Lecture 11: Cosmogenic Nuclides II

Radiocarbon

What’s the big deal?

• Radiocarbon is a useful chronometer
  — Over 0-60 Ka (esp. Holocene and last ice age)
  — t₀ marked by separation from cosmogenic reservoir (e.g., when dying)
• It is carbon
  — A probe of the global carbon cycle
  — Environmental molecular forensics (“natural” or “fossil”?)
• It is recently a transient tracer
  — From bomb testing fallout
• This is a HUGE area of research
  — Paleo-studies, modern research, much contention

Cosmogenic Nuclides II: Radiocarbon

• What’s the big deal?
• A brief history of radiocarbon dating
• Past changes and “calibration curves”
• Marine reservoir effects
• Deep ocean distributions
• The Suess effect
• The nuclear weapons tests
A brief history of radiocarbon

• Radiocarbon discovered in 1940
• Radiocarbon dating proposed in late 1940s
• Revolutionized archeology
  – And then the honeymoon was over
    • The dawning realization that the $^{14}\text{C}/^{12}\text{C}$ in the atmosphere varies with time
    • The half-life was wrong (5730 vs. 5568 years) “Libby half life”
  – Still uses the “Libby Scale” as “Radiocarbon years before 1950”
• Originally measured by gas proportional counters
  – Required several grams of C per sample
• In the 1980s, started using AMS*
  – Required only mg C per sample
  – Now measuring down to the 10 µg range

*Remember slide 17 of Lecture 3?
More on this in Lectures 13 & 14

Before we go on...

• Atmospheric ratio (pre-bomb*, pre-Seuss*)
  – $^{14}\text{C}/^{12}\text{C} \sim 10^{32}$
• Standards:
  – Originally 1950s wood $\Rightarrow f_w = 1.000$
  – Now a N.I.S.T. oxalic acid (Ox-I and Ox-II)
• Reporting:
  – Need to correct/normalize for isotope fractionation, so use $\delta^{13}\text{C}$ measurement to correct to a “standard” fractionation of $\delta^{13}\text{C} = -25\%$,
  – And you most often see radiocarbon reported as an anomaly scale in $\%$
  – And -$1000\%$ means “radiocarbon dead” ($F_M = 0$)

*more later...  

Cosmogenic Nuclides II: Radiocarbon

• What’s the big deal?
• A brief history of radiocarbon dating
• Past changes and “calibration curves”
• Marine reservoir effects
• Deep ocean distributions
• The Seuss effect
• The nuclear weapons tests

Past Changes and Calibration Curves

• We need a “conversion” method because of the screwed up reporting convention (the Libby half-life)
• Evidence from $^{10}\text{Be}$, $^{26}\text{Al}$, $^{36}\text{Cl}$, etc. shows there were production rate changes
• Also ample evidence that there were carbon cycle changes since LGM:
  – In the atmospheric C-inventory
  – In the ocean-atmosphere communication
    • ~65X more C in the oceans than atmosphere
  – In terrestrial/ocean biomass
The “Carbon Cycle”

Only looking at C that is “available” on ~100Ka timescales

“Present day” (pre-anthropogenic)

Inventories in GT
Fluxes in GT $y^{-1}$

How do we “calibrate” radiocarbon?

First choice: tree rings
– Counting (beware “missing years” and local effects)
– Overlapping records matched by dendochronology (tree ring thickness matching)
– Back to ~12.5 Ka BP
– (floating records earlier)


How do we “calibrate” radiocarbon?

Second choice: varved marine sediments & corals
– Counting (beware “missing years”)
– Must account for “marine reservoir effect” and possible changes with time


One Consequence: ambiguities

Sometimes the calibration curve changes with time in a way that there is more than one actual date for a given radiocarbon age: which one is it?
A radiocarbon age has a confidence interval: how does this “map” onto calendar ages?

Bayesian statistics:
Cosmogenic Nuclides II: Radiocarbon

- What’s the big deal?
- A brief history of radiocarbon dating
- Past changes and “calibration curves”
- **Marine reservoir effects**
- Deep ocean distributions
- The Suess effect
- The nuclear weapons tests

**Marine Reservoir Effects**

A 50-100‰ (100-500 y) offset between ocean and atmosphere

Driven by large inorganic carbonate buffer system in the ocean

⇒ slow exchange with atmosphere (~ 1 decade vs. 1 month) and exchange with the deeper ocean

Varies with location/time

---

**Radiocarbon in the deep Pacific**

$$\Delta^{14}C \text{ Decreasing} \Rightarrow$$

$$\Sigma CO_2 \text{ Increasing} \Rightarrow$$

$$A_{14} = \Sigma CO_2 \times \Delta^{14}C \text{ Increasing?} \Rightarrow$$
Deep water $\Delta^{14}C$

Calibration for planetary scale overturning circulation
- OGCM (numerical models)
- Inverse calculations (e.g., Schlitzer, R., 2007 Journal of Physical Oceanography 37, 259-276)

Cosmogenic Nuclides II: Radiocarbon
- What’s the big deal?
- A brief history of radiocarbon dating
- Past changes and “calibration curves”
- Marine reservoir effects
- Deep ocean distributions
- The Suess effect
- The nuclear weapons tests

The Suess Effect
Dilution of atmospheric & oceanic $^{14}CO_2$ with “dead” (fossil fuel) CO$_2$
Seen in tree rings and coral records

Cosmogenic Nuclides II: Radiocarbon
- What’s the big deal?
- A brief history of radiocarbon dating
- Past changes and “calibration curves”
- Marine reservoir effects
- Deep ocean distributions
- The Suess effect
- The nuclear weapons tests
**Bomb Test $^{14}$C**

- Atmospheric nuclear weapons tests 1950-1962
- Nearly doubled atmospheric $^{14}$C inventory
- Seen in tree-rings and actual atmospheric measurements

**Cosmogenic Nuclides II: Radiocarbon**

- What’s the big deal?
- A brief history of radiocarbon dating
- Past changes and “calibration curves”
- Marine reservoir effects
- Deep ocean distributions
- The Suess effect
- The nuclear weapons tests

---

**Bomb Test $^{14}$C**

- Latitudinal structure to atmospheric response
  - Biggest tests in the Northern Hemisphere

---

**Oceanic response ($^{14}$C)**

- And repeat sections:

---

**Effective yield of atmospheric testing (tonnes)**

- 1945: 1 tonne
- 1962: 1000 tonnes

---