De invloed van CO_2 op het klimaat

Mar-23 2022, Lezing Koninklijk Instituut Van Ingenieurs, Wouter Peters




1) Lessen uit het verleden

2) Zijn *wij* een natuurkracht?

3) CO_2 en klimaat in de 21e eeuw

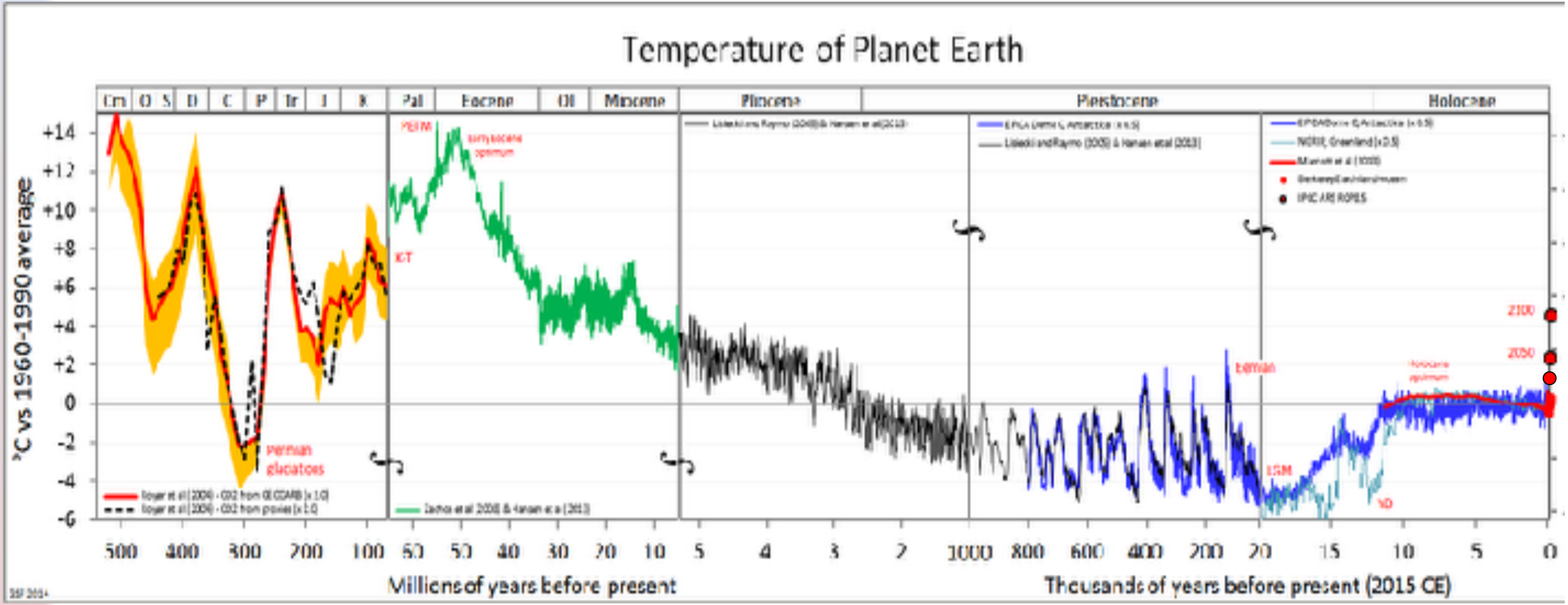


Figure courtesy Wikipedia, Glen Fergus

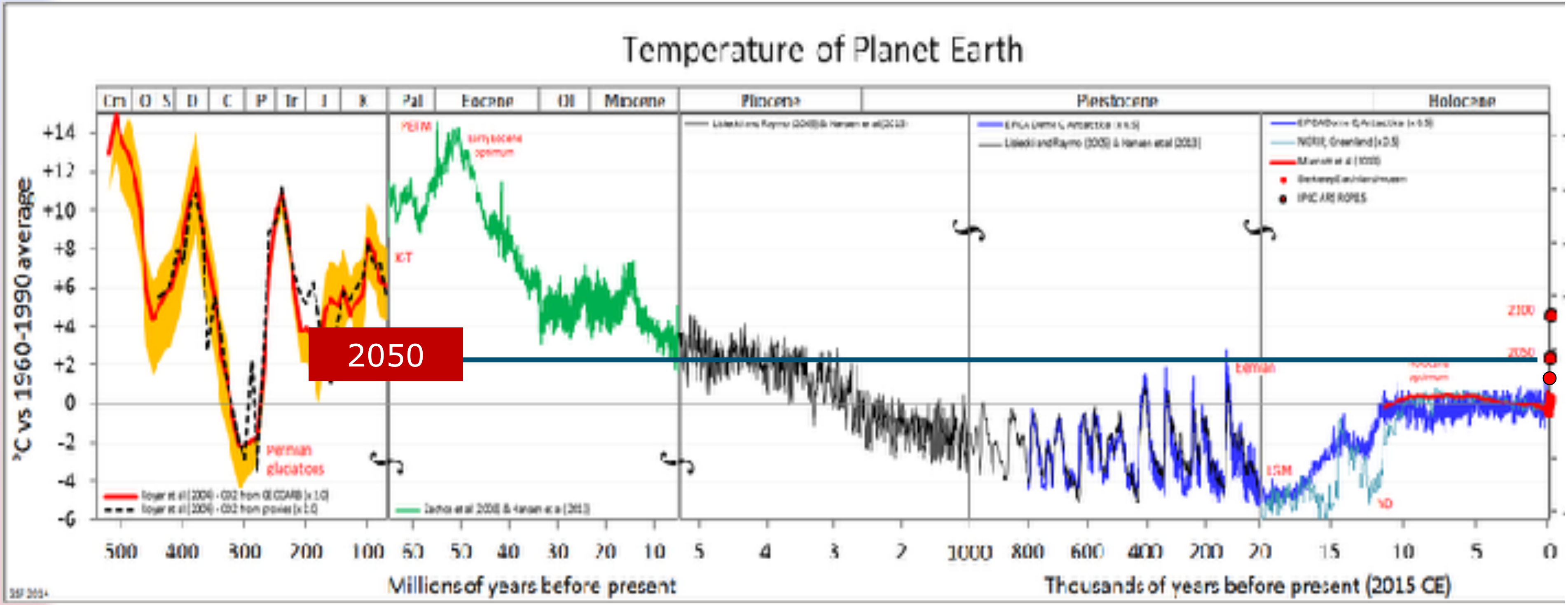


Figure courtesy Wikipedia, Glen Fergus

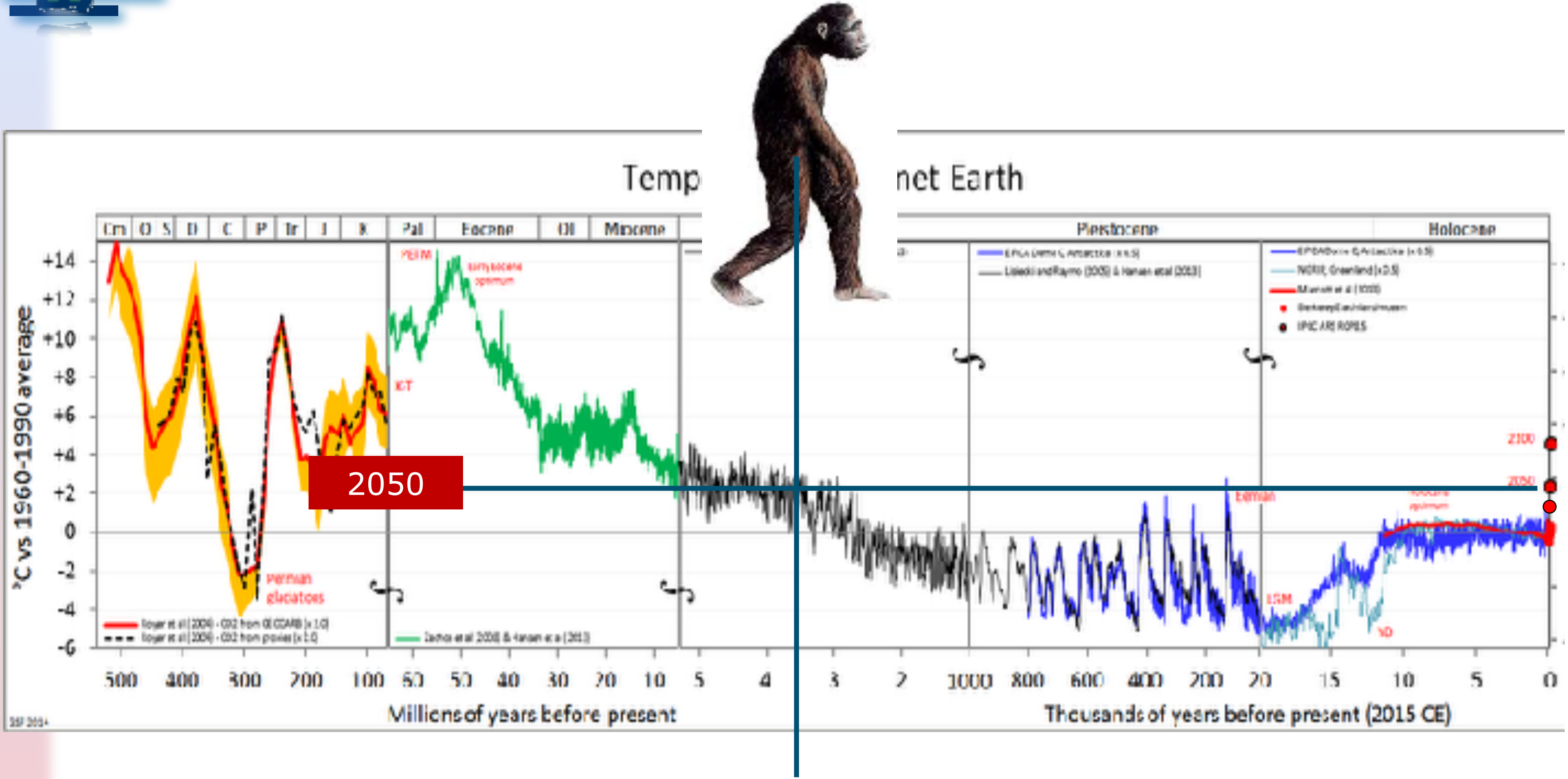


Figure courtesy Wikipedia, Glen Fergus

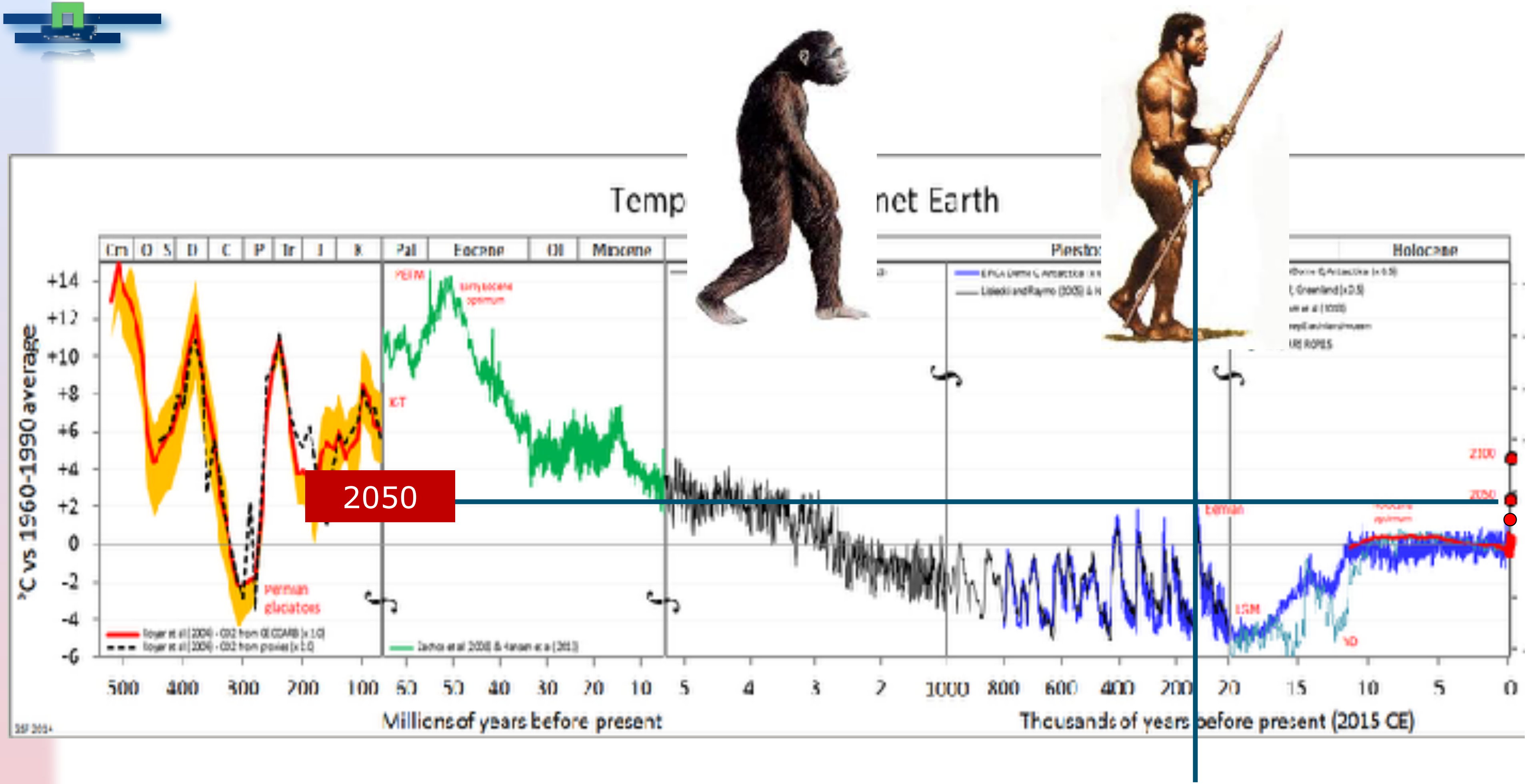
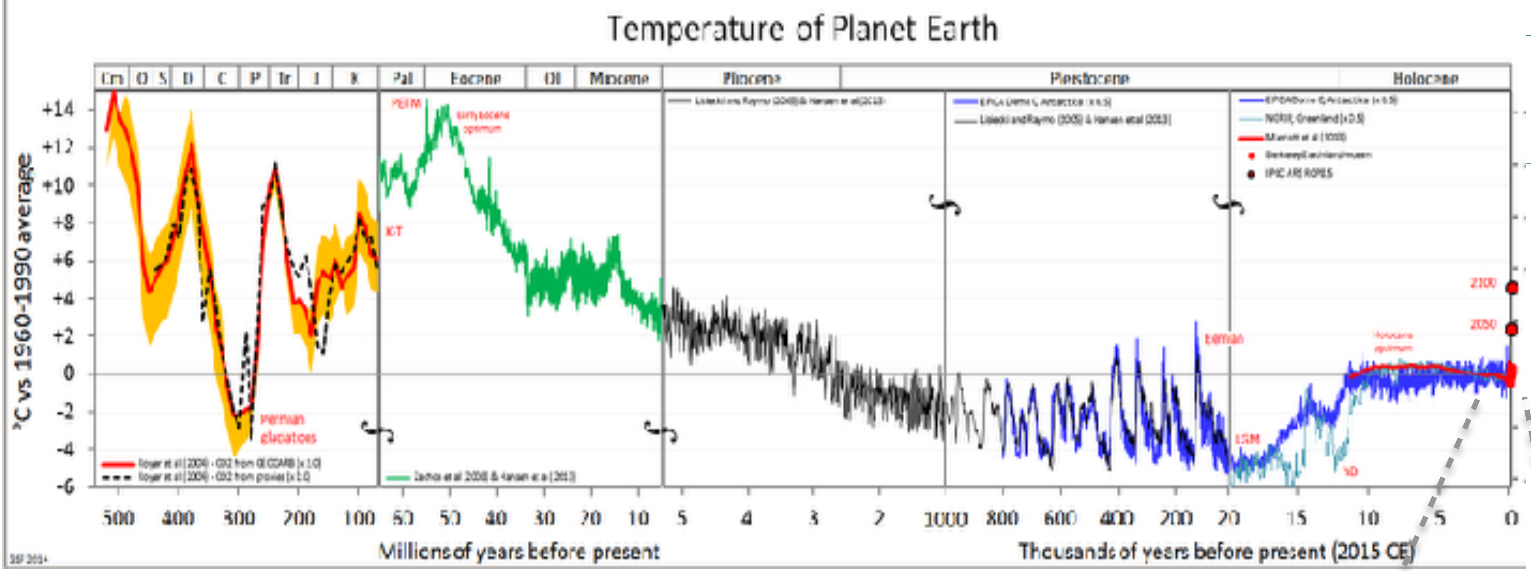
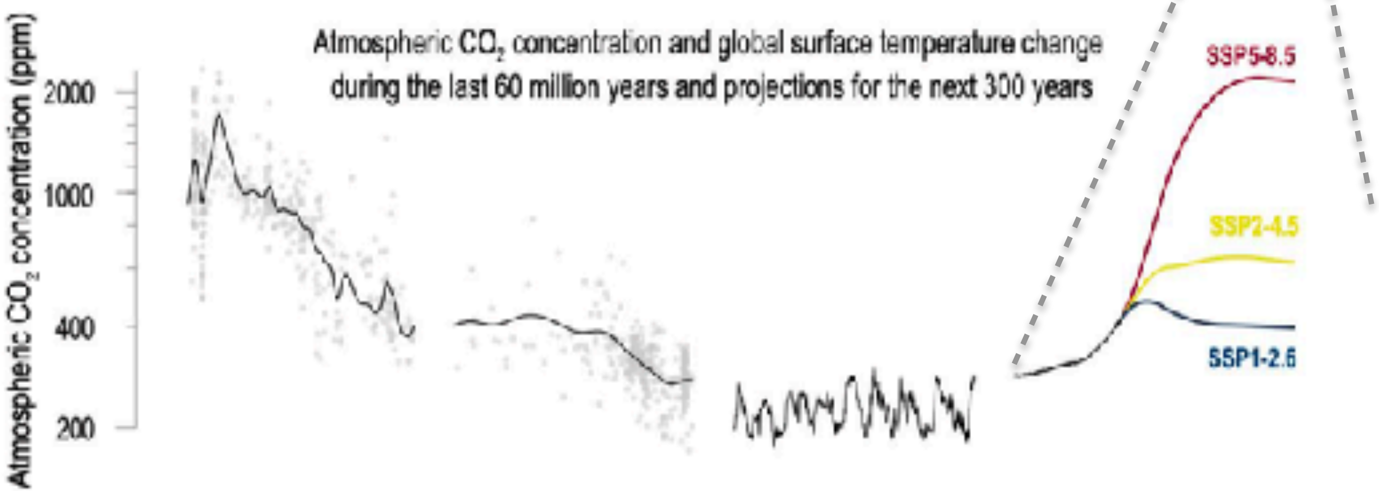


Figure courtesy Wikipedia, Glen Fergus

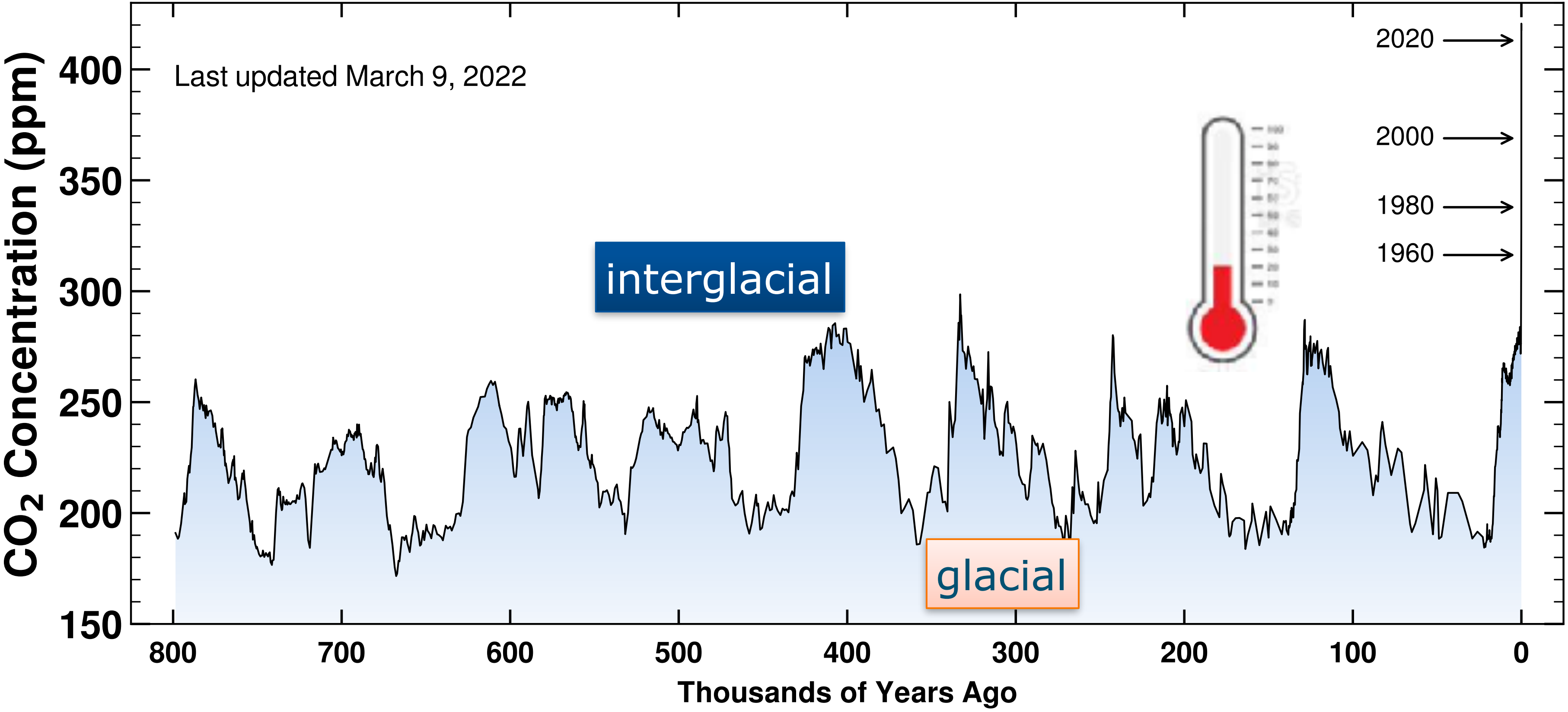


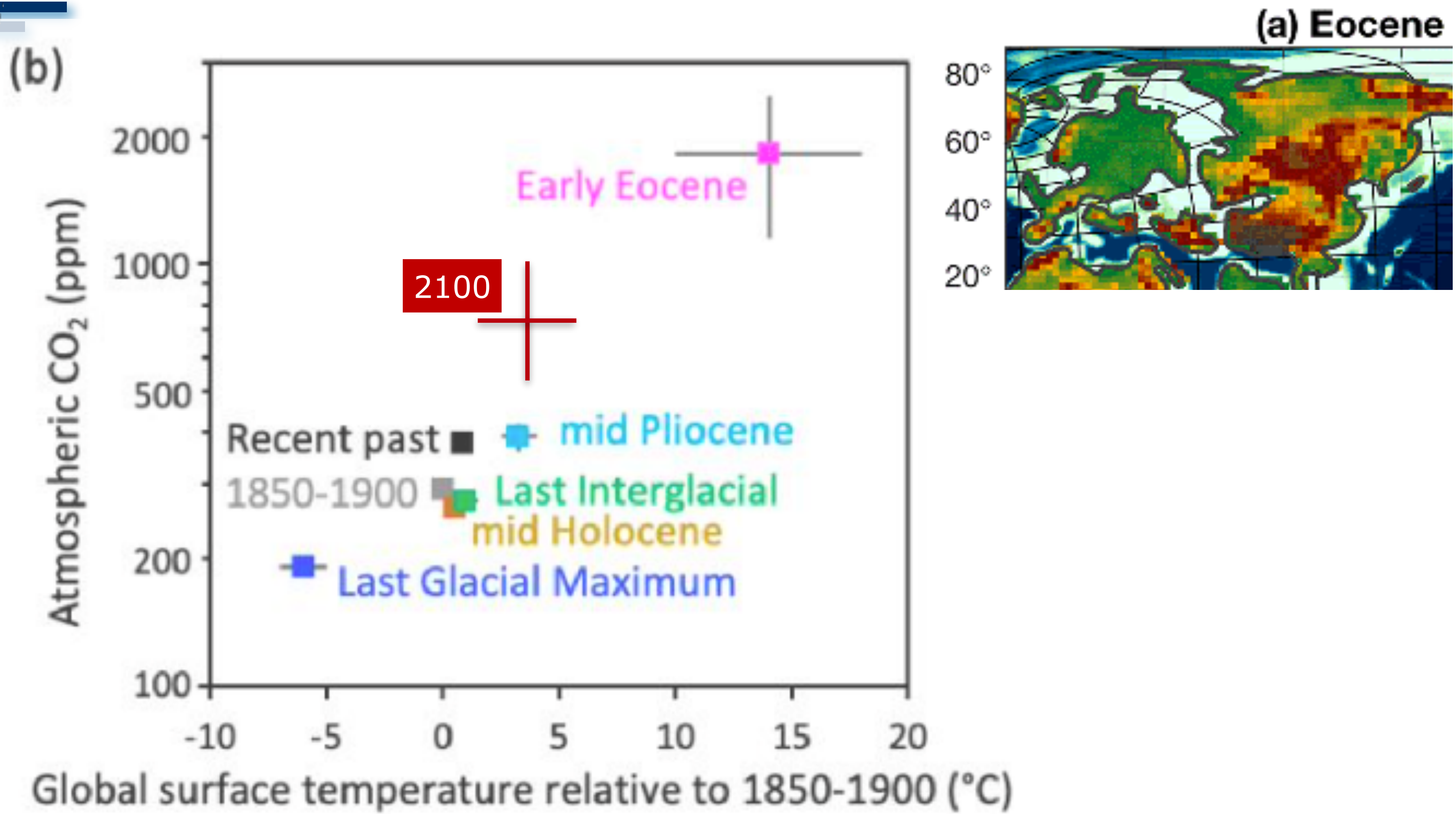
Temperature of Planet Earth
°C vs 1960-1990 average
+14
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
Cm O S D C P Tr J K
Pal Eocene Ol Miocene
Pliocene
Pleistocene
Holocene
Permian glaciations
LGM
2100
2050
500 400 300 200 100 60 50 40 30 20 10 5 4 3 2 1000 800 600 400 200 20 15 10 5 0
Millions of years before present
Thousands of years before present (2015 CE)

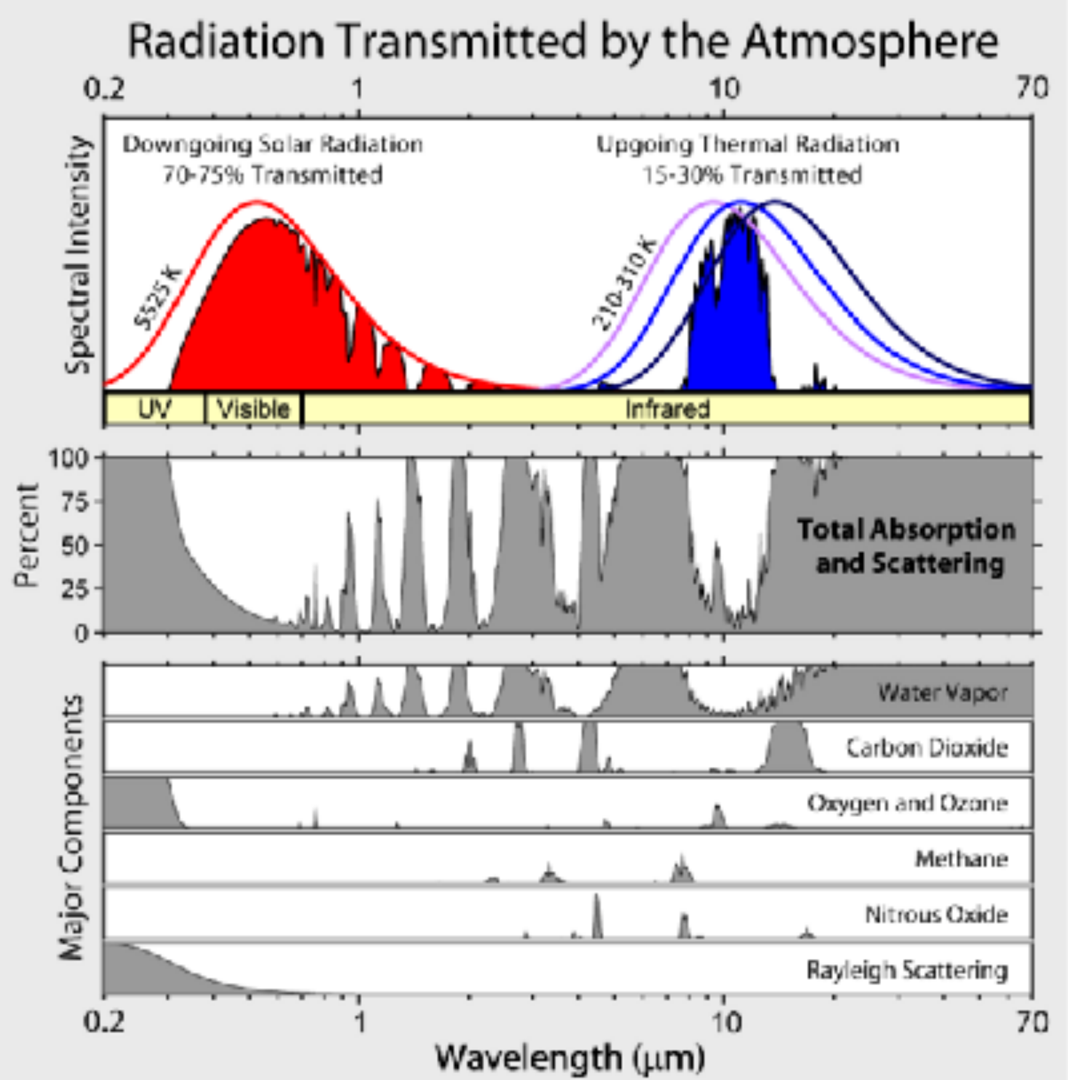


Atmospheric CO2 concentration and global surface temperature change
during the last 60 million years and projections for the next 300 years
Atmospheric CO2 concentration (ppm)
2000
1000
400
200
SSP5-8.5
SSP2-4.5
SSP1-2.6

Ice-core data before 1958. Mauna Loa Data after 1958.



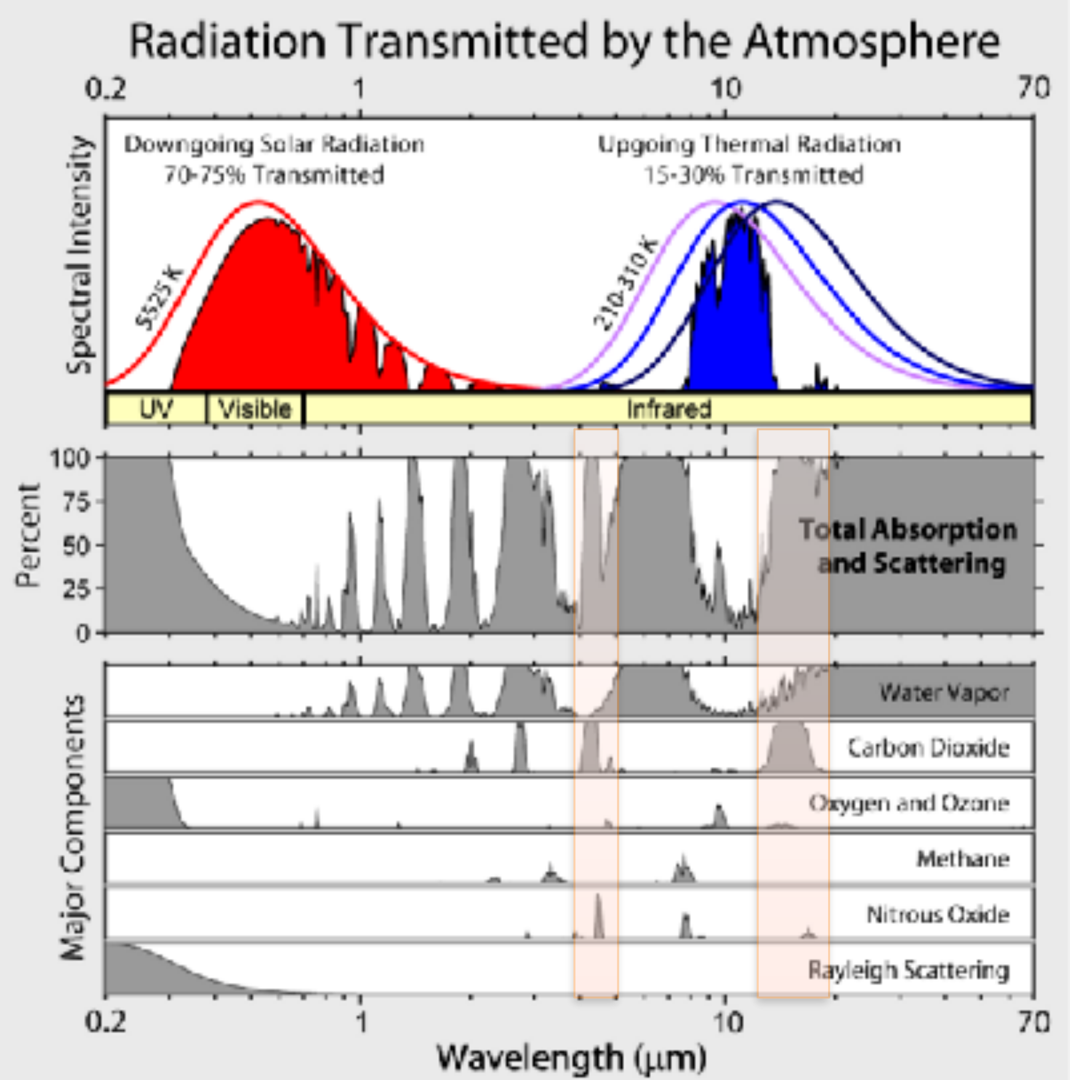

(a) Eocene
80°
60°
40°
20°
(b)
Atmospheric CO2 (ppm)
2000
1000
500
200
100
Early Eocene
2100
Recent past
mid Pliocene
1850-1900
Last Interglacial
mid Holocene
Last Glacial Maximum
-10
-5
0
5
10
15
20
Global surface temperature relative to 1850-1900 (°C)



Seen at the top-of-the-atmosphere

Absorbed by atmosphere

H_2O
CO_2
O_2 en O_3
CH_4
N_2O

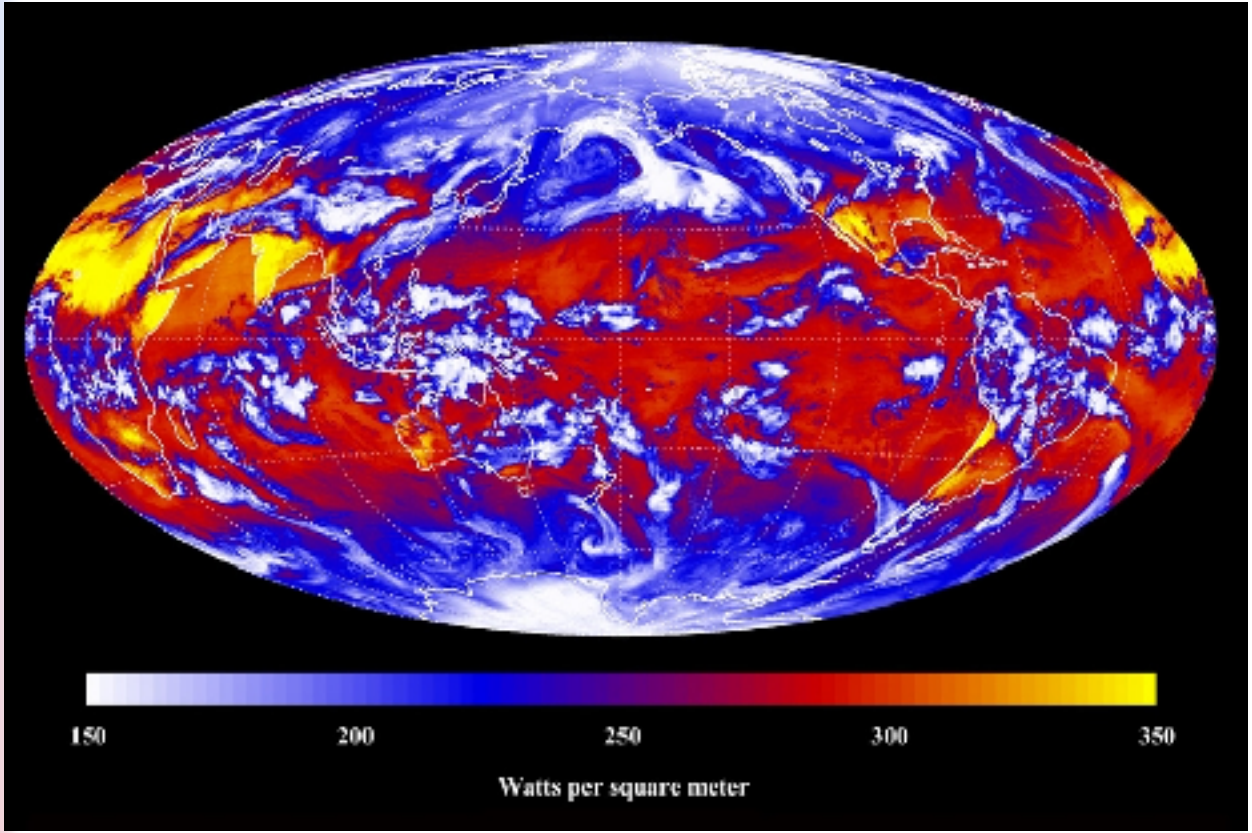


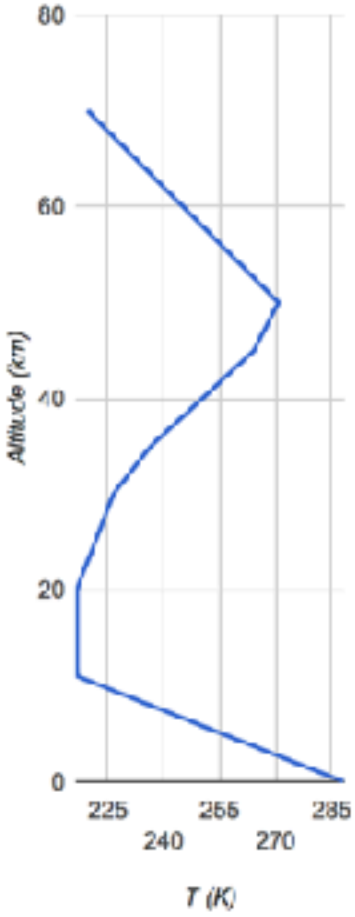
Seen at the top-of-the-atmosphere

Absorbed by atmosphere

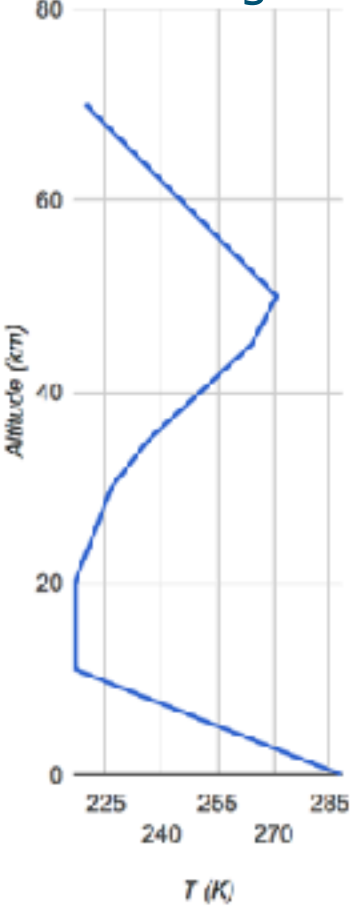
H_2O
CO_2
O_2 en O_3
CH_4
N_2O

T vs height

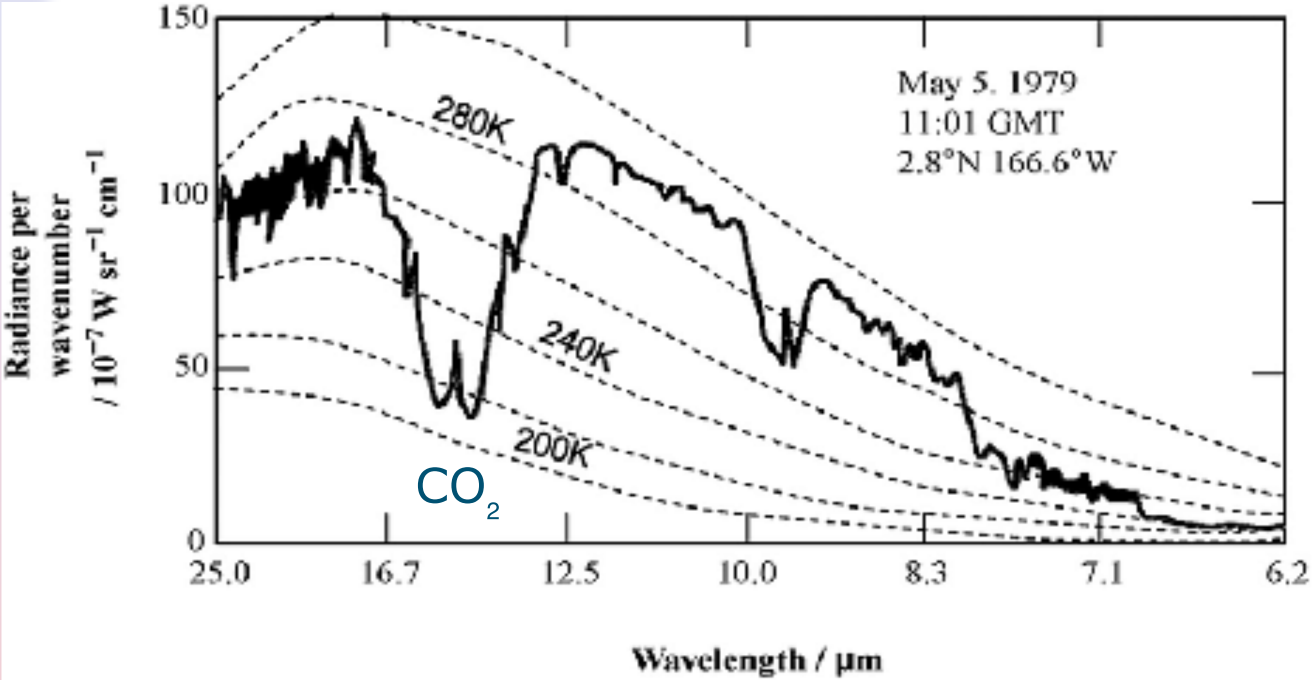

150
200
250
300
350
Watts per square meter


80
60
40
20
0
Altitude (km)
225
255
285
240
270
T (K)

T vs height

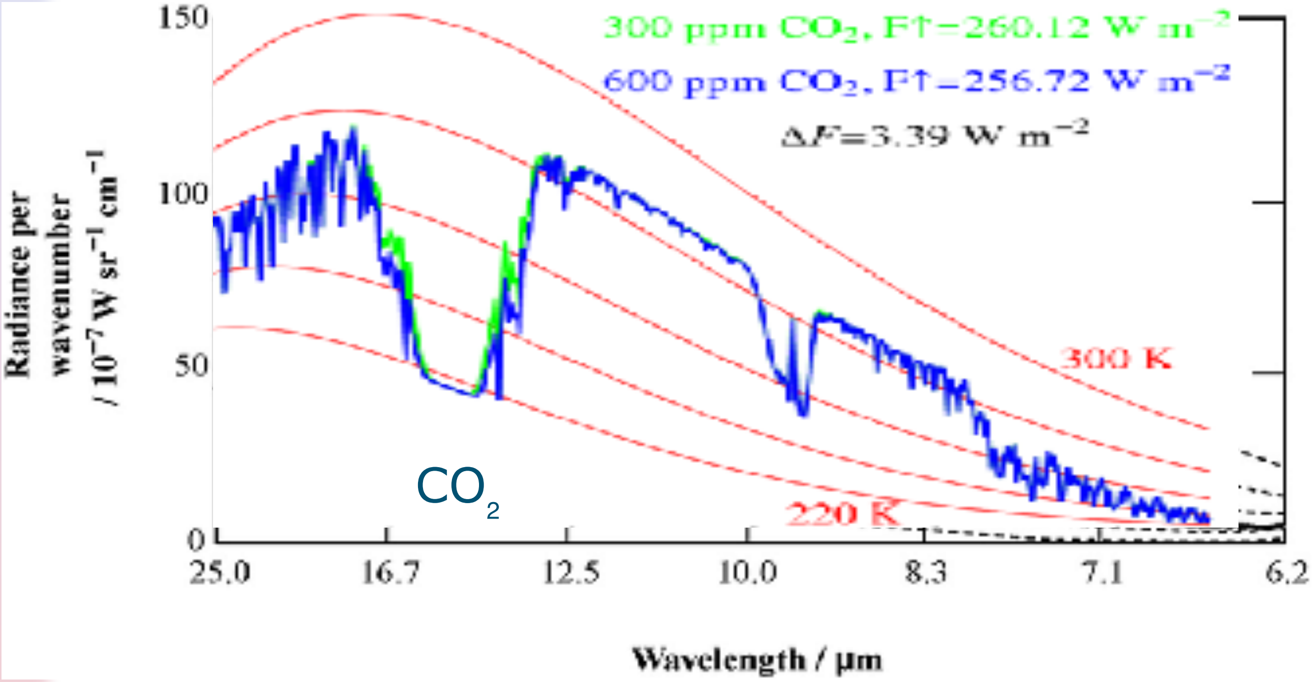


Nimbus-4 satellite

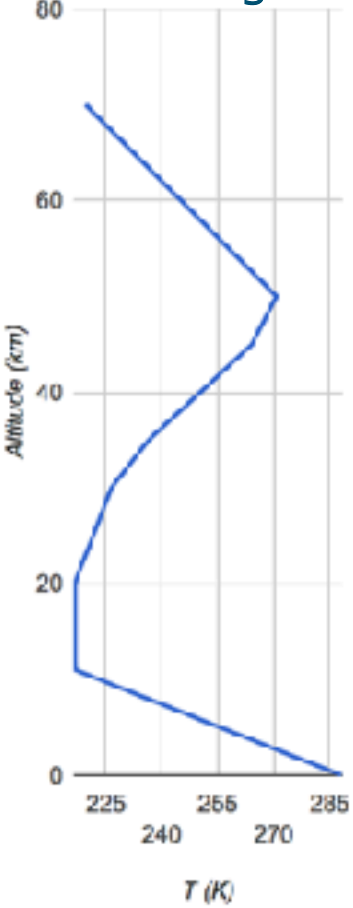


also see http://climateconsensarian.blogspot.com/2016/03/modtran-radiative-atmospheric-model.html

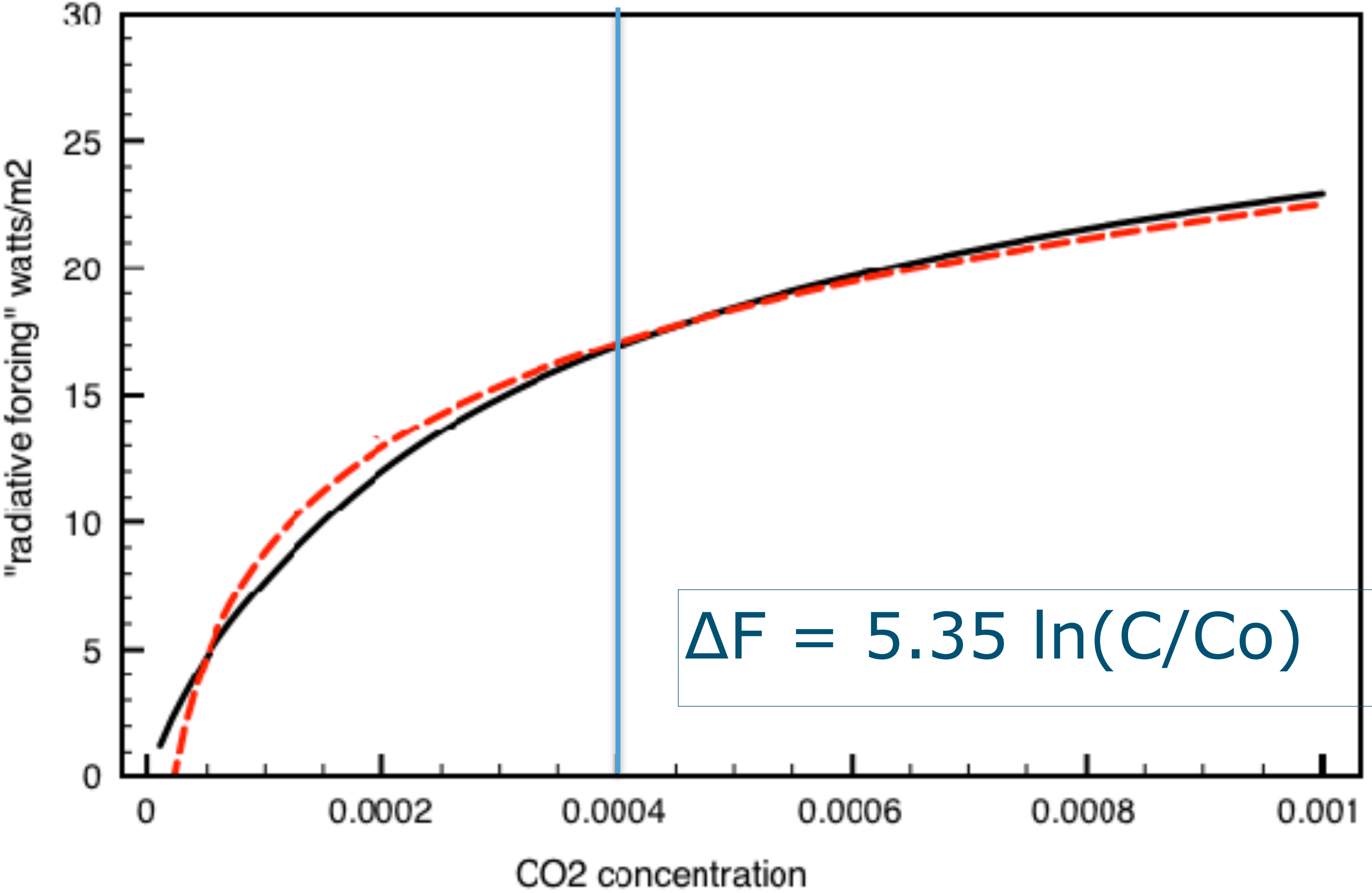
Modtran model calculations



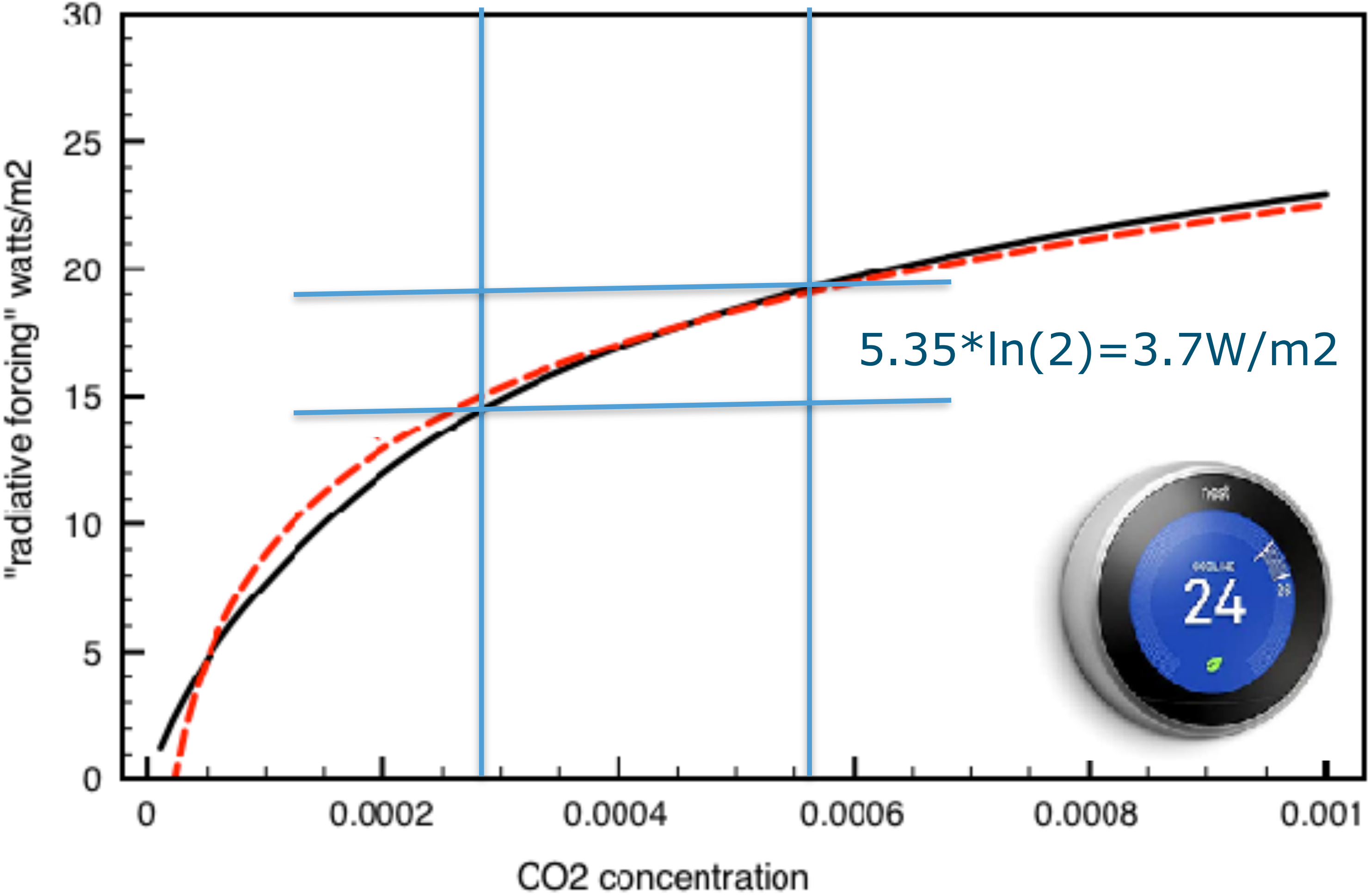
T vs height

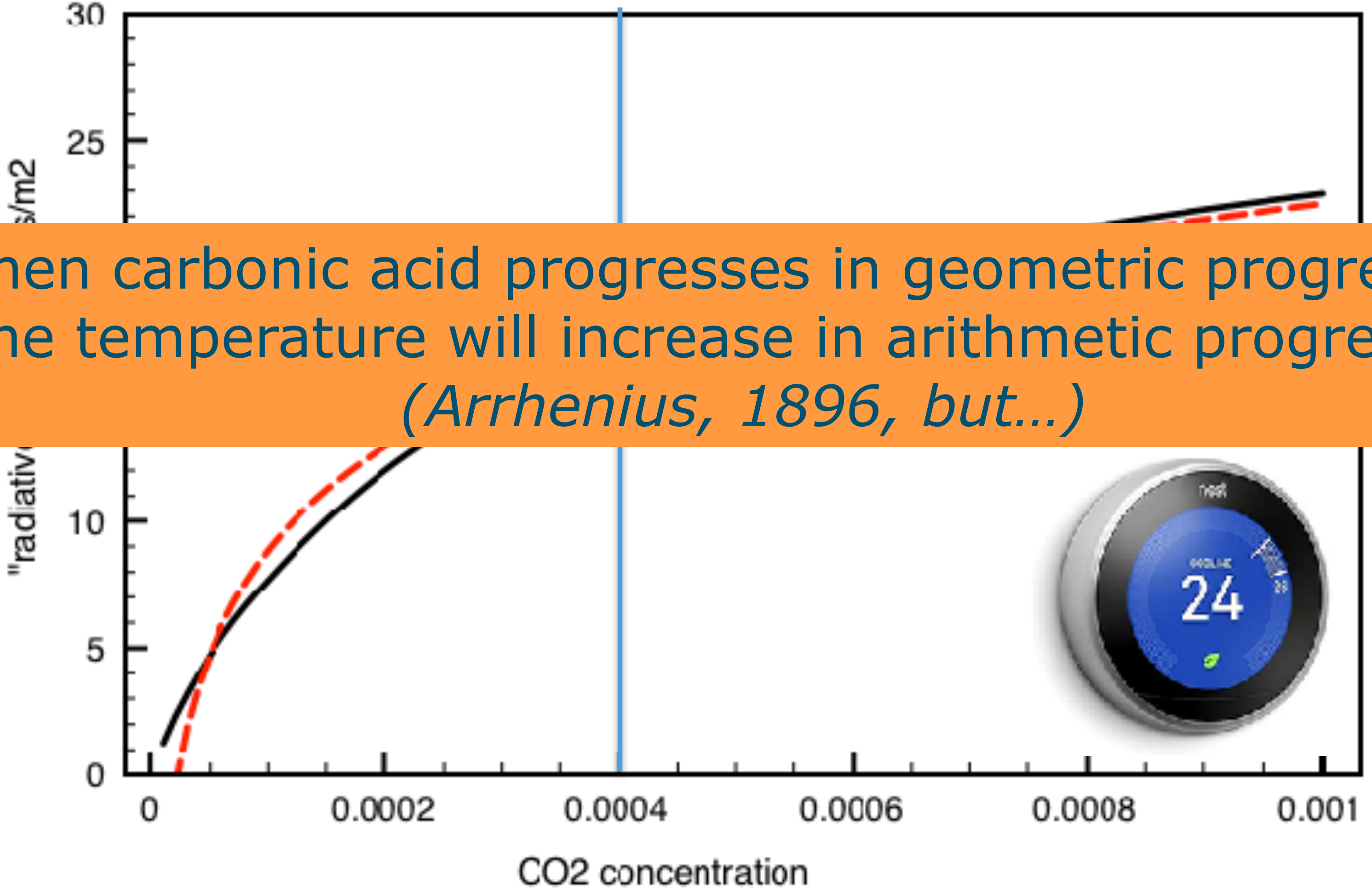


Myhre et al., 1998



$$\Delta F = 5.35 \ln(C/Co)$$


"radiative forcing" watts/m2
30
25
20
15
10
5
0
0
0.0002
0.0004
0.0006
0.0008
0.001
CO2 concentration
5.35*ln(2)=3.7W/m2
24



When carbonic acid progresses in geometric progression, the temperature will increase in arithmetic progression *(Arrhenius, 1896, but…)*

1) ~~Lessen uit het verleden~~

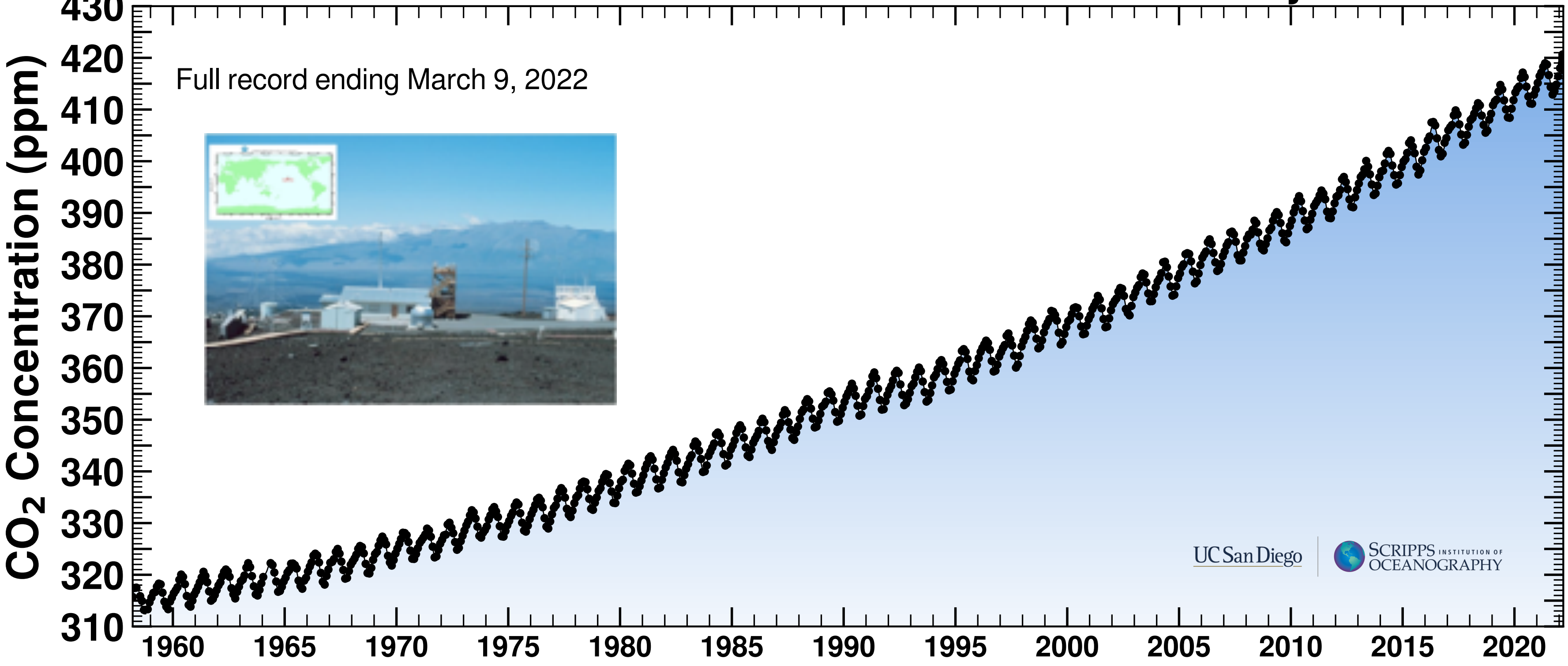
2) Zijn *wij* een natuurkracht?

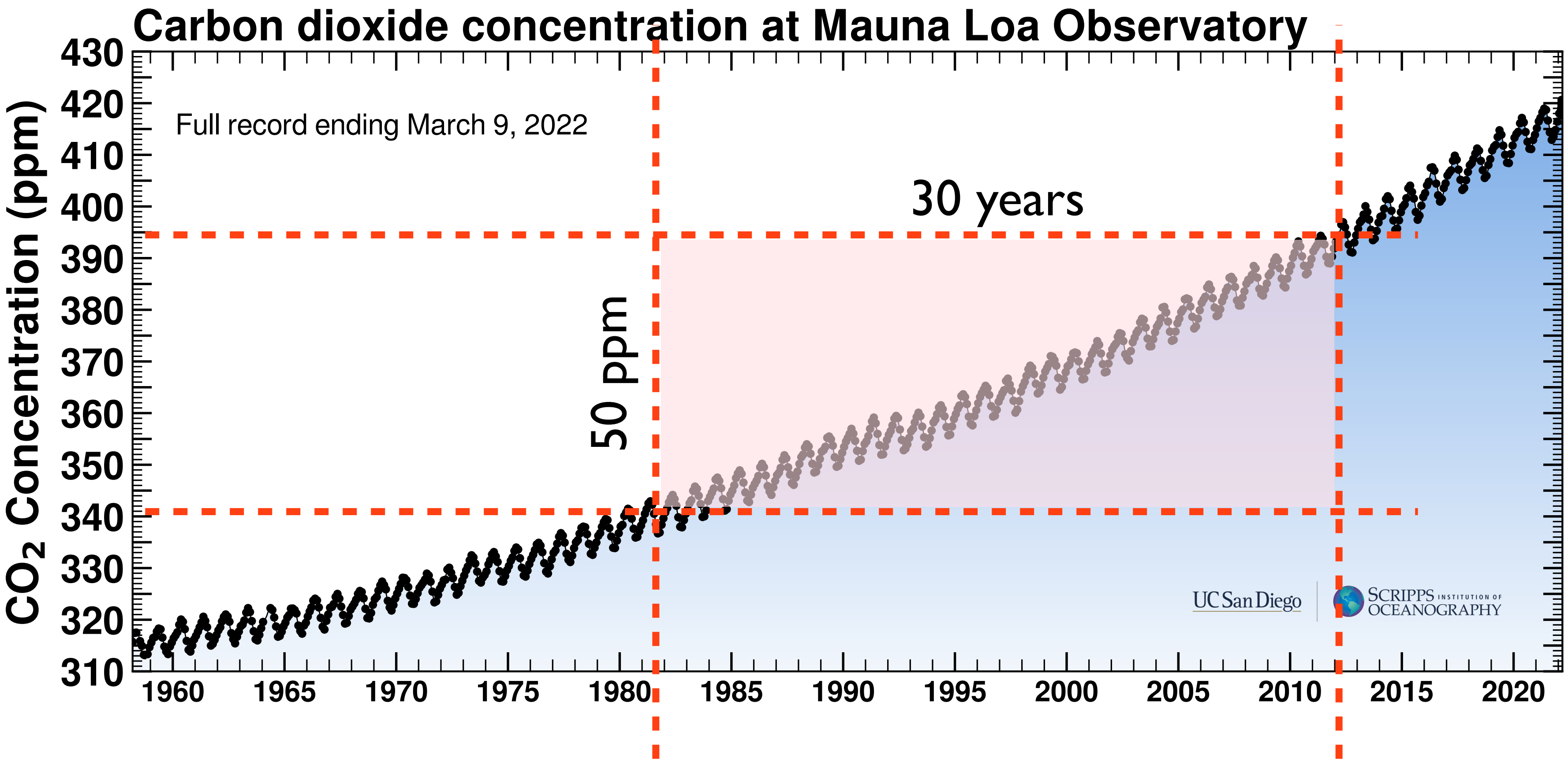
3) CO_2 en klimaat in de 21e eeuw

IPCC 6th assessment report (2022):

The continued growth of atmospheric CO_2 concentrations over the industrial era is *unequivocally* due to emissions from human activities.

Carbon dioxide concentration at Mauna Loa Observatory





Carbon dioxide concentration at Mauna Loa Observatory
Full record ending March 9, 2022
30 years
50 ppm
CO_2 Concentration (ppm)
430
420
410
400
390
380
370
360
350
340
330
320
310
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
UC San Diego
SCRIPPS INSTITUTION OF OCEANOGRAPHY

$$\frac{\Delta[\mathrm{CO_2}]}{\Delta \mathrm{t}} = \mathrm{F_{fossil}} + \mathrm{F_{fire}} + \mathrm{F_{ocean}} + \mathrm{F_{biosphere}}$$

$$\frac{\Delta[CO_2]}{\Delta t} = F_{fossil} + F_{fire} + F_{ocean} + F_{biosphere}$$

CO_2 is nearly inert

1 PgC = 10^{15} g = billion tons

1 PgC = 0.47 ppm

1 ppm = 2.123 PgC

$$\frac{\Delta[CO_2]}{\Delta t} = F_{fossil} + F_{fire} + F_{ocean} + F_{biosphere}$$

$$\left(\frac{395 - 342}{30} \cdot \frac{1}{0.47}\right) = 6 + 2 + F_{ocean} + F_{biosphere}$$

$$3.8 = 6 + 2 + F_{ocean} + F_{biosphere}$$

$$-4.2 = F_{ocean} + F_{biosphere}$$

The global ocean and biosphere are a net sink of carbon dioxide

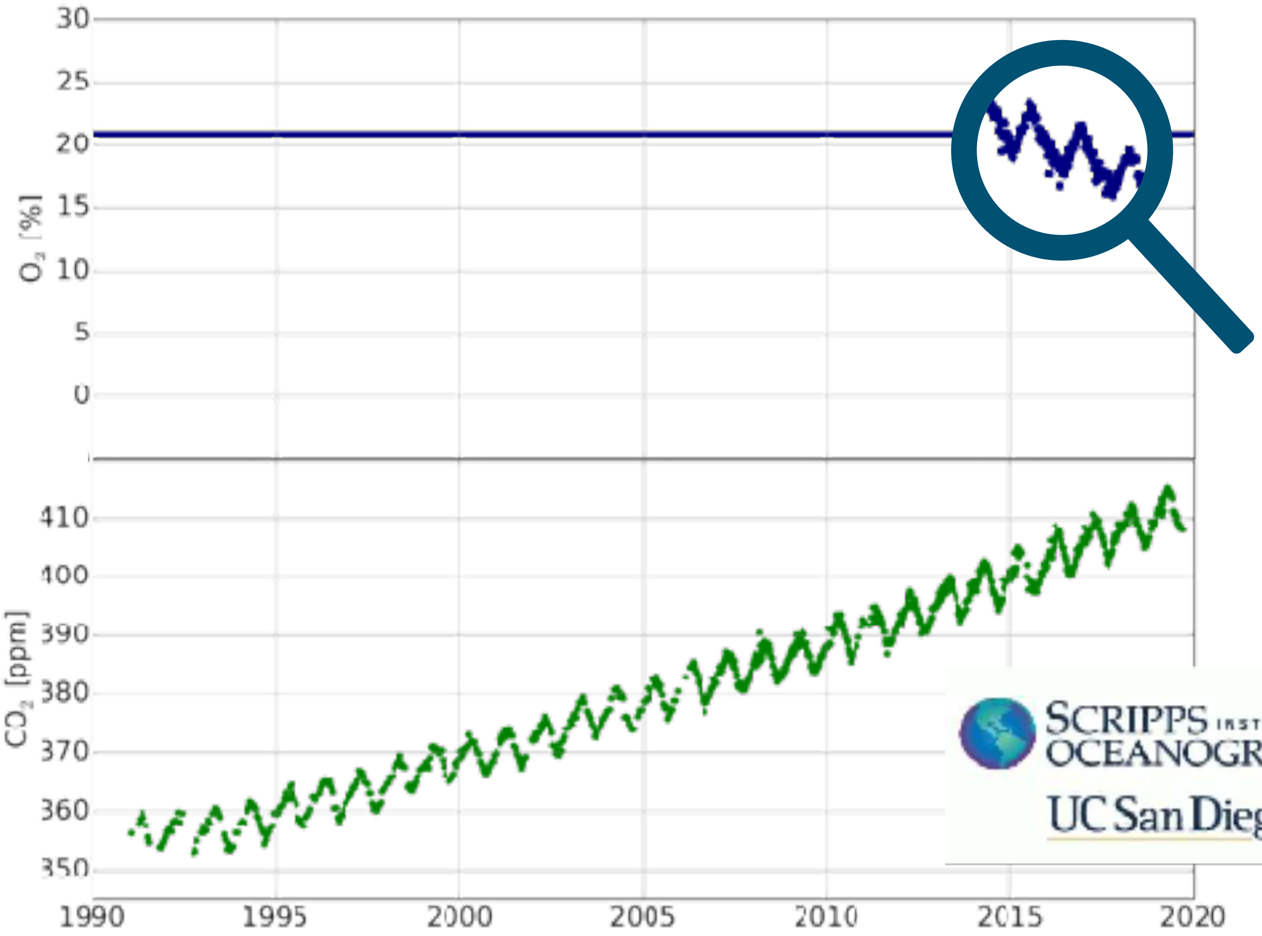
$$\frac{\Delta[CO_2]}{\Delta t} = F_{fossil} + F_{fire} + F_{ocean} + F_{biosphere}$$

$$\left(\frac{395-342}{30} \cdot \frac{1}{0.47}\right) = 6 + 2 + F_{ocean} + F_{biosphere}$$

$$3.8 = 6 + 2 + F_{ocean} + F_{biosphere}$$

$$-4.2 = F_{ocean} + F_{biosphere}$$

Measurements at Mauna Loa, Hawaii



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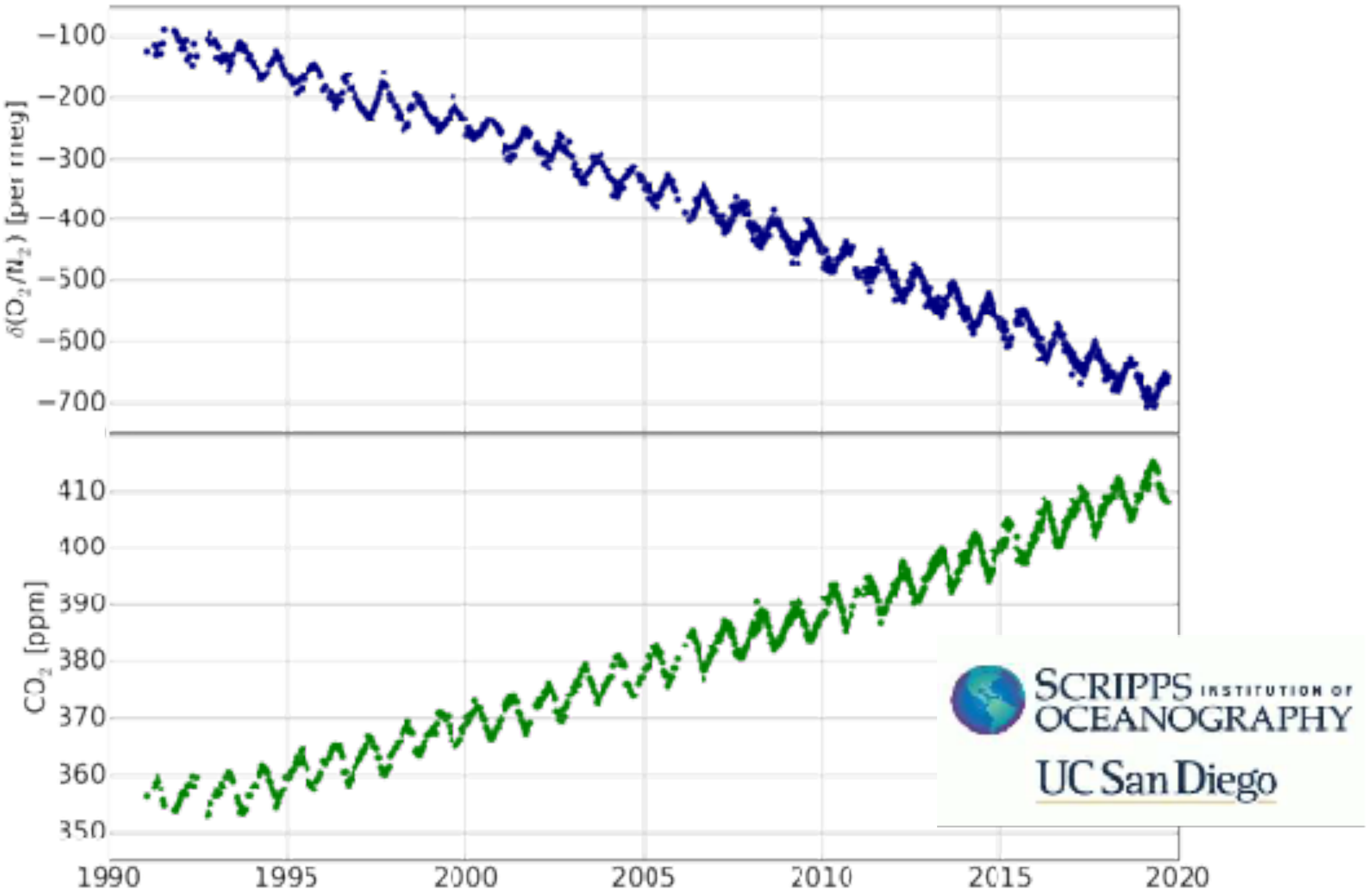
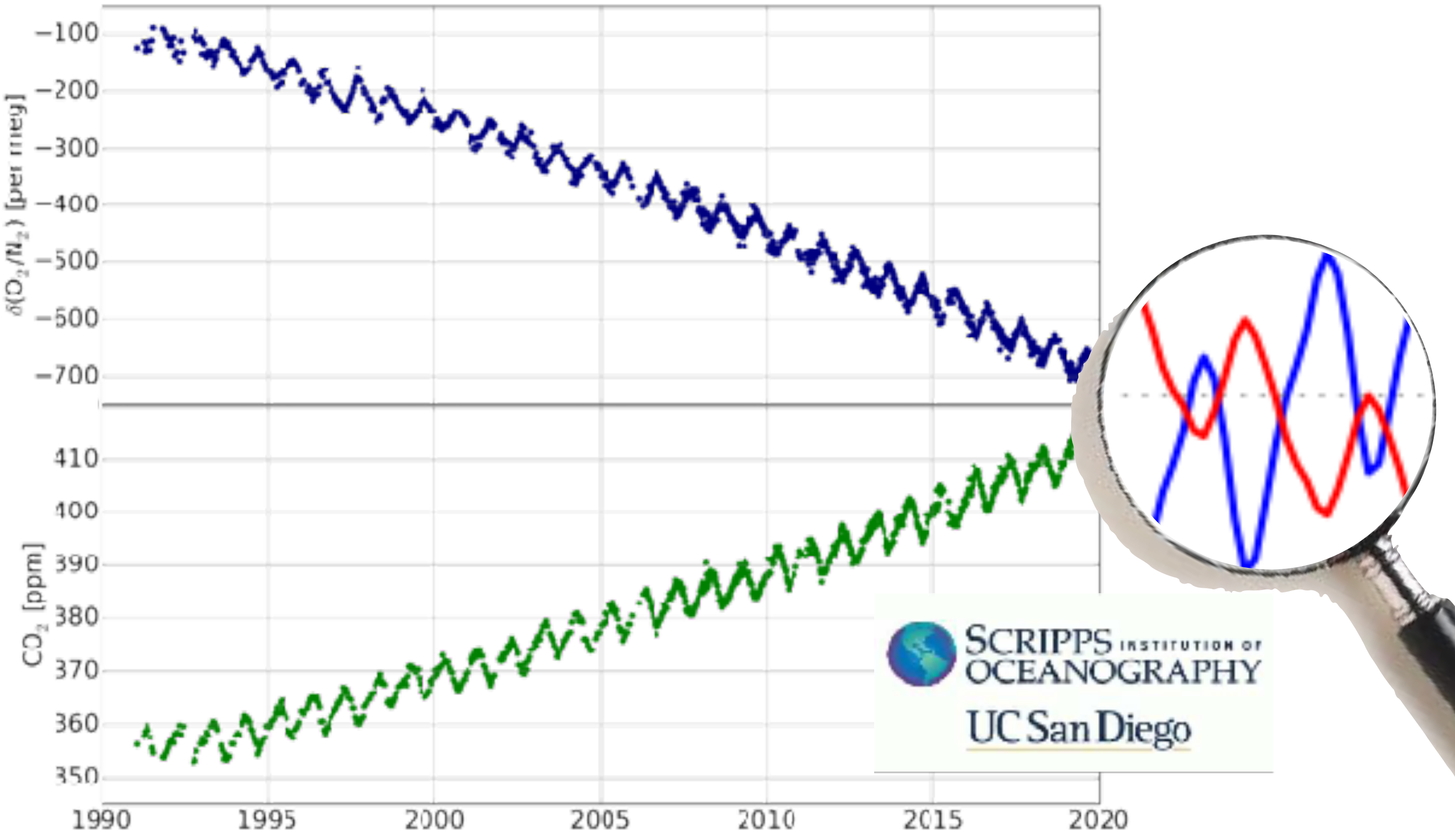
Measurements at Mauna Loa, Hawaii



Measurements at Mauna Loa, Hawaii



O_2 mixing ratios

- O_2/N_2 ratio is measured around the globe
- Variations are small (ppm against a background of 21%)
- Used first by R. Keeling, Manning, and Bender (1993-1996)
- (Simplified) Interpretation partitions ocean/biosphere uptake

O_2 mixing ratios

- A combustion process converts O_2 to CO_2

7:5

$$5\ CH_{1.6} + 7\ O_2 \quad \rightarrow \quad 5\ CO_2 + 4\ H_2O$$

O_2 mixing ratios

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7:5

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- Photosynthesis (←Respiration) converts CO_2 to O_2

1.1:1

$$n\ CO_2 + n\ H_2O \quad \rightarrow \quad (CH_2O)_n + n\ O_2$$

O_2 mixing ratios

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7:5

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1.1:1

$$n\ CO_2 + n\ H_2O \quad \rightarrow \quad (CH_2O)_n + n\ O_2$$

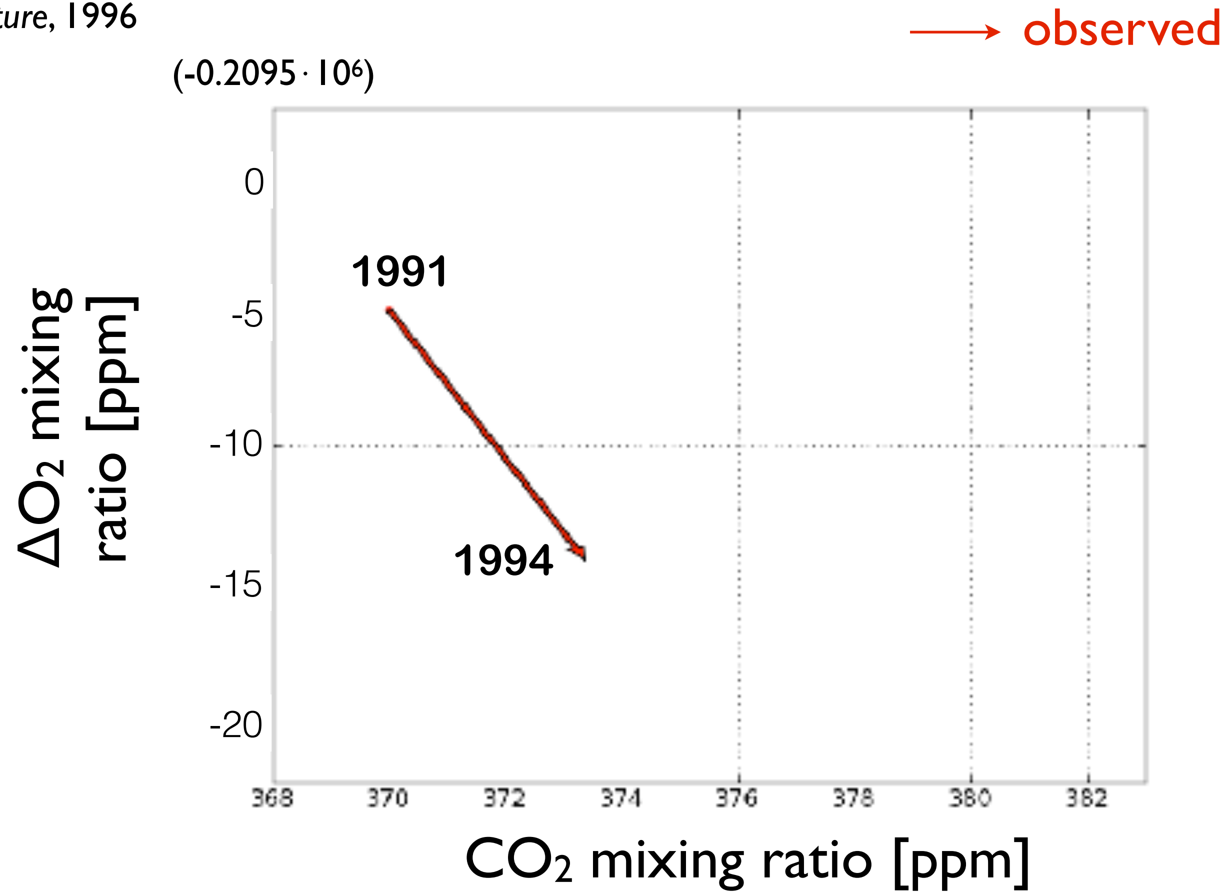
- Ocean exchange does not affect O_2/CO_2

0:1

$$\begin{aligned} CO_2(g) \quad &\Leftrightarrow \quad CO_2 \cdot H_2O \\ CO_2 \cdot H_2O \quad &\Leftrightarrow \quad HCO_3^- + H^+ \\ HCO_3^- \quad &\Leftrightarrow \quad CO_3^{2-} + H^+ \end{aligned}$$

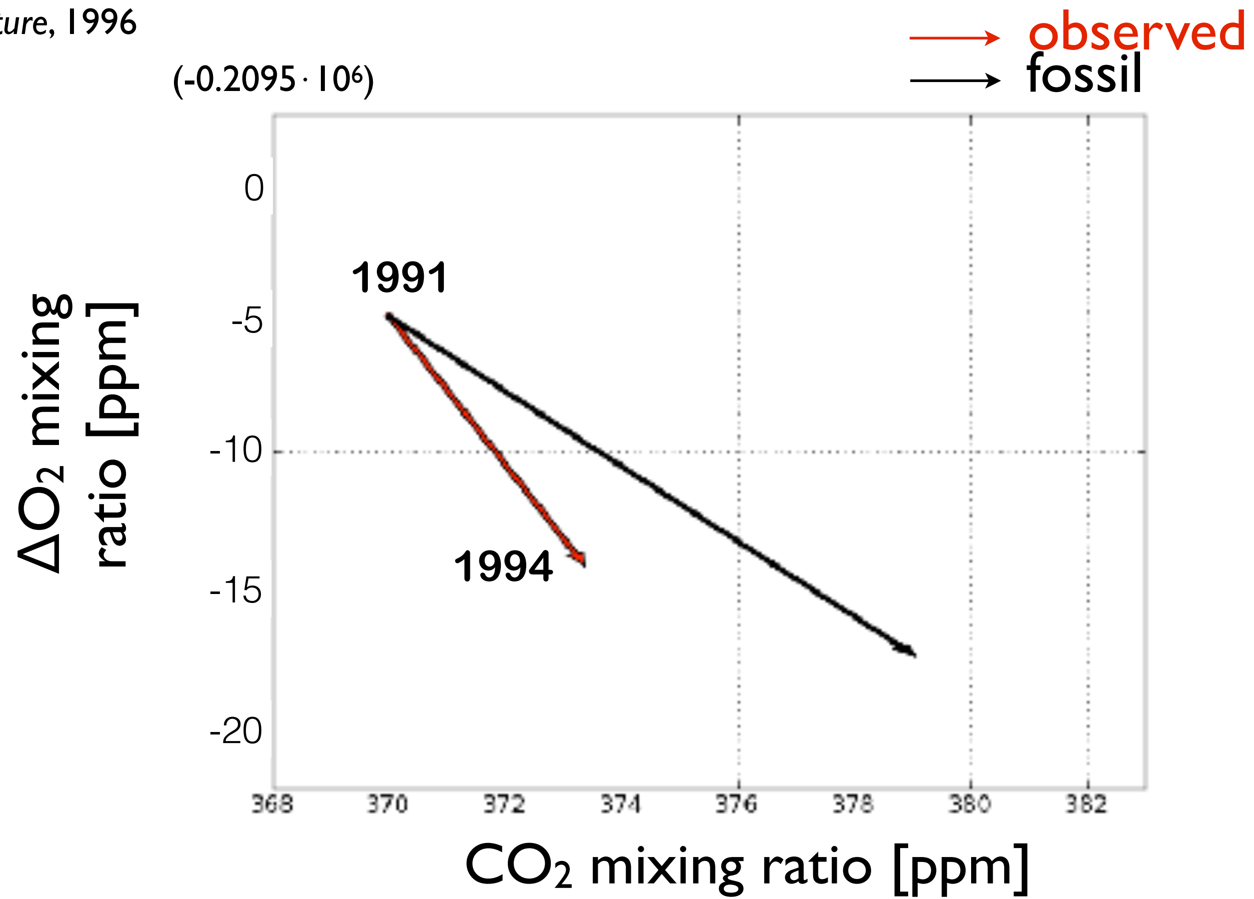
O_2 mixing ratios

Keeling et al., *Nature*, 1996



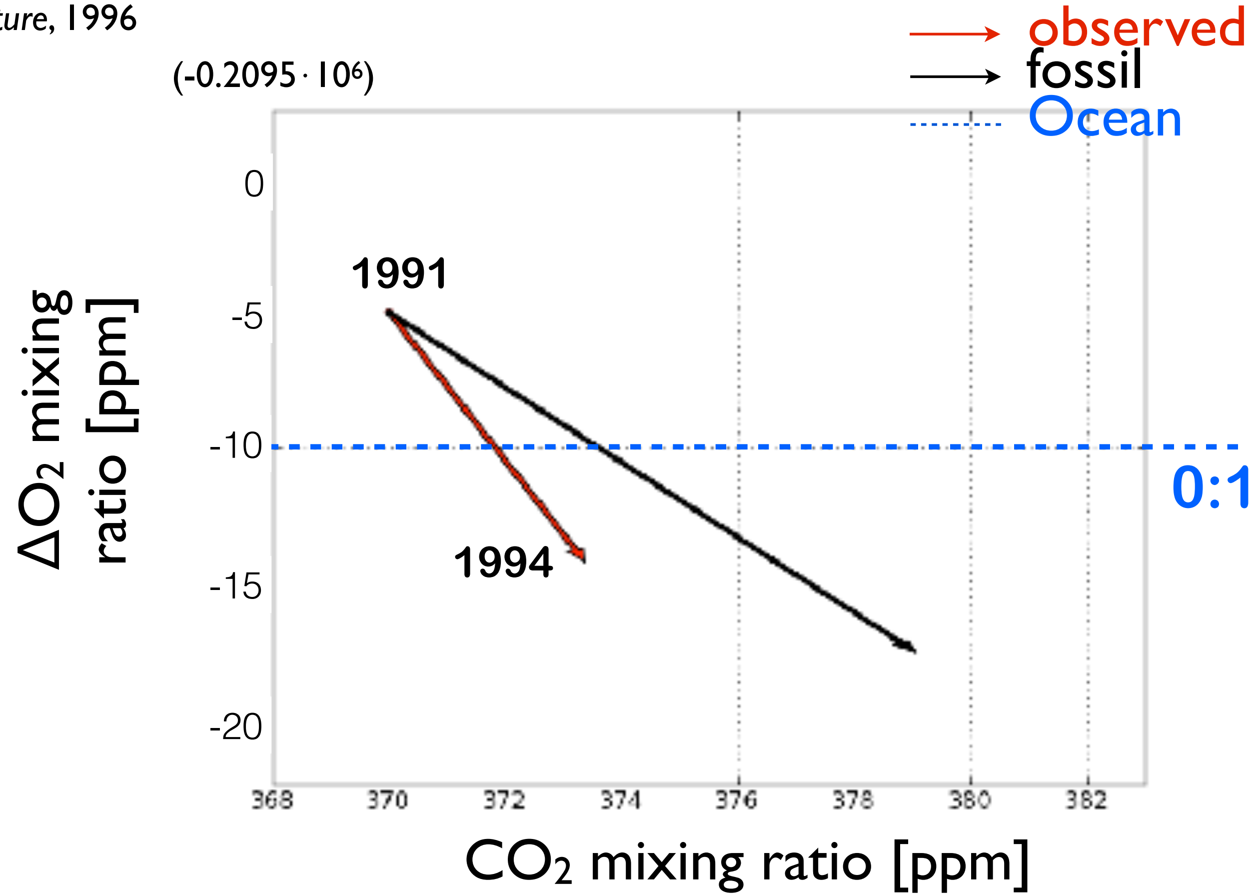
O_2 mixing ratios

Keeling et al., *Nature*, 1996



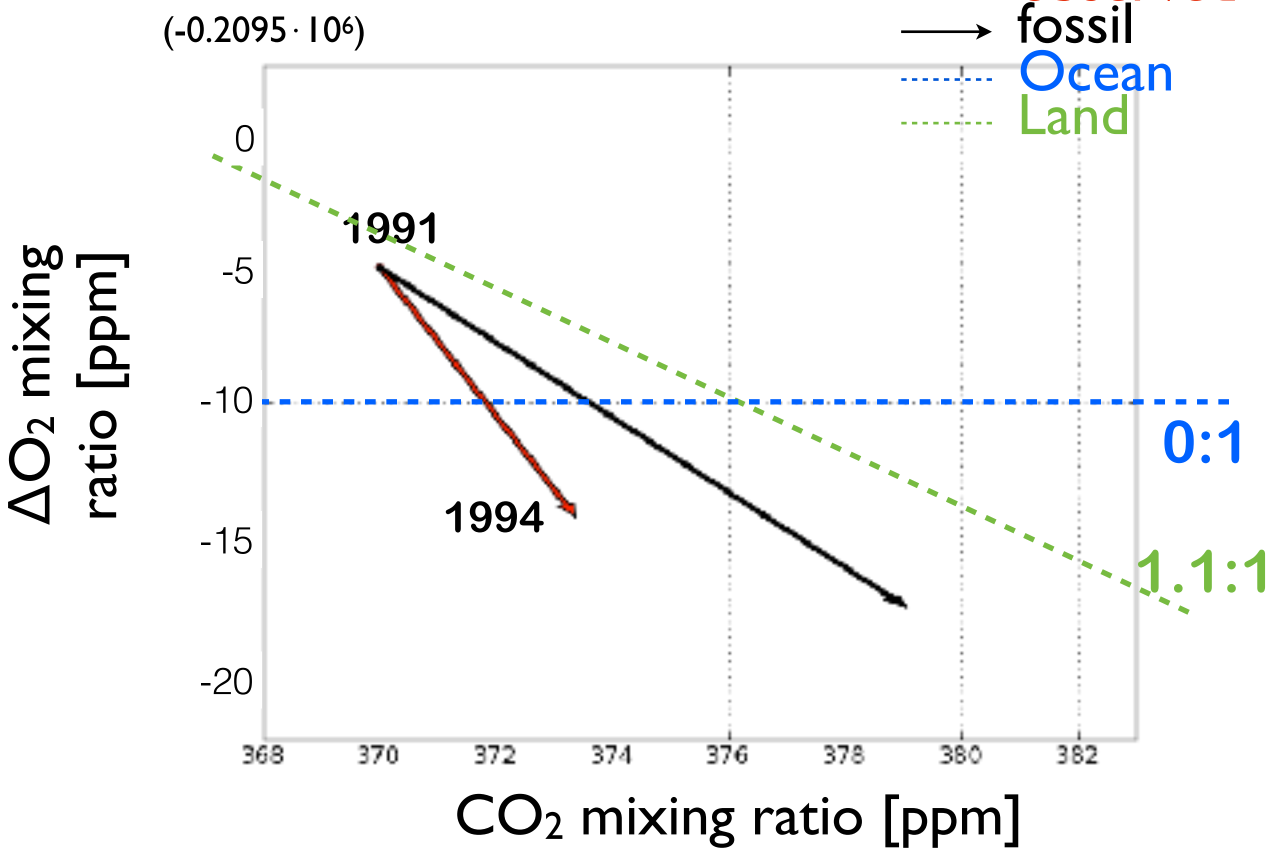
O_2 mixing ratios

Keeling et al.,
Nature, 1996



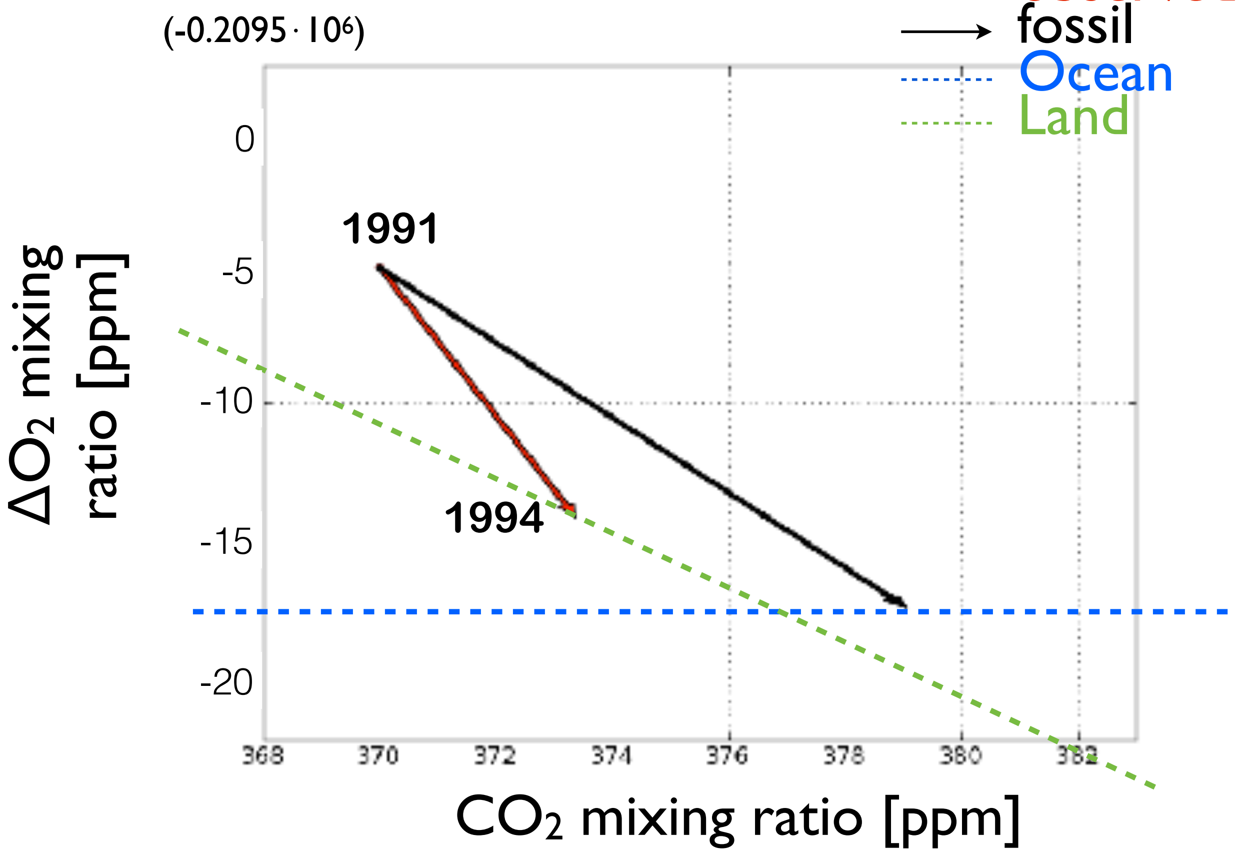
O_2 mixing ratios

Keeling et al.,
Nature, 1996



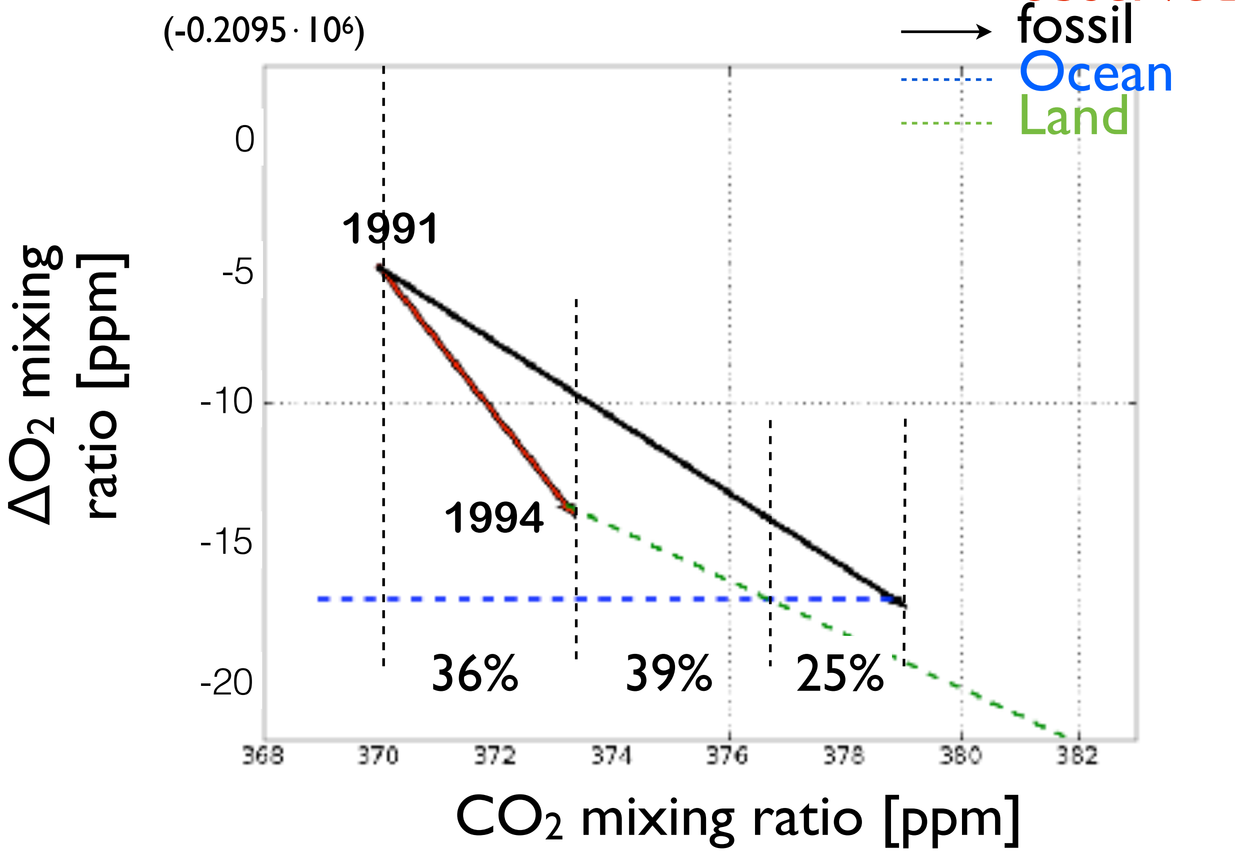
O_2 mixing ratios

Keeling et al., *Nature*, 1996



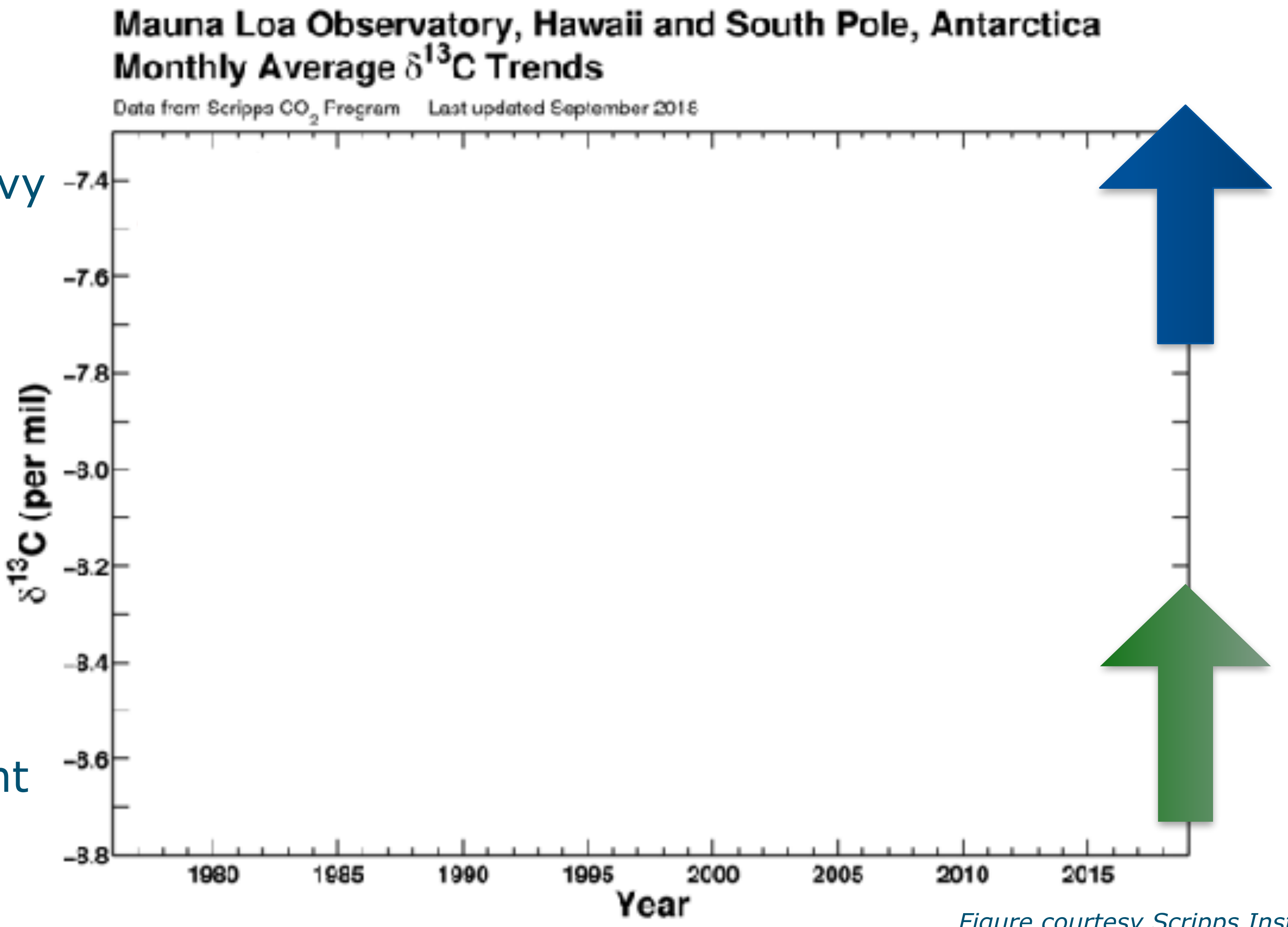
O_2 mixing ratios

Keeling et al.,
Nature, 1996



heavy

light



sink to oceans

sink to vegetation

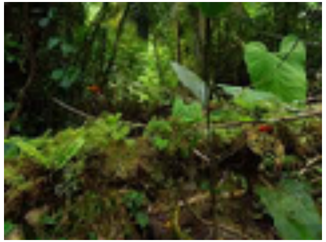
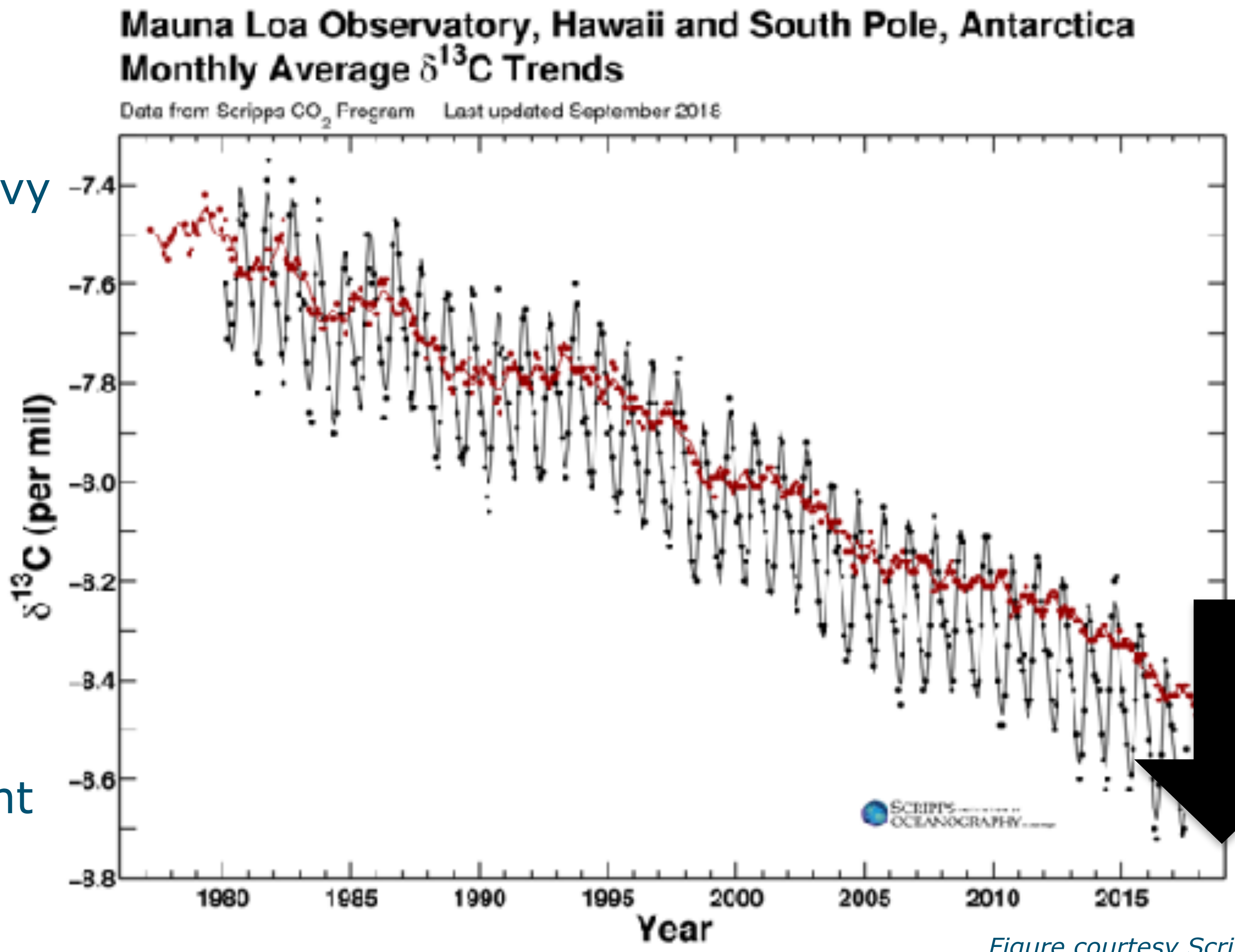


Figure courtesy Scripps Institute of Oceanography heavy



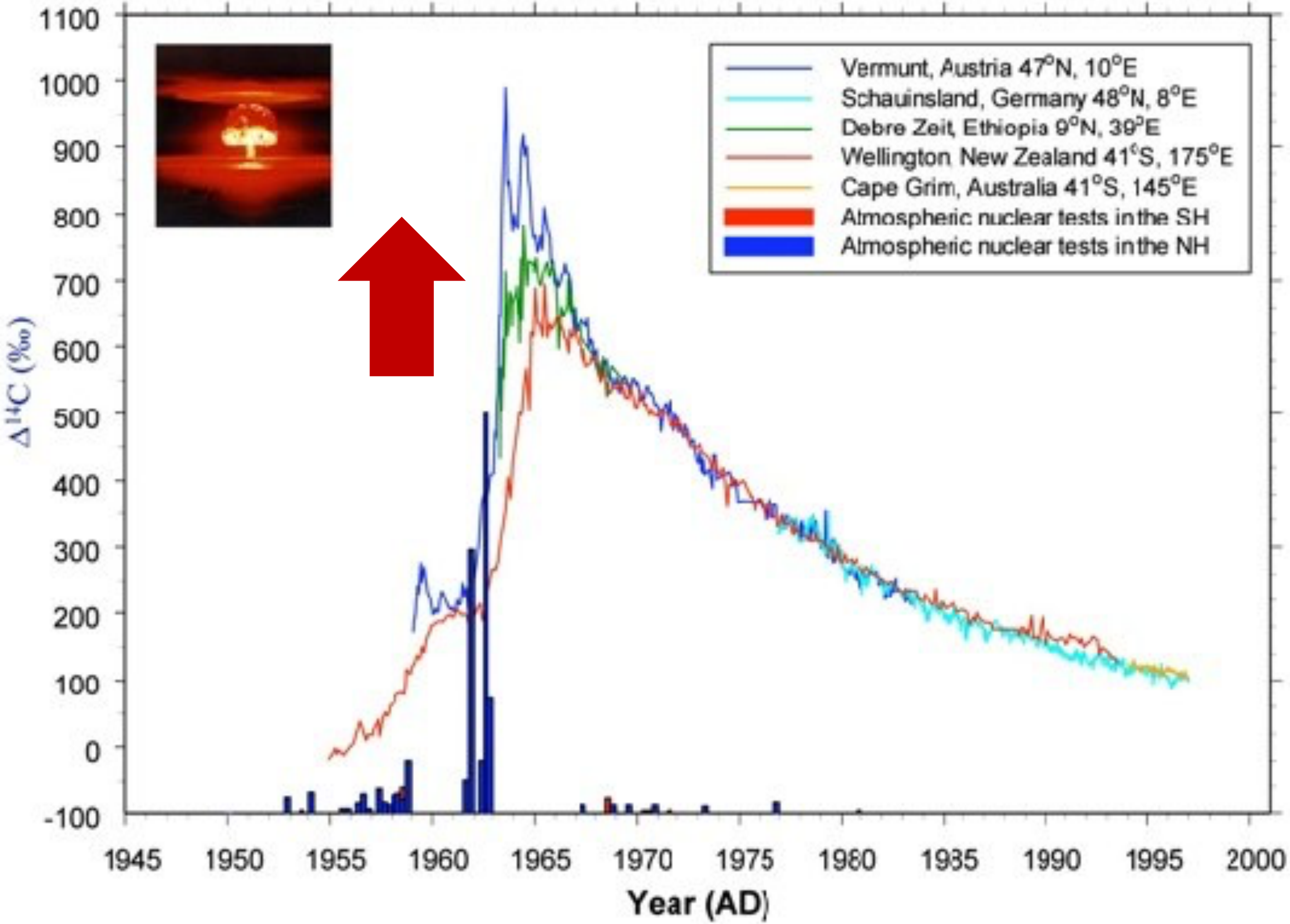
light

source from (fossil) plants

Figure courtesy Scripps Institute of Oceanography

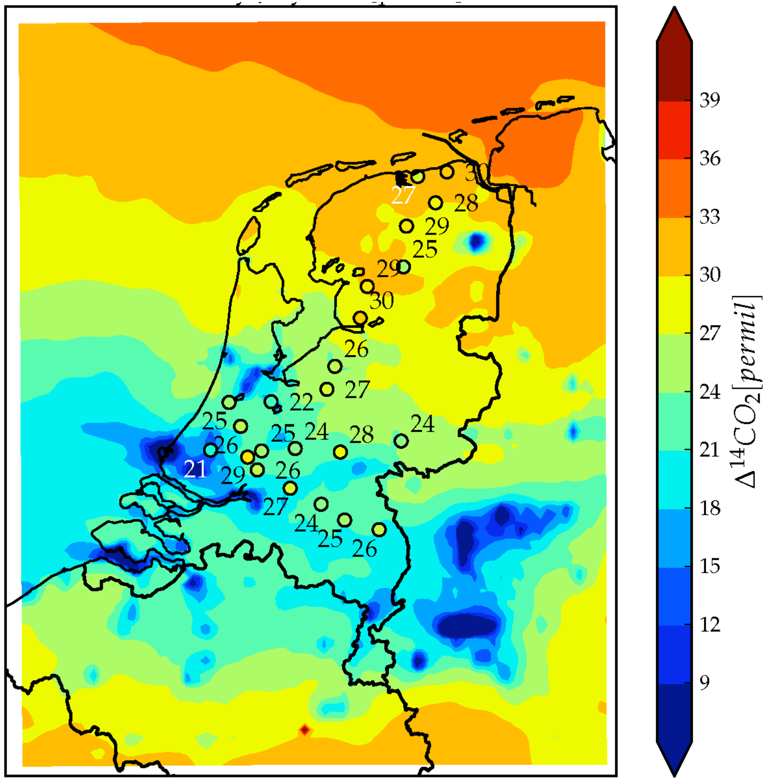

2011
2012
2013
2014


2011
2012
2014



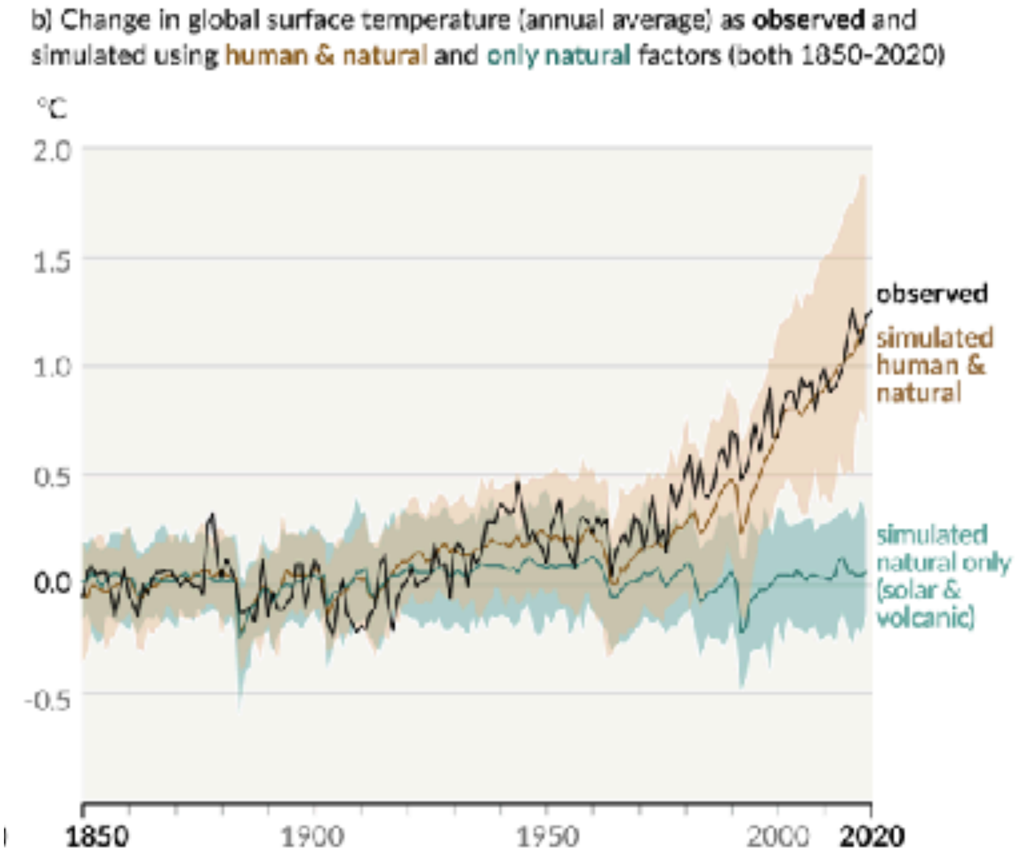
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
Δ14C (‰)
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year (AD)
Vermunt, Austria 47°N, 10°E
Schauinsland, Germany 48°N, 8°E
Debre Zeit, Ethiopia 9°N, 39°E
Wellington, New Zealand 41°S, 175°E
Cape Grim, Australia 41°S, 145°E
Atmospheric nuclear tests in the SH
Atmospheric nuclear tests in the NH

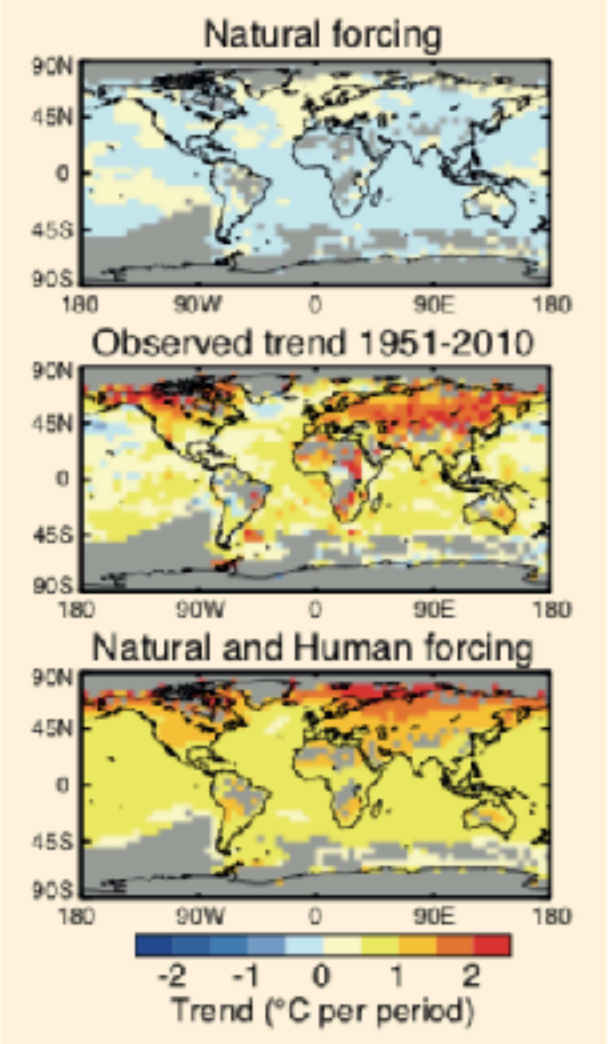
Regional radiocarbon signals (blue = fossil)



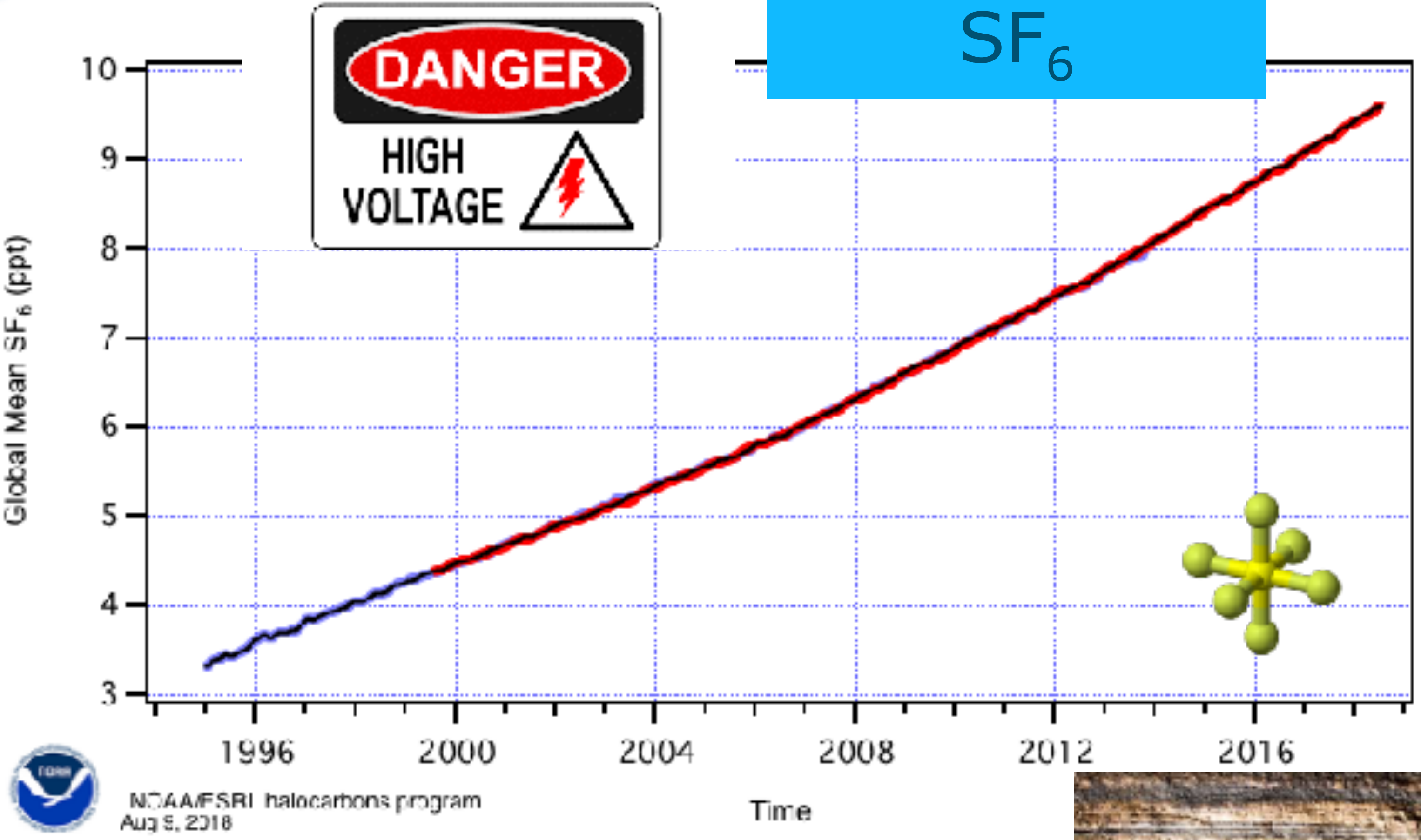
"new C"

"old C"


b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)
°C
2.0
1.5
1.0
0.5
0.0
-0.5
observed
simulated human & natural
simulated natural only (solar & volcanic)
1850
1900
1950
2000
2020


Natural forcing
Observed trend 1951-2010
Natural and Human forcing
90N
45N
0
45S
90S
180
90W
0
90E
180
-2
-1
0
1
2
Trend (°C per period)

SF_6



anthropocene

1) ~~Lessen uit het verleden~~

2) ~~Zijn *wij* een natuurkracht?~~

3) CO_2 en klimaat in de 21e eeuw

- Anthropogenic forcing
- *Cloud+aerosol feedback*
- Carbon-cycle feedback(s)

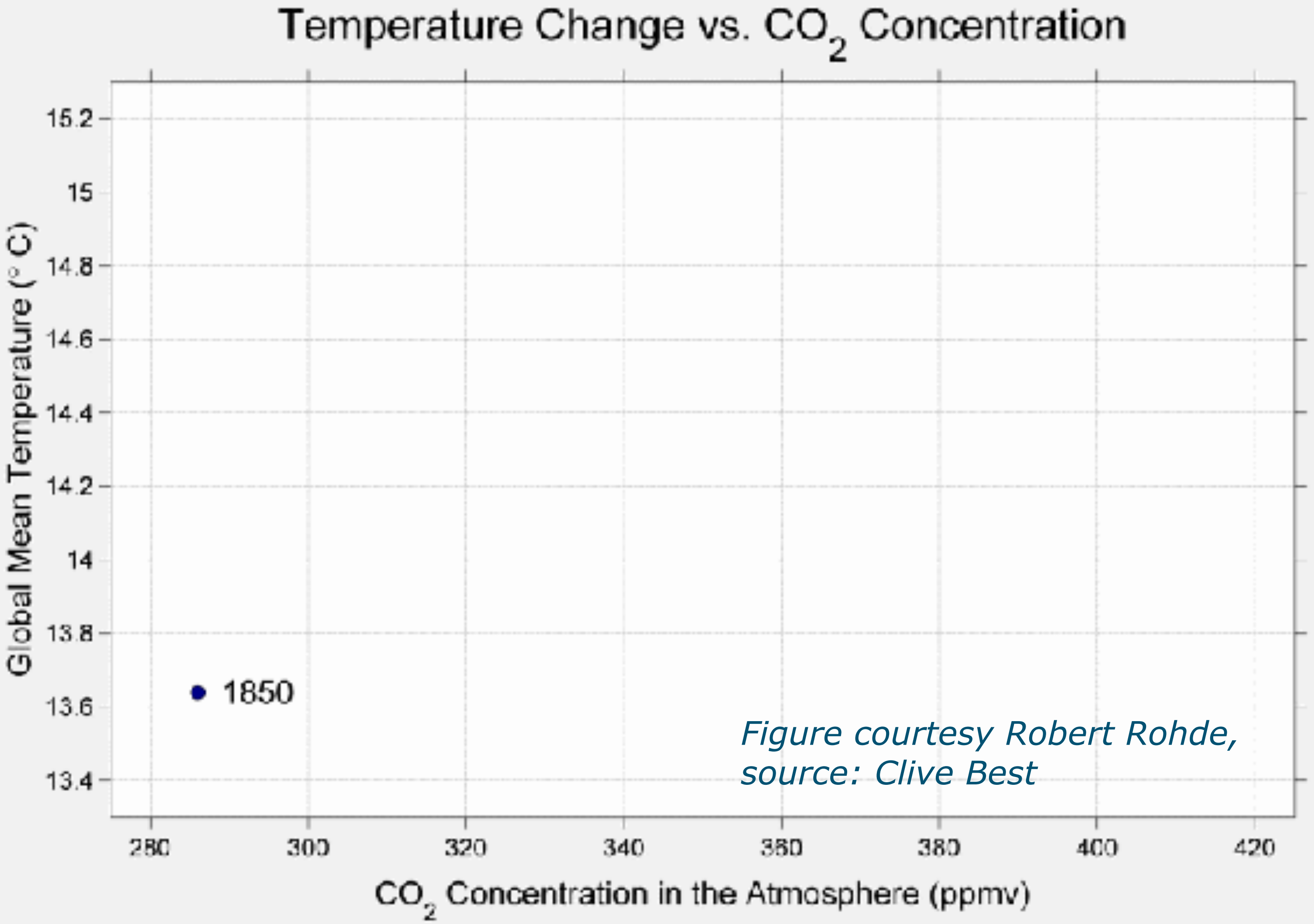
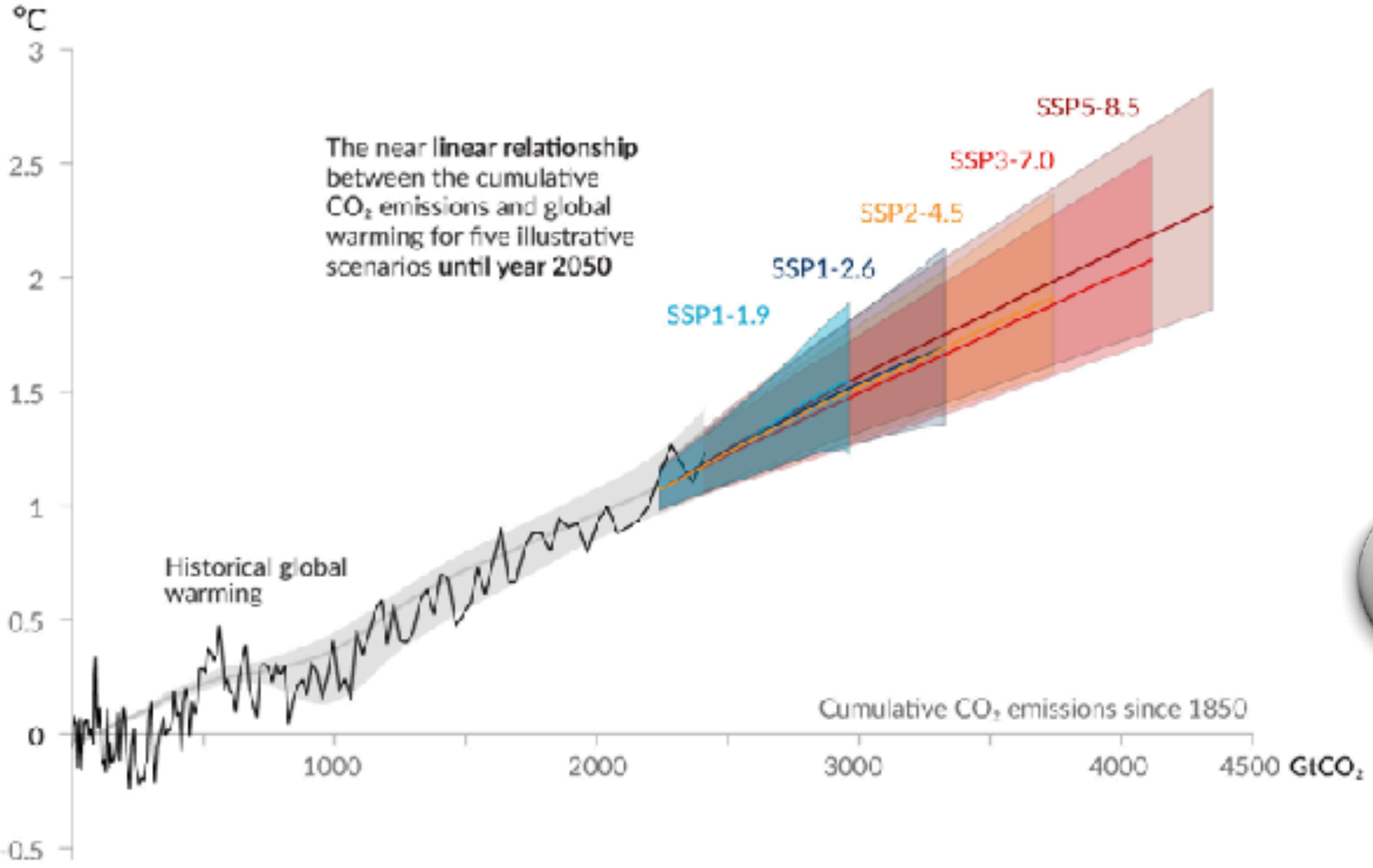


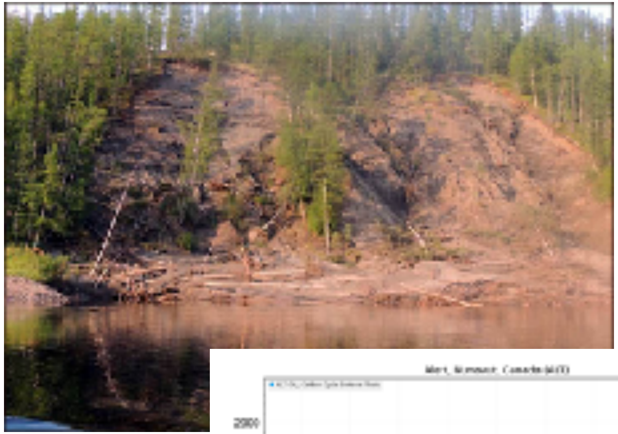
Figure courtesy Robert Rohde, source: Clive Best

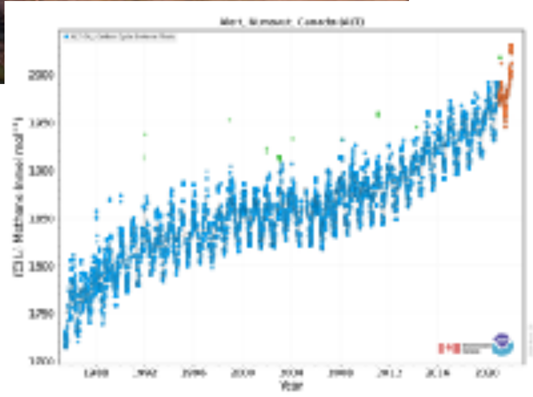
Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)



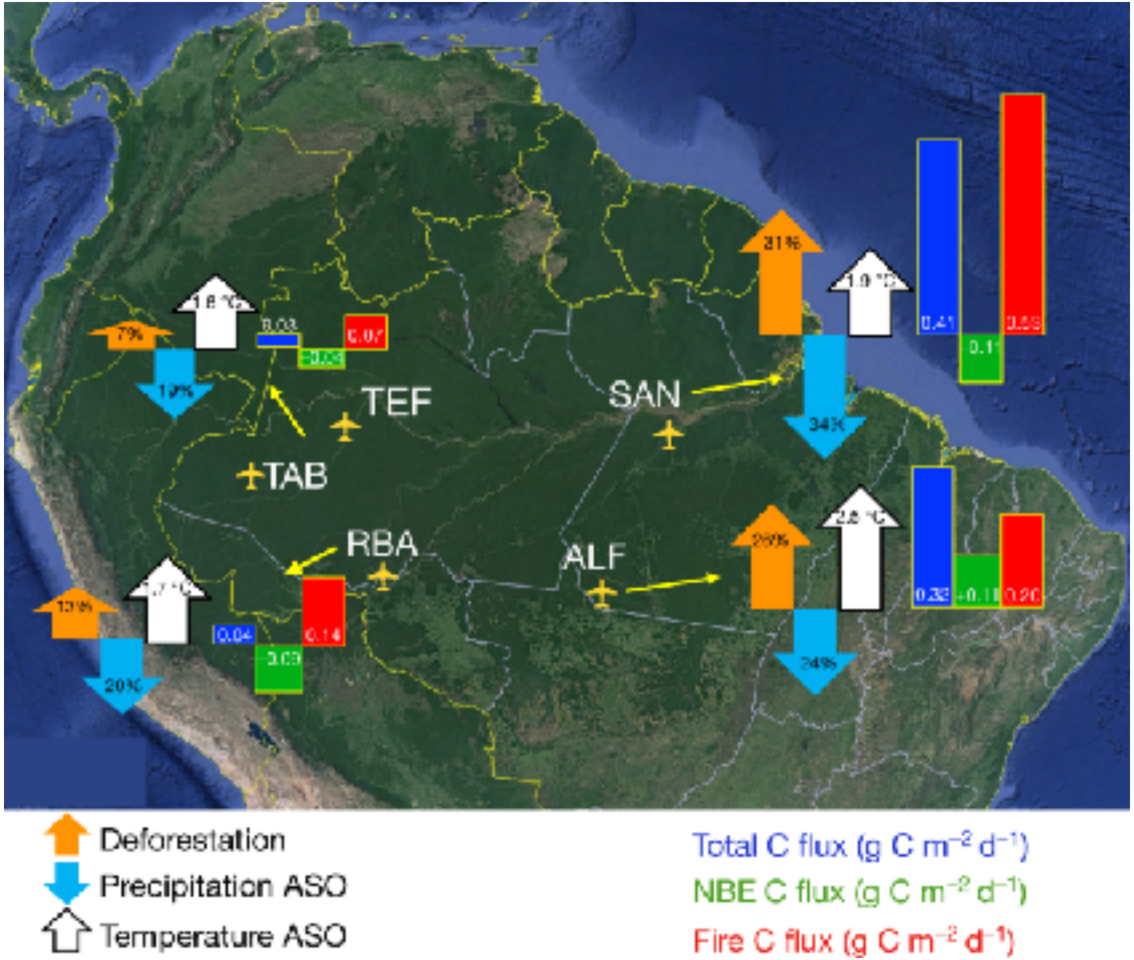
Does nature hold surprises?

- Permafrost GHG release
- Amazon die-back CO_2 release





Airborne Measurements of CO_2 from the Amazon

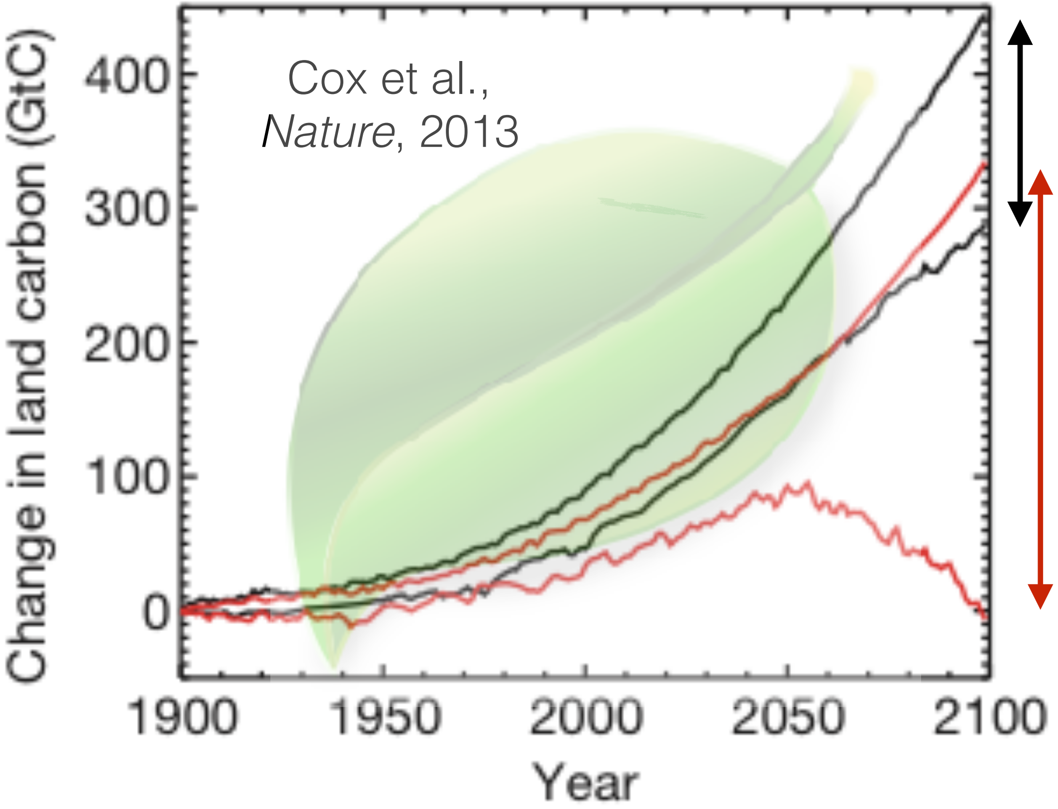


Gatti et al., Nature, 2021

Vragen en discussie

Mar-23 2022, Lezing Koninklijk Instituut Van Ingenieurs, Wouter Peters

Tropics are the main driver of "carbon-climate coupling"



Prescribed atm CO_2,

↑ fertilization

Calculated atm CO_2

↓ ↑ gross primary production

↑ respiration

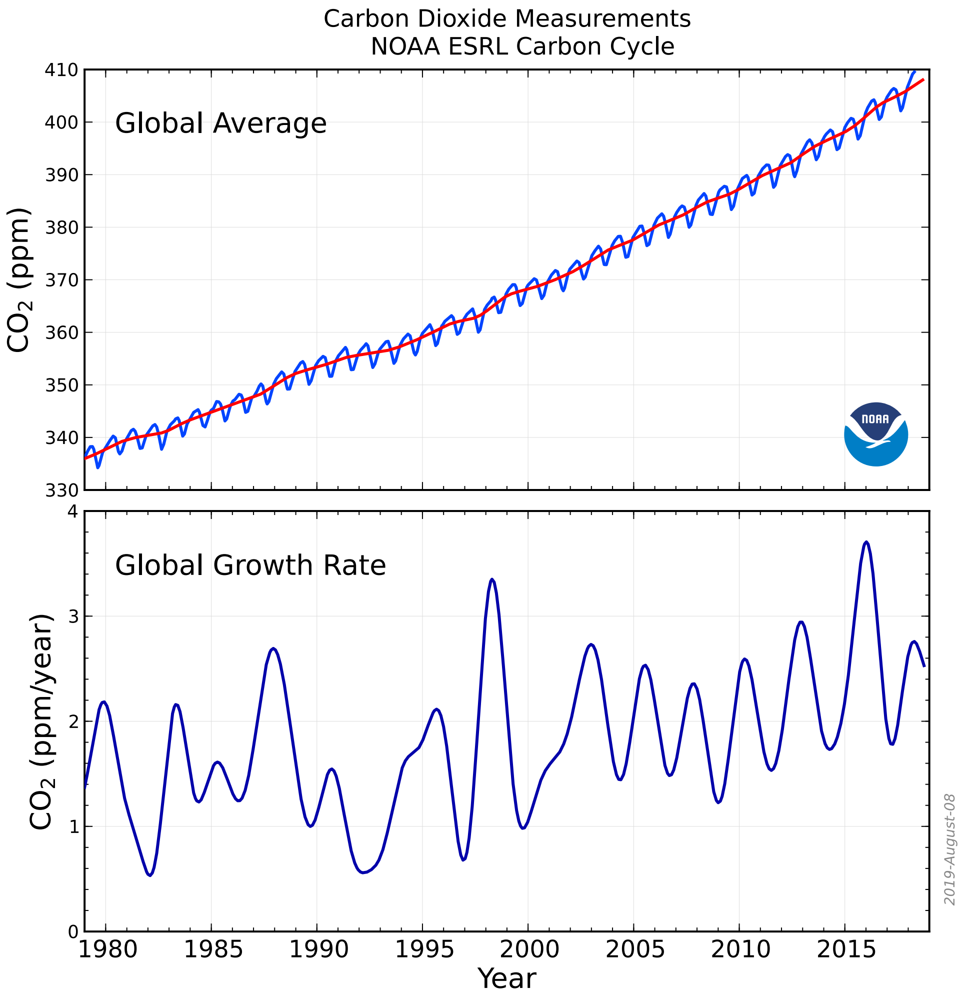
↓↑ evaporation

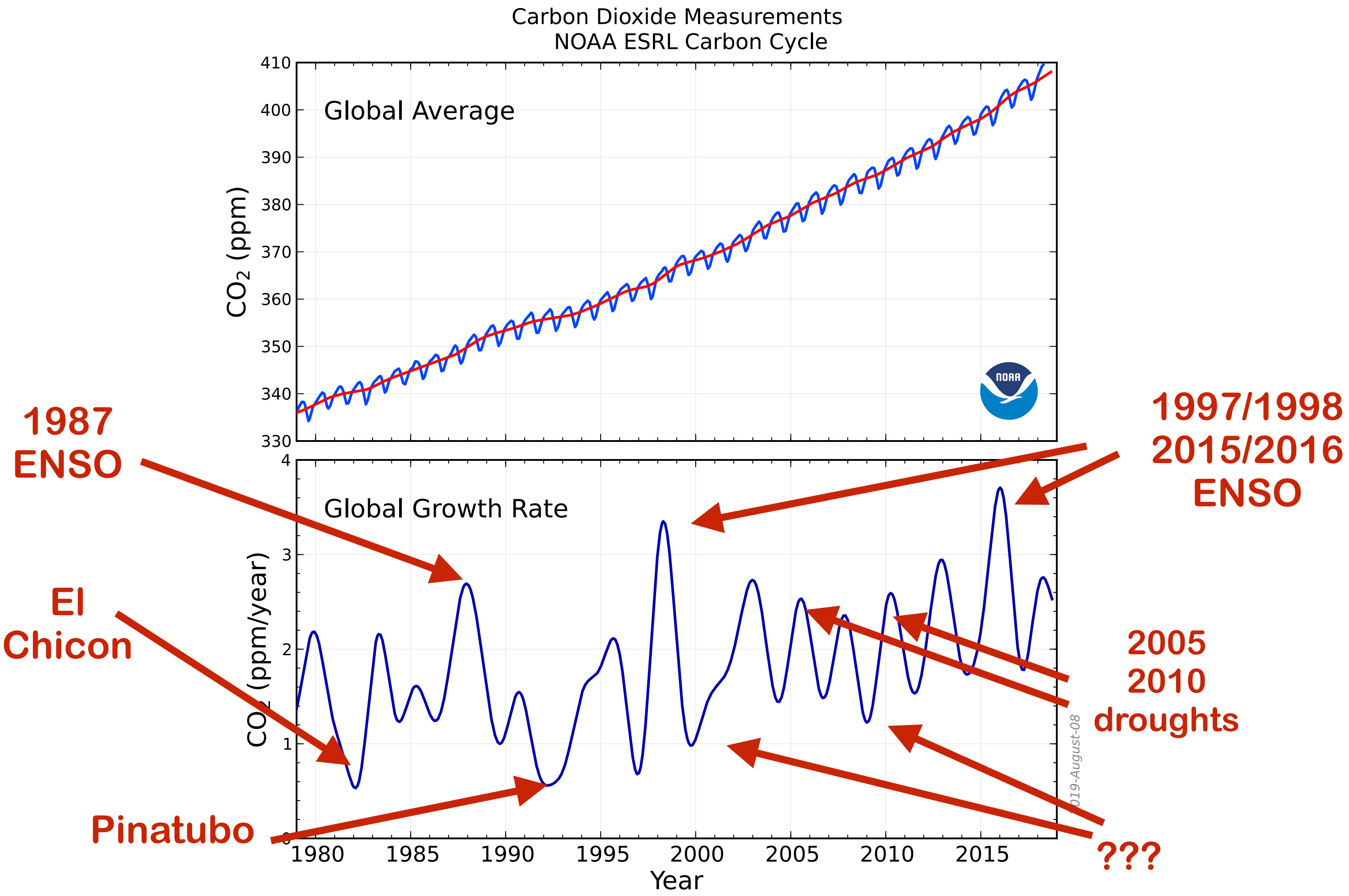
The carbon cycle

$$\frac{d[CO_2]}{dt}(t) = F_{fossil}(t) + F_{fire}(t) + F_{ocean}(t) + F_{biosphere}(t)$$

Instantaneous growth rate of CO_2

$$\frac{d[CO_2]}{dt}(t)$$





Carbon Dioxide Measurements
NOAA ESRL Carbon Cycle
Global Average
CO2 (ppm)
410
400
390
380
370
360
350
340
330
NOAA
Global Growth Rate
CO2 (ppm/year)
4
3
2
1
0
1980
1985
1990
1995
2000
2005
2010
2015
Year
1987 ENSO
El Chicon
Pinatubo
1997/1998 2015/2016 ENSO
2005 2010 droughts
???