Reconstitutions climatiques sur la base d'assemblages polliniques de référence depuis le LGM en Europe

Approche multi-méthodes : transfert, régression et probabiliste

Après biomisation à calibration globale (14C radiocarbon date)

2 biomization schemas for european climate reconstructions

1. Our table (main advantage: hot and cold steppes distinction)
2. Second biomization schema (super PFTs, Binney et al., 2017)
3. Megabiome table implemented in R at >30°N latitudes (Cao and Tian, 2019 and Dallmeyer et al., 2019)

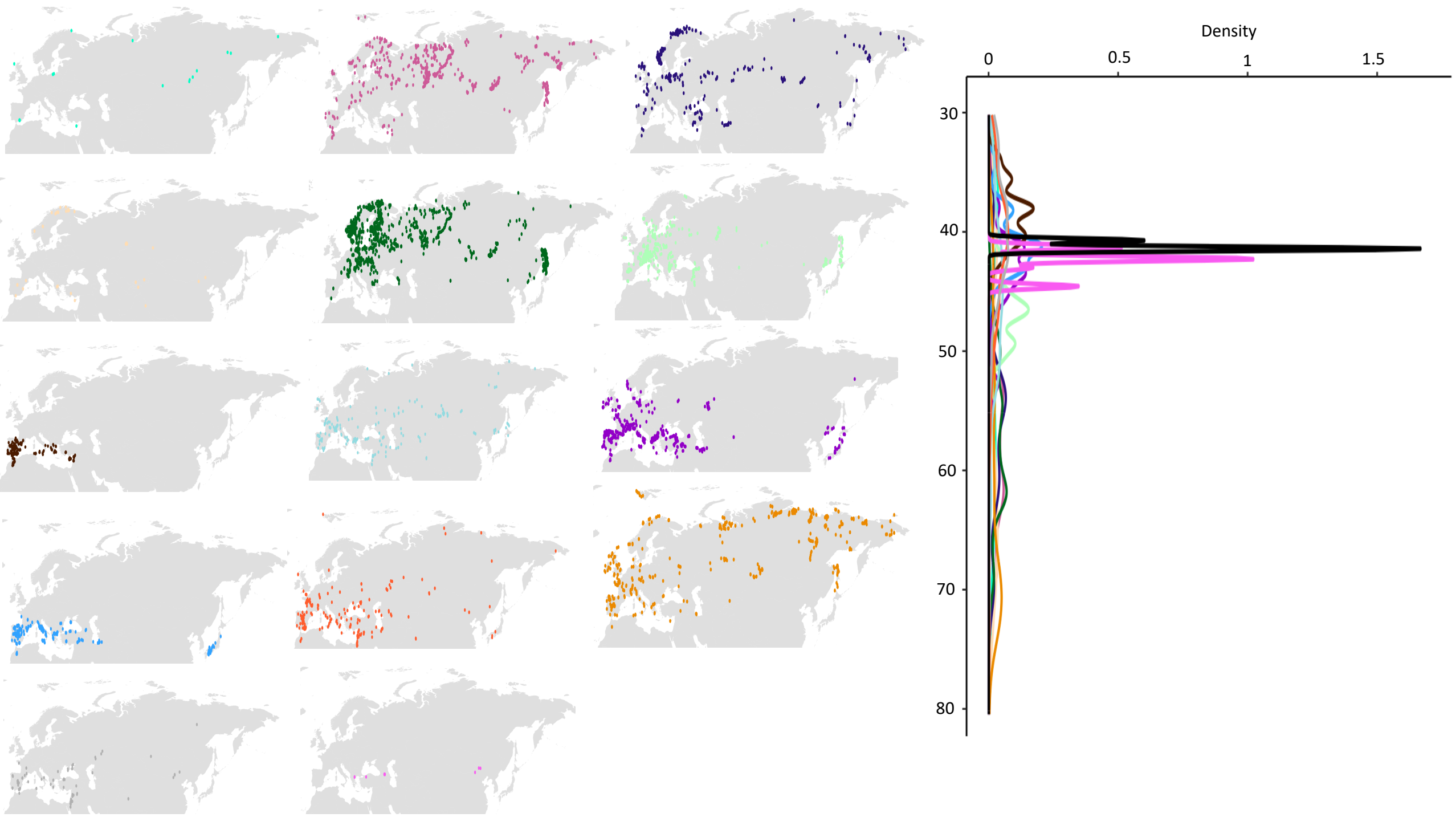
Etat d'avancement – 25 juill. 24

Megabiomes – Binney et al., 2017, Combinaison of pollen-based biome types into megabiomes (Europe)

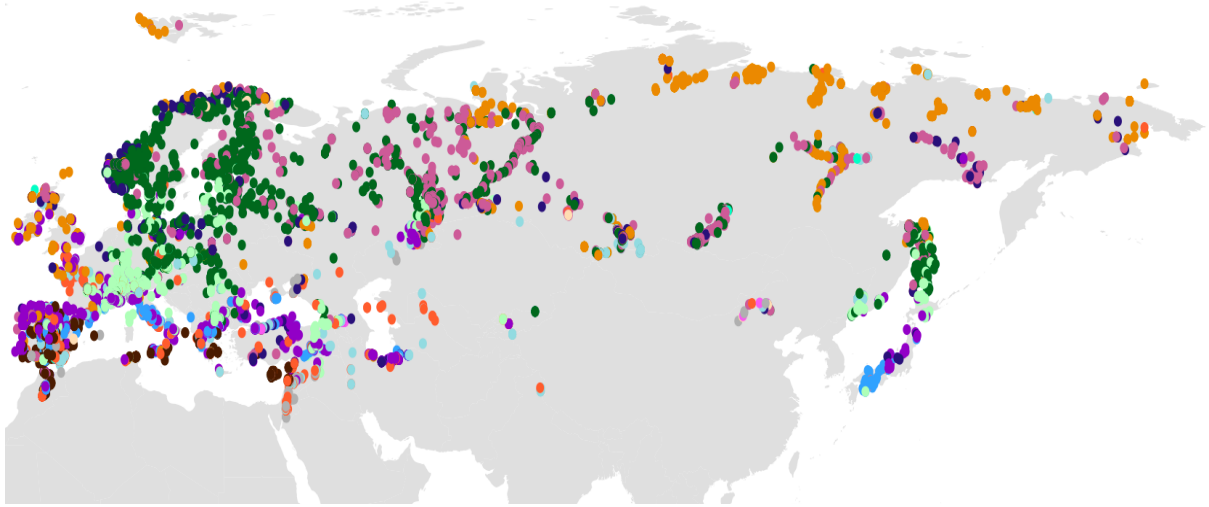
Plant functional types (25)

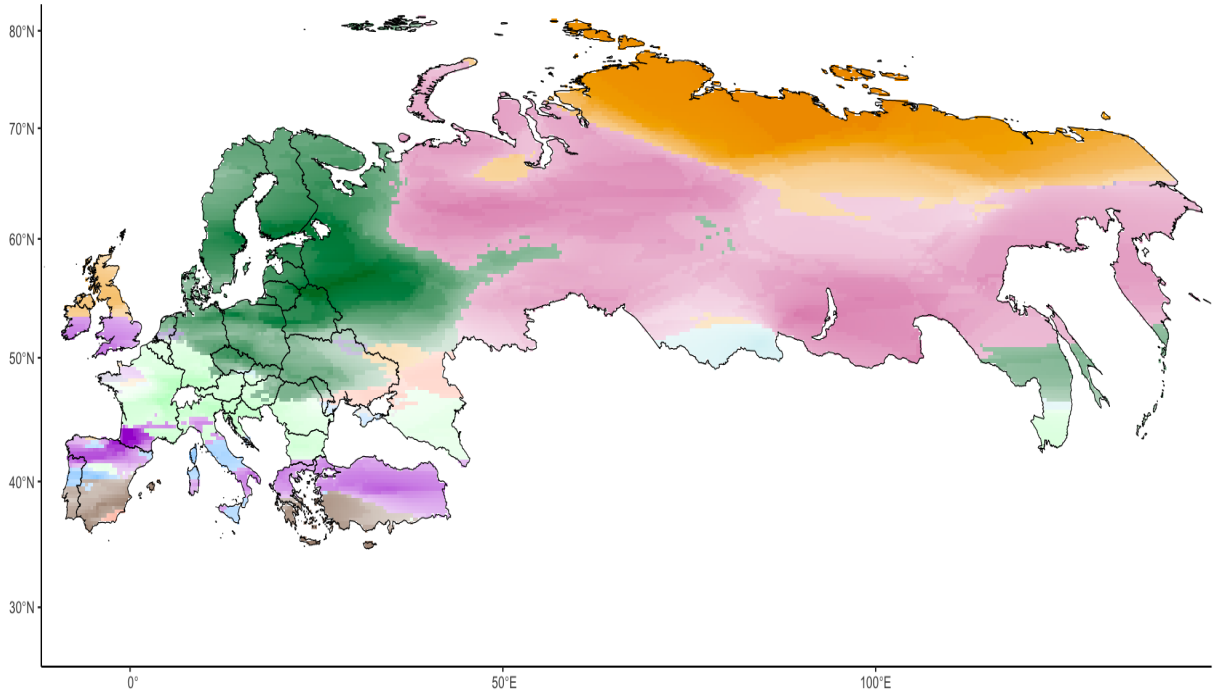
BS
PI
BEC
BCTC
CTC1
TSAA
TSBS
TS
TS1
TS2
WTE
WTE1
WTE2
EC
AA
COGS
H
SF
WAGS
DF
GR
SFDF
AQ
AN
ECPI

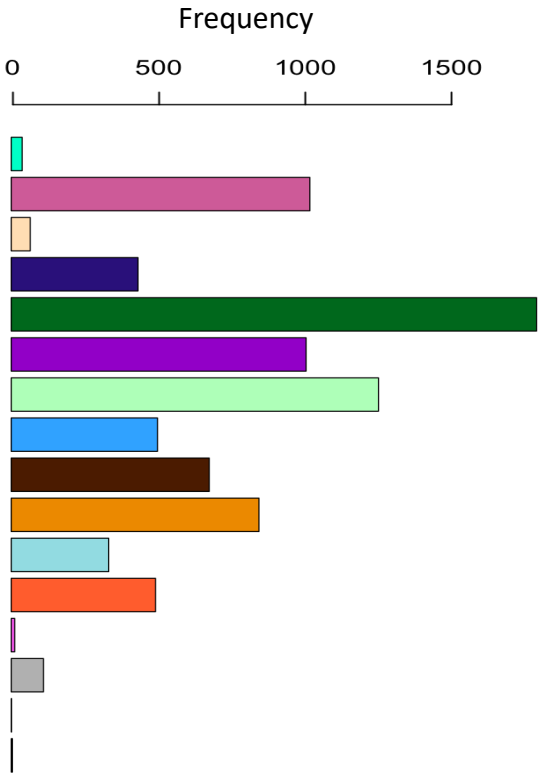
Biome code	**BiomPIONe name**
WAMX	Warm mixed forest
COMX	Cool mixed forest
XERO	Xerophytic shrubs
COCO	Cool conifer forest
TAIG	Taiga
TEDE	Temperate deciduous forest
CLMX	Cold mixed forest
TUND	Tundra
WAST	Warm steppes
CODE	Cold desert
COST	Cool steppes
HODE	Hot desert
ANTH	Anthrogenic
AQUA	Aquatic
CLDE	Cold deciduous forest
PION	Pioner


Density
0
0.5
1
1.5
30
40
50
60
70
80

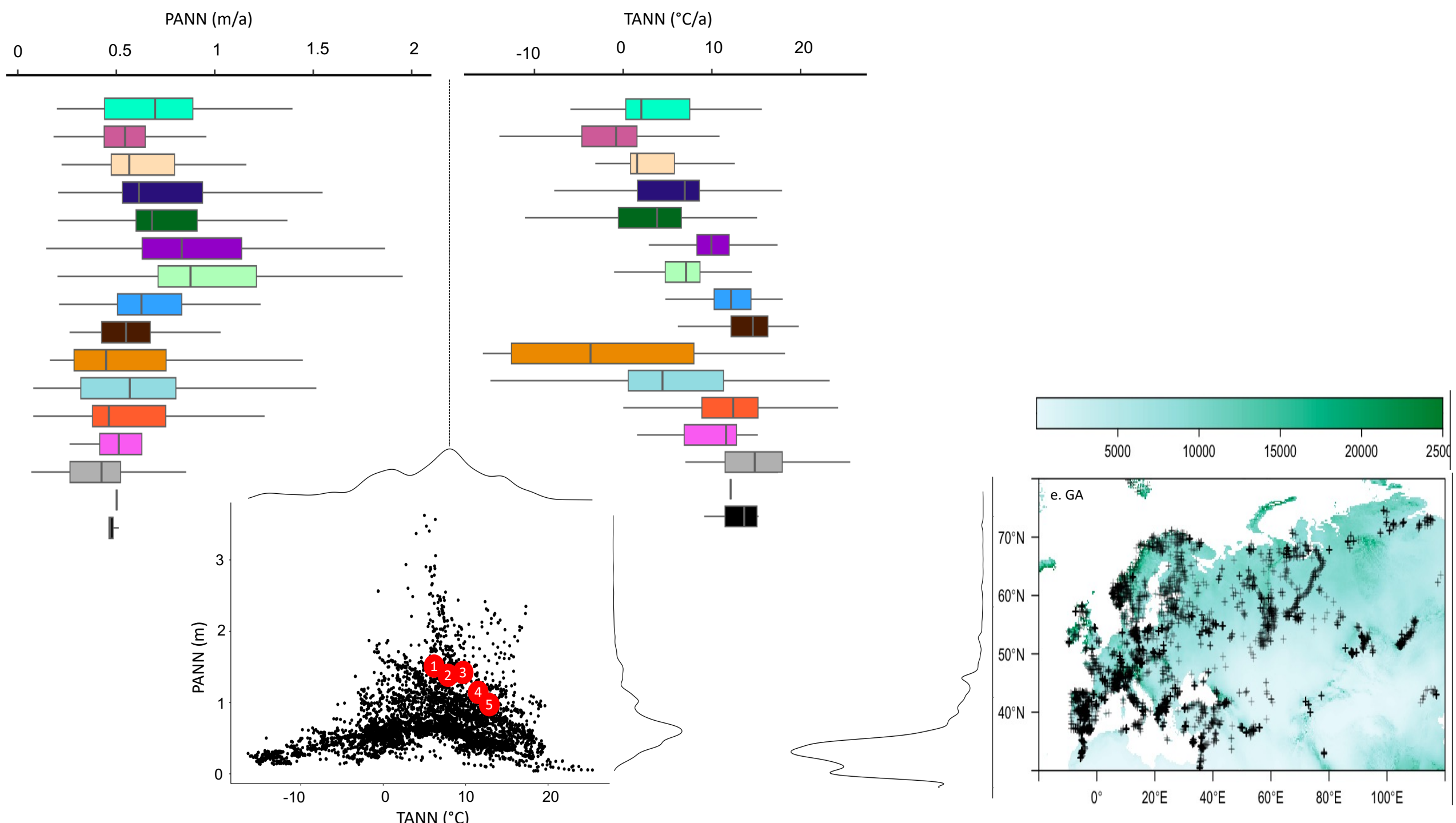
Modern pollen assemblages → dominant biomes

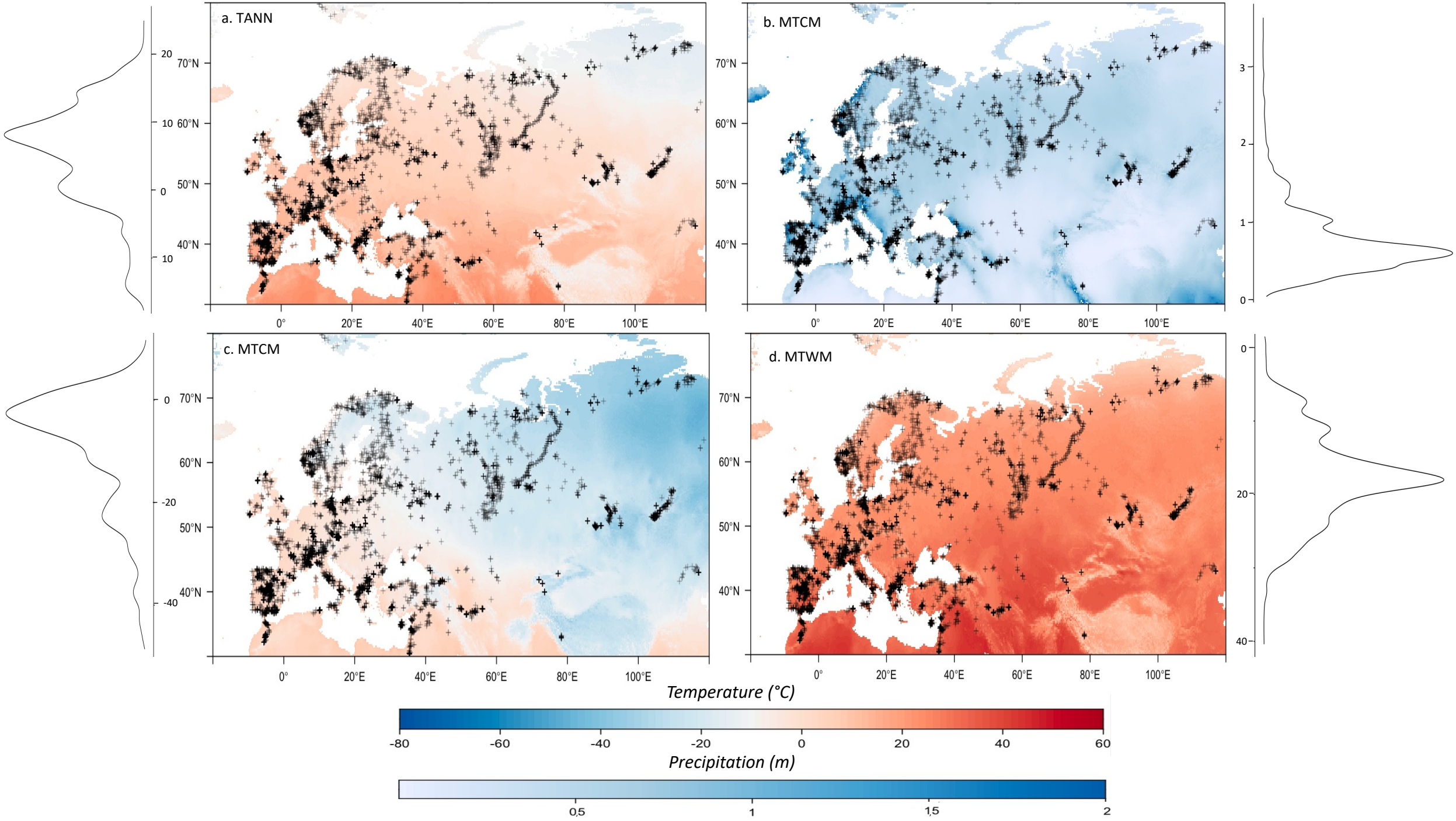


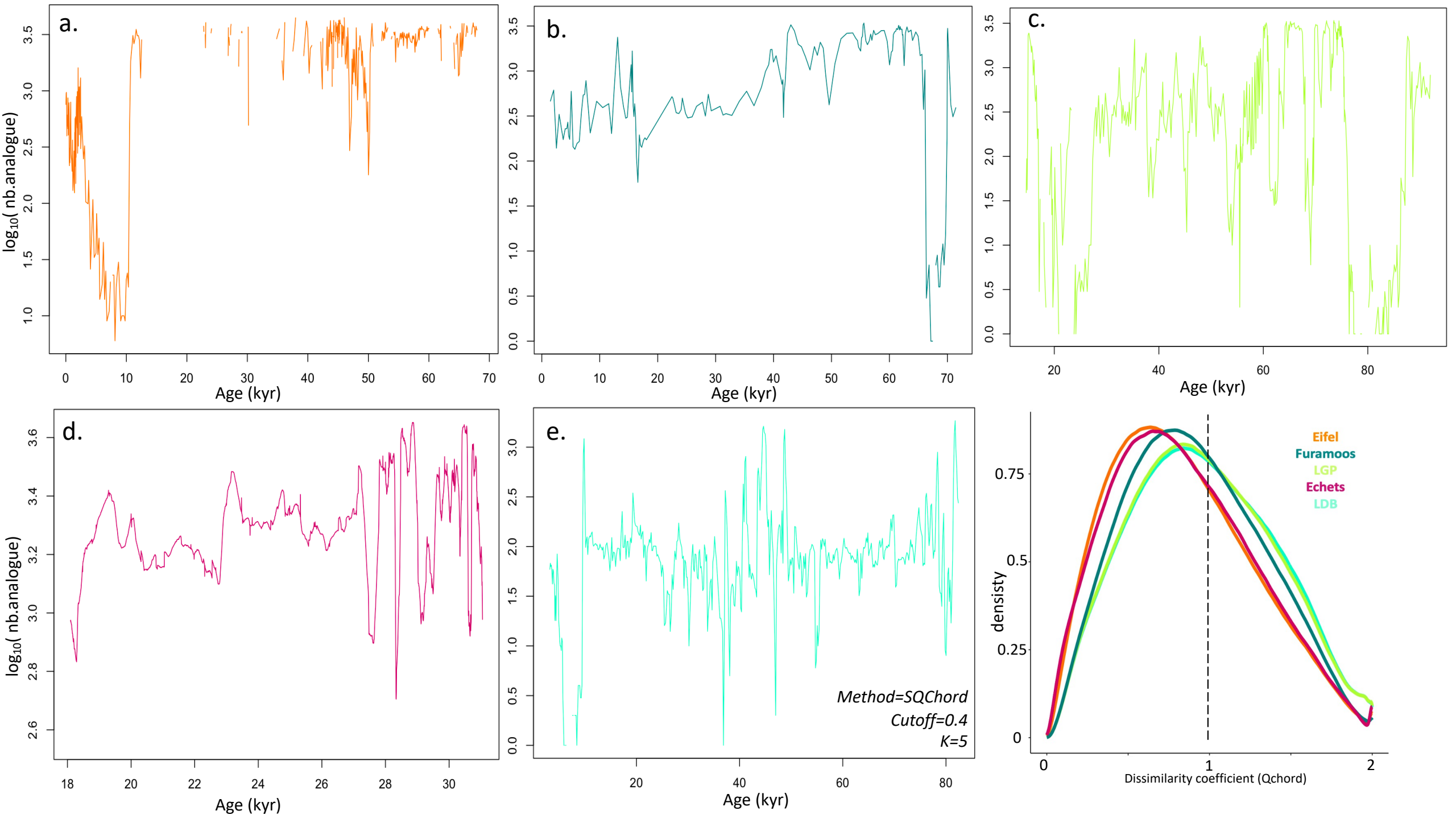




Original biome		
'#65B2FF'	WAMX	Warm mixed forest
'#0020CA'	COMX	Cool mixed forest
'#8EA228'	XERO	Xerophytic shrubs
'#FF9AFD'	COCO	Cool conifer forest
'#BAFF35'	TAIG	Taiga
'#FFBA95'	TEDE	Temperate deciduous forest
'#FFBA35'	CLMX	Cold mixed forest
'#E7E718'	TUND	Tundra
'#E7E718'	WAST	Warm steppes
'#65FF9A'	CODE	Cold desert
'#AE7D20	HODE	Hot desert
'#D29E96'	COST	Cool steppes
'#EE82EE'	ANTH	Anthrogenic
'#0000FF'	AQUA	Aquatic
'#E7E718'	CLDE	Cold deciduous forest
'#F7FFCA'	PION	Pioner


PANN (m/a)
0
0.5
1
1.5
2
TANN (°C/a)
-10
0
10
20
PANN (m)
TANN (°C)
1
2
3
4
5
5000
10000
15000
20000
e. GA
70°N
60°N
50°N
40°N
0°
20°E
40°E
60°E
80°E
100°E


a. TANN
b. MTCM
c. MTCM
d. MTWM
70°N
60°N
50°N
40°N
0°
20°E
40°E
60°E
80°E
100°E
Temperature (°C)
-80
-60
-40
-20
0
20
40
60
Precipitation (m)
0,5
1
1,5
2

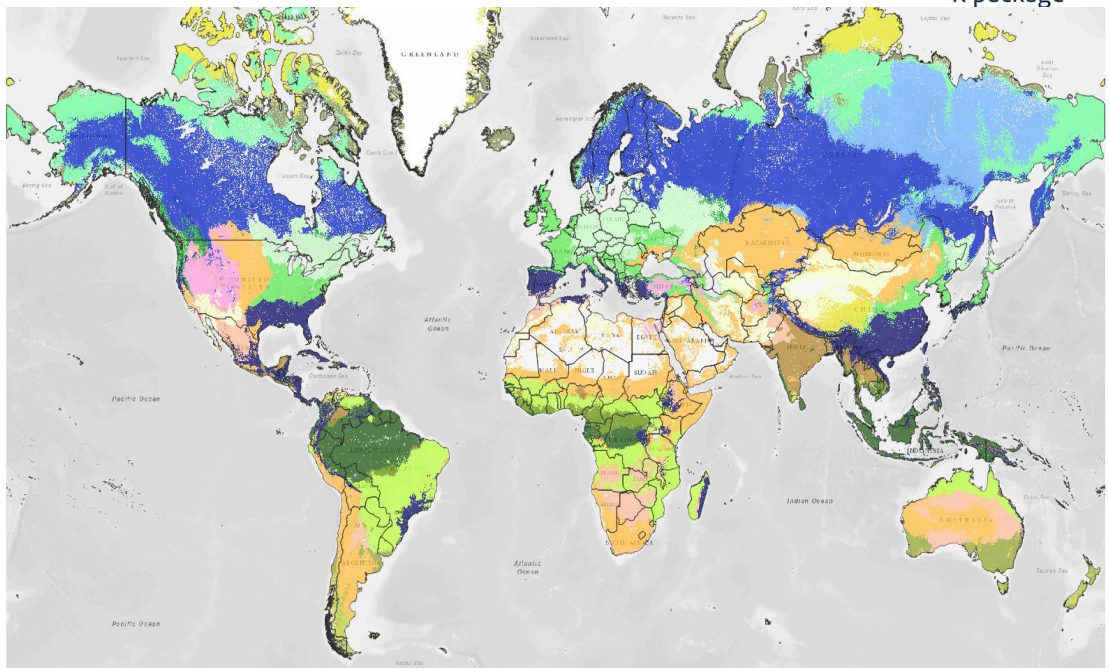

a.
b.
c.
d.
e.
log10(nb.analogue)
Age (kyr)
Method=SQChord
Cutoff=0.4
K=5
Eifel
Furamoos
LGP
Echets
LDB
density
Dissimilarity coefficient (Qchord)

Biomisation – Méthode dérivées des PFTs

R package

Workflow de la méthode

1. Biomisation ‘classique’ par score d’affinité moderne et fossile
2. Sous-ensemble de base de données après homogénéisation
3. Calibration des scores définies par biome
4. Biomisation sans score dominant = moyenne pondérée



Hengl, Tomislav, 2018

Assimilation (i) des taxons à des PFTs
(ii) des seuils propres à chaque taxon pionnier

Estimation des scores d’affinité des taxons par spectres fossiles et modernes en matrice propre type covariance

Combinaison des scores des PFTs pour chaque biome
+ Vectorisation des scores selon dominance taxons entre biome

Estimation des scores d’affinité des biomes par spectre fossile et moderne (scores dominants ou WA par abondance)

$$AS = \sqrt{P.(Abund. - Threshold)}$$

Mesure de dissimilarité entre échantillon et biome

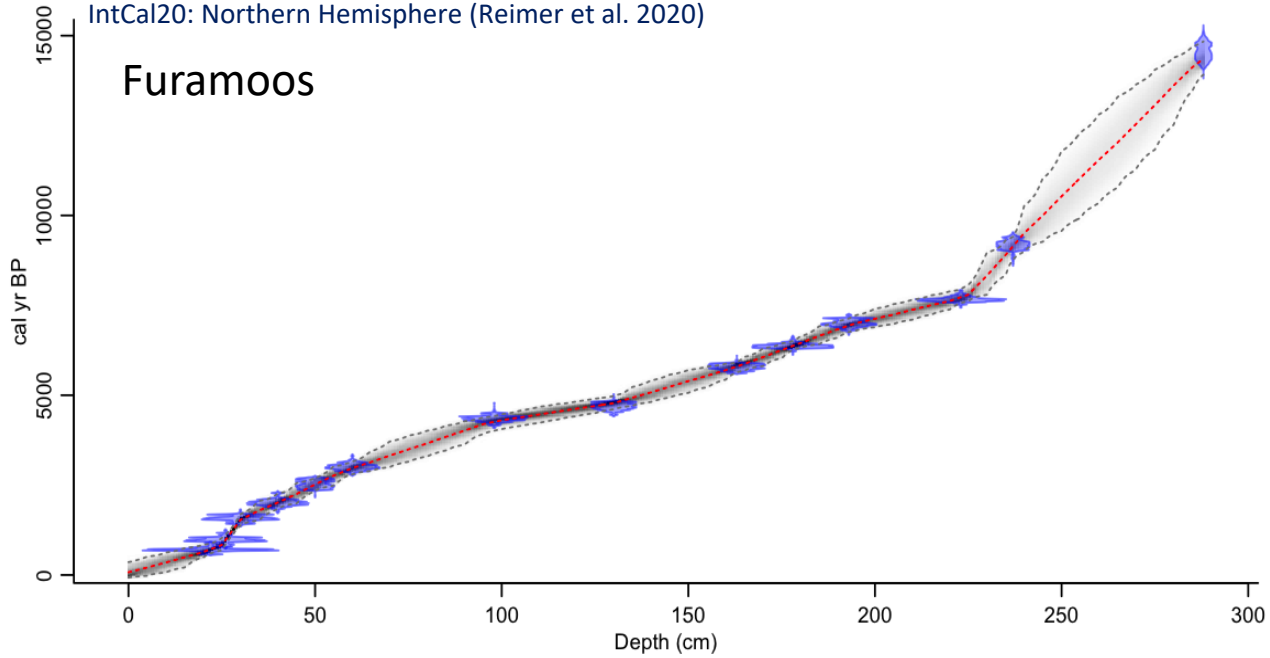
Assimilation de chaque échantillon par biome

Calibration par matrice de scores de biome

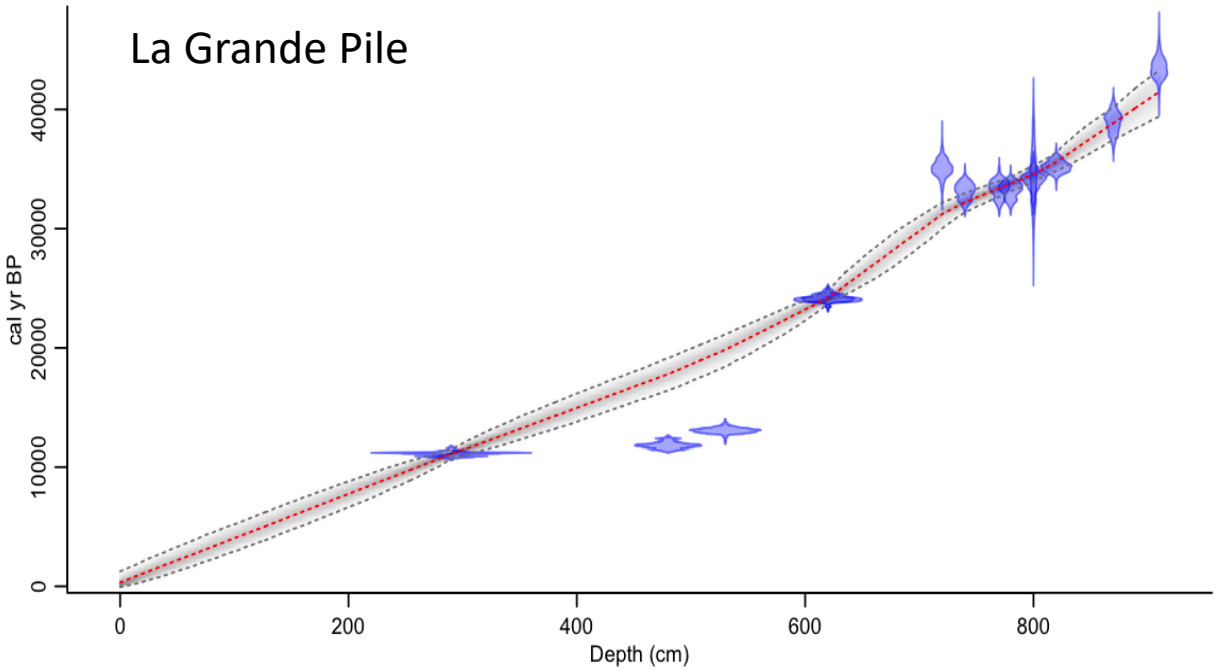
Number	Name *(Latitude, Longitude, Elevation)*	Core *Pollen taxon occurrences* *Depth ranges* *Time period (cal BP)*	References *Pollen records* *Sediment dating*
1	**Eifel** (50°15'00''N, 6°40'00''E, 747 m)	***ELSA-HM1 DE3*** *21* *3-87 m* *0-69 kyr*	*Sirocko et al., 2016* *Sirocko al., 2013*
2	**Füramoos** (47°49'26''N, 6°30'13''E, 660 m)	***FU 1, FU 3*** *46* *0-14 m* *0-42 kyr*	*Kern et al., 2021* *Kern et al., 2021*
3	**La Grande Pile** (09°53'02''N, 6°30'25''E, 250 m)	***GPXX*** *60* *0-19 m* *0-90 kyr*	*Guiot et al., 1989* *Wolliard et al., 1981*
4	**Les Echets** (45°47'00''N, 4°56'00''E, 267 m)	***D*** *21* *0-30 m* *17-35 kyr*	*De Beaulieu et al., 1984* *De Beaulieu et al., 1984*
5	**Le Bouchet** (47°34'17''N, 7°56'05''E, 1 200 m)	***G*** *56* *0.9-16 m* *18-82 kyr*	*Reille et al., 1989* *Thouveny et al., 1989*

IntCal20: Northern Hemisphere (Reimer et al. 2020)

Furamoos

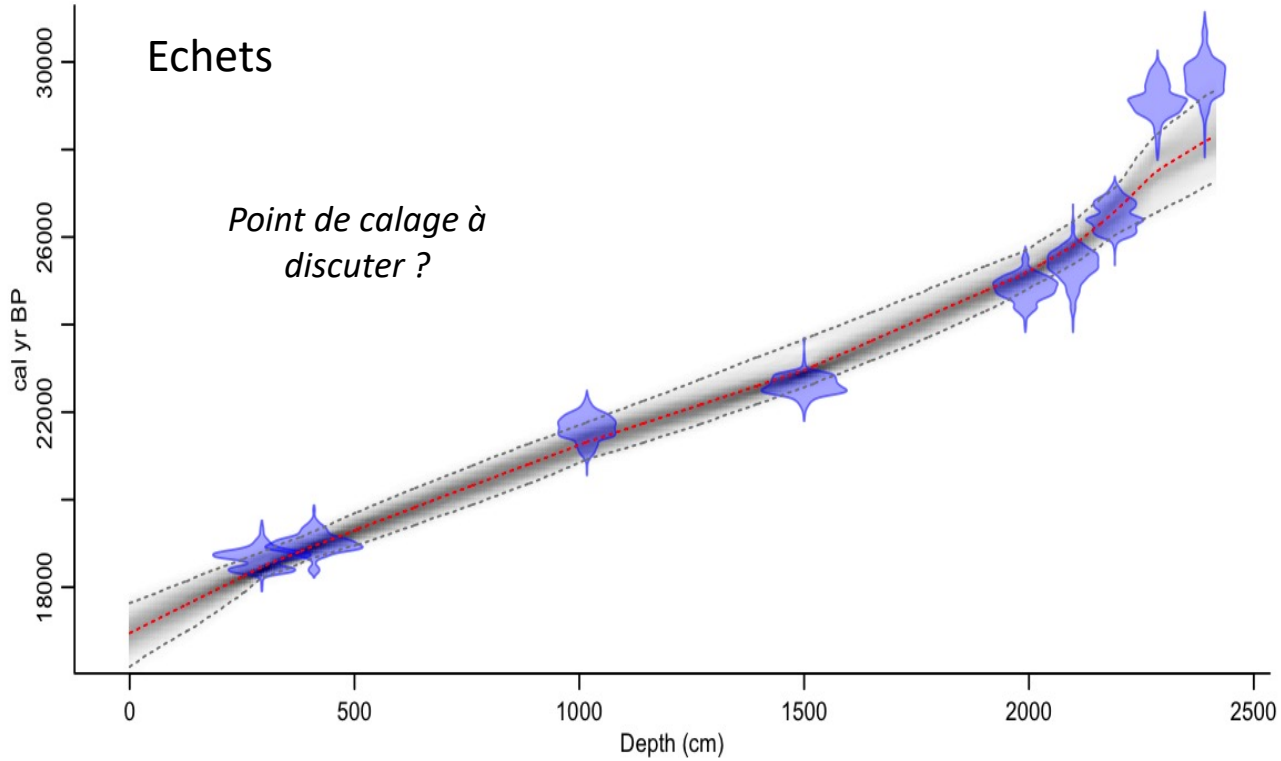


La Grande Pile

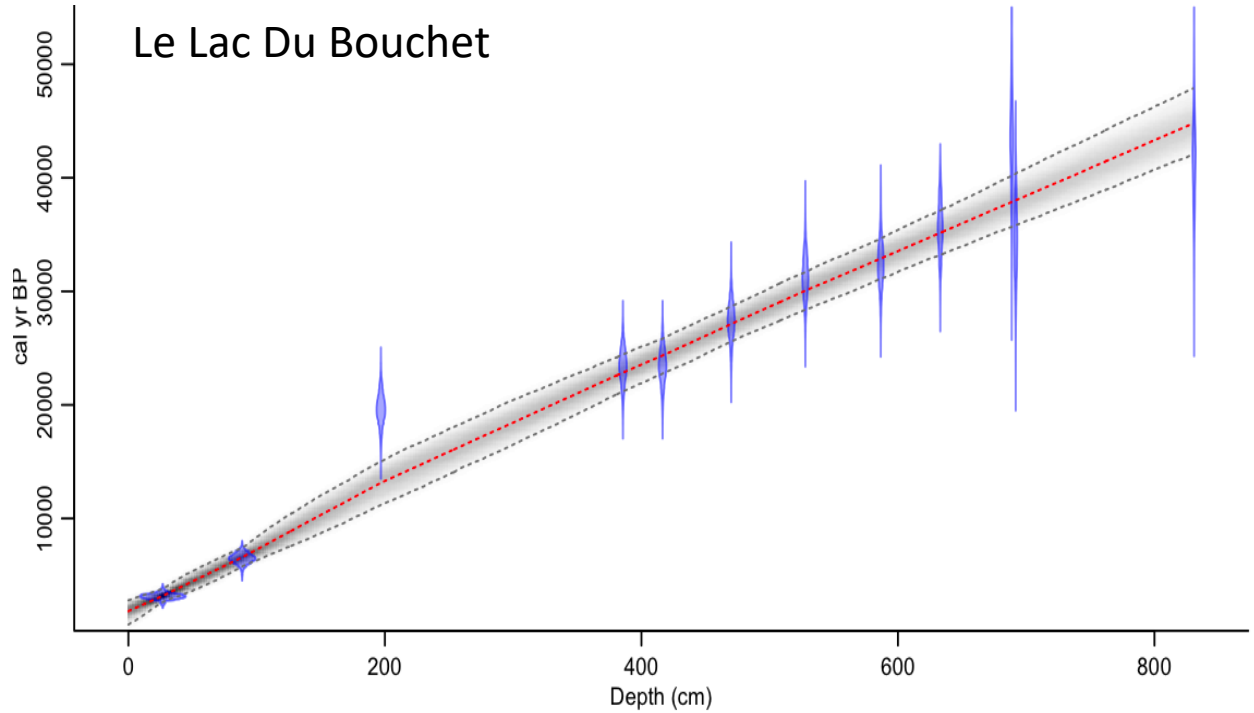


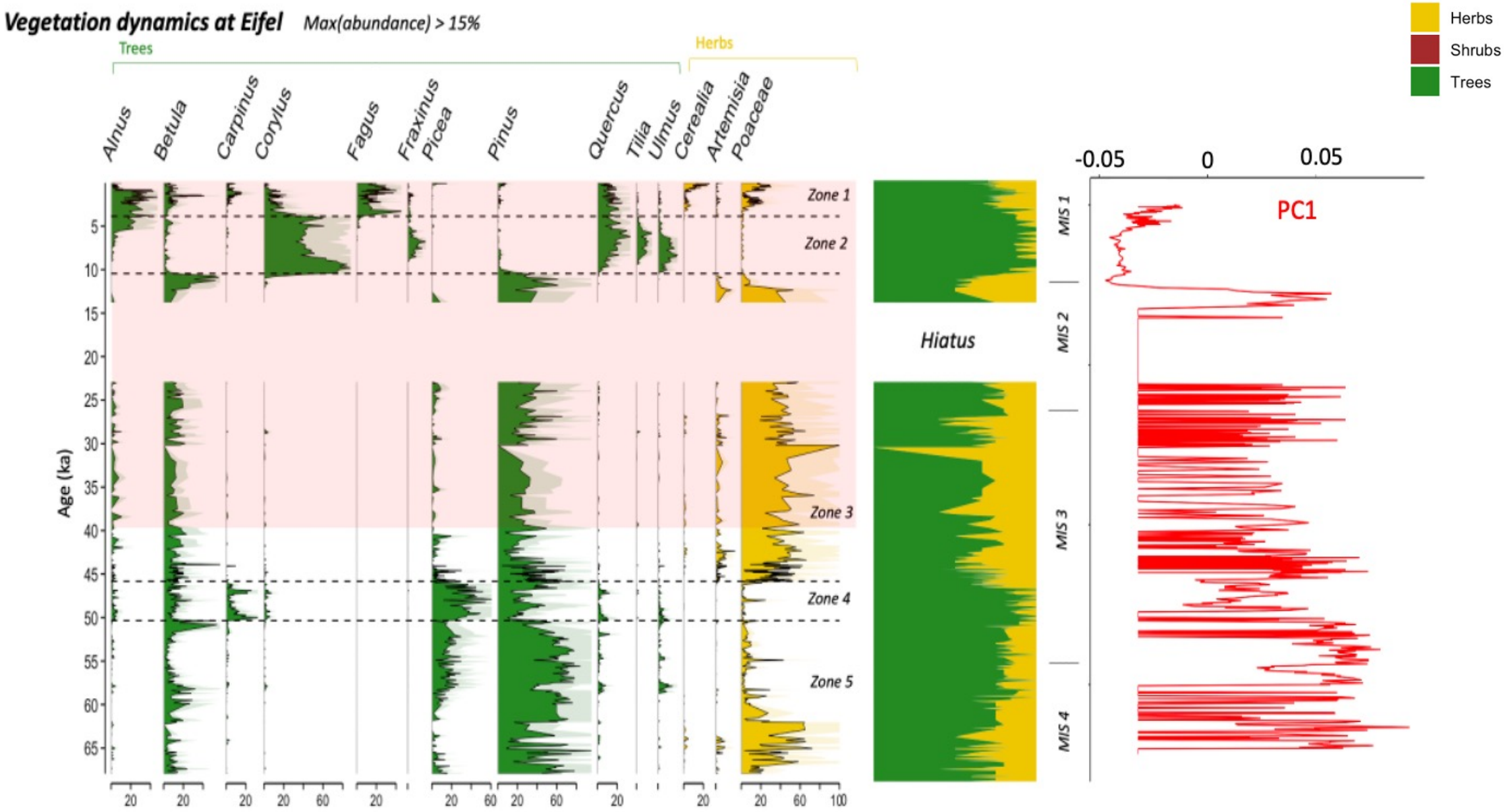
Echets

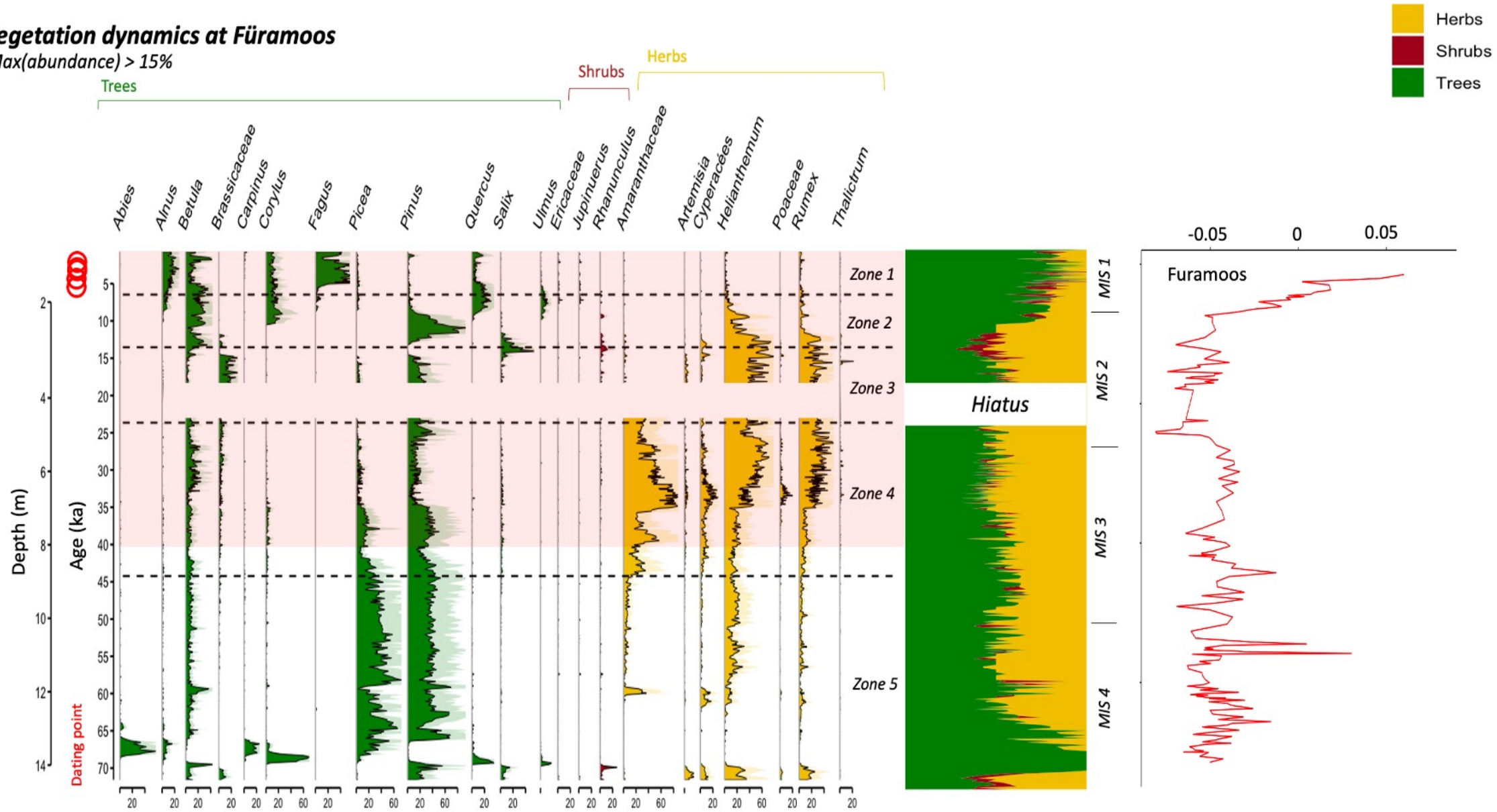
Point de calage à discuter ?

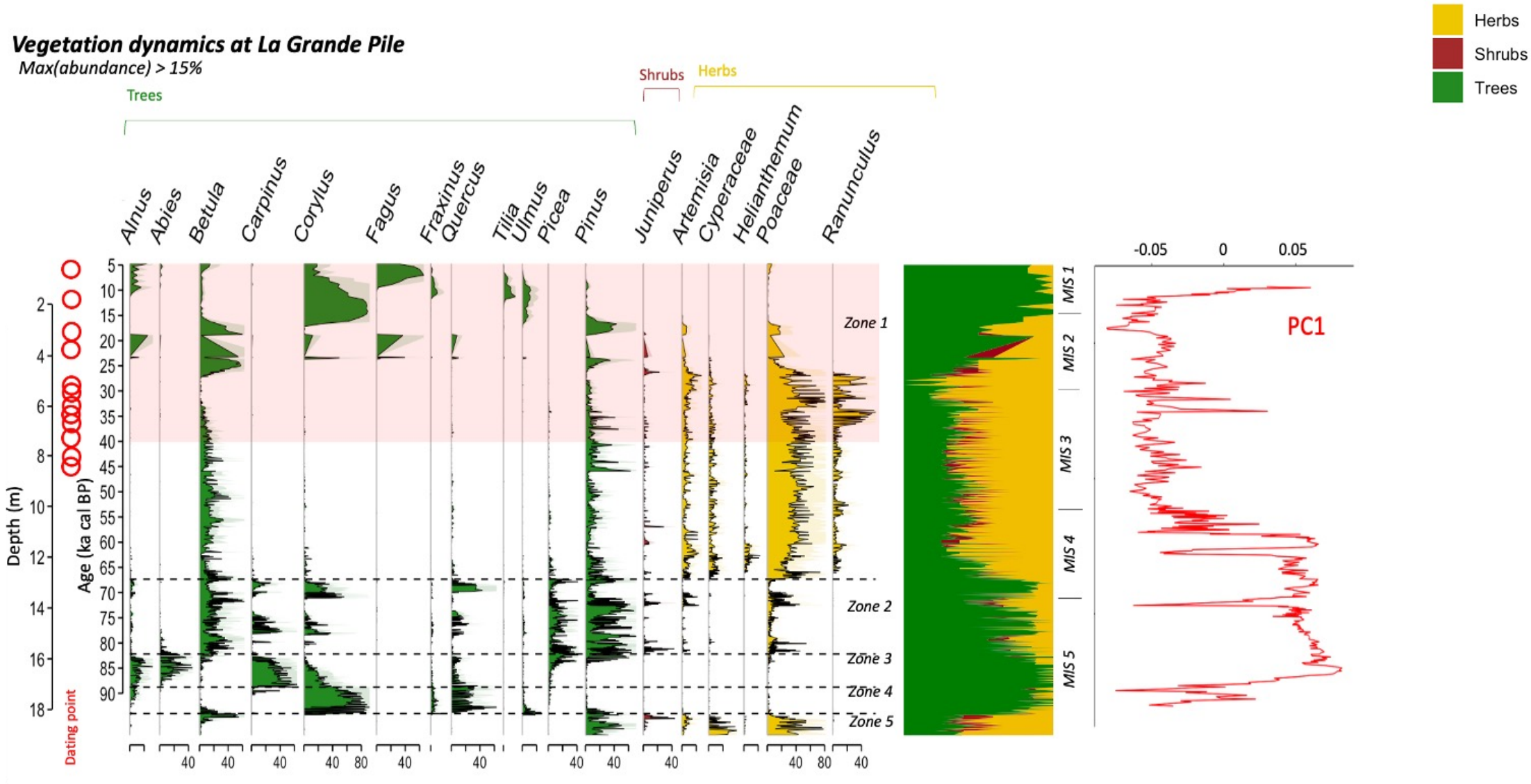


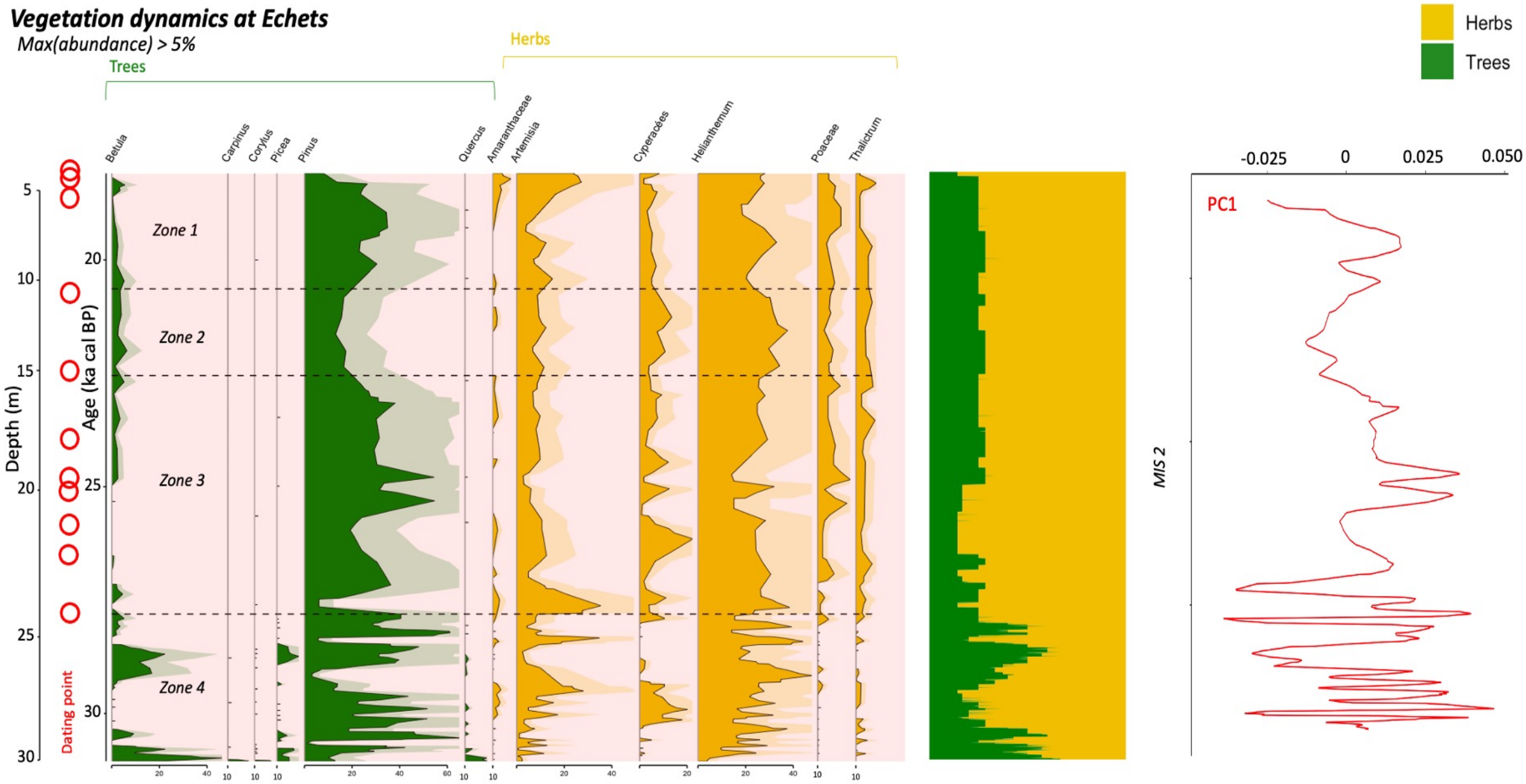
Le Lac Du Bouchet

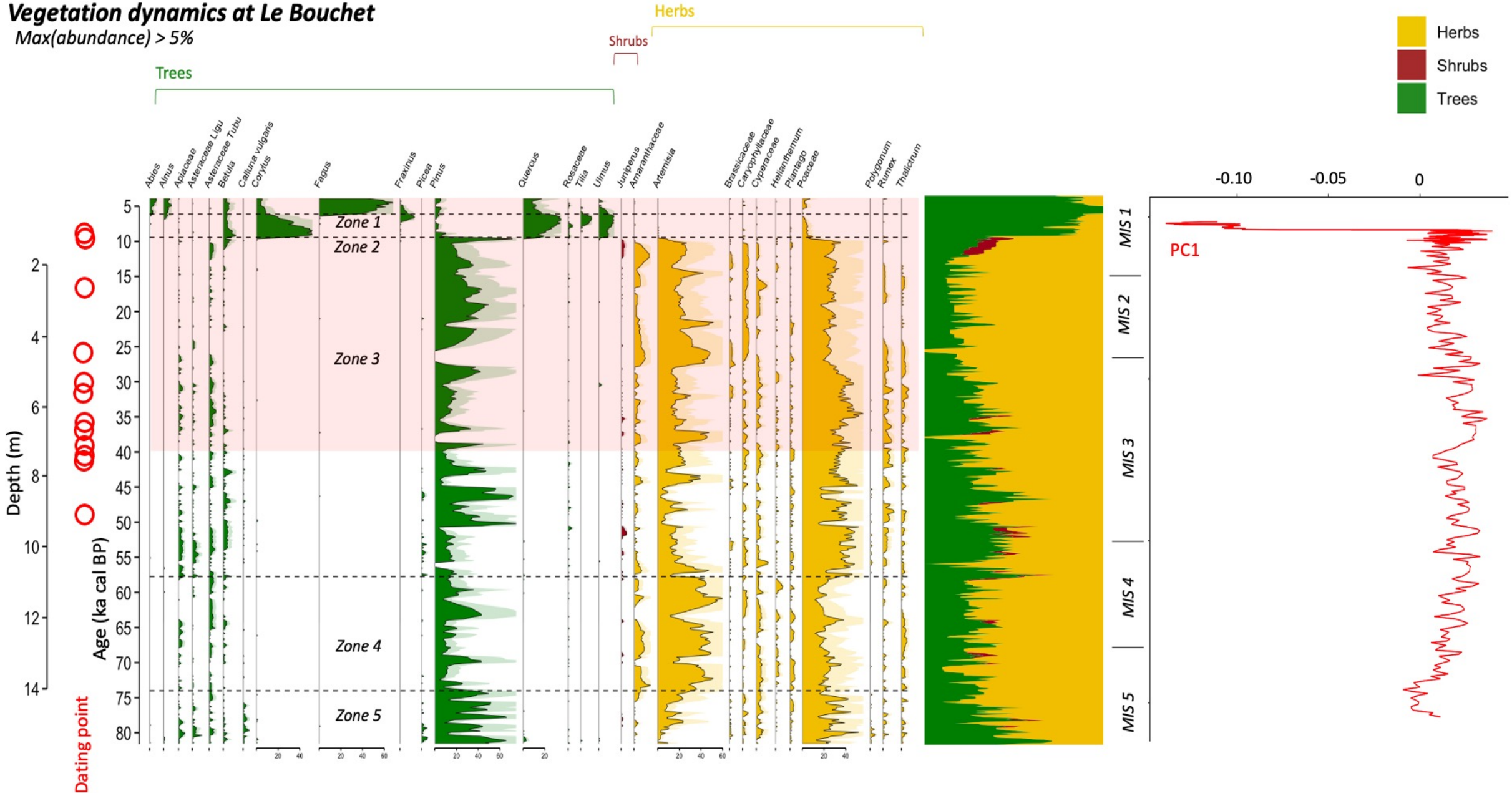


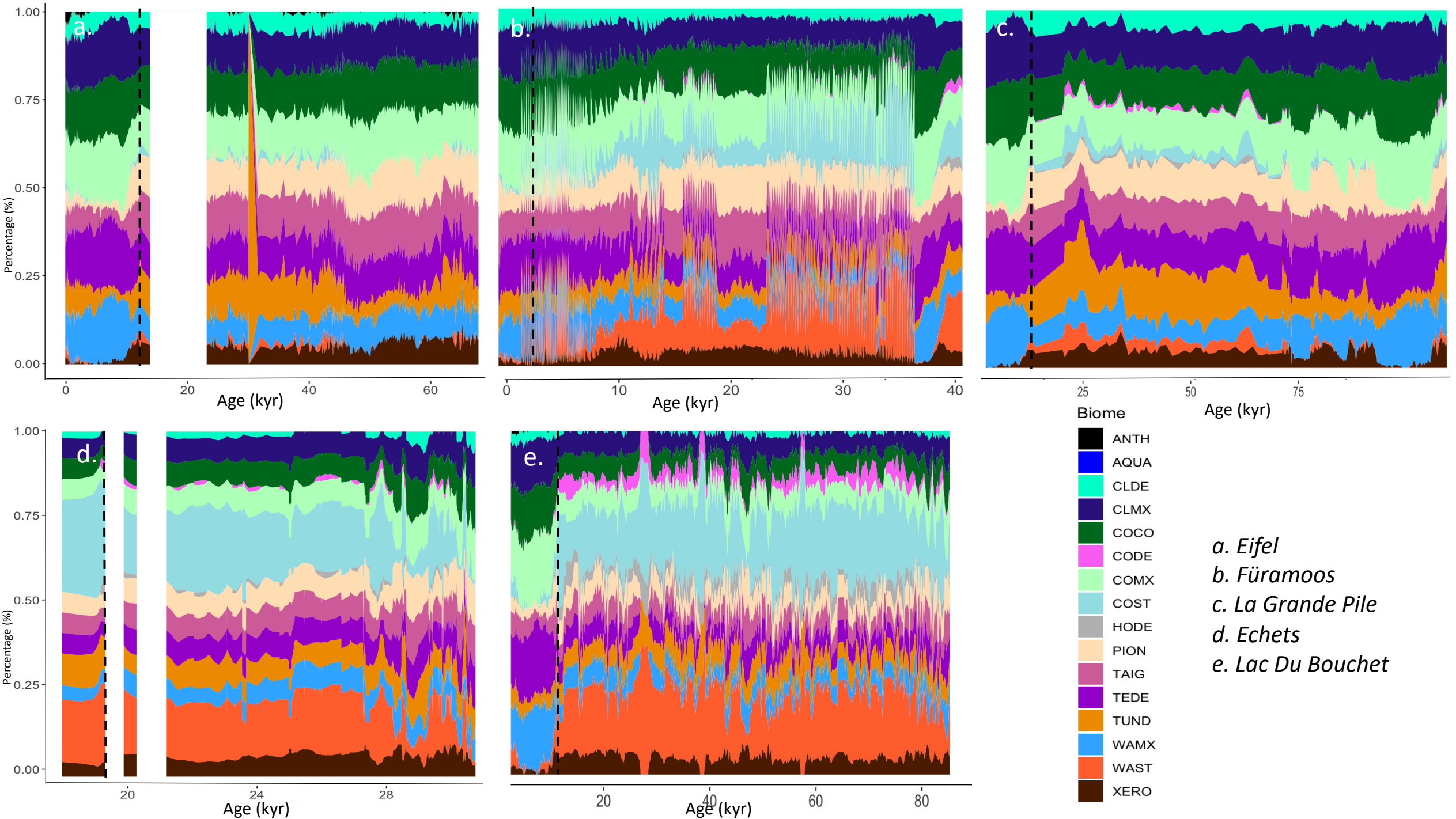

Vegetation dynamics at Eifel
Max(abundance) > 15%
Trees
Herbs
Alnus
Betula
Carpinus
Corylus
Fagus
Fraxinus
Picea
Pinus
Quercus
Tilia
Ulmus
Cerealia
Artemisia
Poaceae
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Age (ka)
Hiatus
MIS 1
MIS 2
MIS 3
MIS 4
-0.05
0
0.05
PC1
Herbs
Shrubs
Trees

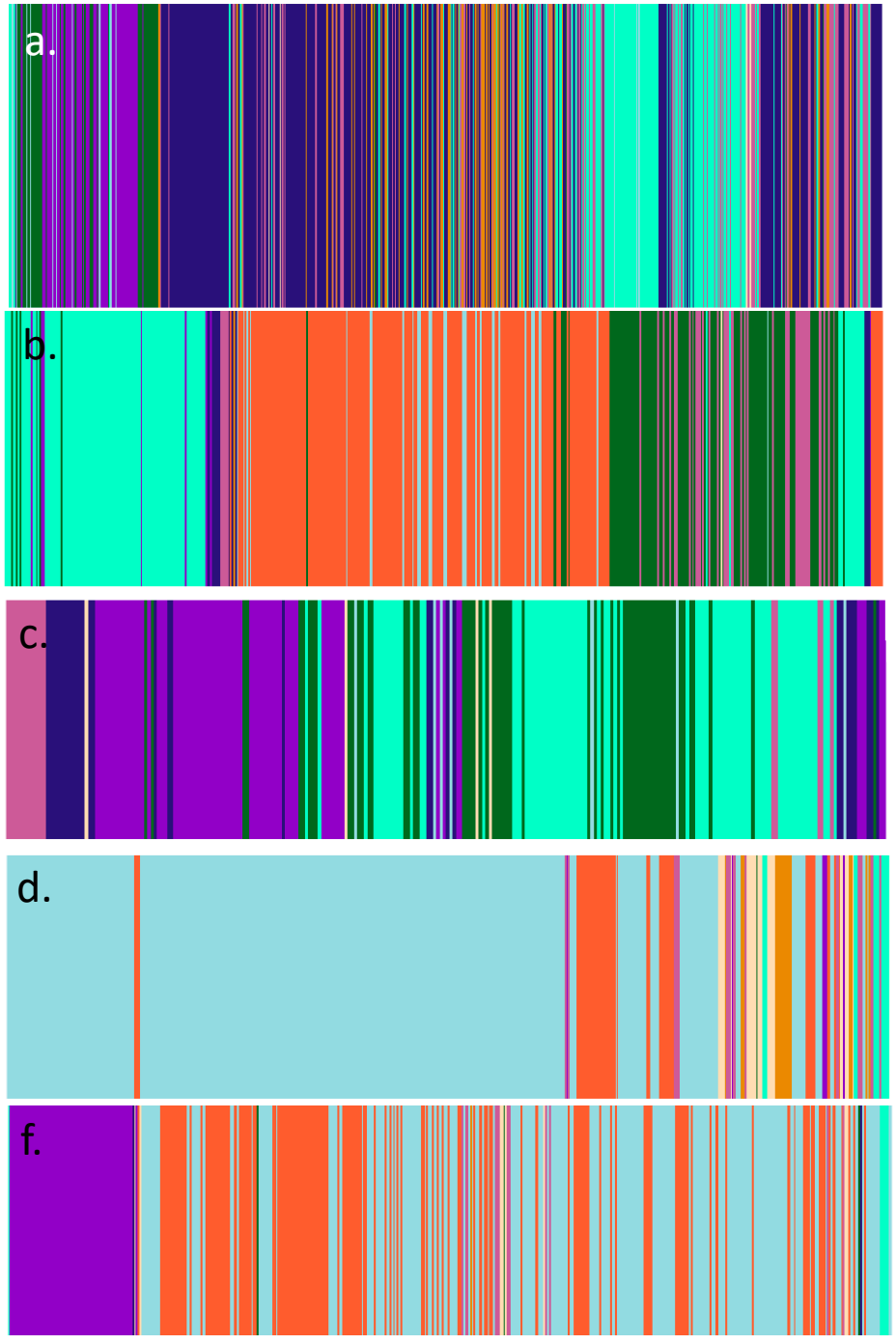

Vegetation dynamics at Füramoos
Max(abundance) > 15%
Herbs
Shrubs
Trees
Trees
Shrubs
Herbs
Abies
Alnus
Betula
Brassicaceae
Carpinus
Corylus
Fagus
Picea
Pinus
Quercus
Salix
Ulmus
Ericaceae
Jupinuerus
Rhanunculus
Amaranthaceae
Artemisia
Cyperacées
Helianthemum
Poaceae
Rumex
Thalictrum
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Depth (m)
Age (ka)
Dating point
Hiatus
MIS 1
MIS 2
MIS 3
MIS 4
-0.05
0
0.05
Furamoos


Vegetation dynamics at La Grande Pile
Max(abundance) > 15%
Herbs
Shrubs
Trees
Trees
Shrubs
Herbs
Alnus
Abies
Betula
Carpinus
Corylus
Fagus
Fraxinus
Quercus
Tilia
Ulmus
Picea
Pinus
Juniperus
Artemisia
Cyperaceae
Helianthemum
Poaceae
Ranunculus
Depth (m)
Age (ka cal BP)
Dating point
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
MIS 1
MIS 2
MIS 3
MIS 4
MIS 5
-0.05
0
0.05
PC1

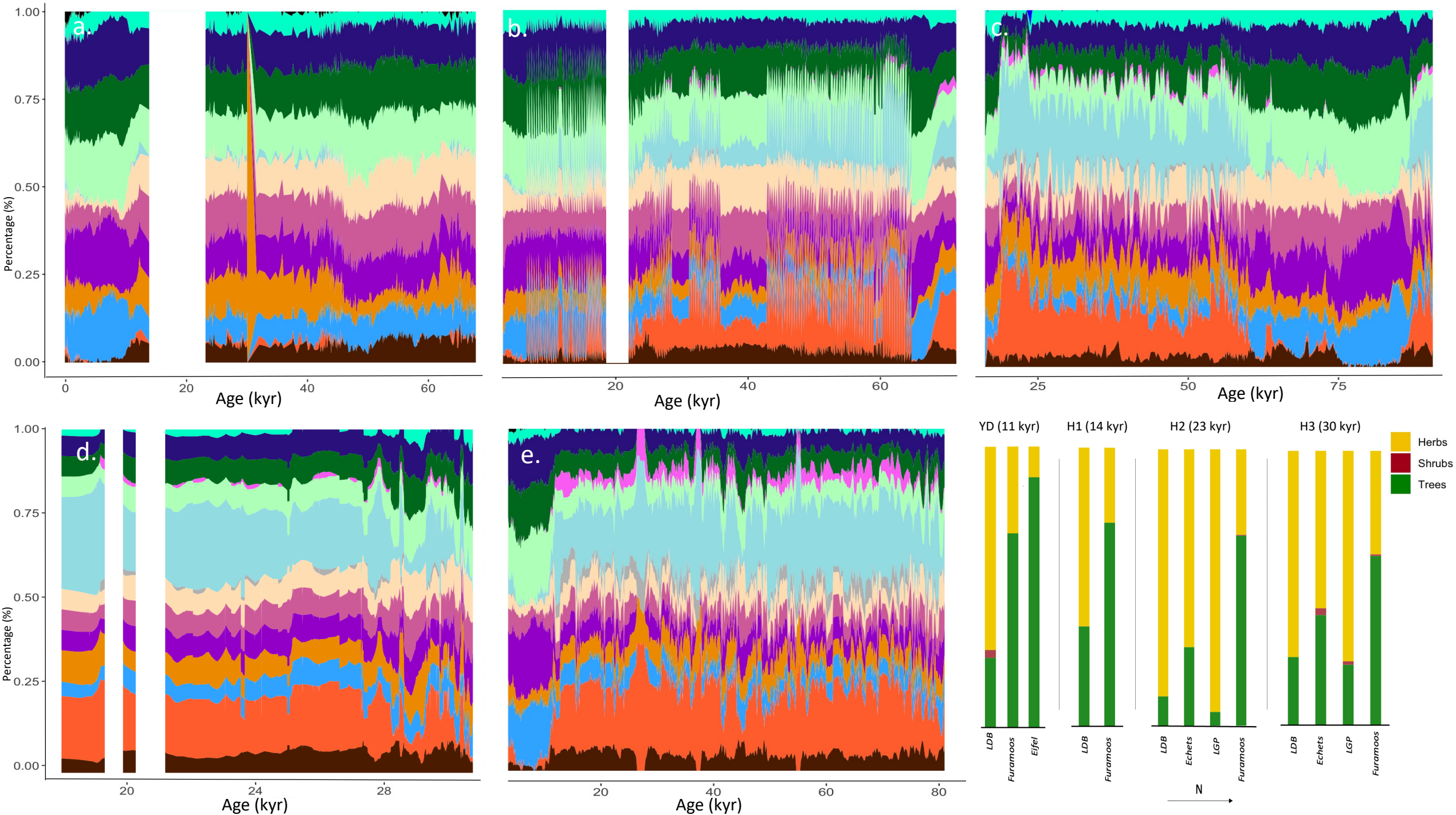

Vegetation dynamics at Echets
Max(abundance) > 5%
Trees
Herbs
Herbs
Trees
Betula
Carpinus
Corylus
Picea
Pinus
Quercus
Amaranthaceae
Artemisia
Cyperacées
Helianthemum
Poaceae
Thalictrum
Zone 1
Zone 2
Zone 3
Zone 4
Depth (m)
Age (ka cal BP)
Dating point
MIS 2
PC1
-0.025
0
0.025
0.050


Vegetation dynamics at Le Bouchet
Max(abundance) > 5%
Herbs
Shrubs
Trees
Abies
Alnus
Apiaceae
Asteraceae Ligu
Asteraceae Tubu
Betula
Calluna vulgaris
Corylus
Fagus
Fraxinus
Picea
Pinus
Quercus
Rosaceae
Tilia
Ulmus
Juniperus
Amaranthaceae
Artemisia
Brassicaceae
Caryophyllaceae
Cyperaceae
Helianthemum
Plantago
Poaceae
Polygonum
Rumex
Thalictrum
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Depth (m)
Age (ka cal BP)
Dating point
MIS 1
MIS 2
MIS 3
MIS 4
MIS 5
PC1
-0.10
-0.05
0


a.
b.
c.
d.
e.
Percentage (%)
1.00
0.75
0.50
0.25
0.00
0
20
40
60
10
30
25
50
75
Age (kyr)
Biome
ANTH
AQUA
CLDE
CLMX
COCO
CODE
COMX
COST
HODE
PION
TAIG
TEDE
TUND
WAMX
WAST
XERO
a. Eifel
b. Füramoos
c. La Grande Pile
d. Echets
e. Lac Du Bouchet



a. Eifel
b. Füramoos
c. La Grande Pile
d. Echets
e. Lac Du Bouchet

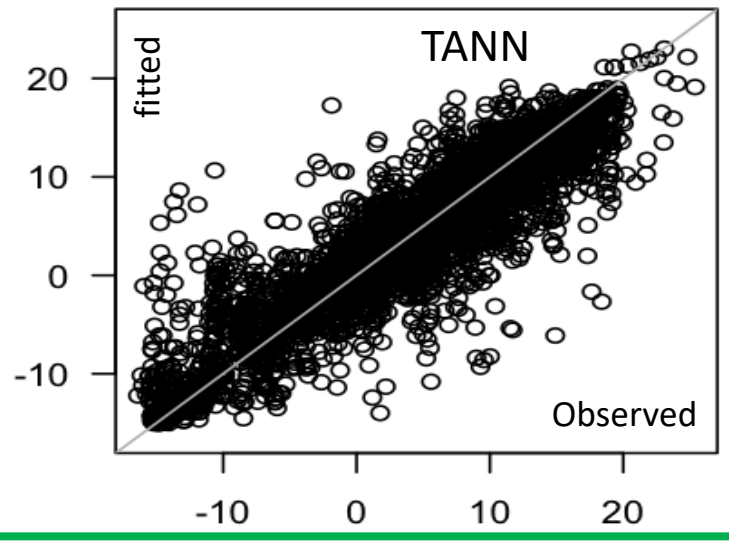

a.
b.
c.
d.
e.
Percentage (%)
1.00
0.75
0.50
0.25
0.00
0
20
40
60
25
50
75
24
28
80
Age (kyr)
YD (11 kyr)
H1 (14 kyr)
H2 (23 kyr)
H3 (30 kyr)
Herbs
Shrubs
Trees
LDB
Furamoos
Eifel
Echets
LGP
N

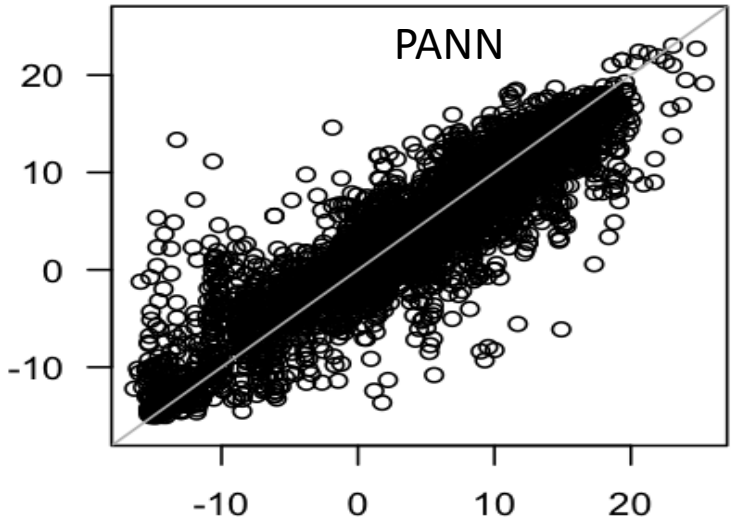
Inferred vs. Observed

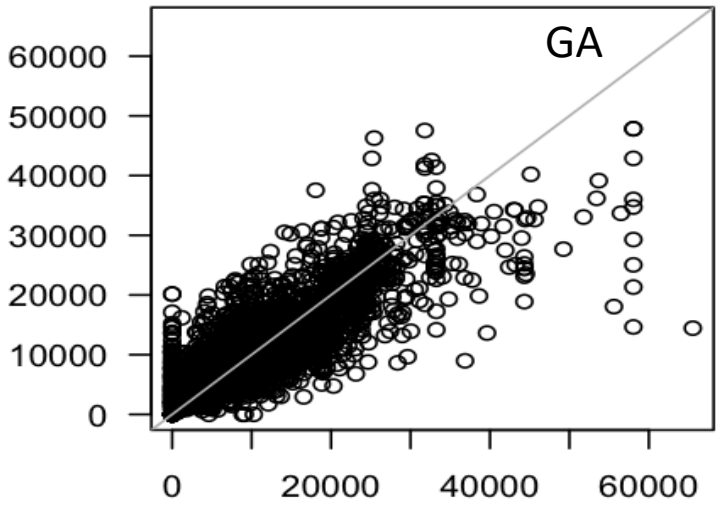
Leave-one-out errors

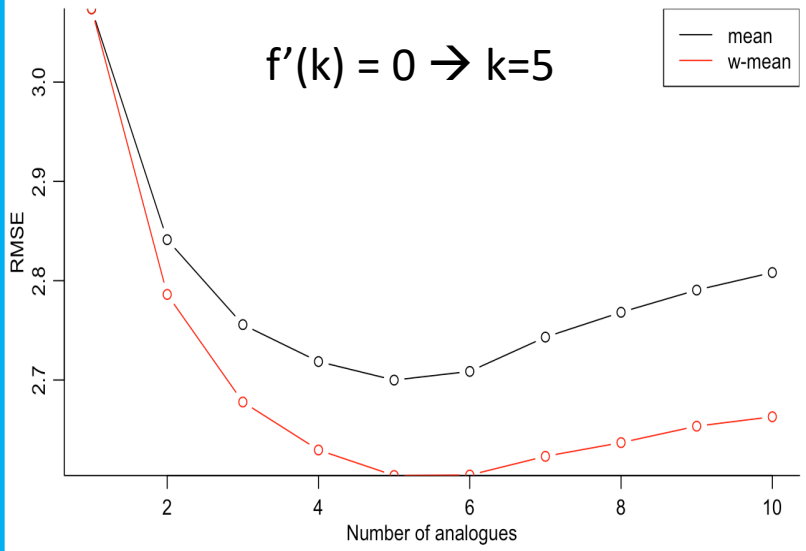
Nb. Taxon = 56
Nb. Modern = 8446
Dist.method = sq.chord

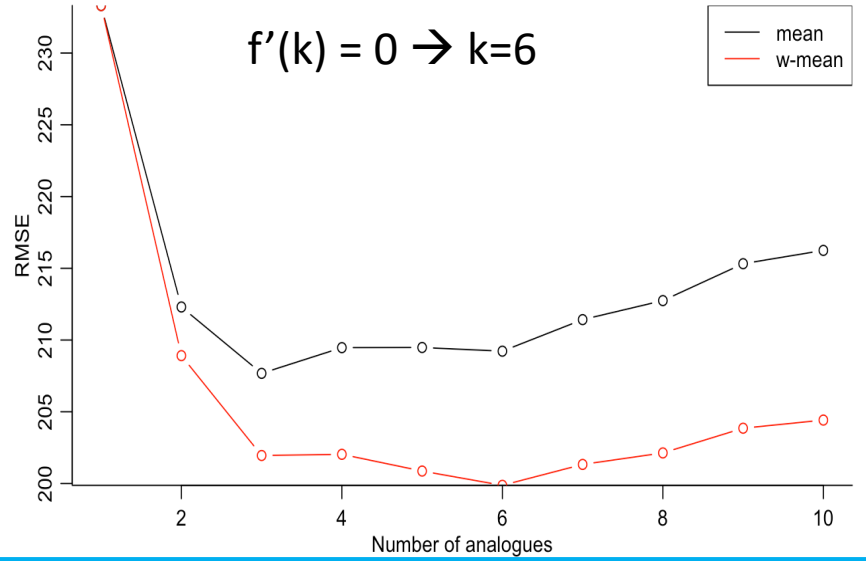
Bootstrap=TRUE
Nb. Boot = 500

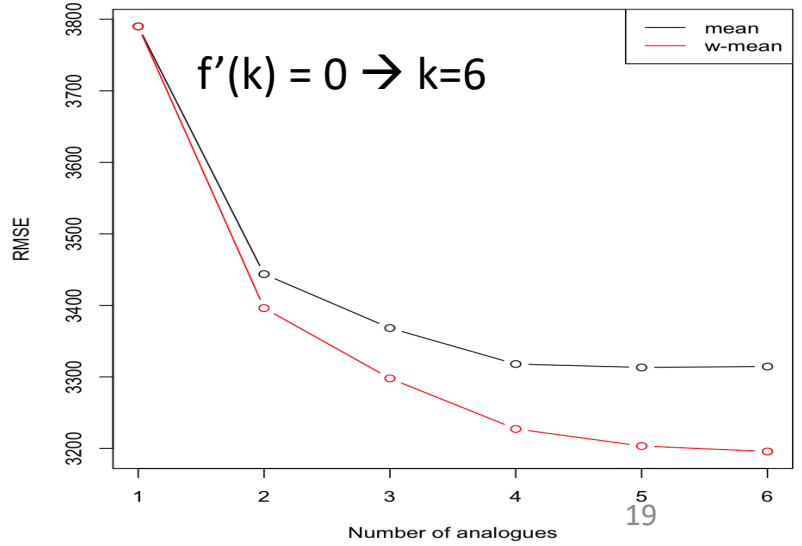


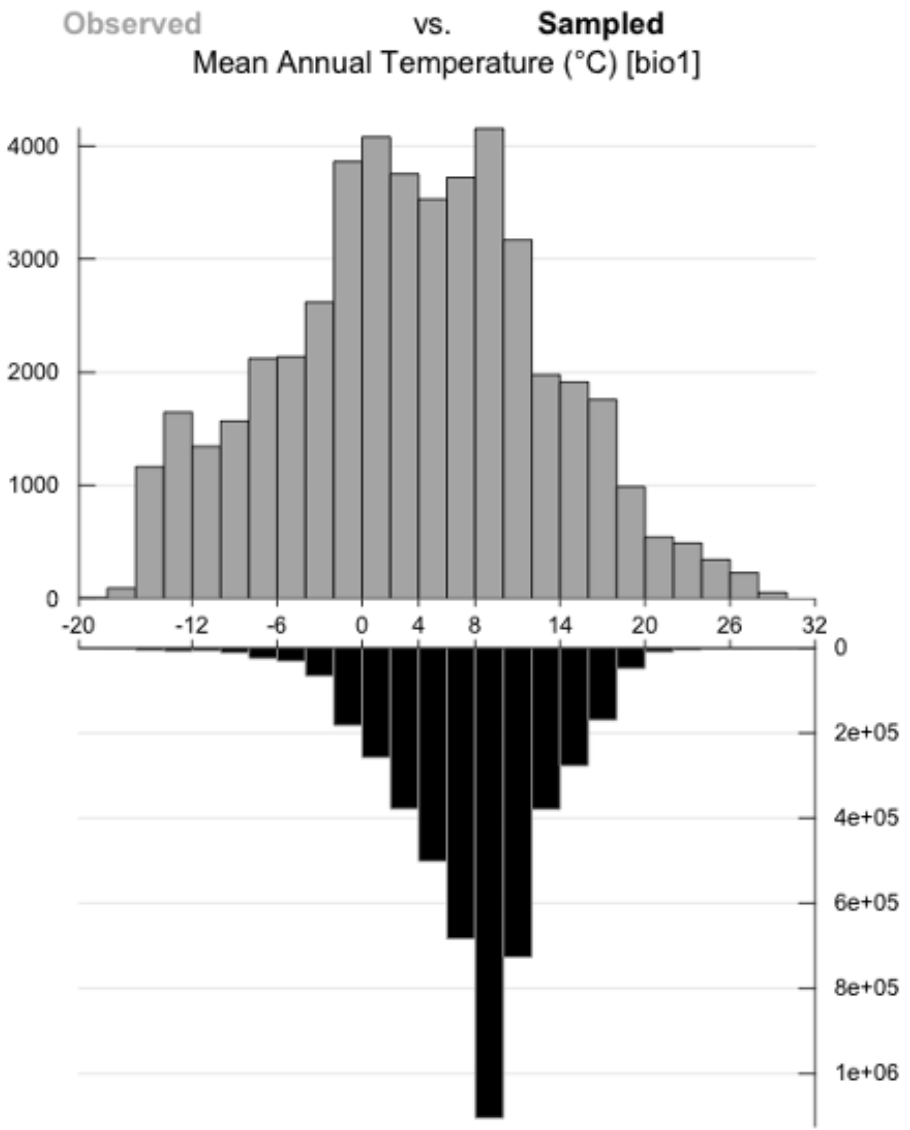


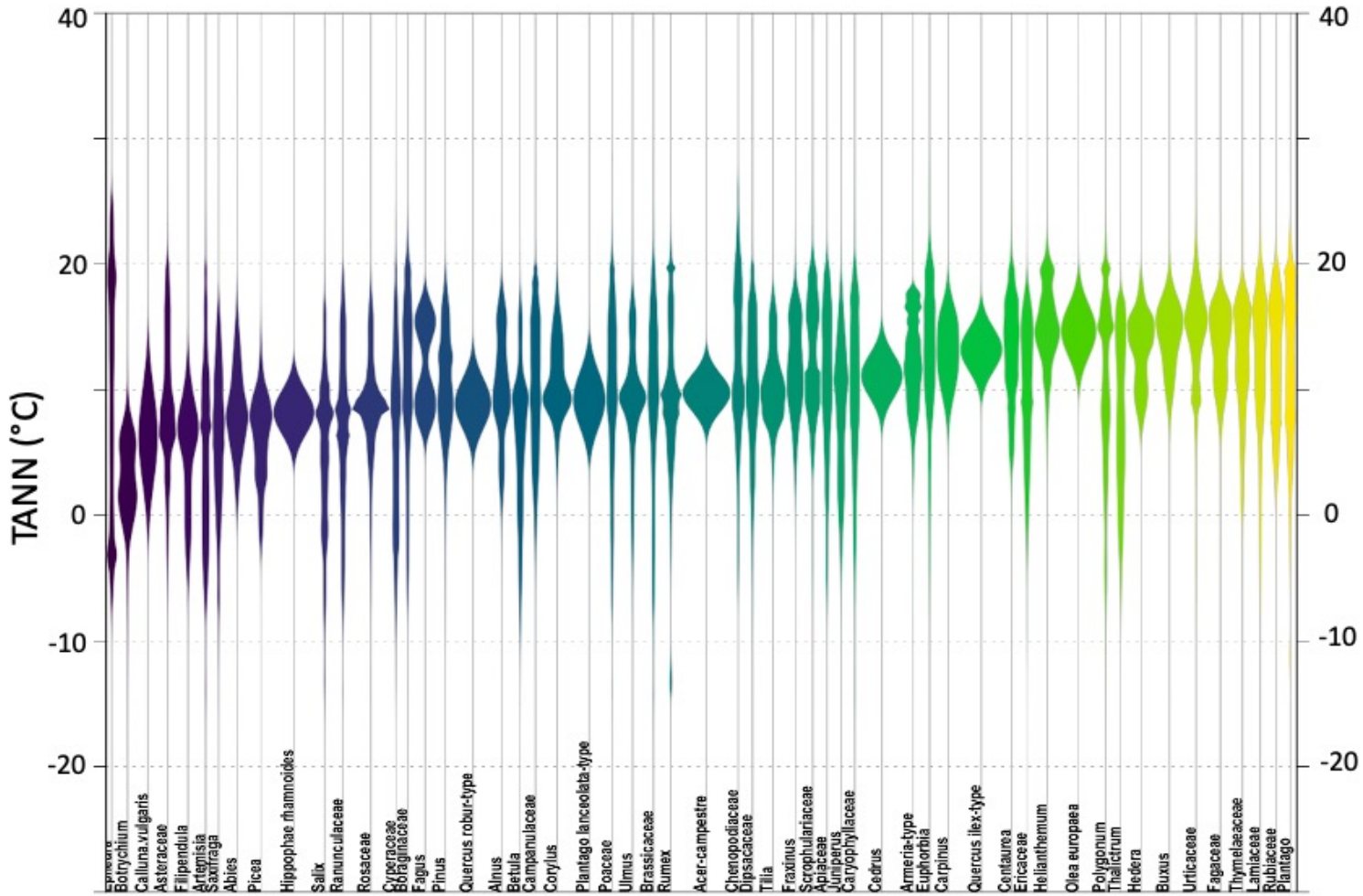




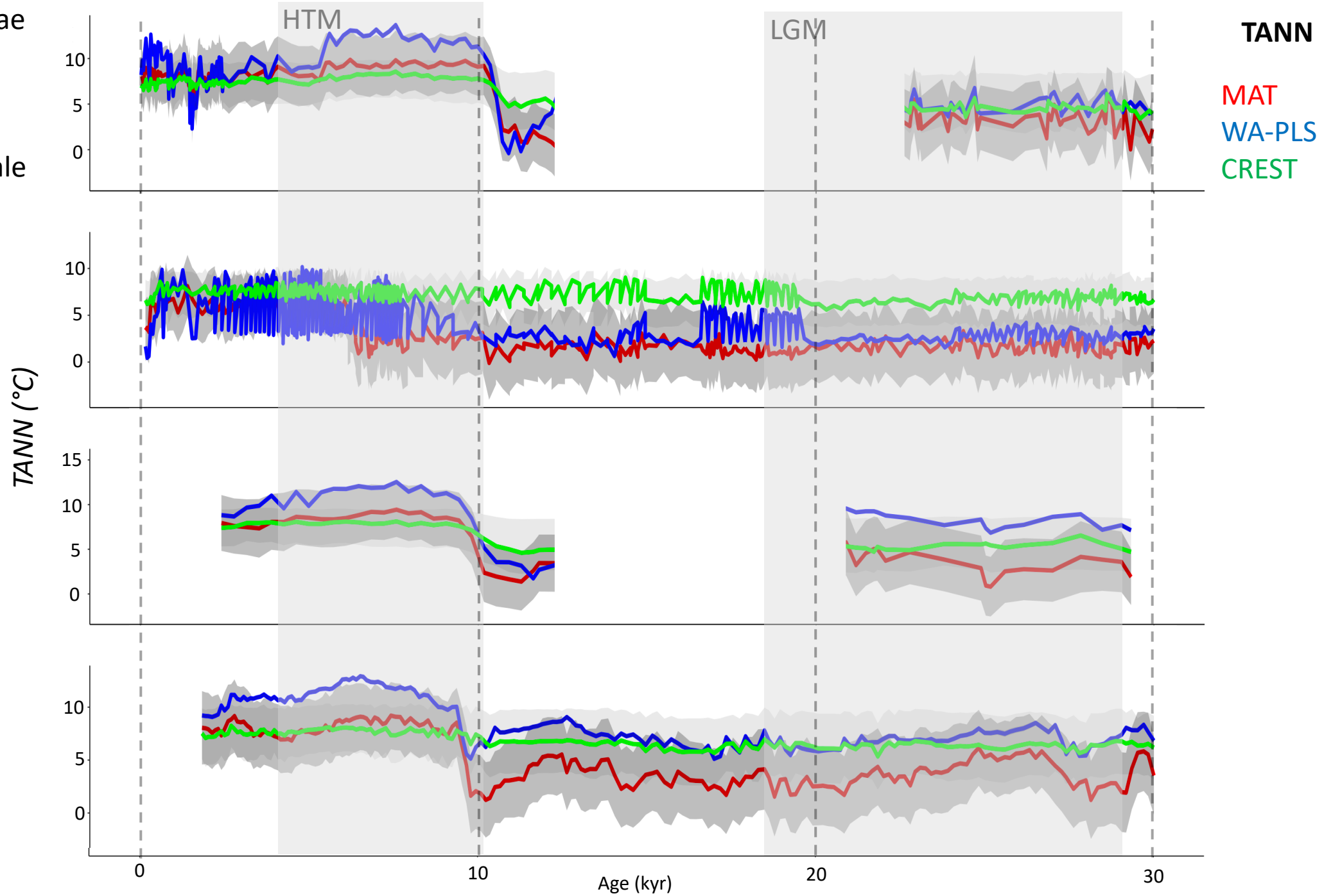




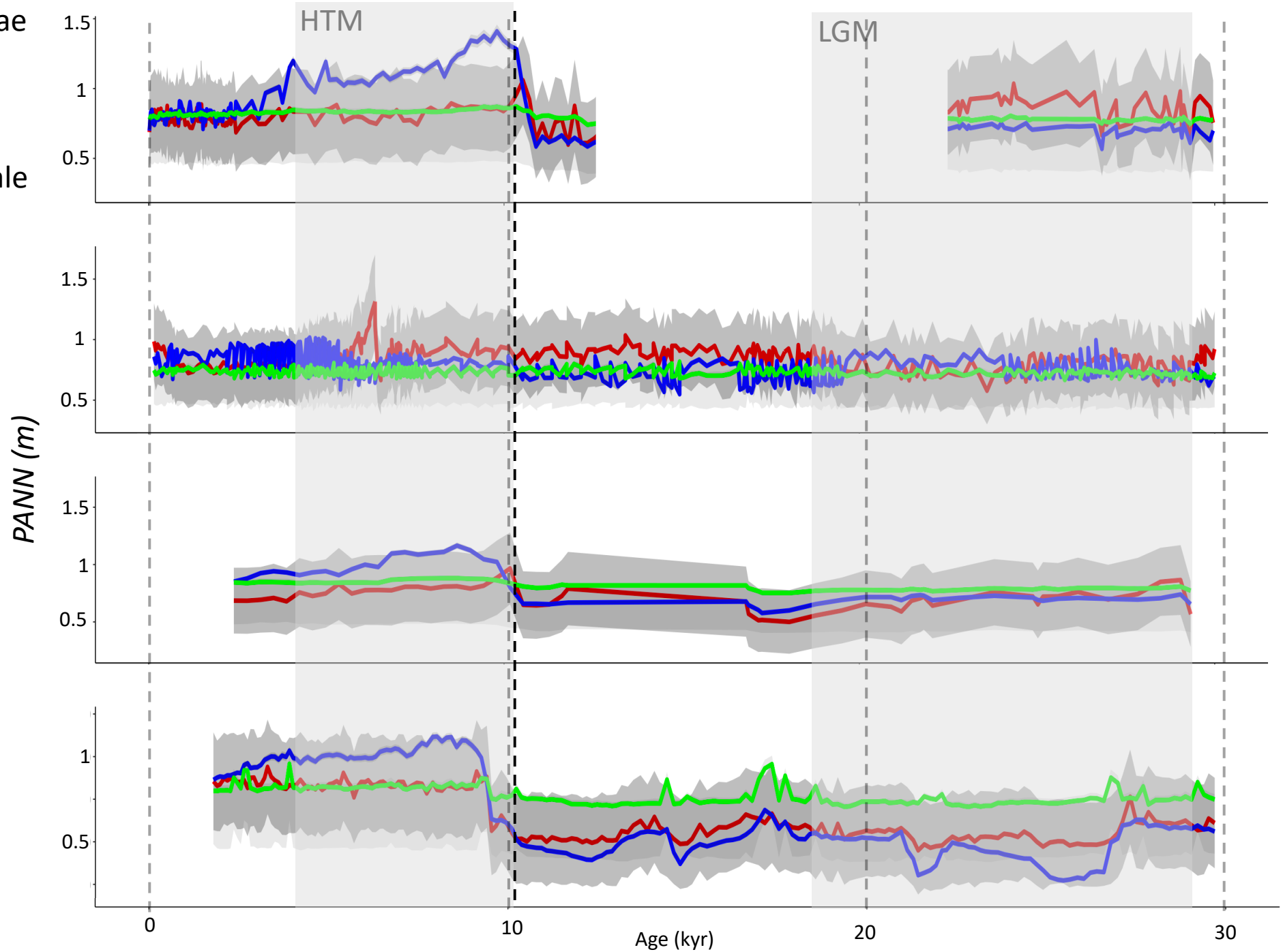

Observed vs. Sampled
Mean Annual Temperature (°C) [bio1]
4000
3000
2000
1000
0
-20
-12
-6
0
4
8
14
20
26
32
0
2e+05
4e+05
6e+05
8e+05
1e+06


TANN (°C)
40
20
0
-10
-20
Botrychium
Calluna.vulgaris
Asteraceae
Filipendula
Artemisia
Saxifraga
Abies
Picea
Hippophae rhamnoides
Salix
Ranunculaceae
Rosaceae
Cyperaceae
Boraginaceae
Fagus
Pinus
Quercus robur-type
Alnus
Betula
Campanulaceae
Corylus
Plantago lanceolata-type
Poaceae
Ulmus
Brassicaceae
Rumex
Acer-campestre
Chenopodiaceae
Dipsacaceae
Tilia
Fraxinus
Scrophulariaceae
Apiaceae
Juniperus
Caryophyllaceae
Cedrus
Armeria-type
Euphorbia
Carpinus
Quercus ilex-type
Centaurea
Ericaceae
Helianthemum
Olea europaea
Polygonum
Thalictrum
Hedera
Buxus
Urticaceae
Fagaceae
Thymelaeaceae
Lamiaceae
Rubiaceae
Plantago

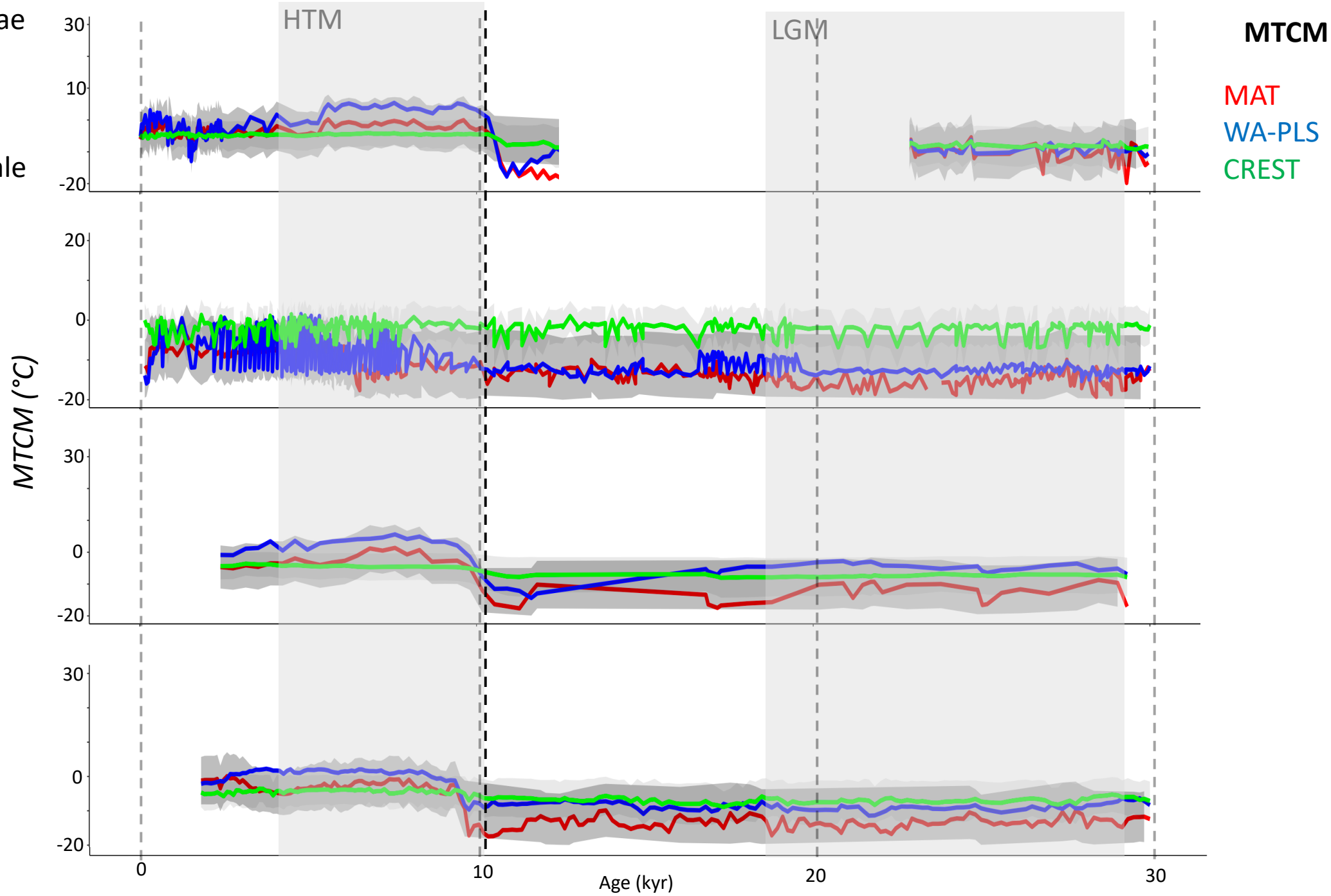
Avec Cyperaceae
WAPLS non biomisé
MAT et CREST calibration locale



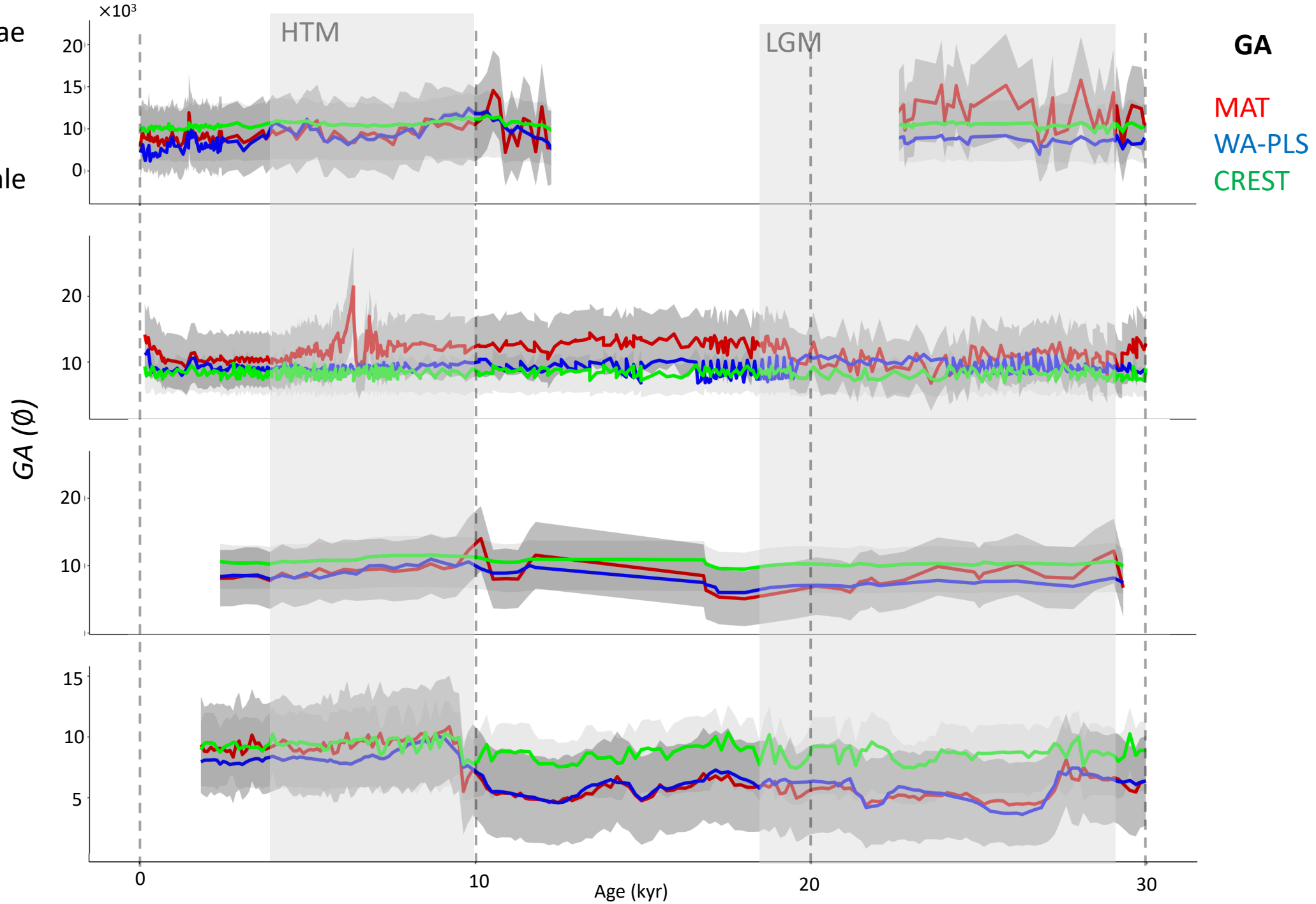
Avec Cyperaceae
WAPLS non biomisé
MAT et CREST calibration locale



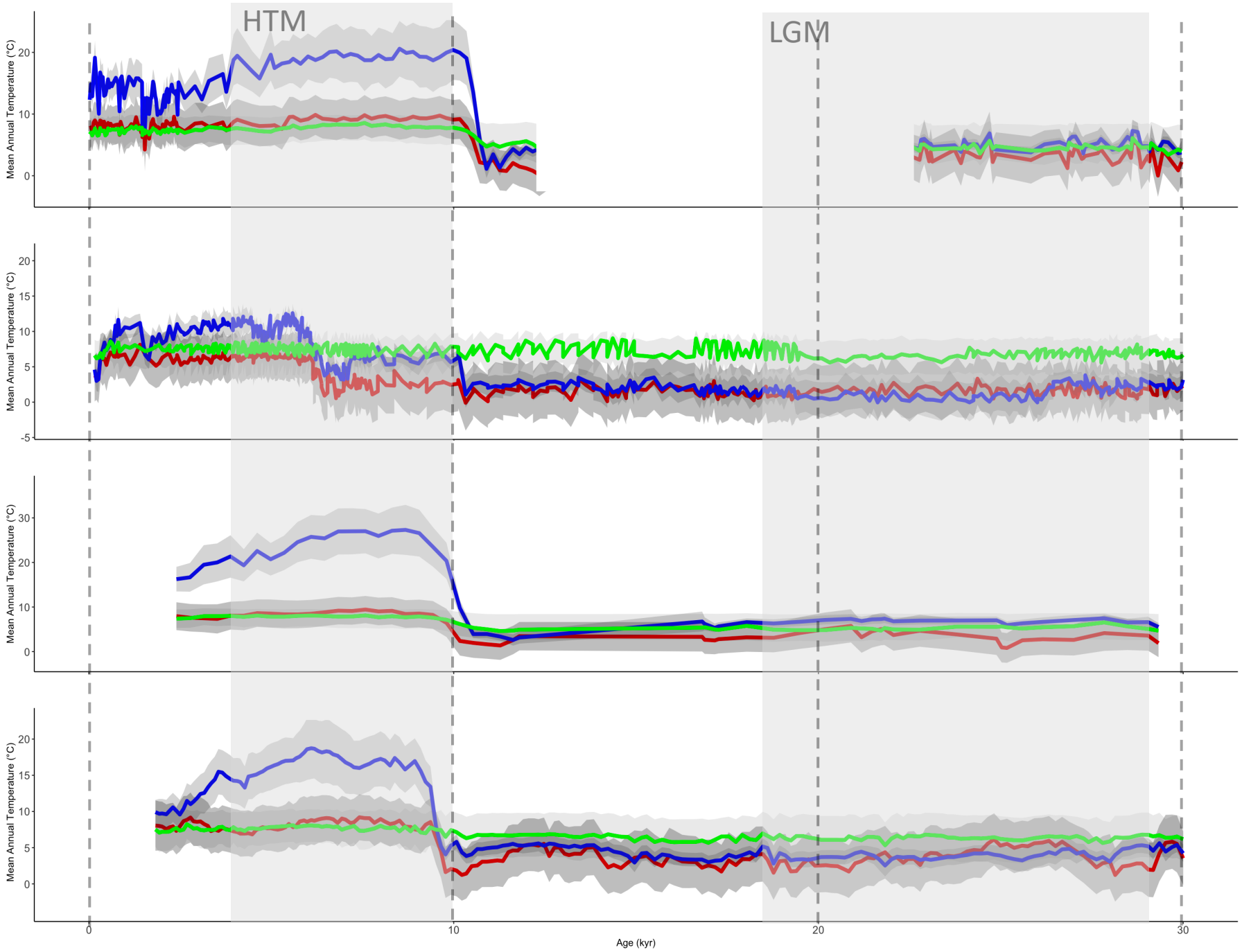
Avec Cyperaceae
WAPLS non biomisé
MAT et CREST calibration locale



Avec Cyperaceae
WAPLS non biomisé
MAT et CREST calibration locale

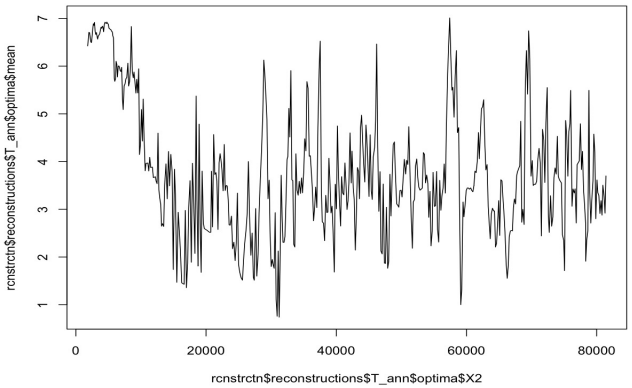


Avec Cyperaceae MAT, WAPLS et CREST calibration locale



CREST outputs/biome LDB

CLDE



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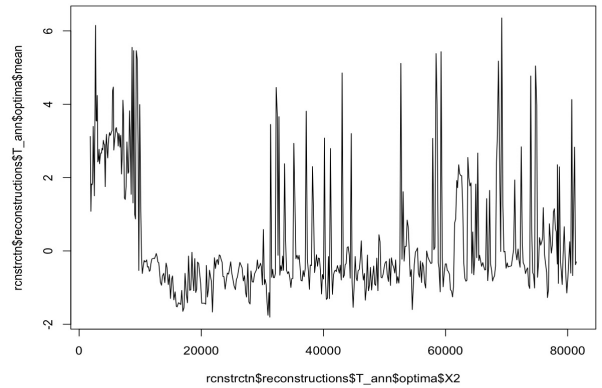

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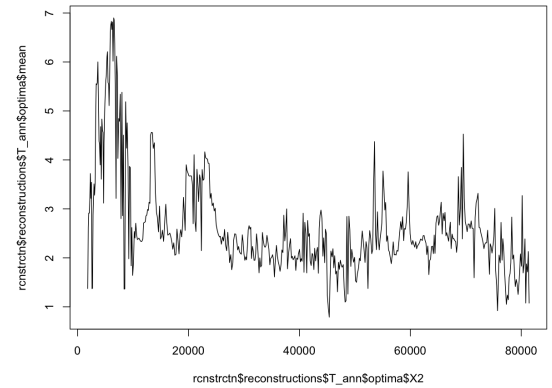

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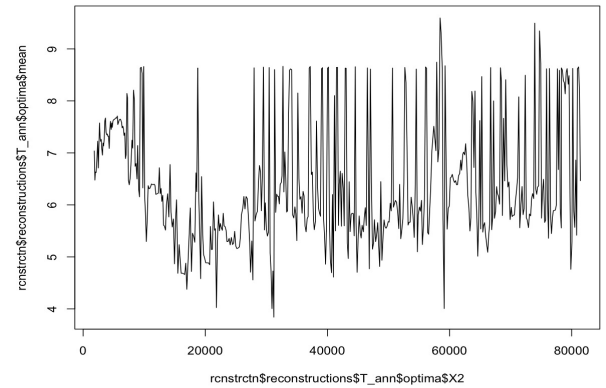

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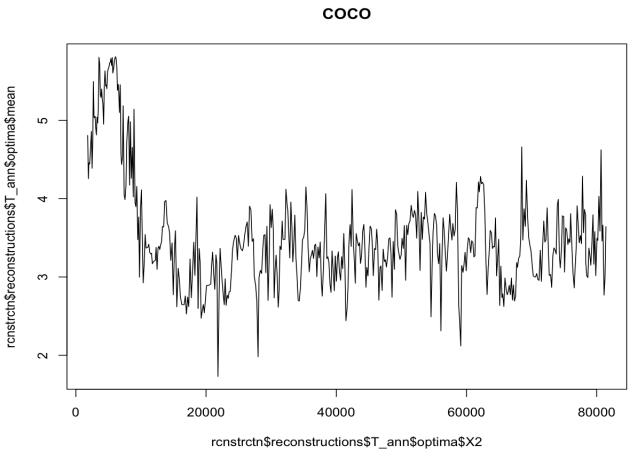

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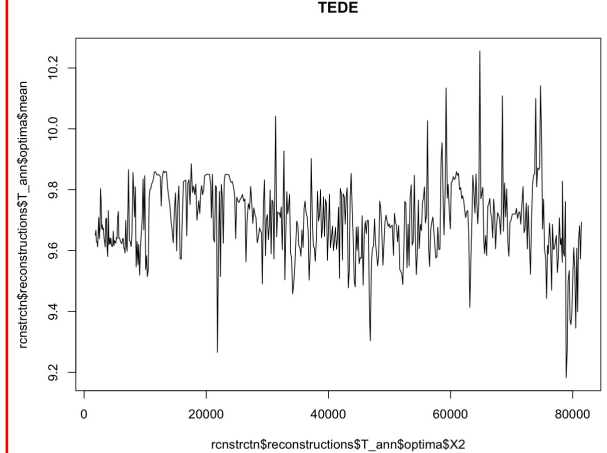

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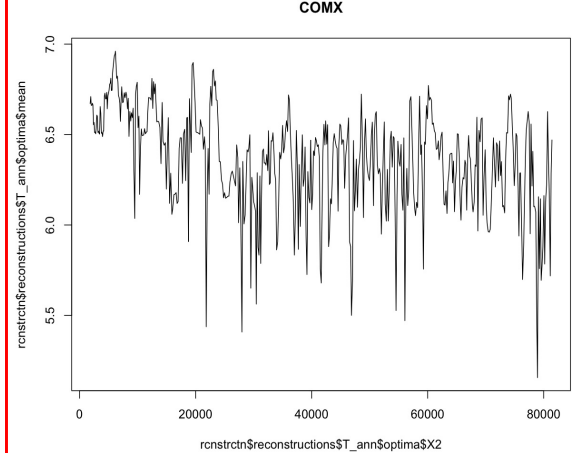

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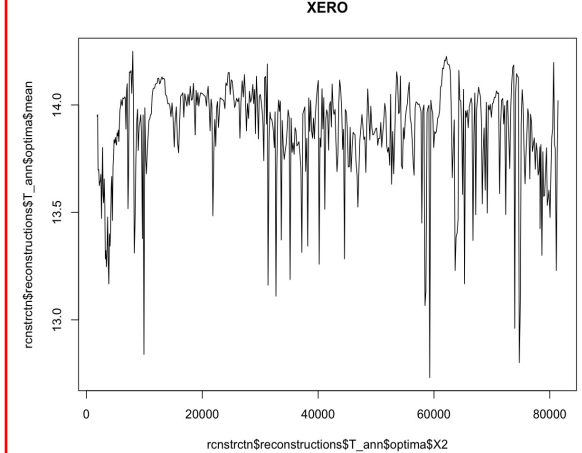

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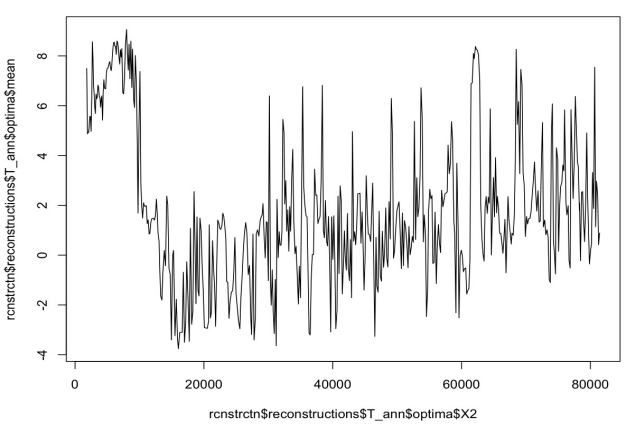

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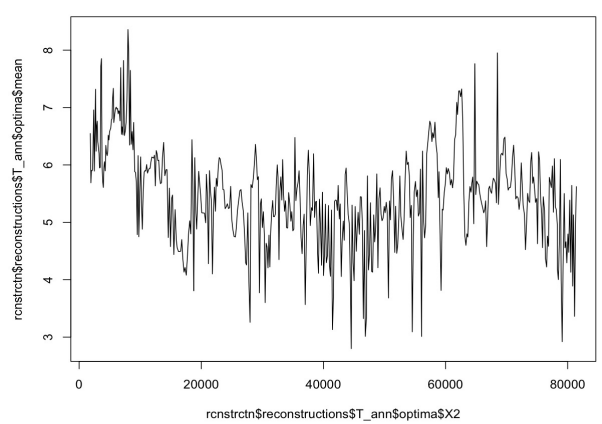

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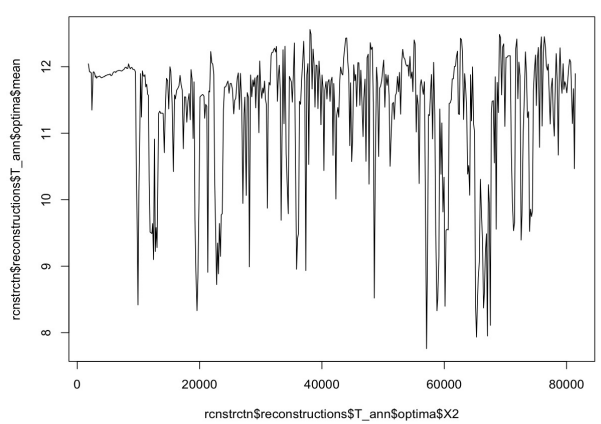

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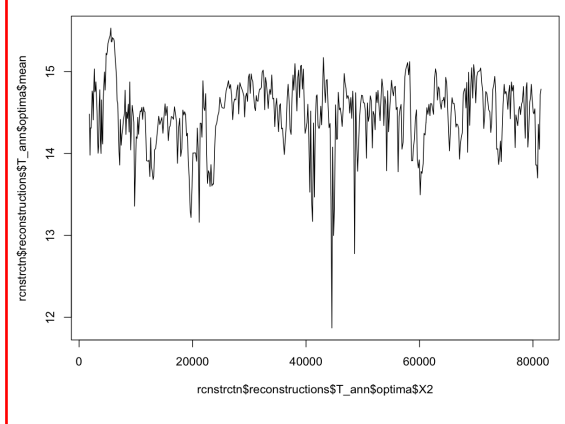

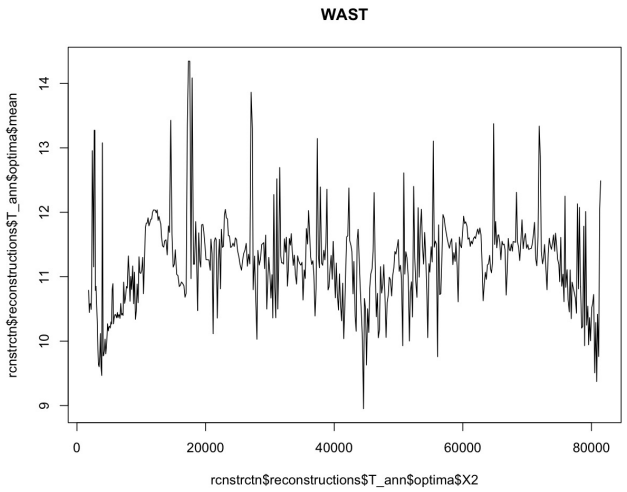
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12
13
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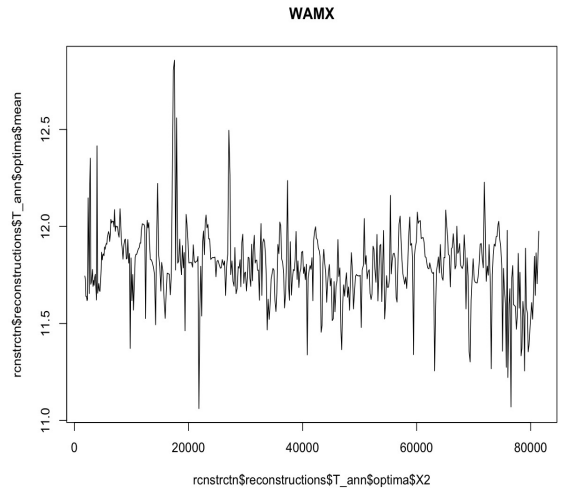
60000
80000
rcnstrctn$reconstructions$T_ann$optima$X2


WAMX
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11.5
12.0
12.5
0
20000
40000
60000
80000
rcnstrctn$reconstructions$T_ann$optima$X2

A venir …

Fossil sites (altitude)	ΔLGM cooling (°C)	ΔLGM precip (mm)	ΔLGM Aridity Index (Ø)
Eifel (747 m)	-4.45±3.56 -3.21±0.87 -2.12±4.21	168±293 8±40 -777±38	3822±4462 1398±461 701±6016
Furamoos (660 m)	-1.70±3.34 -1.12±0.64 0.14±4.51	-198±323 -100±83 -28±470	-3527±4910 -1735±971 -1178±5967
La Grande Pile (250 m)	-4.76±3.35 -1.32±2.14 0.14±4.51	-16±301 -168±41 -28±470	-114±4542 -809±912 -1178±5967
Lac du Bouchet (1 200 m)			

Annexe. Pollen taxon diagrams in 5 sites. Classification proposes 4 Classes: Arboral (AP), Shurb, No-Arboral and Aquatic vegetation.

Arboral vegetation (AP)	Shrub vegetation	Herbaceous vegetation (NAP)		Aquatic
Betula	Juniperus	Poaceae	Gentianaceae ind.	Myriophyllum
Pinus	Betula nana	Cyperaceae	Centaurea scabiosa, t.nigra, Centaurium, Gentiana & Swertia	Nymphae
Corylus	Caprifoliaceae t. Lonicera & Sambucus	Artemisia	Lamiaceae t. Mentha, Hedysarum & Teucrium	Alisma
Quercus	Ephedra t. distachya & fragilis	Brassicaceae	Plantago t. lanceolata, major, media & montana	Menyanthes
Ulmus	Ericaceae t. ind. & Calluna	Caryophyllaceae	Polygonaceae ind.	Potamogeton
Alnus	Hippophae	Chenopodiaceae/Amaranthaceae	Polygonum bistorta & t.aviculare	Sparganium
Tilia	Rhamnaceae t.Paliucrus & Ramnus	Helianthemum	Ranunculaceae t.Trollius	Lemna minor
Fraxinus excelsior	Ribes	Thalictrum	Rumex	Typha
Salix	Myrica	Ranunculaceae ind.	Sanguisorba minor	
Hedera	Viburnum	Armeria	Saxifraga t. granulata & t.oppositifolia	
Acer	Viscum	Boraginaceae t. Cerinthe & Onosma	Scrophulariaceae ind. & t.Euphrasia	
Abies		Campanulaceae	Valerianaceae ind. & t.Valeriana	
Carpinus		Cichorioidae	Urticaceae	
Fagus		Crocus	Euphorbia	
Larix		Dipsaceae/Caprifoliaceae t. Dipsacus & Scabiosa	Apiaceae ind., t.Heracleum, Hydrocotyle, Pimpinella, Seseli, Apium, Pleurospernum	
Picea		Ericaceae t. Listera ovata	Filipendula	
Rosaceae t. Prunus & Sorbus		Fabaceae ind., t. Lotus, Onomis, Trifolium & Genista	Sanguisorba officinalis	

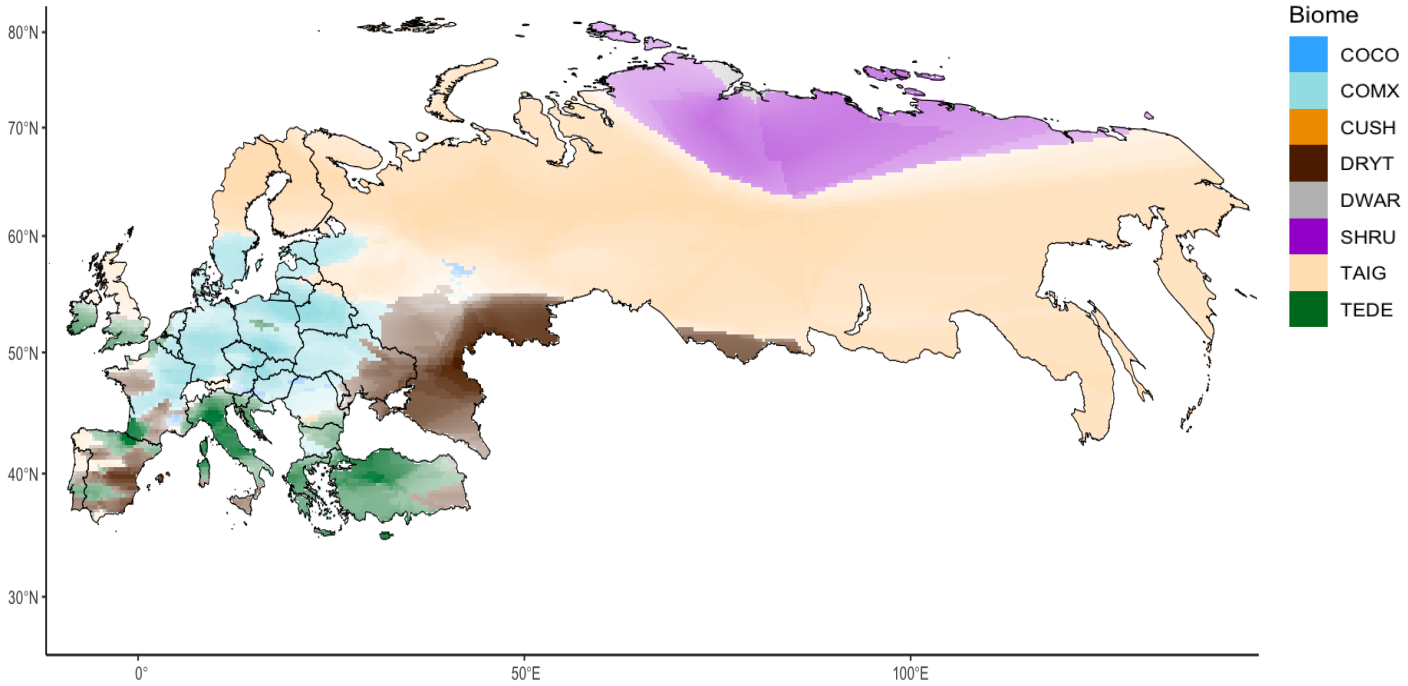
Megabiomes – Binney et al., 2017, Combinaison of pollen-based biome types into megabiomes (Europe)

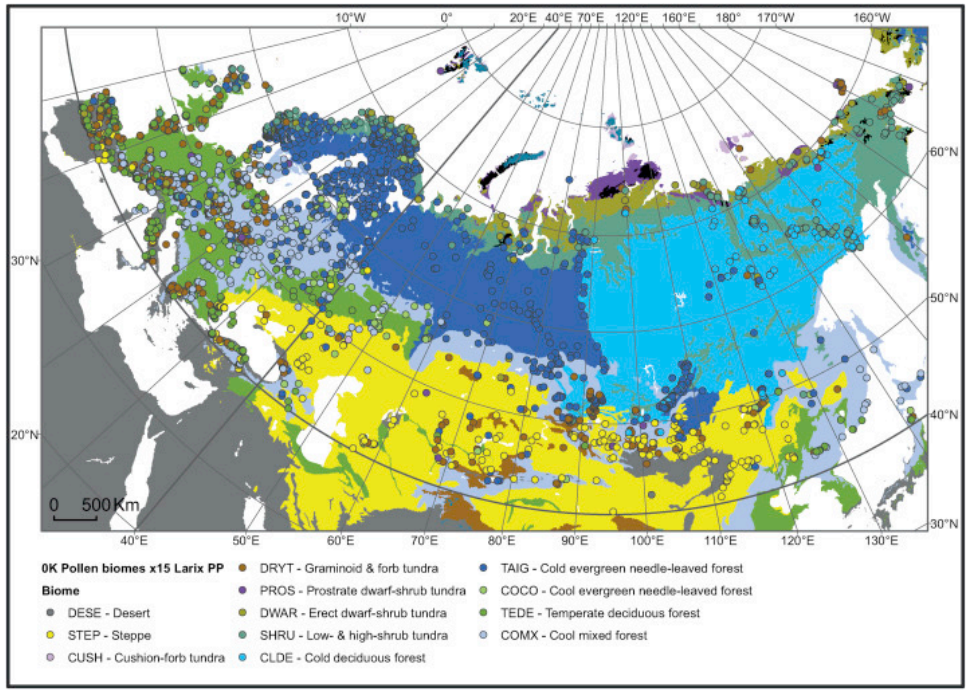
Plant functional types (30)

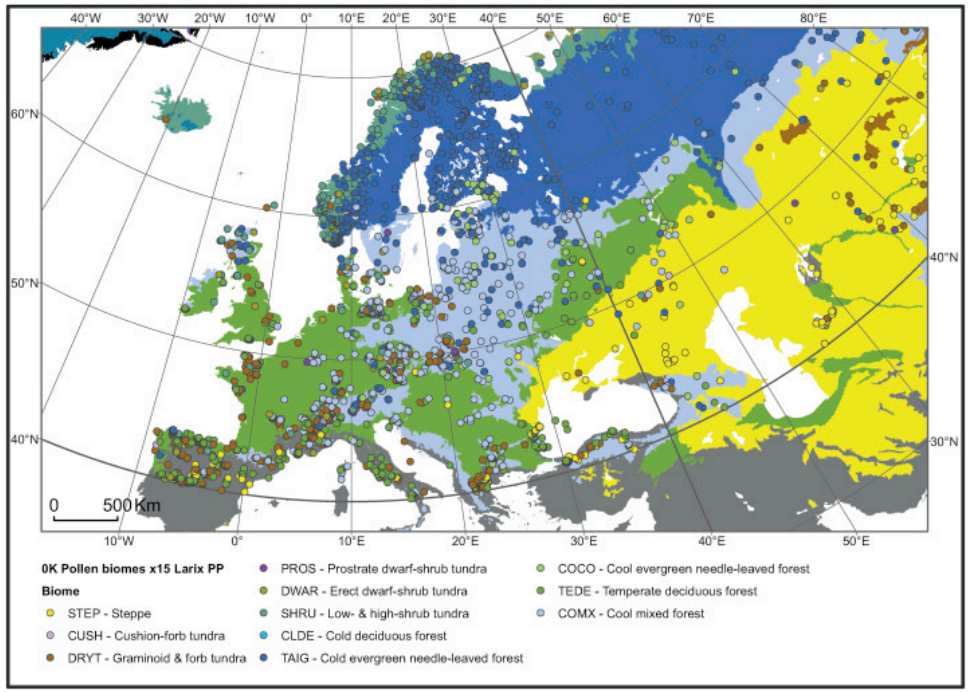
Bog moss (Sphagnum)
Grass graminoid
Sedge graminoid
Rush graminoid
Rosette or cushion forb
Arctic forb
Boreal or temperate drought-tolerant forb
Arctic cold-deciduous malacophyll broad-leaved prostrate dwarf shrub
Arctic evergreen malacophyll broad-leaved prostrate dwarf shrub
Arcto-boreal evergreen needle-leaved prostrate dwarf shrub
Arcto-boreal cold-deciduous malacophyll broad-leaved erect dwarf shrub
Arcto-boreal evergreen malacophyll broad-leaved erect dwarf shrub
Arcto-boreal cold-deciduous malacophyll broad-leaved low or high shrub
Arcto-boreal evergreen malacophyll broad-leaved low or high shrub
Arcto-boreal evergreen needle-leaved low or high shrub
Boreal cold-deciduous malacophyll broad-leaved low or high shrub
Boreal evergreen malacophyll broad-leaved low or high shrub
Boreal or temperate drought-tolerant cold-deciduous or evergreen malacophyll broad-leaved low or high shrub
Boreal evergreen needle-leaved tree
Boreal cold-deciduous needle-leaved tree
Boreal cold-deciduous malacophyll broad-leaved tree
Eurythermic evergreen needle-leaved tree
Temperate evergreen needle-leaved tree
Maritime evergreen needle-leaved tree
Cool-temperate evergreen needle-leaved tree
Temperate (spring-frost avoiding) cold-deciduous malacophyll broad-leaved tree
Temperate (spring-frost tolerant) cold-deciduous malacophyll broad-leaved tree
Temperate (spring-frost intolerant) cold-deciduous malacophyll broad-leaved tree
Temperate evergreen malacophyll broad-leaved woody plants
Desert forb/shrub

Biome code	**Biome name**
DESE	desert
CUSH	cushion-forb tundra
DRYT	dry tundra: graminoids and forbs
PROS	prostrate dwarf-shrub tundra
DWAR	erect dwarf-shrub tundra
SHRU	low- and high-shrub tundra
STEP	temperate grassland
CLDE	cold deciduous forest
TAIG	cold evergreen needle-leaved forest
COCO	cool evergreen needle-leaved forest
TEDE	temperate deciduous forest
COMX	cool mixed forest

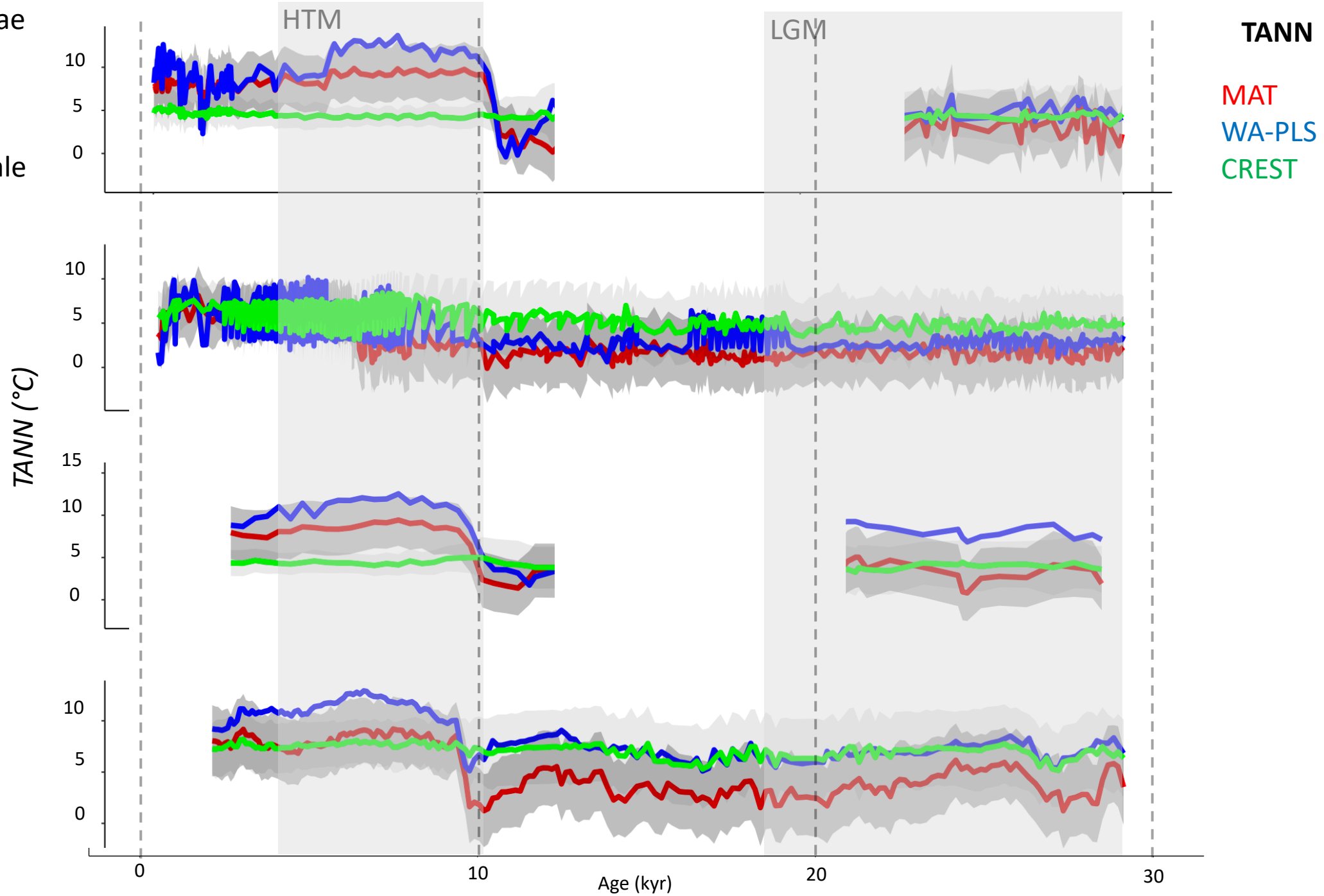
Modern pollen assemblages → dominant biomes







Avec Cyperaceae
WAPLS non biomisé
MAT et CREST calibration locale



Annexe. Relationship between biome classification and mega-biome reported in *Hegel et al., 2018*.
From this table, we test the relatability of our classification in this global spatial resolution.

Biome schema	*Initial Biome classification*	*Mega biome Classification (Hegel et al., 2018)*	*Our original biome classification in Europe*
tropical evergreen broadleaf forest	tropical evergreen broadleaf forest	tropical forest	NA
tropical semi-evergreen broadleaf forest	tropical semi-evergreen broadleaf forest	tropical forest	NA
tropical deciduous broadleaf forest and woodland	tropical deciduous broadleaf forest and woodland	tropical forest	NA
warm-temperate evergreen and mixed forest	warm-temperate evergreen broadleaf and mixed forest	warm-temperate forest	WAMX
cool-temperate rainforest	wet sclerophyll forest	warm-temperate forest	WAMX
cool evergreen needleleaf forest	cool evergreen needleleaf forest	temperate forest	COMX/COCO
cool mixed forest	cool mixed forest	temperate forest	COMX/COCO
temperate deciduous broadleaf forest	temperate deciduous broadleaf forest	temperate forest	COMX/COCO
cold deciduous forest	cold deciduous forest	boreal forest	CLMX/CLDE/TAIG
cold evergreen needleleaf forest	cold evergreen needleleaf forest	boreal forest	CLMX/CLDE/TAIG
temperate sclerophyll woodland and shrubland	temperate sclerophyll woodland and shrubland	savanna and dry woodland	TEDE
temperate evergreen needleleaf open woodland	temperate evergreen needleleaf open woodland	savanna and dry woodland	TEDE
tropical savanna	tropical savanna	savanna and dry woodland	NA
	temperate deciduous broadleaf savanna	savanna and dry woodland	TEDE
xerophytic woods/scrub	tropical xerophytic shrubland	grassland and dry shrubland	XERO/WAST
steppe	tropical grassland	grassland and dry shrubland	XERO/WAST
desert	desert	desert	HODE/CODE/COST
graminoid and forb tundra	graminoid and forb tundra	dry tundra	TUND
erect dwarf shrub tundra	erect dwarf-shrub tundra	tundra	TUND
low and high shrub tundra	low and high shrub tundra	tundra	TUND
prostrate dwarf shrub tundra	prostrate dwarf-shrub tundra	tundra	TUND

Annexe. Comparison between five pollen and climate reconstruction results for each reference period of time, in terms of altitude, class of vegetation, dominant biomes and reconstructed climate variables from 2 methods.

Error of the climate parameters are 2σ.

Chronological reference period Fossil site	Altitude (m a.s.l)	Pollen fraction per vegetation class (%)			3 dominant biomes (scores) *(1)*	TANN (°C)	PANN (mm)	GA (Ø)
		AP	Shrub	NAP				
Younger Dryas (~11 kyr)								
Eifel	747							
Füramoos	660							
La Grande Pile	250							
Echets	267							
Lac du Bouchet	1 200							
H1 (~14 kyr)								
Eifel	747							
Füramoos	660							
La Grande Pile	250							
Echets	267							
Lac du Bouchet	1 200							
H2 (~23 kyr)								
Eifel	747							
Füramoos	660							
La Grande Pile	250							
Echets	267							
Lac du Bouchet	1 200							
H3 (~30 kyr)								
Eifel	747							
Füramoos	660							
La Grande Pile	250							
Echets	267							
Lac du Bouchet	1 200							