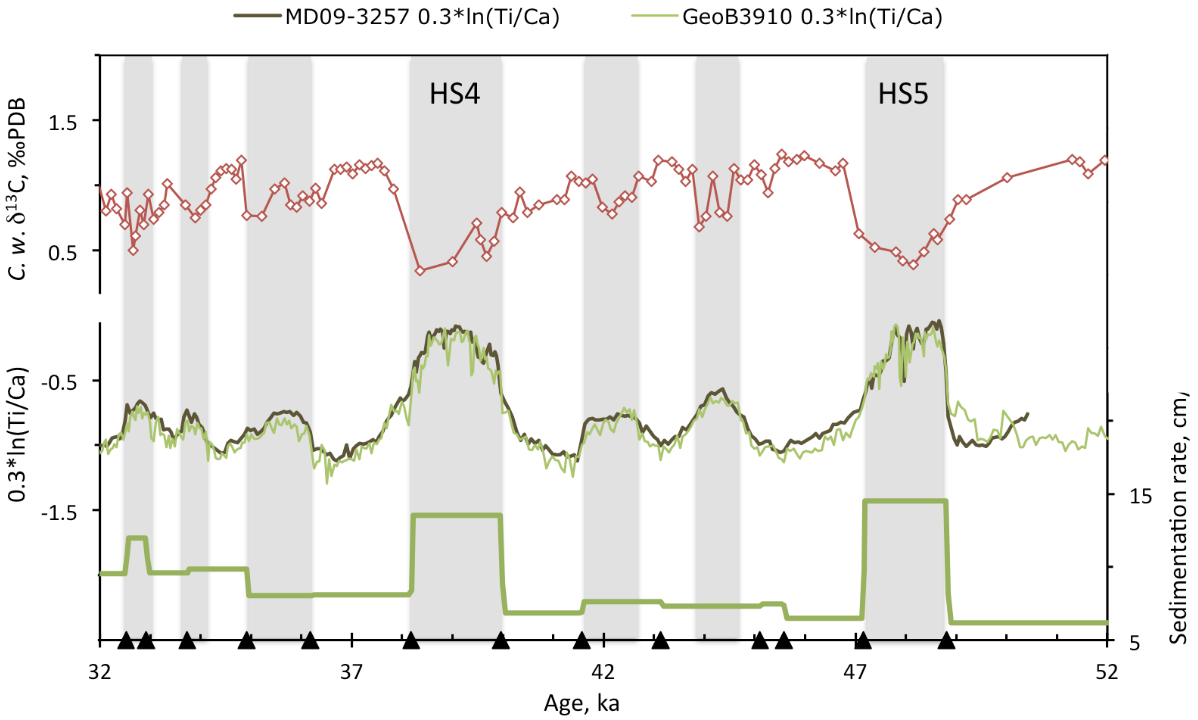

Figure S1. Alignment of GeoB3910-2 ln(Ti/Ca) to MD09-3257 ln(Ti/Ca) signal over the time interval 32-50 ka, i.e. the portion of the *C. wuellerstorfi* δ^{13}C ($\delta^{13}C_{Cw}$) record consisting in GeoB3910 measurements. From top to bottom: GeoB3910-2 $\delta^{13}C_{Cw}$, GeoB3910-2 and MD09-3257 ln(Ti/Ca) (both multiplied by 0.3 for graphic purposes), GeoB3910-2 sedimentation rate. Triangles denote alignment pointers between GeoB3910-2 and MD09-3257 ln(Ti/Ca) signals. The uncertainty on the tie points relative timing ranges from 70 to 150 y (mean uncertainty = 102 y) over the time interval 32-50 ka. NB: It is lower and ranges from 80 to 110 y (mean uncertainty = 90 y) over the time interval 32-38 ka, over which the cross-wavelet analysis yields a mean relative phase of 247 ± 89 y between $\delta^{13}C_{Cw}$ and Pa/Th.

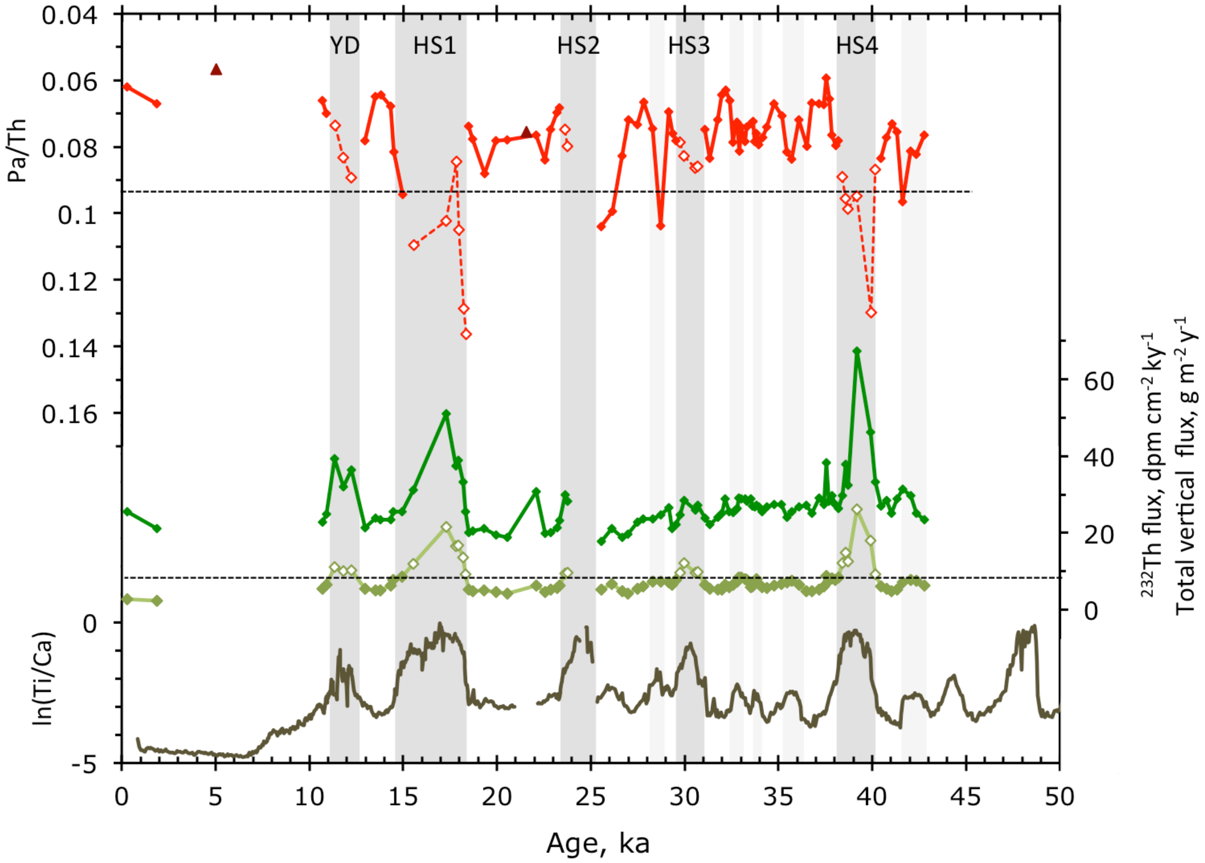

Figure S2. MD09-3257 sedimentary Pa/Th, ^{230}Th-normalized ^{232}Th flux (olive green), total vertical flux (green), and ln(Ti/Ca) versus calendar age. Dark triangles denote two sedimentary Pa/Th data points that were measured on core GeoB3910 by J. Lippold (all data given in Table S1). Olive green empty symbols denote ^{232}Th flux values larger than 9 dpm cm^{-2} ky^{-1} (black dotted line) and correspond to samples within the main precipitation events PE0 to PE4. Horizontal black dotted lines indicate the Pa/Th production ratio (0.093) and ^{232}Th flux threshold of 9 dpm cm^{-2} ky^{-1}.

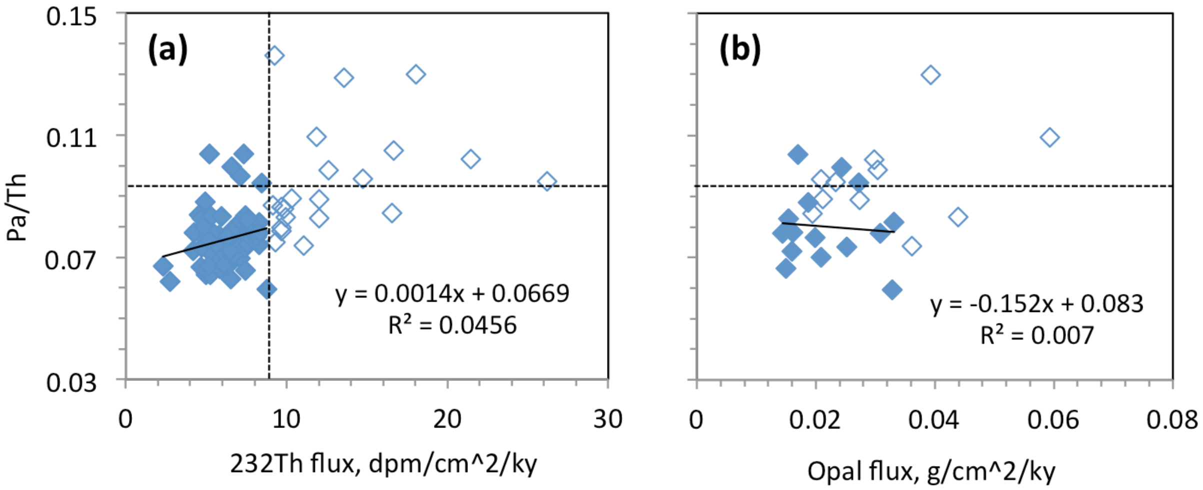

Figure S3. MD09-3257 sedimentary Pa/Th versus **(a)** ^{230}Th-normalized ^{232}Th flux, and **(b)** opal flux. Empty symbols denote ^{232}Th flux values larger than 9 dpm cm^{-2} ky^{-1}. Empty symbols correspond to samples within the main precipitation events PE0 to PE4 (Fig. S2). New opal measurements were added to the ones published in (Burckel et al., 2015). The new opal measurements were generated by Fourier transform infrared spectroscopy, as described in (Vogel et al., 2016) (all data are given in Table S2). The black dotted lines correspond to those of Fig. S2.

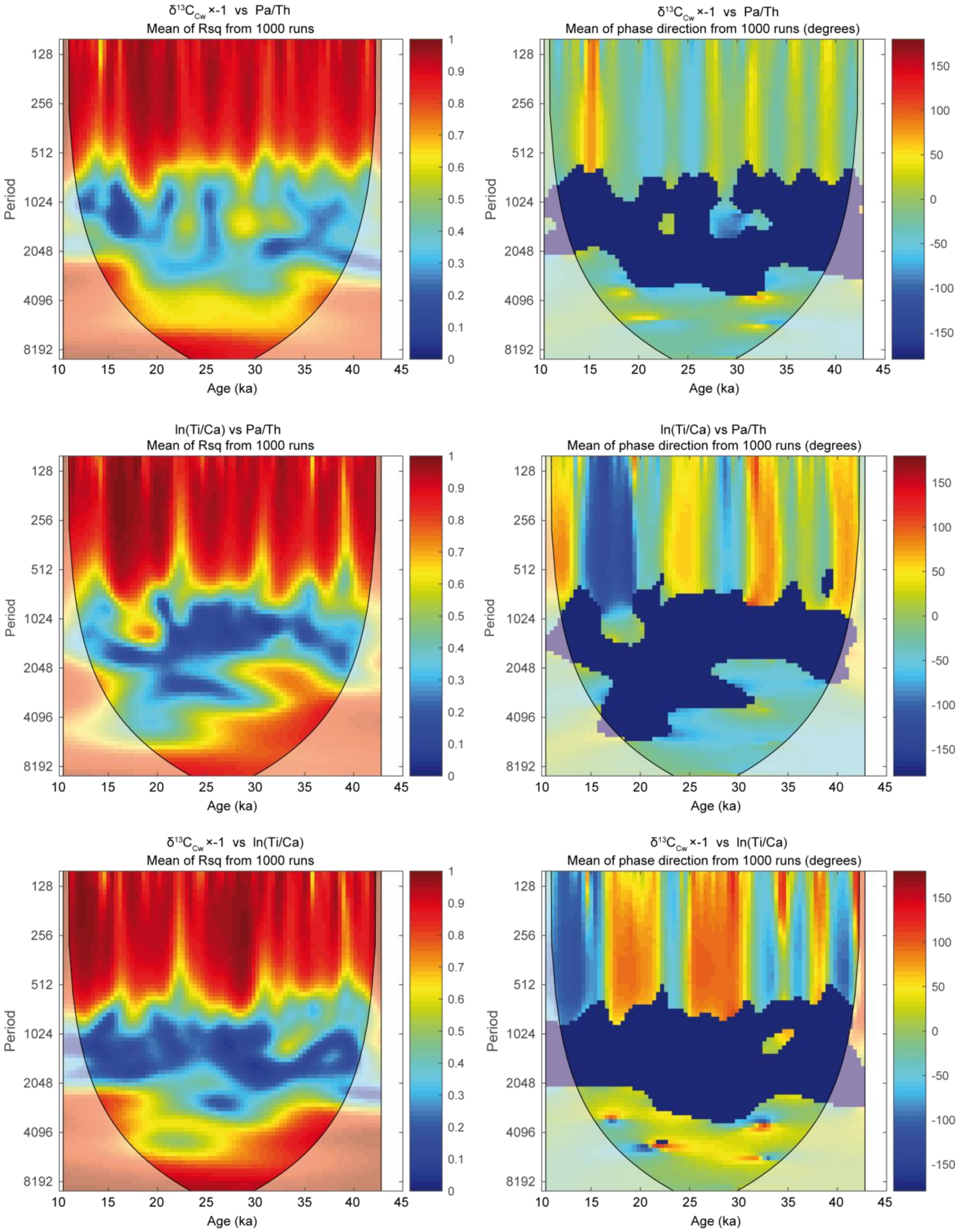

Figure S4. Cross-wavelet results obtained when the time series are resampled with a time step of 400 y. Results are meaningful for periods > 800 y (corresponding to a Nyquist frequency = 1/(2*400 y)).

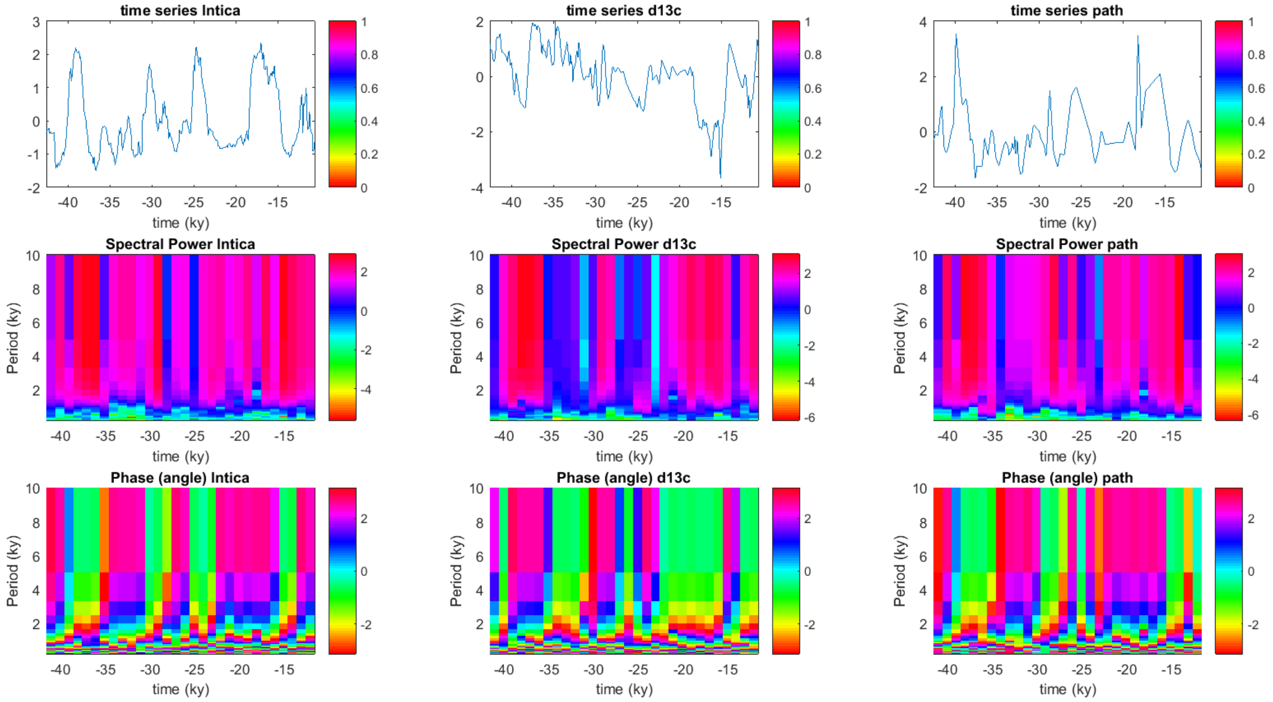

Figure S5. Spectrograms of MD09-3257 ln(Ti/Ca), sedimentary Pa/Th, and composite $\delta^{13}C_{Cw}$ records obtained computing finite time Fourier transforms dividing the signal in 20 windows, with 10 overlaps and using 100 frequencies. Upper panels: normalized signals. Middle and lower panels: power spectra and absolute phases, respectively, of each signal taken separately. Spectral amplitude is mostly concentrated in periods longer than 2 ky and decreases with the period. This kind of power spectral density is typical of turbulent climate time series (Lovejoy and Schertzer, 1990). Sensitivity (not shown) suggest that results for periods larger than 6 ky are not interpretable due to the short duration of the analyzed records.

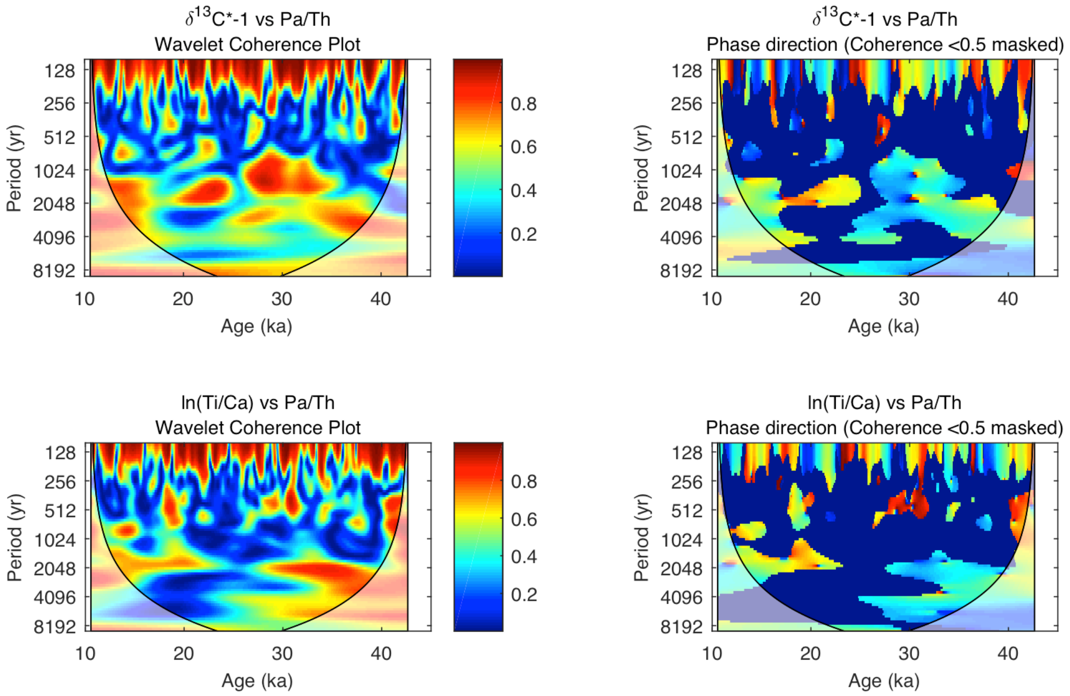

Figure S6. Cross-wavelet results obtained for the subset of Pa/Th data points not affected by large particle fluxes.

References

Burckel, P., Waelbroeck, C., Gherardi, J.-M., Pichat, S., Arz, H., Lippold, J., Dokken, T., and Thil, F.: Atlantic Ocean circulation changes preceded millennial tropical South America rainfall events during the last glacial, Geophys. Res. Lett., 42, 411-418, 2015.

Lovejoy, S., and Schertzer, D.: Multifractals, universality classes and satellite and radar measurements of cloud and rain fields, Journal of Geophysical Research: Atmospheres, 95, 2021-2034, 1990.

Vogel, H., Meyer-Jacob, C., Thöle, L., Lippold, J. A., and Jaccard, S. L.: Quantification of biogenic silica by means of Fourier transform infrared spectroscopy (FTIRS) in marine sediments, Limnology and oceanography: methods, 14, 828-838, 2016.

R script

```
library(readxl)
library(writexl)
# imports three time series (d13C, PaTh, and ln_TiCa)
mydata = read_xlsx("./input/MD09-3257_data_100y_norm.xlsx")
nline<-length(mydata$Age)

# initializes variables
r13C_vs_PaTh<-NULL
r13C_vs_TiCa<-NULL
rPaTh_vs_TiCa<-NULL
pval13C_vs_PaTh<-NULL
pval13C_vs_TiCa<-NULL
pvalPaTh_vs_TiCa<-NULL
lagm<-NULL
dummy<-NULL
d13C<-matrix(data=NA,nrow=nline,ncol=1)
shiftd13C<-matrix(data=NA,nrow=nline,ncol=length(-10:10))
PaTh<-matrix(data=NA,nrow=nline,ncol=1)
shiftPaTh<-matrix(data=NA,nrow=nline,ncol=length(-10:10))
ln_TiCa<-matrix(data=NA,nrow=nline,ncol=1)

# computes correlation coefficient r[m] for lag = -m*100 --> -100
for (m in -10:-1) {
 j=m+11
 for (i in 1:(nline+m)) {
   d13C[i]<-mydata$d13C[i]
   shiftd13C[i,j]<-mydata$d13C[i-m]
   PaTh[i]<-mydata$PaTh[i]
   shiftPaTh[i,j]<-mydata$PaTh[i-m]
   ln_TiCa[i]<-mydata$ln_TiCa[i]
 }
  # computes r for d13C vs PaTh
  ct=cor.test(PaTh,shiftd13C[,j],alternative=c("two.sided"),method=c("spearman"),exact=NULL,conf.level=0.95,c
  ontinuity=FALSE)
  r13C_vs_PaTh[j]<-ct$estimate
  pval13C_vs_PaTh[j]<-ct$p.value

  # computes r for d13C vs ln_TiCa
  ct=cor.test(ln_TiCa,shiftd13C[,j],alternative=c("two.sided"),method=c("spearman"),exact=NULL,
  conf.level=0.95,continuity=FALSE)
 r13C_vs_TiCa[j]<-ct$estimate
 pval13C_vs_TiCa[j]<-ct$p.value

  # computes r for PaTh vs ln_TiCa
  ct=cor.test(ln_TiCa,shiftPaTh[,j],alternative=c("two.sided"),method=c("spearman"),exact=NULL,
  conf.level=0.95,continuity=FALSE)
 rPaTh_vs_TiCa[j]<-ct$estimate
```

```
  pvalPaTh_vs_TiCa[j]<-ct$p.value
  lagm[j]<-m*100
}

# computes correlation coefficient r[m] for lag = 0 --> m*100
for (m in 0:10) {
  j=m+11
  for (i in (1+m):nline) {
    d13C[i]<-mydata$d13C[i]
    shiftd13C[i,j]<-mydata$d13C[i-m]
    PaTh[i]<-mydata$PaTh[i]
    shiftPaTh[i,j]<-mydata$PaTh[i-m]
    ln_TiCa[i]<-mydata$ln_TiCa[i]
  }
  # computes r for d13C vs PaTh
   ct=cor.test(PaTh,shiftd13C[,j],alternative=c("two.sided"),method=c("spearman"),exact=NULL,conf.level=0.95,c
ontinuity=FALSE)
  r13C_vs_PaTh[j]<-ct$estimate
  pval13C_vs_PaTh[j]<-ct$p.value

  # computes r for d13C vs ln_TiCa
   ct=cor.test(ln_TiCa,shiftd13C[,j],alternative=c("two.sided"),method=c("spearman"),exact=NULL,
   conf.level=0.95,continuity=FALSE)
  r13C_vs_TiCa[j]<-ct$estimate
  pval13C_vs_TiCa[j]<-ct$p.value

  # computes r for PaTh vs ln_TiCa
   ct=cor.test(ln_TiCa,shiftPaTh[,j],alternative=c("two.sided"),method=c("spearman"),exact=NULL,
   conf.level=0.95,continuity=FALSE)
  rPaTh_vs_TiCa[j]<-ct$estimate
  pvalPaTh_vs_TiCa[j]<-ct$p.value
  lagm[j]<-m*100
}

dummy<-data.frame(lagm=lagm,r13C_vs_PaTh=r13C_vs_PaTh,pval13C_vs_PaTh=pval13C_vs_PaTh,
r13C_vs_TiCa=r13C_vs_TiCa,pval13C_vs_TiCa=pval13C_vs_TiCa,rPaTh_vs_TiCa=rPaTh_vs_TiCa,
pvalPaTh_vs_TiCa=pvalPaTh_vs_TiCa)
write_xlsx(dummy,"./output/output_100y.xlsx")
matplot (lagm, cbind (r13C_vs_PaTh,r13C_vs_TiCa,rPaTh_vs_TiCa), pch = 19)
```