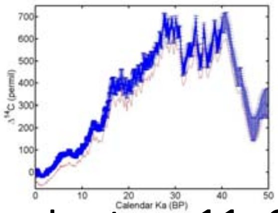
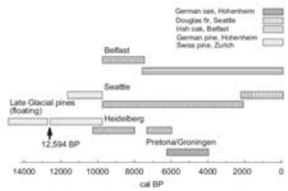
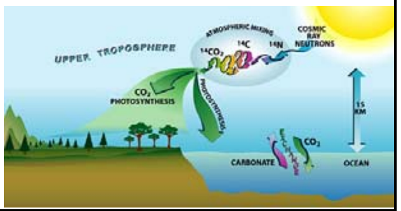




Lecture 11: Cosmogenic Nuclides II

Radiocarbon



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

What's the big deal?

- Radiocarbon is a useful chronometer
  - Over 0-60 Ka (esp. Holocene and last ice age)
  - t_0 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

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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 $^{14}C/^{12}C$ 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*)
  - $^{14}C/^{12}C \sim 10^{-12}$
- Standards:
  - Originally 1950s wood → $f_M = 1.000$
  - Now a N.I.S.T. oxalic acid (Ox-I and Ox-II)
- Reporting:
  - Need to correct for/normalize for isotope fractionation, so use $\delta^{13}C$ measurement to correct to a "standard" fractionation of $\delta^{13}C$ =-25‰, so we have

$$(F_M)_{Corr} = F_M \cdot \left(\frac{(1-25/1000)}{(1+\delta^{13}C/1000)} \right)^2$$ ← This isn't quite right**

  - And you most often see radiocarbon reported as an anomaly scale in ‰

$$\Delta^{14}C = \left[(F_M)_{Corr} \cdot e^{-\lambda(t_c - 1950)} - 1 \right] \times 1000‰$$

  - Looks like, but **isn't** an isotope ratio anomaly!
  - And -1000‰ mean "radiocarbon dead" ($F_M = 0$)

*more later…

**Southon, J.R., 2011. Radiocarbon 53, 691-704.

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Past Changes and Calibration Curves

- We need a "conversion" method because of the screwed up reporting convention (the Libby half-life)
- Evidence from ^{10}Be, ^{26}Al, ^{36}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

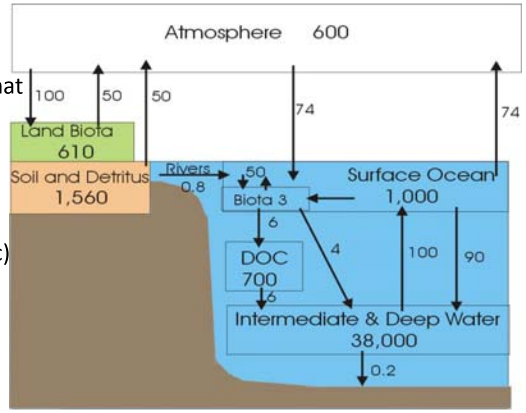
The “Carbon Cycle”

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

“Present day” (pre-anthropogenic)

Inventories in GT

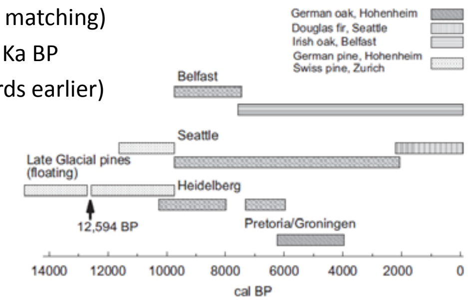
Fluxes in GT y^{-1}



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)

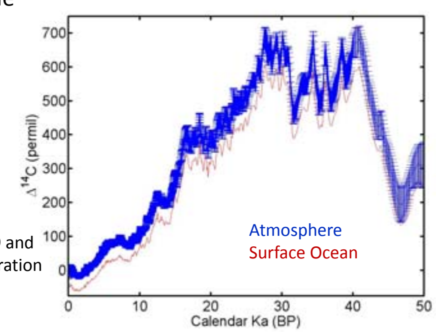


Kromer, B. (2009) Radiocarbon and dendrochronology. *Dendrochronologia* **27** p15-19

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

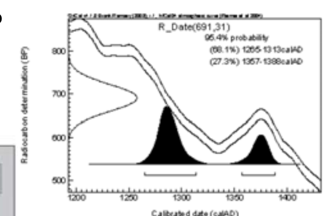


Reimer, P.J. *et al* (2009) INTCAL09 and MARINE09 radiocarbon age calibration curves, 0-50,000 years cal BP. *Radiocarbon* **51** p1111-1150

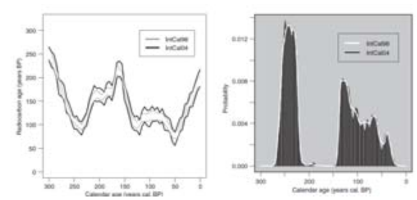
One Consequence: ambiguities

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:



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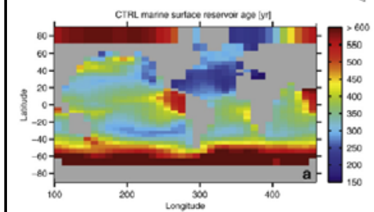
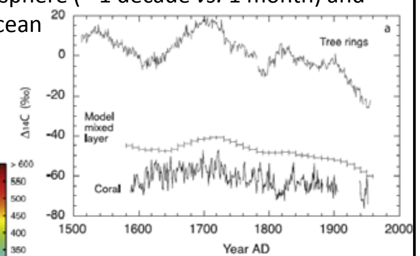
Marine Reservoir Effects

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





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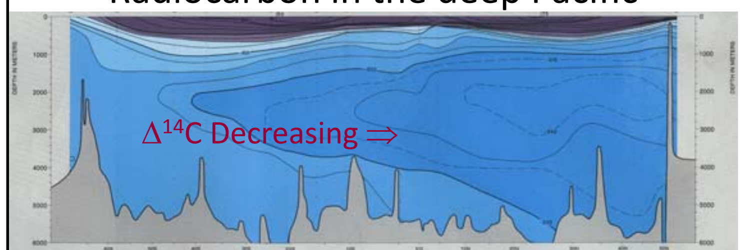
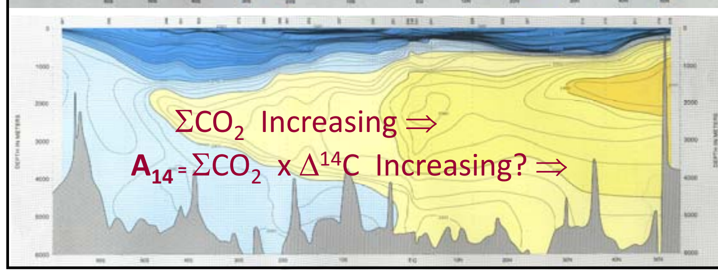
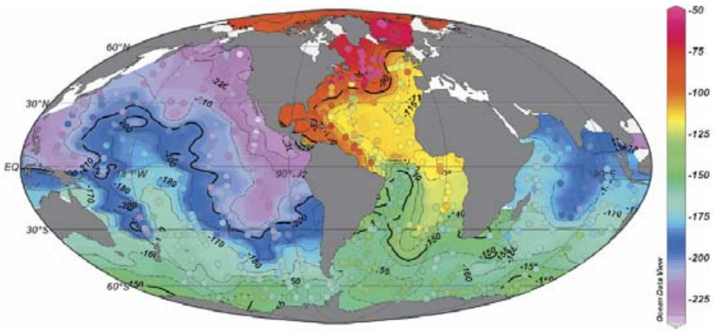
Radiocarbon in the deep Pacific





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)

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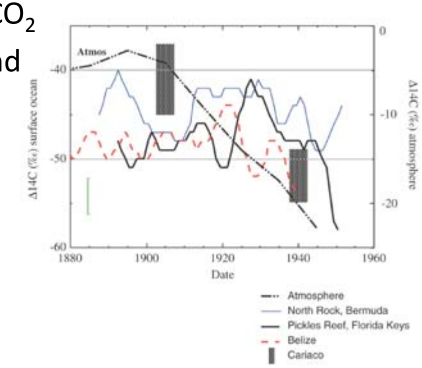
The Suess Effect

Dilution of atmospheric & oceanic $^{14}CO_2$ with "dead" (fossil fuel) CO_2

Seen in tree rings and coral records



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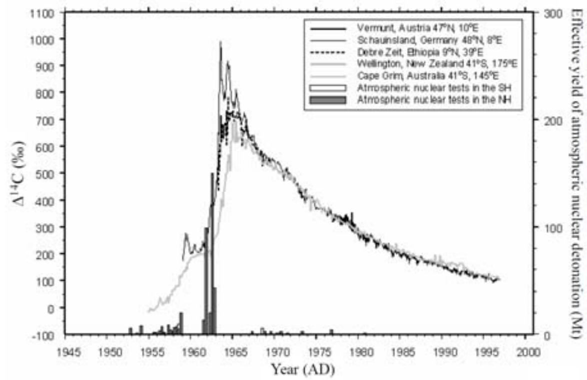
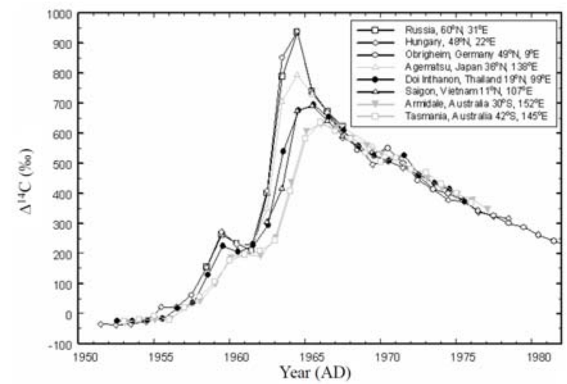
Bomb Test ^{14}C

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



Bomb Test ^{14}C

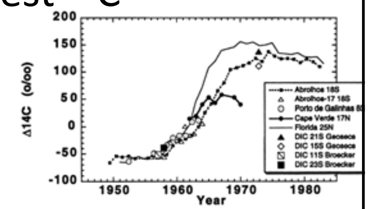
- Latitudinal structure to atmospheric response
  - Biggest tests in the Northern Hemisphere

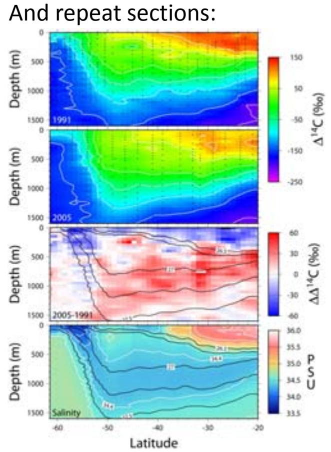


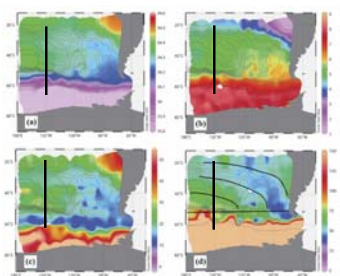
Bomb Test ^{14}C

Oceanic response (coral records) →

And repeat sections:







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