Radiocarbon as tracer in atmospheric research

Felix R. Vogel

Nobelprice for Chemistry 1960

W.J. Libby

"Seldom has a single discovery in chemistry had such an impact on the thinking in so many fields of human endeavor."

-Nobel Committee (1960)

Applications of Radiocarbon

Dating in archeology and historical sciences

Dating of paleoclimate archive

Reconstruction of solar activity

Neuroscience and medicine

Tracer studies on ground water flow, plant physiology, etc…

Understanding the exchange processes in the global carbon cycle (atmosphere-biosphere-ocean)

Determine the partition of fossil fuel of atmospheric CO_2

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Atmospheric ^{14}C in CO_2

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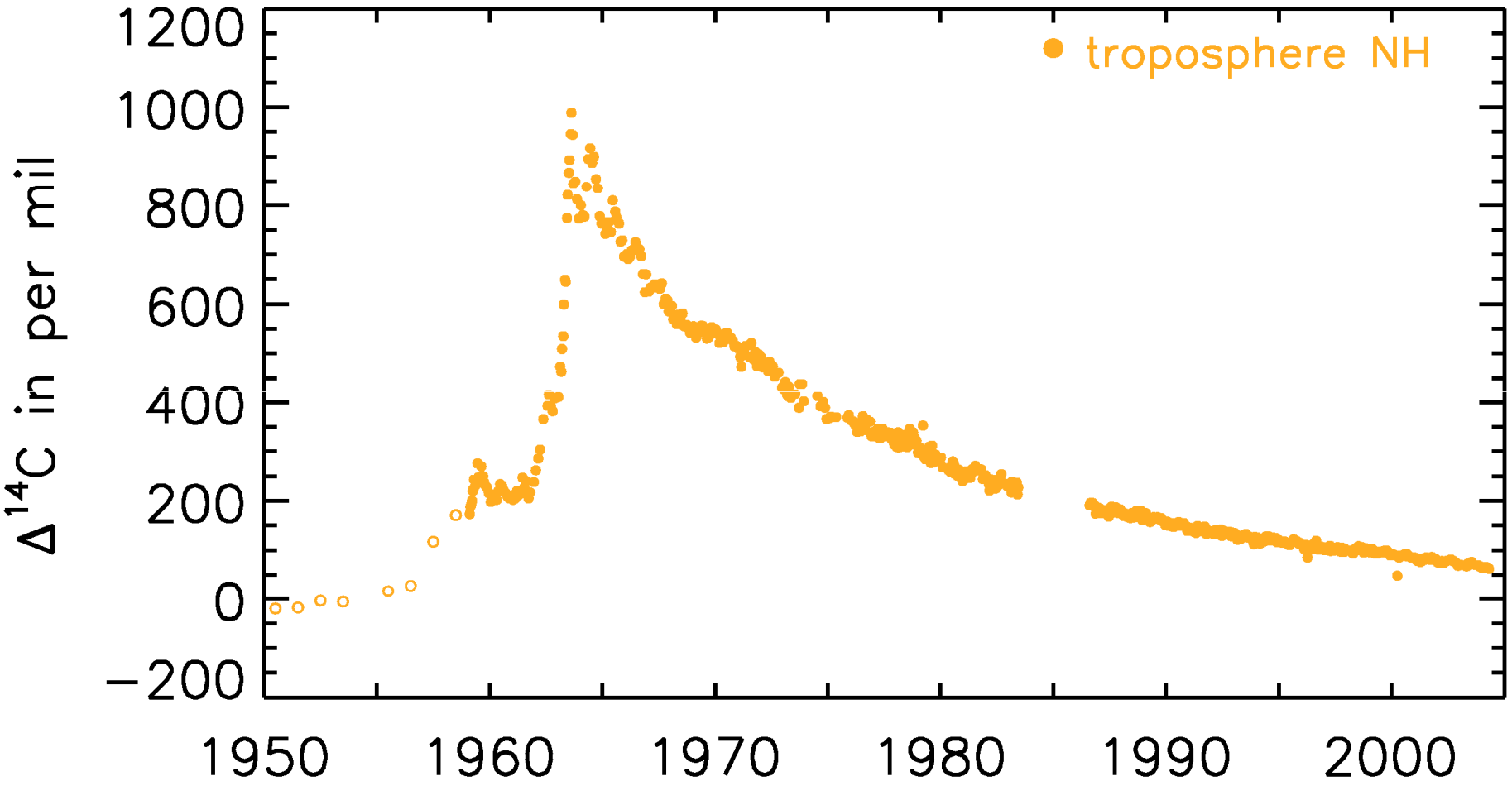

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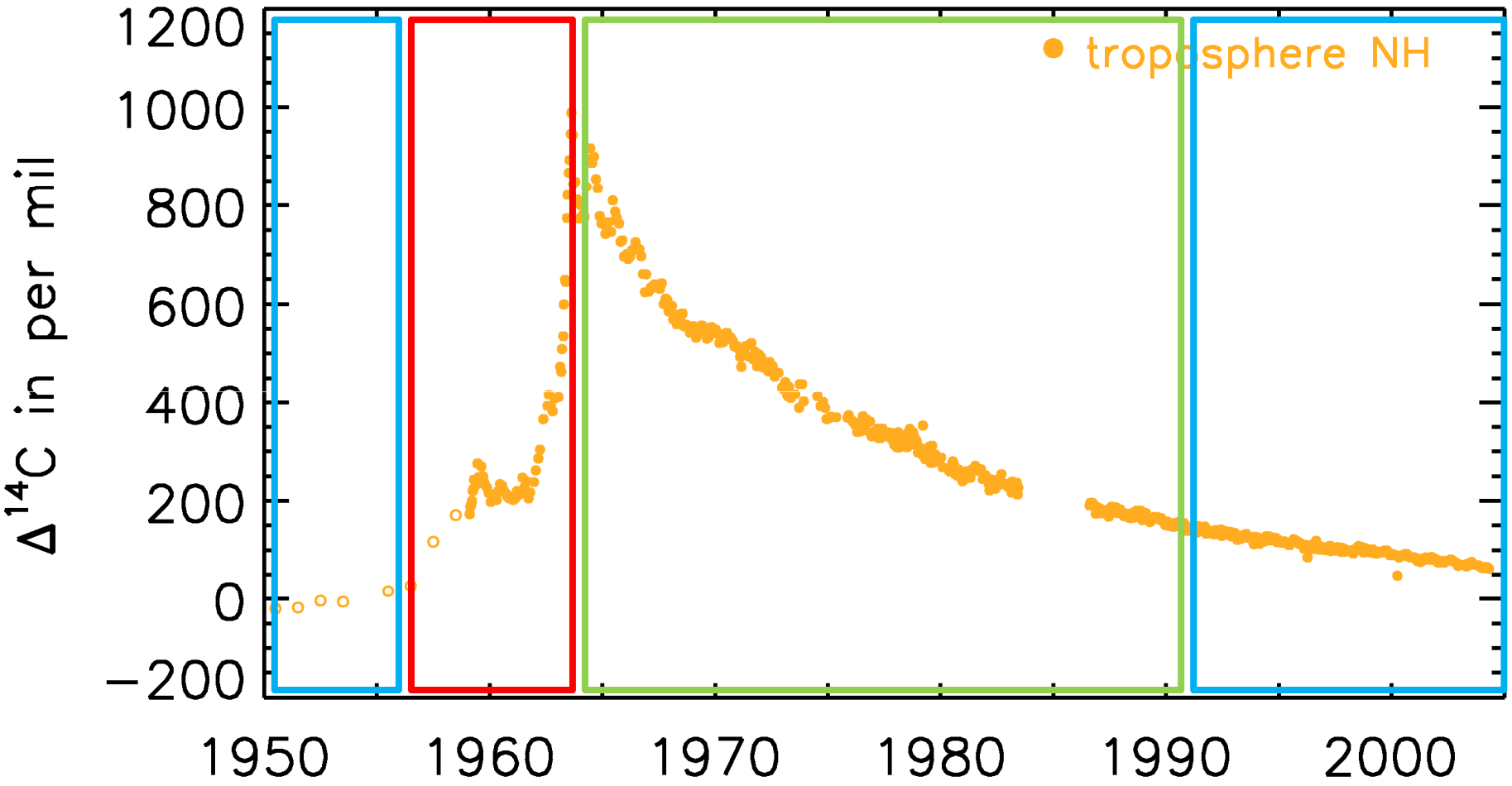

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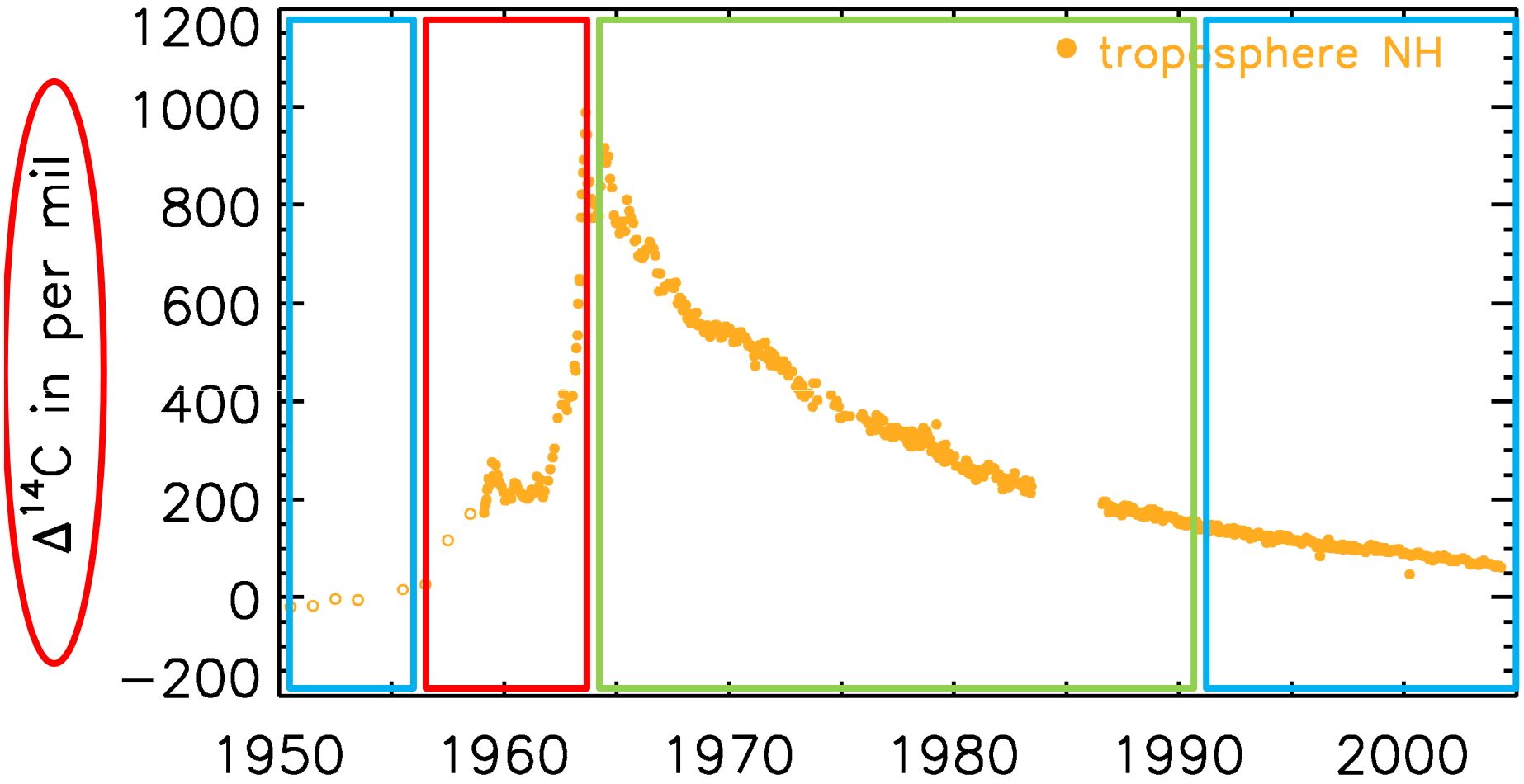

The delta notation

Classical definition

$$ {}^{i}\delta = \frac{{}^{i}R_{Sample}}{{}^{i}R_{Standard}} - 1 $$

$$ {}^{i}R = \frac{{}^{13}C}{{}^{12}C}; \quad \frac{{}^{18}O}{{}^{16}O}; \quad \text{etc.} $$

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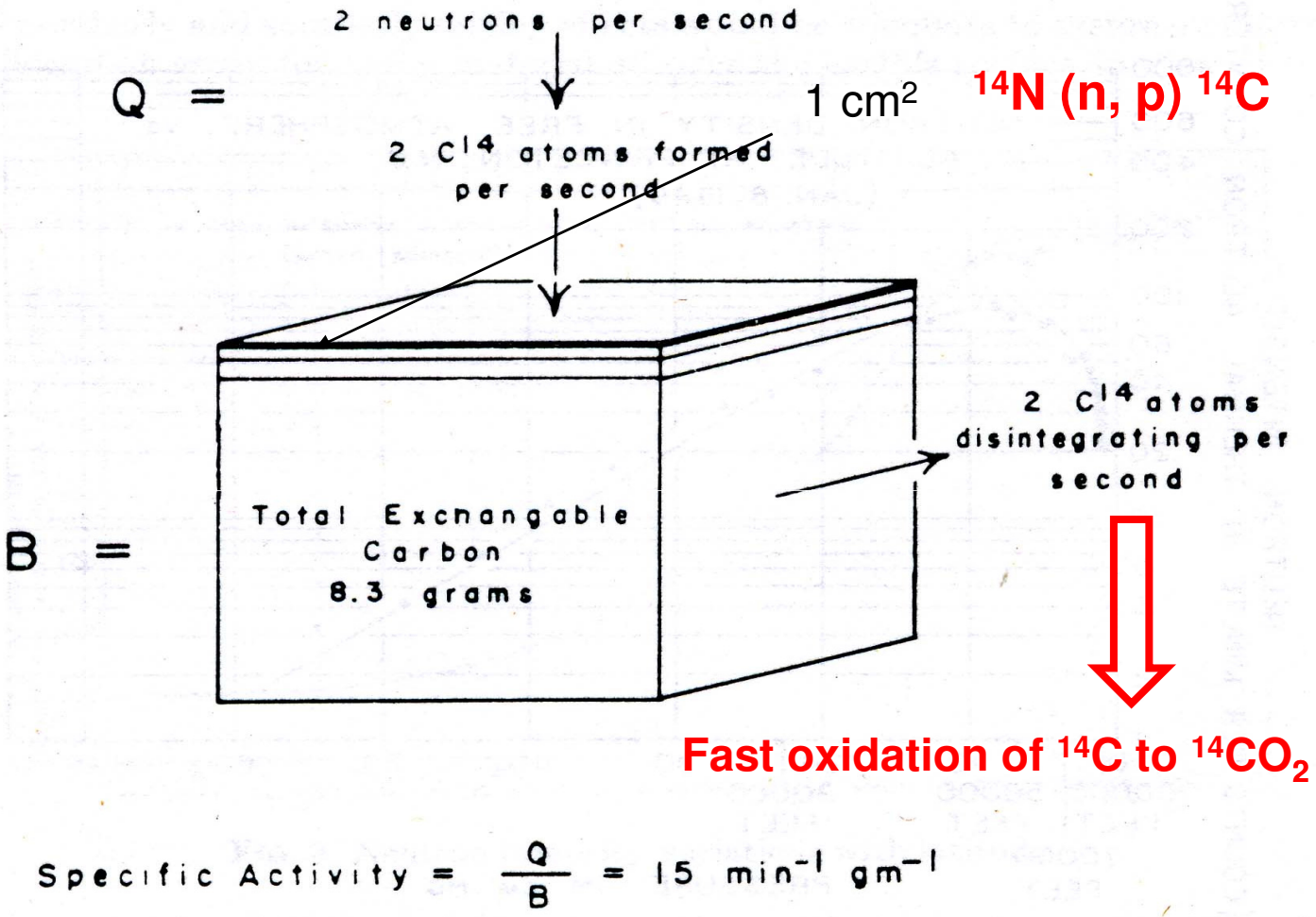
Correcting for fractionation effects:

$$\Delta^{14}C = \delta^{14}C\,(\delta^{13}C \text{ normalised}) \quad (\times 10^{3}\ ‰)$$

Natural production of ^{14}C (Libby 1960, Nobel prize lecture)



^{14}N (n, p) ^{14}C

Fast oxidation of ^{14}C to $^{14}CO_2$

FIG. 1. Schematic showing carbon 14 production mechanism.

Properties of radiocarbon

Rare ($^{12}C/^{14}C$) ≈ 10^{-12}

Radioactive ($T_{1/2}$ = 5700a)

Everywhere in the (short) carbon cycle

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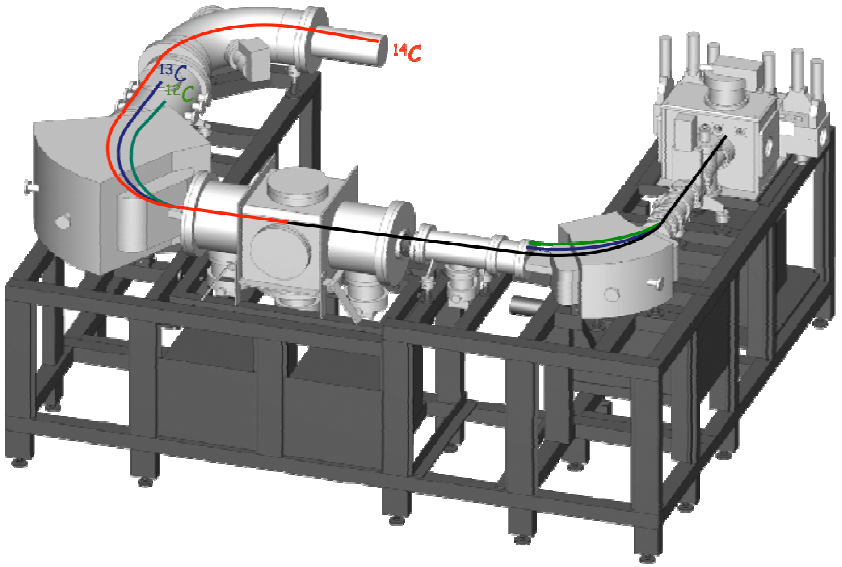
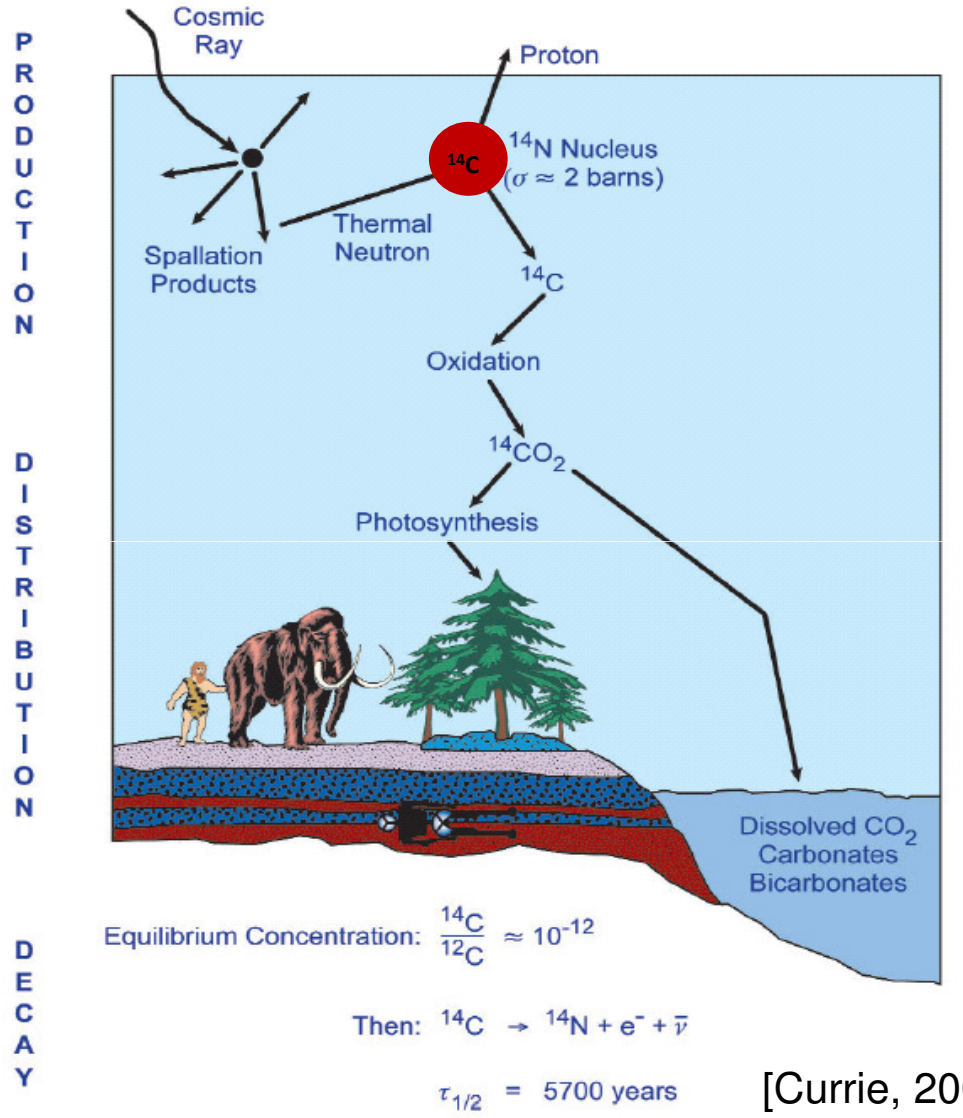
Proportional counting chambers

Accelerator Mass Spectrometry



Production and fate of ^{14}C



[Currie, 2004]

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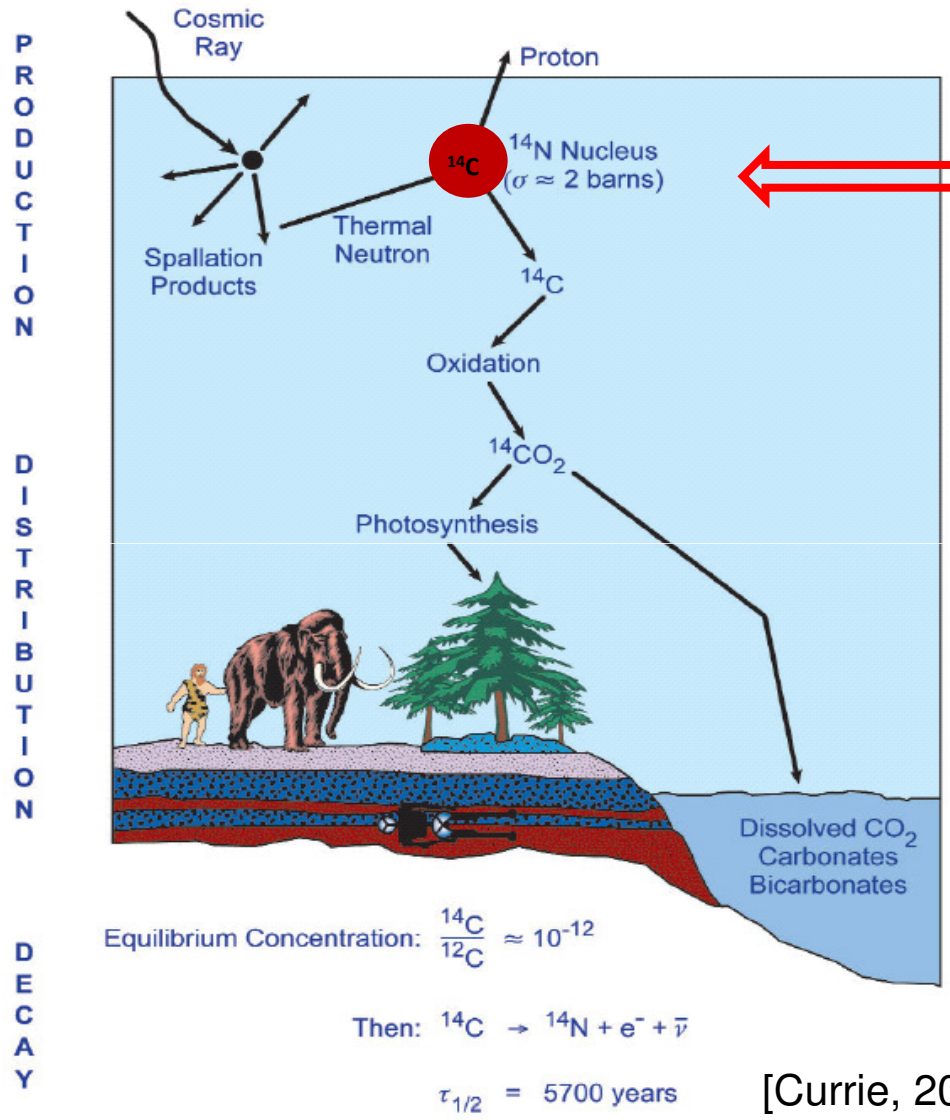
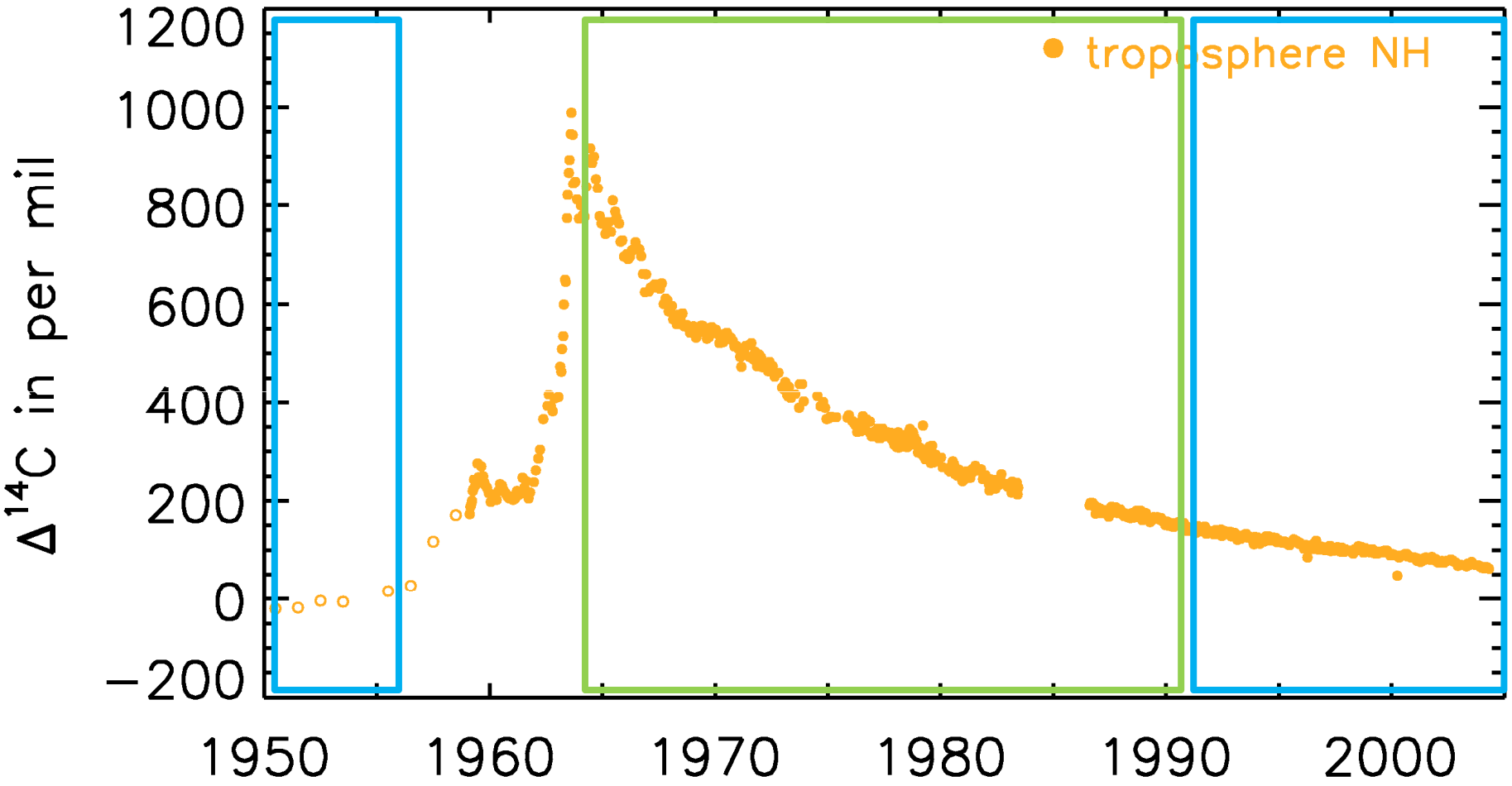


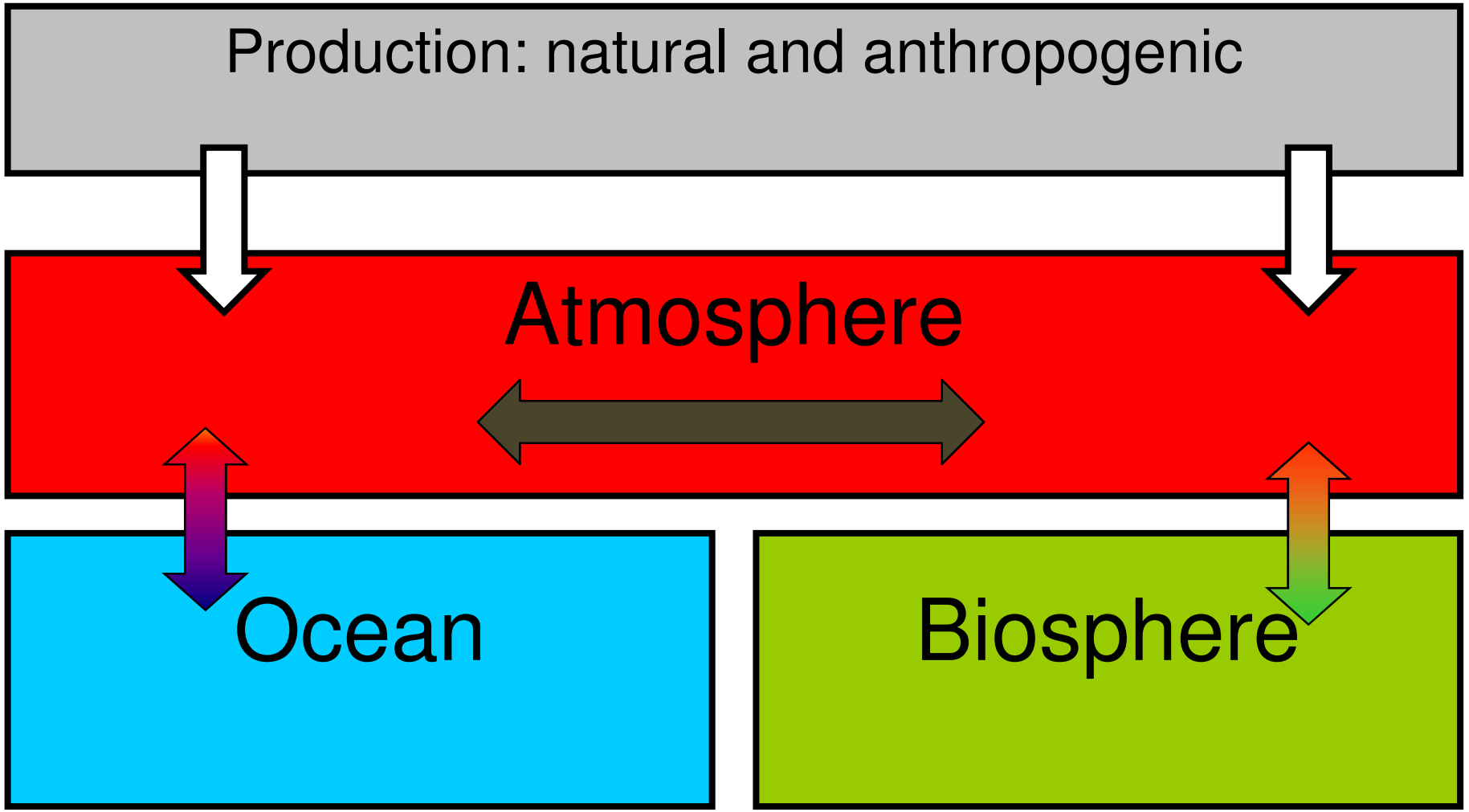
Nuclear bomb tests

[Currie, 2004]

Atmospheric ^{14}C in CO_2



$^{14}CO_2$ propagation in the carbon cycle



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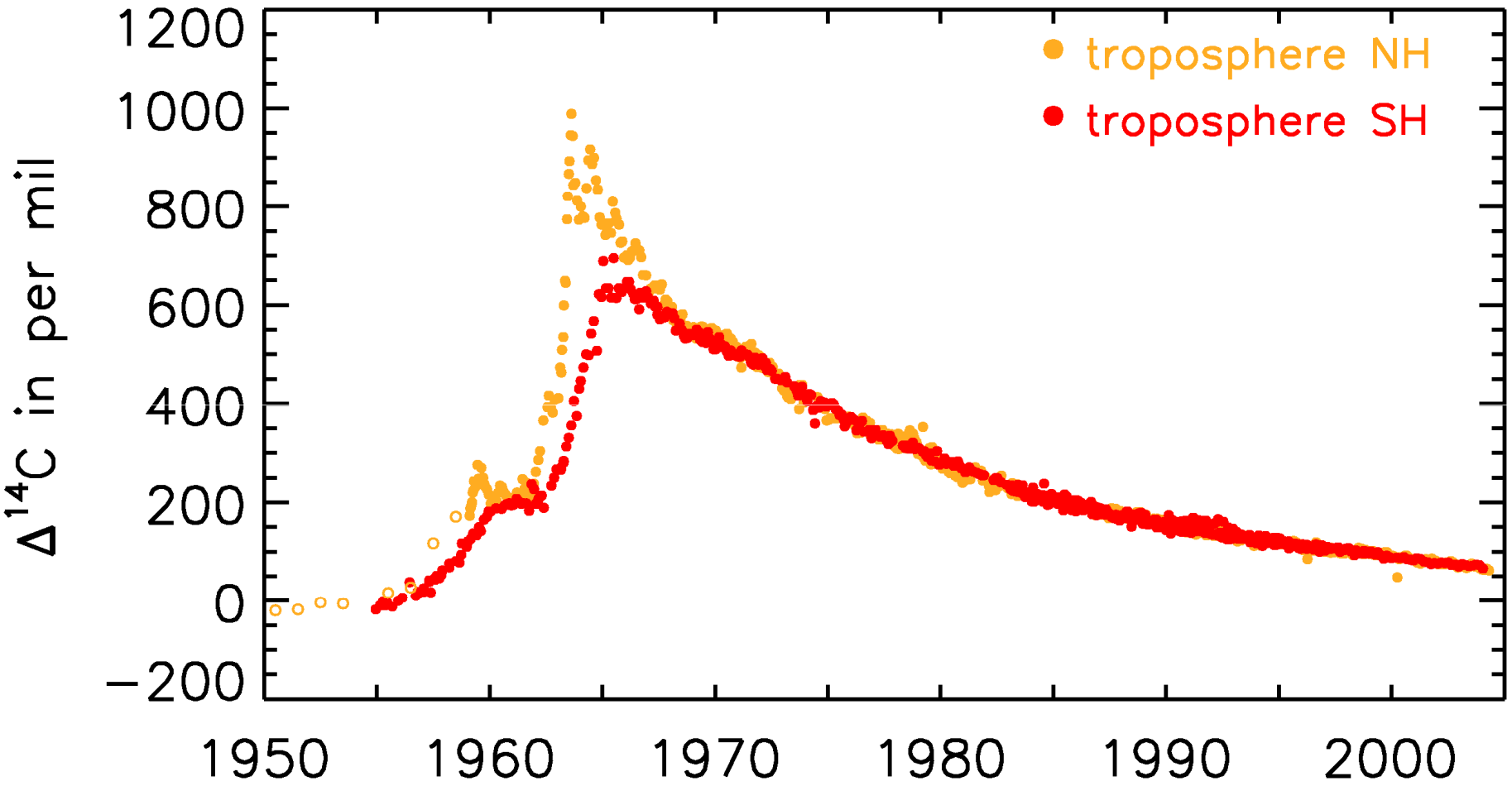

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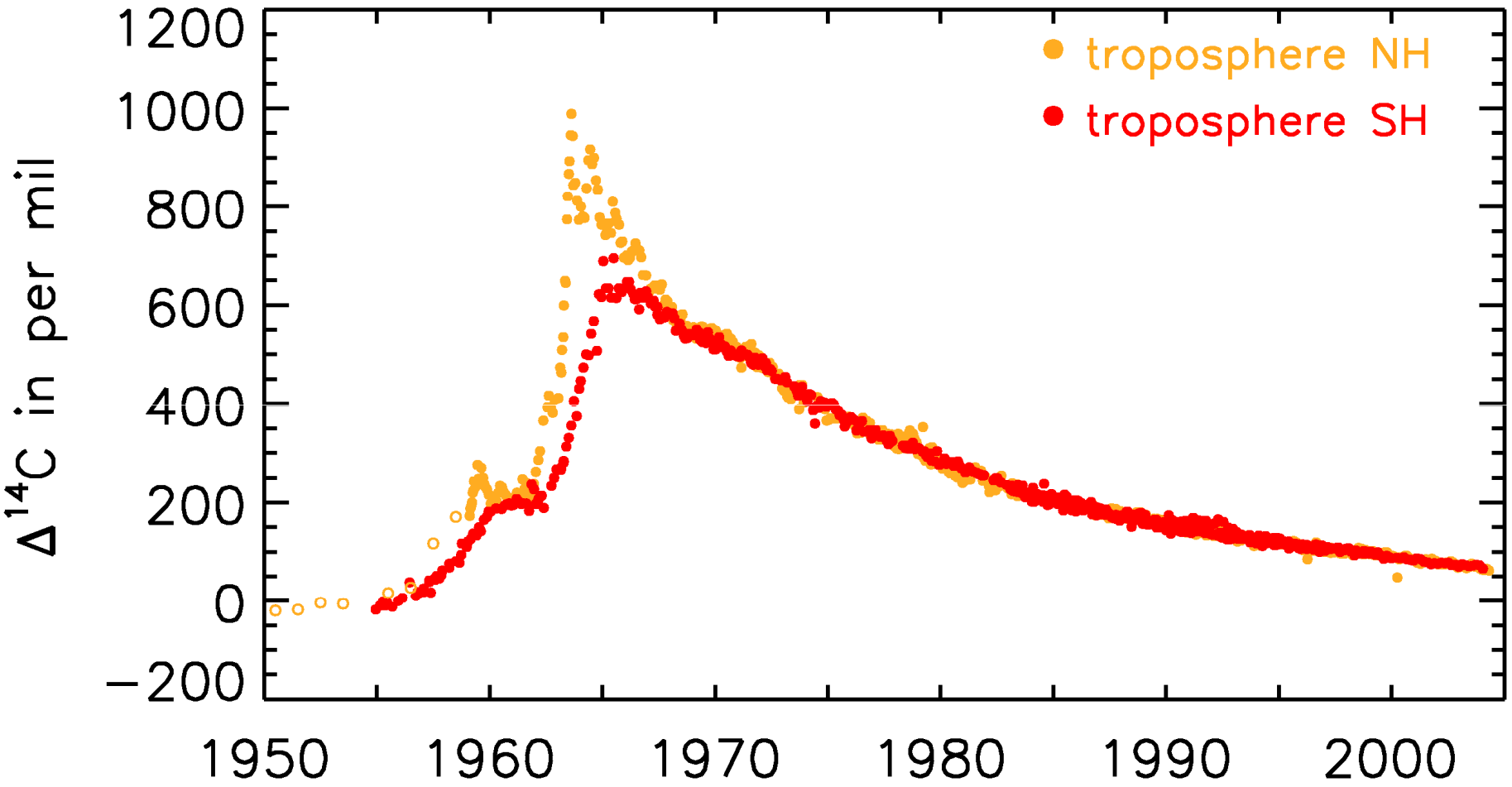

Determine inter-hemispheric exchange rate

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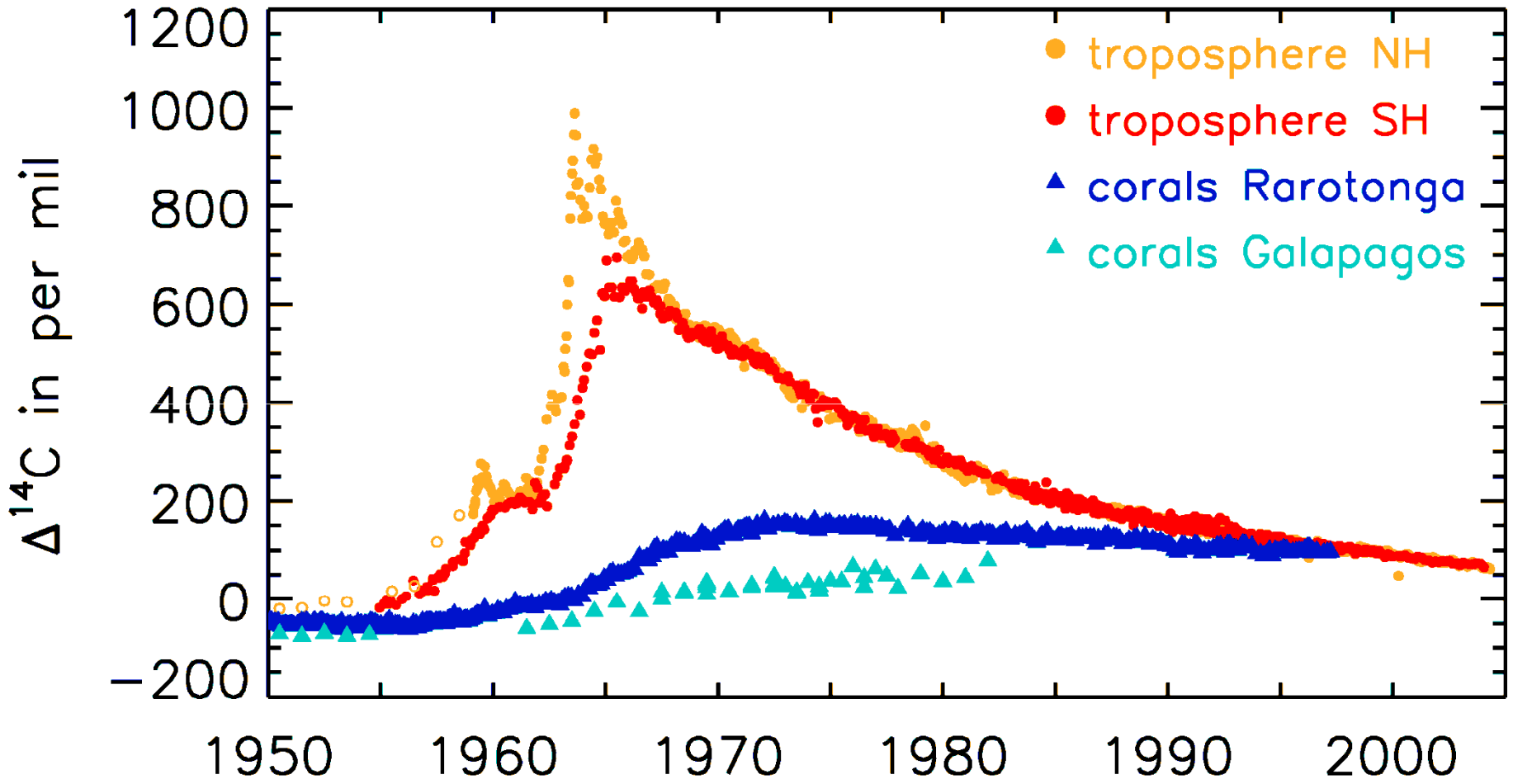

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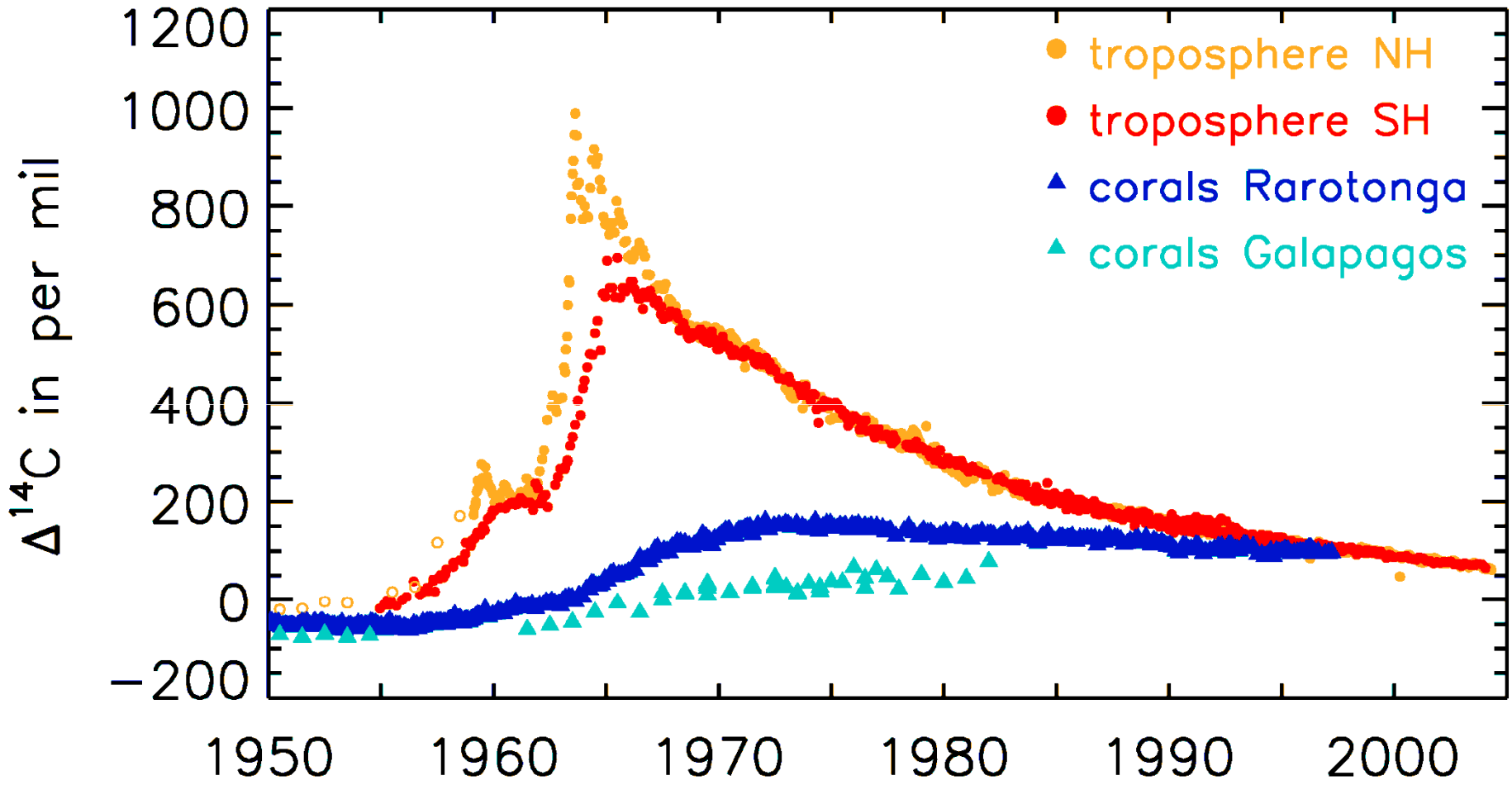

Determine the exchange rate of ocean and atmosphere

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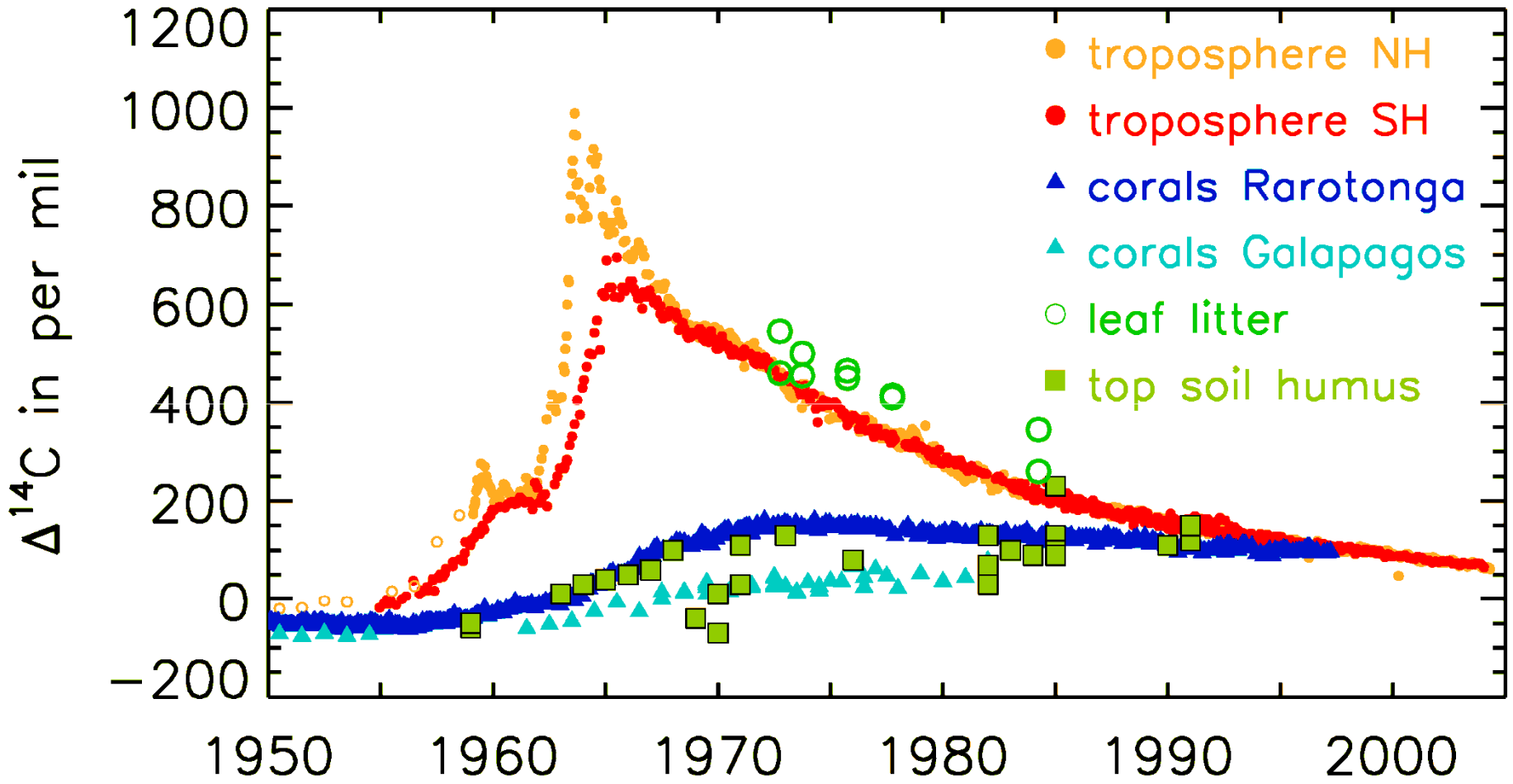

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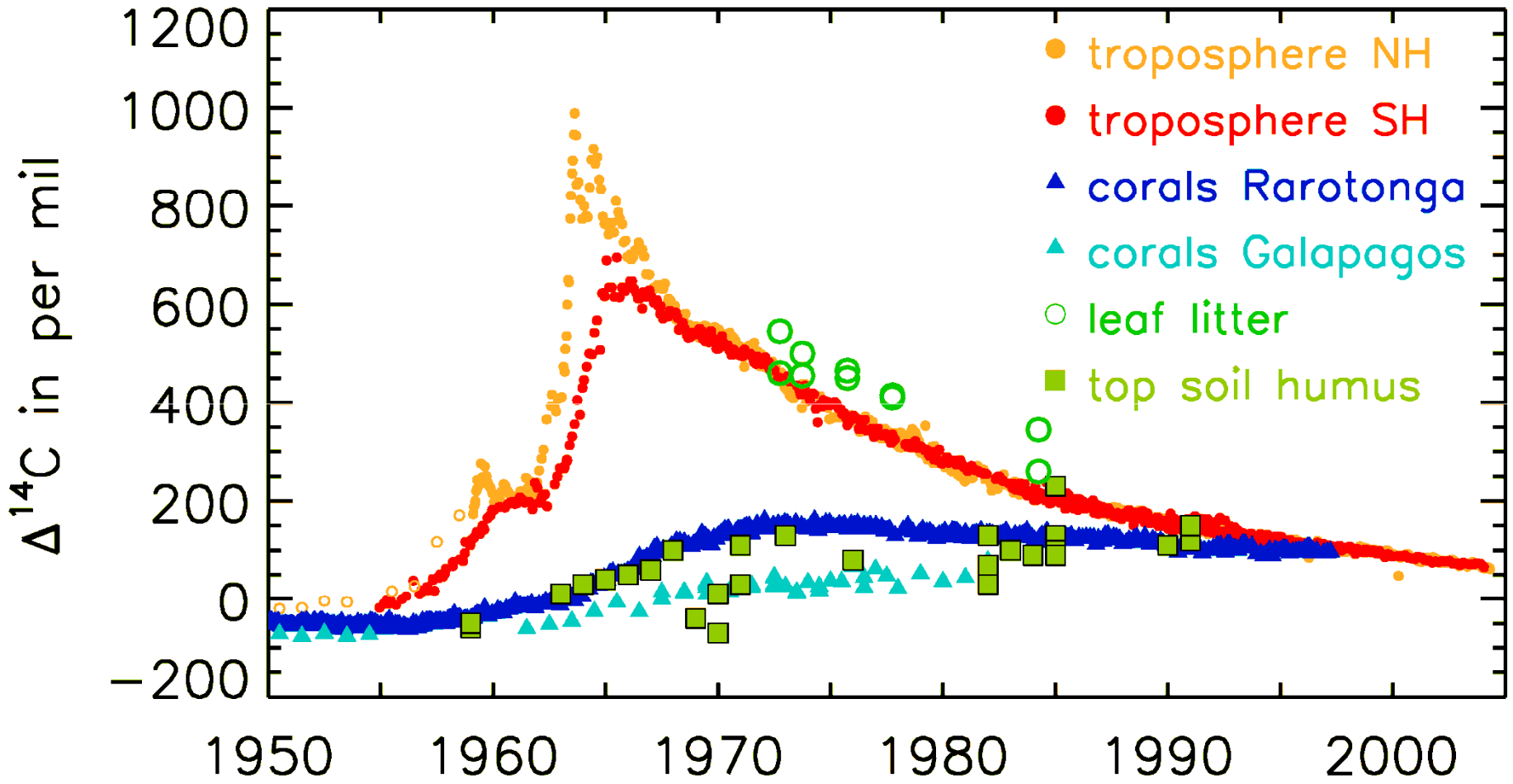
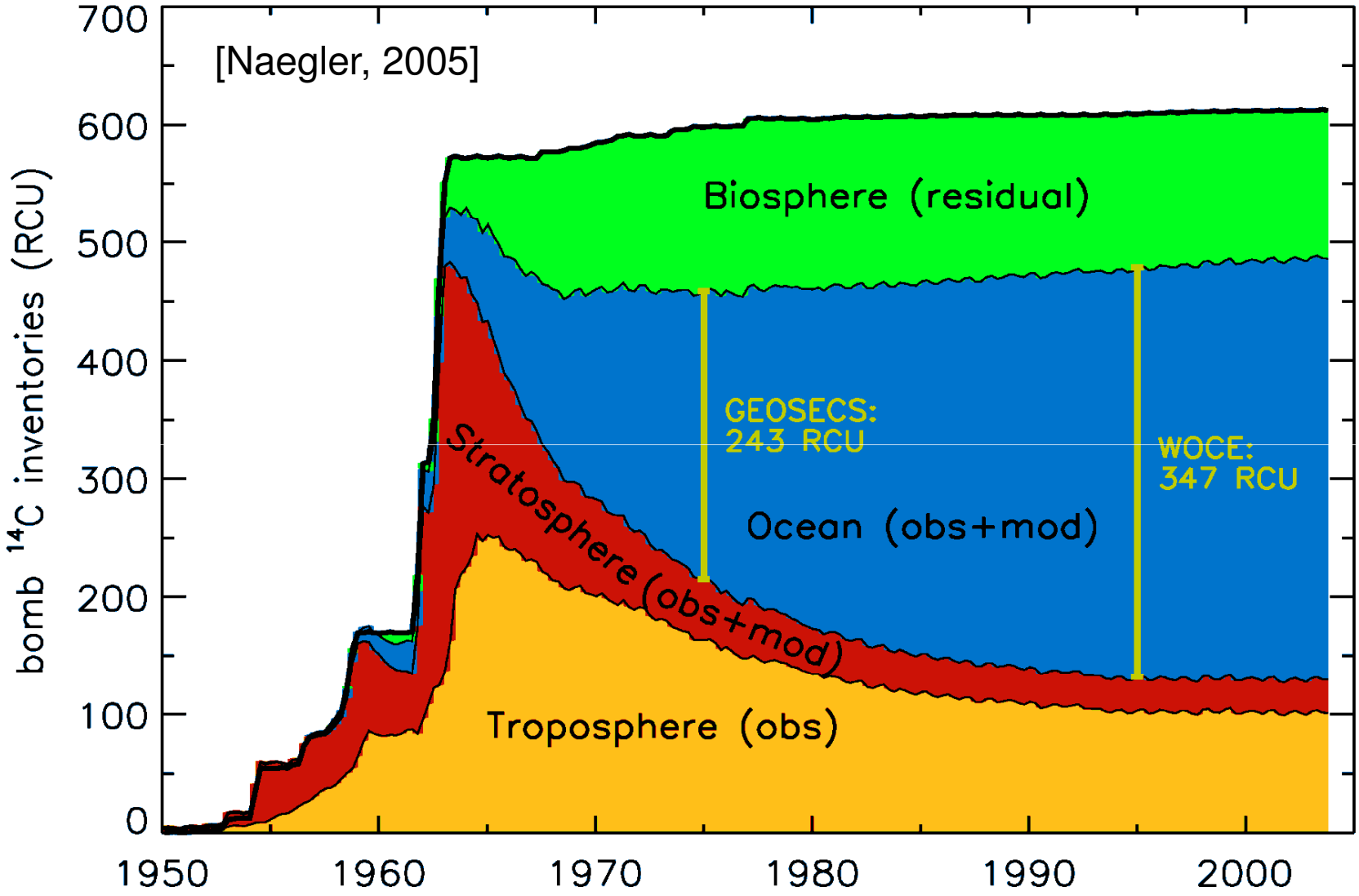


Determine the “age“ of biogenic carbon pools

Global inventory of ^{14}C



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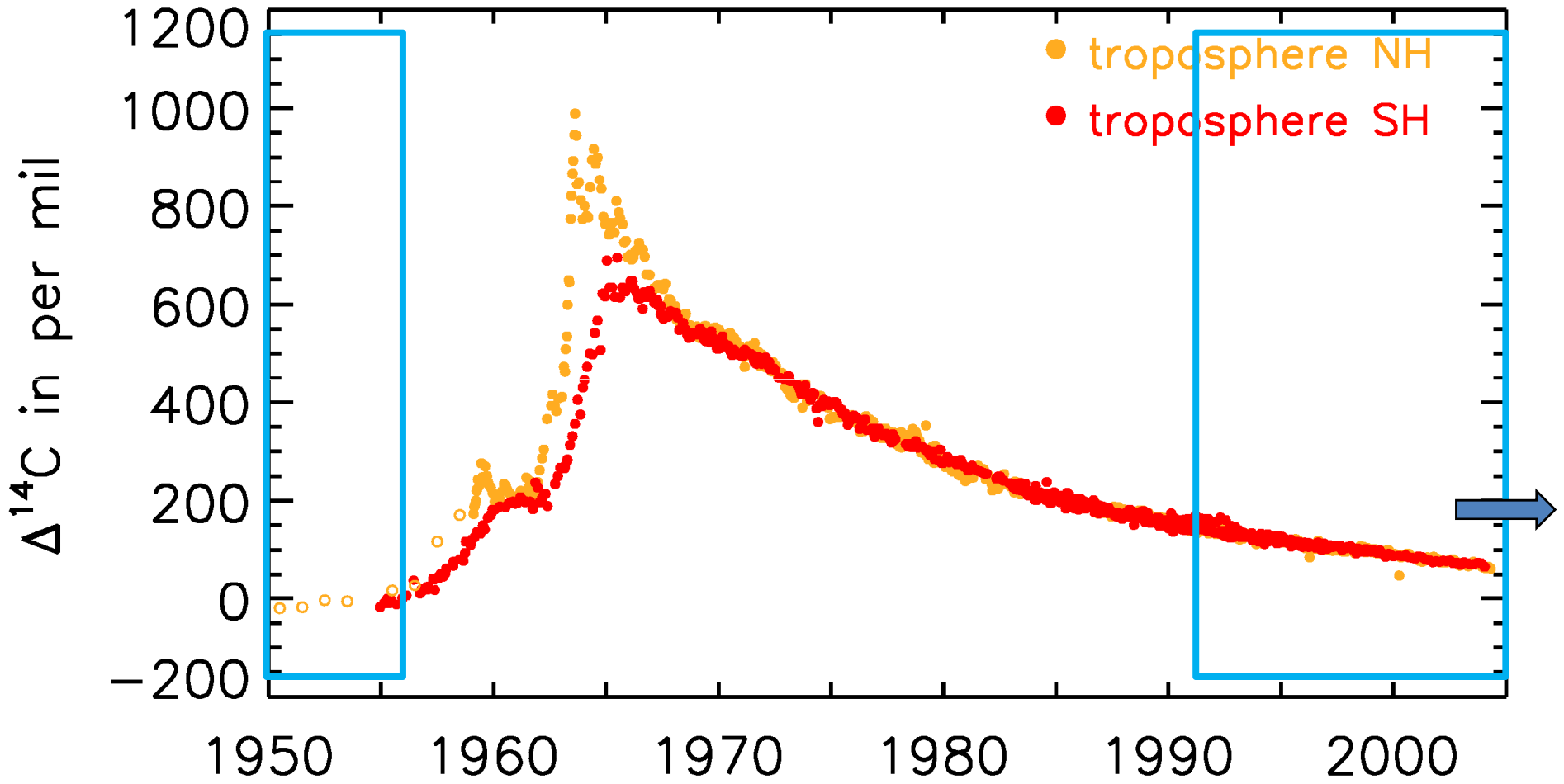
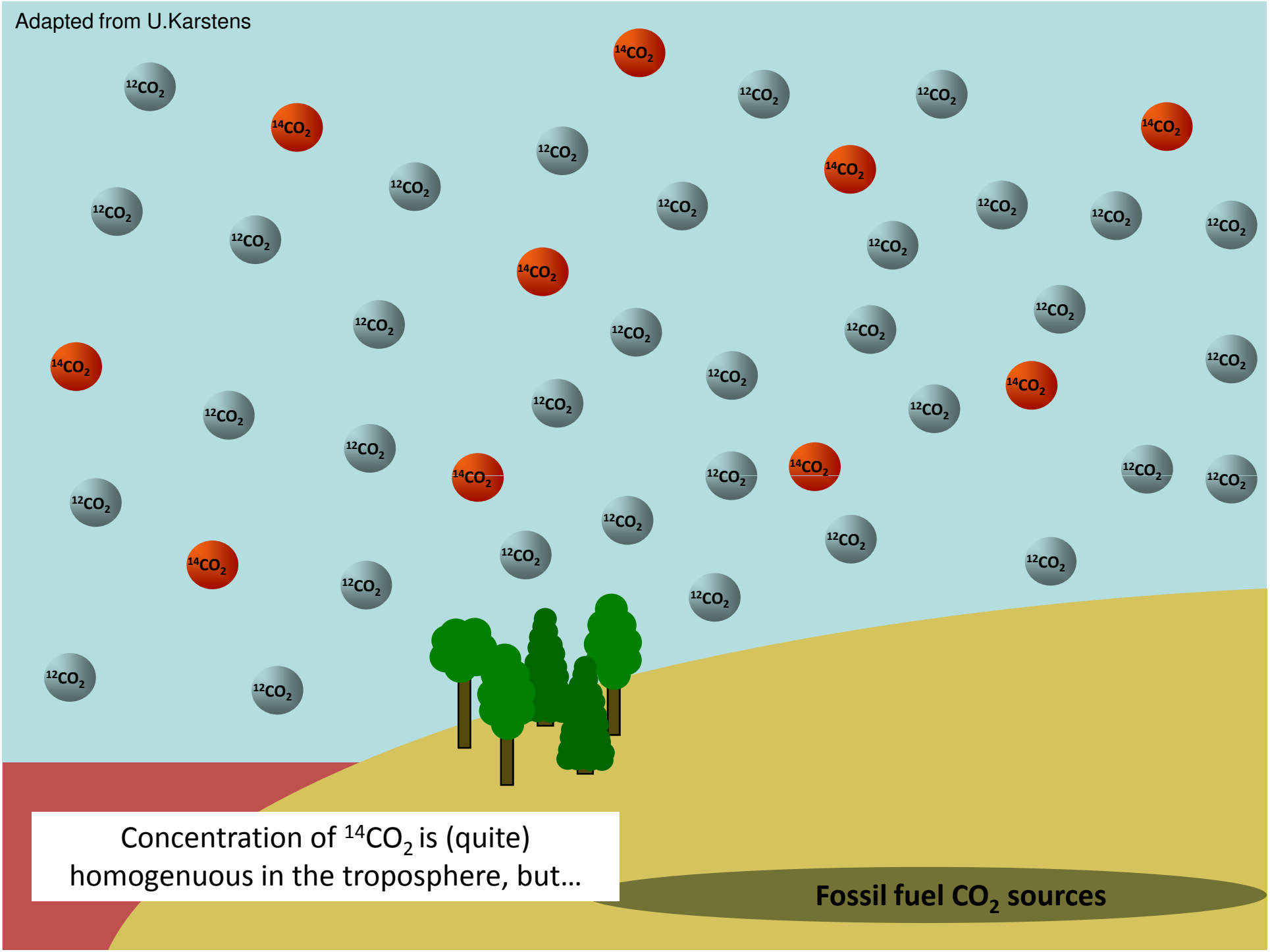
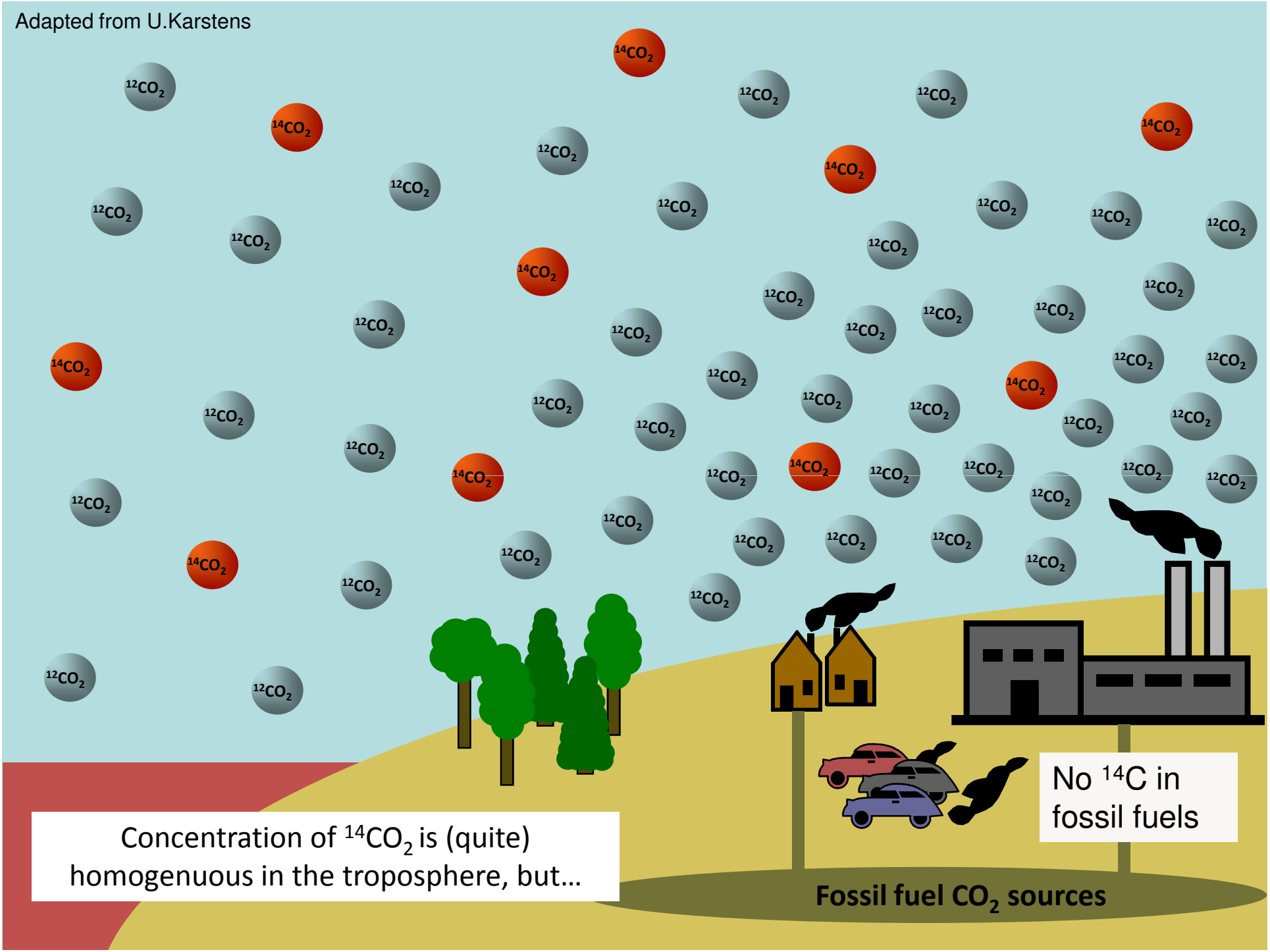



Adapted from U.Karstens
$^{12}CO_2$
$^{14}CO_2$
Concentration of $^{14}CO_2$ is (quite) homogenuous in the troposphere, but…
Fossil fuel CO_2 sources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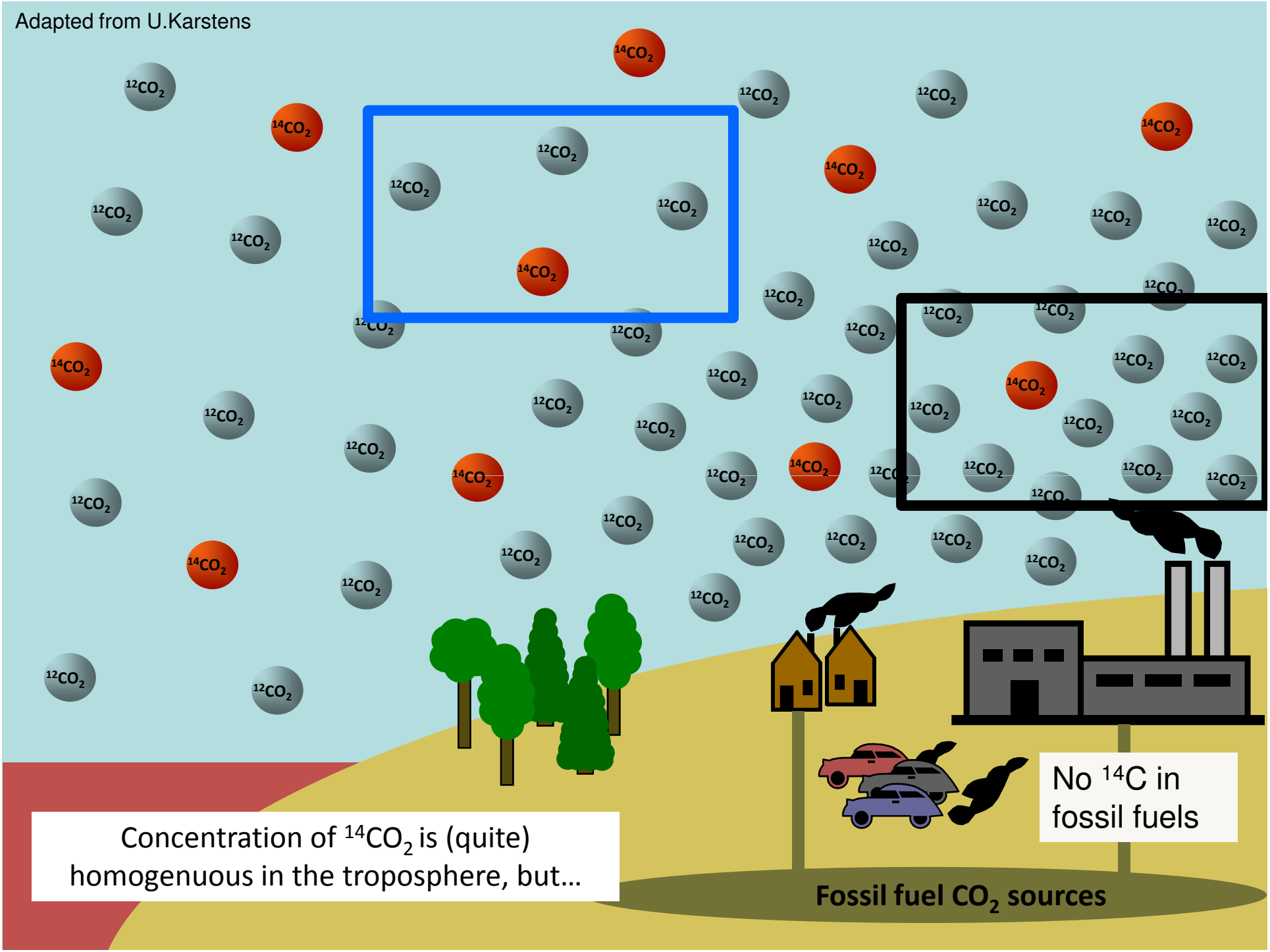
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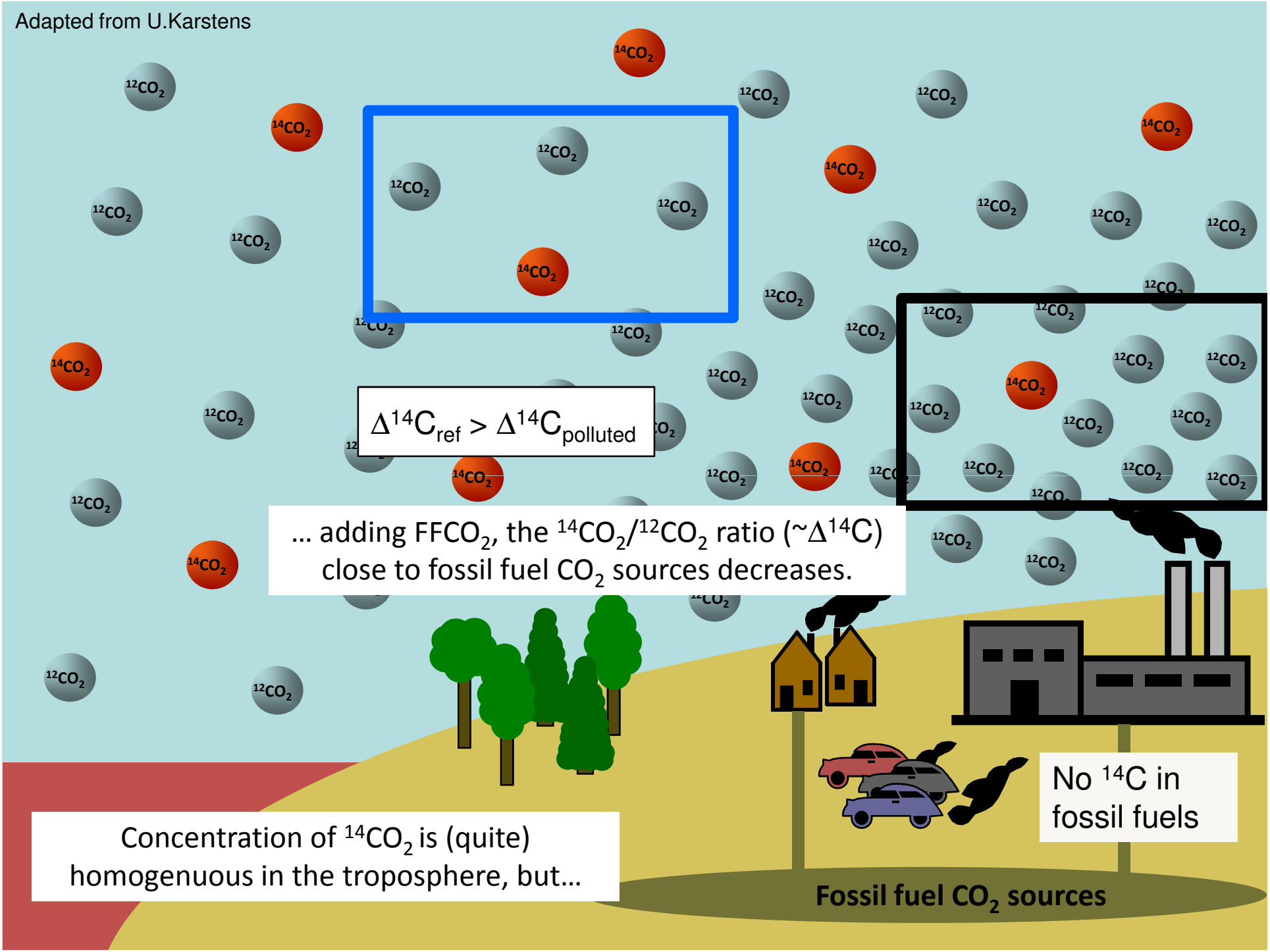
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$^{14}CO_2$
$^{12}CO_2$
$\Delta^{14}C_{ref} > \Delta^{14}C_{polluted}$
… adding $FFCO_2$, the $^{14}CO_2/^{12}CO_2$ ratio (~$\Delta^{14}C$) close to fossil fuel CO_2 sources decreases.
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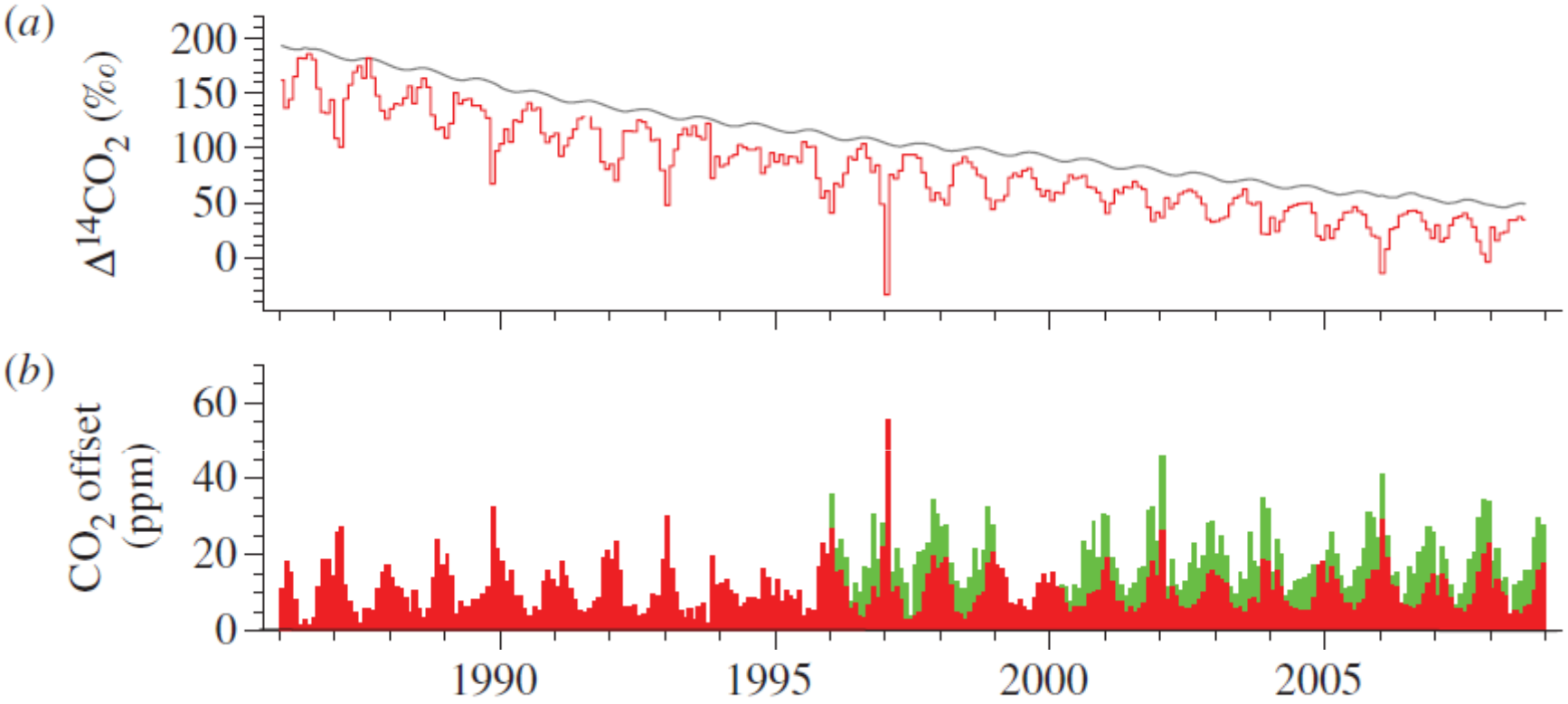
Determing fossil fuel from radiocarbon observations

Levin et al. 2010 and Vogel et al. 2011



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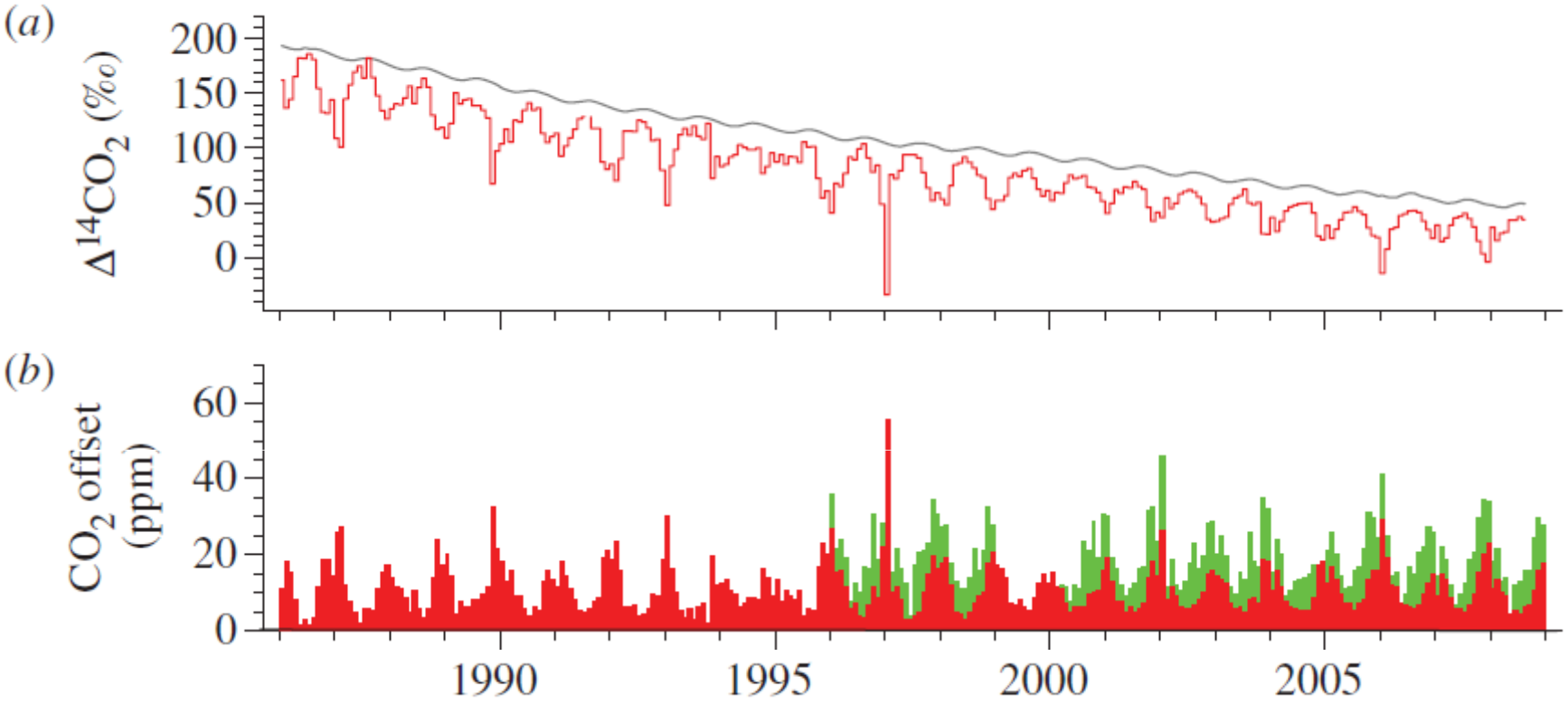
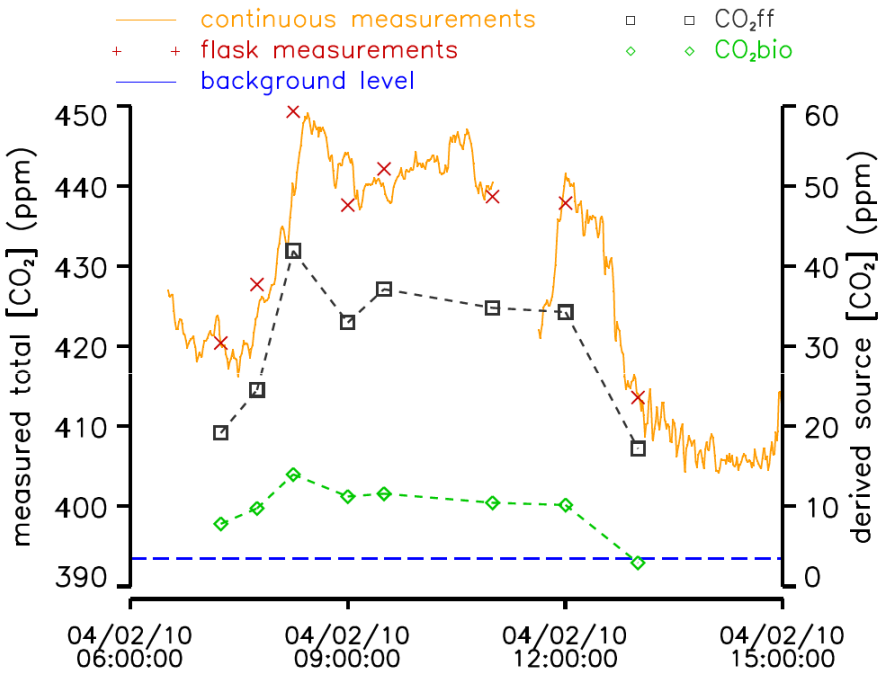


Derive the seasonal cycle of fossil fuel CO_2 in the atmosphere

Long-term monitoring of changes in $FFCO_2$

Determing fossil fuel from radiocarbon observations

Observations – Paris, France



[Lopez et al. 2013]

Understand urban CO_2 signals

Determing fossil fuel from radiocarbon observations

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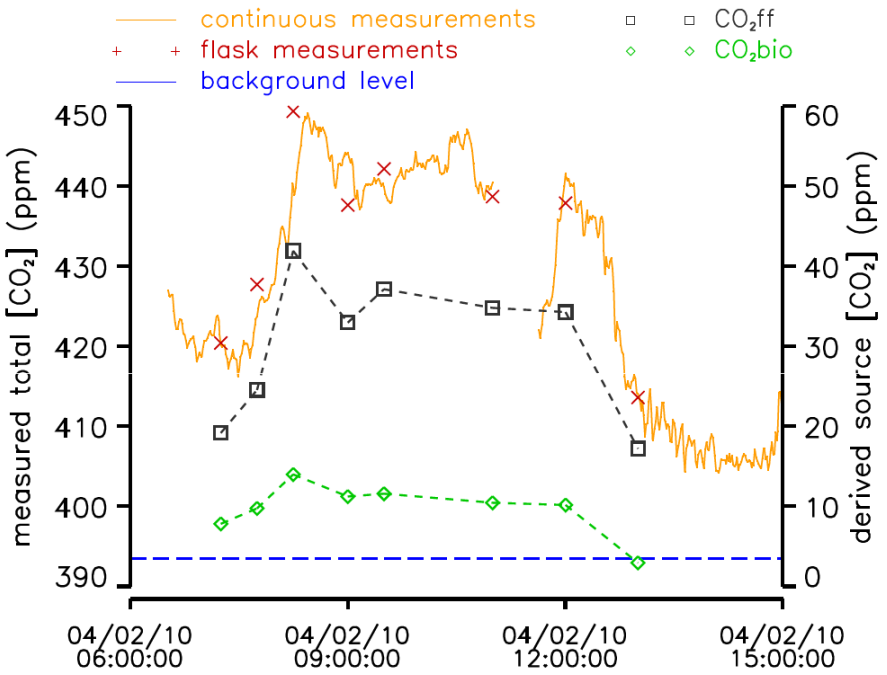

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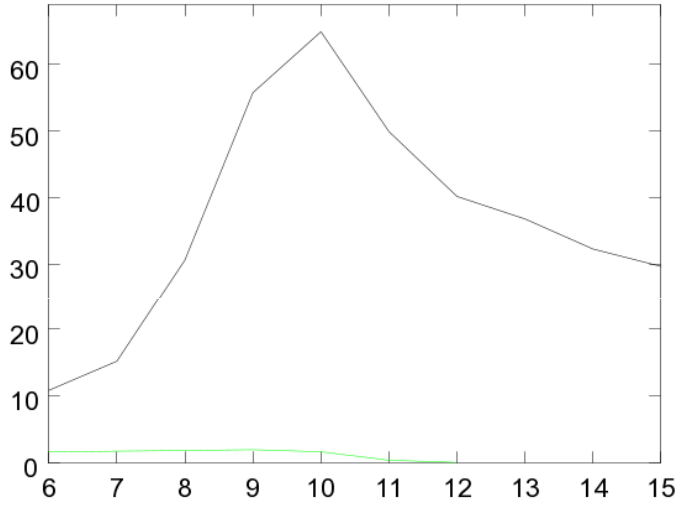
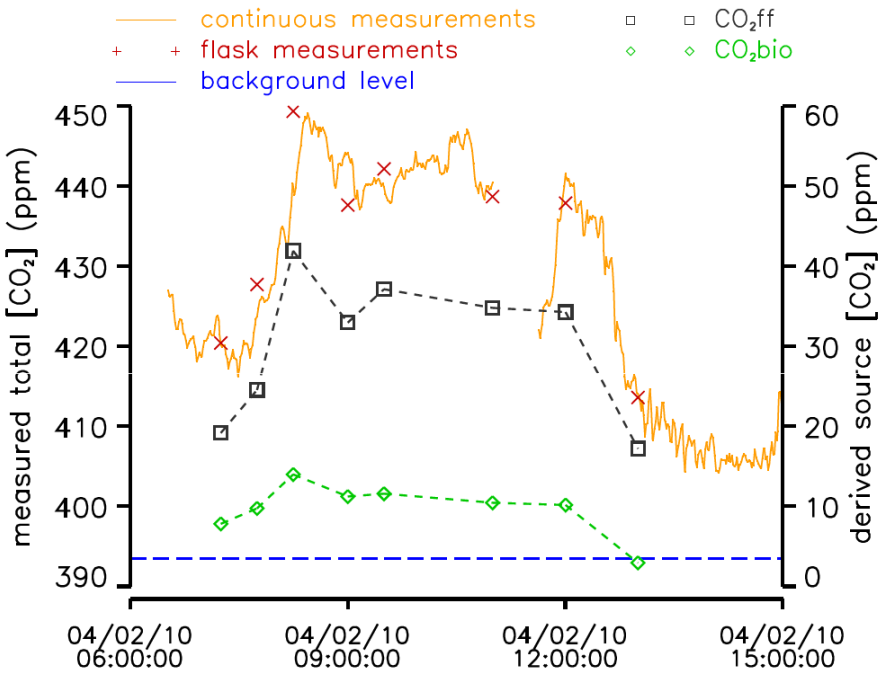
Simulation – Paris, France



Understand urban CO_2 signals and improve models

Determing fossil fuel from radiocarbon observations

Observations – Paris, France



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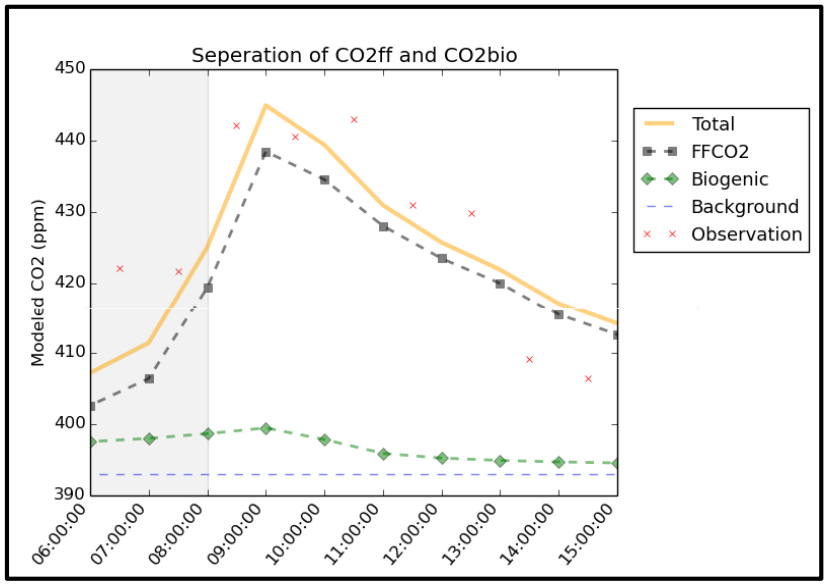

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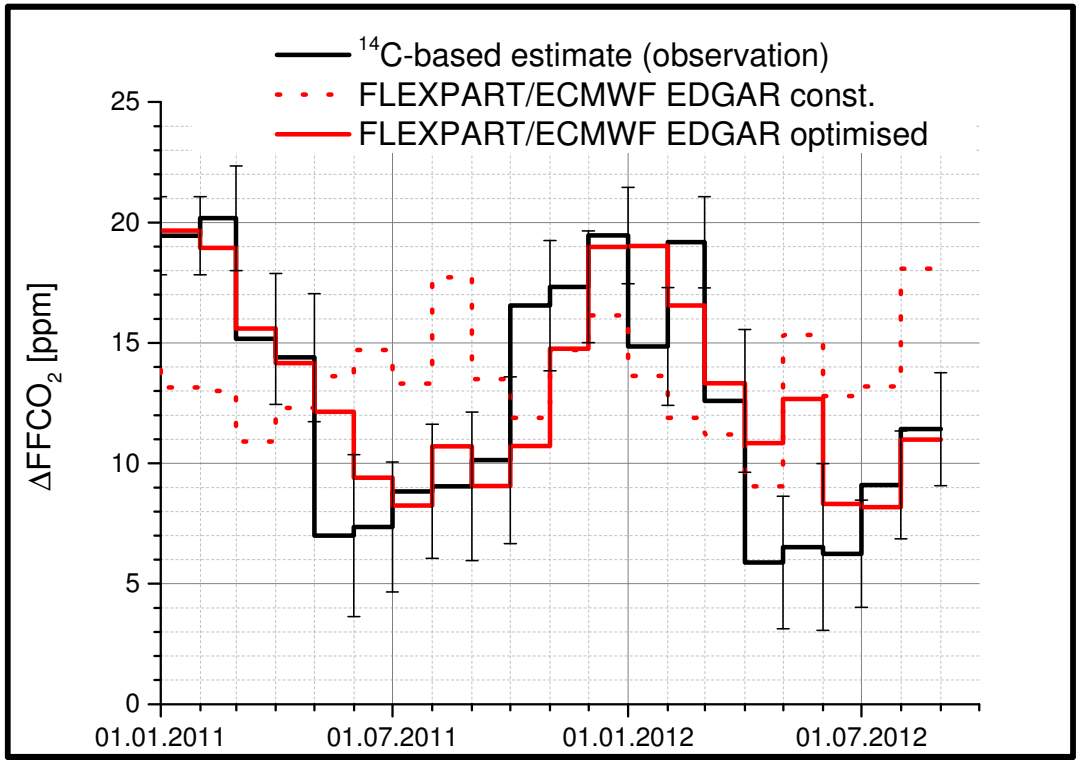

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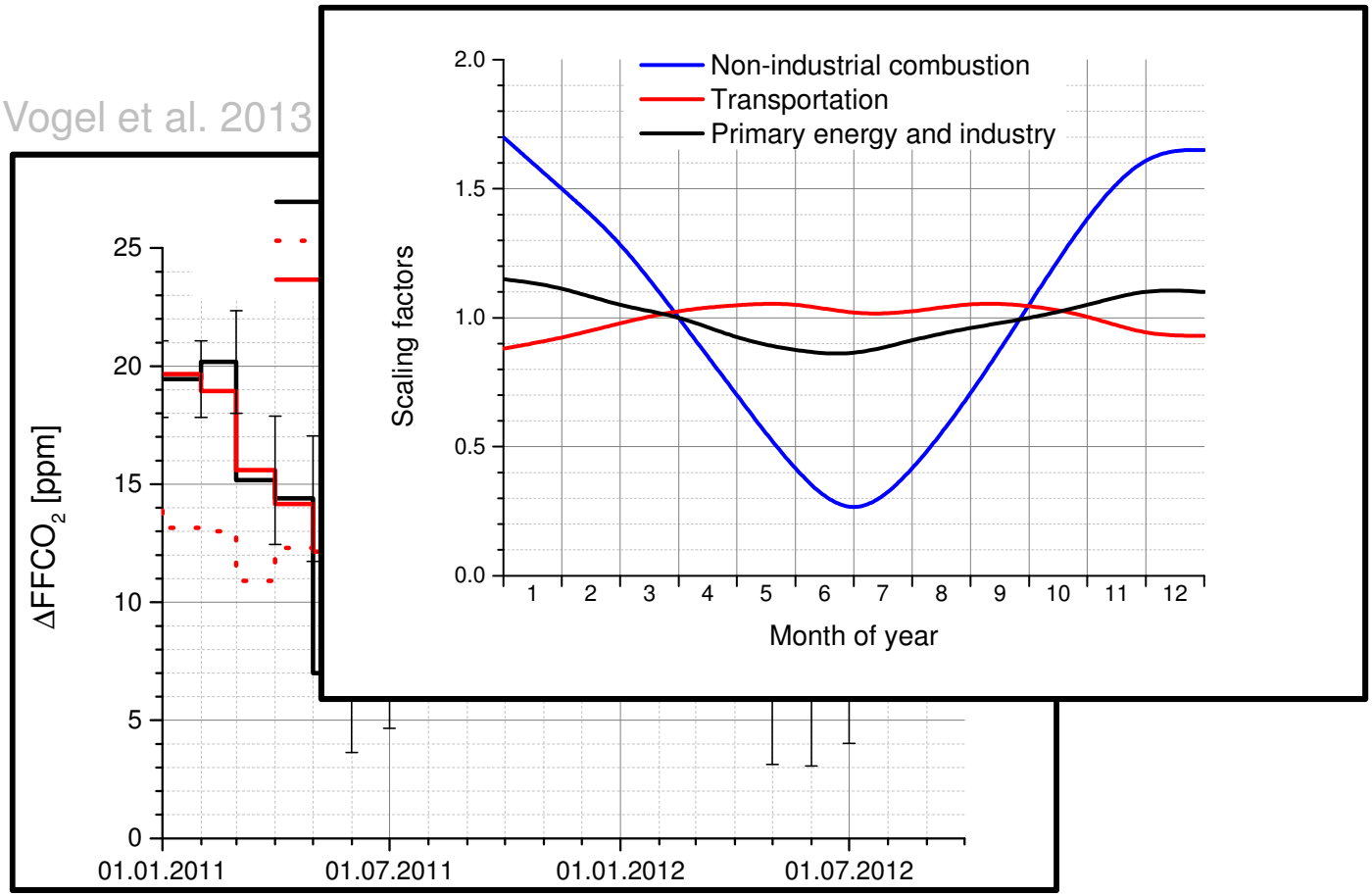

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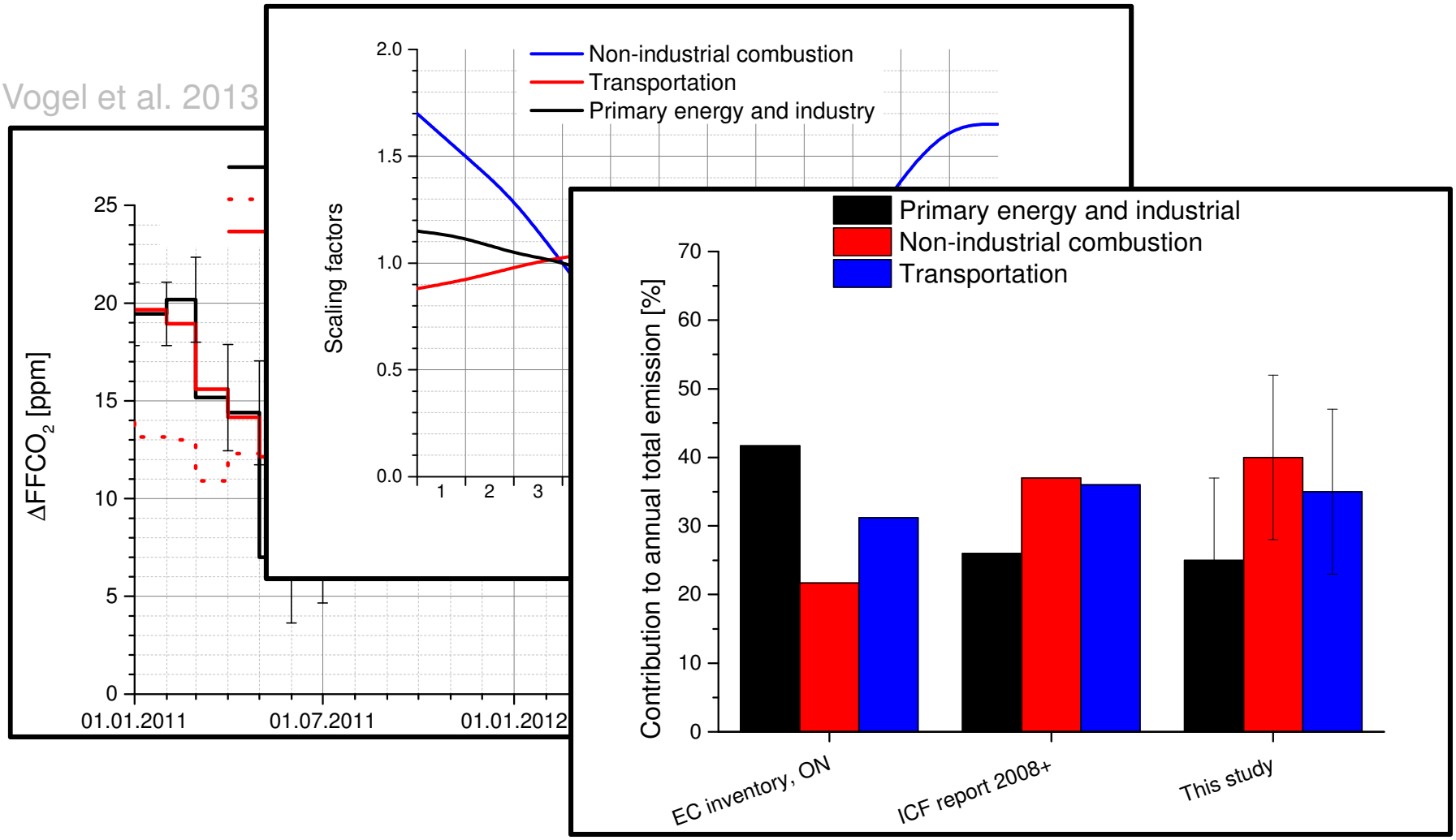

Determine the contribution of different emission sectors (i.e. categories)

Summary

Radiocarbon is used across many fields of research

It is produced naturally and anthropogenically and is distributed in the whole (living) carbon cycle

Concentrations are low and measurement techniques still complex/costly

Radiocarbon helped to reveal the interaction of the major compartments of the carbon cycle by following its dispersion after the bomb-peak 1950-1960ies

It can be used to determine the fraction of modern versus fossil fuel CO_2 and

When combined with modelling studies radiocarbon can be used to derive emission estimates for urban areas and help to identify specific sources (categories)

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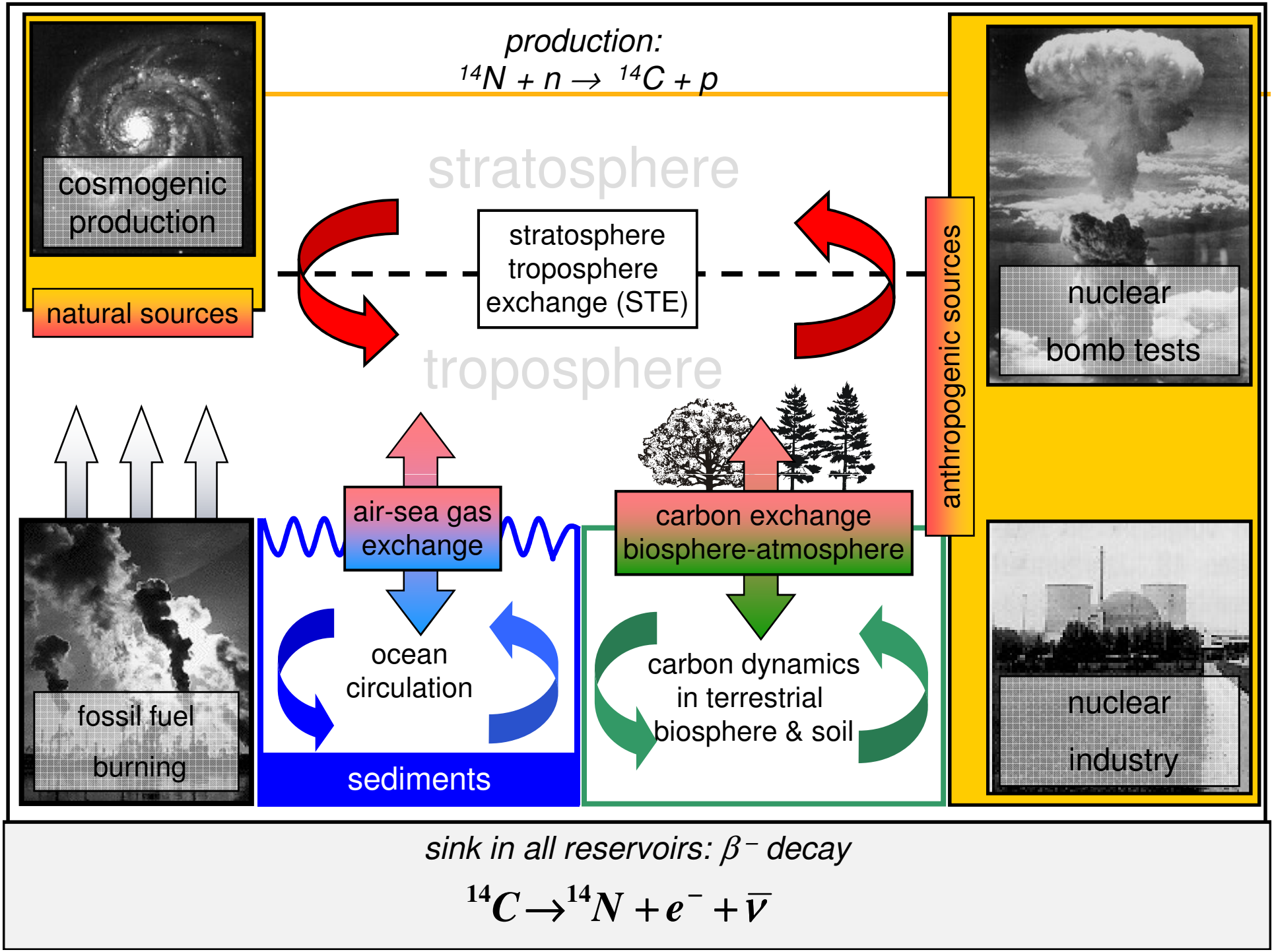
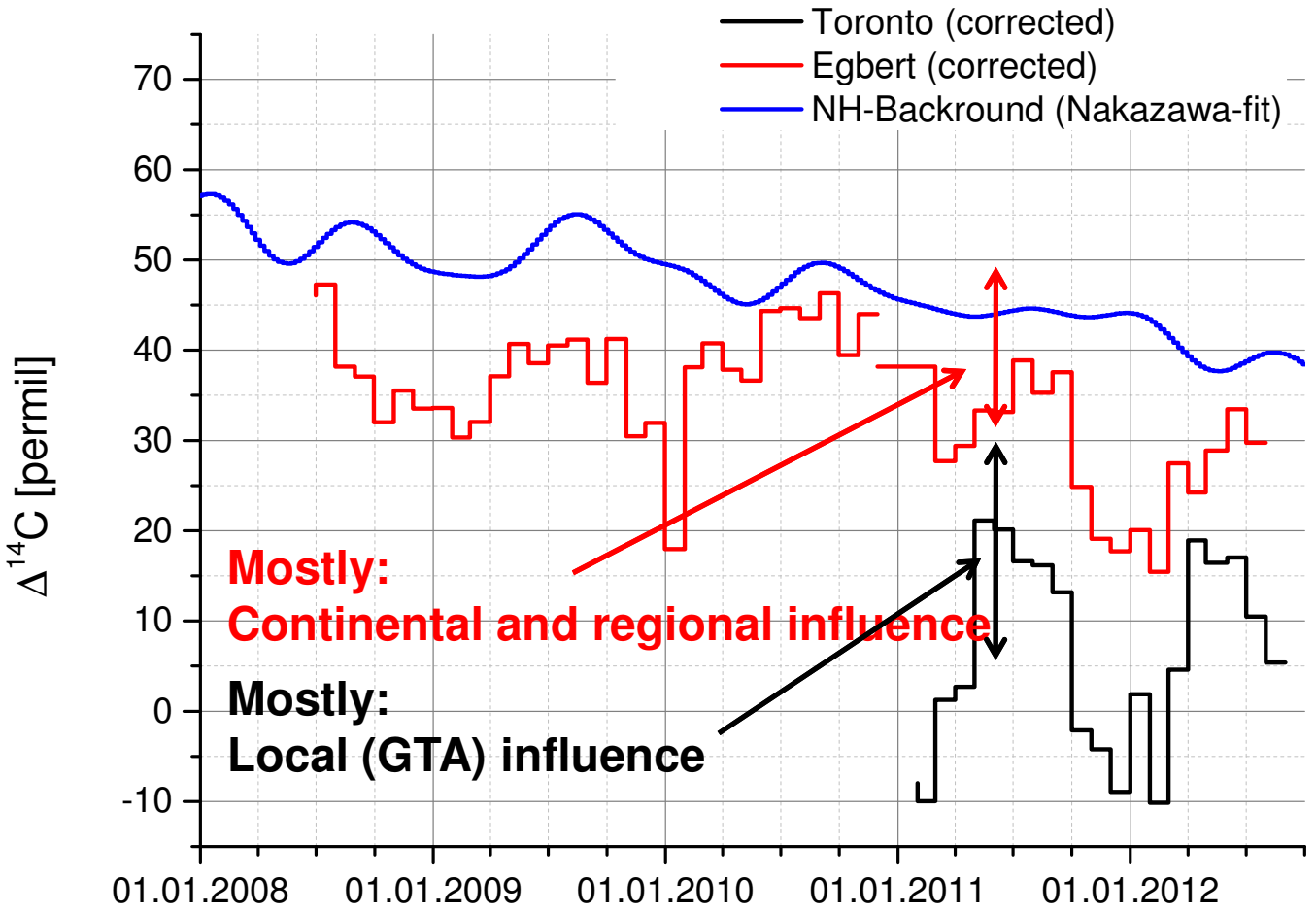

production:
$^{14}N + n \rightarrow {}^{14}C + p$
cosmogenic production
natural sources
stratosphere
stratosphere troposphere exchange (STE)
troposphere
anthropogenic sources
nuclear bomb tests
air-sea gas exchange
carbon exchange biosphere-atmosphere
fossil fuel burning
ocean circulation
carbon dynamics in terrestrial biosphere & soil
sediments
nuclear industry
sink in all reservoirs: β^- decay
$^{14}C \rightarrow {}^{14}N + e^- + \bar{\nu}$

[For Egbert data and correction terms see: Vogel et al, Radiocarbon 2013]



Significant ^{14}C depletion for Egbert and Toronto observations

[Naegler, 2005]