Partitioning of terrestrial carbon sources using $^{14}$CO$_2$: observations and modeling

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sensitivity to fossil fuel CO$_2$ ($C_{ff}$)

$1/\lambda_{14C} = 8223$ yr

$\Delta^{14}C_{\%o} = \left(\frac{^{14}C:C_{sa}}{^{14}C:C_{std}} - 1\right) \times 1000$

fossil fuel CO$_2$ $\Delta = -1000\%o$ (i.e. zero $^{14}C$ content)

ambient atm. (& other CO$_2$ sources) $\Delta = \sim +50\%o$

$$\frac{\Delta\Delta_{ff-atm}}{C_{atm}} = \frac{-1050\%o}{390ppm} = \sim-2.7 \%o/ppm$$

- detection of $\sim1$ ppm for recently-added fossil-fuel derived CO$_2$ ($C_{ff}$) requires measurement precision of $\sim2\%o$
- detection is unbiased if other contributions to tropospheric $^{14}C$ distribution over large land areas are small
• distribution of $C_{ff}$ dominates $\Delta^{14}CO_2$ signal over NH land areas (figures scaled according to mass balance relation of -2.7‰/ppm)

• small differences primarily due to terrestrial disequilibrium flux of $^{14}C$ (quantifiable)

• near-surface $\Delta^{14}C$ gradients ~14 ‰ for this week in Jan. 2006 (~8x precision)
quantification of $C_{ff}$

$$C_{obs} = C_{bg} + C_{ff} + C_{r} + C_{p}$$

$$\Delta_{obs} C_{obs} = \Delta_{bg} C_{bg} + \Delta_{ff} C_{ff} + \Delta_{r} C_{r} + \Delta_{p} C_{p}$$

and setting $\Delta_{p} = \Delta_{bg}$:

$$C_{ff} = \frac{C_{obs}(\Delta_{obs} - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}} - \frac{C_{r}(\Delta_{r} - \Delta_{bg})}{\Delta_{ff} - \Delta_{bg}}$$

- right hand term is correction to $C_{ff}$ of ~0.2 - 0.5 ppm (i.e., $C_{r}$ and $\Delta_{r}$ can be independently quantified)
- $C_{ff}$ detection effectively limited by quadrature sum uncertainty of two $^{14}$C measurements ($\Delta_{obs}, \Delta_{bg}$)
- isolation of $C_{ff}$ delivers net $C_{bio}$ (w/ same uncertainty as for $C_{ff}$)

Turnbull et al. 2006
CU-UCI 1σ repeatability ($\Delta^{14}$C ‰)

NWT3 by measurement order:
- manual = 43.25 ± 1.60
- Crex = 43.26 ± 1.65

NWT4 by measurement order:
- manual = -31.43 ± 1.59
- Crex = -31.46 ± 1.63

NWT3 by extraction order:
- NWT3

NWT4 by extraction order:
- NWT4

NWT3 and NWT4 replaced NWTstd (near exhaustion) in late 2009
NWTstd 1σ repeatability 2003-2009 = 1.8 ‰

report 1σ repeatability or 1σ single sample precision, whichever is larger
samples from 5-6 yrs of bi-weekly vertical aircraft profiles in area of significant regional emissions and outflow
3-ht. sampling for $^{14}\text{CO}_2$, 9-ht. for all other gases
isolation of $C_{ff}$ and $C_{bio}$, CMA+NHA

- Obs fr. ~300 and ~2000 masl (vs. 4000 m ‘bg’ in FT)
- $C_{ff}$ detectable year round (1-10 ppm)

$C_{obs} = C_{bg} + C_{ff} + C_{bio}$

$\Delta_{obs} = \Delta_{bg} + \Delta_{ff}$
300 m obs only, CMA+NHA

- Sharpens view of biospheric signal (vs. raw CO₂ enhancement)
- C_{bio} large even in winter (~60% of total winter-time enhancement) despite urban/industrial observational footprint
- CO₂-only methods: can not assume urban enhancements are due to C_{ff}
- C_{ff} and C_{bio} independently useful
growing observational footprint

annual average sensitivity for all PBL $^{14}$C obs

[Miller et al., 2012]

since late ‘09 from ~thrice weekly tower (PBL) $^{14}$C obs (excludes INX, MWO)

$^{14}$C footprint sufficient for meaningful guidance of CarbonTracker, using both $^{14}$C and CO$_2$ as obs constraints

circled sites: collaborative w/ LLNL/CAMS

STILT/WRF
The use of $^{14}\text{C} + \text{CO}_2$ in CT to improve NEE

F_{ff} prior (given 0 uncertainty) NEE posterior retrieval

deviation $F_{ff}$ prior from actuals will lead directly to bias in retrieved $F_{bio}$ (NEE) from inversion of $C_{obs}$

\[ \frac{dC_{obs}}{dt} = F_{ff} + F_{bio} + F_{fire} \]

$F_{ff}$ is large w.r.t net annual $F_{bio}$, and.. extrapolation of $F_{ff}$ inventories will not capture $F_{ff}$ anomalies associated with sustained heat and cold waves
use of $^{14}$C + CO$_2$ in CT to improve NEE

deviation $F_{ff}$ prior from actuals will lead directly to bias in retrieved $F_{bio}$ (NEE) from inversion of $C_{obs}$

$$\frac{dC_{obs}}{dt} = F_{ff} + F_{bio} + F_{fire}$$

relax $F_{ff}$ prior uncertainty to permit guidance by $^{14}$C obs where available
\[ C_{atm} d\Delta/dt = (\Delta_{\text{foss}} - \Delta_{\text{atm}}) F_{\text{foss}} + \Delta_{\text{dis}} F_{\text{surf-gross}} + isoF_{\text{cosm}} + isoF_{\text{nuc}} \]

$^{14}$C fluxes from \textit{a priori} geophysical estimates & CT FF (no tuning): \textit{budget terms properly balanced, if not correct}
residuals, NWR

90% within measurement error, bias = -0.5 per mil
TM5-\textsuperscript{14}C vs. Lower Trop. obs, US

\textsuperscript{14}C: $1.08 \pm 0.06$, $r^2=0.69$

CO\textsubscript{2} (post opt.): $r^2=0.49$

2000-2400 m

BAO

all other PBL

monthly mean Site-NWR gradients, $F_{\text{foss}}$ from CT
(climatological m_m obs = 132 site_mos fr. \~{}2500 obs)
summary

• developed scientifically meaningful $^{14}$C measurement capability

• expanded observational footprint to US national scale (and elsewhere)

• propose moving forward w/ $^{14}$C and CO$_2$ as dual observational constraints in CarbonTracker (for NEE, C$_{ff}$ emissions verification)

• evaluating tracer:C$_{ff}$ emissions ratios [Miller et al., JGR-A, 2012] nationally, updating absolute emissions estimates for correlate gases