The Age of River-Transported Carbon:

New Data from African Catchments and a Global Perspective.

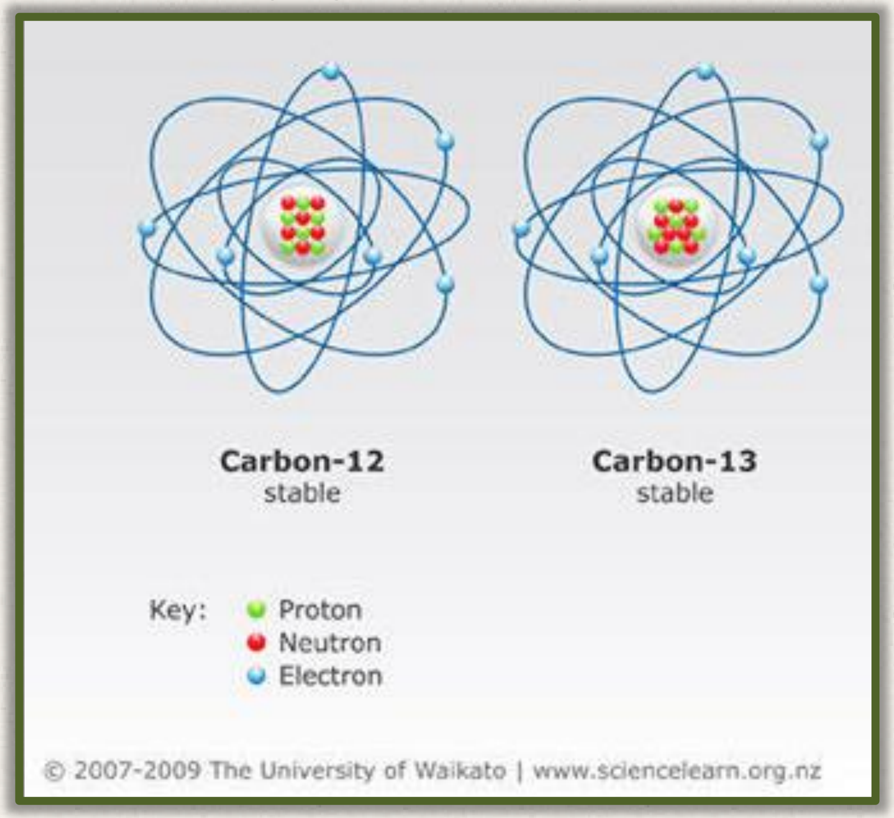
Trent R. Marwick, Fredrick Tamooh, Cristian R. Teodoru,

Alberto V. Borges, François Darchambeau & Steven Bouillon

KU LEUVEN
ULg UNIVERSITÉ de Liège
erc European Research Council

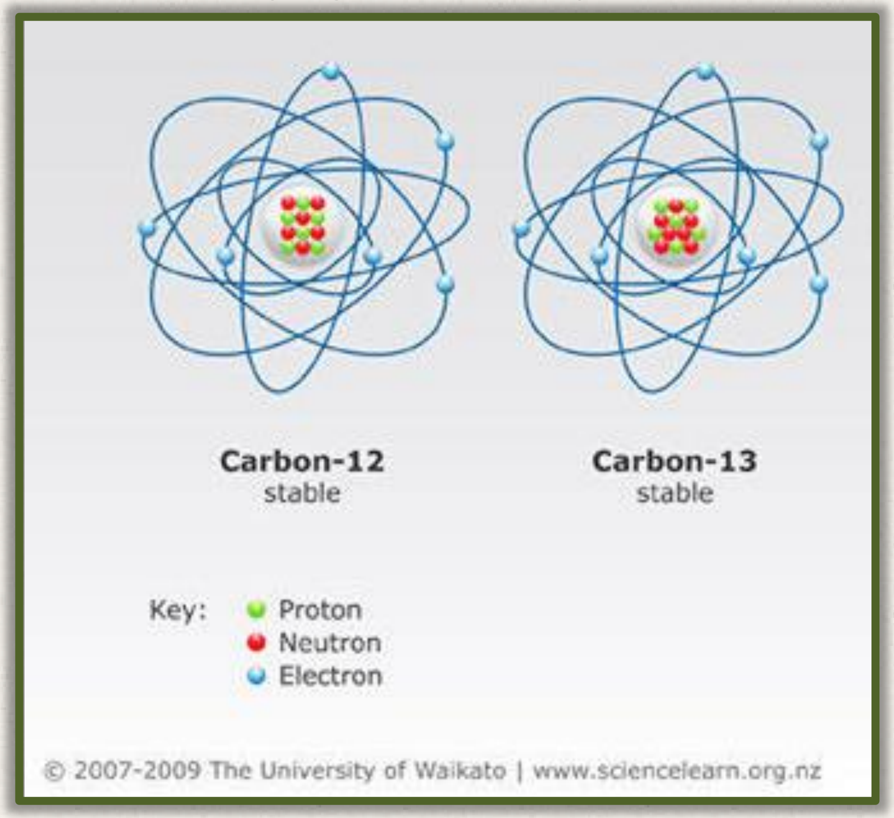
Carbon Isotopes

The reason we're all here…

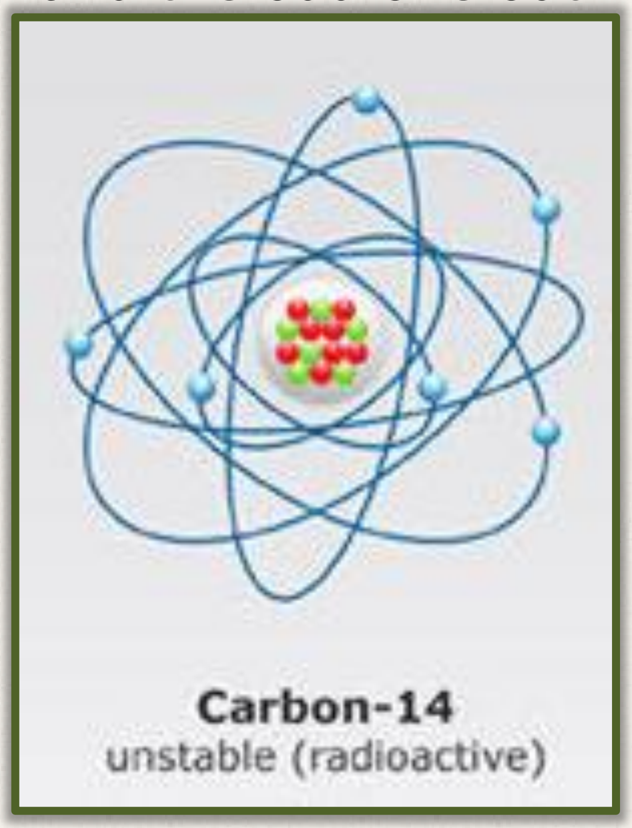


Carbon Isotopes

The reason we're all here…

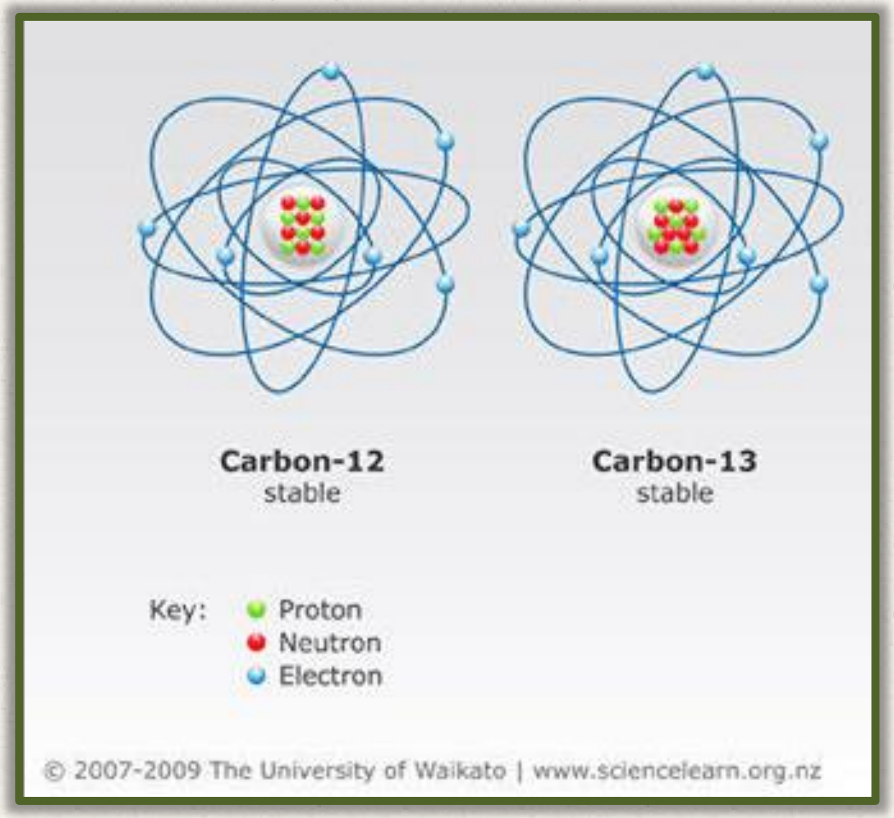


and the odd one out

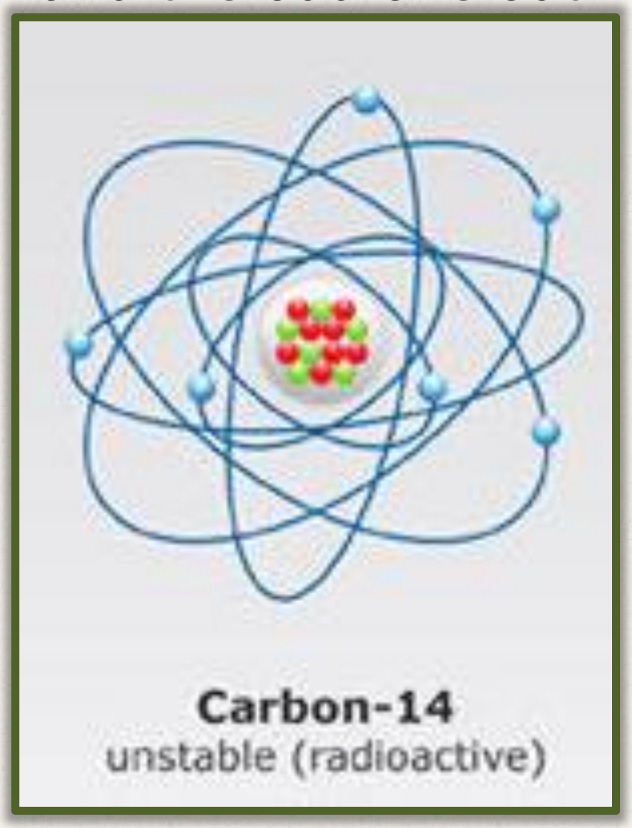


Carbon Isotopes

The reason we're all here… and the odd one out



+

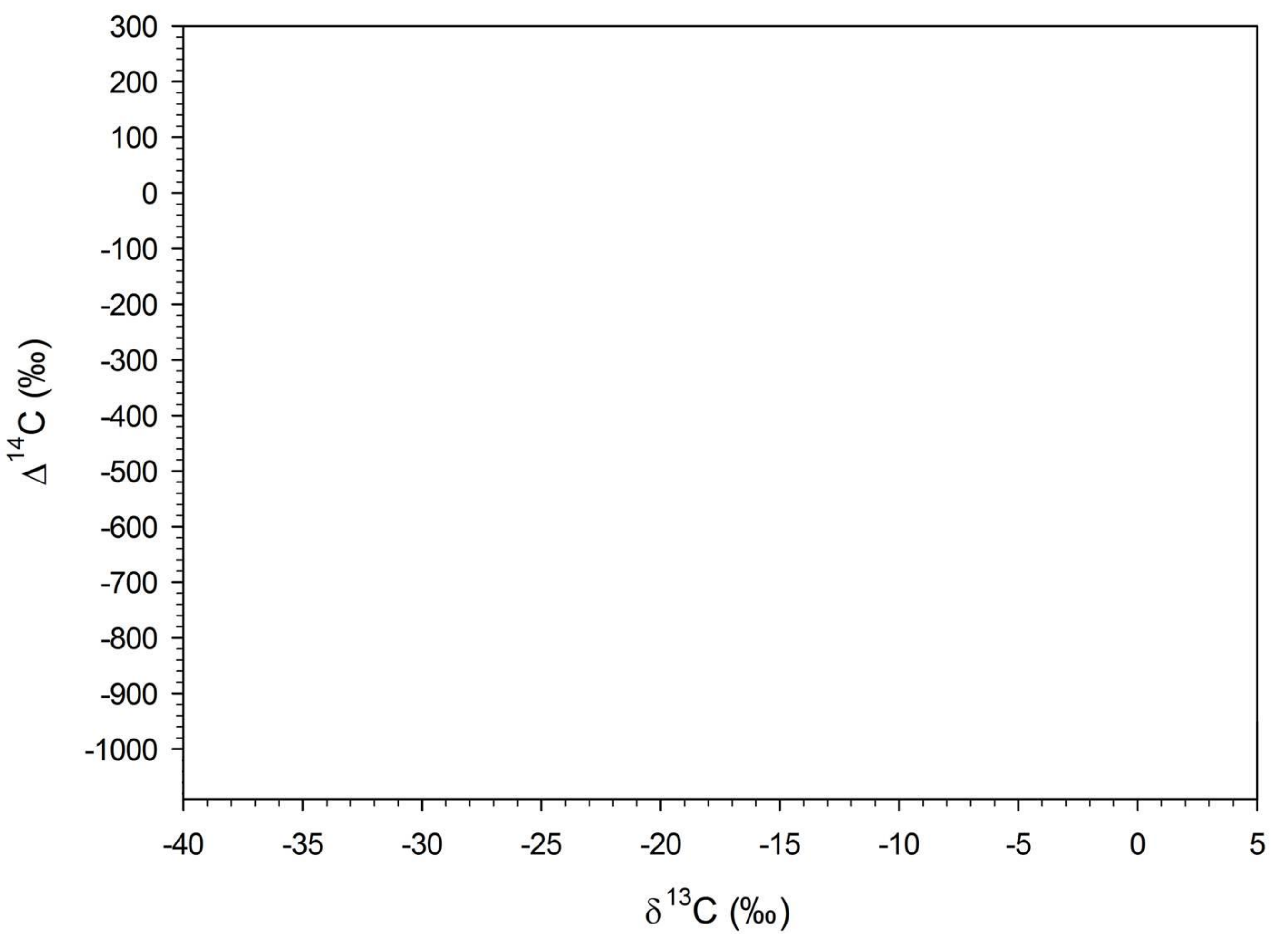


=

A powerful tracer of riverine carbon origin and age

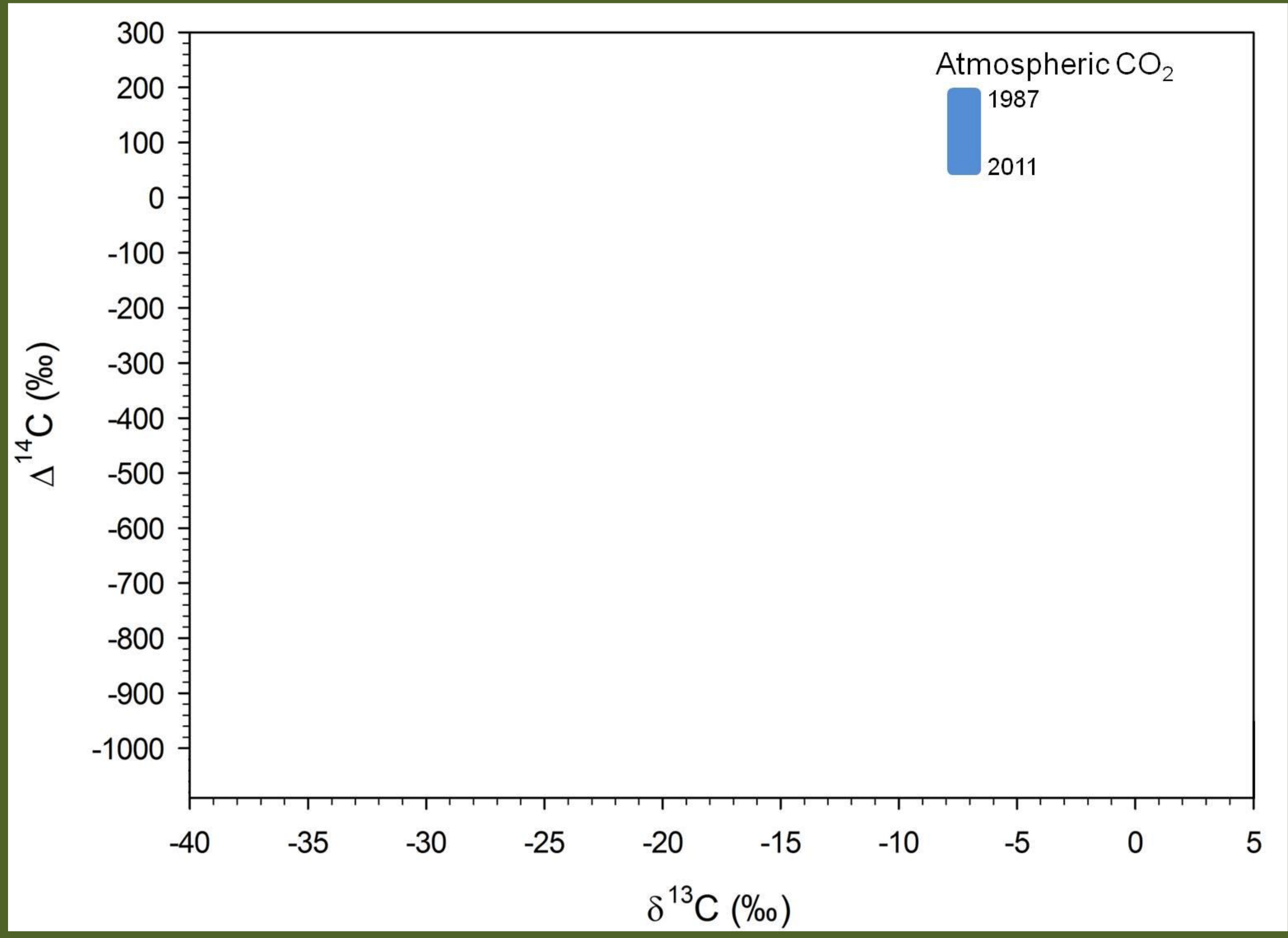
Riverine Carbon Origin

A powerful tracer of riverine carbon origin and age



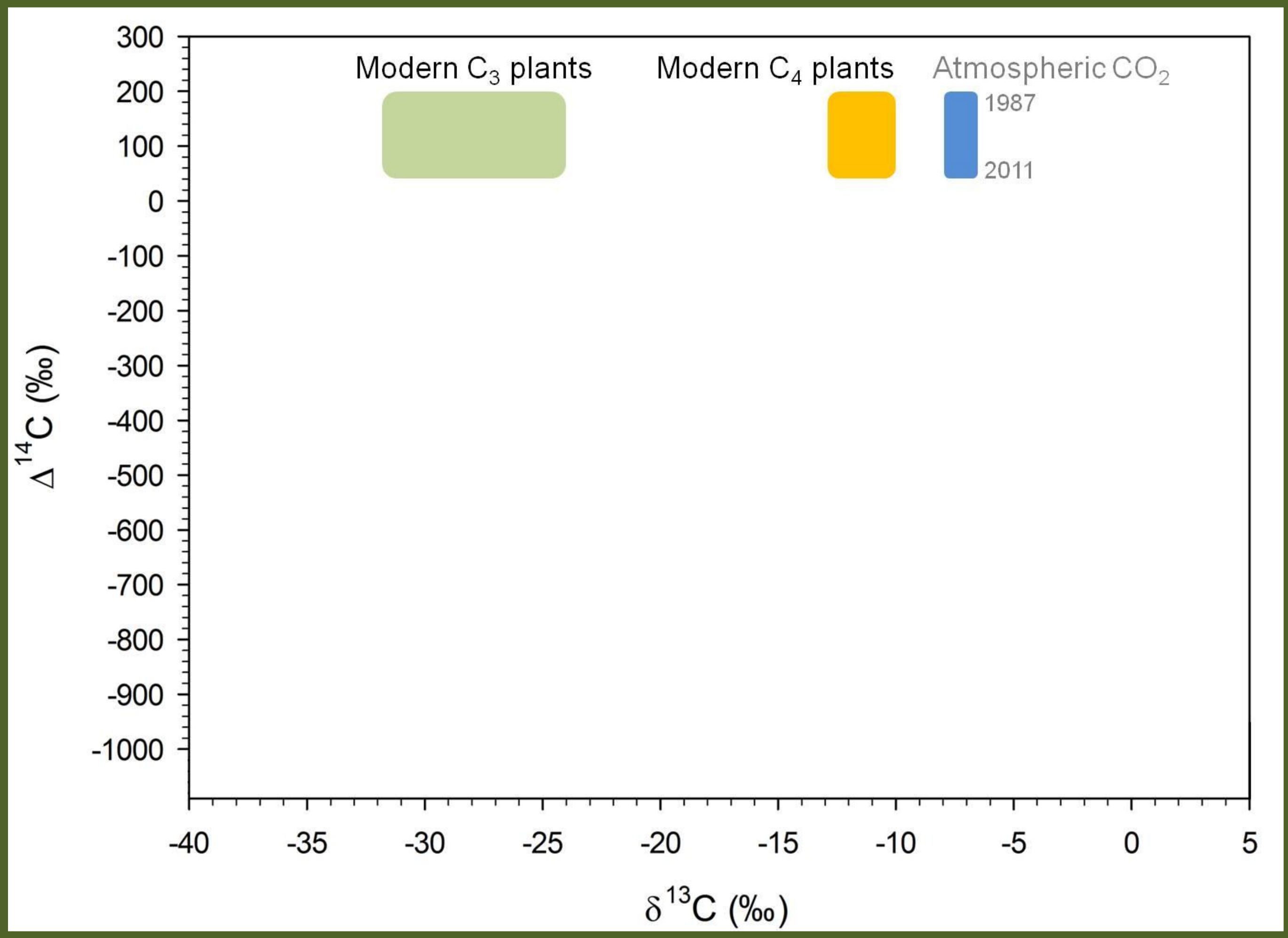
Riverine Carbon Origin

A powerful tracer of riverine carbon origin and age



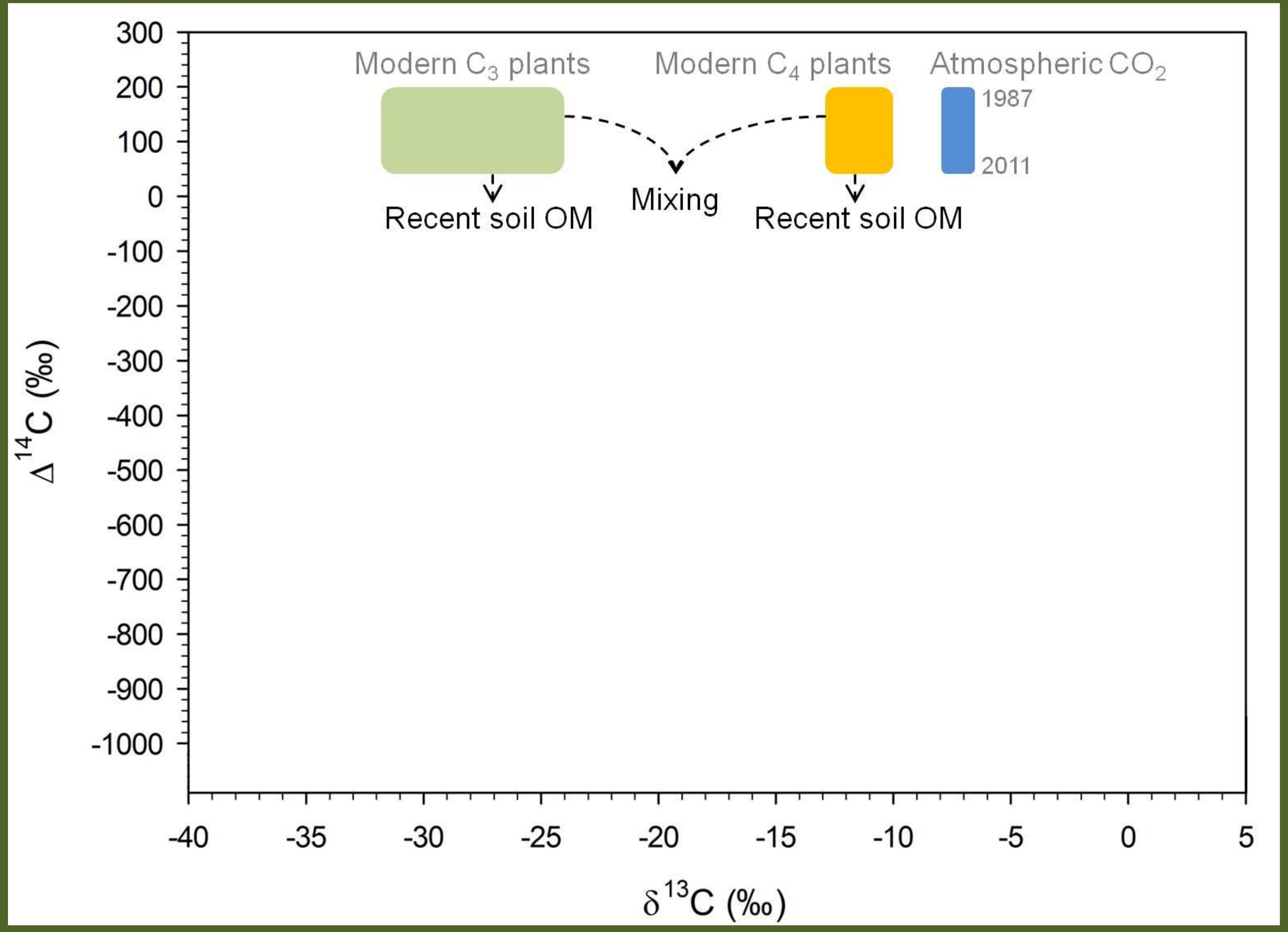
Riverine Carbon Origin

A powerful tracer of riverine carbon origin and age



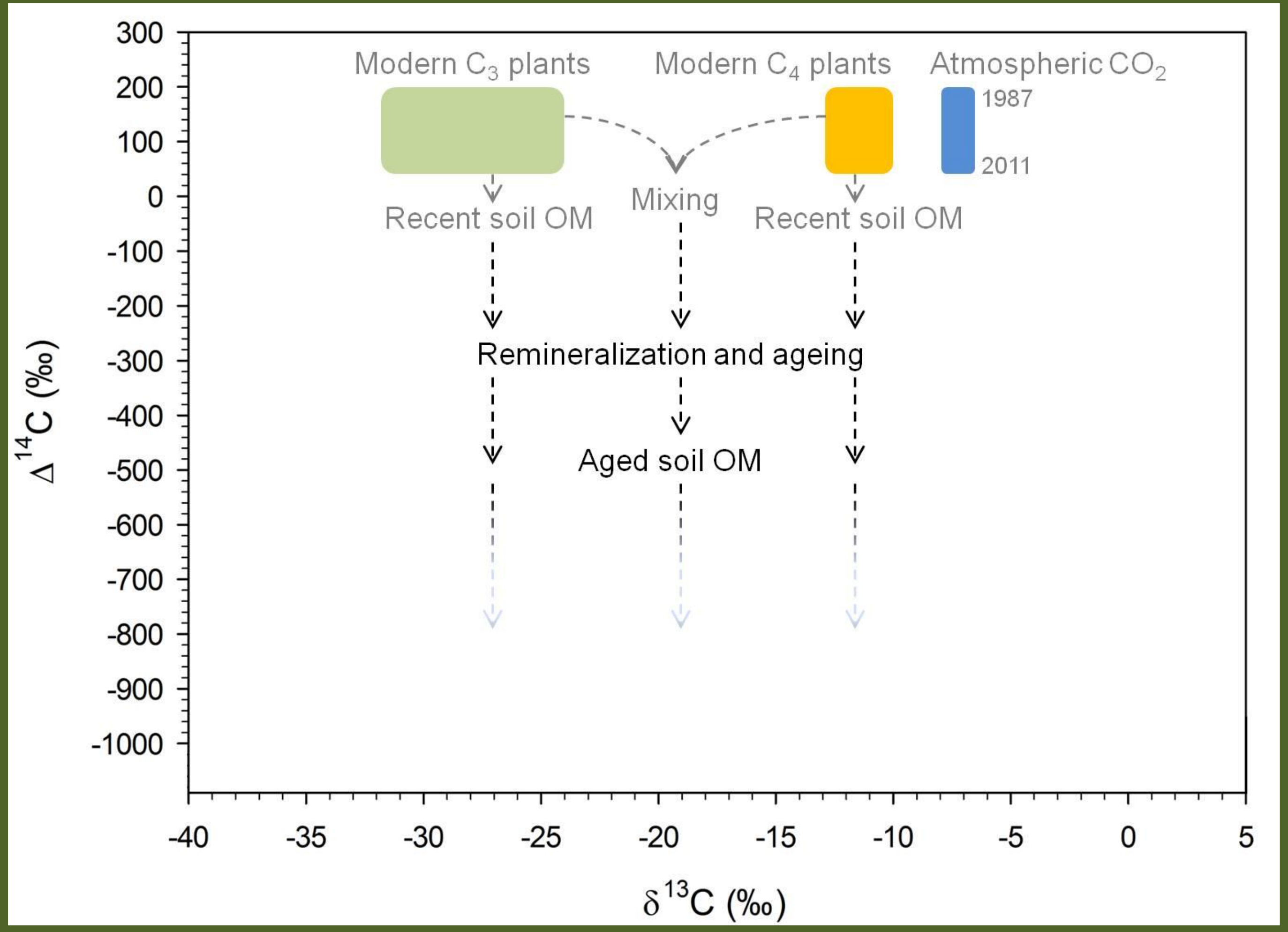
Riverine Carbon Origin

A powerful tracer of riverine carbon origin and age



Riverine Carbon Origin

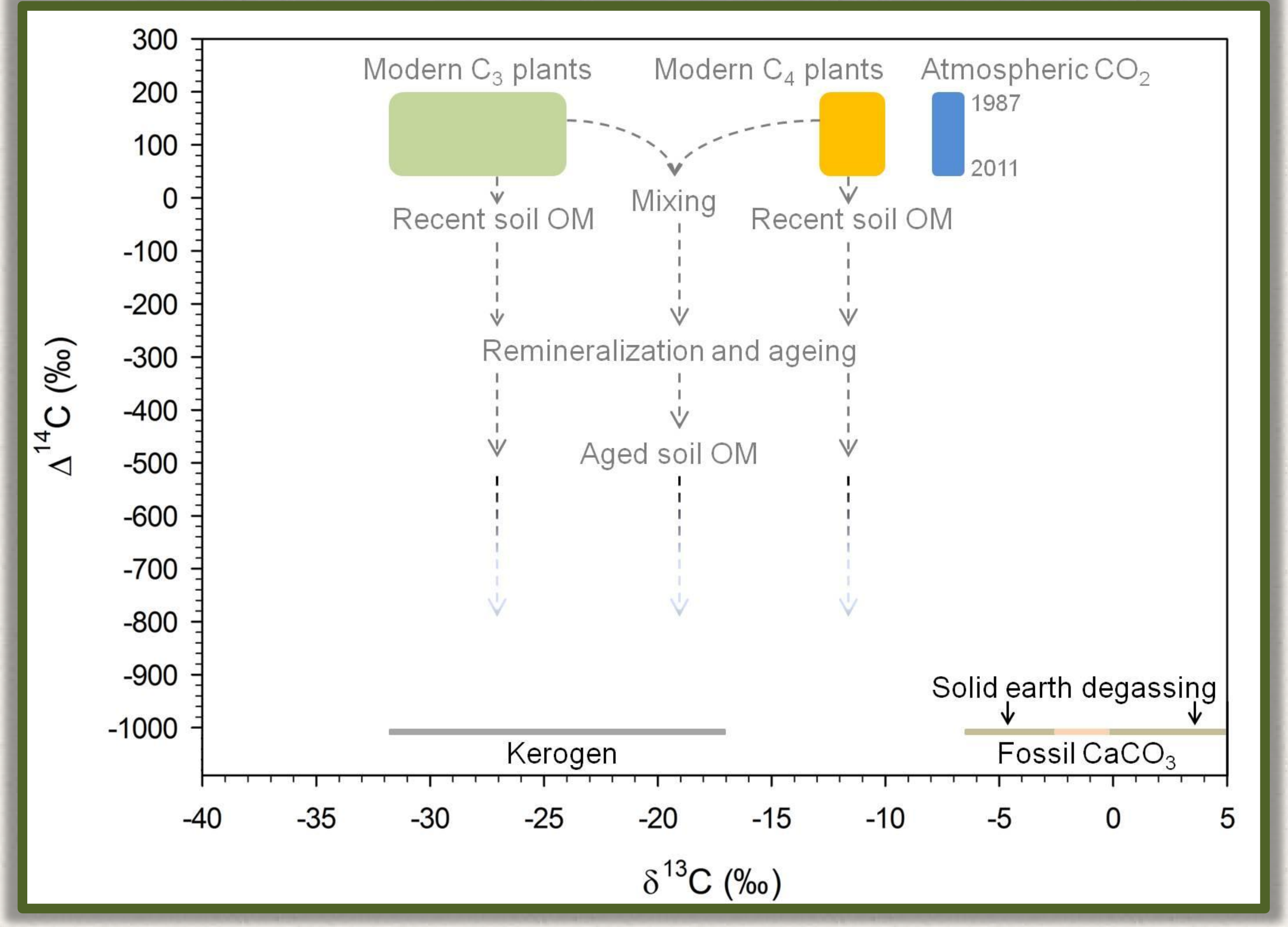
A powerful tracer of riverine carbon origin and age



KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

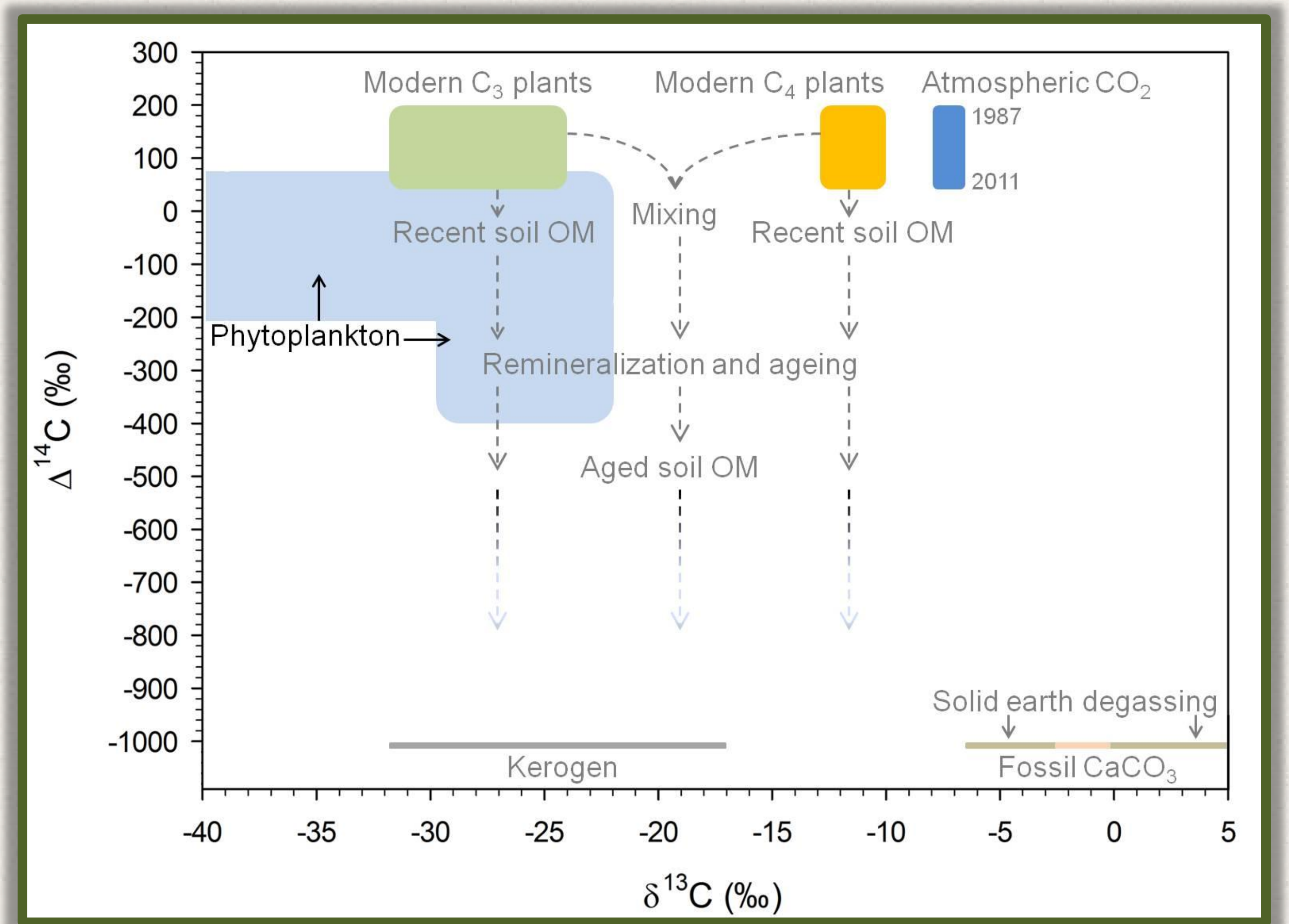
Riverine Carbon Origin

A powerful tracer of riverine carbon origin and age



Riverine Carbon Origin

A powerful tracer of riverine carbon origin and age



The Premise

Although riverine ^{14}C data have been examined at regional scales, there have been no attempts to compile a global dataset and assess general patterns of riverine ^{14}C at such a scale.

The Objectives

1. *To compile literature ^{14}C (and paired ancillary) riverine data.*

The Objectives

1. *To compile literature ^{14}C (and paired ancillary) riverine data.*

2. *To fill one existing regional gap in the global riverine ^{14}C database (i.e. African streams and rivers).*

The Objectives

1. To compile literature ^{14}C (and paired ancillary) riverine data.

2. To fill one existing regional gap in the global riverine ^{14}C database (i.e. African streams and rivers).

3. To look for general ^{14}C patterns at the global scale using an assortment of biogeochemical proxies.

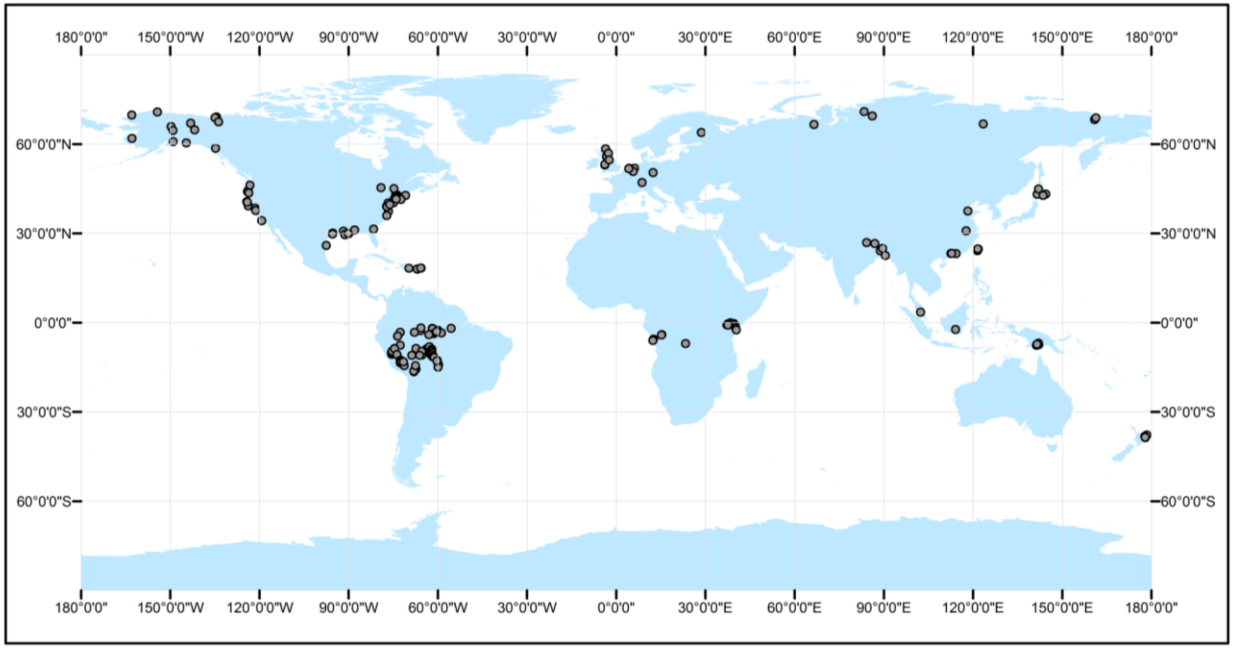
The Objectives

1. *To compile literature ^{14}C (and paired ancillary) riverine data.*
2. *To fill one existing regional gap in the global riverine ^{14}C database (i.e. African streams and rivers).*
3. *To look for general ^{14}C patterns at the global scale using an assortment of biogeochemical proxies.*
4. *To provide first estimates for the age of river-transported C pools from the global ^{14}C compilation.*

The Objectives

1. To compile literature ^{14}C (and paired ancillary) riverine data on:

1. Particulate Organic Carbon (POC)
2. Dissolved Organic Carbon (DOC)
3. Dissolved Inorganic Carbon (DIC)

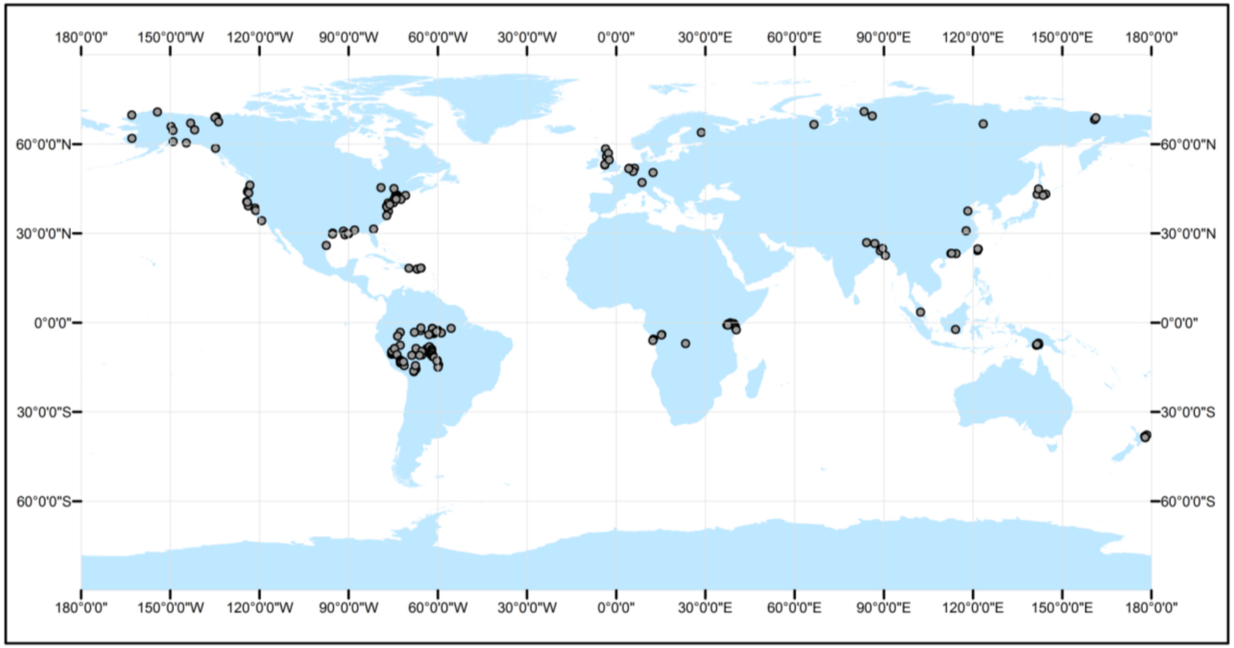


KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

Objective 1 - Literature data compilation

Peer-reviewed publications = 58
Individual river basins ≈ 100 (Not a '*global synthesis*'!)
$\Delta^{14}C_{POC}$ (+ paired $\delta^{13}C_{POC}$) = 464 (+ 409)
$\Delta^{14}C_{DOC}$ (+ paired $\delta^{13}C_{DOC}$) = 604 (+ 416)
$\Delta^{14}C_{DIC}$ (+ paired $\delta^{13}C_{DIC}$) = 209 (+ 197)(Not evading CO_2)
Ancillary data = >1500 data points

(e.g. total suspended matter, %POC of TSM, bulk C concentrations)

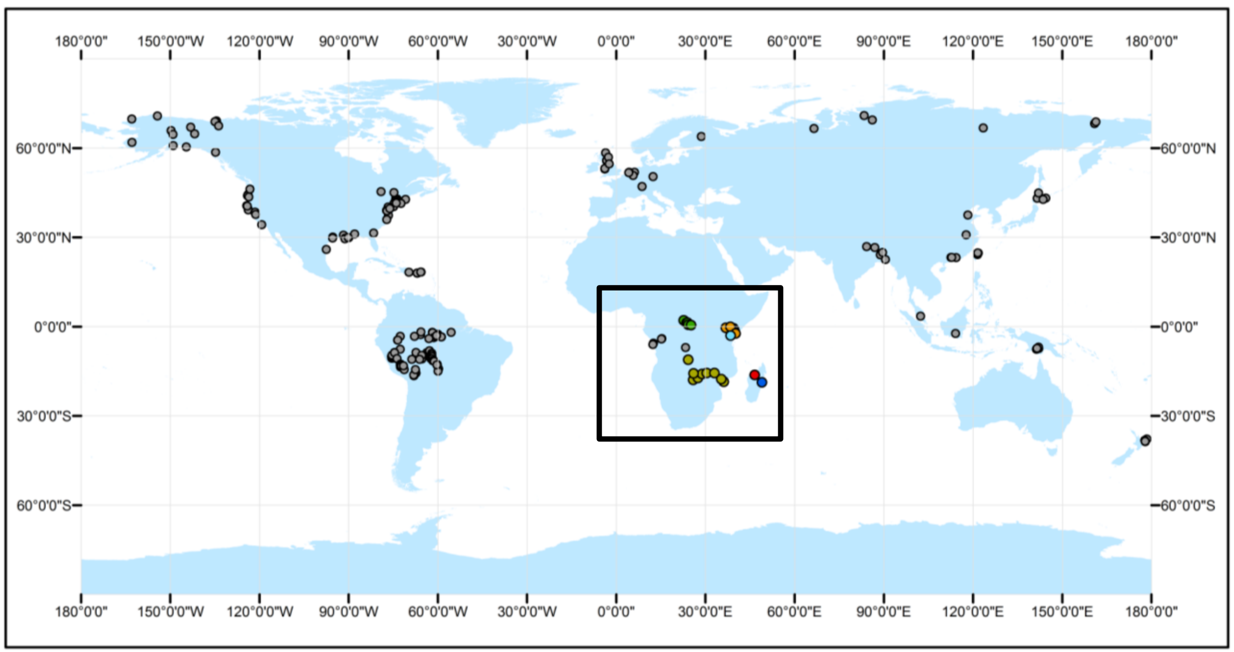


KU LEUVEN
ULg UNIVERSITÉ de Liège
erc European Research Council

The Objectives

1. *To compile literature riverine ^{14}C (and paired ancillary) data.*

2. *To fill one existing regional gap in the global riverine ^{14}C database (i.e. African streams and rivers).*



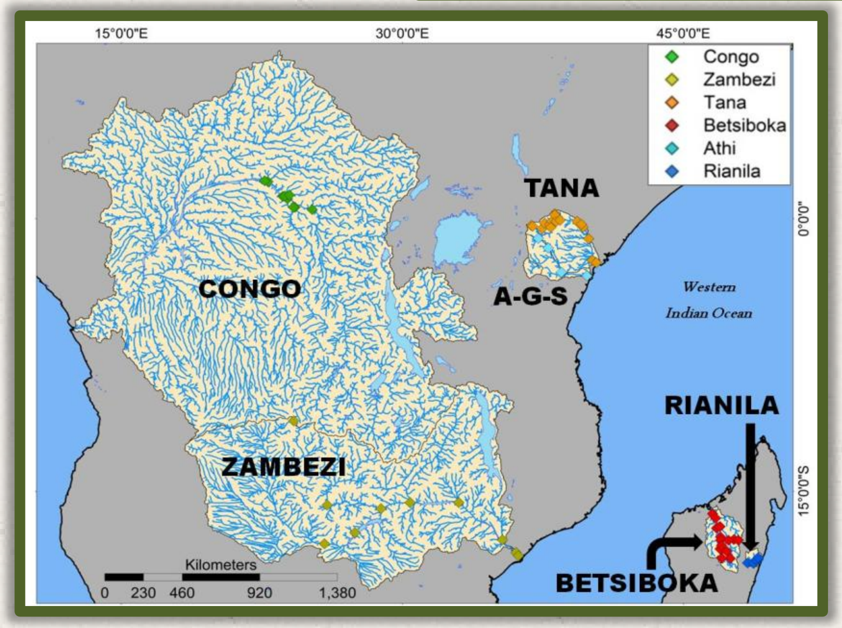
KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

Objective 2 - African riverine ^{14}C

Congo DR Congo

Athi-Galana-Sabaki (A-G-S) Kenya

Zambezi Zambia/Mozambique



Tana Kenya

Betsiboka Madagascar

Rianila Madagascar

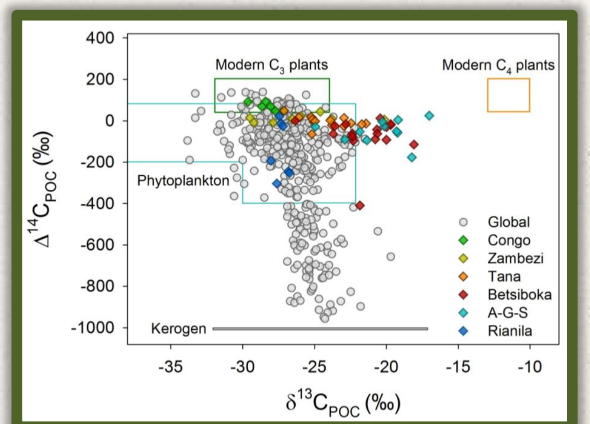
KU LEUVEN
ULg UNIVERSITÉ de Liège
erc European Research Council

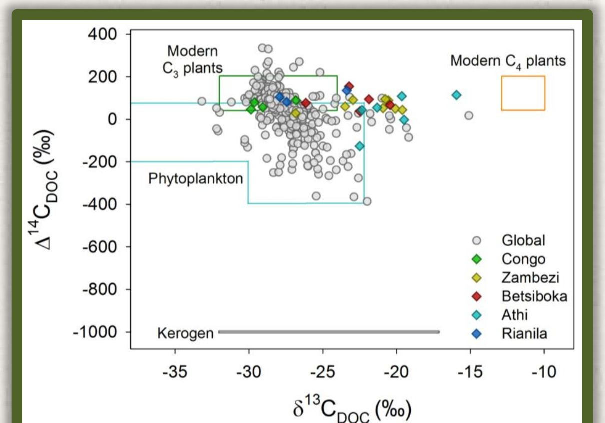
The Objectives

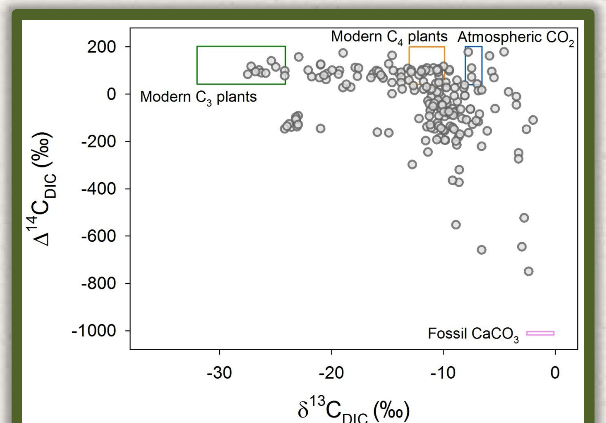
1. To compile literature ^{14}C (and paired ancillary) riverine data.

2. To fill one existing regional gap in the global riverine ^{14}C database (i.e. African streams and rivers).

3. To look for general ^{14}C patterns at the global scale using an assortment of biogeochemical proxies.

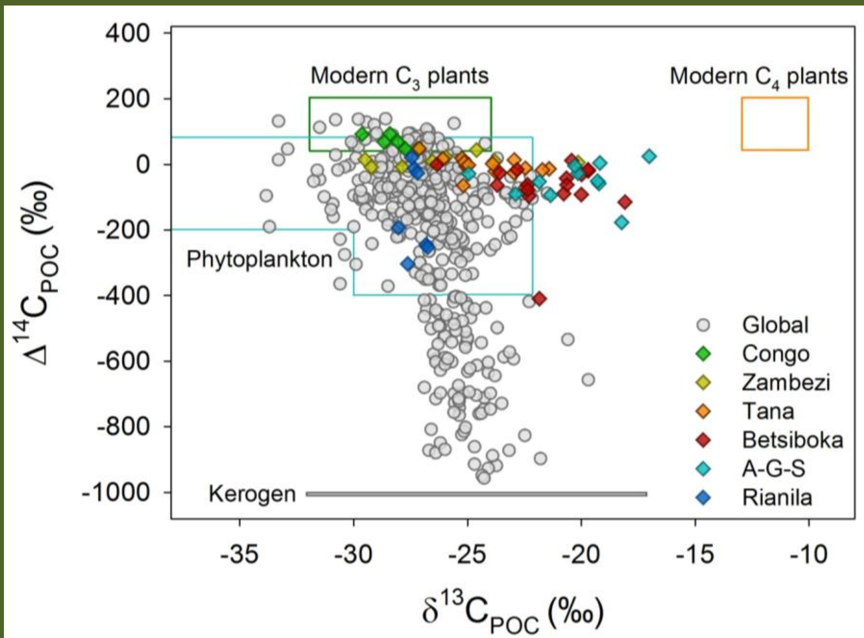


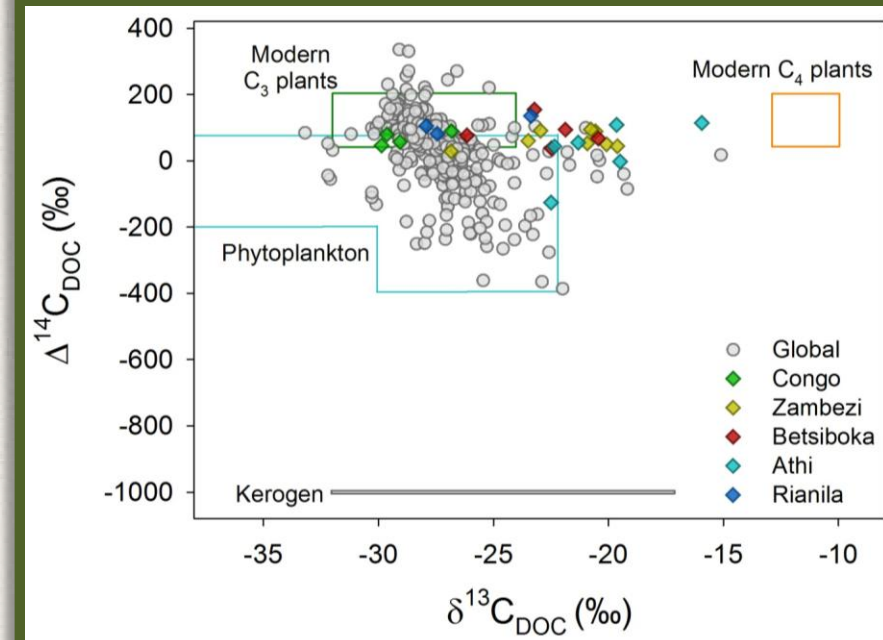




Objective 3 - Global riverine $\delta^{13}C$ and $\Delta^{14}C$

At least 3 primary OM sources required to constrain global riverine POC and DOC





1. ^{14}C-dead fossilized C_3 OM
2. Contemporary terrestrial C_3 OM
3. Contemporary terrestrial C_4 OM

Evidence of instream autotrophic sources?

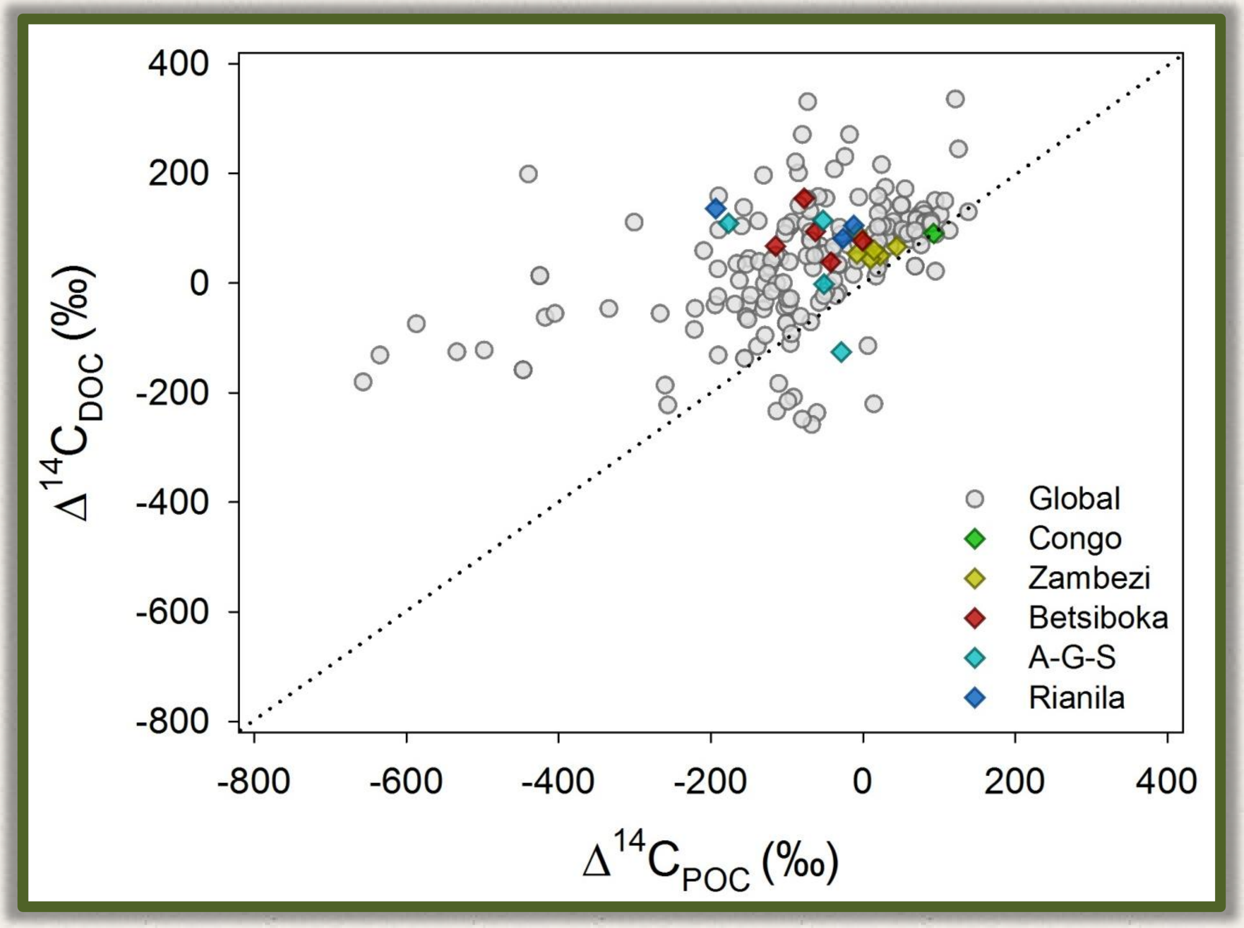
Where is the pure C_4 riverine POC?

1. Aged soil OM
2. Contemporary terrestrial C_3 OM
3. Contemporary terrestrial C_4 OM

Constrained age relative to POC.

Objective 3 - Global $DO^{14}C$ patterns

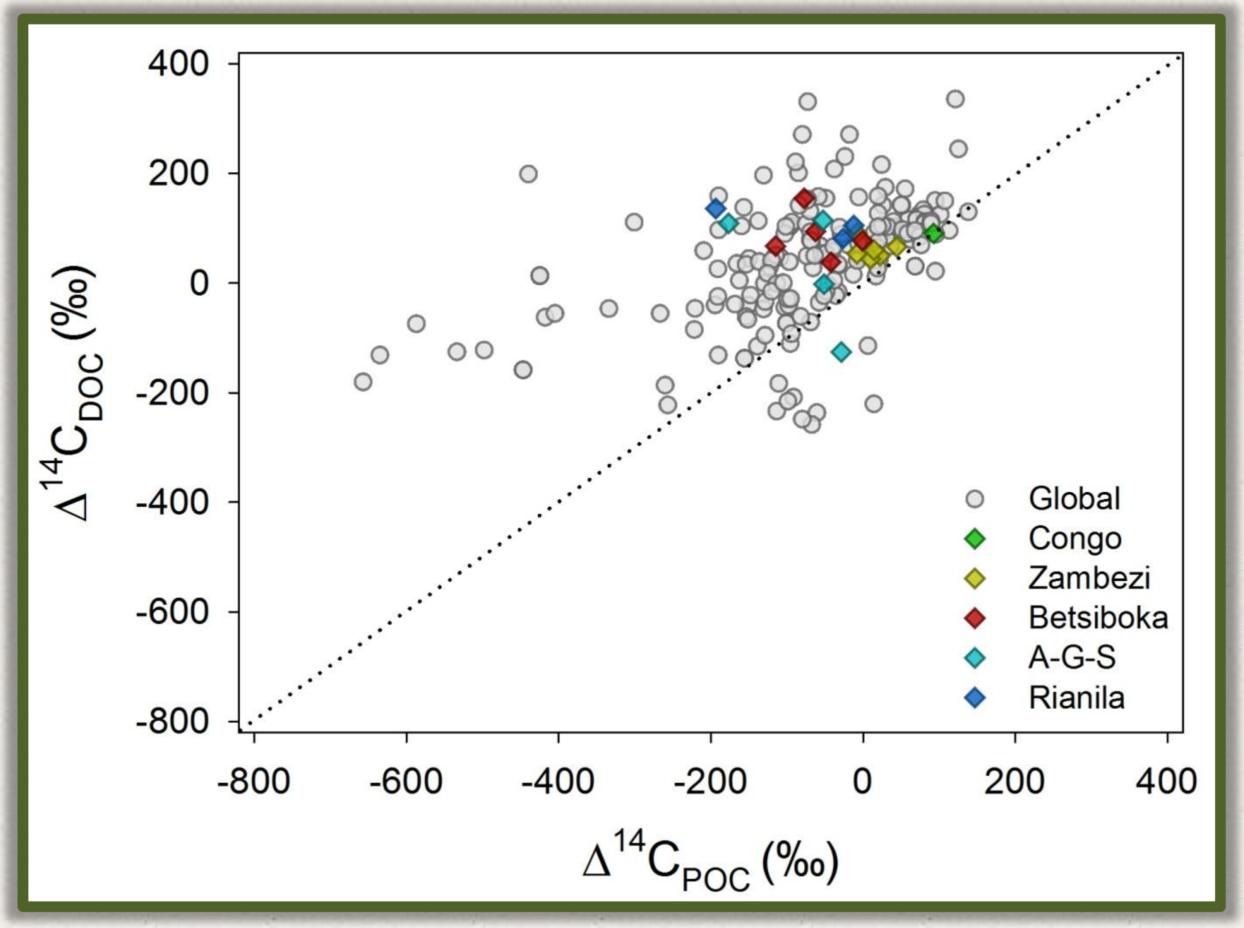
90% of POC samples older than paired DOC samples



Why?

Objective 3 - Global $DO^{14}C$ patterns

90% of POC samples older than paired DOC samples



POC
Mechanical weathering

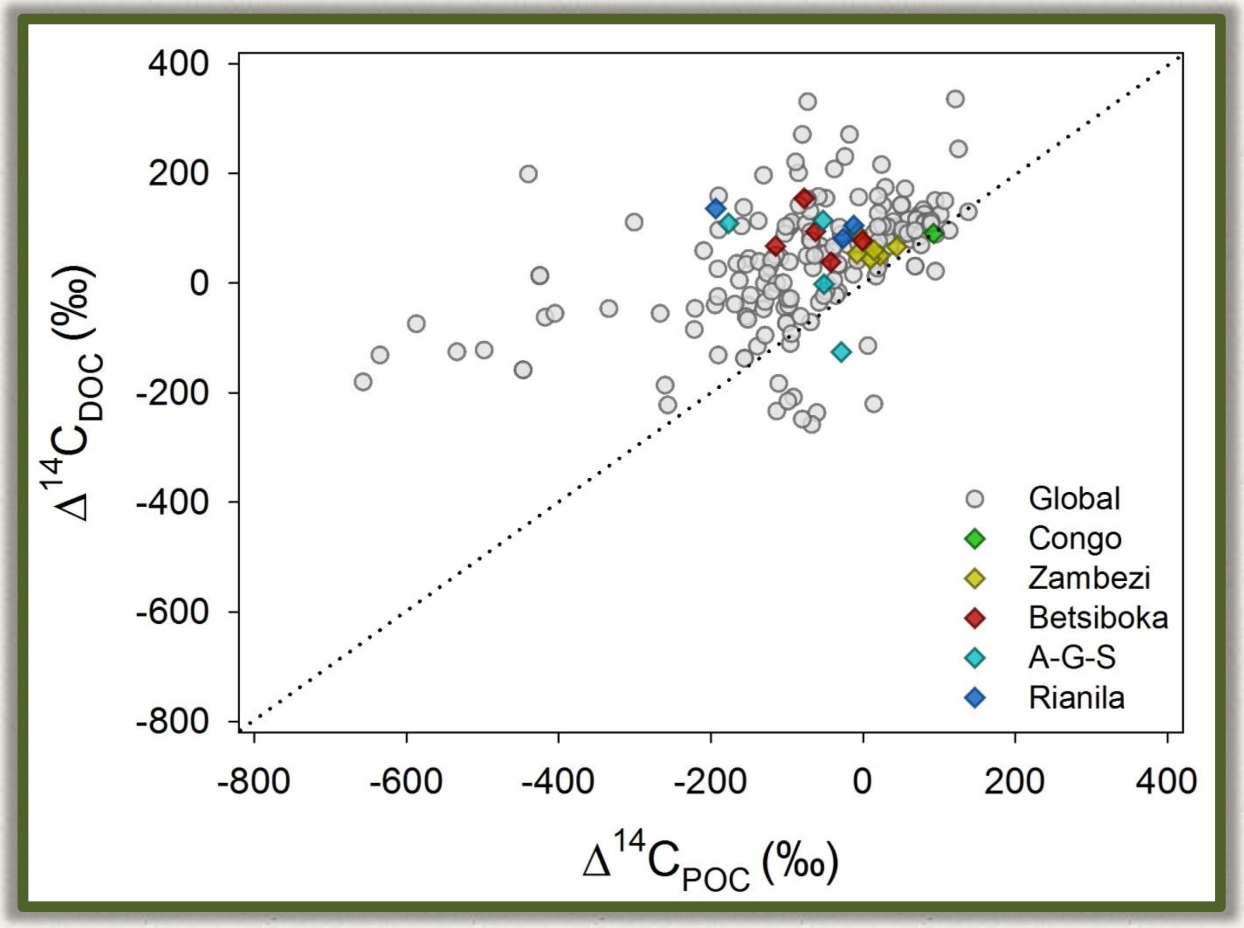
DOC
Chemical weathering
- recently fixed carbon
- below ground production

Why?

Differences in dominant **weathering** and **transport** mechanisms

Objective 3 - Global DO^{14}C patterns

90% of POC samples older than paired DOC samples



POC
Mechanical weathering

Deposition/re-suspension
i.e. POC 'spiralling'

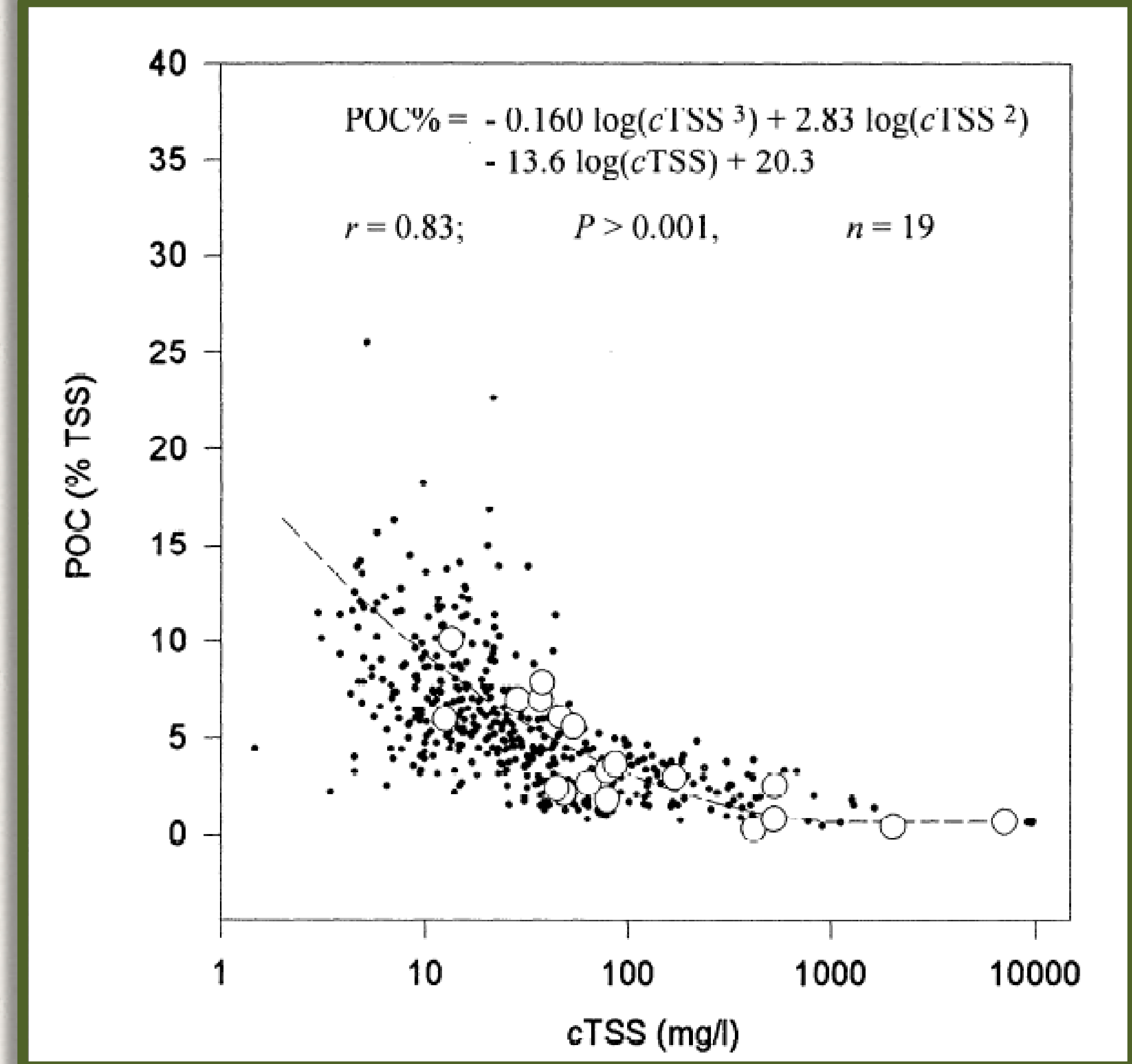
DOC
Chemical weathering

Rapid export from the basin

Why?

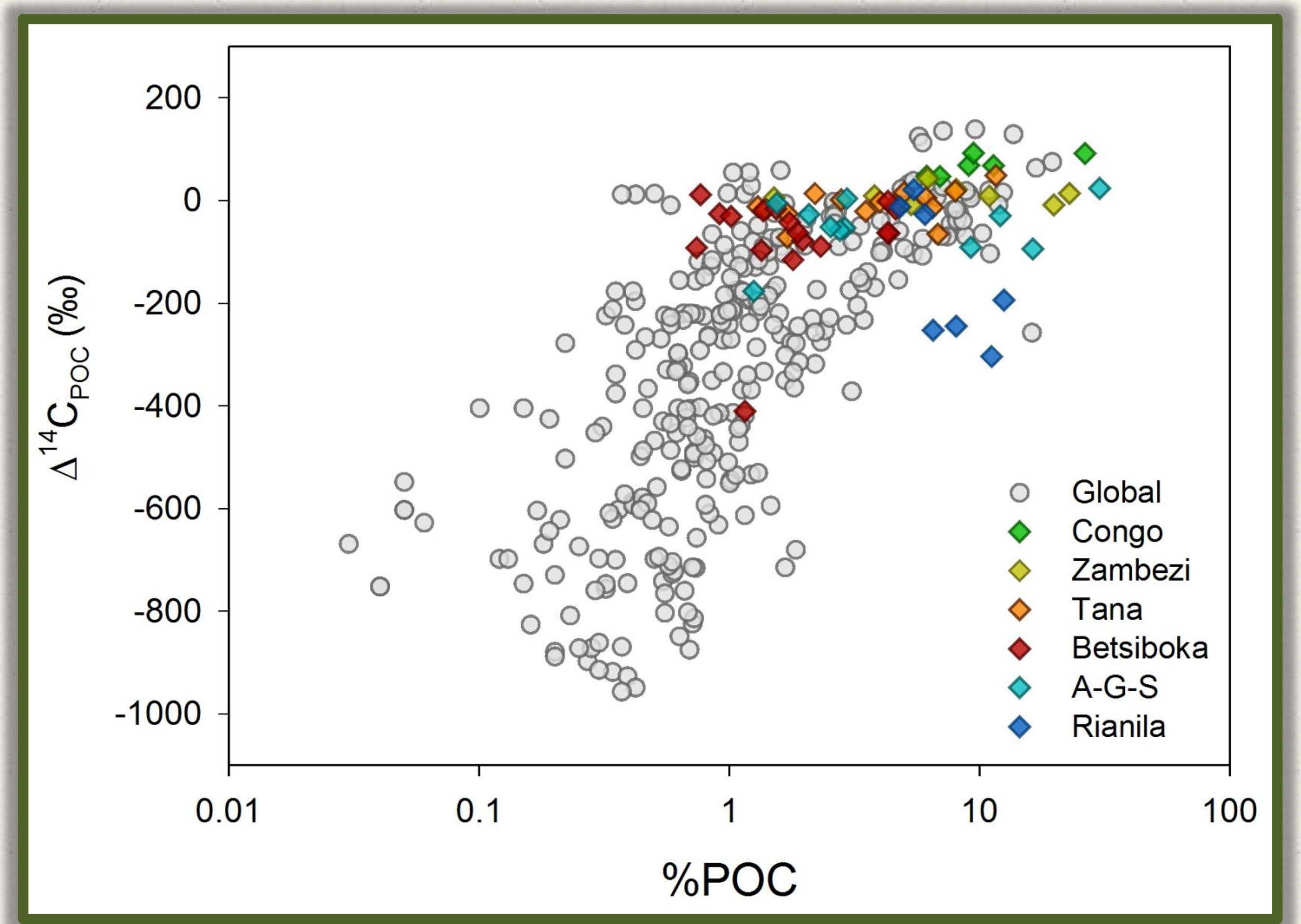
Differences in dominant **weathering** and **transport** mechanisms

Objective 3 - Global PO^{14}C patterns

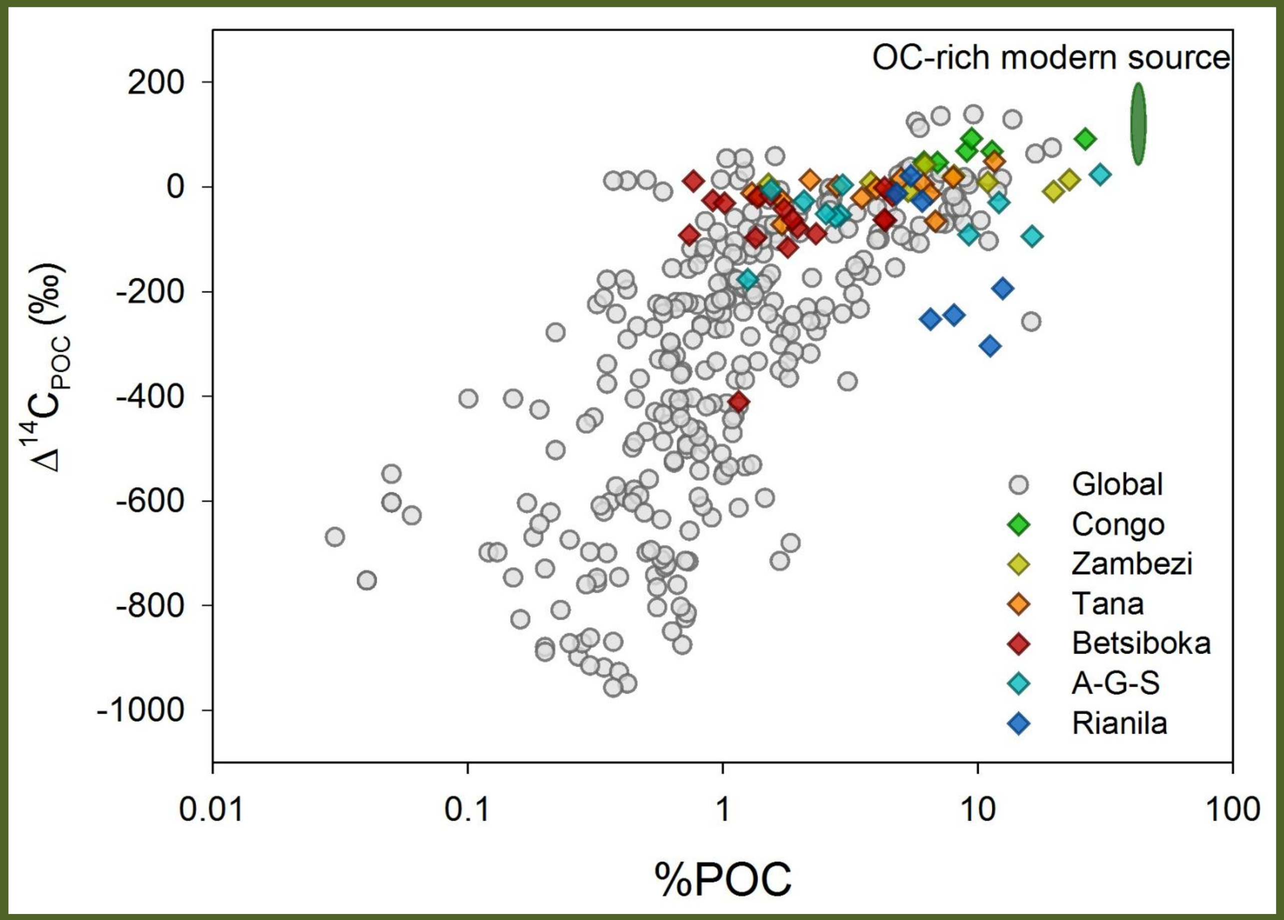


Ludwig and Probst (1996) GBC

Objective 3 - Global $PO^{14}C$ patterns



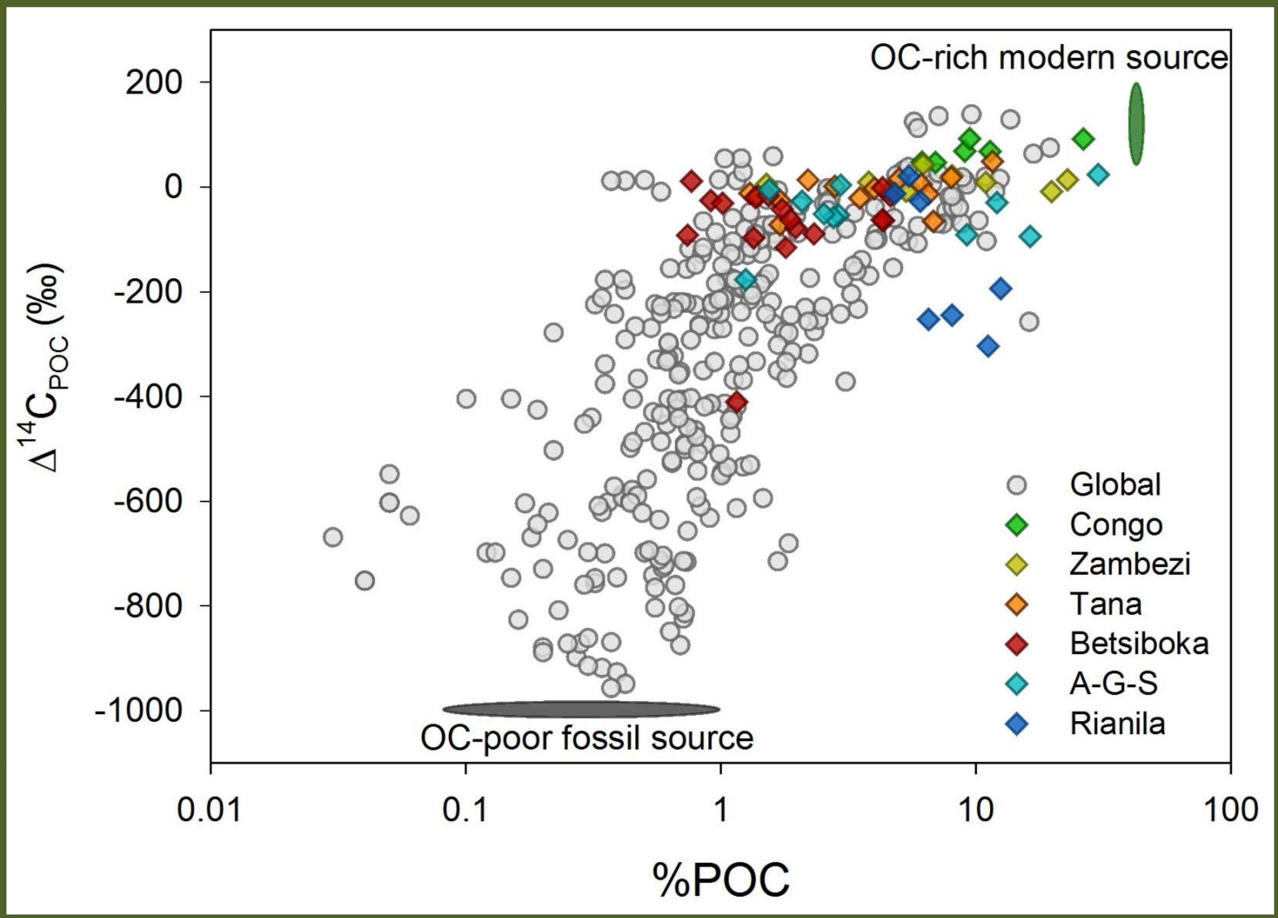
Objective 3 - Global PO^{14}C patterns



Modern terrestrial plant OM

Aquatic primary producers

Objective 3 - Global PO^{14}C patterns



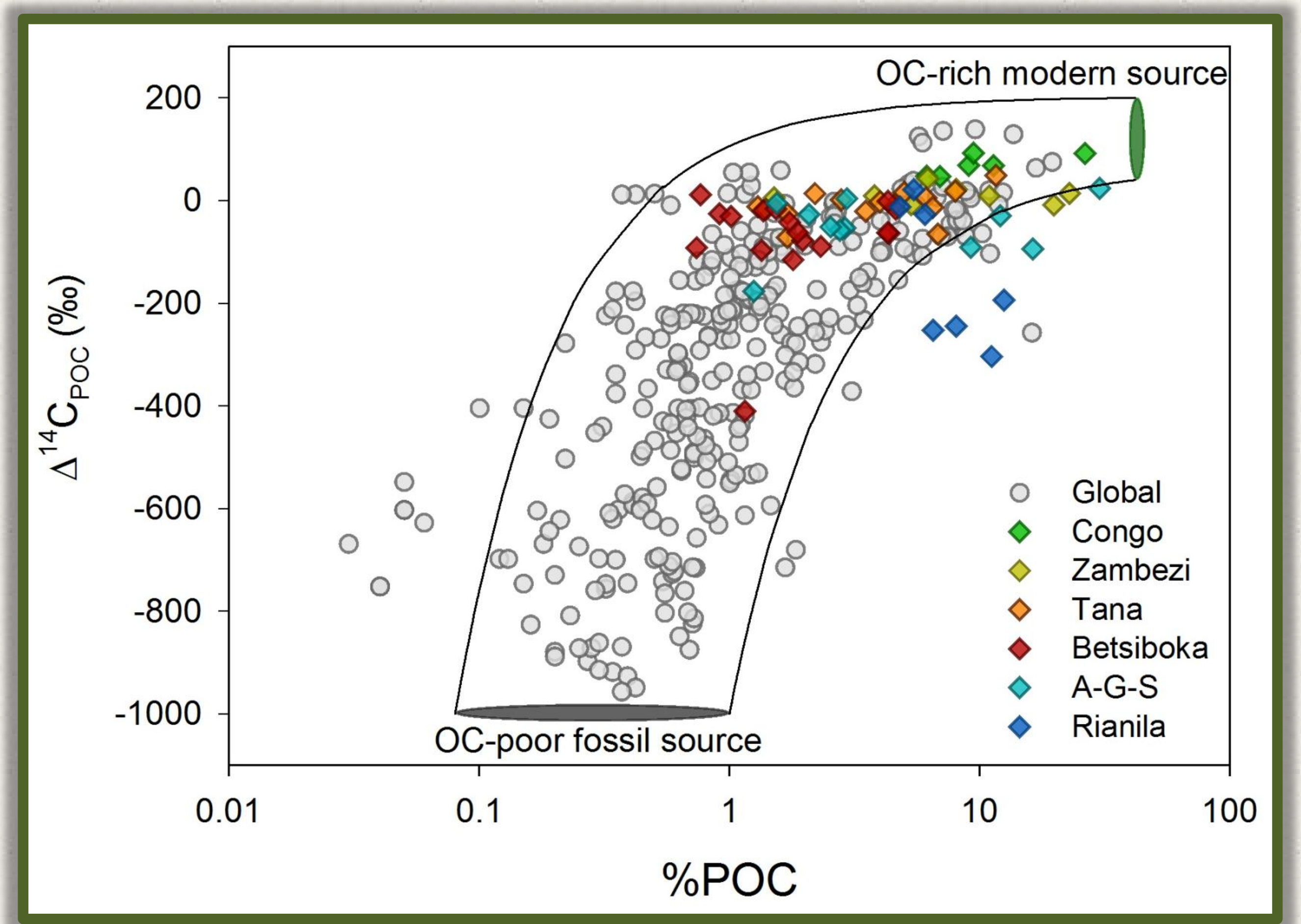
Modern terrestrial plant OM

Aquatic primary producers

Kerogen (e.g. shales)

KU LEUVEN
ULg Université de Liège
erc European Research Council

Objective 3 - Global $PO^{14}C$ patterns



Modern terrestrial plant OM

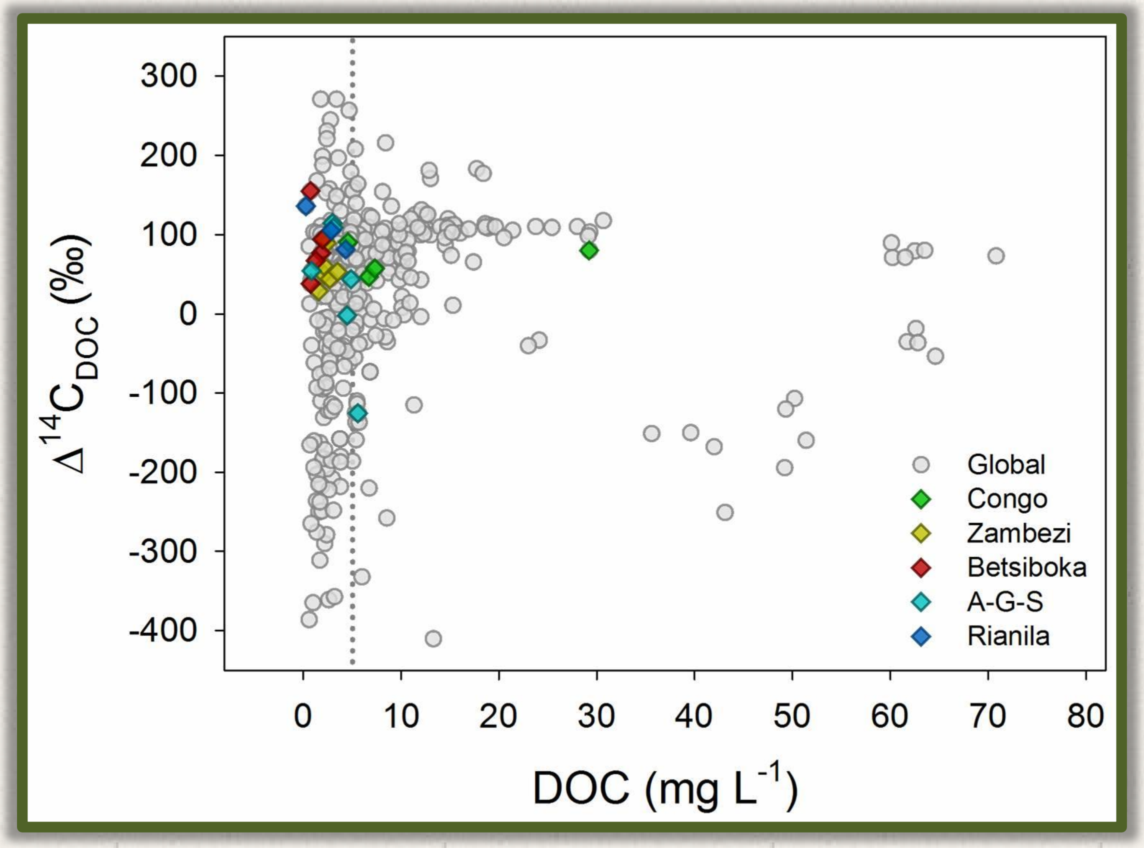
Aquatic primary producers

Kerogen (e.g. shales)

KU LEUVEN ULg Université de Liège erc European Research Council

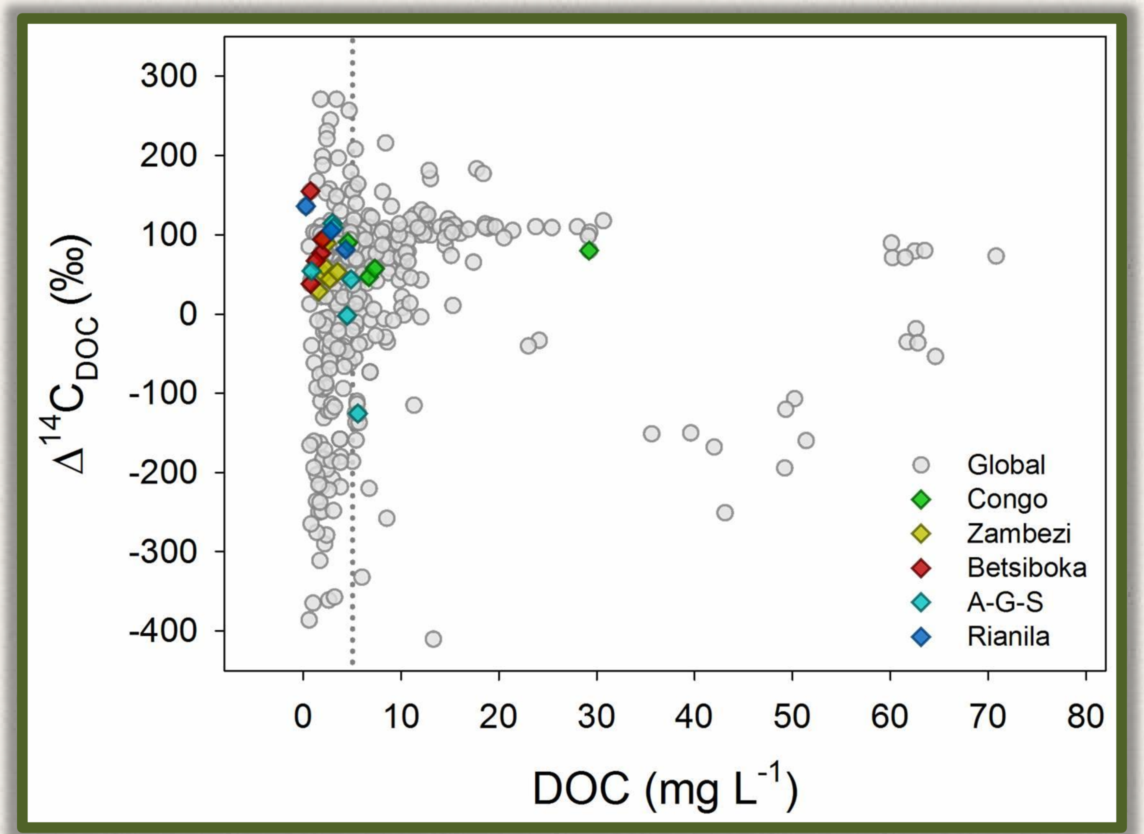
Objective 3 - Global $DO^{14}C$ patterns

Global mean riverine DOC concentration of ~5.5 mg L^{-1}



Objective 3 - Global $DO^{14}C$ patterns

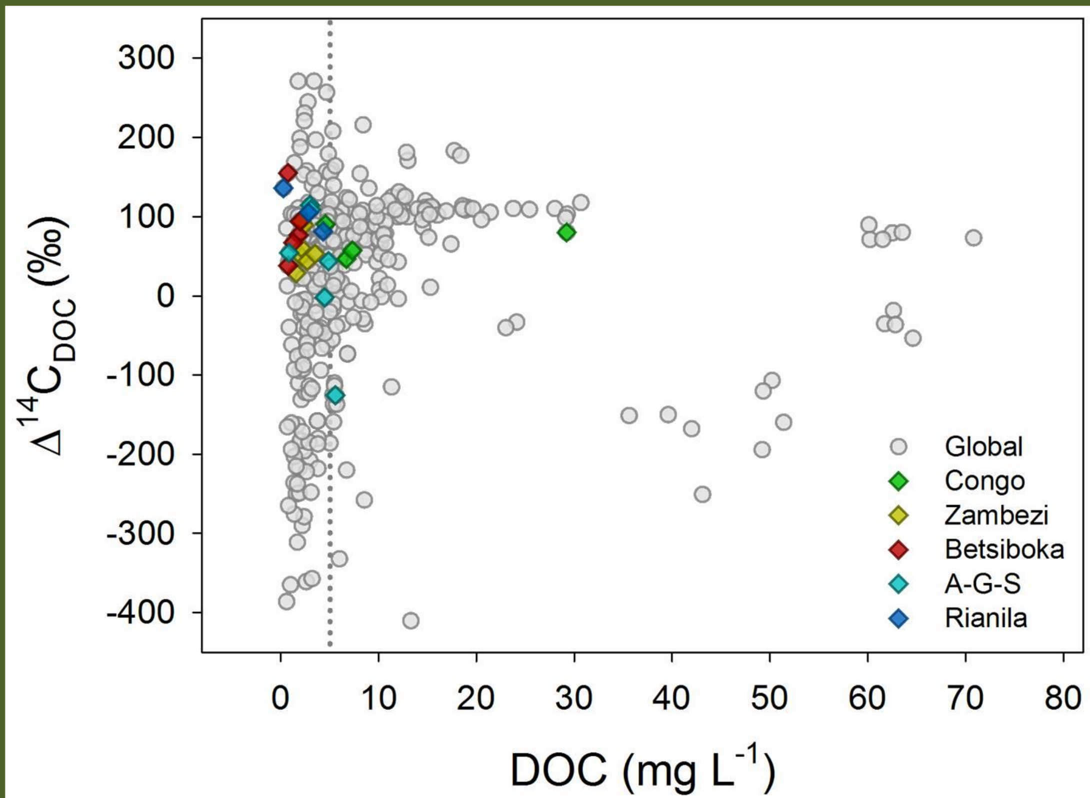
Global mean riverine DOC concentration of ~5.5 mg L^{-1}



≤ 5.5	DOC (mg C L^{-1})	> 5.5
222	*n*	157
+6‰	Average $\Delta^{14}C_{DOC}$	+48‰
129‰	S.D.	97‰
+38‰	Median $\Delta^{14}C_{DOC}$	+77‰

Objective 3 - Global $DO^{14}C$ patterns

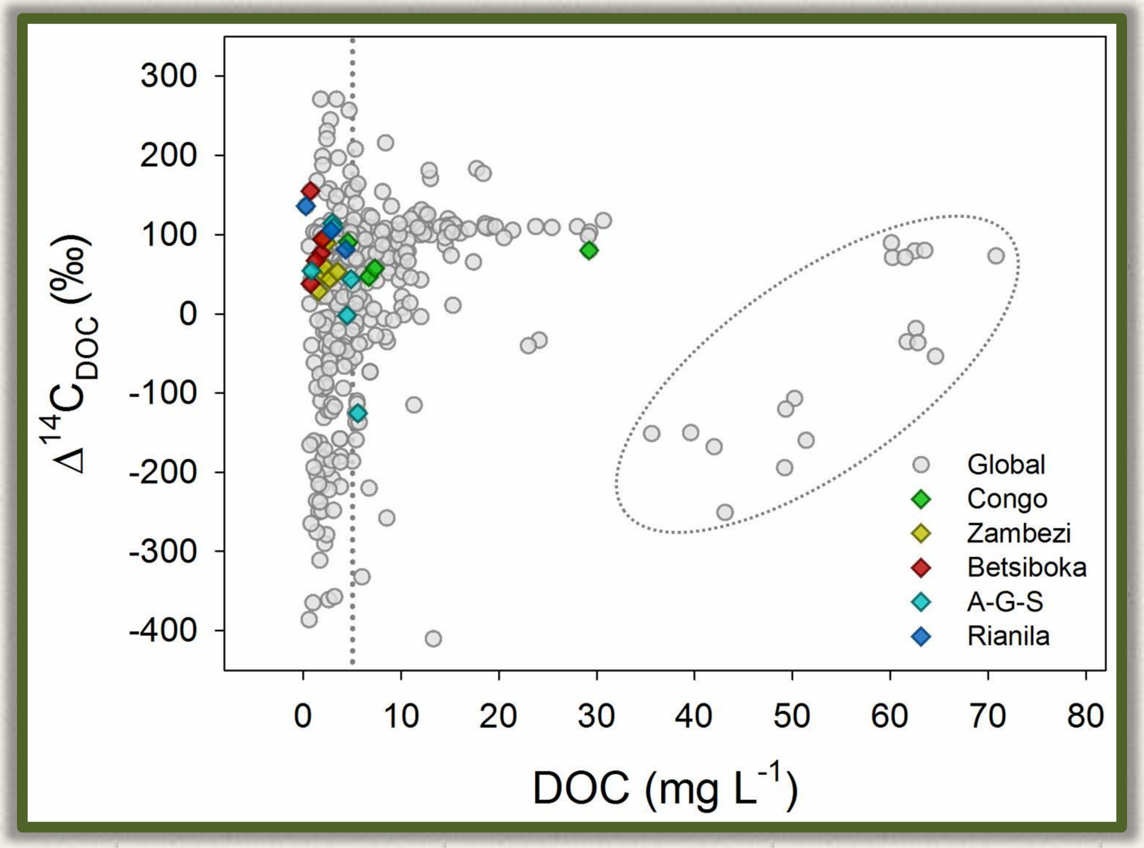
Global mean riverine DOC concentration of ~5.5 mg L^{-1}



≤ 5.5	DOC (mg C L^{-1})	> 5.5
222	*n*	157
+6‰	Average $\Delta^{14}C_{DOC}$	+48‰
129‰	S.D.	97‰
+38‰	Median $\Delta^{14}C_{DOC}$	+77‰

Objective 3 - Global $DO^{14}C$ patterns

Global mean riverine DOC concentration of ~5.5 mg L^{-1}



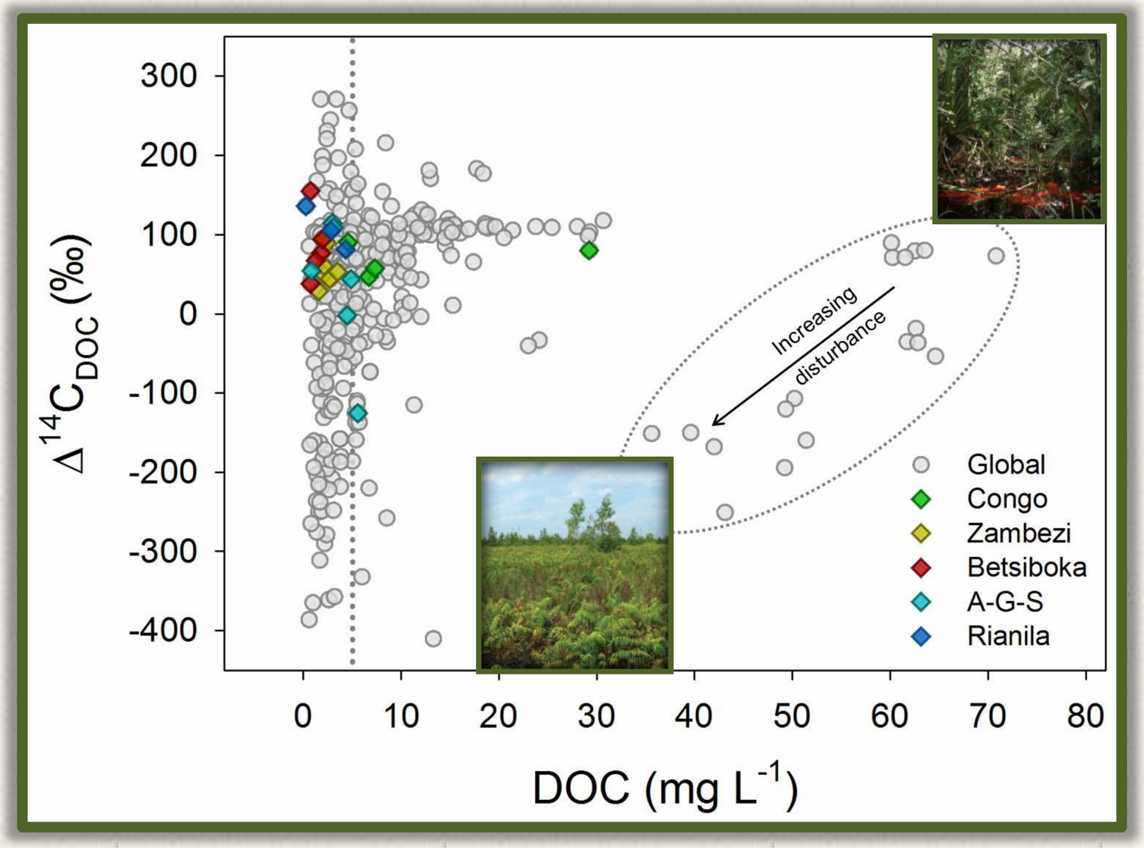
≤ 5.5	DOC (mg C L^{-1})	> 5.5
222	*n*	157
+6‰	Average $\Delta^{14}C_{DOC}$	+48‰
129‰	S.D.	97‰
+38‰	Median $\Delta^{14}C_{DOC}$	+77‰

Except **Moore *et al.*** (2013, *Nature*)

KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

Objective 3 - Global DO^{14}C patterns

Global mean riverine DOC concentration of ~5.5 mg L^{-1}



≤ 5.5	DOC (mg C L^{-1})	> 5.5
222	*n*	157
+6‰	Average $\Delta^{14}C_{DOC}$	+48‰
129‰	S.D.	97‰
+38‰	Median $\Delta^{14}C_{DOC}$	+77‰

Except **Moore *et al.*** (2013, *Nature*)

Undrained tropical peat swamp forests of Indonesia **export modern DOC**

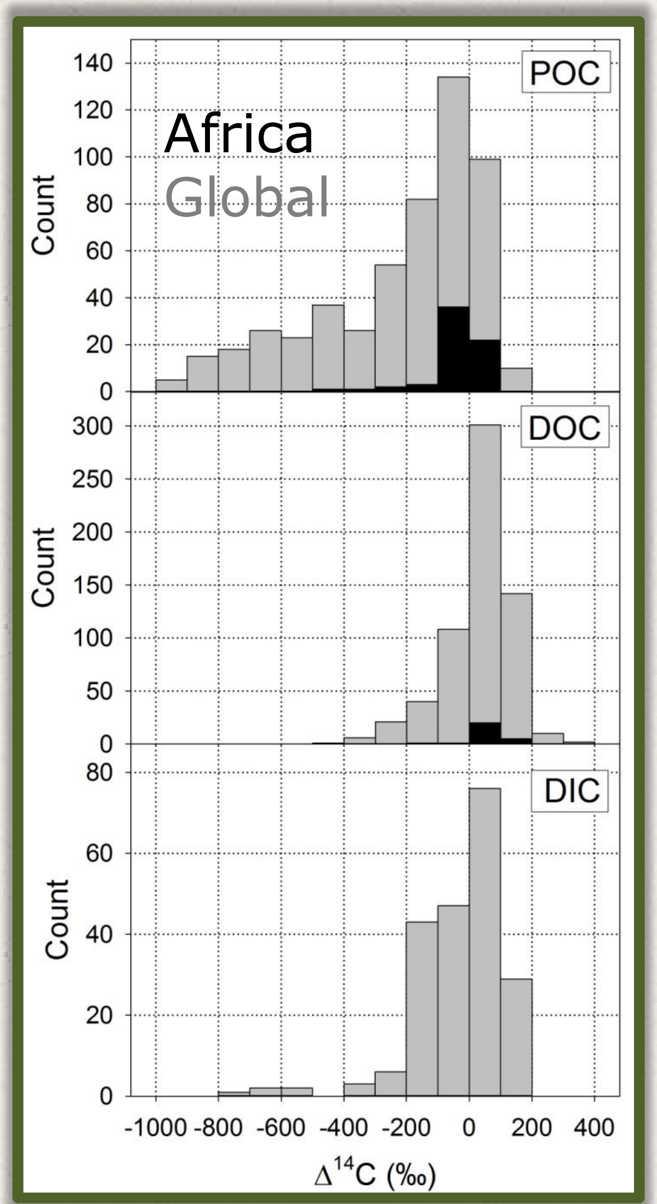
Drained tropical peat swamp forests of Indonesia **export aged DOC**

The Objectives

1. To compile literature ^{14}C (and paired ancillary) riverine data.
2. To fill one existing regional gap in the global riverine ^{14}C database (i.e. African streams and rivers).
3. To look for general ^{14}C patterns at the global scale using an assortment of biogeochemical proxies.
4. To provide first estimates for the age of river-transported C pools from the global ^{14}C compilation.

KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

Objective 4 - Global riverine ^{14}C age



^{14}C Age = ~4200 yr BP to modern

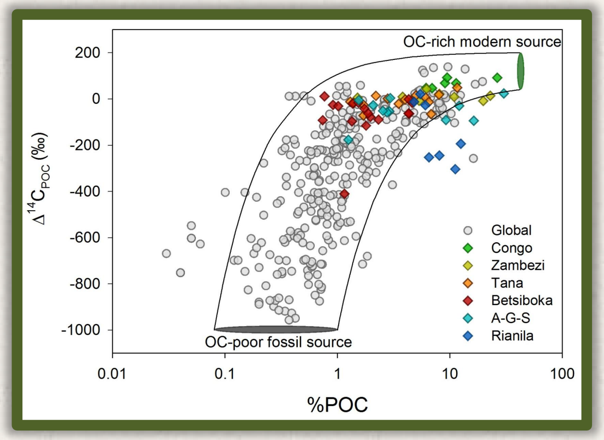
^{14}C Age = fossil to modern

^{14}C Age = ~1000 yr BP to modern

^{14}C Age = ~4200 yr BP to modern

^{14}C Age = ~11100 yr BP to modern

Objective 4 - Global riverine $PO^{14}C$ age

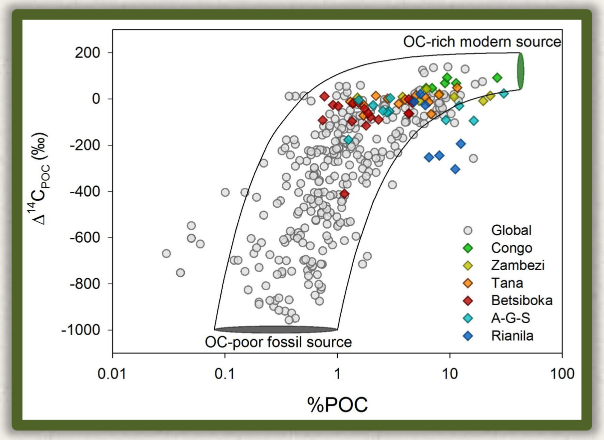


+

NEWS2 model (*Mayorga et al.*, 2010)

- Riverine nutrient export (here, TSM + POC)
- >4200 river basins

Objective 4 - Global riverine $PO^{14}C$ age



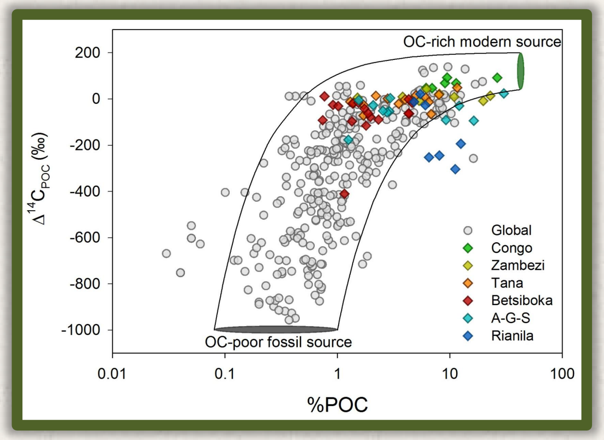
+

NEWS2 model (*Mayorga et al.*, 2010)

- Riverine nutrient export (here, TSM + POC)
- >4200 river basins

TSM class (mg L^{-1})	% to POC flux	Median $\Delta^{14}C_{POC}$ (*n*)
0-10	0.4	-8 (23)
10-100	26.9	-65 (72)
100-1000	34.7	-148 (81)
1000-10000	30.7	-276 (32)
>10000	7.3	-746 (31)

Objective 4 - Global riverine PO^{14}C age



+

<u>NEWS2 model</u> (*Mayorga et al.*, 2010)

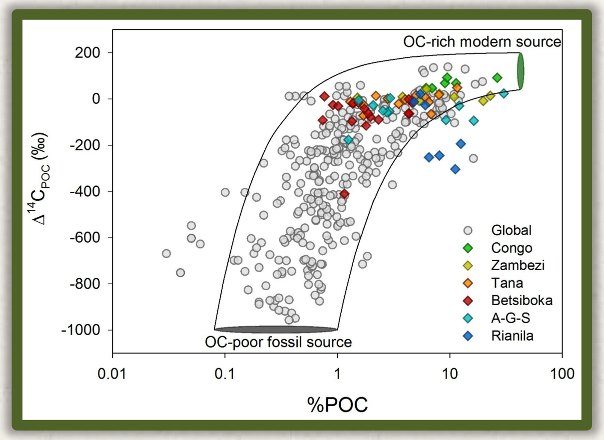
- Riverine nutrient export (here, TSM + POC)
- >4200 river basins

TSM class (mg L^{-1})	% to POC flux	Median $\Delta^{14}C_{POC}$ (*n*)
0-10	0.4	-8 (23)
10-100	26.9	-65 (72)
100-1000	34.7	-148 (81)
1000-10000	30.7	-276 (32)
>10000	7.3	-746 (31)

Estimate global riverine **$\Delta^{14}C_{POC}$** signature of **−208‰ (~1800 y^{-1} BP)**

Average contribution of **fossil C sources** of **20%**

Objective 4 - Global riverine $PO^{14}C$ age



\+ NEWS2 model (*Mayorga et al.*, 2010)

- Riverine nutrient export (here, TSM + POC)
- >4200 river basins

TSM class (mg L^{-1})	% to POC flux	Median $\Delta^{14}C_{POC}$ (*n*)
0-10	0.4	-8 (23)
10-100	26.9	-65 (72)
100-1000	34.7	-148 (81)
1000-10000	30.7	-276 (32)
>10000	7.3	-746 (31)

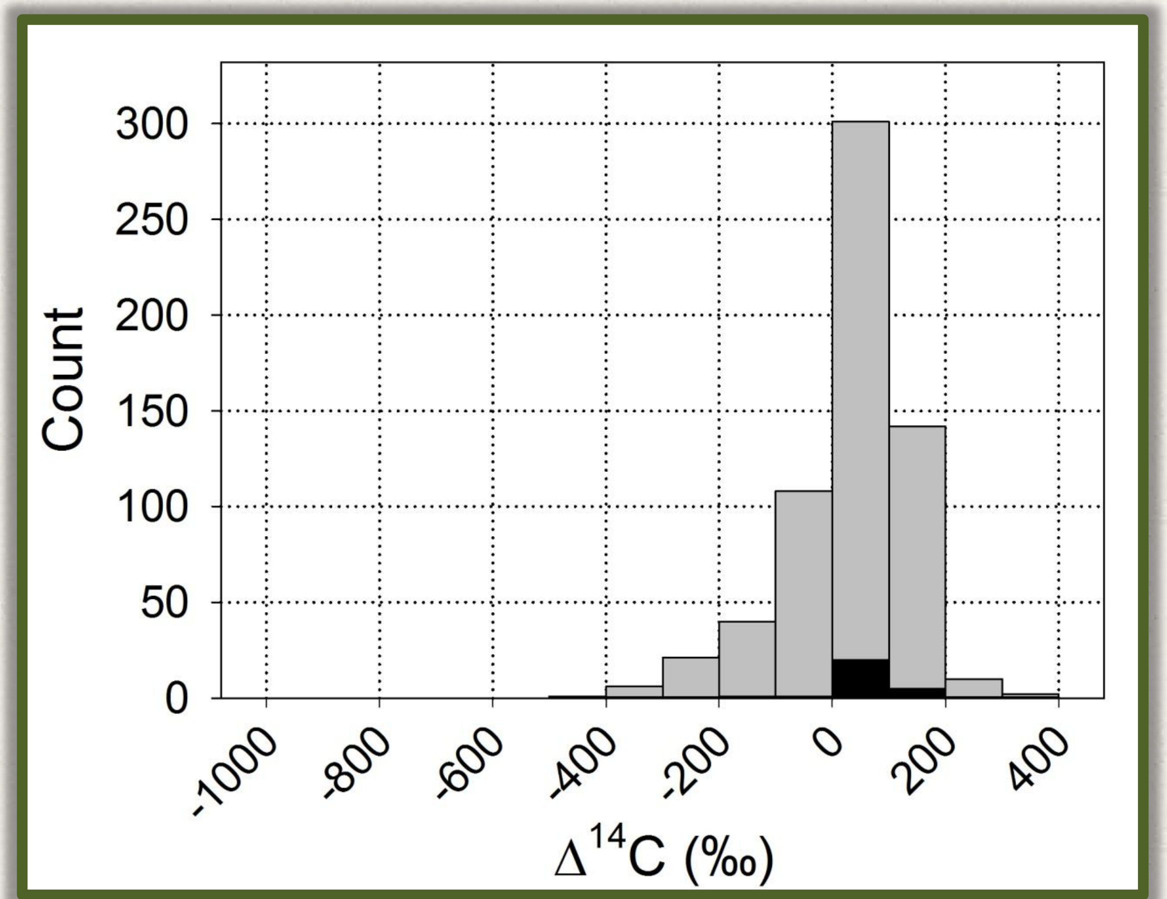
Estimate global riverine **$\Delta^{14}C_{POC}$** signature of **−208‰ (~1800 y^{-1} BP)**

Average contribution of **fossil C sources** of **20%**

Importance of highly turbid rivers in the delivery of aged C to coastal zones

Objective 4 - Global riverine DO^{14}C age

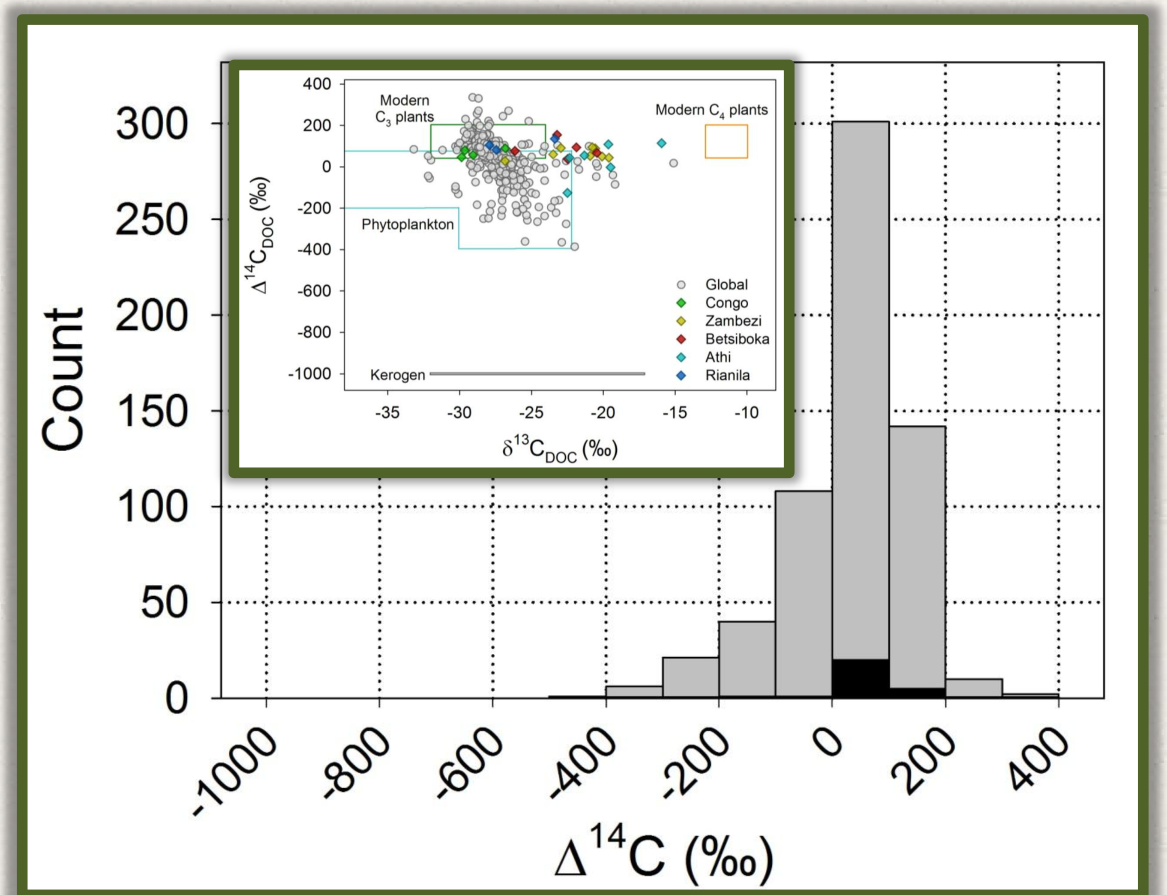
Mean $\Delta^{14}C_{DOC}$ = +30‰ ≈ Median $\Delta^{14}C_{DOC}$ =+51‰



KU LEUVEN
ULg UNIVERSITÉ de Liège
erc European Research Council

Objective 4 - Global riverine $DO^{14}C$ age

Mean $\Delta^{14}C_{DOC}$ = +30‰ ≈ Median $\Delta^{14}C_{DOC}$ =+51‰

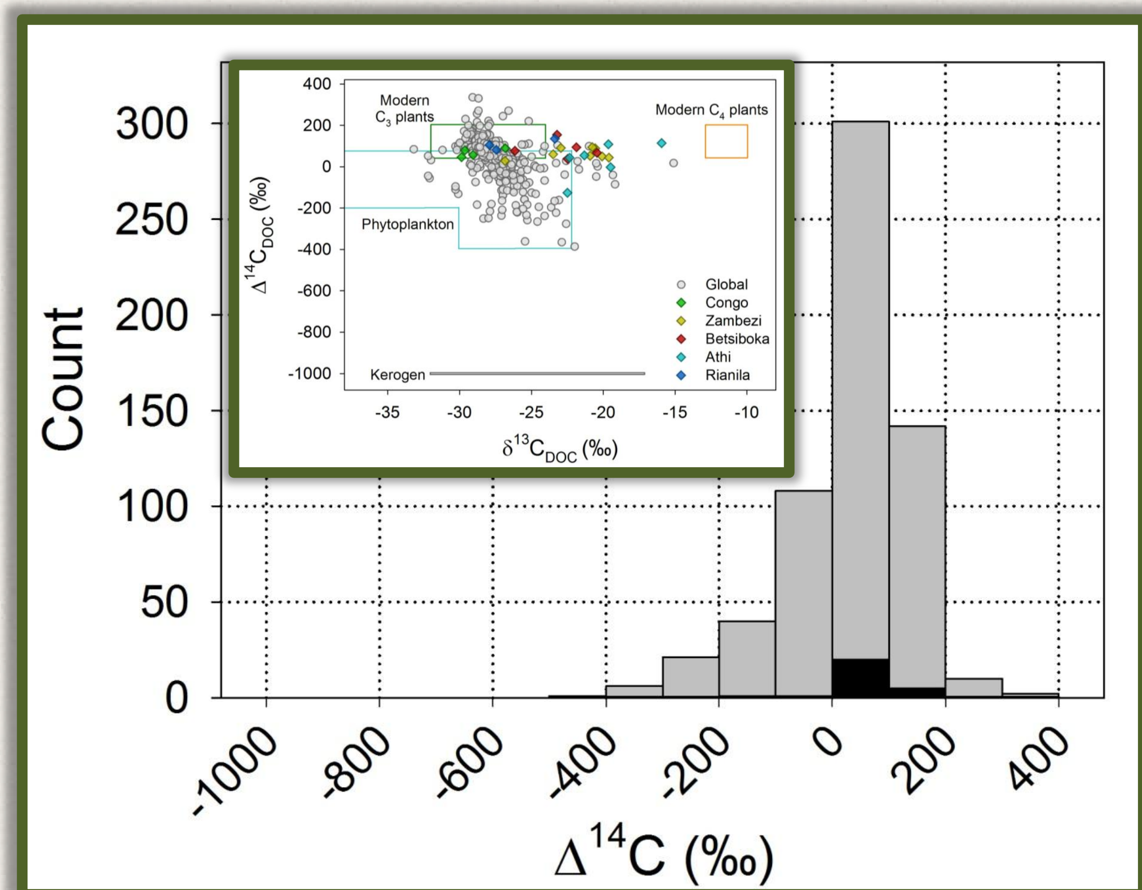


Riverine DOC typically of *modern C_3 origin*

KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

Objective 4 - Global riverine $DO^{14}C$ age

Mean $\Delta^{14}C_{DOC}$ = +30‰ ≈ Median $\Delta^{14}C_{DOC}$ =+51‰

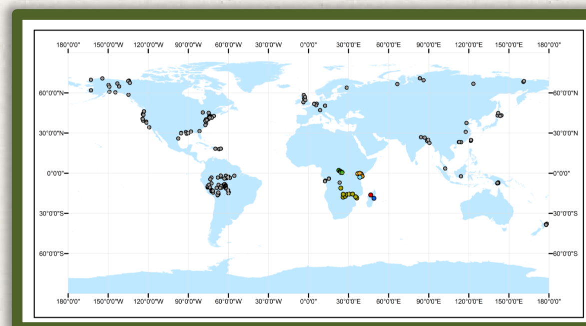


Riverine DOC typically of *modern C_3 origin*

<u>Possible caveats:</u>

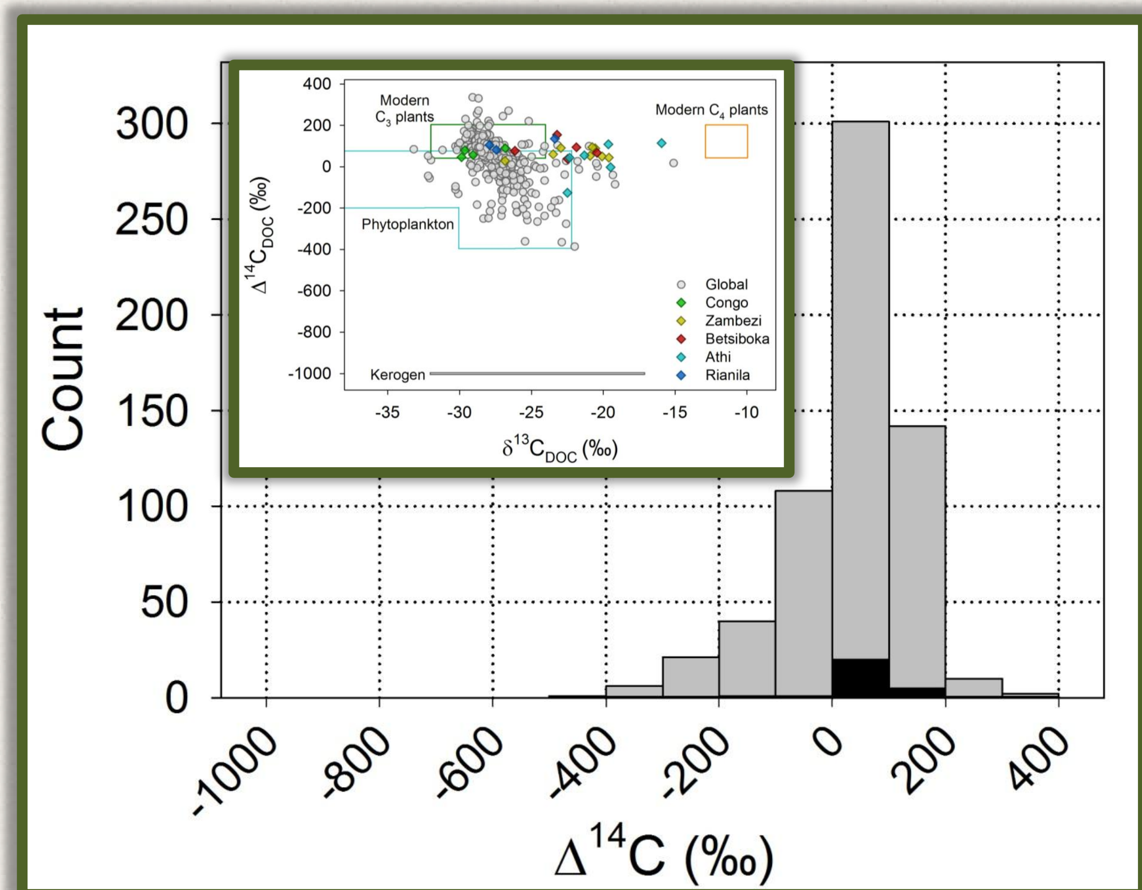
Most $^{14}C_{DOC}$ data from:

1. Small basins
2. Focus on basin export
3. Single site sampling



Objective 4 - Global riverine DO^{14}C age

Mean $\Delta^{14}C_{DOC}$ = +30‰ ≈ Median $\Delta^{14}C_{DOC}$ =+51‰

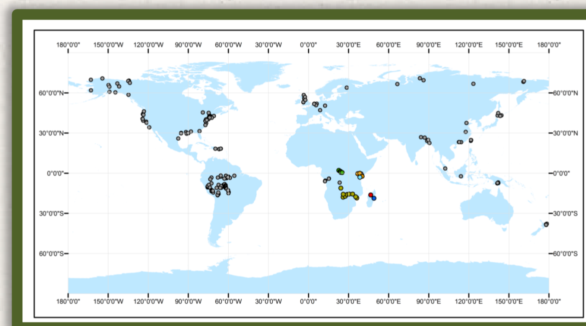


Riverine DOC typically of *modern* C_3 *origin*

<u>Possible caveats:</u>

Most $^{14}C_{DOC}$ data from:

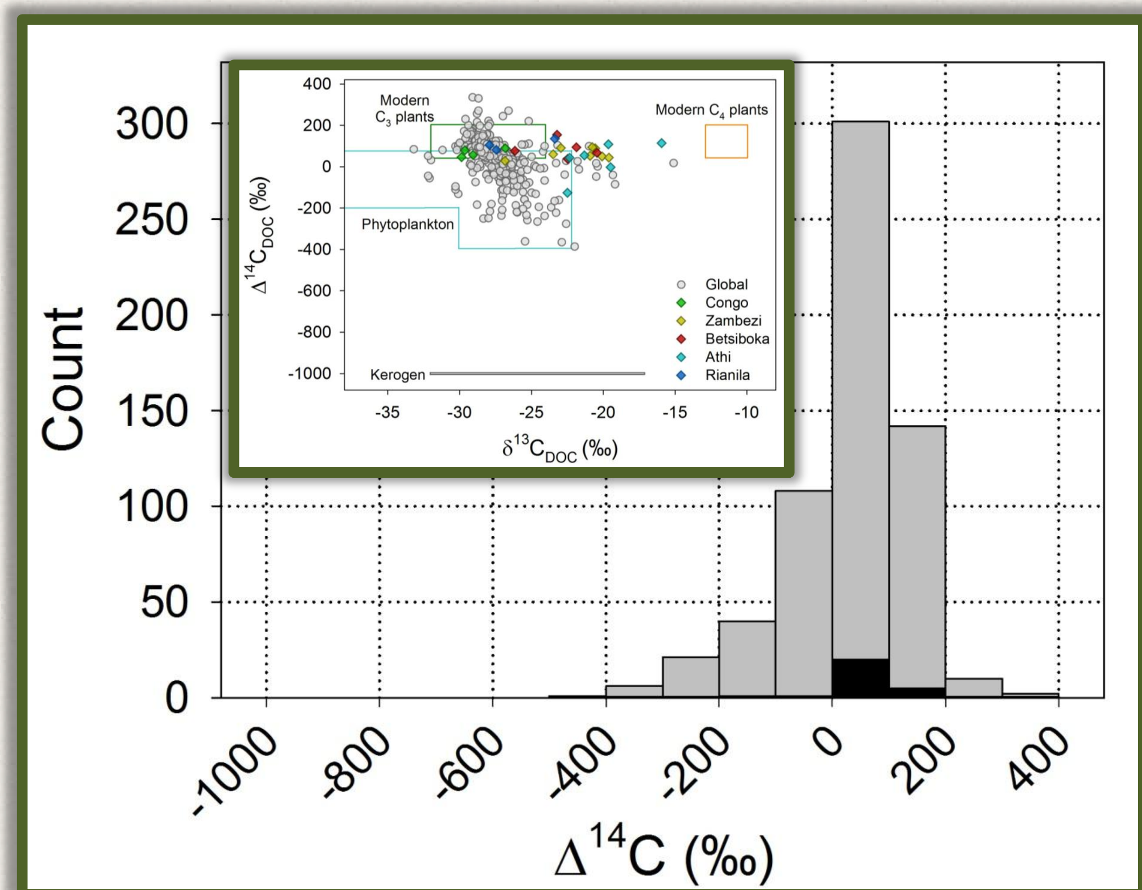
1. Small basins
2. Focus on basin export
3. Single site sampling



Downstream processing + preferential mineralization?

Objective 4 - Global riverine $DO^{14}C$ age

Mean $\Delta^{14}C_{DOC}$ = +30‰ ≈ Median $\Delta^{14}C_{DOC}$ =+51‰

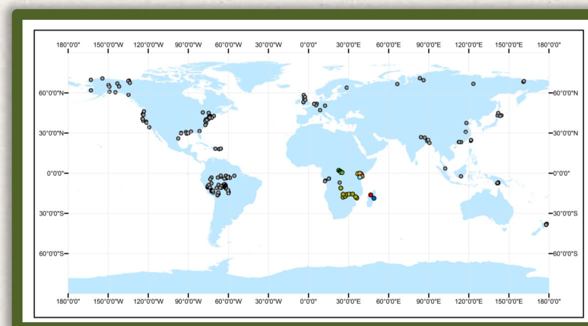


Riverine DOC typically of *modern C_3 origin*

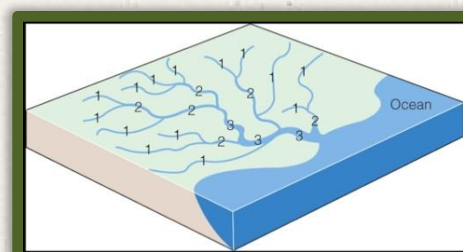
<u>Possible caveats:</u>

Most $^{14}C_{DOC}$ data from:

1. Small basins
2. Focus on basin export
3. Single site sampling



Downstream processing + preferential mineralization?

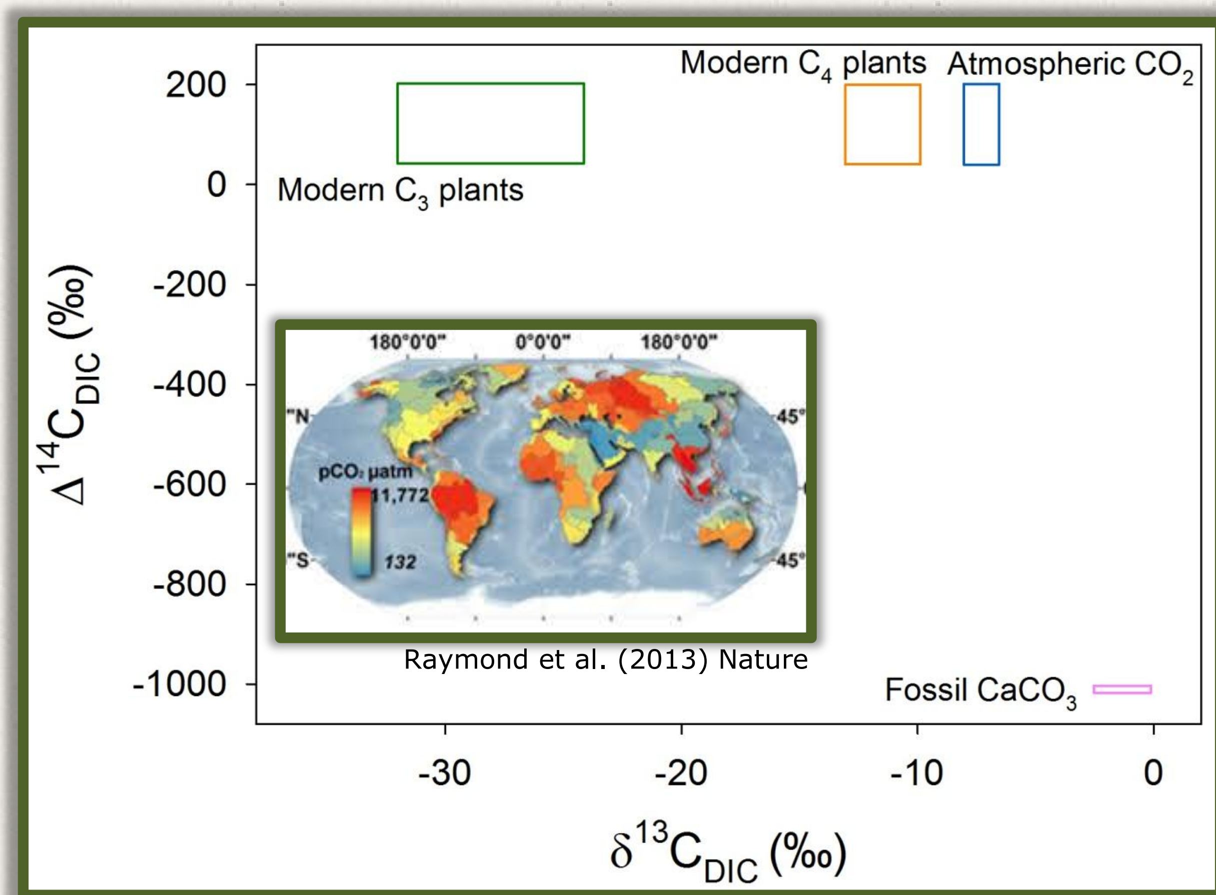


$\Delta^{14}C_{OC}$ and stream order?

Objective 4 - Global riverine DI^{14}C age

Freshwater CO_2 evasion ≈ 2.1 Pg C y^{-1}

(Equivalent to approximately 1/5 of annual anthropogenic CO_2 emissions!)

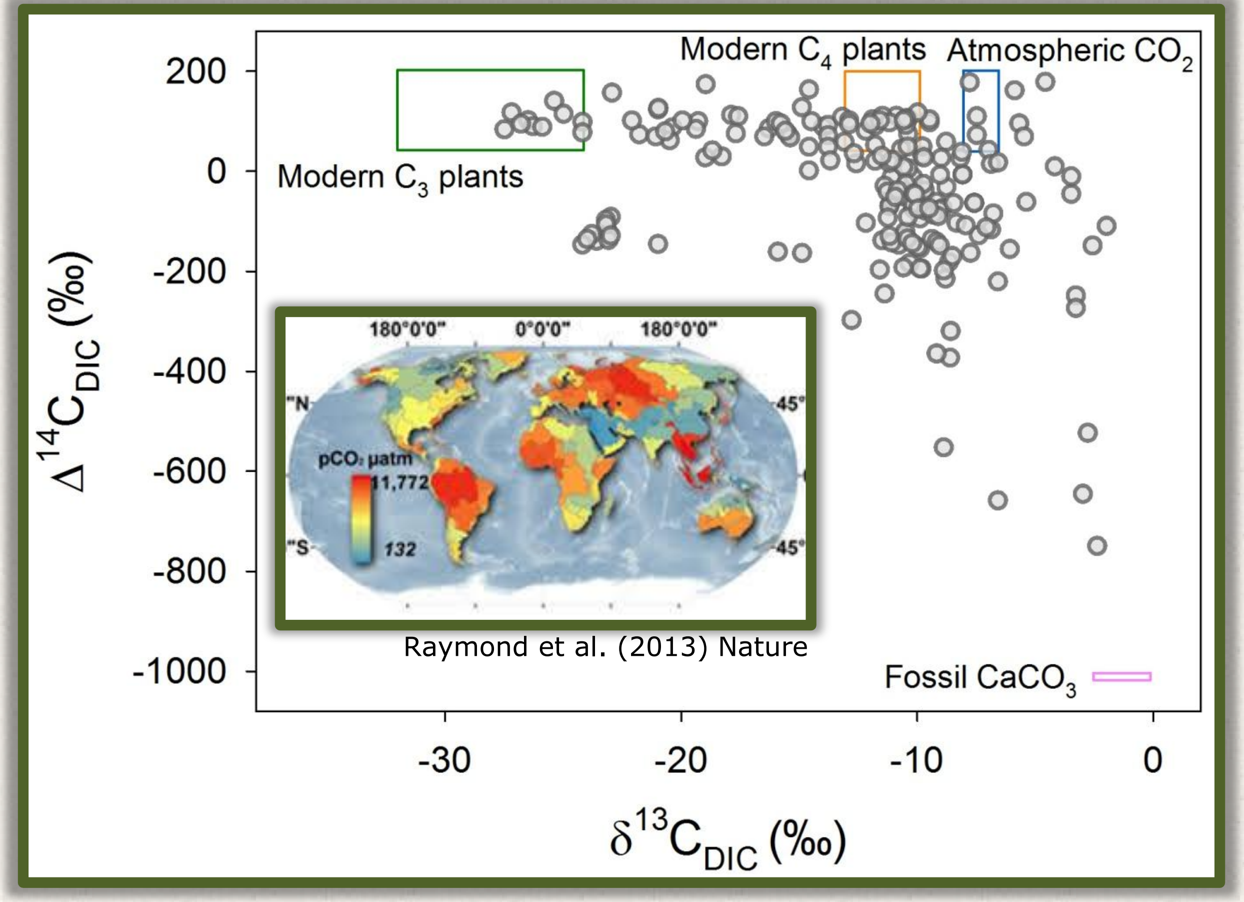


Terrestrial respiration vs aquatic mineralization?

Objective 4 - Global riverine $DI^{14}C$ age

Largely consistent with a continuous spectrum between 2 main end-members

1. Modern DIC with a low $\delta^{13}C$ signature (silicate-weathering driven by respiration of modern, C_3-derived OM)



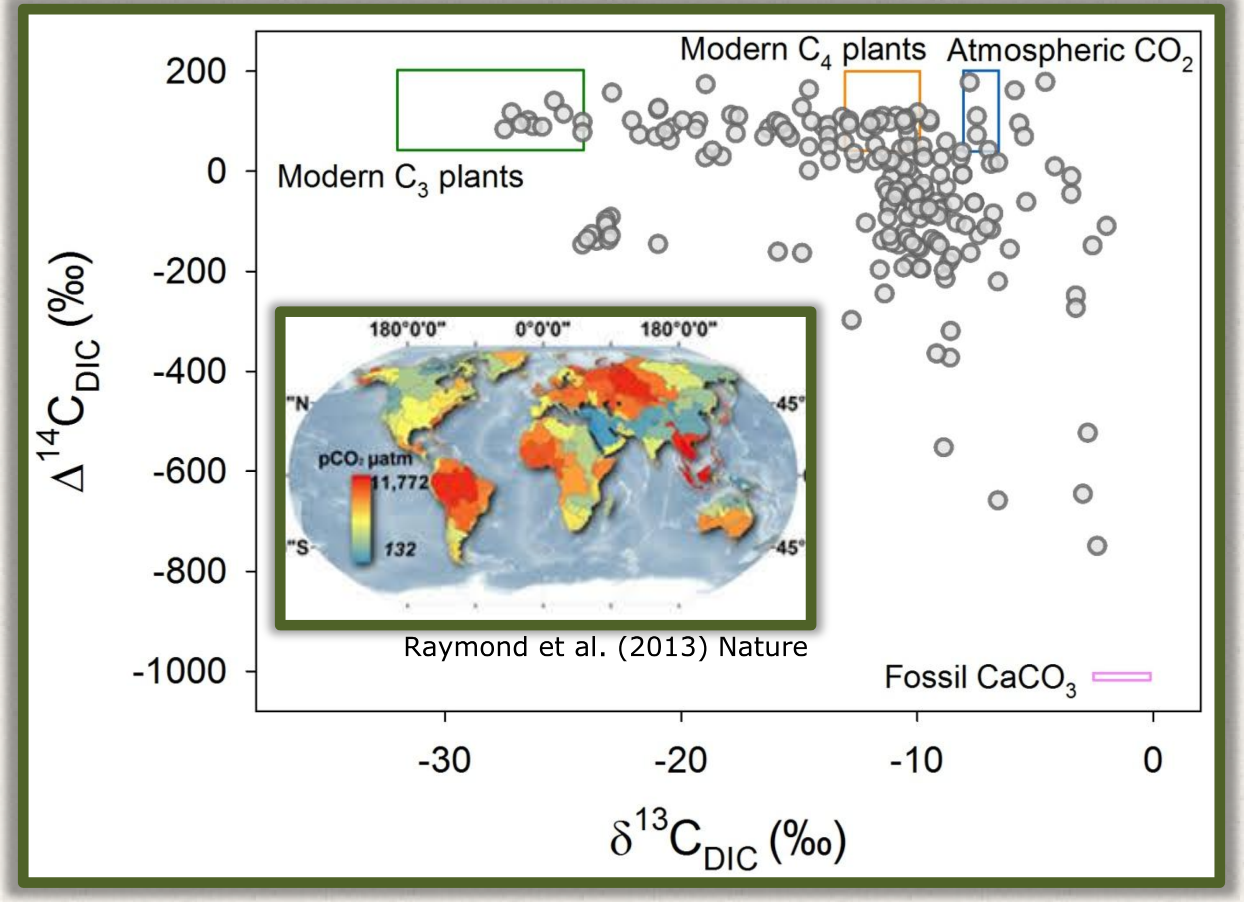
Raymond et al. (2013) Nature

KU LEUVEN ULg UNIVERSITÉ de Liège erc European Research Council

Objective 4 - Global riverine DI^{14}C age

Largely consistent with a continuous spectrum between 2 main end-members

1. Modern DIC with a low $\delta^{13}C$ signature
   (silicate-weathering driven by respiration of modern, C_3-derived OM)



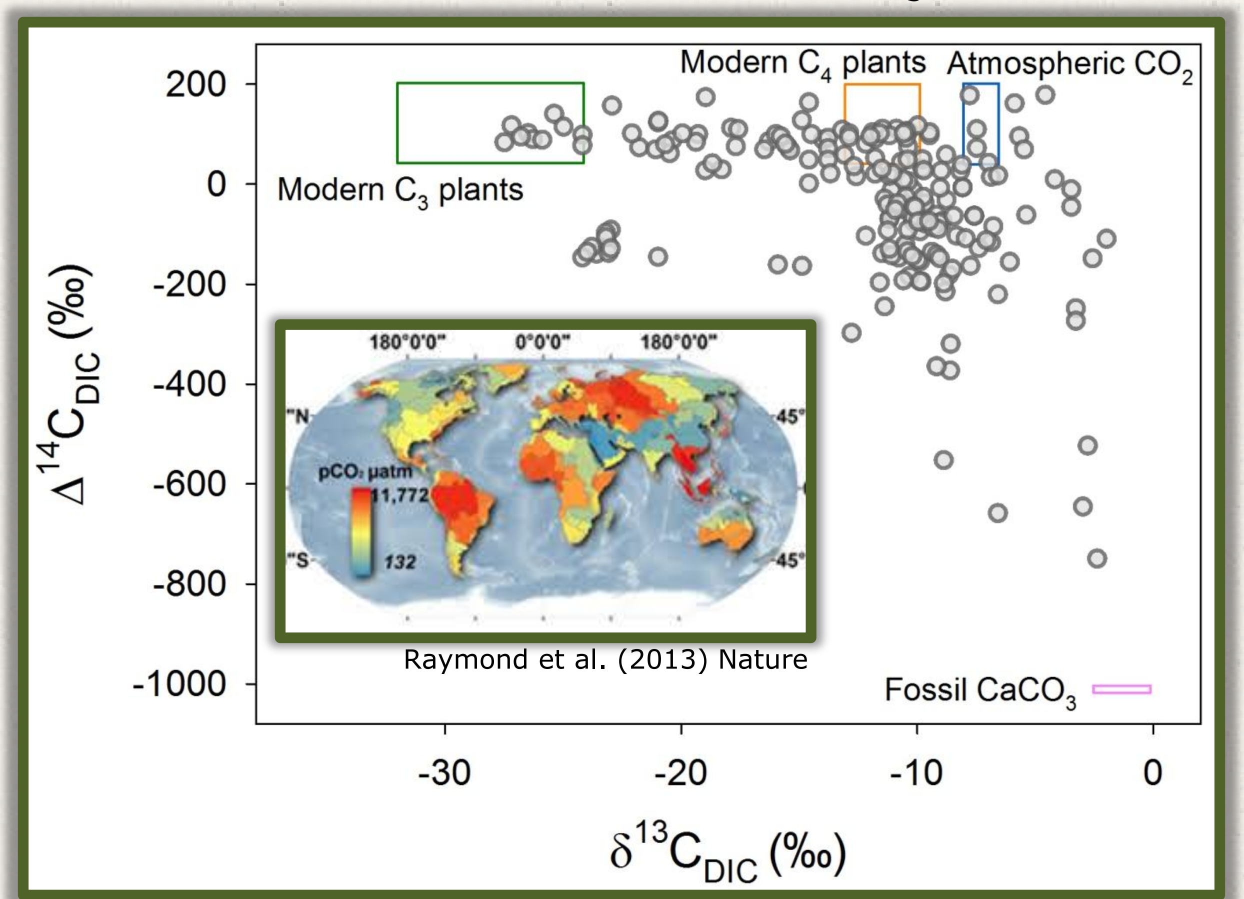
Raymond et al. (2013) Nature

2. An old end-member with a ^{13}C-enriched signature
   (waters in which weathering of fossil carbonates dominate)

Objective 4 - Global riverine $DI^{14}C$ age

Considering that:

1. The median $\Delta^{14}C_{DIC}$ value is modern (+2‰, n=209), and
2. The dataset is partially influenced by fossil $CaCO_3$ weathering



Hints at the prevalence of relatively recent sources of respiratory CO_2 in most river systems

Conclusions

1. We estimate a global riverine POC age of ~1800 yr BP

2. Global riverine DOC is typically of modern C_3 origin

3. Data indicate that DIC is sourced from respiratory CO_2 in most river systems

Conclusions

1. We estimate a global riverine POC age of ~1800 yr BP

2. Global riverine DOC is typically of modern C_3 origin

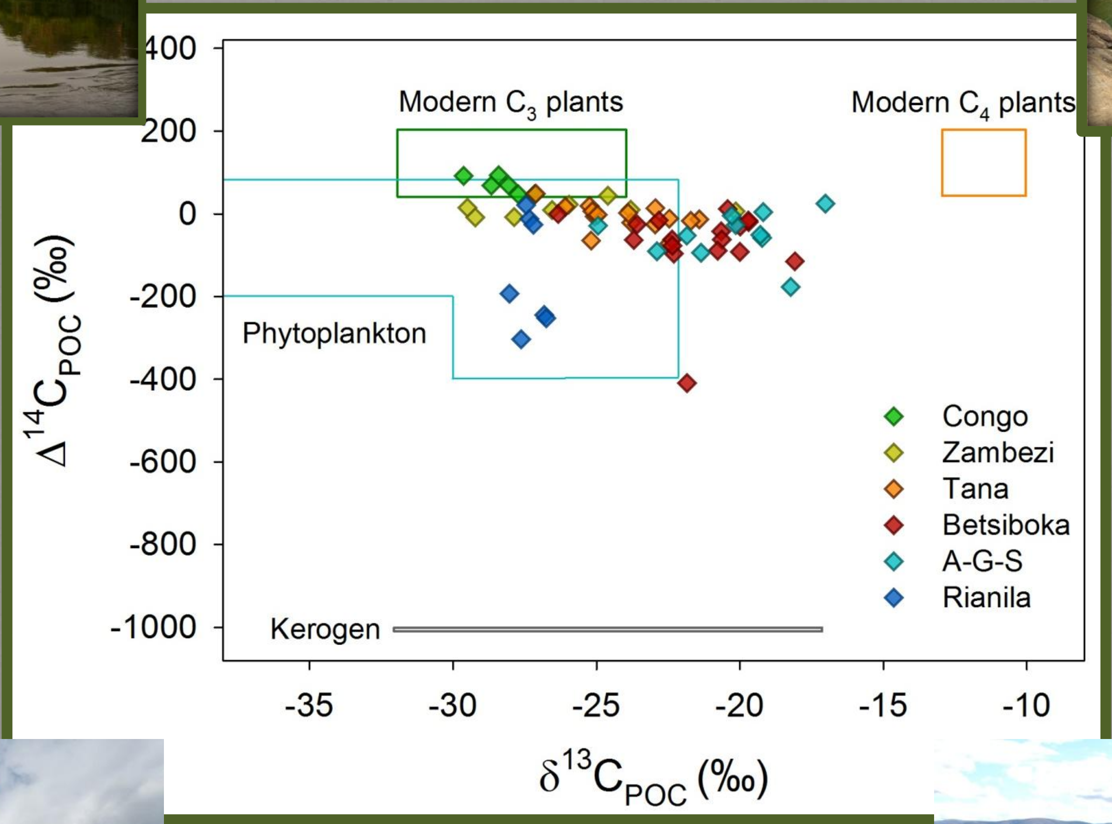
3. Data indicate that DIC is sourced from respiratory CO_2 in most river systems

Final Remarks

1. Ancillary data (e.g. C concentrations, $\delta^{13}C$ data) are not always reported, leading to a crucial loss of information

2. A greater basin-wide focus will undoubtedly provide further direction as to the extent of within-river processing of the aged versus modern C fractions

Objective 2 - African riverine $PO^{14}C$

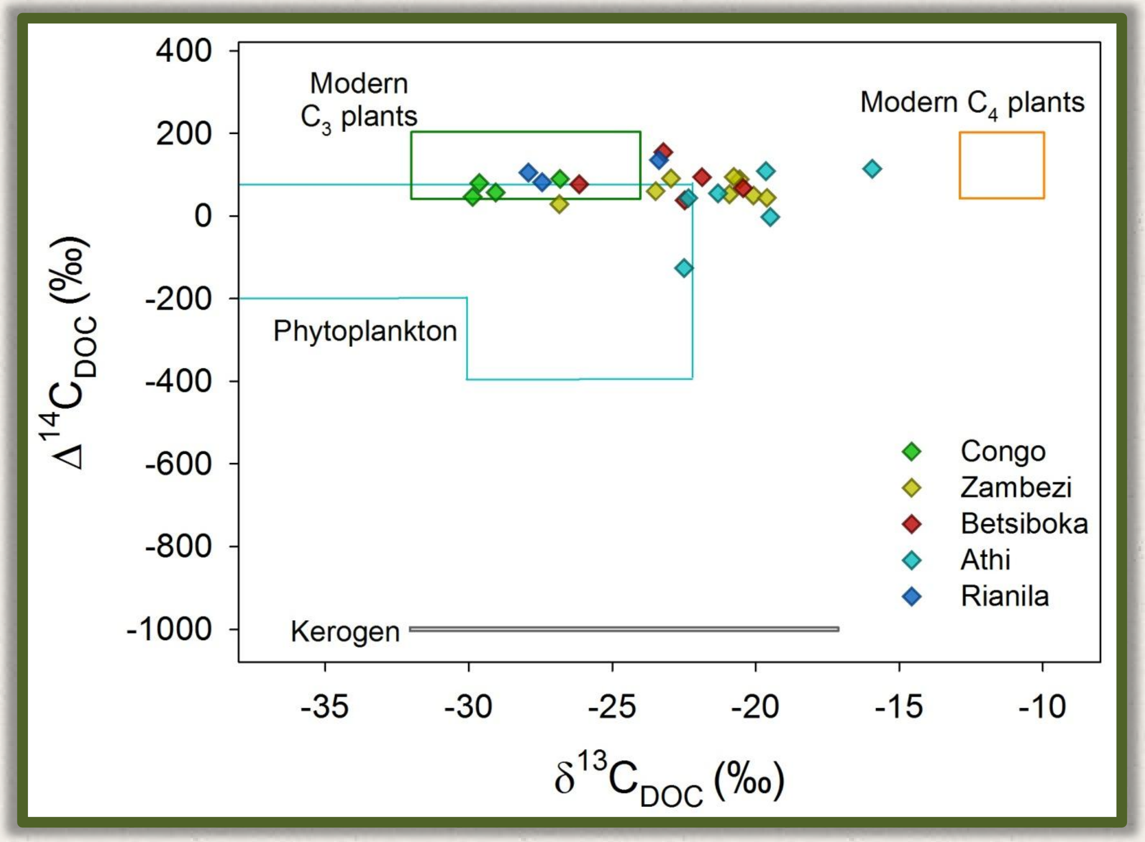


KU LEUVEN

ULg UNIVERSITÉ de Liège

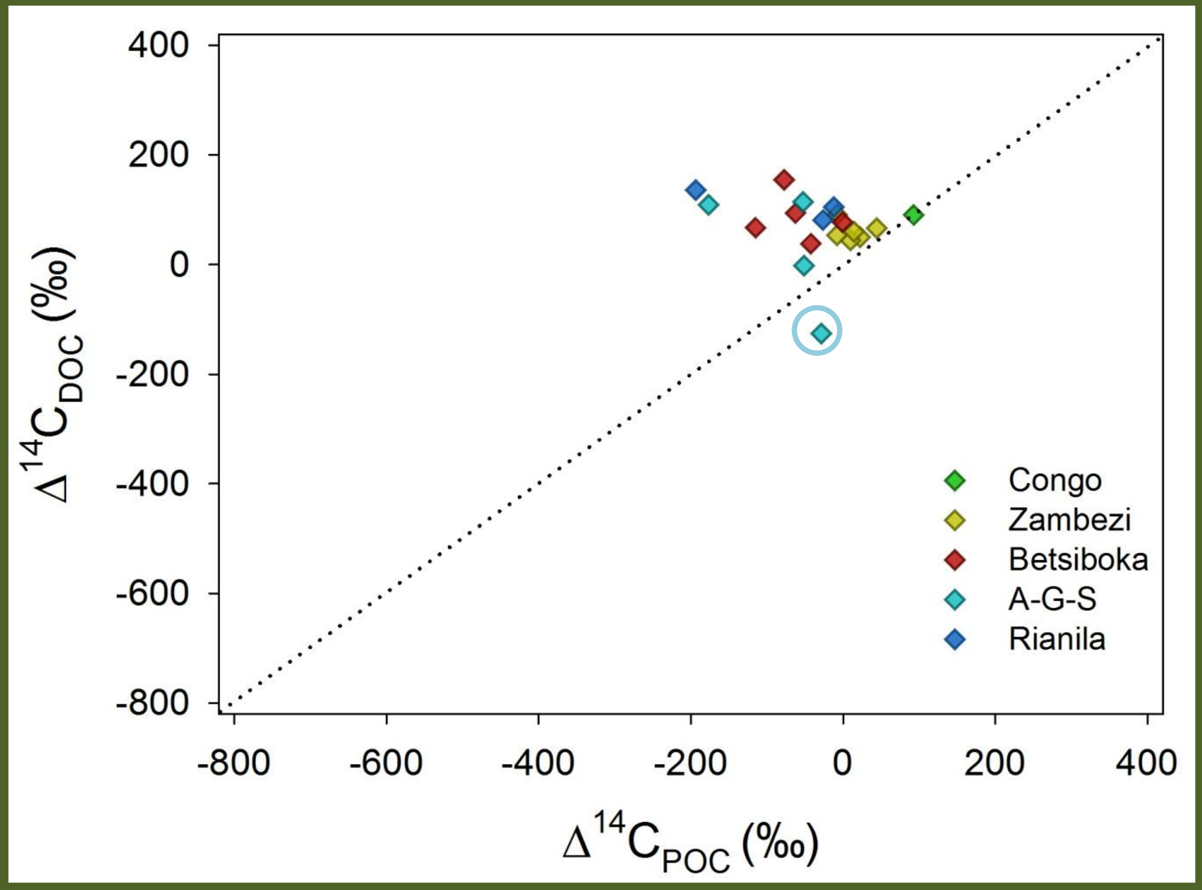
erc European Research Council

Objective 2 - African riverine DO^{14}C



OC – African Rivers

POC pool generally older than the DOC pool



hotstuffclimatenet.org

kenyawater.wordpress.com