Lecture 7: Human causation

Learners: *Ice Ages and Climate*

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Jonathan F. Ormes

JFOrmes@gmail.com

What drove climate over Earth's history

1. The bombardment of comets and meteorites
2. The solar intensity
3. Plate tectonics and motions
   - Volcanism
4. Greenhouse gases
5. Earth's orbit
   - eccentricity, precession and obliquity (tilt)
6. Internal variability
7. Human activities (Can we prove it?)

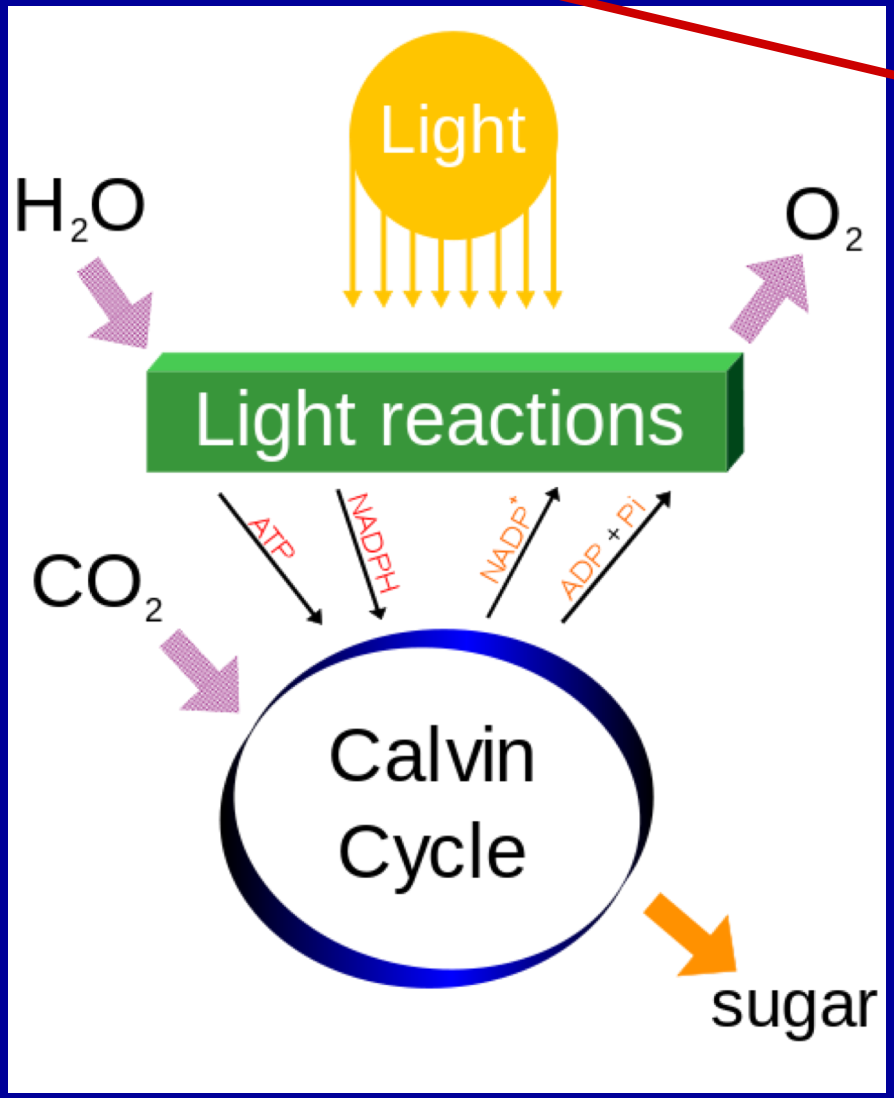
Human Causation

Can we find a "smoking gun"?

How do we know the increase in CO_2 didn't come from volcanos (e.g. maybe those hiding under the sea)?

Photosynthesis

$6CO_2 + 12H_2O + light \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$



Isotopes!
C can be ^{12}C, ^{13}C or even ^{14}C

This explains why you have to water plants (12 in 6 out).

The plant uses $^{12}CO_2$ or $^{13}CO_2$ or even $^{14}CO_2$ to make the sugar.

Light provides the energy to drive the process. It takes less energy to use the lighter carbon, ^{12}C.

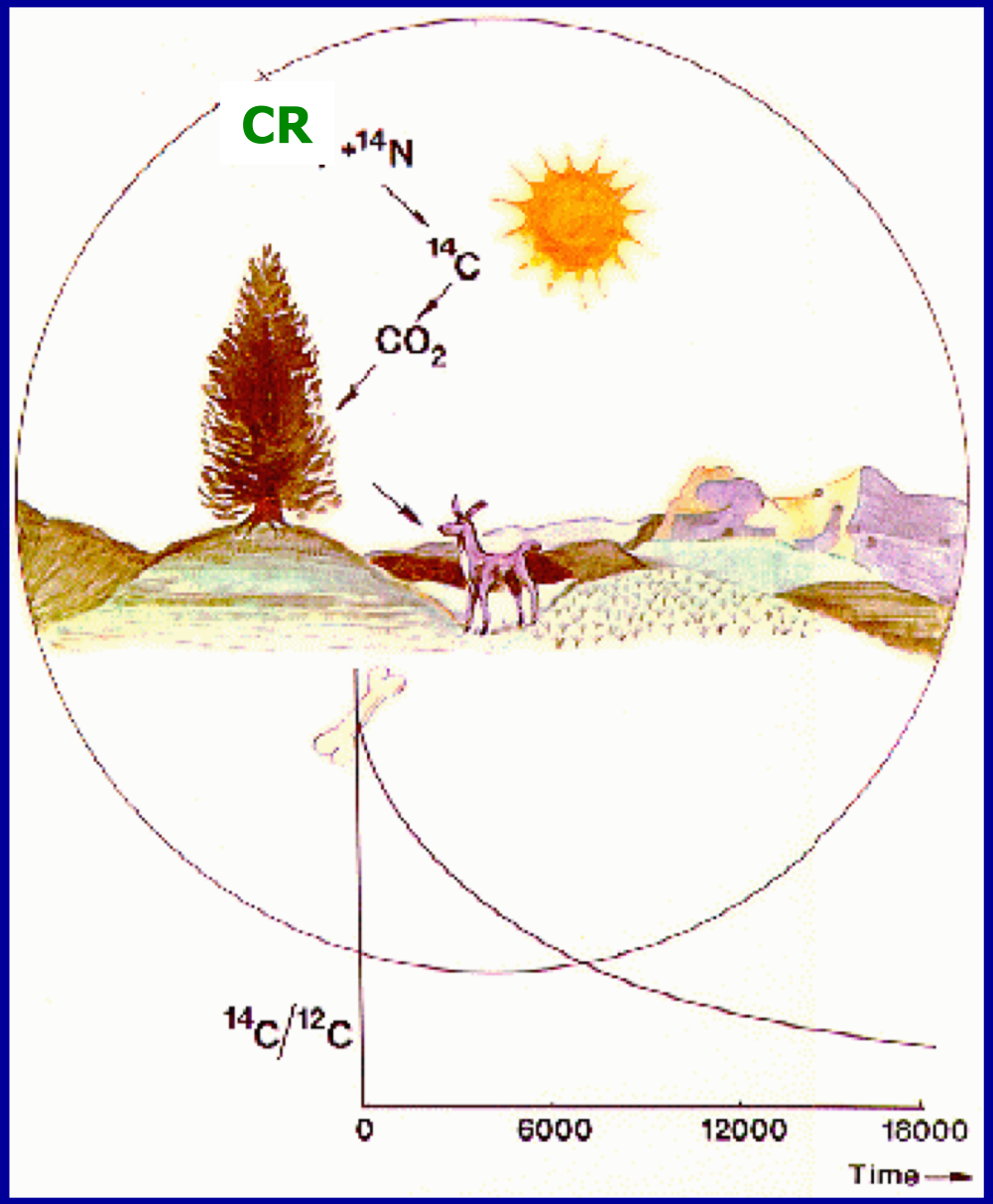
Different plants use different photosynthetic processes (C3 & C4), but both processes deplete ^{13}C & ^{14}C.

$^{13}C/^{12}C$ inside plants is less than $^{13}C/^{12}C$ in air

$^{13}C/^{12}C$ & $^{14}C/^{12}C$ lower

$^{13}C/^{12}C$ & $^{14}C/^{12}C$ higher

Production of ^{14}C



high energy cosmic rays (CR) interact with nuclei in the atmosphere to produce slow moving neutrons

CR + A > p′ + A′ + *neutrons*

The neutrons interact with ^{14}N to make ^{14}C

$n + {}^{14}N \rightarrow {}^{14}C + p$

^{14}C decays naturally back to ^{14}N

$t_{1/2}$ = 5730 years

Live plants take up some $^{14}CO_2$

- Give confirmation of tree ring dates.
- Date archeological sites
  - e.g. construction beams and fire pits
- After several half lives (e.g. 20,000 years) most of the ^{14}C has decayed; what's left is undetectable.
- There is no ^{14}C remaining in fossil fuel.
- Add C from fossil fuel to atmosphere, fraction of ^{14}C will decrease.

Reduced $^{13}C/^{12}C$ in plants and fossil fuels.

- Plants find it easier (takes less energy) to use the lightest isotopes when they convert sunlight and CO_2 into food. (Mass of ^{12}C is less than mass of ^{13}C.)

Young plants

550Myr old plants

The $^{13}CO_2/^{12}CO_2$ story

"In the beginning" $^{13}C/^{12}C$ ratio has the "natural" or universal abundance.

- Ratio of $^{13}CO_2/^{12}CO_2$ in the air was the "natural" abundance when coal & oil were formed.
- Plants slightly decrease the $^{13}CO_2/^{12}CO_2$ ratio.
- Varies slightly with the kind of plant (or microbes) from which the ancient hydrocarbon was formed.
- That reduced ratio reappears when the plant is burned.

What are we really comparing with?

- The standard ratio of $^{13}C/^{12}C$ was established originally based on a Cretaceous marine fossil, *Belemnitella americana*, which was found in the Peedee Formation in South Carolina. This material had an anomalously high $^{13}C/^{12}C$ ratio (0.01118). The standard has been corrected slightly to be 0.01123720 and is established as $\delta^{13}C$ value of zero.
  - These numbers don't matter. You just need to know there is a standard.

The $^{13}CO_2/^{12}CO_2$ story

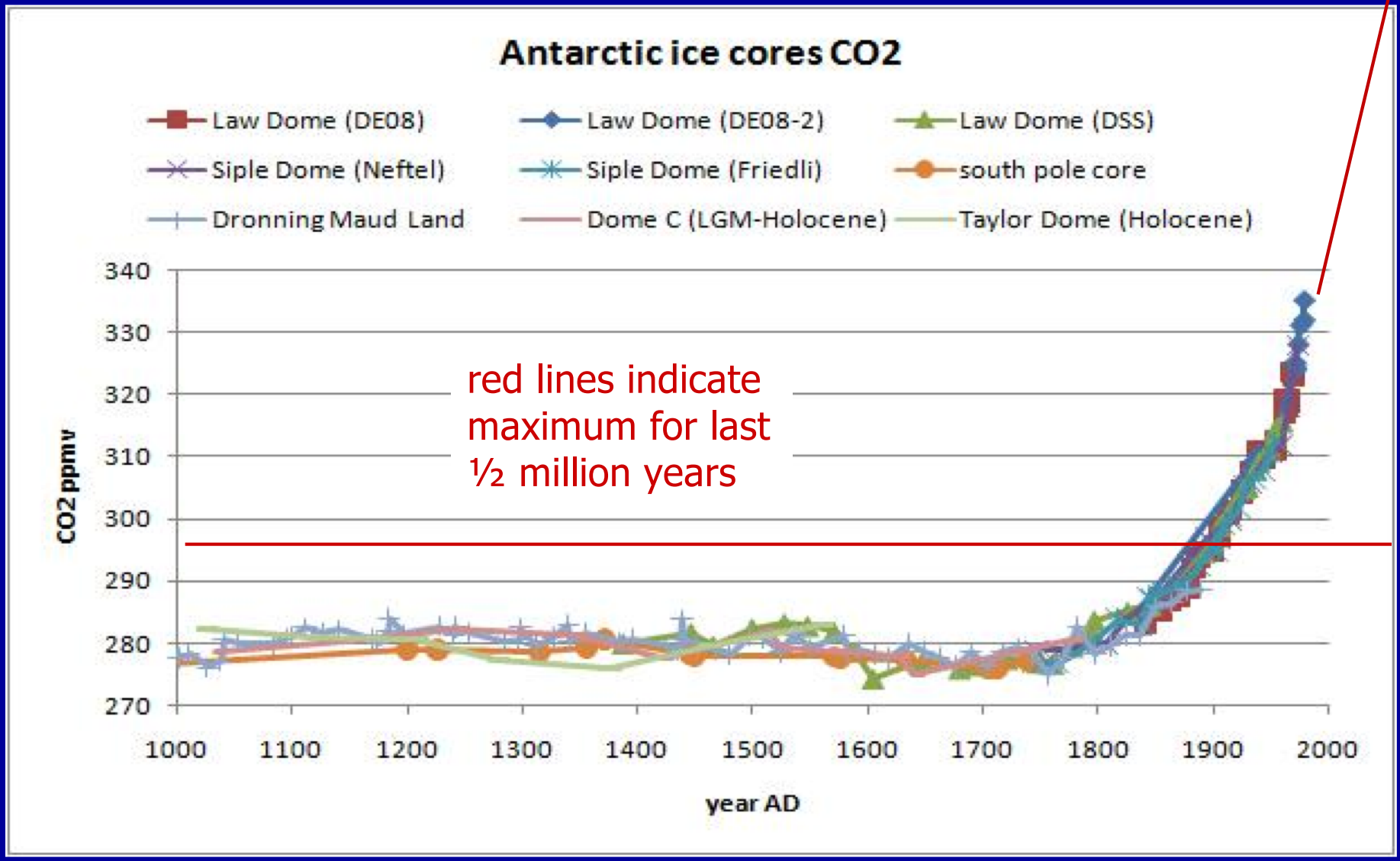
- There is now 410 ppm of CO_2 [$^{12+13+14}CO_2$] in the atmosphere (after contamination by the burning of carbon based fuels became significant – our hypothesis, 285 ppm).

- So (410-285)/400 = **30%** of the CO_2 (in air) comes from burning carbon based materials.

Atmospheric CO_2 rates

- Volcanoes: 0.035 to 0.12 GtC per year
- Human activities: 9.5 GtC (2010)

Current 410 ppm
1/3 of CO_2 in air added since 1800



How much of the CO_2 is put there since 1850?

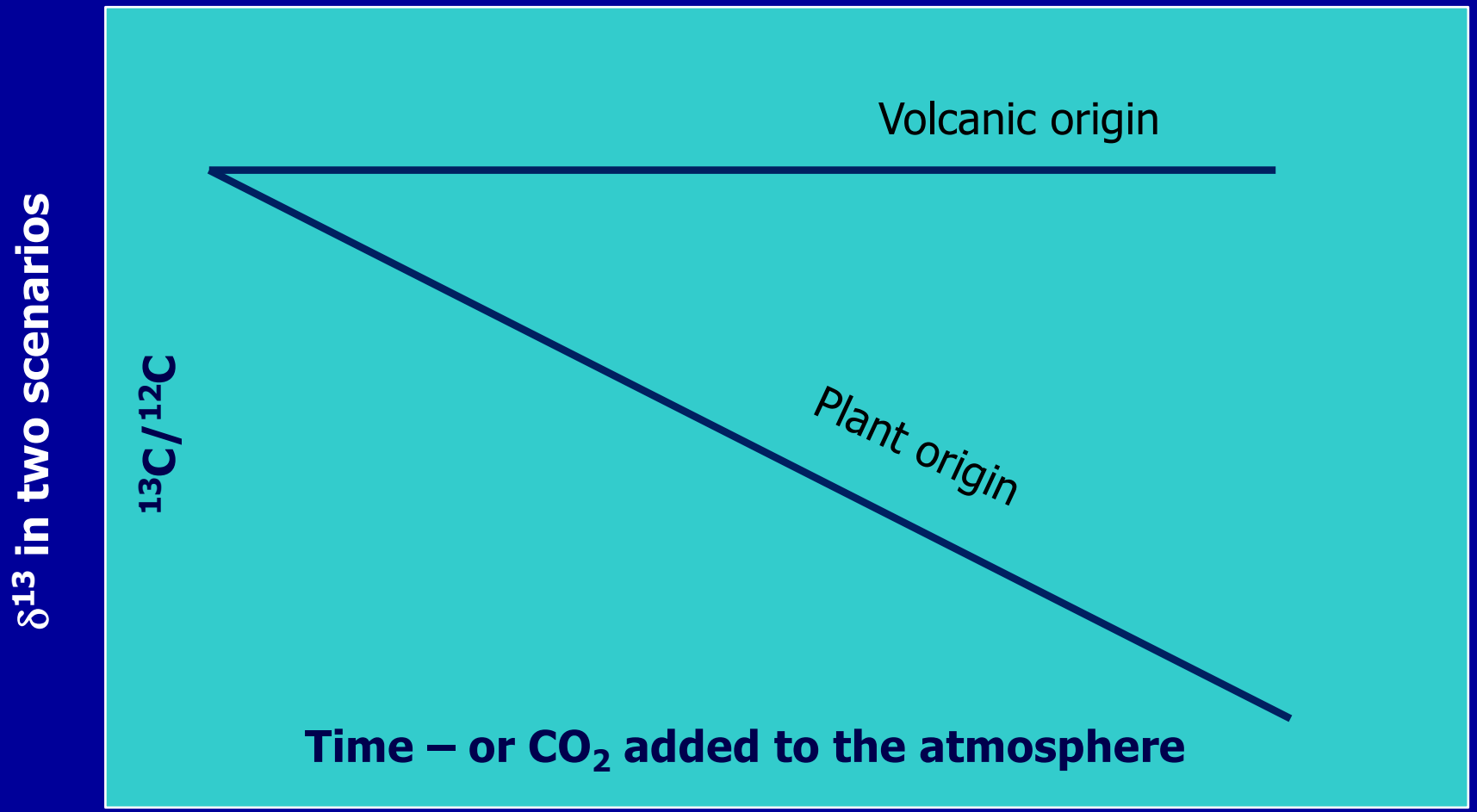
410ppm – 285ppm = **125**ppm

125ppm/**410**ppm = **30%**

$$\delta^{13}C = \frac{\left[\left(\frac{^{13}C}{^{12}C}\right)_{sample} - \left(\frac{^{13}C}{^{12}C}\right)_{standard}\right]}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} * 1000\%$$

This δ formula is used for other isotopes, e.g. ^{14}C

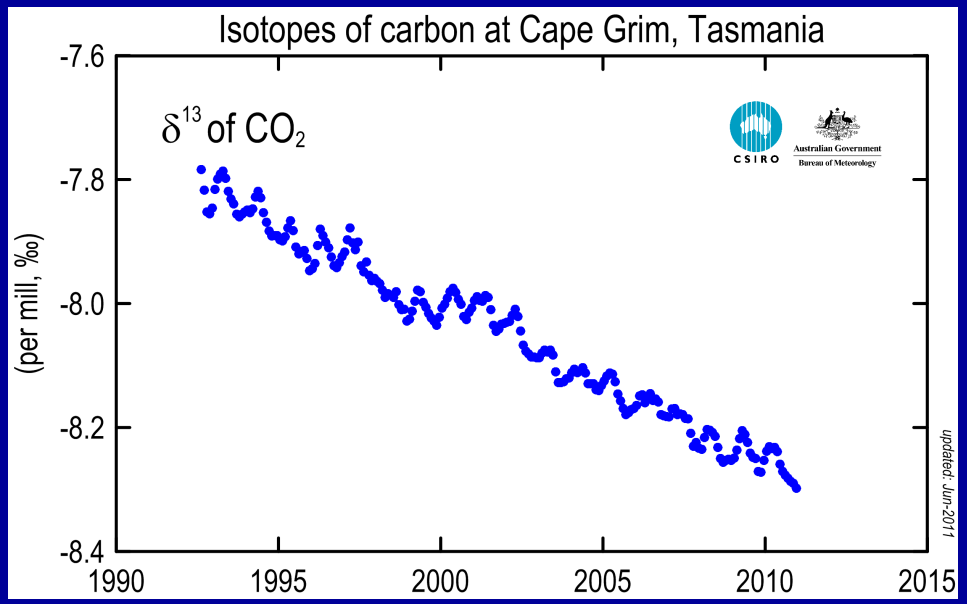
$\delta^{13}C$ vs. time, a measure of the fractional amount of $^{13}CO_2$ relative to $^{12}CO_2$

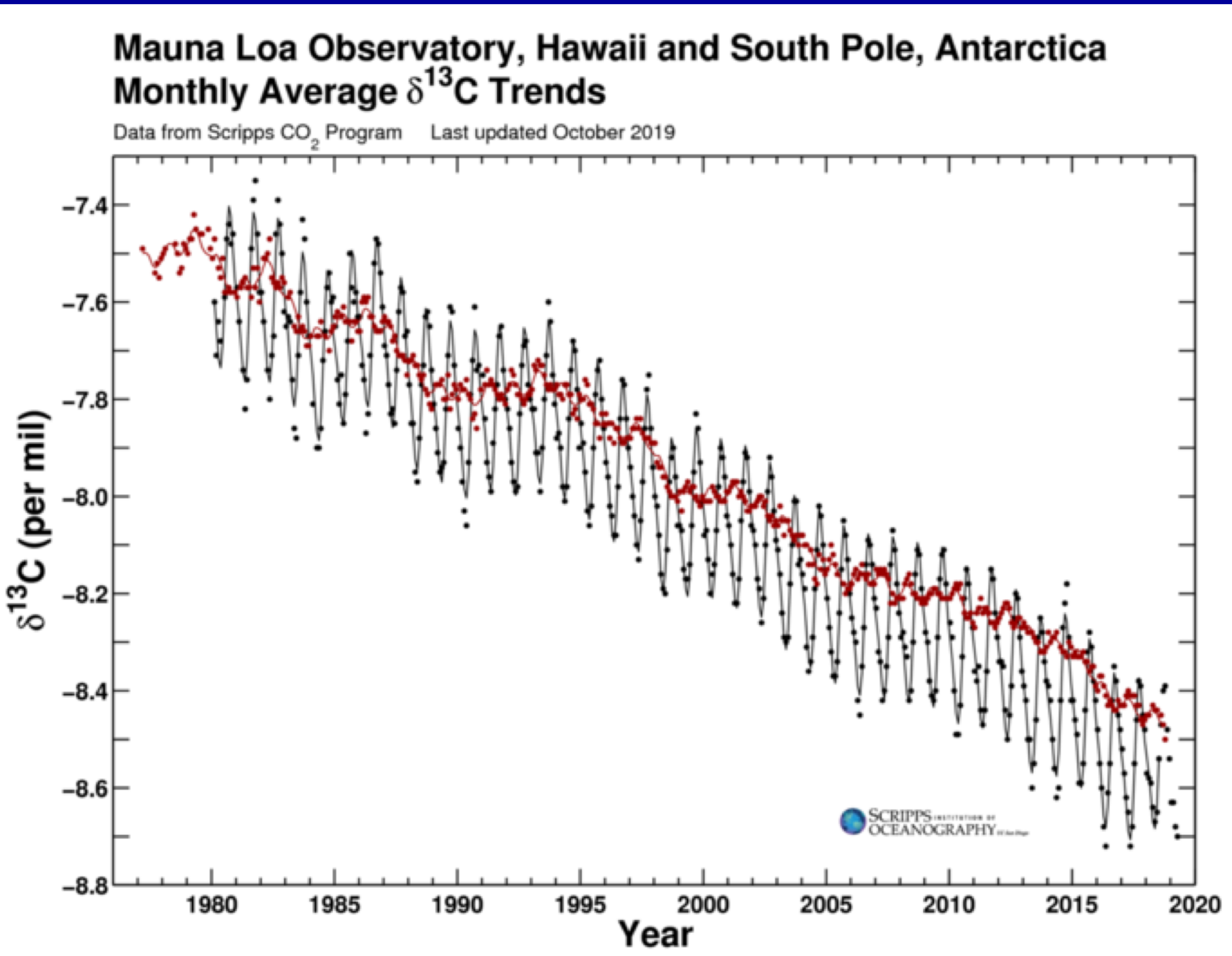


What happens when we burn carbon fuels?

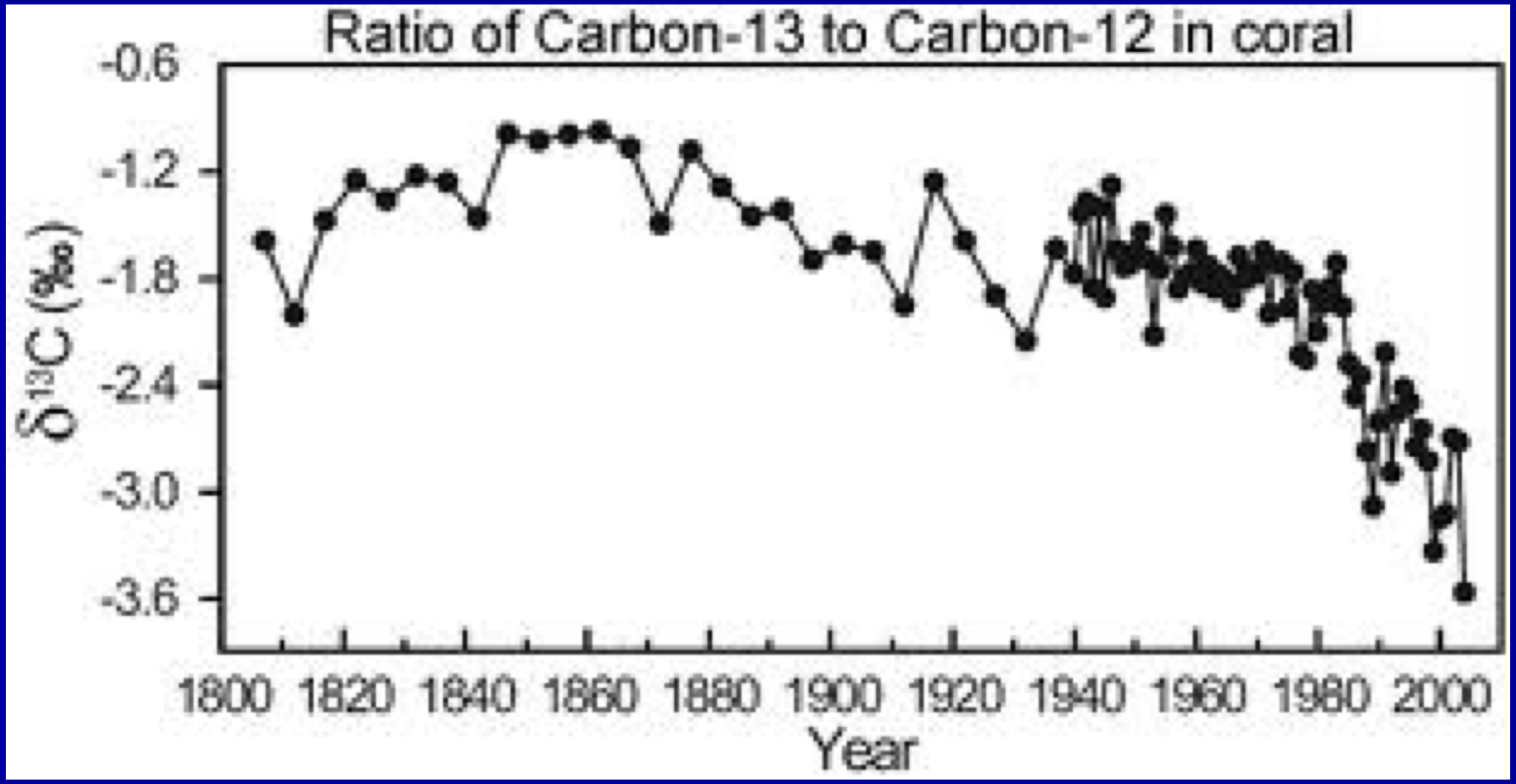
- We burn wood, plants, coal & oil now releasing the carbon to the atmosphere. There will be less $^{13}C/^{12}C$ because the plant that captured it took in less ^{13}C (and ^{14}C) as it grew.

- We see that the ratio goes down as more the CO_2 is put into the air.




Mauna Loa Observatory, Hawaii and South Pole, Antarctica
Monthly Average δ13C Trends
Data from Scripps CO2 Program
Last updated October 2019
δ13C (per mil)
−7.4
−7.6
−7.8
−8.0
−8.2
−8.4
−8.6
−8.8
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Hypothesis is tested in corals



"Evidence for ocean acidification in the Great Barrier Reef of Australia", G. Wei et al. 2009, Geochimica et Cosmochimica Acta Volume 73, Issue 8, 15 April 2009, Pages 2332–2346

Fossil fuel plants have no $^{14}CO_2$

- After several half lives (e.g. 10,000 years) most of the ^{14}C has decayed; what's left is undetectable.
- There is no ^{14}C remaining in fossil fuel.
- Add C from fossil fuel to atmosphere, fraction of ^{14}C will decrease.
  - ^{12}C increases as we add CO_2, but $^{14}CO_2$ must decrease
  - Adding a zero fraction to something that increases

We proved the CO_2 comes from plants, but are they really old plants: coal, oil ?

- For this we turn to another isotope of carbon, ^{14}C.

410 ppm		**285 ppm**		**125 ppm**
$^{12+13+14}CO_2$(observed)	=	$^{12+13+14}CO_2$(before homo)	+	$^{12+13}CO_2$(fossil)
Measure the ^{14}C fraction		should have ^{14}C		should have no ^{14}C

Expect ^{14}C in atmosphere to be going down

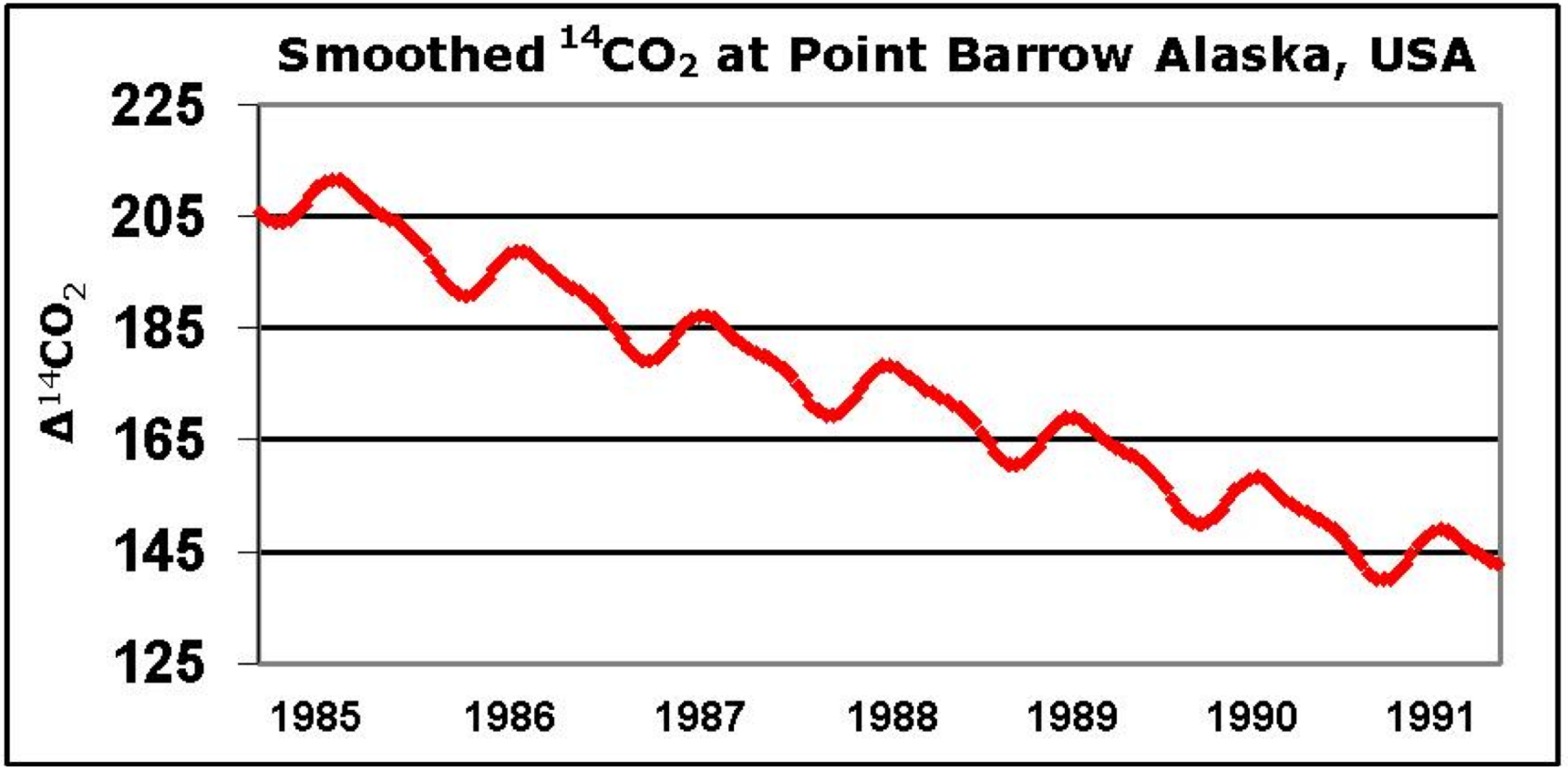
We proved the CO_2 comes from plants, but could they be young plants?

410 ppm **285 ppm** **125 ppm**

$^{12+13+14}CO_2$(obs.) = $^{12+13+14}CO_2$(before homo) + $^{12+13+14}CO_2$(young)

Measure the ^{14}C fraction should have ^{14}C should have some ^{14}C

Expect ^{14}C in atmosphere to be staying steady

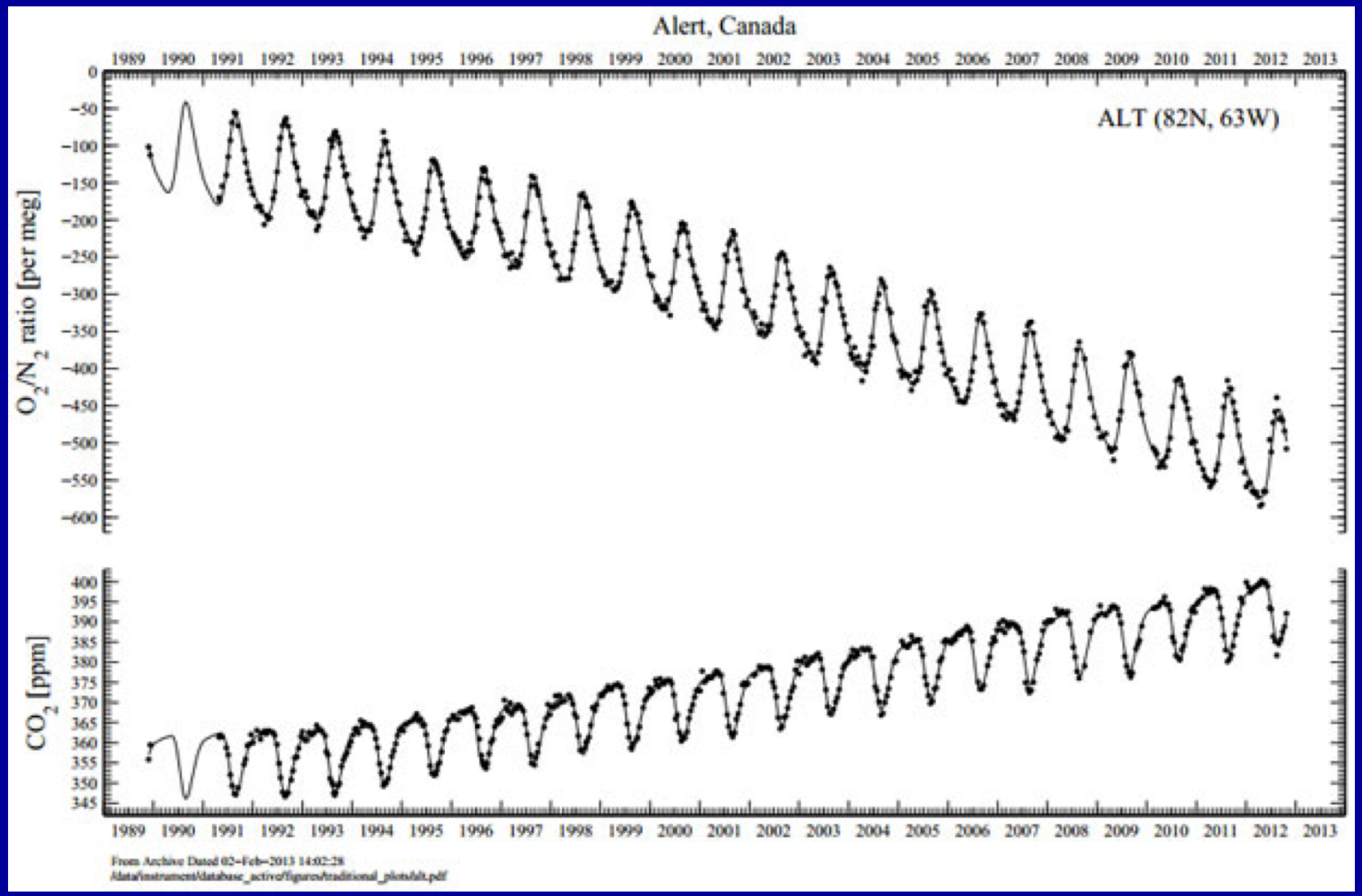


Fossil fuels have no ^{14}C (half-life 5739 yrs).
Declining $^{14}CO_2$ indicates the recently added atmospheric CO_2 is from ancient material, not from plants that grew and died recently.
(Careful about bomb tests!)

Oxygen used by burning

O_2/N_2 ratio

CO_2 (ppm)



The observed downward trend is 19 'per meg' per year. This corresponds to losing 19 O_2 molecules out of every 1 million O_2 molecules in the air/year.

http://scrippso2.ucsd.edu

Alternative explanations??

I know of no other explanation for the simultaneous decreases in the ratios of $^{13}CO_2/^{12}CO_2$ and $^{14}CO_2/^{12}CO_2$ in the atmosphere and in corals (and decreasing O_2/N_2).

If you know of one, please inform the instructor.

Summary of Evidence for Anthropogenic changes

- Changes in the infrared spectrum from the sky (as seen from Earth) and from the Earth (as seen from space)
- Warming (and rising) troposphere and cooling stratosphere
- Nights warming faster than days and winters faster than summers (not the sun)
- Decreasing $^{13}CO_2$ points to fossil fuels (atmosphere and corals), ^{14}C is decreasing (not fresh growth)
- O_2 being depleted from burning fossil fuels
- Atmospheric warming and cooling vs. altitude as predicted by modeling
- Ocean warming patterns as predicted by modeling

10 Indicators of a Human Fingerprint on Climate Change

Less heat escaping to space

Shrinking thermosphere

Cooling stratosphere

Rising tropopause

Less oxygen in the air

More fossil fuel carbon in the air

30 billion tonnes of CO_2 per year

More heat returning to Earth

Nights warming faster than days

More fossil fuel carbon in coral

Conclusions

- The slow decline of the heavy isotopic versions of CO_2, $^{13}CO_2$ and $^{14}CO_2$, prove the CO_2 being added to the atmosphere is from burning ancient hydrocarbons.
- There are many other pieces of corroborating evidence that the CO_2 increase has an anthropogenic origin.
- The fraction of CO_2 from human activities is currently about 30%.