Using 50 years of radiocarbon data to quantify soil carbon dynamics in New Zealand pastures: the missing link for robust soil carbon models?

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Why is soil carbon turnover important to quantify?

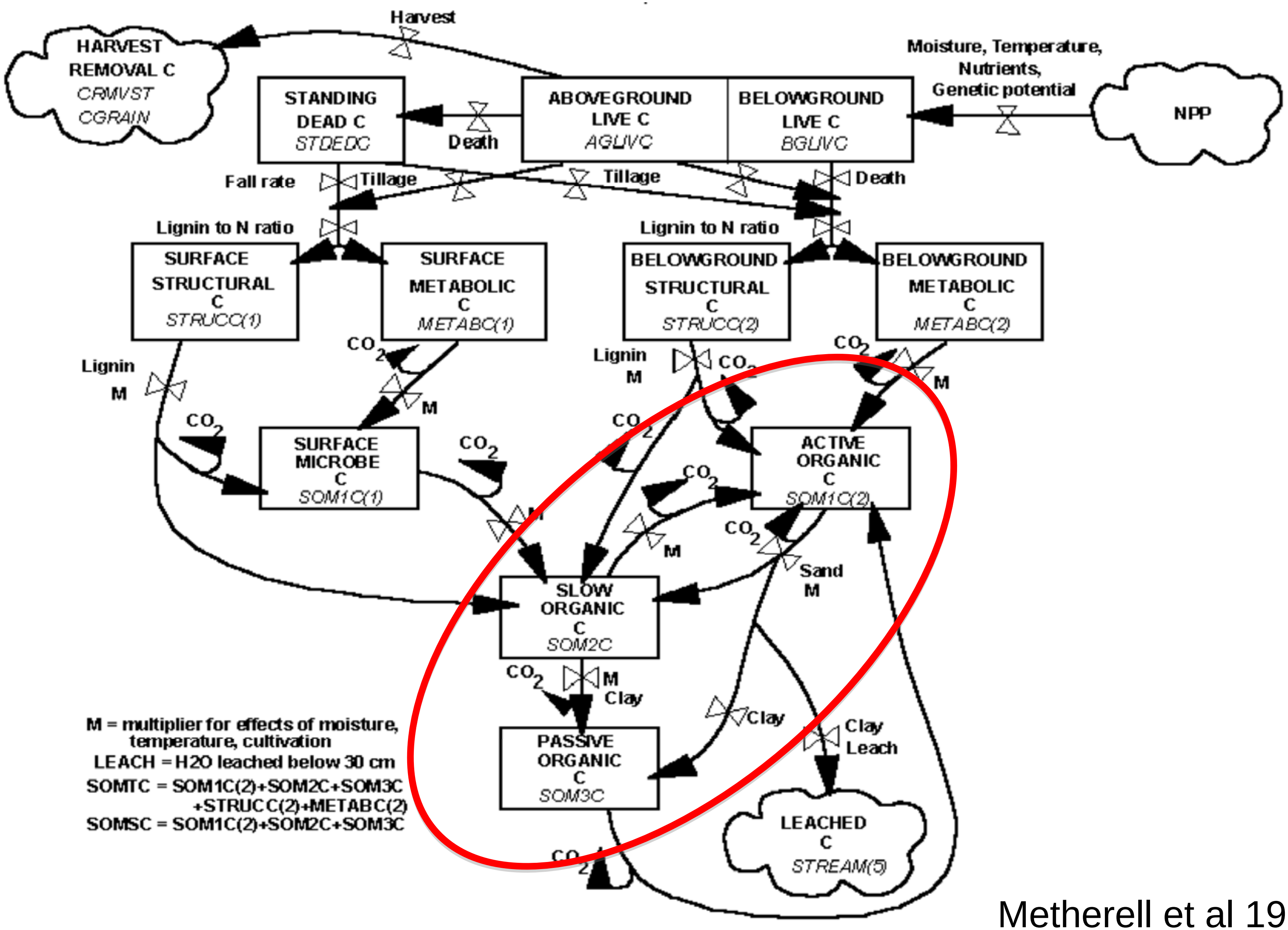
- Understanding in ecosystem biogeochemistry models (parameterisation).

$$k_i = flux_i \,/\, stock_i$$

- Rate of soil C change following a change in land use or management
  - Kyoto & Copenhagen
  - ETS development
  - Lifecycle analysis

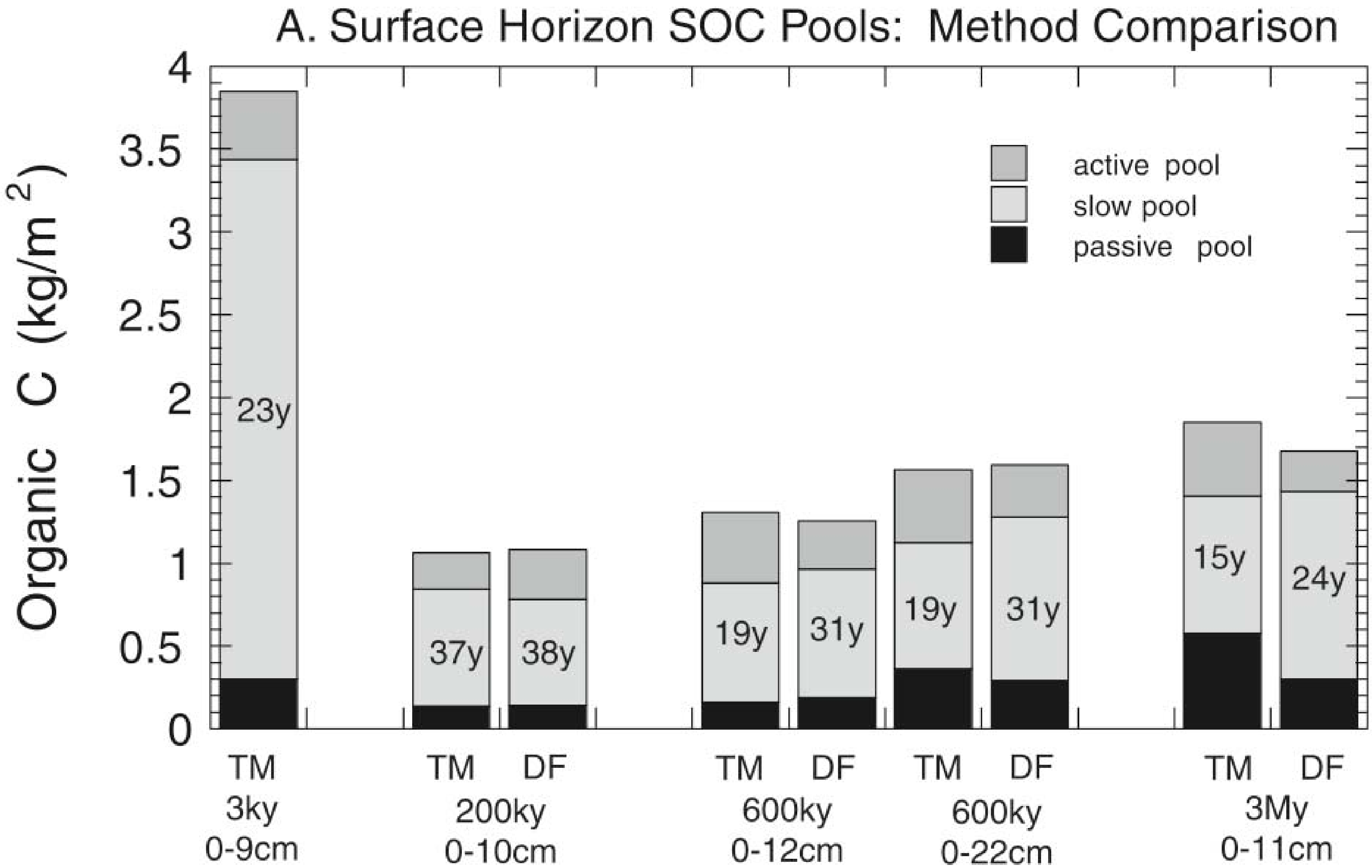
- Sensitivity of the soil C pool to climate change

Are these model pools un-measurable?



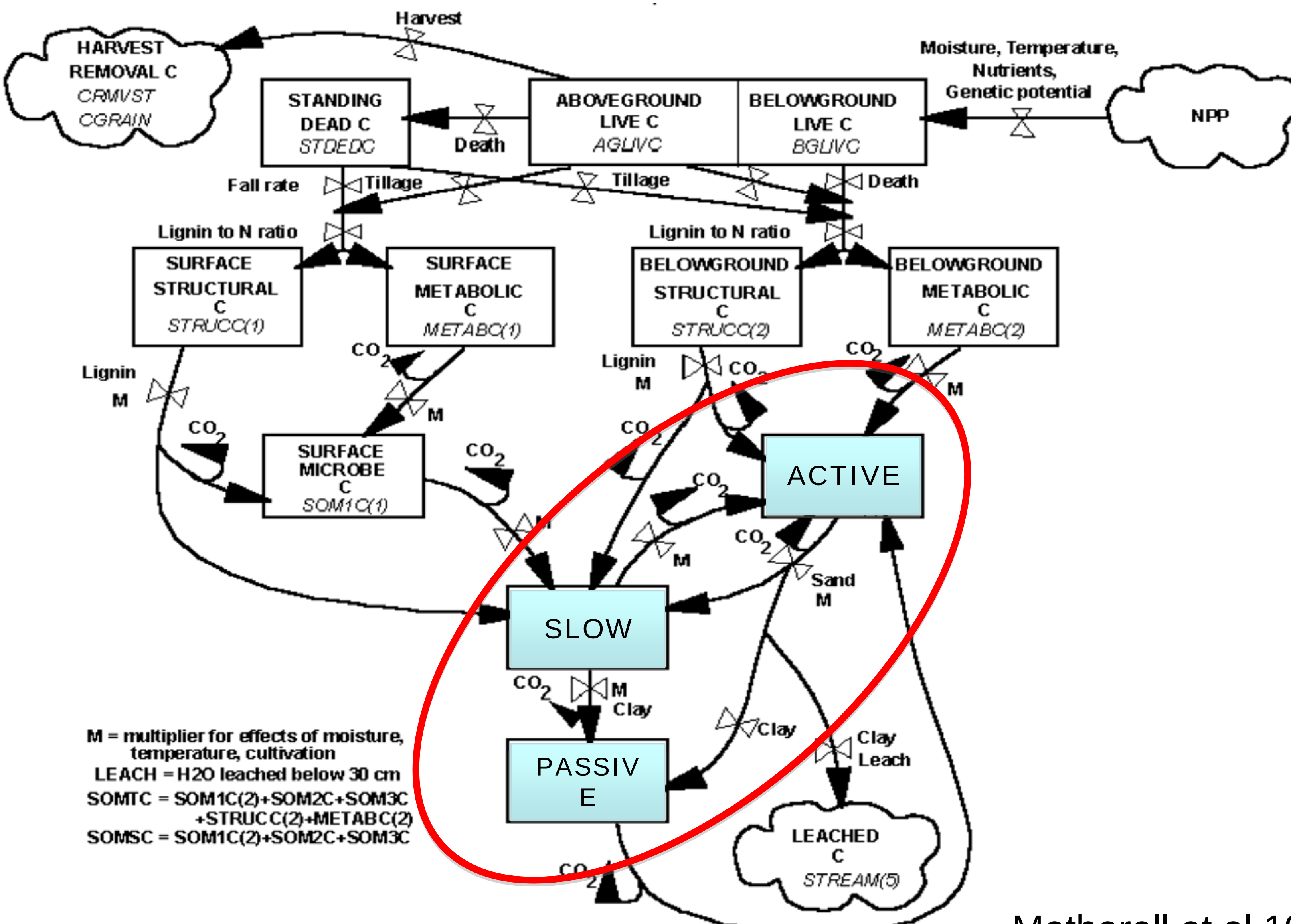
Metherell et al 1993

Are these model pools un-measurable?



Baisden et al 2002a Global Biogeochemical Cycles

These model pools are measurable.



Metherell et al 1993

Methods to quantify soil carbon turnover rate (k)

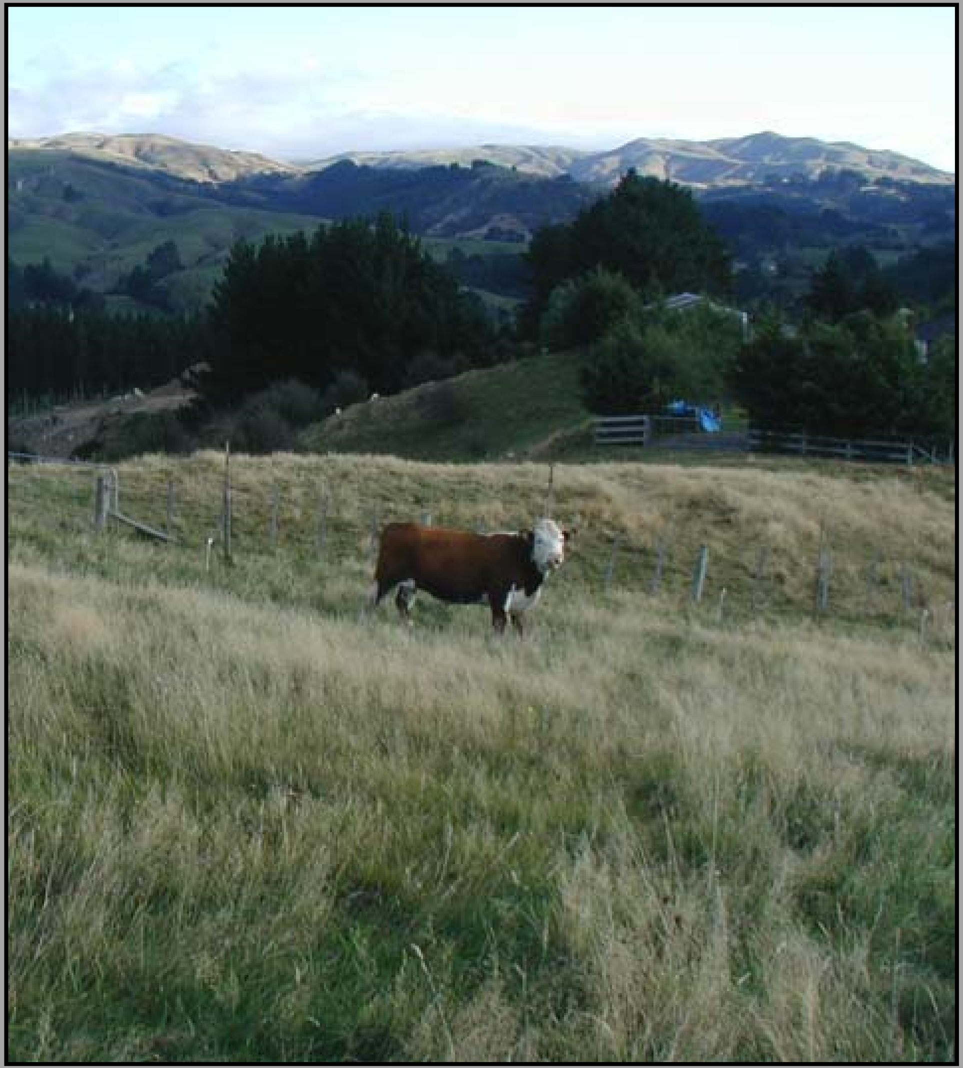
- k = Flux / Stock

- Tracer (isotope) studies

- Biomarker loss rate following change

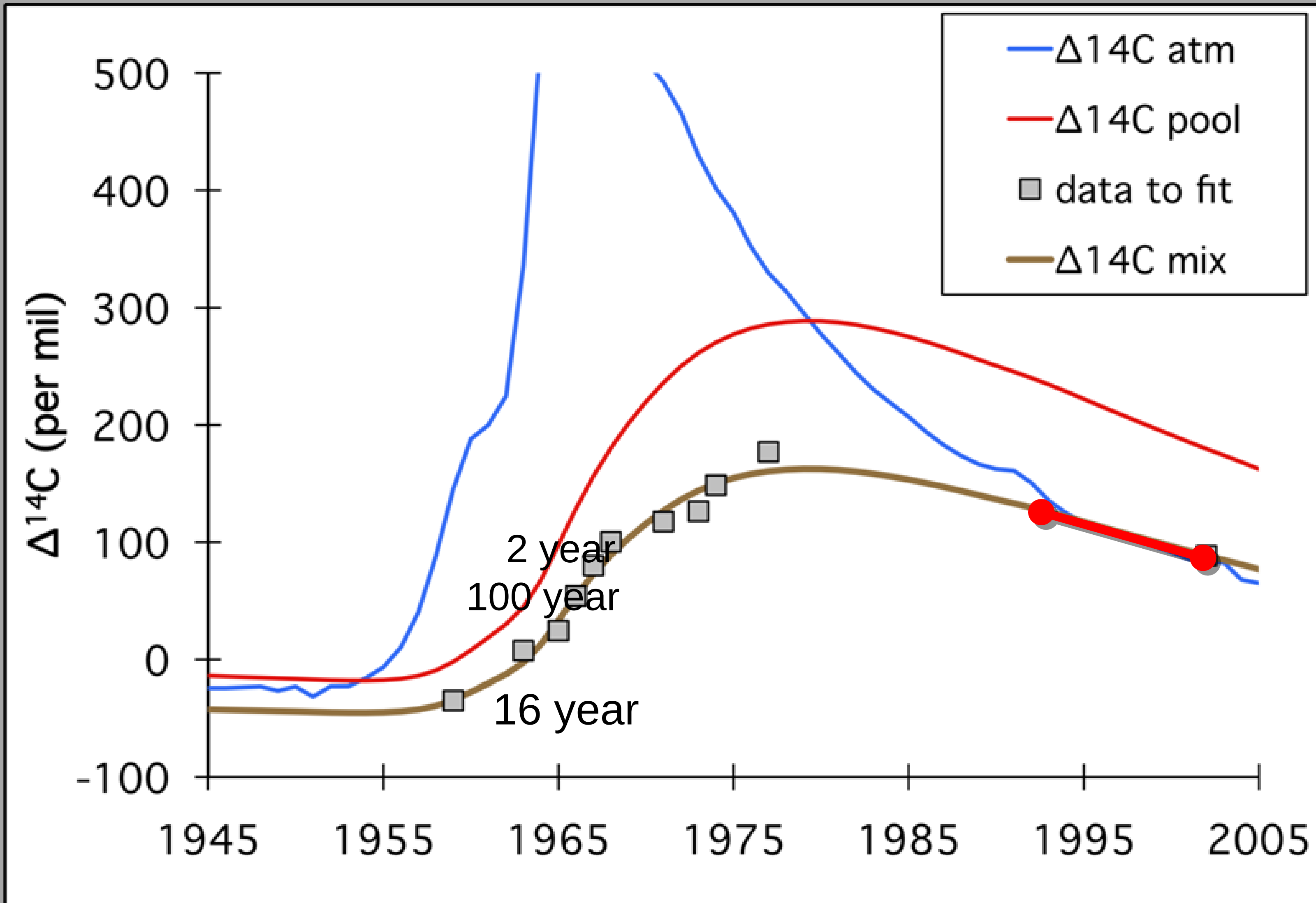
- $\delta^{13}C$ following C3/C4 vegetation change

- "Natural" $\Delta^{14}C$ (radioactive clock + H-bomb)



Judgeford, New Zealand
O'Brien & Stout, 1978
Baisden & Parfitt, 2007

Judgeford Soil, New Zealand (41° S)



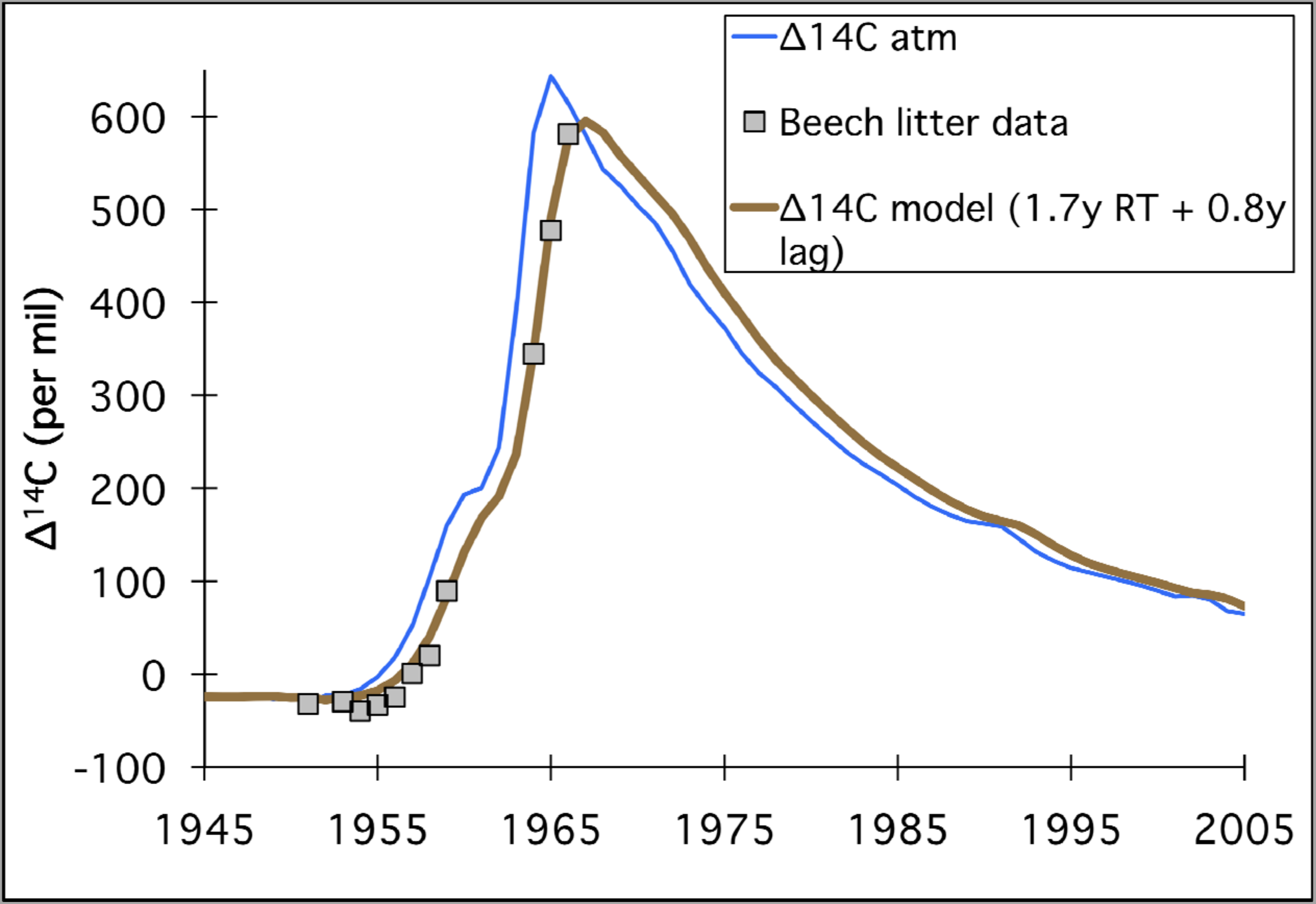
Three Assumptions are Critical
(without time-series samples)

- **Pitfall 1: A small component of old carbon (Fraction Passive).** Example: 10% charred C.
- **Pitfall 2: Lag times. The sampled soil may have received carbon that was been part of another carbon pool for some time**
    - Deep soil may receive inputs from overlying soil
    - Light fraction receives inputs from litter, which may reside on evergreen trees for 10 years
- **Pitfall 3: Changing Input Rates (Pool Size)**
    - Soil fraction begins forming after land-use change

We now have a database of ~400 time-series measurements.

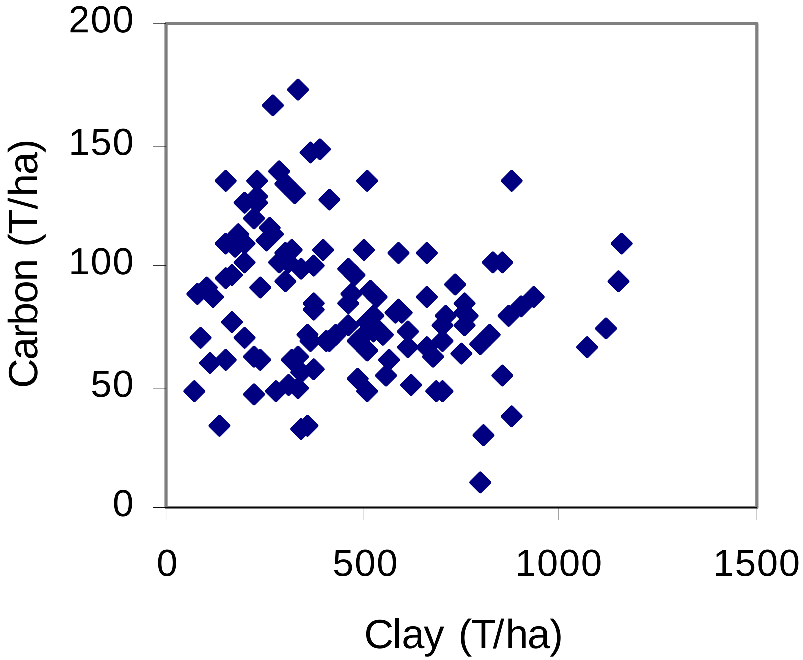
Lag time: How long does it take a leaf to fall?

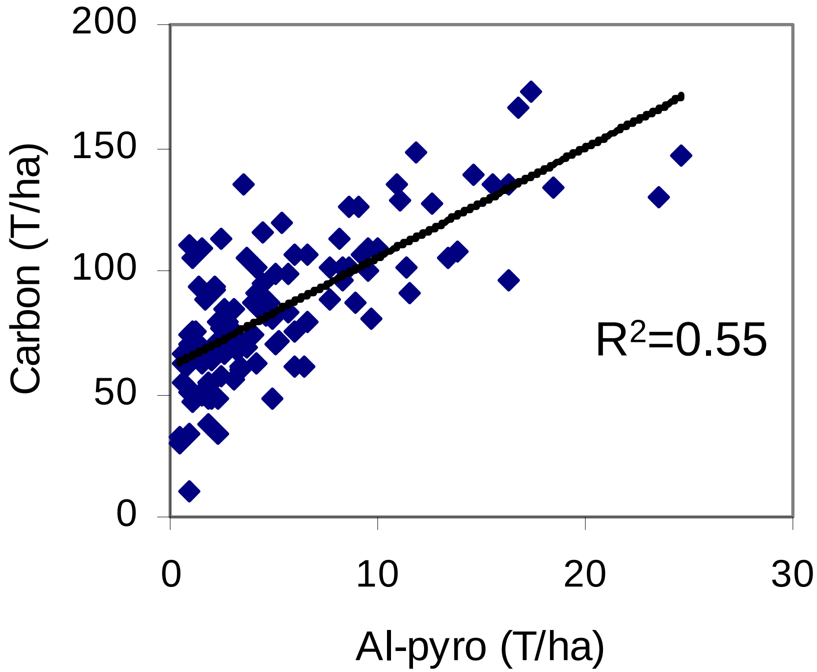
Beech (*Nothofagus spp*) leaves were collected at 41° S from the forest floor



Soil organic matter and Al in NZ soils (0–20 cm)

Percival et al. SSSAJ 2000

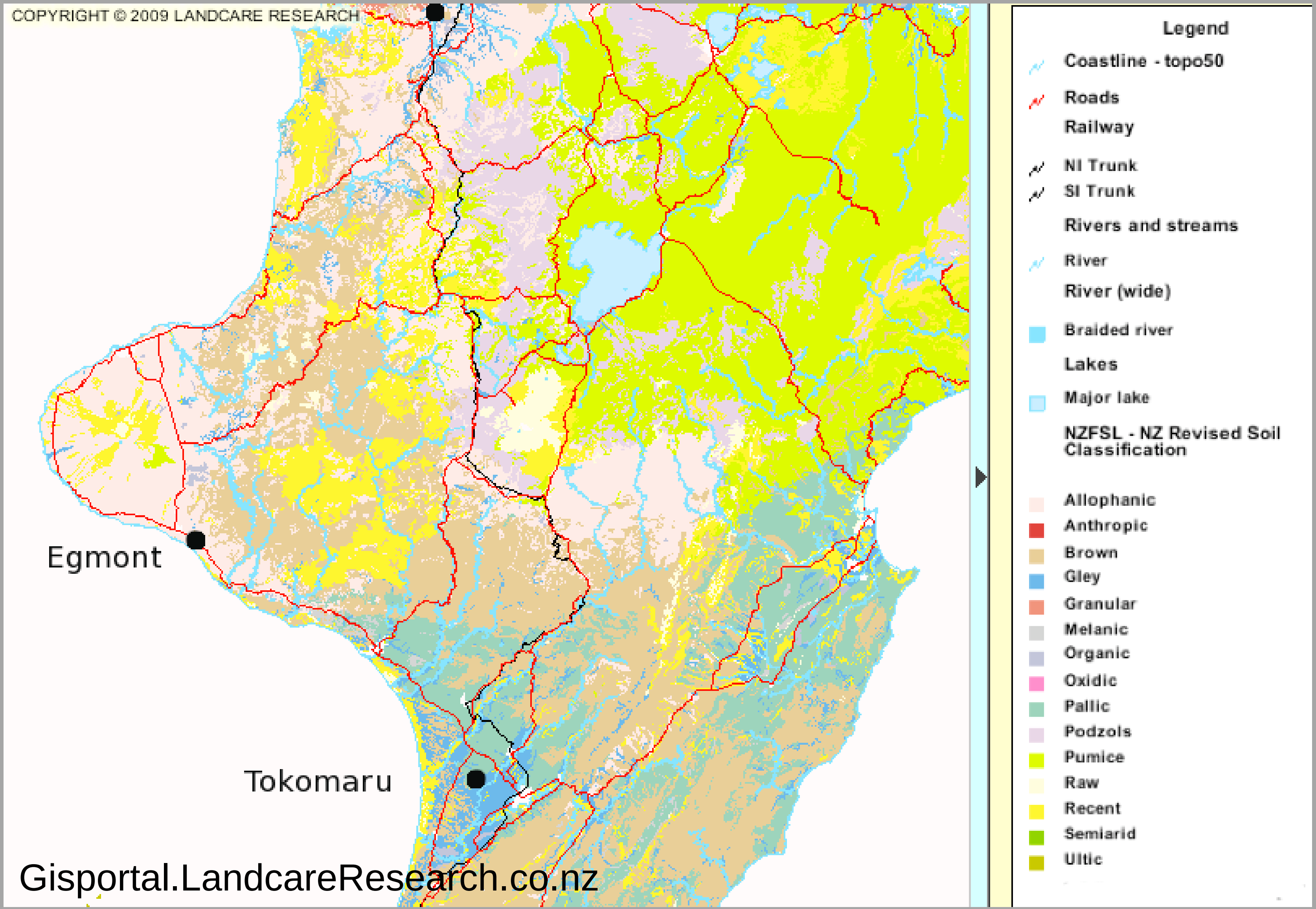




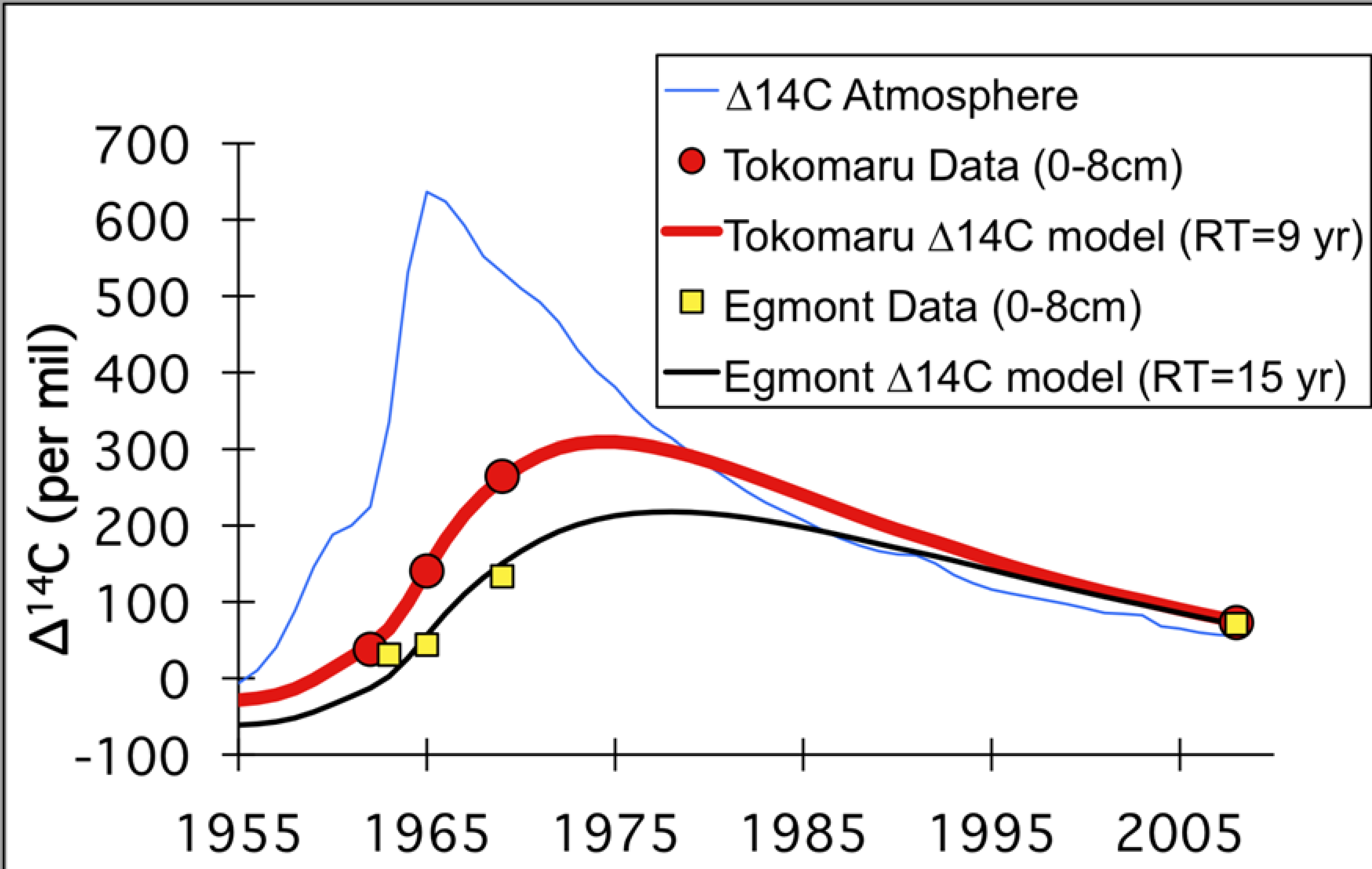
- Regression for all soils f(Al_py) R^2=0.6
- Regression allophanic soils f(Al_py) R^2=0.5
- Multiple regression allophanic soils

f(Al_py, Fe_d, rain) R^2=0.8

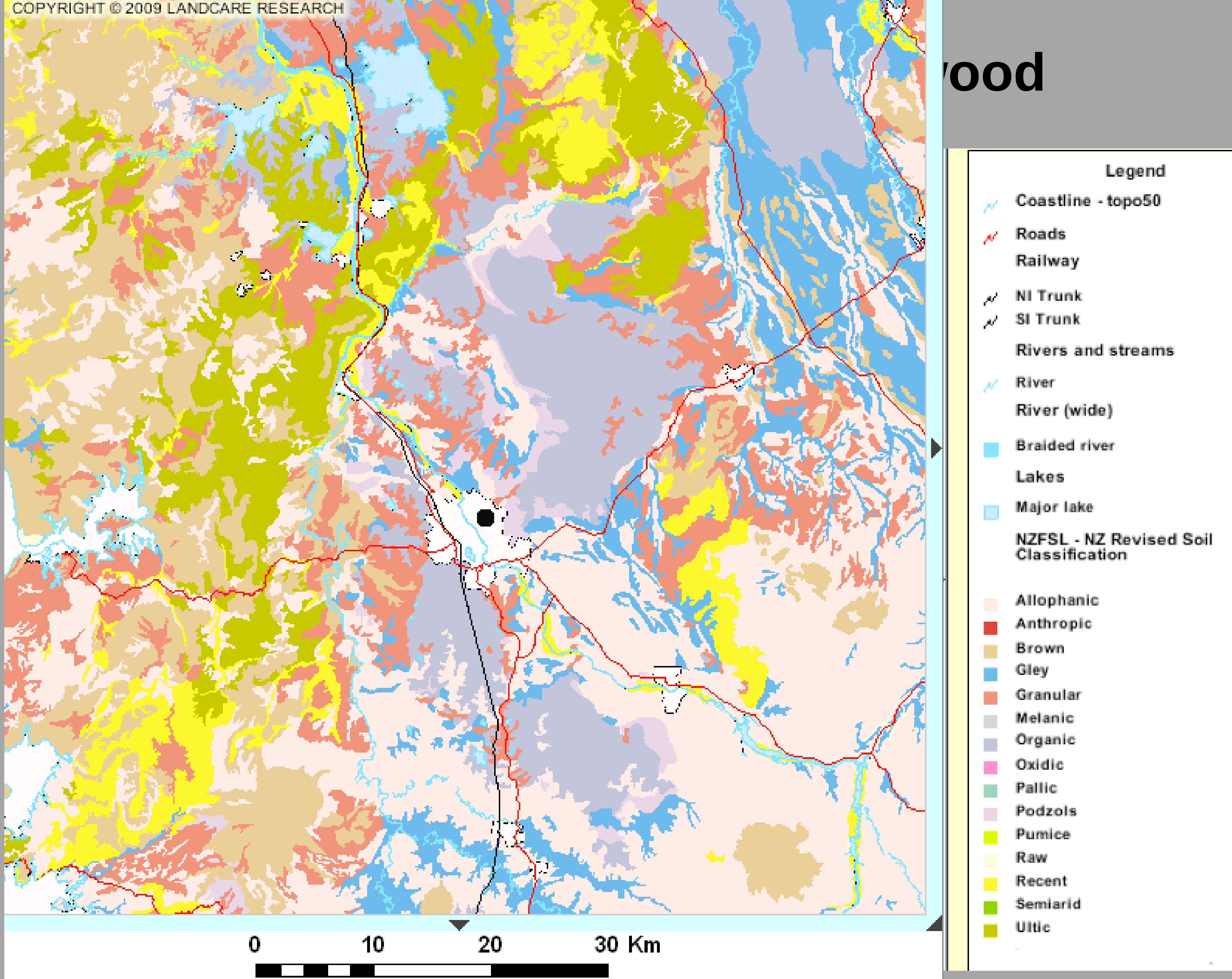
Comparison 1: Tokumaru vs Egmont



Comparison 1: Tokumaru vs Egmont



ood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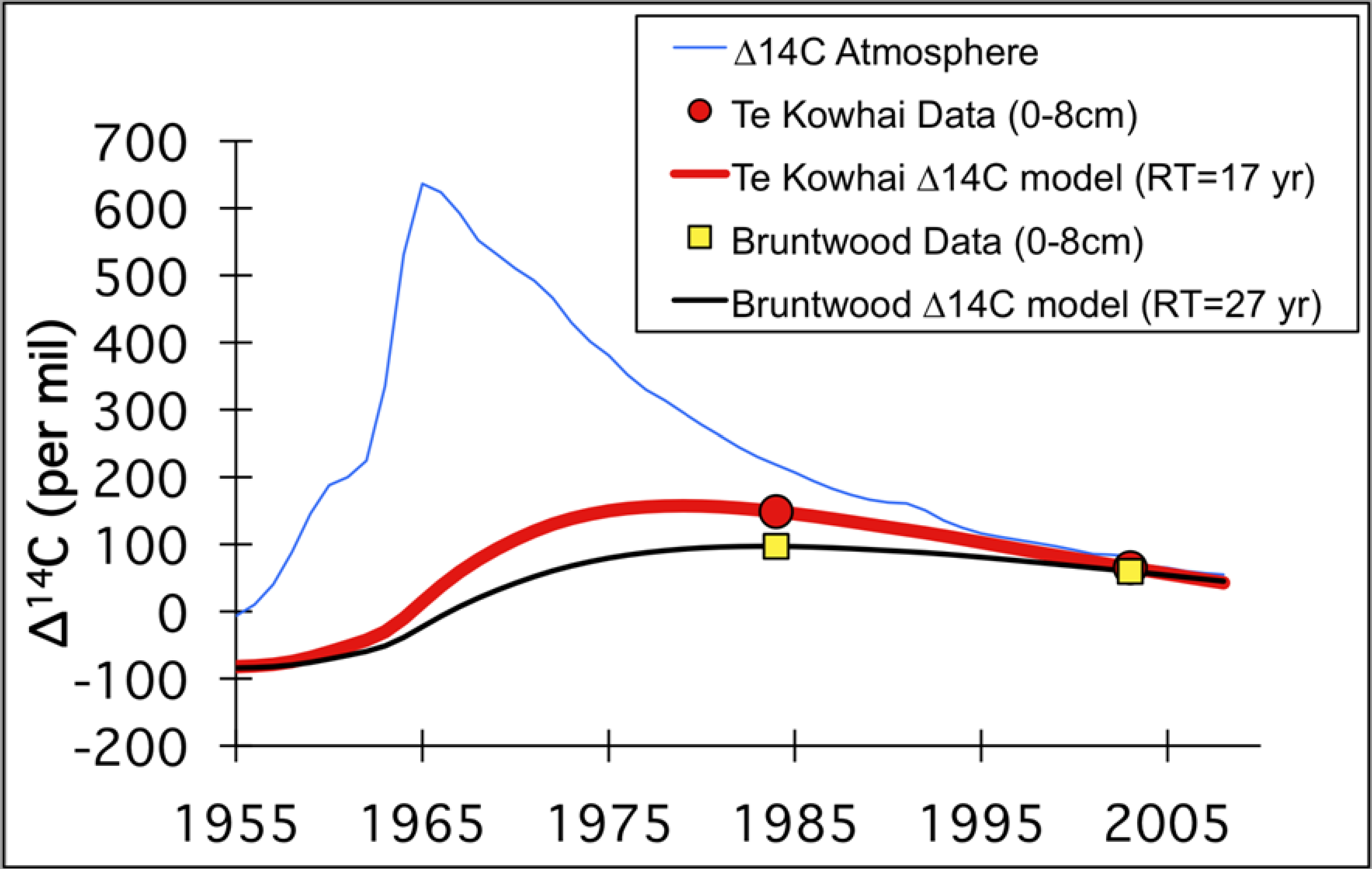
0
10
20
30 Km
Legend
Coastline - topo50
Roads
Railway
NI Trunk
SI Trunk
Rivers and streams
River
River (wide)
Braided river
Lakes
Major lake
NZFSL - NZ Revised Soil Classification
Allophanic
Anthropic
Brown
Gley
Granular
Melanic
Organic
Oxidic
Pallic
Podzols
Pumice
Raw
Recent
Semiarid
Ultic

Comparison 2: Te Kowhai vs Bruntwood



But Bruntwood had observed C losses. Non-steady state?

What can we do with this information?

- The ultimate goal is represent SOM turnover so it can be used in ecosystem models.

Soil C turnover (Mg C ha^{-1} y^{-1}) =

C stock x (1 – Frac Passive) x k

For Egmont: ANPP=5.3

90 Mg C ha^{-1} x (0.86) x 1/15 y^{-1} = 5 Mg C ha^{-1} y^{-1}

For Tokomaru: ANPP=5.4

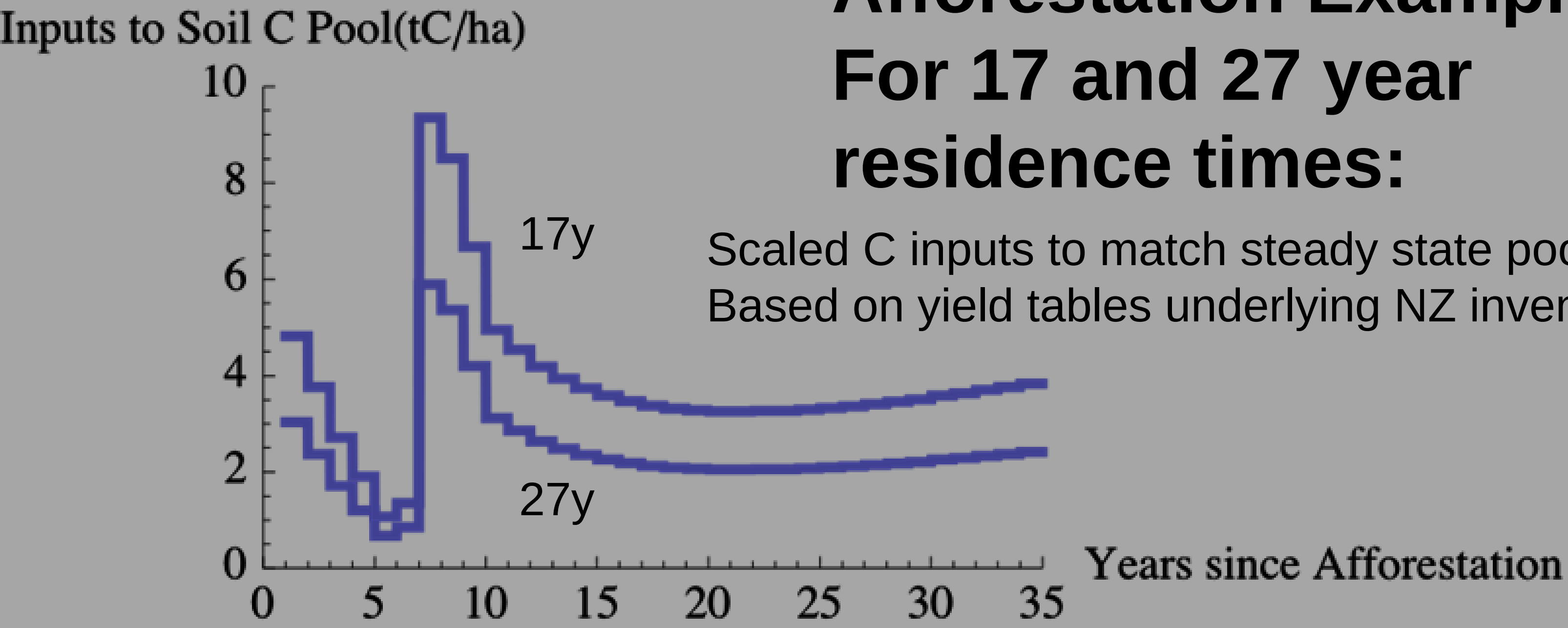
60 Mg C ha^{-1} x (0.83) x 1/9 y^{-1} = 5 Mg C ha^{-1} y^{-1}

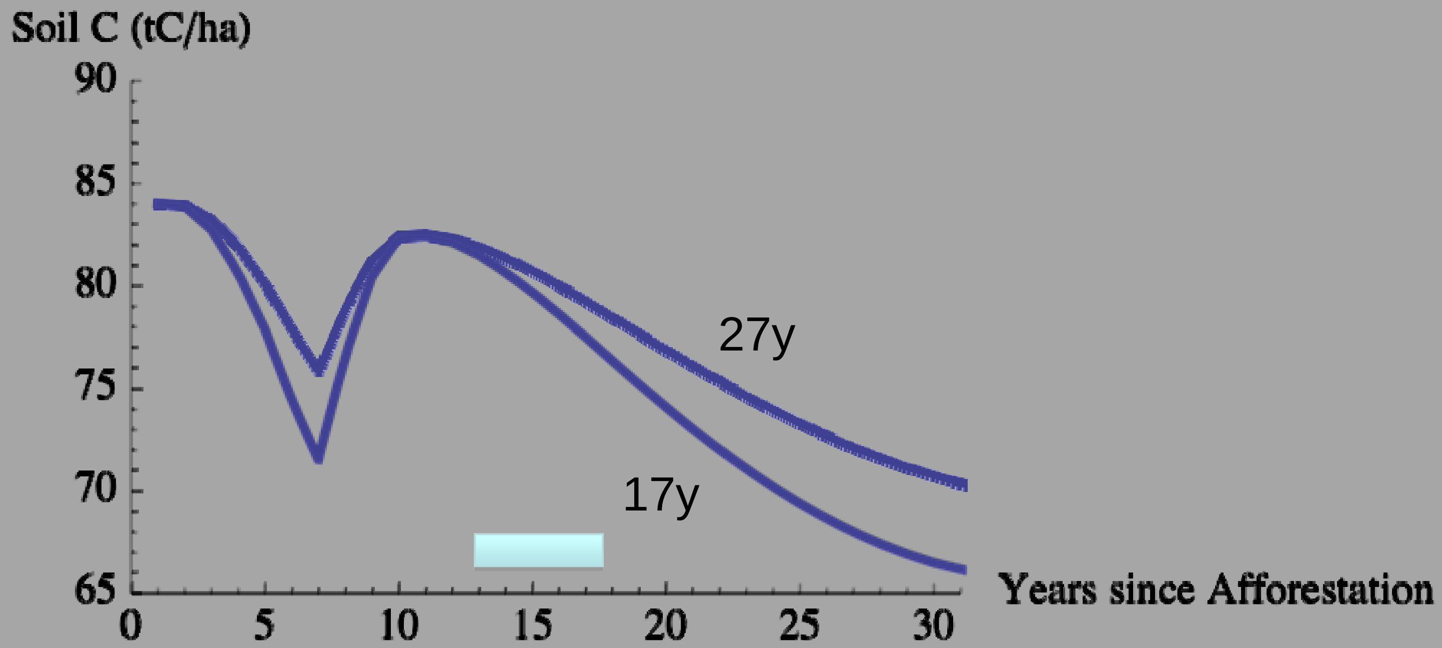
Afforestation example:
Why residence times can matter…

- New Zealand's post 1989 planted forests are currently estimated to remove 4.6 Tg C from the atmosphere each year during 2008-12.
- These net removals work out to 8.3 tC ha^{-1} y^{-1}.
- Current estimates place soil C losses at 10 tC ha^{-1} over 20 years, but the timing of soil C losses is poorly understood.
- How much will soil C loss subtract from the 8.3 tC ha^{-1} y^{-1} of net removals NZ gets credit for.
  - All?
  - None?

Afforestation Example: For 17 and 27 year residence times:

Scaled C inputs to match steady state pool size
Based on yield tables underlying NZ inventory





Conclusions

- Appropriate use of ^{14}C can resolve residence times with high accuracy when archived samples are available.
  - Two times of sampling provide greatly improved residence times over a single time.
- A large suite of data from the 'bomb spike' period helps to resolve how to develop models.
- Robust residence times improve calculations related to pool sizes, turnover, and rates of change. Other data (e.g. NPP, respiration) should be integrated in calculations/models if available.

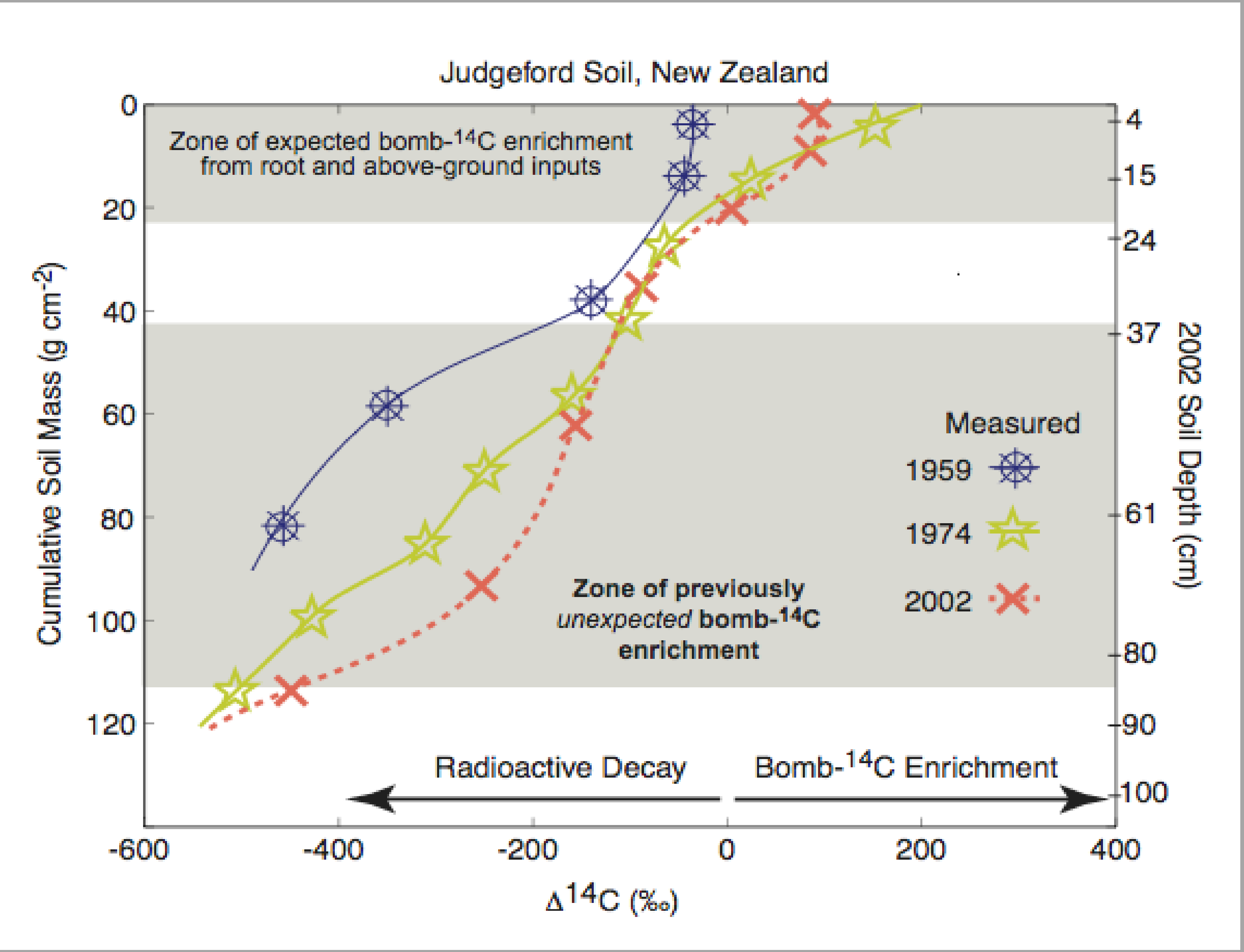
We also do this:

- **Solve for these parameters as a function of soil depth, studying soil fractions & DOM**
- **Where soil C has been lost (or gained) between two samplings, we can solve for the $\Delta^{14}C$ of the C lost (or gained)**
- **Develop complementary biomarker methods (e.g. lignin-derived compounds)**

Thanks

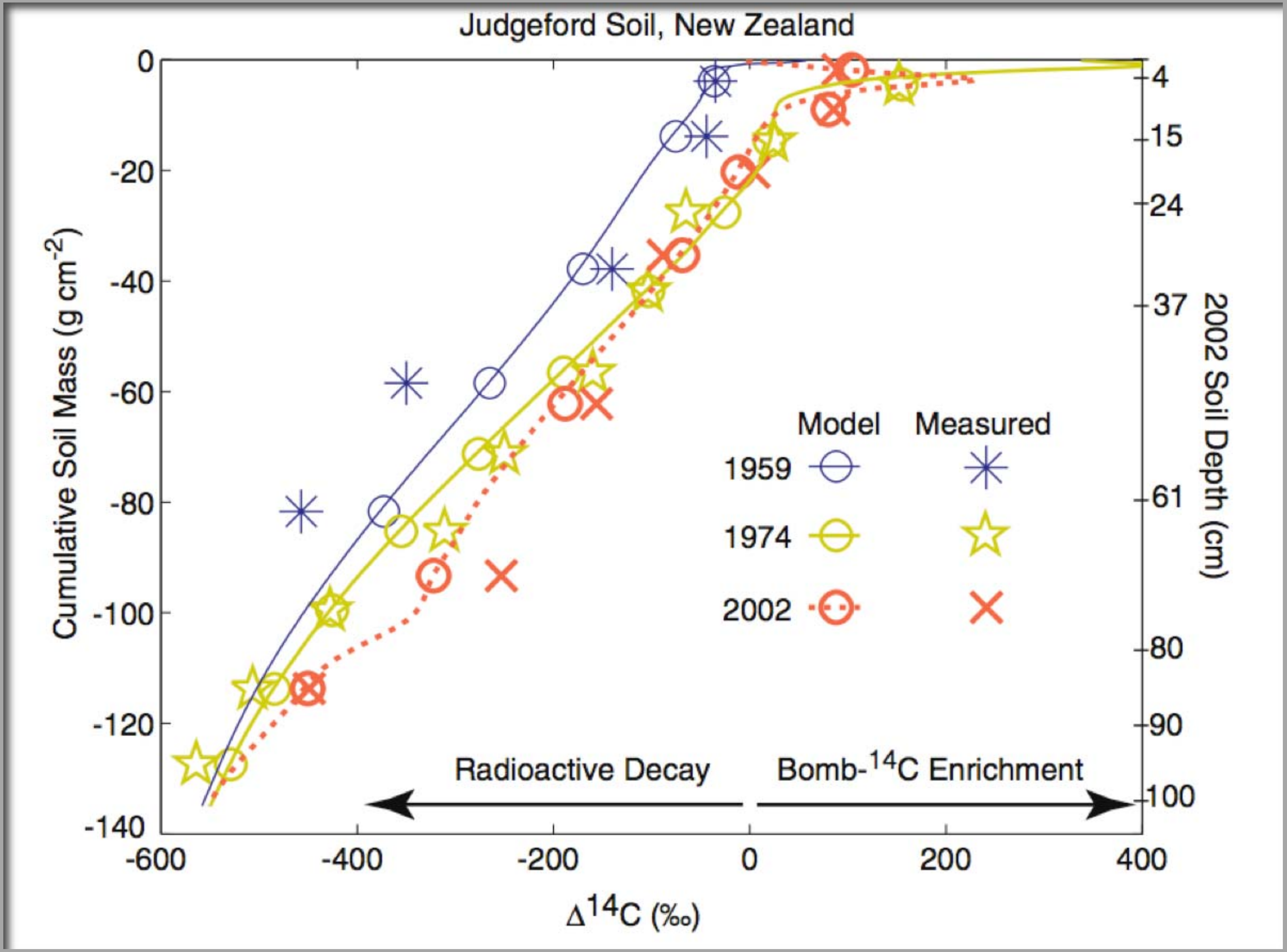
- I look forward to discussing collaborations
- Huge thanks to co-workers past and present!

How does ^{14}C move through soil?



Baisden W, Parfitt R. 2007. 85(1):59-68.

How does ^{14}C move through soil?



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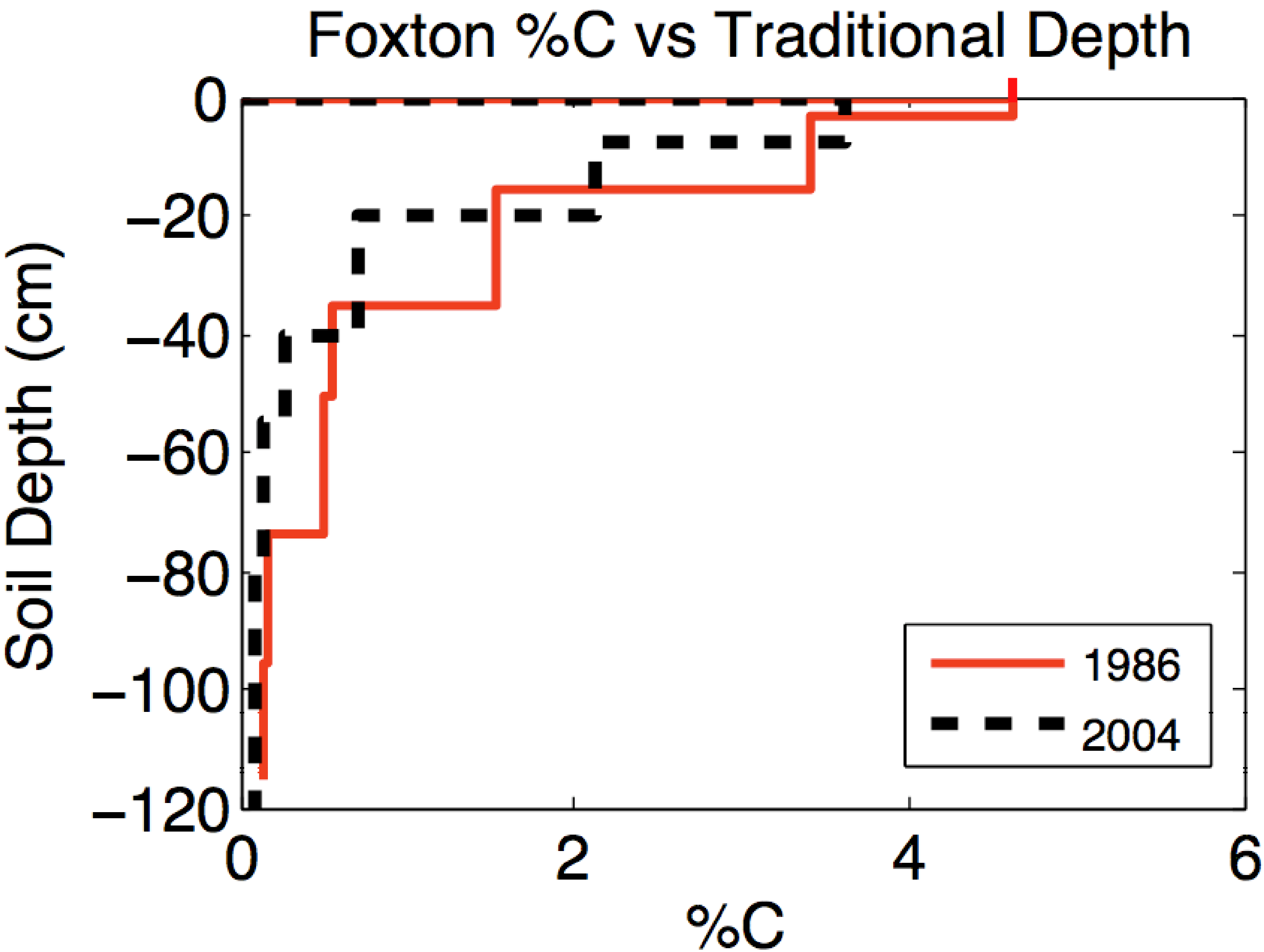
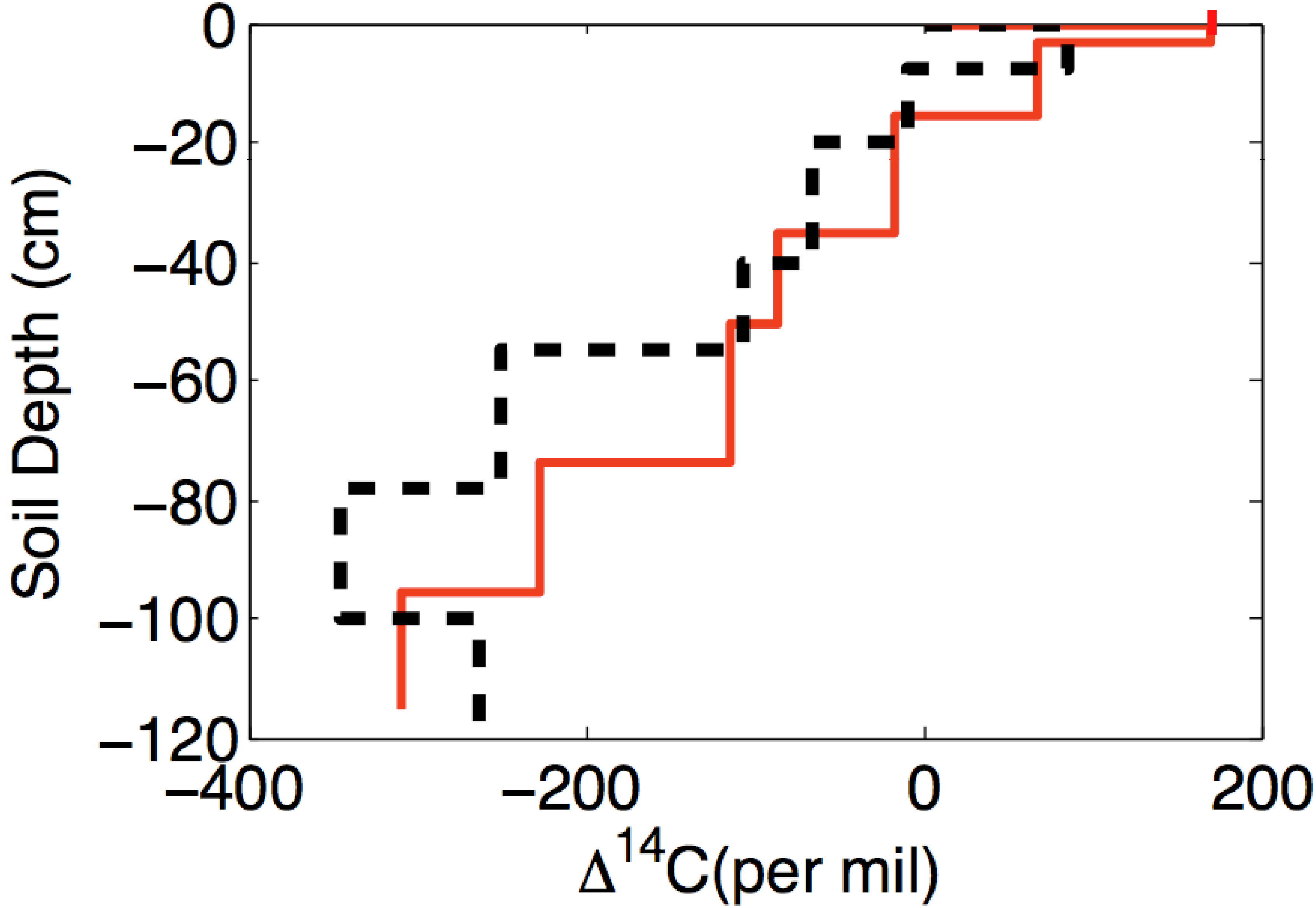
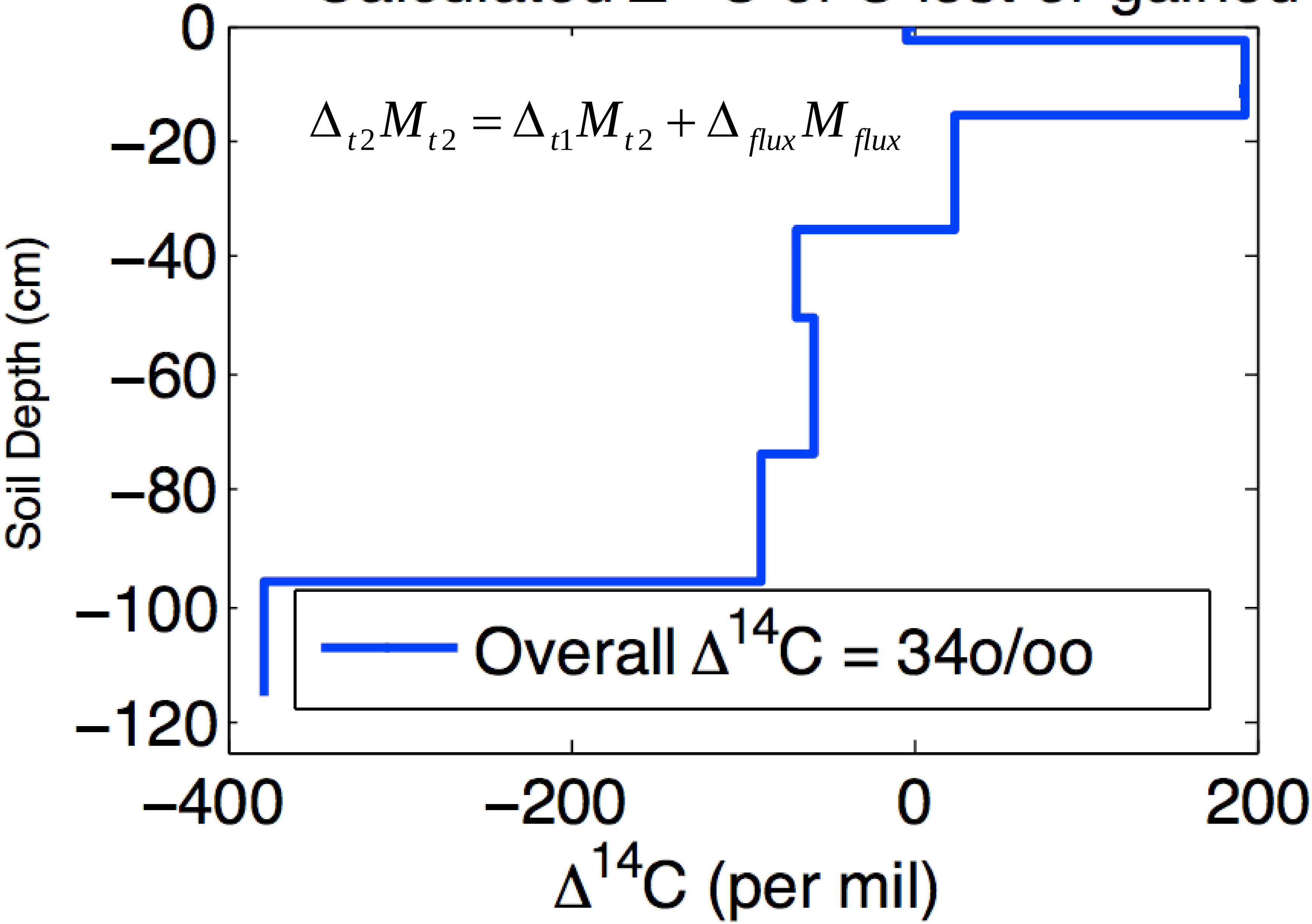


Foxton %C vs Traditional Depth
0
−20
−40
−60
−80
−100
−120
Soil Depth (cm)
0
2
4
6
%C
1986
2004

Foxton $\Delta^{14}C$ vs Traditional Depth



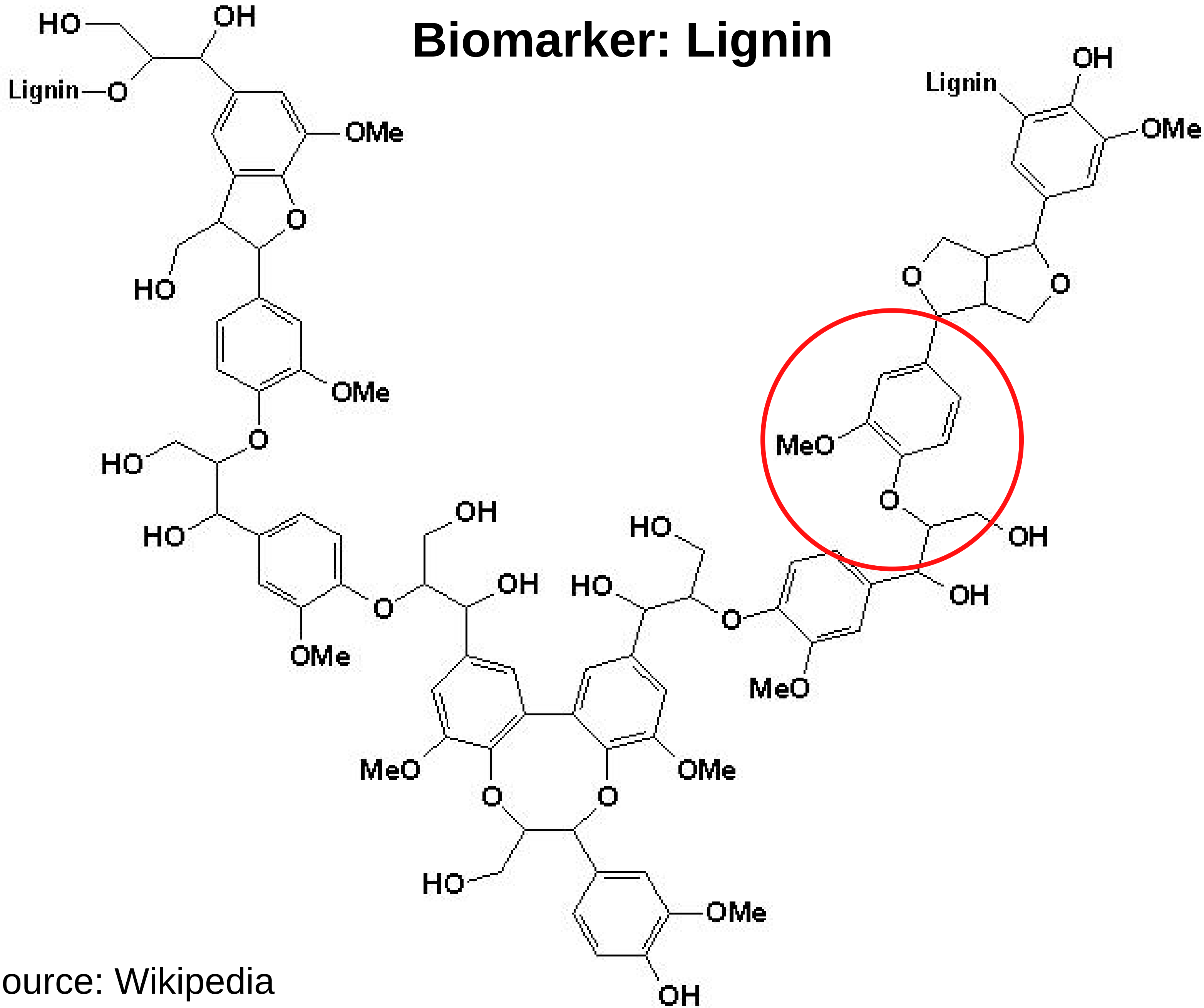
Calculated $\Delta^{14}C$ of C lost or gained



^{14}C Conclusions

- Resampled soil profiles are well-suited to the use of ^{14}C to identify the age of C lost from each horizon.
- This can be completed after the use of ^{137}Cs to quantify erosion and deposition.
- In the Foxton profile, and other similar soils, pre-European forest-derived soil C is being lost below 40 cm, while “bomb ^{14}C” is being lost near the surface and accounts for most of the C loss from the profile.
- Consistent results from this approach confirm the validity of most resampled sites.

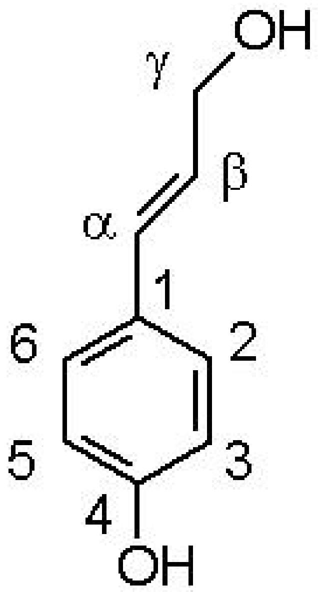
Biomarker: Lignin

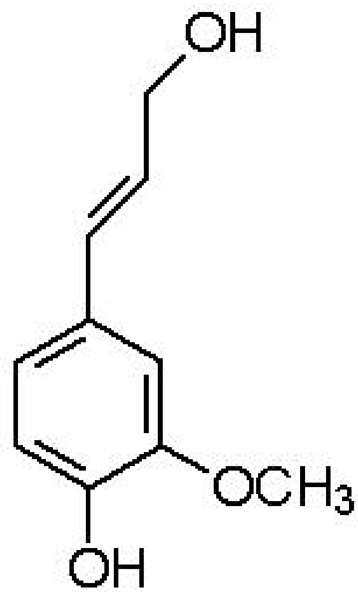


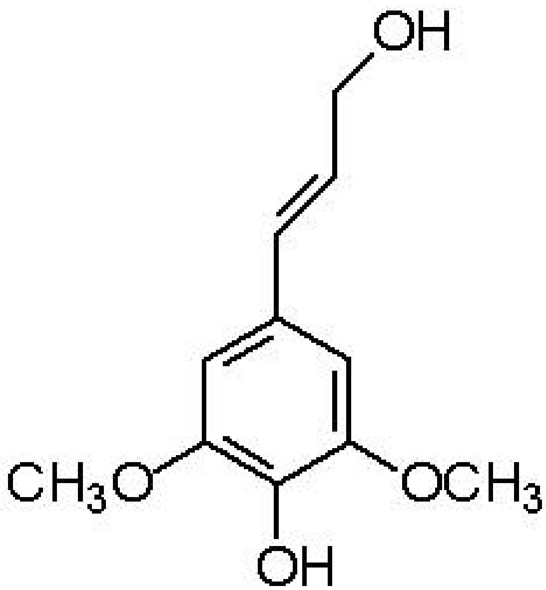
Source: Wikipedia

Examples of Lignin Monomers

Source: Wikipedia







	P-hydroxyphenol	**G**uaiacol	**S**yringyl
	30-50% of non-woody <15% of woody	>90% of conifer ~50% angiosperm	~50% of angiosperms
CuO	p-hydroxybenzoic acid	Vanillic Acid	Syringic Acid
THM	As 4-methoxy benzoic acid, methyl ester (P6)	As 3,4-dimethoxy benzoic acid, methyl ester (G6)	As 3,4,5-trimethoxy benzoic acid, methyl ester (S6)

Relative change in C and lignin-derived compounds for surface horizons

Method	Data	Crookston	Koputaroa	Himatangi
Dry Comb.	%OC	2%	-11%	-21%
	p-hydroxybenzaldehyde	-1%	-15%	-42%
	p-hydroxyacetophenone	12%	-13%	-40%
	p-hydroxybenzoic acid	-36%	-44%	-30%
	p-hydroxycinnamic acid	-9%	-27%	-26%
	ferulic acid	-19%	-37%	-29%
CuO	vanillin	12%	-45%	-51%
	acetovanillone	24%	-37%	-44%
	vanillic acid	-11%	-39%	-37%
	syringealdehyde	-29%	-20%	-44%
	acetosyringone	-4%	-11%	-39%
	syringic acid	-24%	-19%	-32%
	S6	13%	-69%	-28%
THM	G6	-9%	-66%	-28%
	P6	68%	-83%	-65%

Relative % change in C, P6, G6 & S6 for surface horizons

Soil	%C	P6	G6	S6
Crookston	2%		-9%	13%
TeKowhai	-2%		-3%	-4%
Bruntwood	-5%		6%	-16%
Koputaroa	-11%		-66%	-69%
Himatangi	-49%	213%	72%	66%

- **Ongoing losses of forest-derived lignin appear to be occurring in some soils.**
- **Many soils do not appear to be stabilising grass-derived lignin. P6 stabilisation is correlated with C gain/loss.**
- **Resampled profiles are well-suited to this technique, alleviating some concerns about chemolytic procedures.**

Relative % change in C, P6, G6 & S6 for 1st & 2nd horizons

Soil	%C	P6	G6	S6
Crookston	2%	68%	-9%	13%
TeKowhai	-2%	-35%	-3%	-4%
Bruntwood	-5%	-58%	6%	-16%
Koputaroa	-11%	-83%	-66%	-69%
Himatangi	-21%	-65%	-28%	-28%

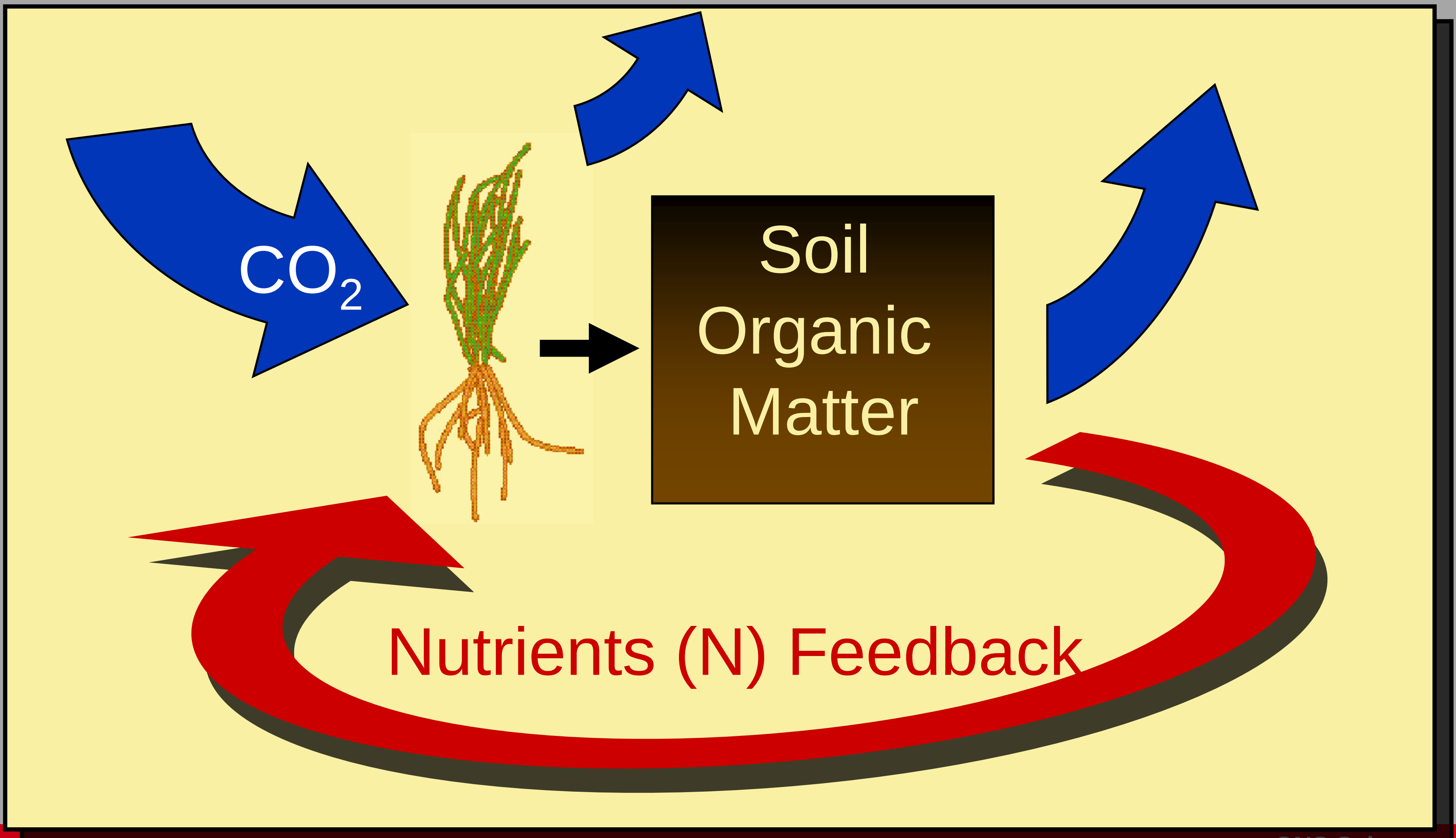
Soil	%C	P6	G6	S6
TeKowhai	8%	53%	34%	-4%
Bruntwood	-24%	-58%	-46%	-60%
Himatangi	-49%	213%	72%	66%

Overall Conclusions

- **Resampled soil profiles are well-suited to the use of ^{14}C, ^{137}Cs and biomarker tracers to identify reasons for apparent C (and N) losses.**
- **Analyses on selected profiles support the hypotheses that:**
  1. **Soil C and N changes may be due to erosion and deposition;**
  2. **Pre-European forest-derived organic matter is being lost;**
  3. **Changes in litter quality or microbial processes are reducing the amount of plant-derived OM stabilized in soil**
- **Caution should be used in extrapolating these results; ongoing work focuses on additional profiles and biomarker compounds.**

Goal: constrain SOM dynamics

- Radiocarbon (open system with isotope tracer)
- Nutrient cycling (~closed system)



Pitfall 3: Changing Input Rates (Pool Size)

Modeled by changing inputs at 1950