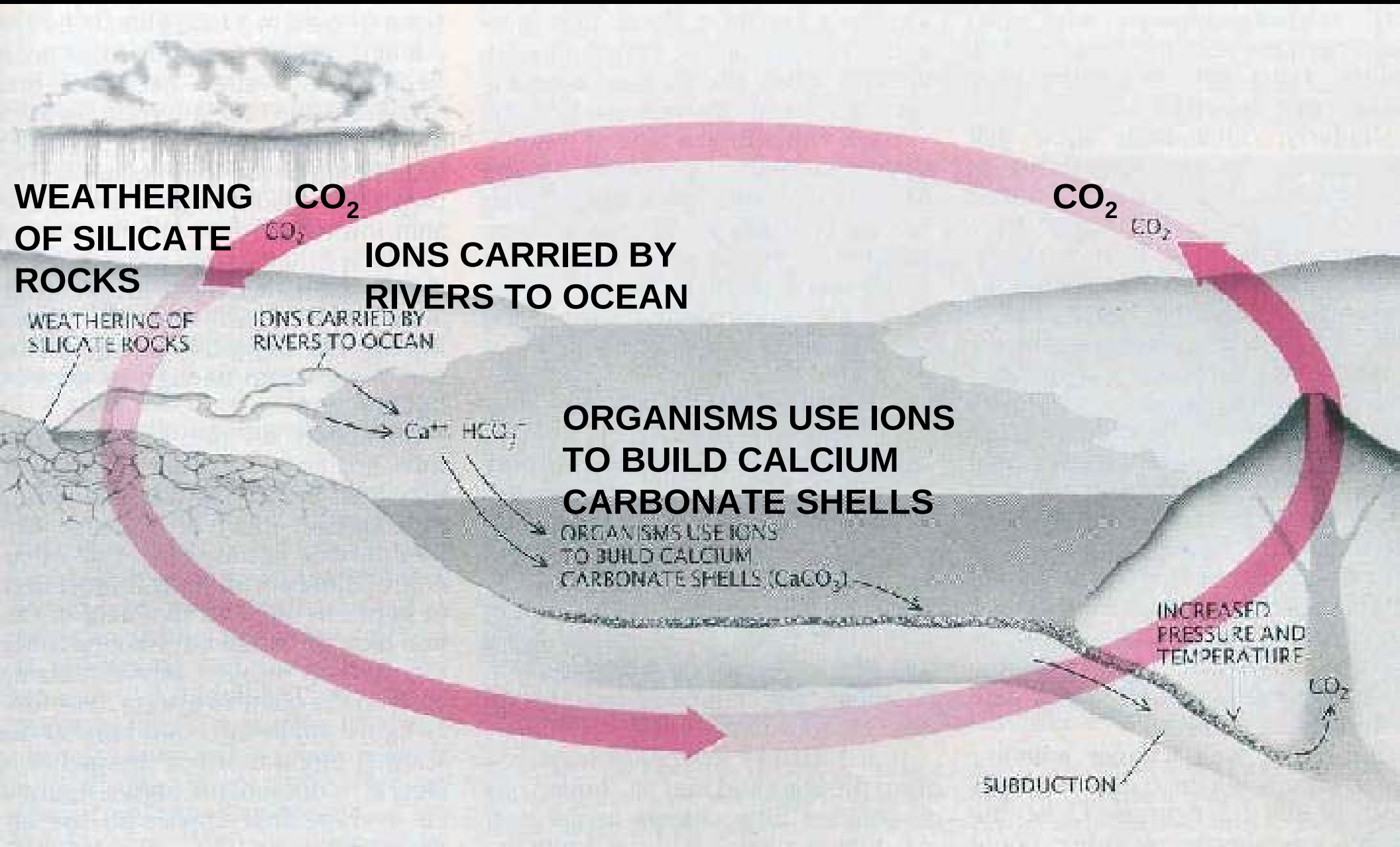


Image source unknown

The long-term global carbon cycle

- Jacques Joseph Ebelman (1845)

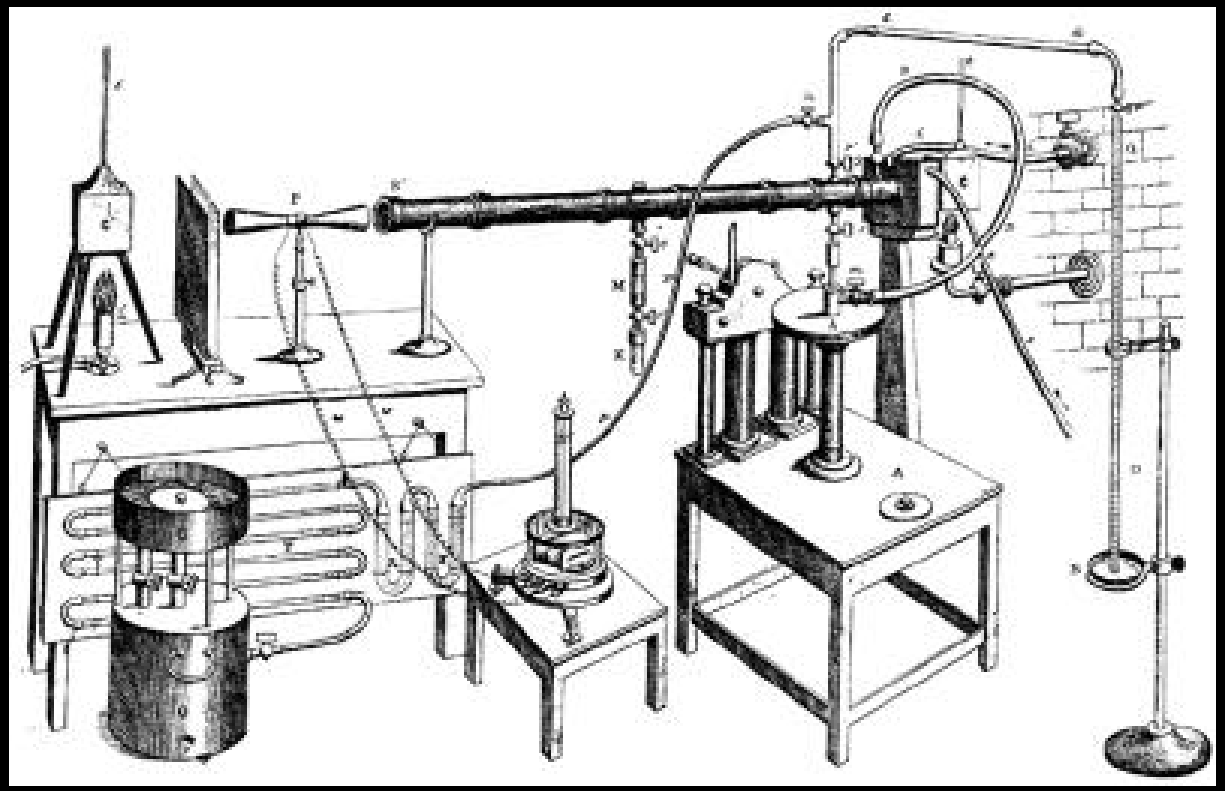
  "… in ancient geologic epochs the atmosphere was denser and richer in CO_2, and perhaps O_2, than at present. To a greater weight of the gaseous envelope should correspond a stronger condensation of solar heat and some atmospheric phenomena of a greater intensity."

Translation: Berner and Maasch

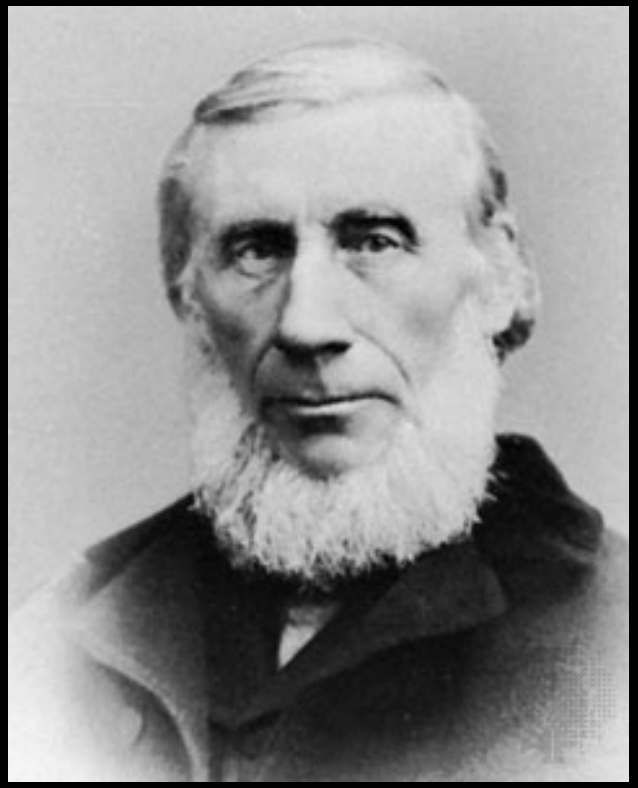
CO_2 greenhouse effect

Quantified by John Tyndall in 1861

Measured absorption by CO_2 and H_2O



The first ratio spectrophotometer



John Tyndall

From J.R.Fleming, *Historical Perspectives on Climate Change,* 1998

Carbon cycle (Arvid Högbom,1894)

"Carbonic acid is supplied to the atmosphere by the following processes:

(1) volcanic exhalations and geologic phenomena connected therewith;

(2) combustion of carbonaceous meteorites in the higher regions of the atmosphere;

(3) combustion and decay of organic bodies;

(4) decomposition of carbonates;

(5) release of CO_2 dissolved in seawater because of temperature increase or reduction in CO_2 partial pressure;

(6) liberation of carbonic acid mechanically enclosed in minerals on their fraction or decomposition."

Translation: Arrhenius, Berner and Veronis

Carbon cycle (Arvid Högbom,1894)

"The carbonic acid of the air is consumed chiefly by the following processes:

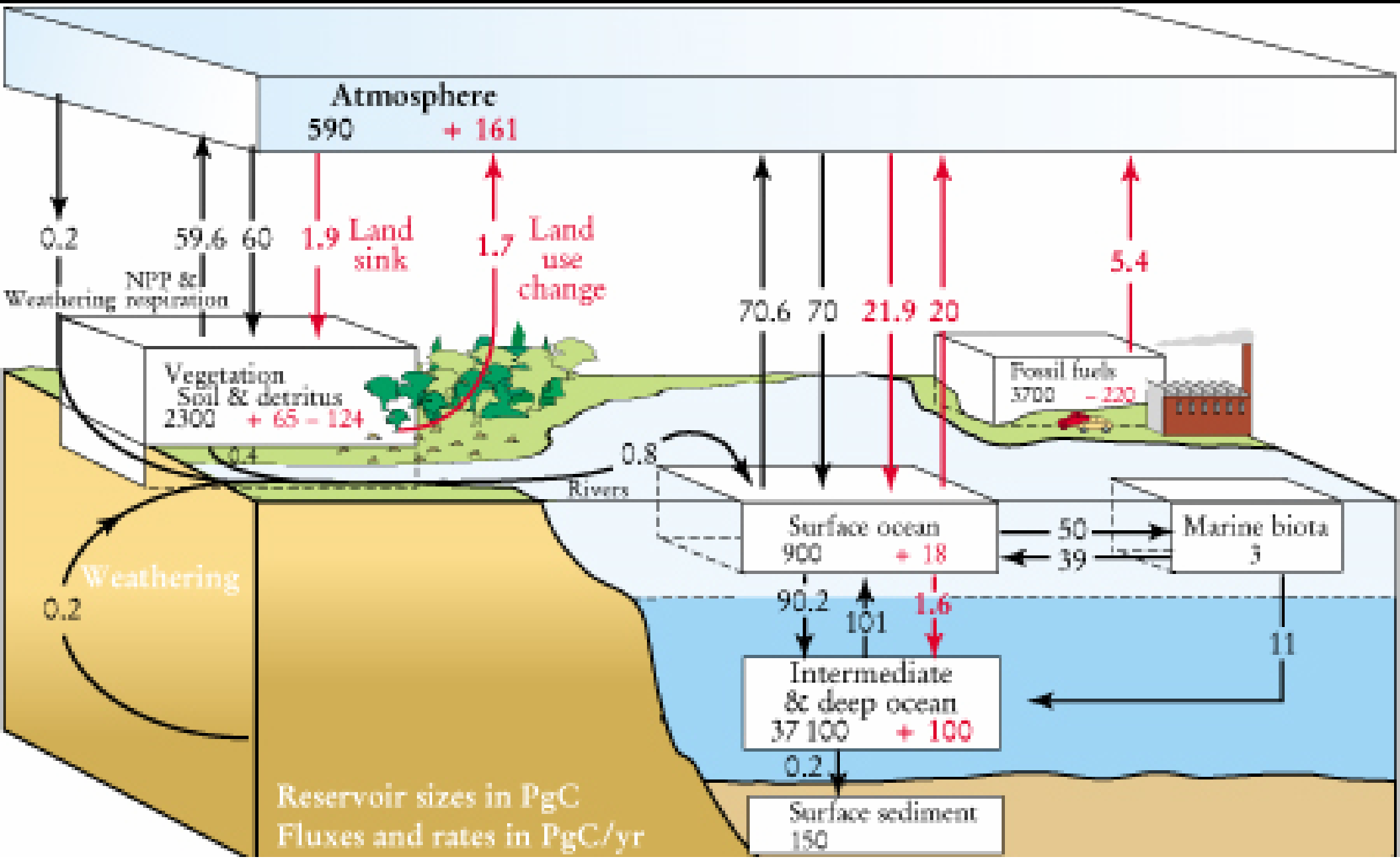
(7) formation of carbonates from silicates on weathering;

(8) the consumption of carbonic acid by vegetative processes;

(9) the absorption of CO_2 in the sea"

Translation: Arrhenius, Berner and Veronis

The short-term carbon cycle (Gruber and Sarmiento, 2002)

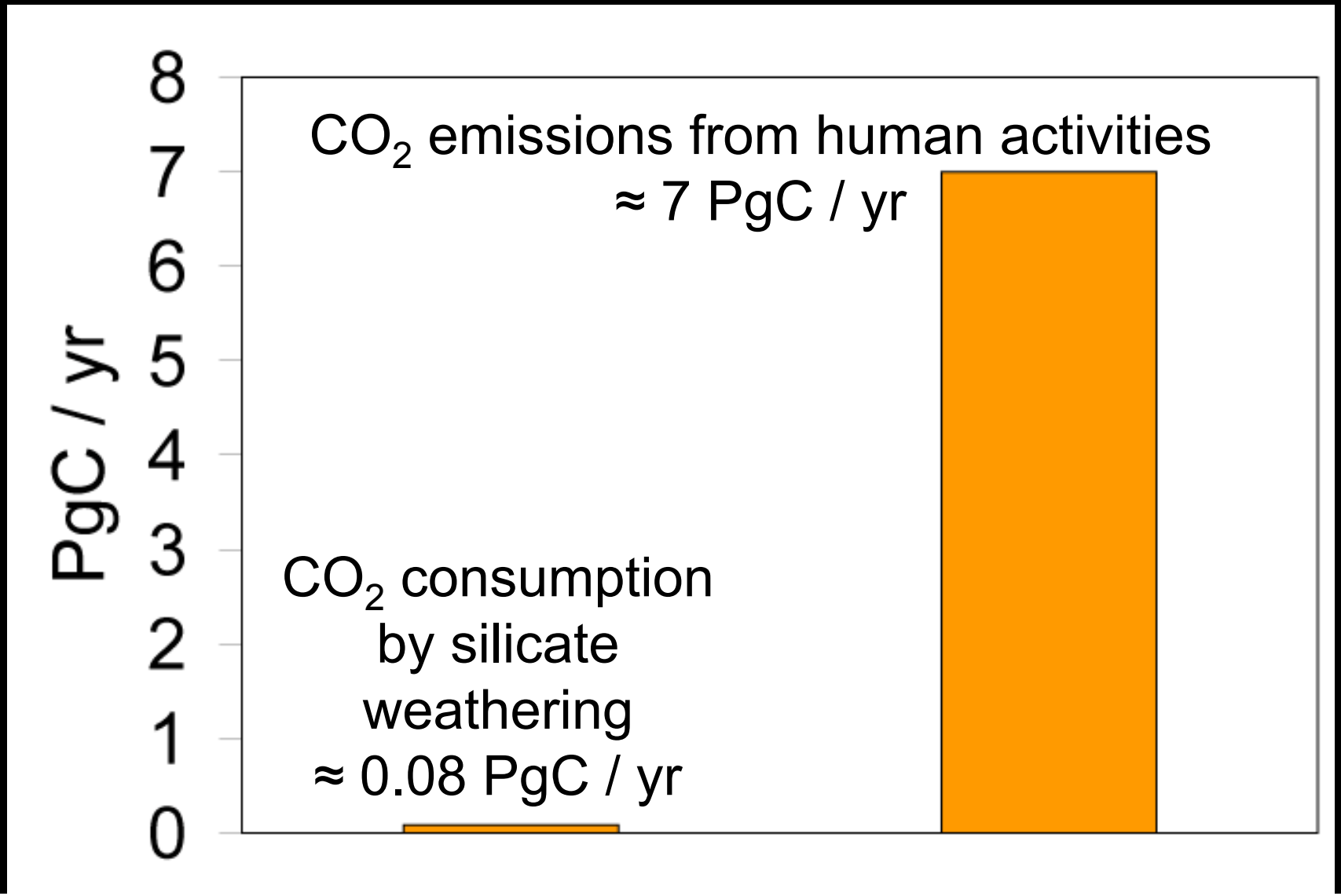


The carbon cycle (Högbom,1894)

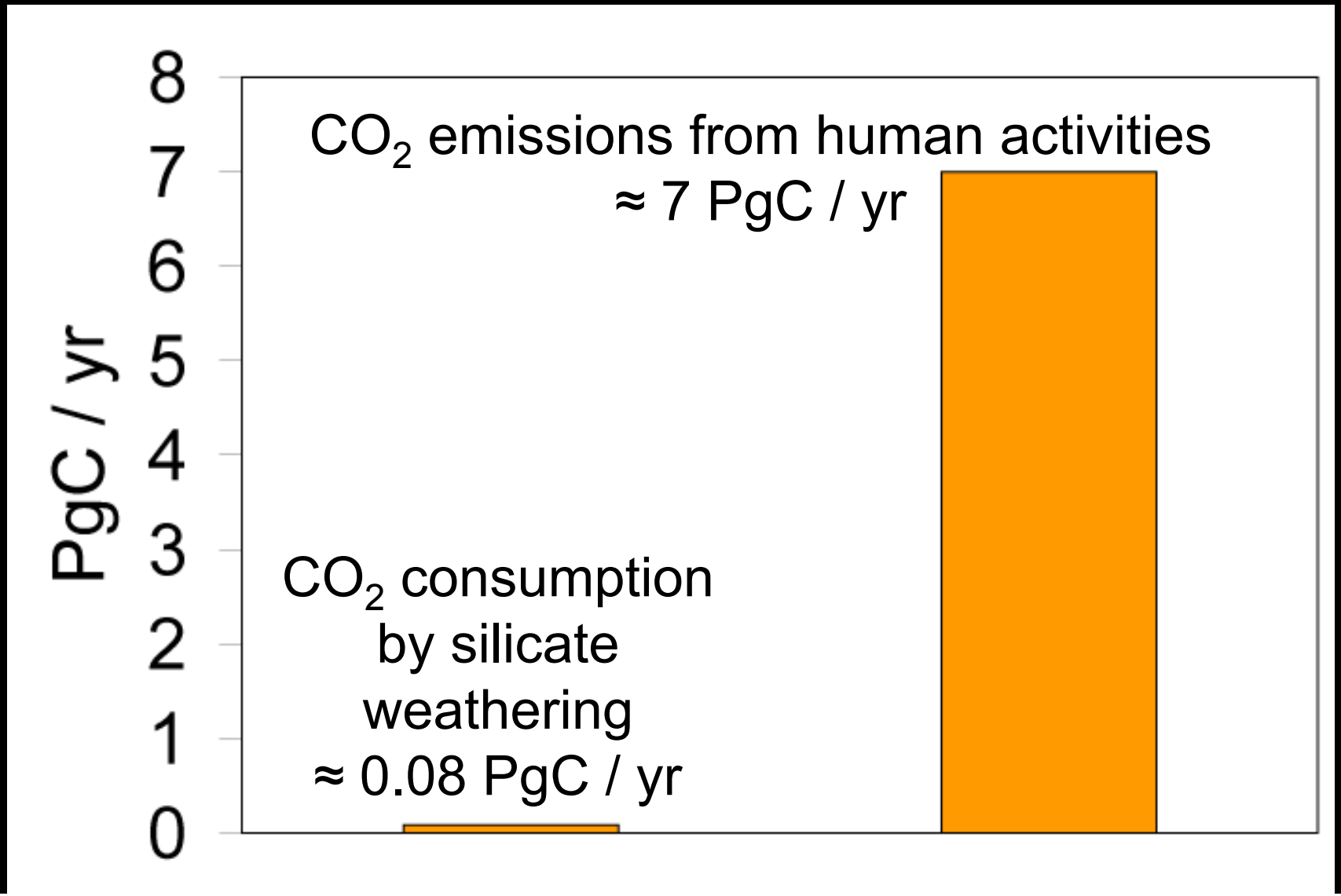
- *The world's present production of coal reaches in round numbers 500 millions of tons per annum…*
  - *Transformed into carbonic acid, this quantity would correspond to about a thousandth part of the carbonic acid in the atmosphere*
- *…. This quantity of carbonic acid, which is supplied to the atmosphere chiefly by modern industry, may be regarded as completely compensating the quantity of carbonic acid that is consumed in the formation of limestone (or other mineral carbonates) by the weathering or decomposition of silicates.*

Translation: Arrhenius

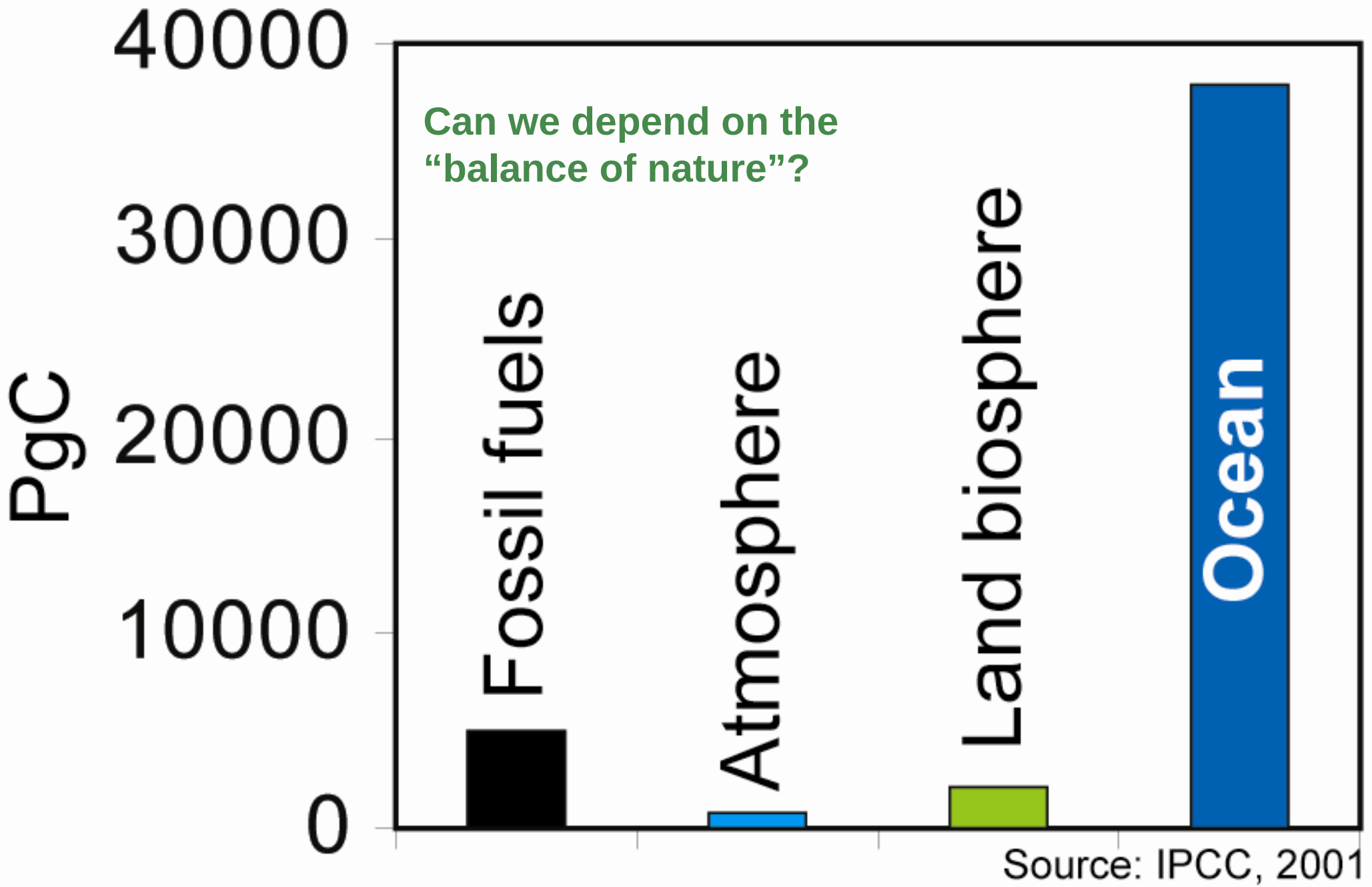
Högbom was wrong about how fast silicate weathering could remove anthropogenic CO_2 emissions



The time scale of removal of excess CO_2 by silicate weathering is > 100,000 years



Carbon reservoirs



The "Revelle factor" (1957)

- If atmospheric pCO_2 increased 10%
  - people used to think that ocean carbon content would increase by 10%
  - Roger Revelle and Hans Seuss (1957) realized that, due to ocean chemistry, ocean carbon content would increase only about 1%

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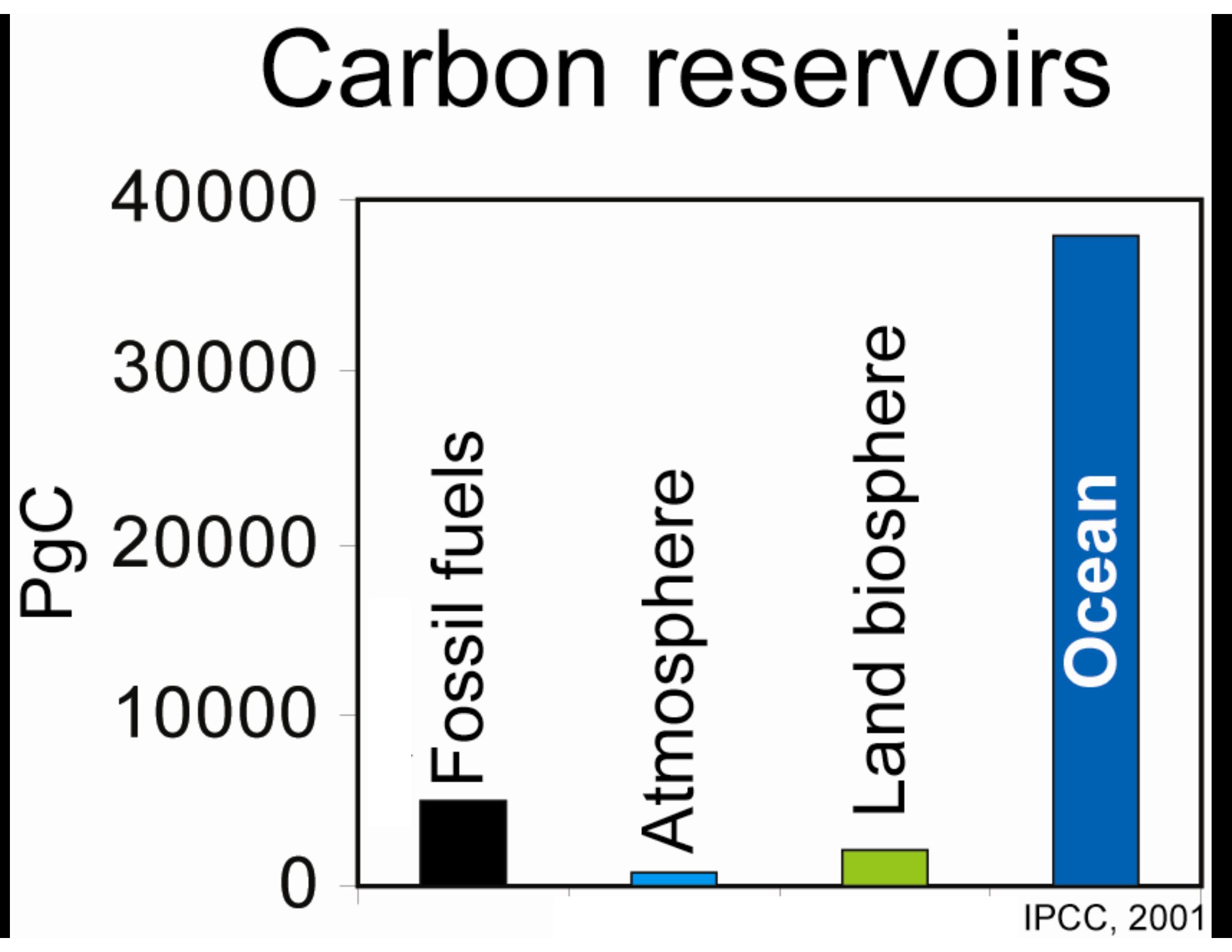
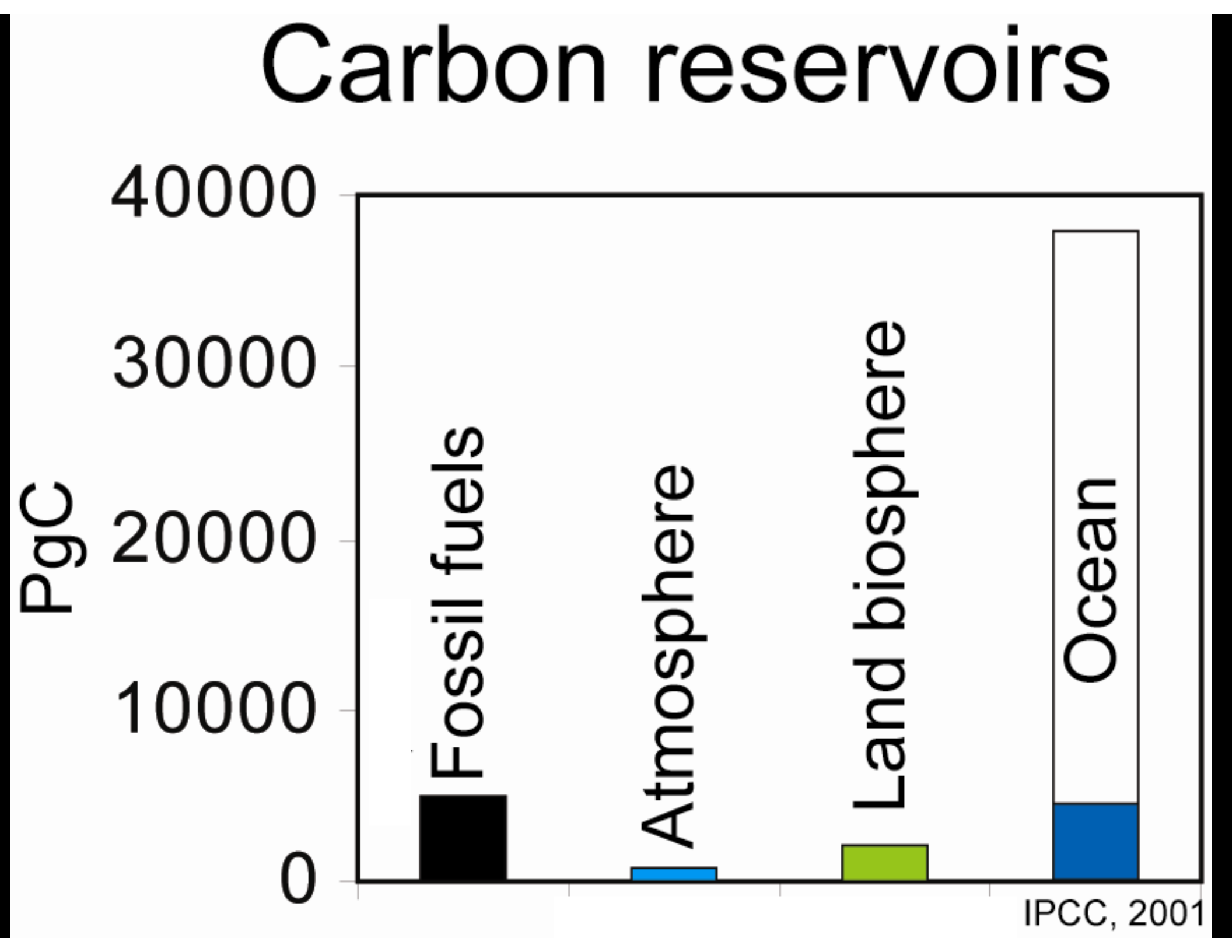
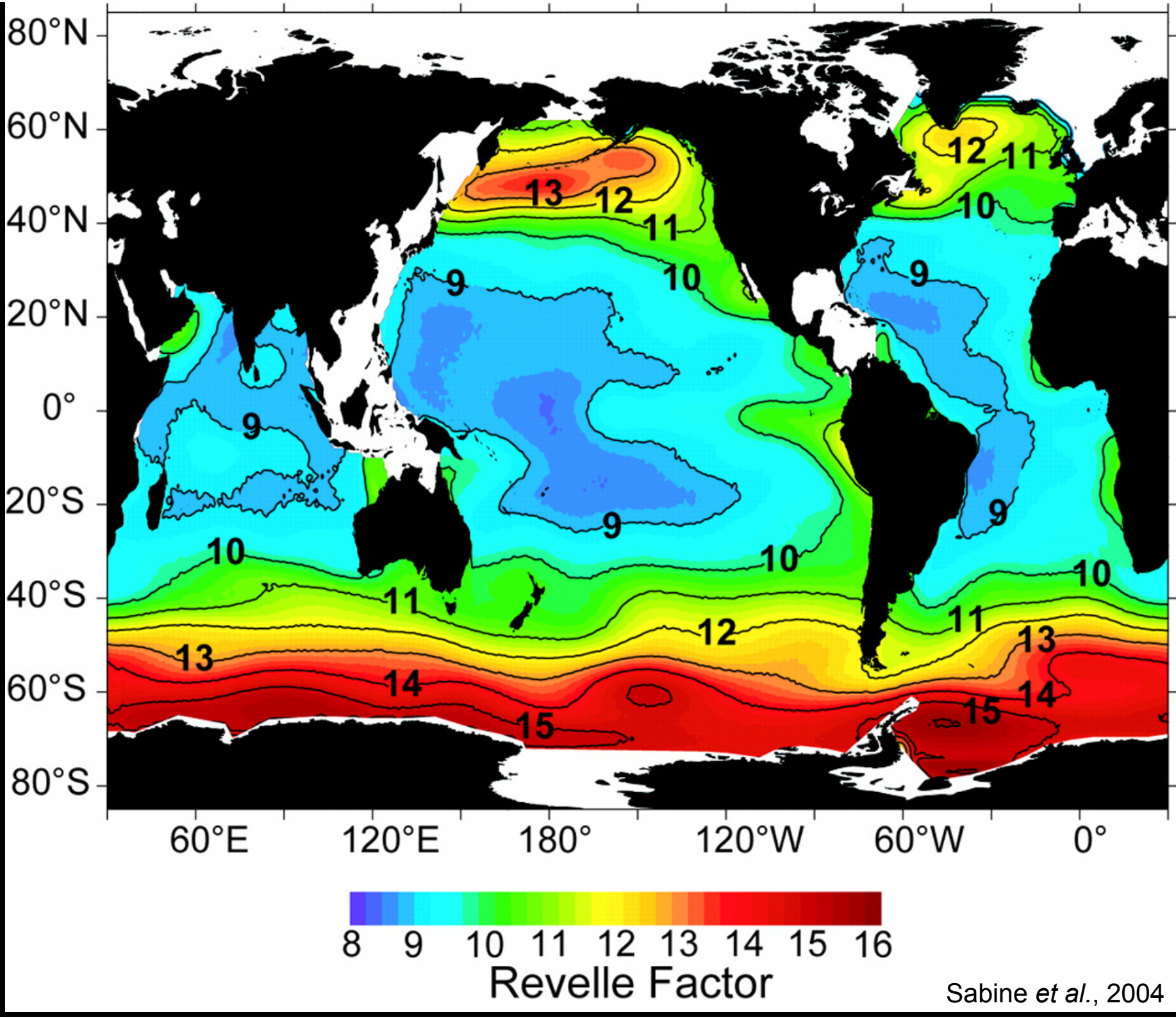
"Revelle factor" ≈ 10

Carbon reservoirs



Carbon reservoirs

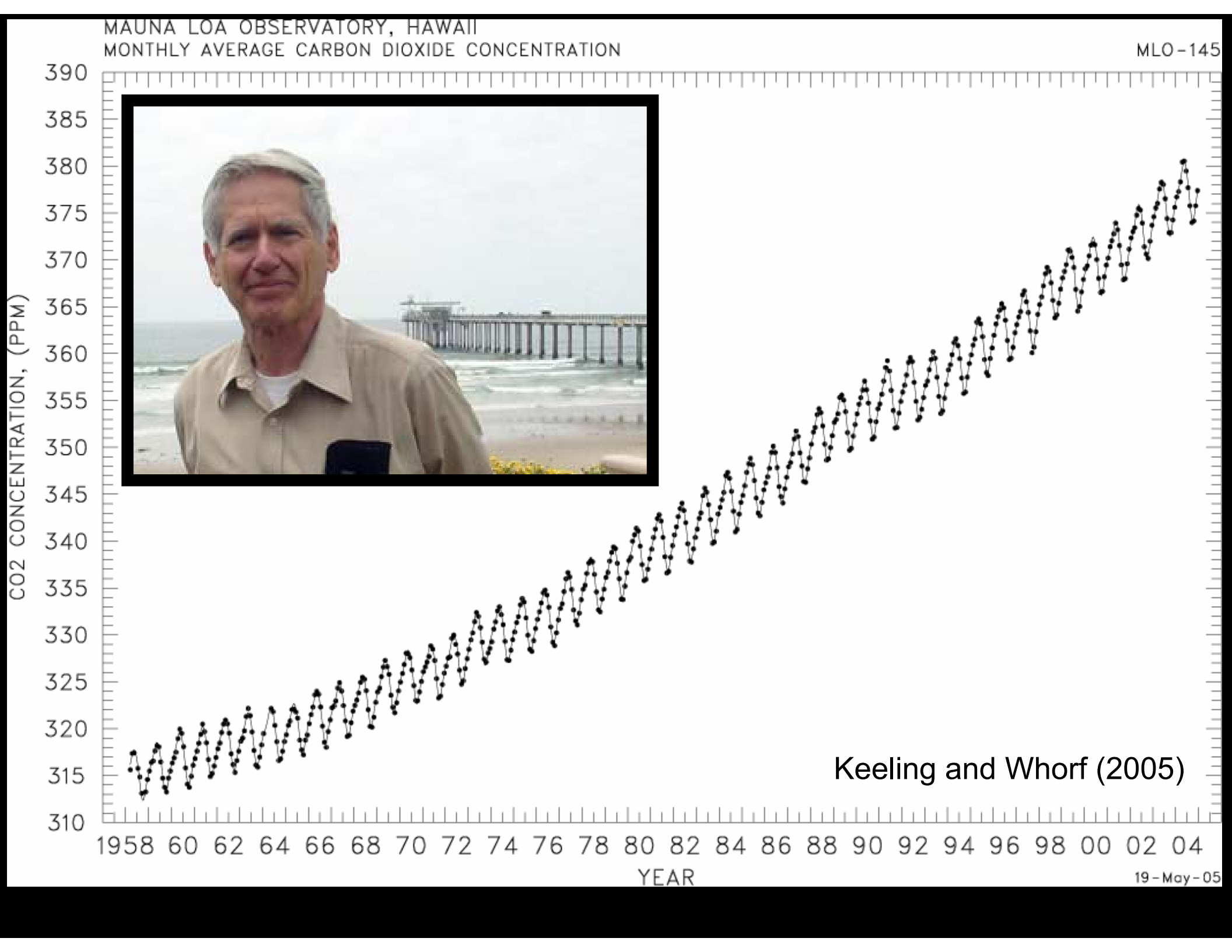


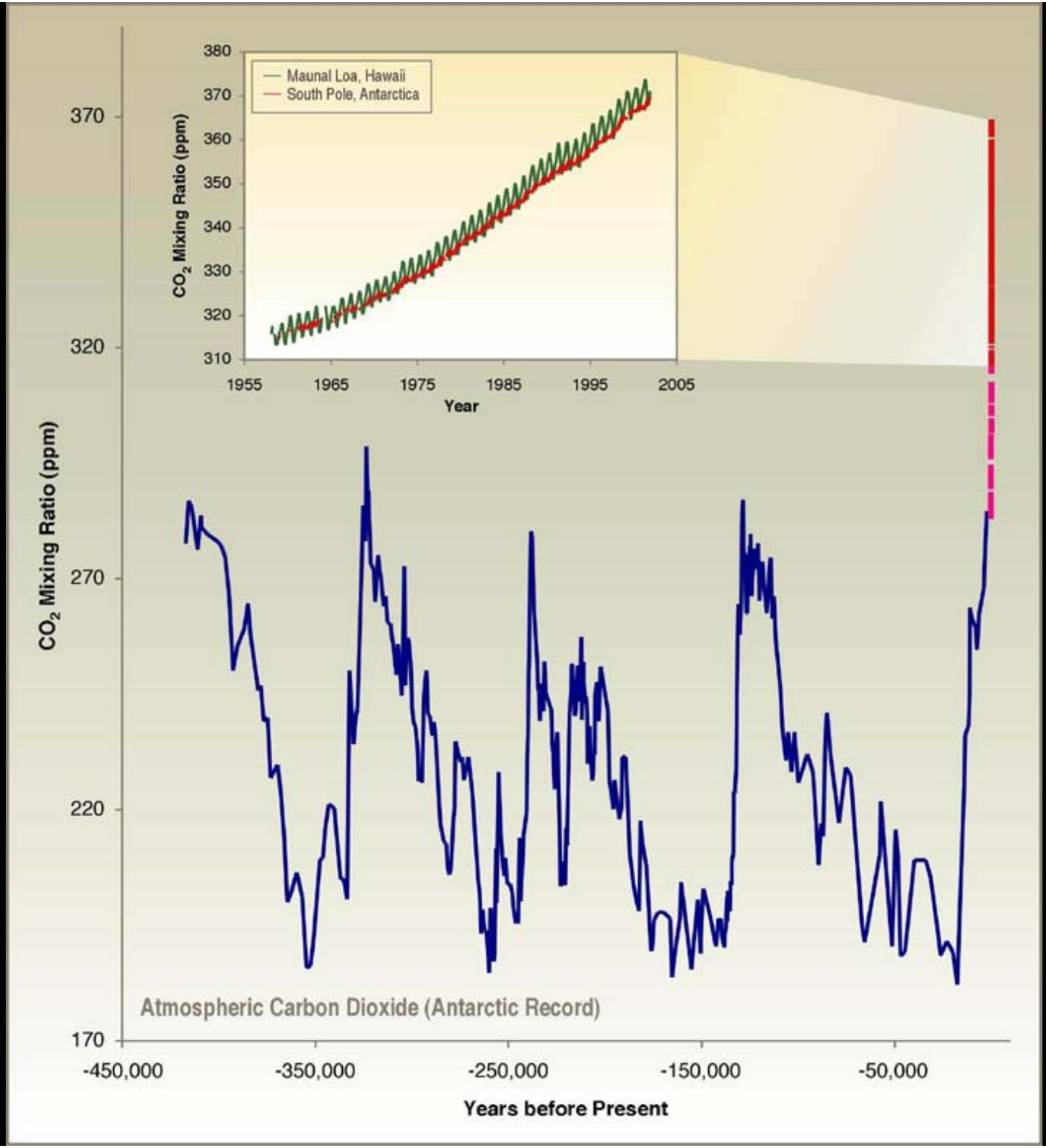


Sabine *et al.*, 2004

Charles David Keeling

20 April 1928 – 20 June 2005

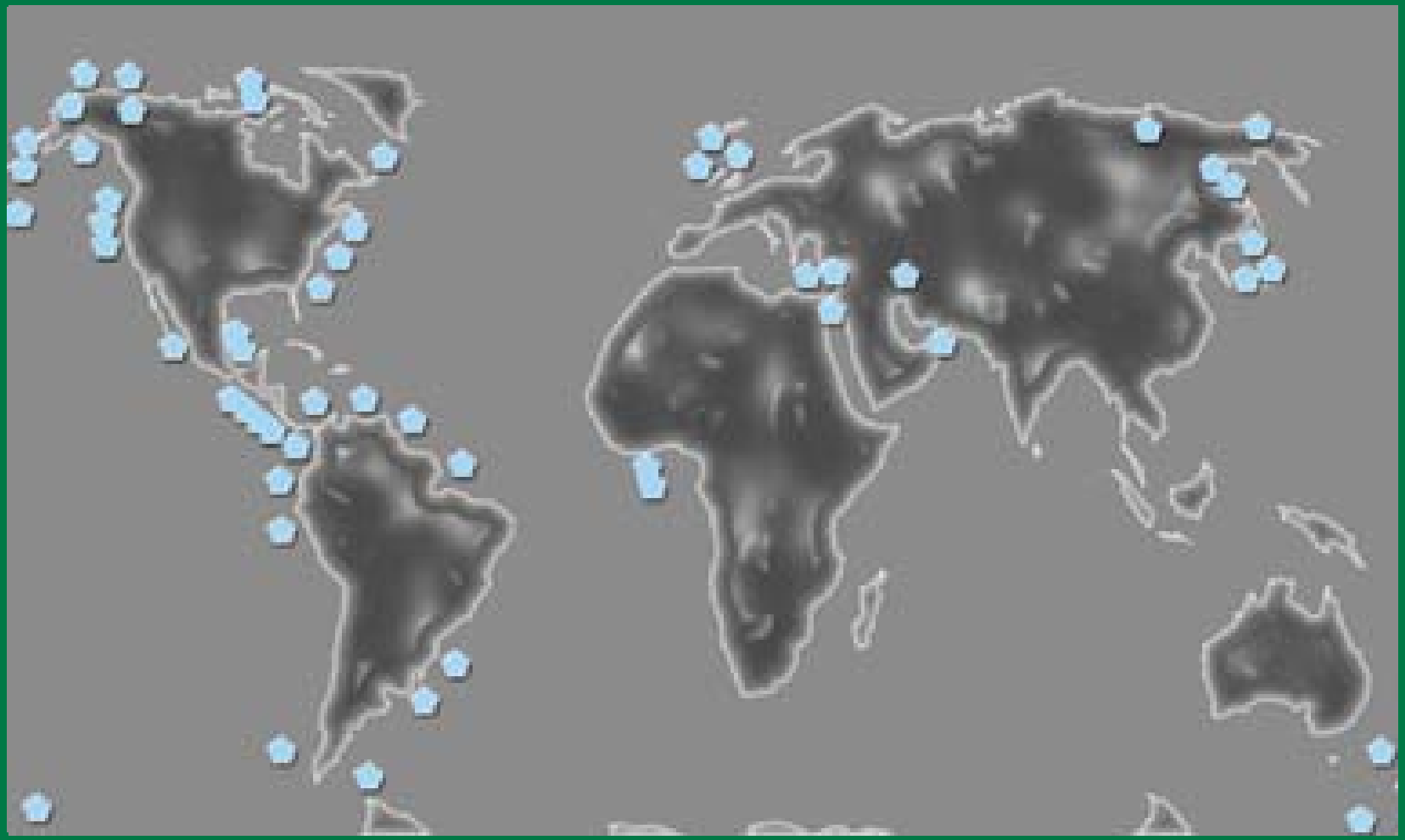

MAUNA LOA OBSERVATORY, HAWAII
MONTHLY AVERAGE CARBON DIOXIDE CONCENTRATION
MLO-145
CO2 CONCENTRATION, (PPM)
390
385
380
375
370
365
360
355
350
345
340
335
330
325
320
315
310
1958 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 00 02 04
YEAR
19-May-05
Keeling and Whorf (2005)


Maunal Loa, Hawaii
South Pole, Antarctica
CO_2 Mixing Ratio (ppm)
380
370
360
350
340
330
320
310
1955
1965
1975
1985
1995
2005
Year
CO_2 Mixing Ratio (ppm)
370
320
270
220
170
Atmospheric Carbon Dioxide (Antarctic Record)
-450,000
-350,000
-250,000
-150,000
-50,000
Years before Present

How high will atmospheric pCO_2 get?

How much fossil fuel is there?

The fuel of the future may be ice that burns



Methane hydrates, a promising natural gas resource, are believed to reside throughout the globe in sea-floor sediments and permafrost.

ORNL

The fuel of the future may be ice that burns

Energy Bulletin

Published on Sunday, January 2, 2005 by Petroleum News

North Slope gas hydrates starting to look feasible

By Alan Bailey

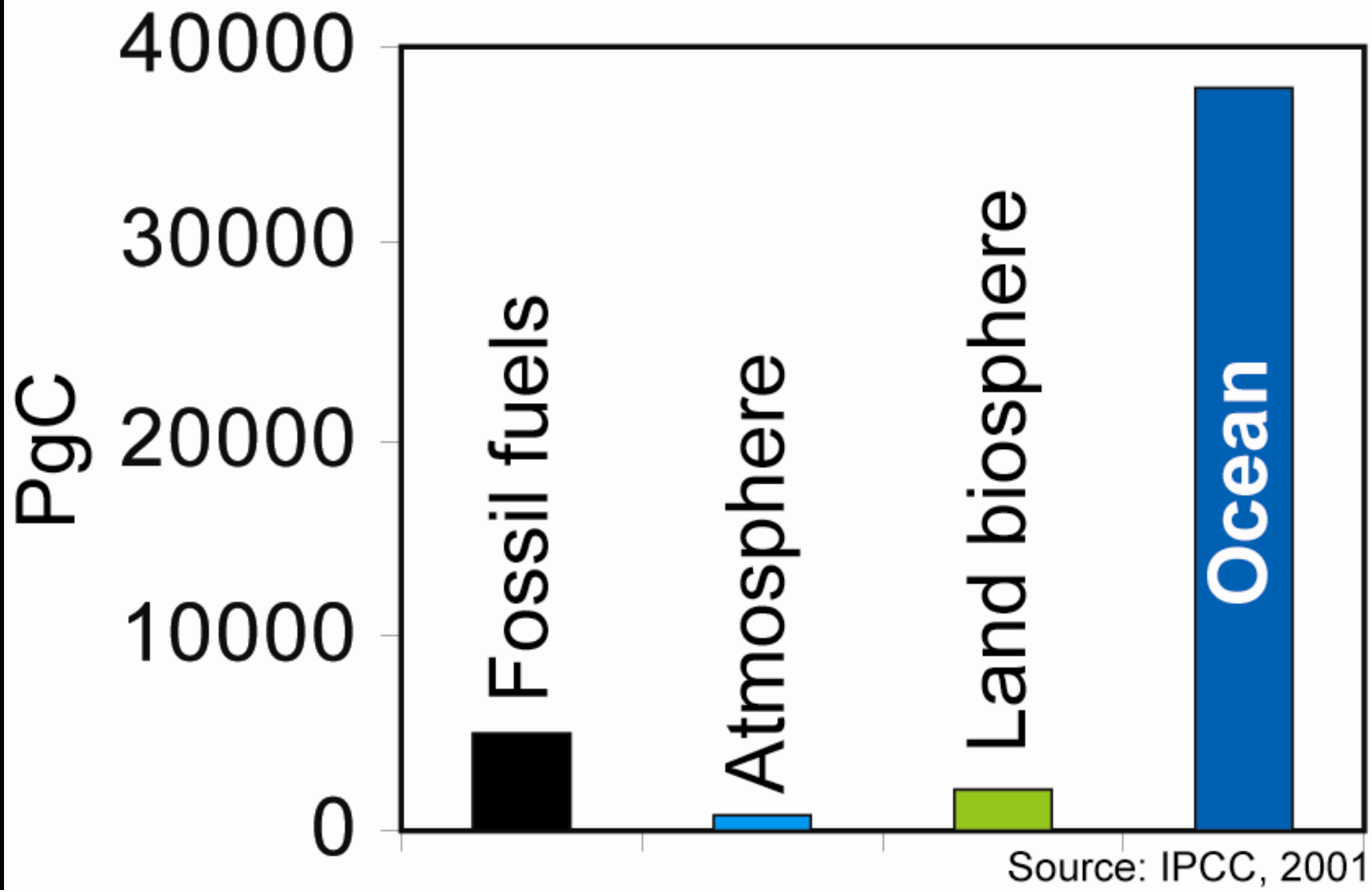
An investigation team reports that gas hydrates could become a source of natural gas within a few years

According to a 2001 report by the Minerals Management Service as much as 519 trillion cubic feet of natural gas could lie under the permafrost of northern Alaska in the form of gas hydrates. With the prospect of a gas export line from the North Slope, could any of this vast resource be brought to market?

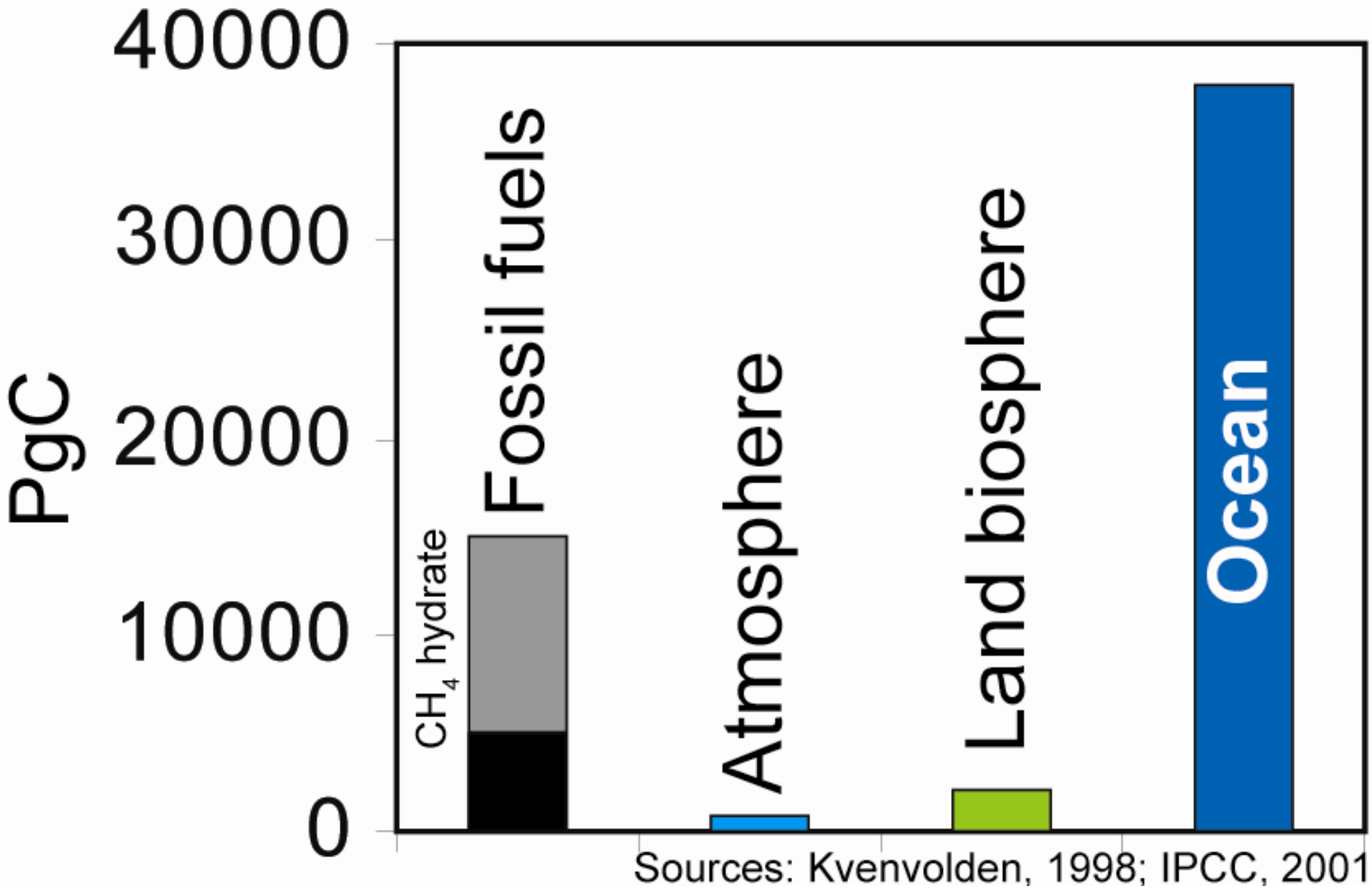
Methane hydrates, a promising natural gas resource, are believed to reside throughout the globe in sea-floor sediments and permafrost.

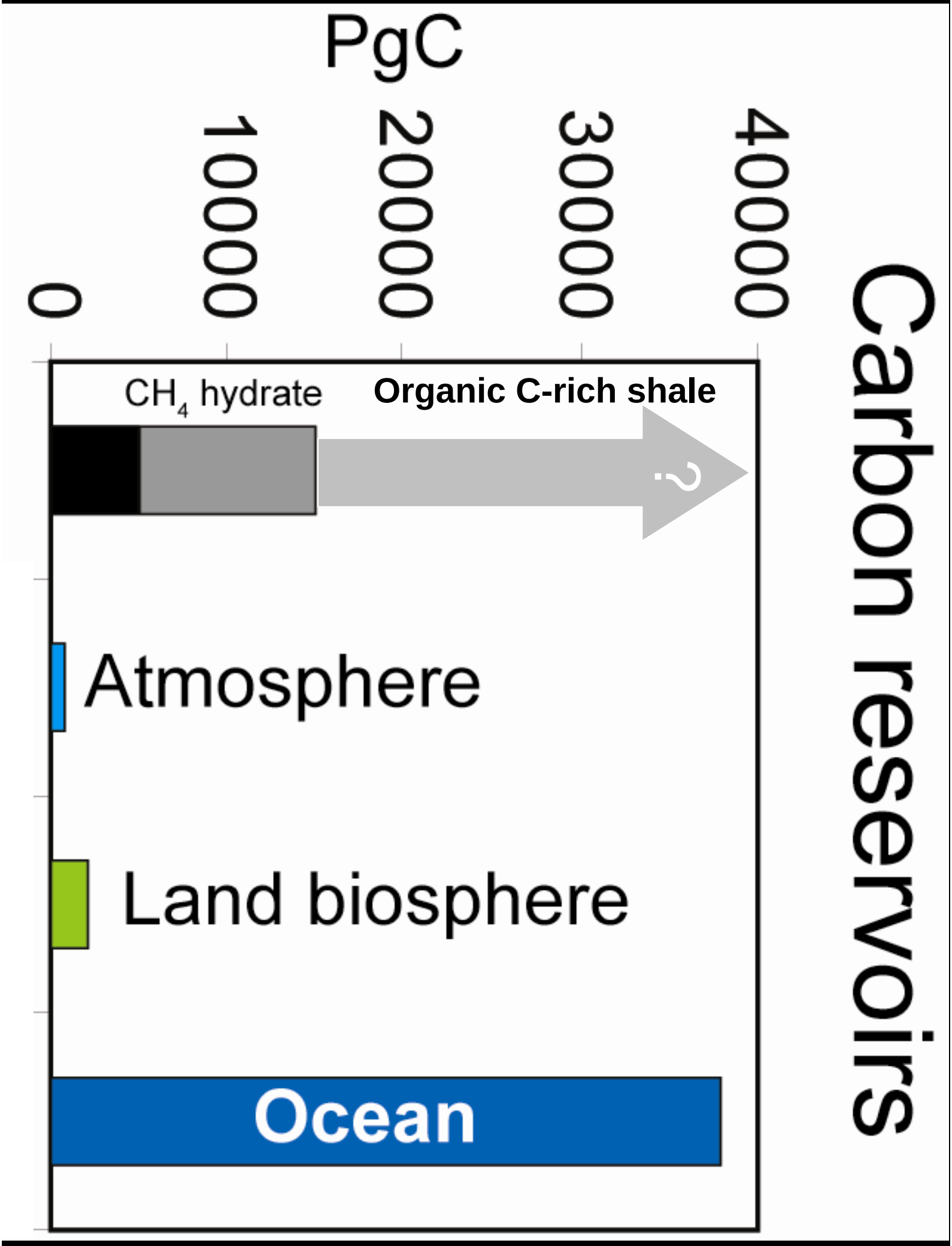
ORNL

Carbon reservoirs

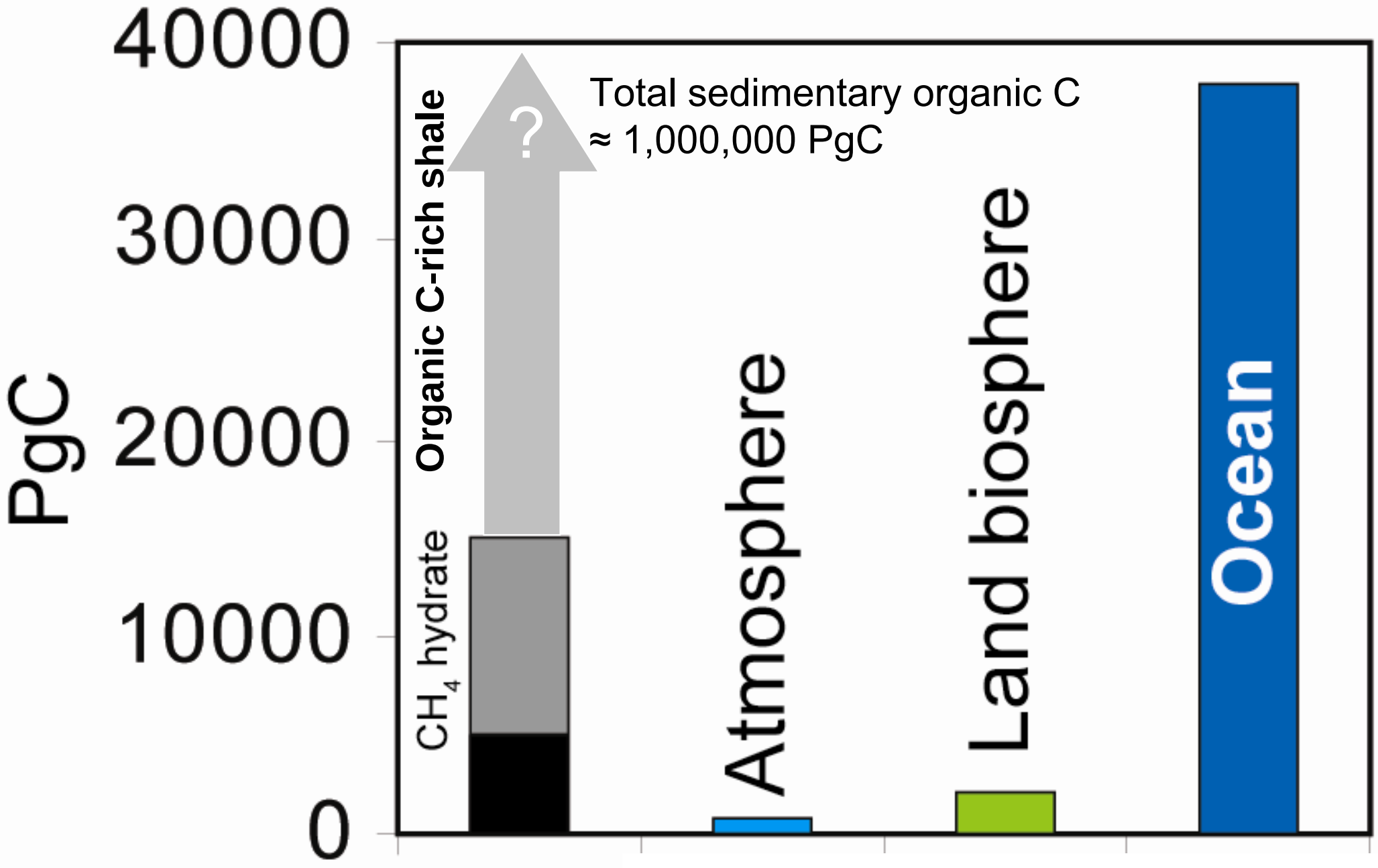


Carbon reservoirs

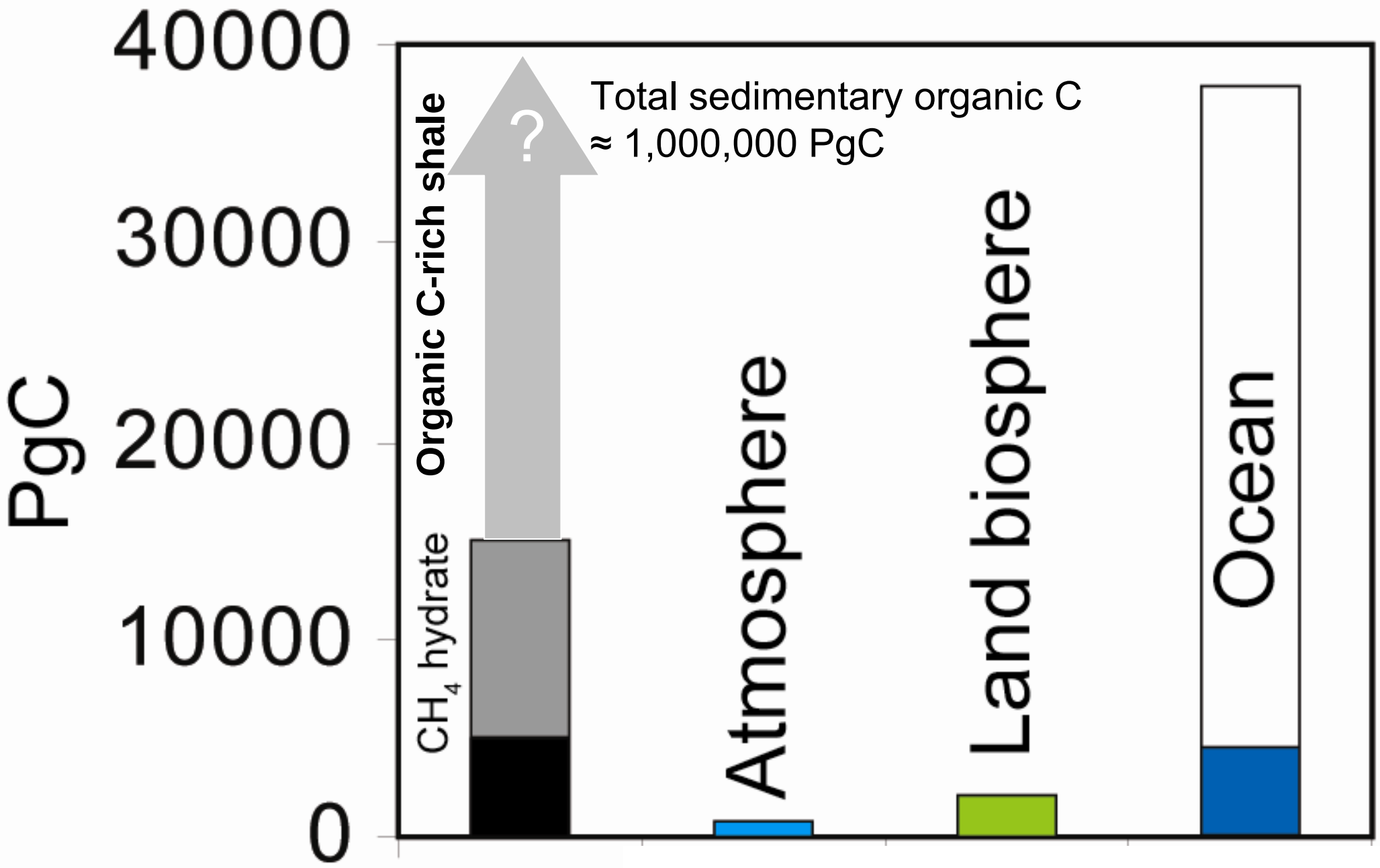


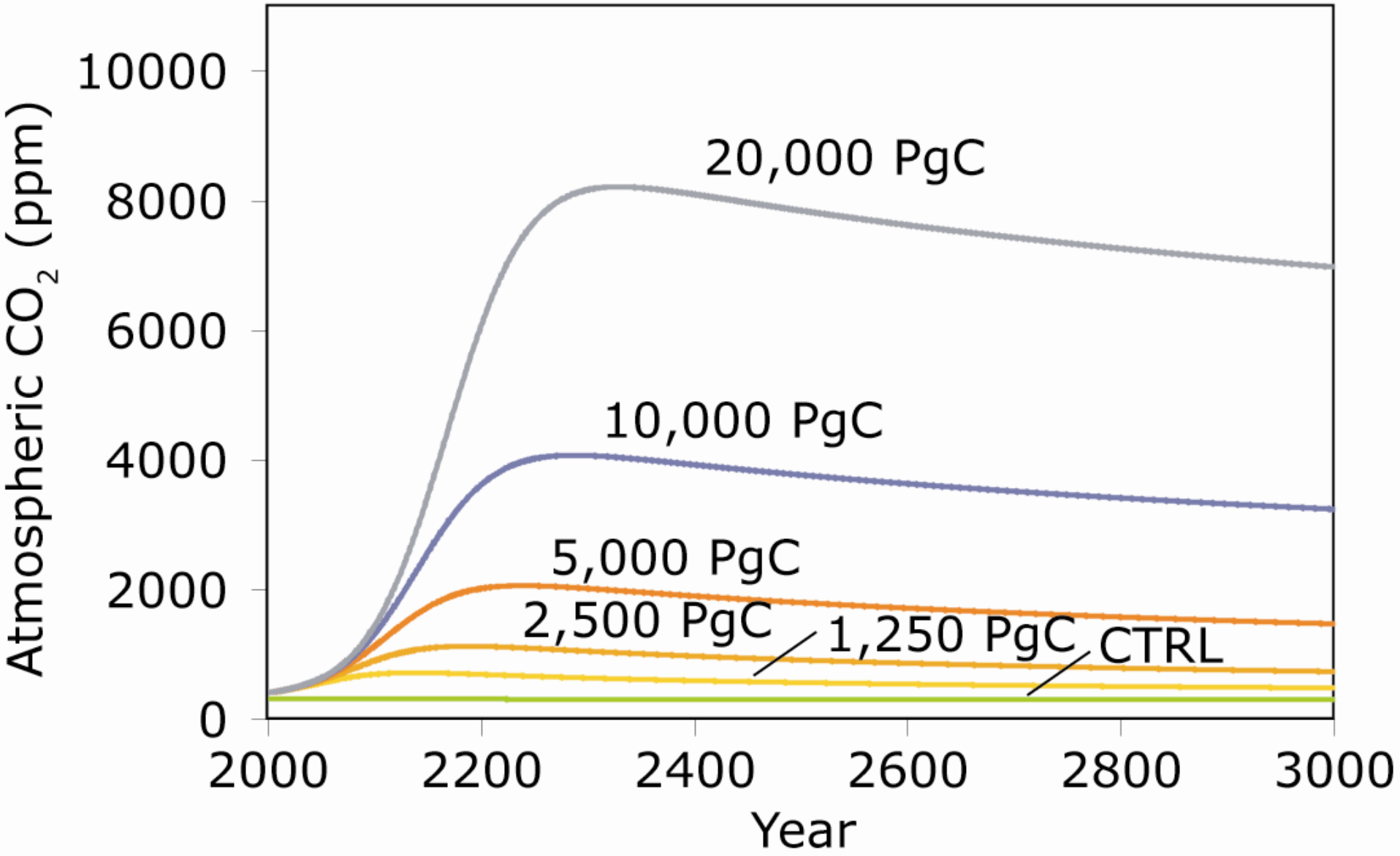

PgC
0
10000
20000
30000
40000
Carbon reservoirs
CH_4 hydrate
Organic C-rich shale
?
Atmosphere
Land biosphere
Ocean

Carbon reservoirs



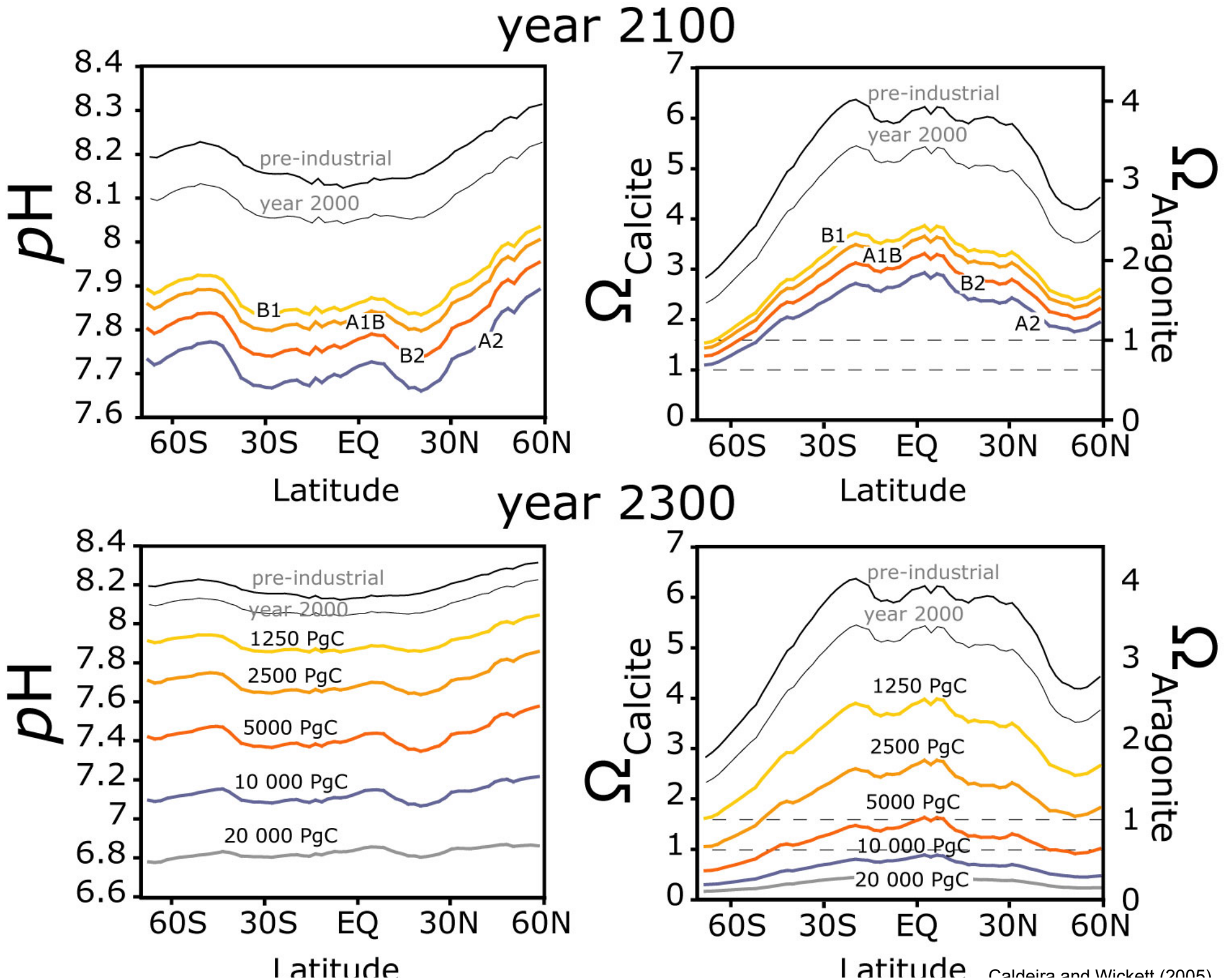
Carbon reservoirs





Amounts include total fossil-fuel plus net land biosphere emissions to the atmosphere

Caldeira and Wickett (2005)



Caldeira and Wickett (2005)

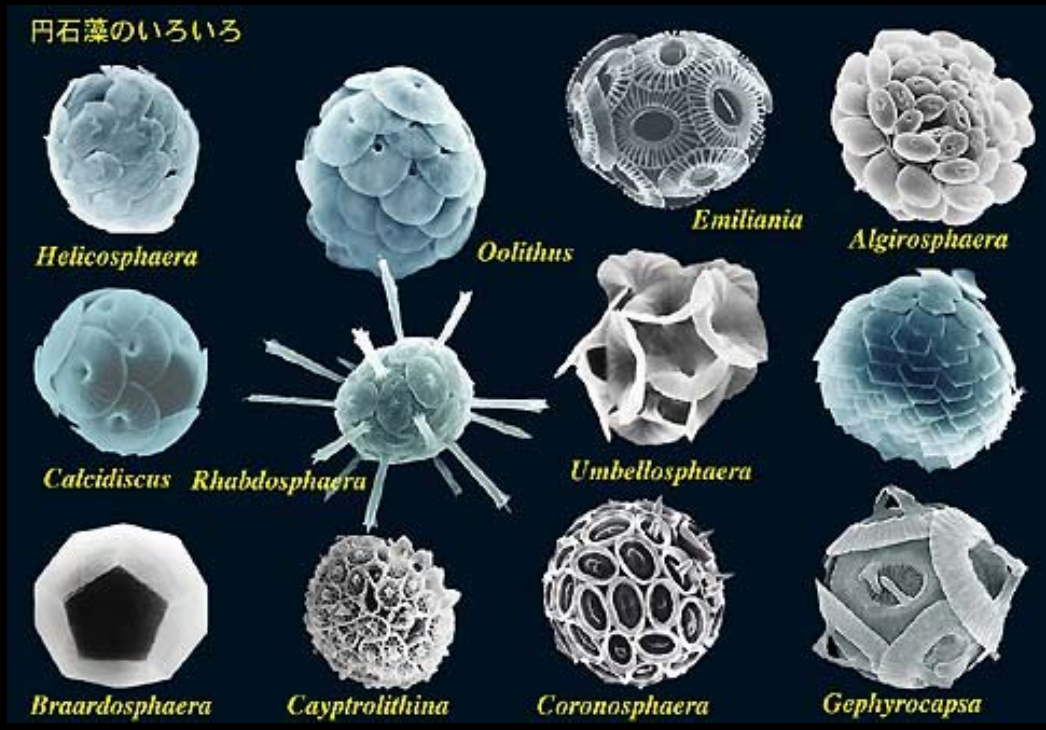
Ocean acidification

- CO_2 is corrosive to the shells and skeletons of many marine organisms

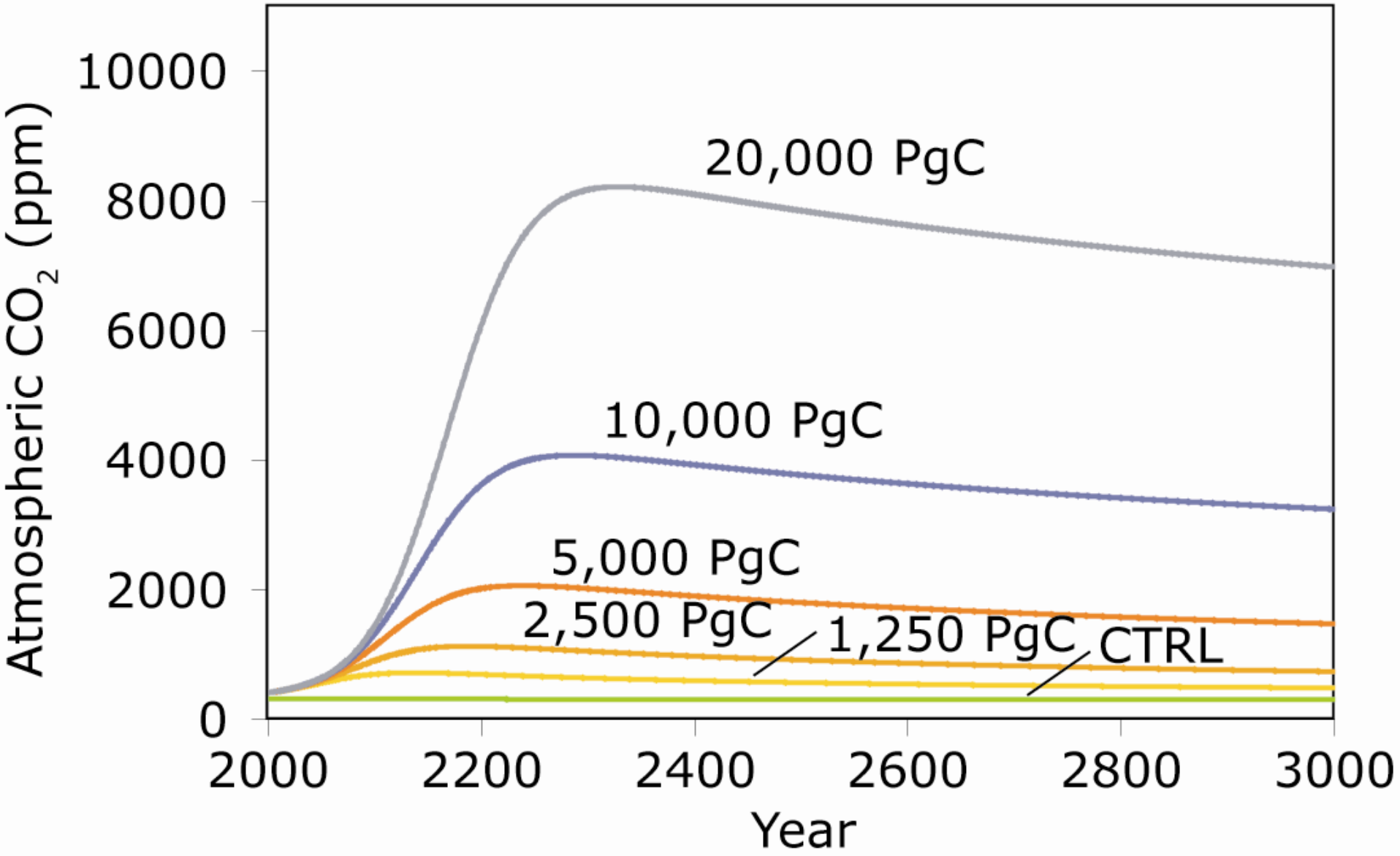
Corals

Photo: Missouri Botanical Gardens

Calcareous plankton



http://www.biol.tsukuba.ac.jp/~inouye



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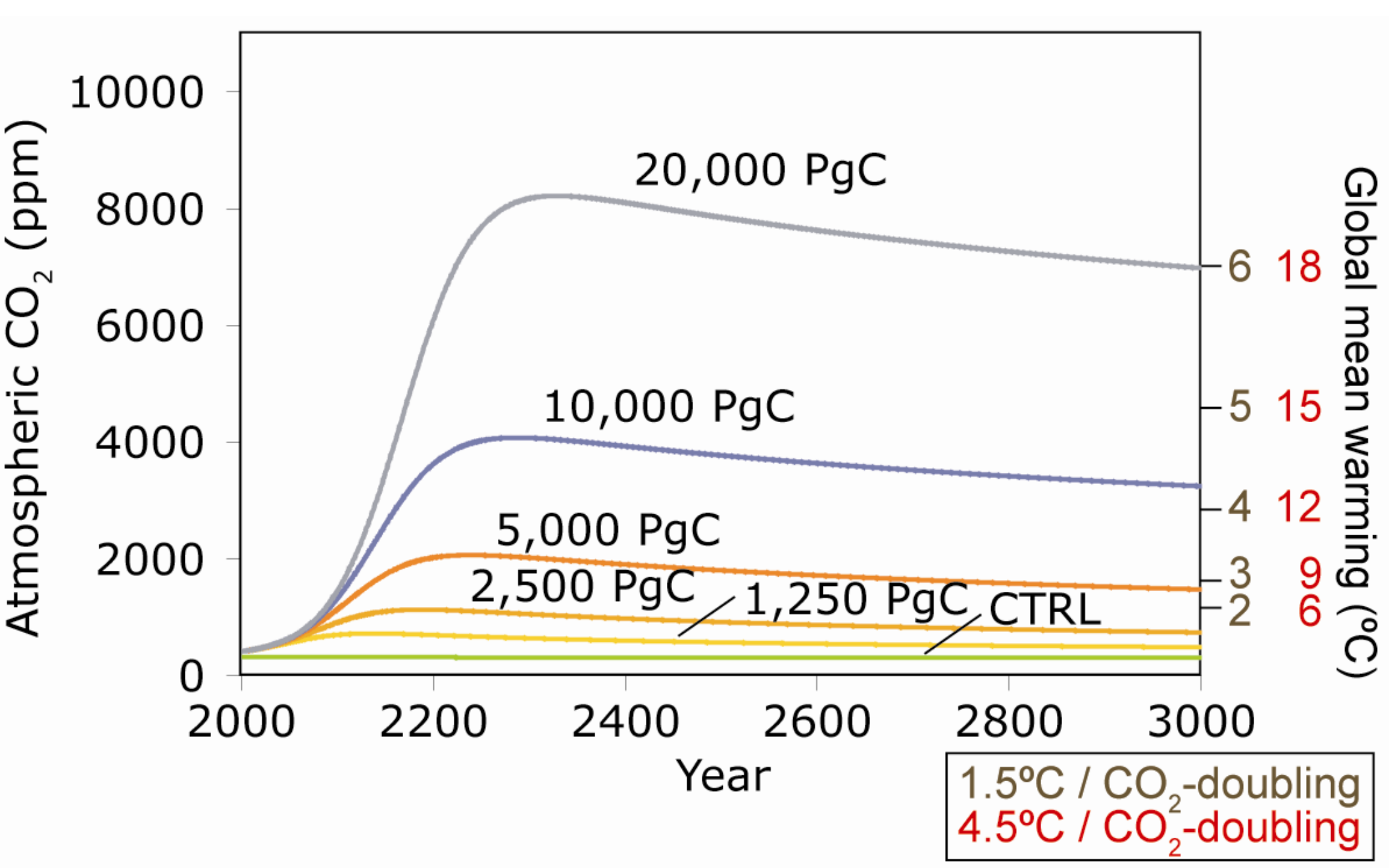

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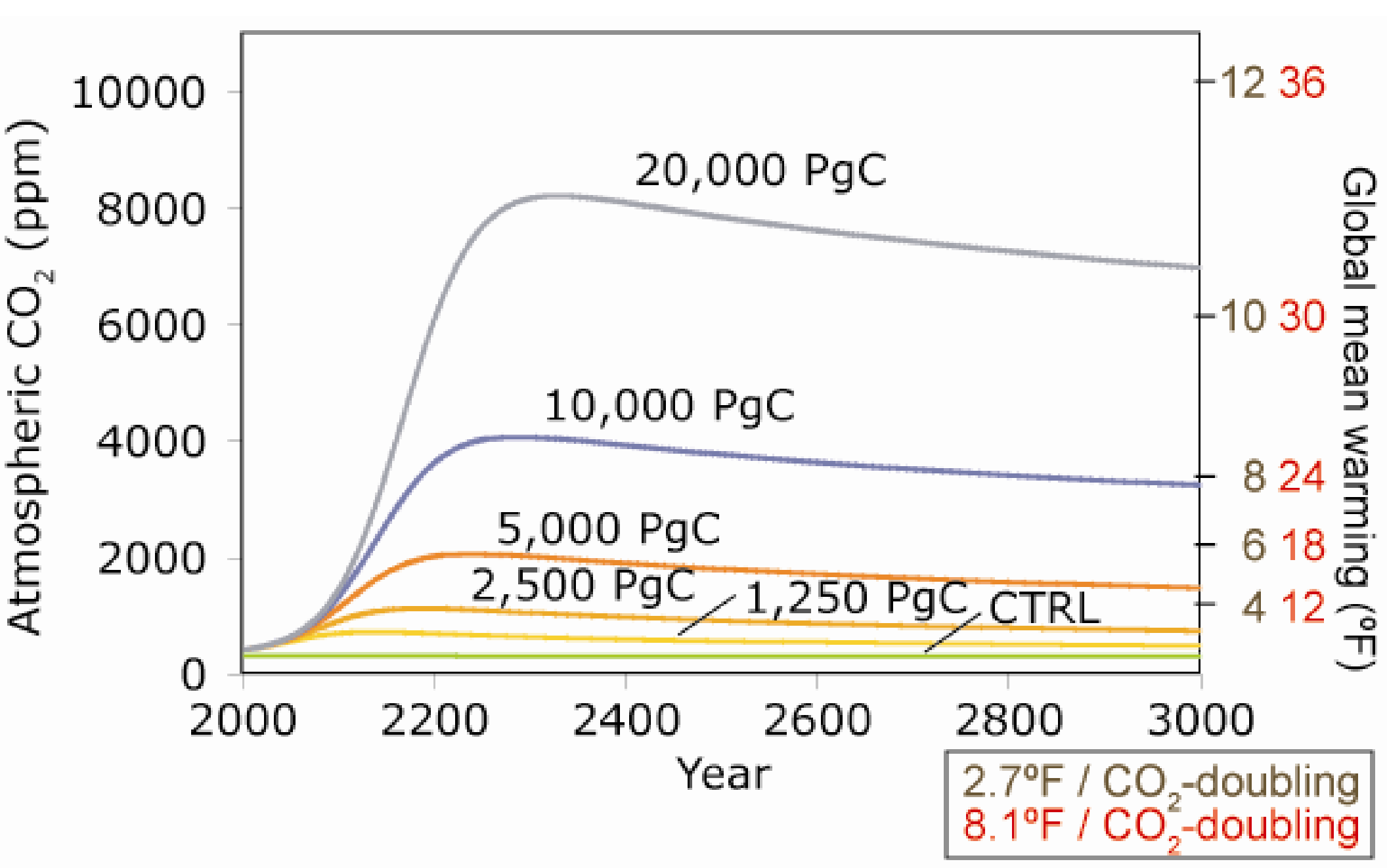


Amounts represent total fossil-fuel plus net land biosphere emissions

Caldeira and Wickett (2005)

Atmospheric CO_2 and climate change

- With a 2ºC per century warming, temperature bands in the mid-latitudes march poleward at a rate of 10 m (30 ft) per day

C.D. Friedrich, 1821
Solitary Tree,
National Gallery, Berlin

If this tree were at the southern end of its range, could it march north fast enough to remain in the cool weather it likes?

West Antarctic ice sheet not in jeopardy

December 1, 1998
Web posted at: 12:35 PM EST

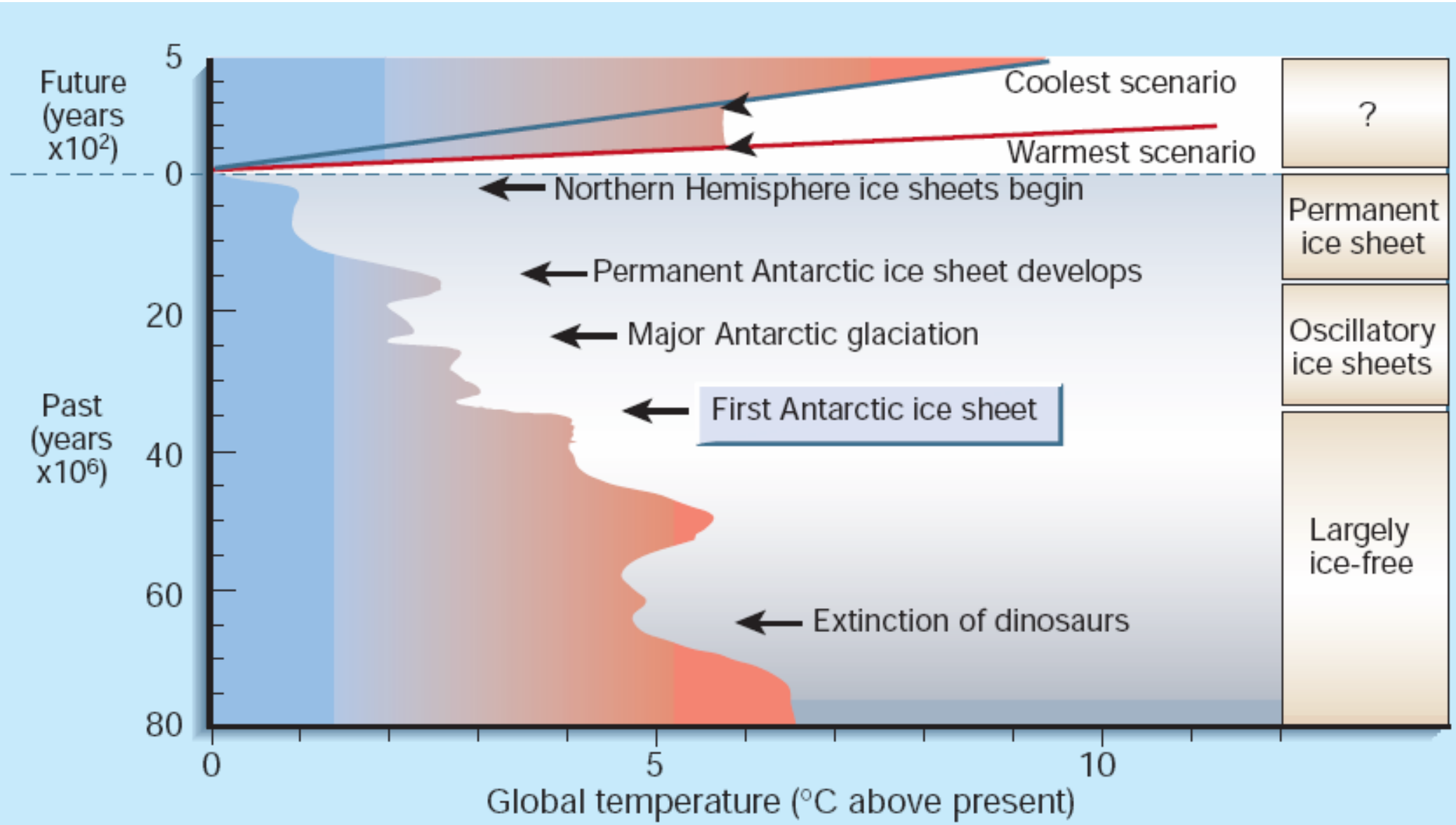
By Environmental News Network staff

(ENN) -- The west Antarctic ice sheet is not melting rapidly, is reasonably stable and has been so for more than a century, according to an international team of scientists.

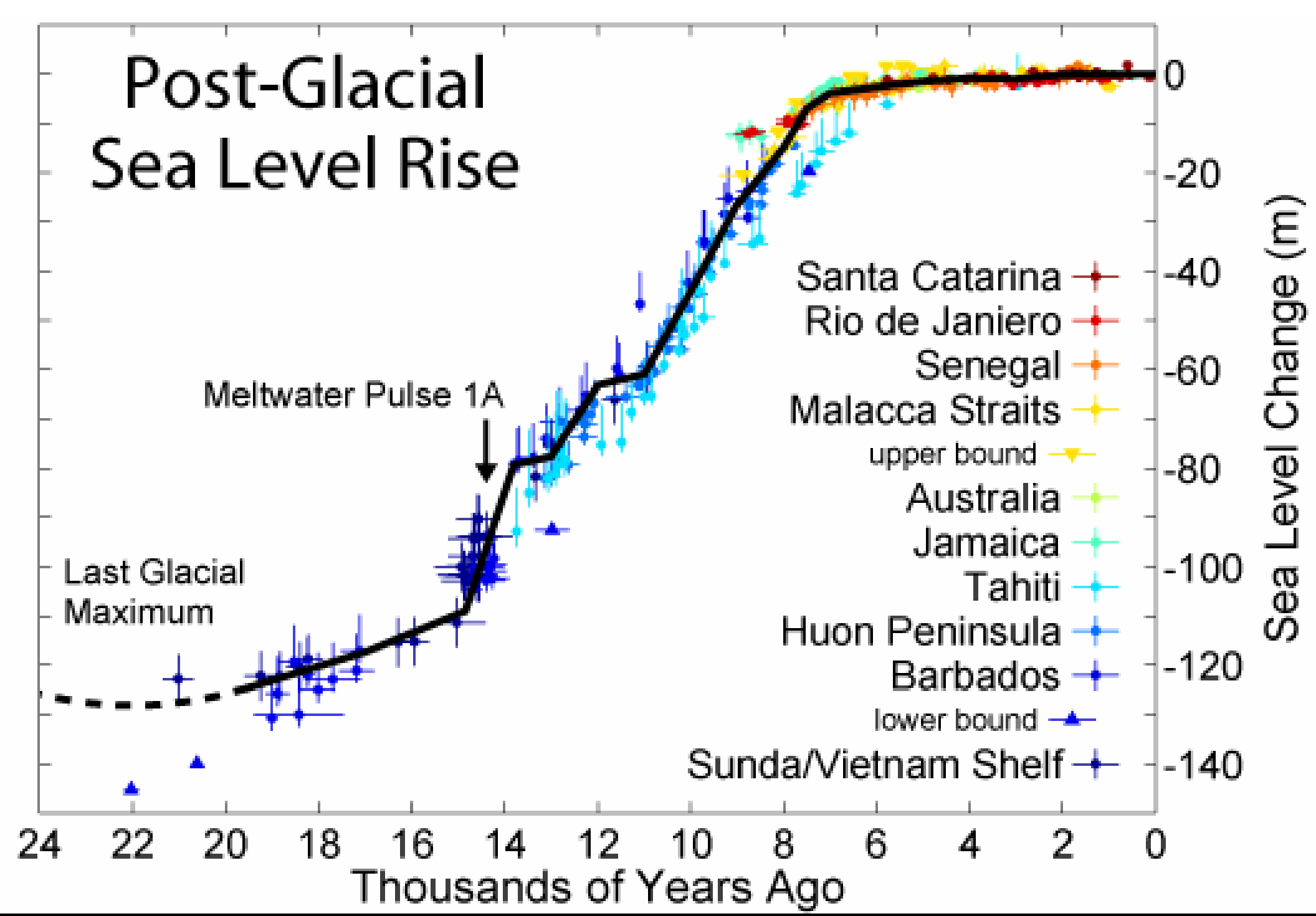
The ice sheet is the largest grounded repository of ice on the planet and some scientists caught up in the debate over global warming have argued that the melting of this ice sheet would lead to a dramatic rise in sea levels.

Courtesy NASA

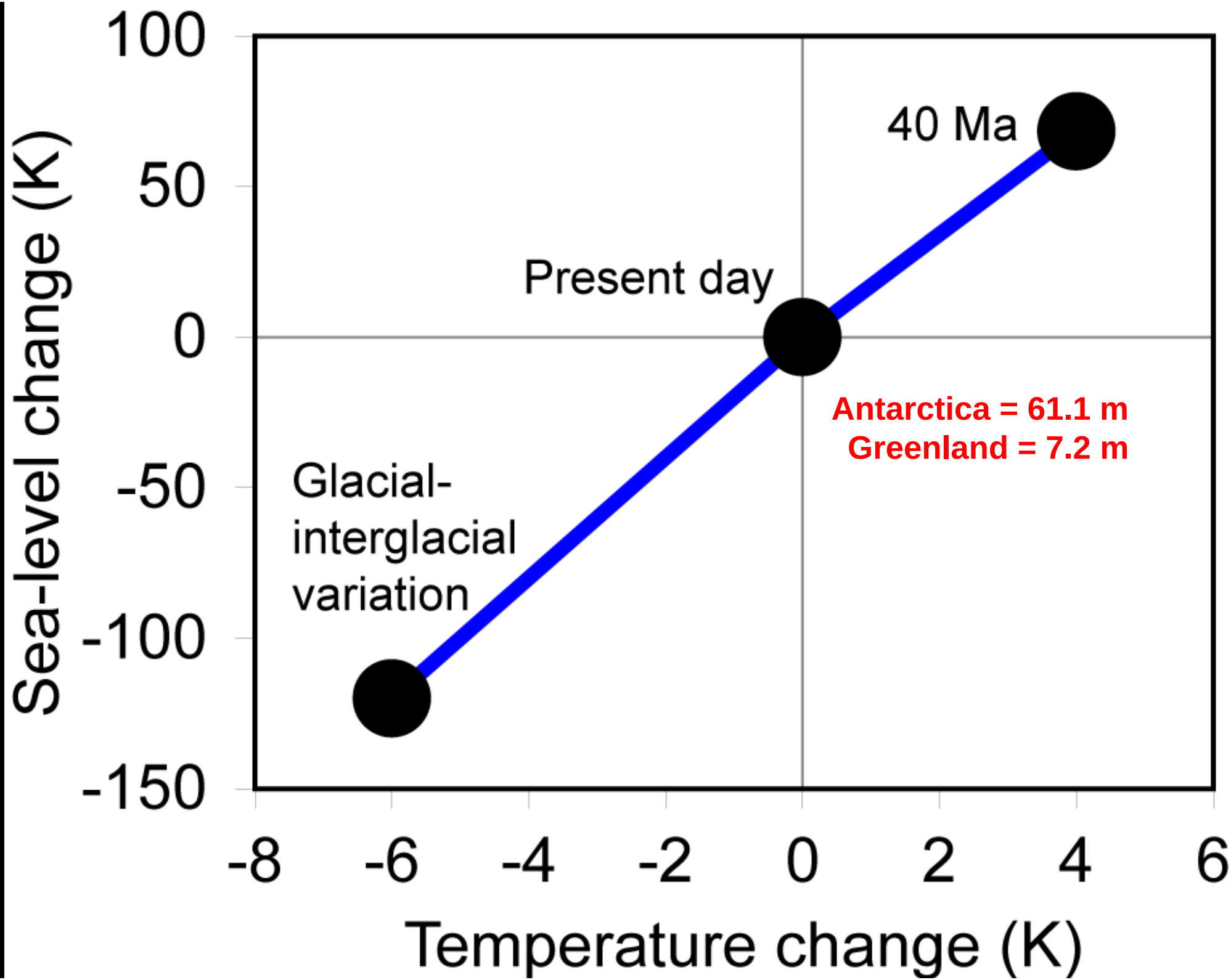
An international team of scientists analyzed five years of satellite radar measurements covering a large part of the Antarctic ice sheet in an effort to determine if there is any direct evidence of the ice sheet melting.



Barrett, 2003



Fleming et al. 1998, Fleming 2000, & Milne et al. 2005


100
50
0
-50
-100
-150
Sea-level change (K)
40 Ma
Present day
Glacial-
interglacial
variation
Antarctica = 61.1 m
Greenland = 7.2 m
-8
-6
-4
-2
0
2
4
6
Temperature change (K)

If CO_2 emissions continue unabated, we risk commitment to 7000 years of 1 cm per year sea-level rise (on average)

70 m of total sea level rise (over 220 ft)

AP Photo: http://www.bafi.org

Increasing destructiveness of tropical cyclones over the past 30 years

Kerry Emanuel[1]

NATURE|Vol 436|4 August 2005

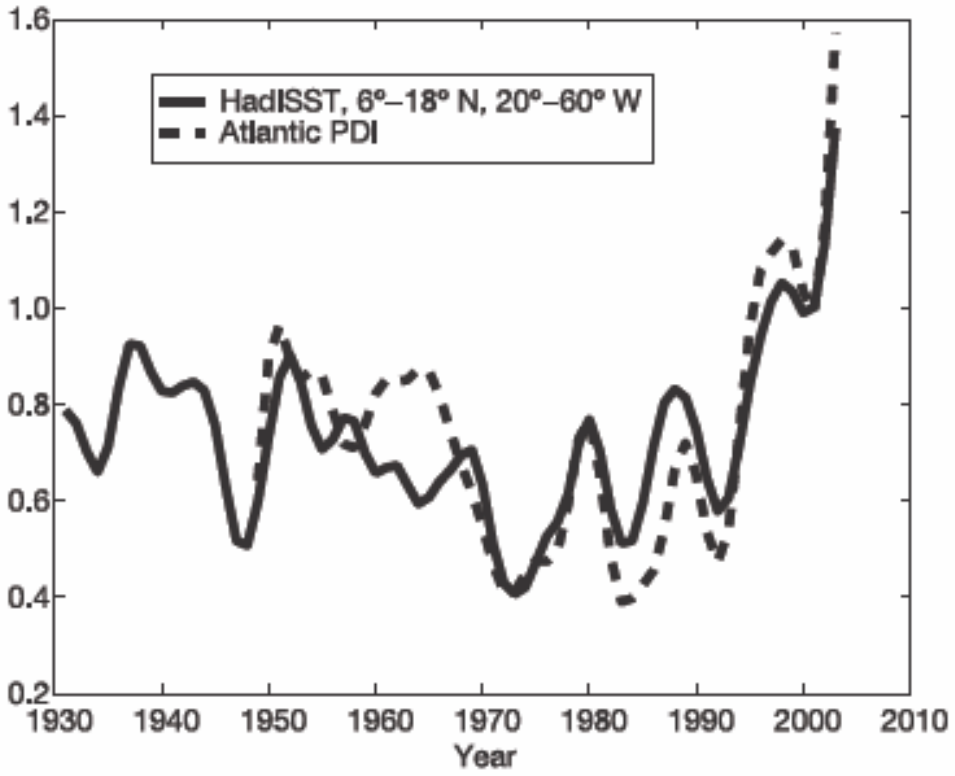


Figure 1 | A measure of the total power dissipated annually by tropical cyclones in the North Atlantic (the power dissipation index, PDI) compared to September sea surface temperature (SST). The PDI has been multiplied by 2.1×10^{-12} and the SST, obtained from the Hadley Centre Sea Ice and SST data set (HadISST)[22], is averaged over a box bounded in latitude by 6° N and 18° N, and in longitude by 20° W and 60° W. Both quantities have been smoothed twice using equation (3), and a constant offset has been added to the temperature data for ease of comparison. Note that total Atlantic hurricane power dissipation has more than doubled in the past 30 yr.

Continued CO_2 emission will lead to warmer sea-surface temperatures

Warmer sea-surface temperatures have been associated with increase hurricane intensity

Jeff Schmaltz, MODIS Rapid Response Team NASA GSFC

- Our present trajectory is risking severe environmental damage that could last thousands of years.

- We know that sooner or later we will need to stop emitting CO_2 to the atmosphere.

- We can stop emitting vast amounts of CO_2
  - sooner (before we cause great damage) or
  - later (and risk severe and irreversible damage)