GPR data deconvolution

18 Dezember 2019

Note:

- This R-package is still in development, and therefore some of the functions may change in a near future.
- If you have any questions, comments or suggestions, feel free to contact me (in english, french or german): emanuel.huber@alumni.ethz.ch.

Table of Contents

Objectives of this tutorial

- Learn how to apply the deconvolution scheme of Schmelzbach and Huber (2015) to GPR data

Note that his tutorial will not explain you the math/algorithms behind the different processing methods.

We follow the approach proposed by Schmelzbach and Huber (2015), Efficient Deconvolution of Ground-Penetrating Radar Data, IEEE Transactions on Geosciences and Remote Sensing 53 (9), 5209-5217, doi:10.1109/TGRS.2015.2419235.

Download the pdf

Preliminary

- Read the tutorial Basic GPR data processing to learn more about the processing methods
- Download the data 2012_10_06_cornino.zip. The data can be also downloaded on Zenodo DOI:10.5281/zenodo.2586189.svg and can be cited as follow: Huber, Emanuel (2019), GPR data used to test the efficient deconvolution method of Schmelzbach and Huber (2015), doi:10.5281/zenodo.2586189.
- Unzip the data

Install/load RGPR

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```
# install "devtools" if not already done
if(!require("devtools")) install.packages("devtools")
devtools::install_github("emanuelhuber/RGPR")
library(RGPR)       # load RGPR in the current R session
```

- Set the working directory:

```
DIR <- "~/2012_10_06_cornino"  # adapt that to your directory structure
setwd(DIR)    # set the working directory
getwd()         # Return the current working directory (just to check)
```

Read the data

```
x <- readGPR(dsn = "yyline3.DT1")
x <- x[1:300, ]
```

GPR data deconvolution

First wave break and time zero estimation

Quantify first wave break:

```
tfb <- firstBreak(x, w = 20, method = "coppens", thr = 0.05)
plot(pos(x), tfb, pch = 20, ylab = "first wave break",
     xlab = "position (m)")
```

Convert first wave break to time-zero and set time-zero

```
t0 <- firstBreakToTime0(tfb, x)
time0(x) <- mean(t0)     # set time0
```

DC-shift

```
x1 <- dcshift(x)
```

Time zero correction

To shift the traces to time-zero, use the function `time0Cor` (the `method` argument defines the type of interpolation method)

```
x2 <- time0Cor(x1, method = "pchip")
```

Dewow

Remove the low-frequency components (the so-called “wow”) of the GPR record:

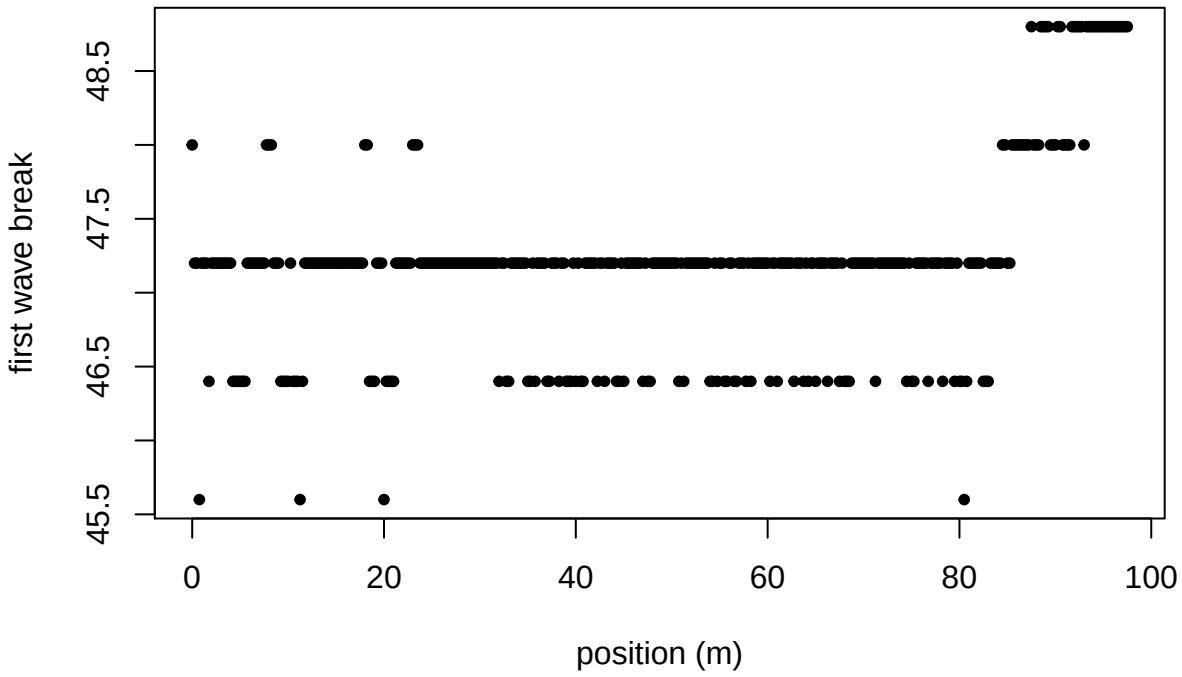


Figure 1: plot first wave break time

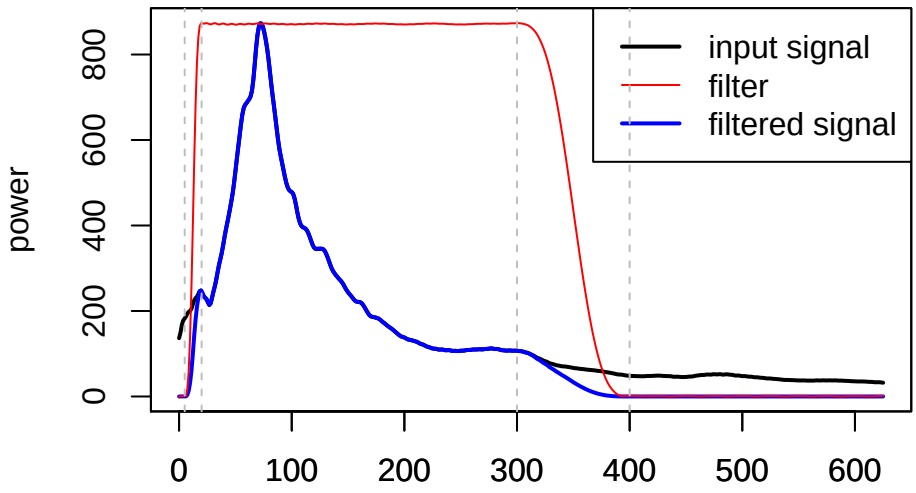
```
x3 <- dewow(x2, type = "runmed", w = 50)      # dewowing:
plot(x3)                                      # plot the result
```

```
plot(x3 - x2)                              # plot the difference
```

Frequency filter

To remove low (dewow) and high (noise) frequency (large bandpass to minimise the introduction of artifact)

```
x4 <- fFilter(x3, f = c(5, 20, 300, 400), type = "bandpass",
              plotSpec = TRUE)
```



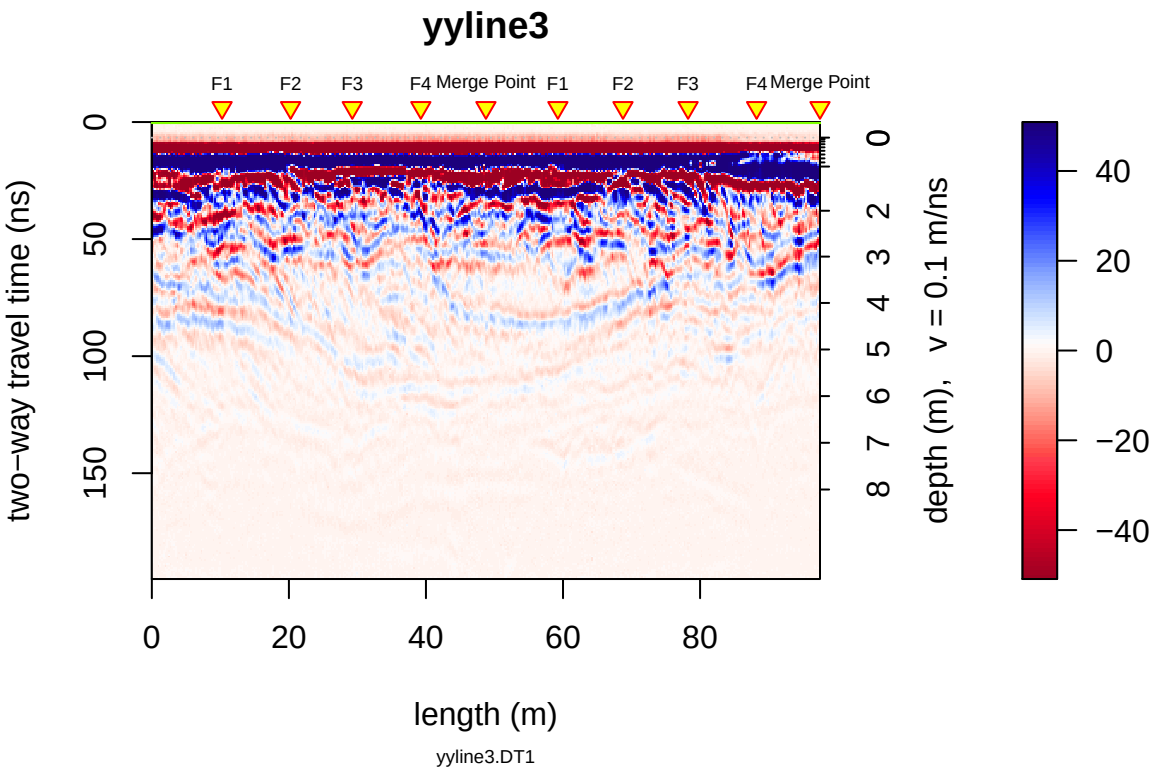


Figure 2: plot after dewow

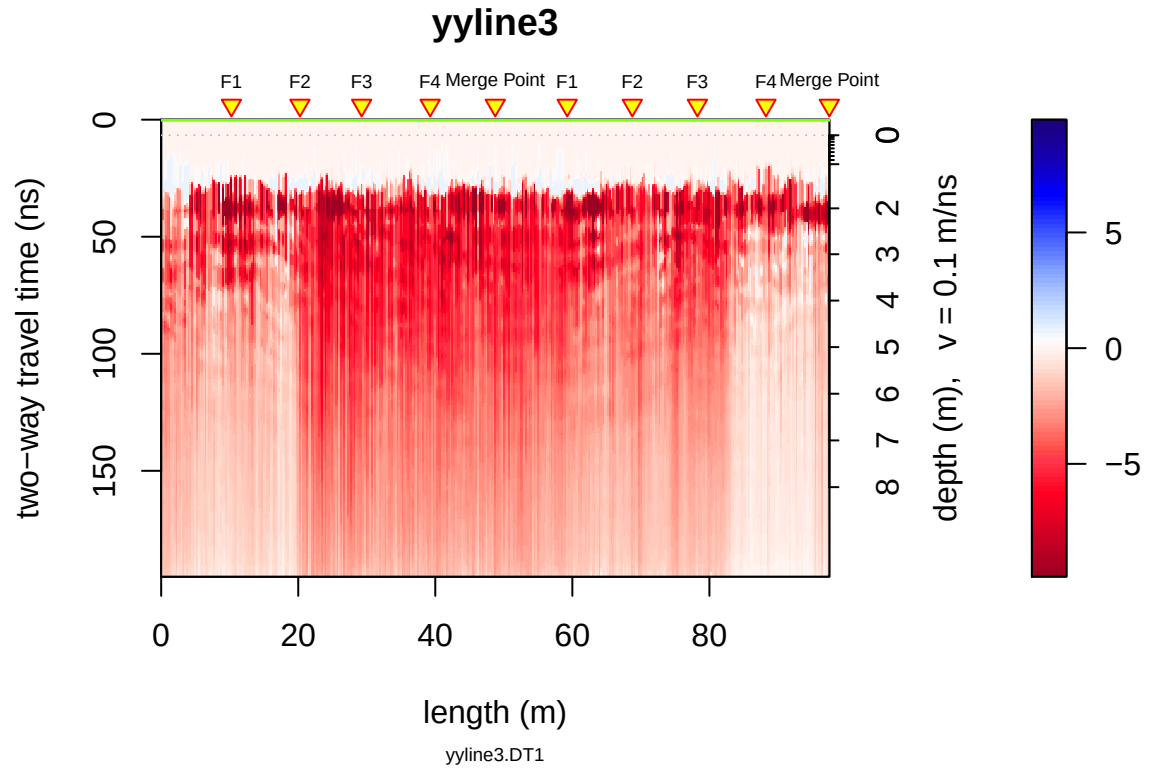
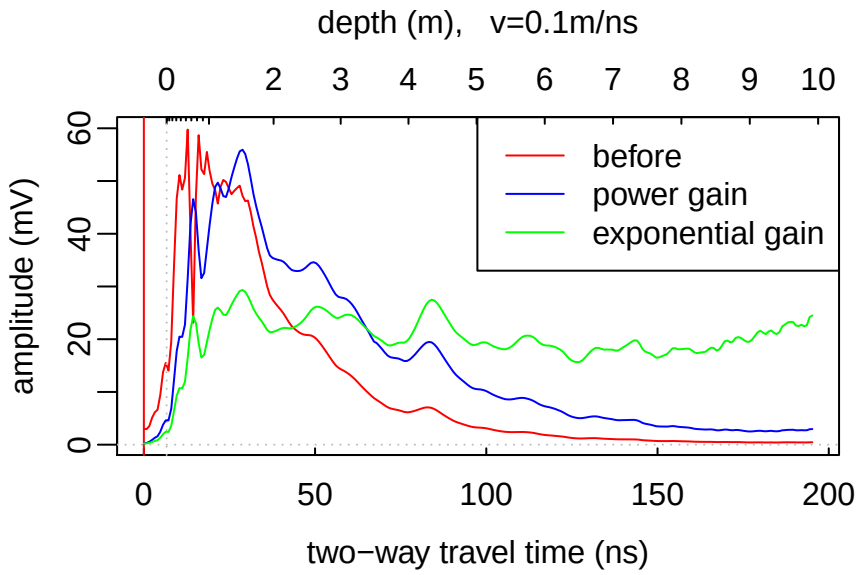


Figure 3: plot after dewow

Time gain

Apply a power gain and a spherical gain to compensate for geometric wave spreading and attenuation (Kruse and Jol, 2003; Grimm et al., 2006).

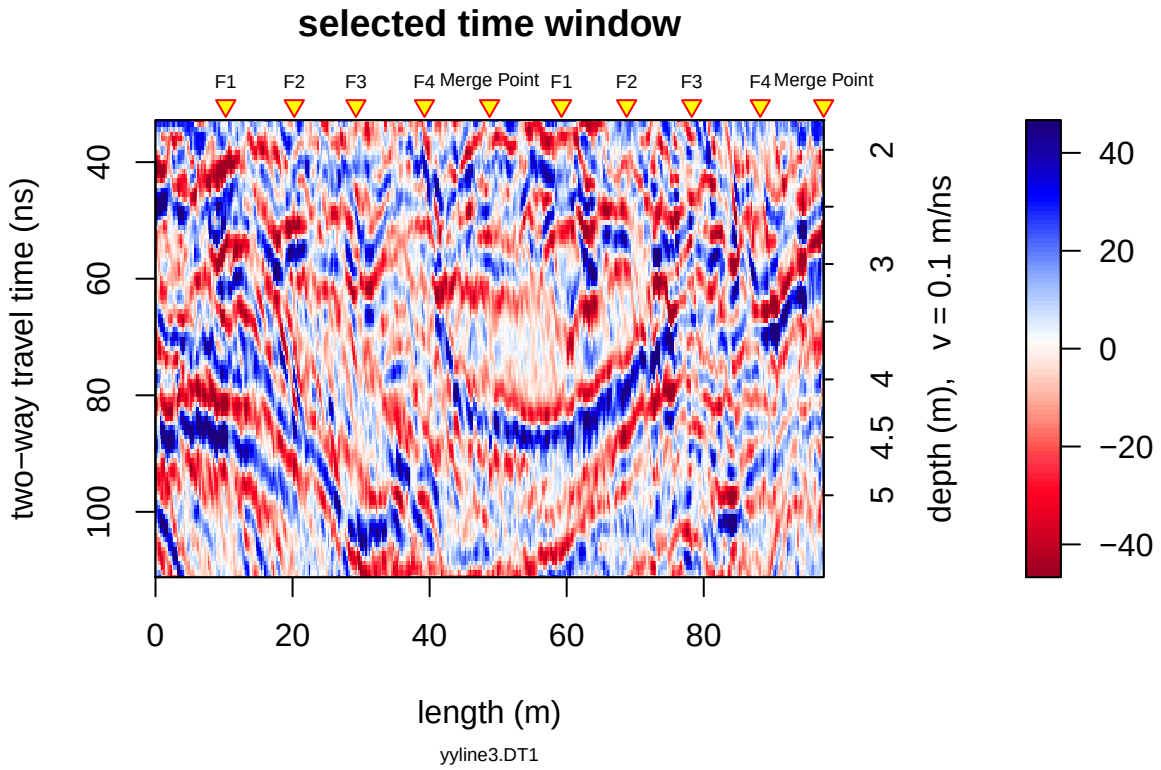
```
# power gain (compensate geometric spreading)
x5 <- gain(x4, type ="power",  alpha = 1, t0 = 0, te = 200)
# exponential gain (compensate for attenuation)
x6 <- gain(x5, type ="exp",  alpha = 0.023, t0 = 30, te = 180)

trPlot(traceStat(envelope(x4)), col = "red", main="")
trPlot(traceStat(envelope(x5)), col = "blue", add=TRUE)
trPlot(traceStat(envelope(x6)), col = "green", add=TRUE)
legend("topright",legend=c("before","power gain", "exponential gain"),
       lwd=c(1,1,1), col=c("red","blue","green"))
```



Mixed phase deconvolution

Select the time window on which the deconvolution will be applied:

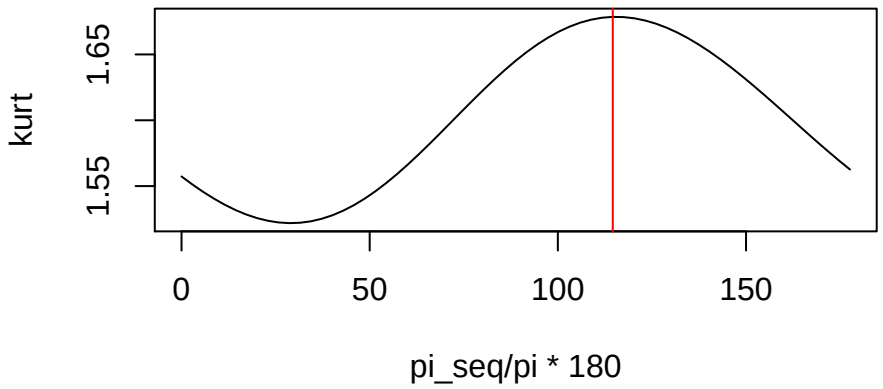
```
tWin <- c(32, 112)  # ns
W <- which(depth(x6) > tWin[1] & depth(x6) < tWin[2])

plot(x6[W, ], main = "selected time window")
```



Minimum-phase deconvolution and phase rotation

Apply the mixed-phase deconvolution: spiking deconvolution + phase rotation that maximise the kurtosis of the GPR data.

```
x_dec <- deconv(x6, method="mixed-phase", W = tWin , wtr = 5, nf = 35,
                mu = 0.00001)
```




```
x <- x6@data[,1]
npad <- 0
phi <- 0.324
  n <- length(x)
  x <- c(rev(head(x, npad)), x, rev(tail(x, npad)))    # add MANU
  nf <- length(x)
  X <- stats::fft(x)
  # phi2 <- numeric(nf)
```

```
  # phi2[2:(nf/2)] <- phi
  phi2 <- rep(phi, nf)
  phi2[(nf/2+1):(nf)] <- -phi
  Phase <- exp( complex(imaginary = 1) * phi2)
  xcor <- stats::fft(X*Phase, inverse=TRUE)/nf
  return(Re(xcor)[npad + 1:n])

  xrot <- phaseRotation(x6, 0.234)
  xrot <- phaseRotation(x6[,1], 0.234)
```

Estimated phase rotation: 114.59°.

The function `deconv()` (when `method = "mixed-phase"`) returns a list of following elements:

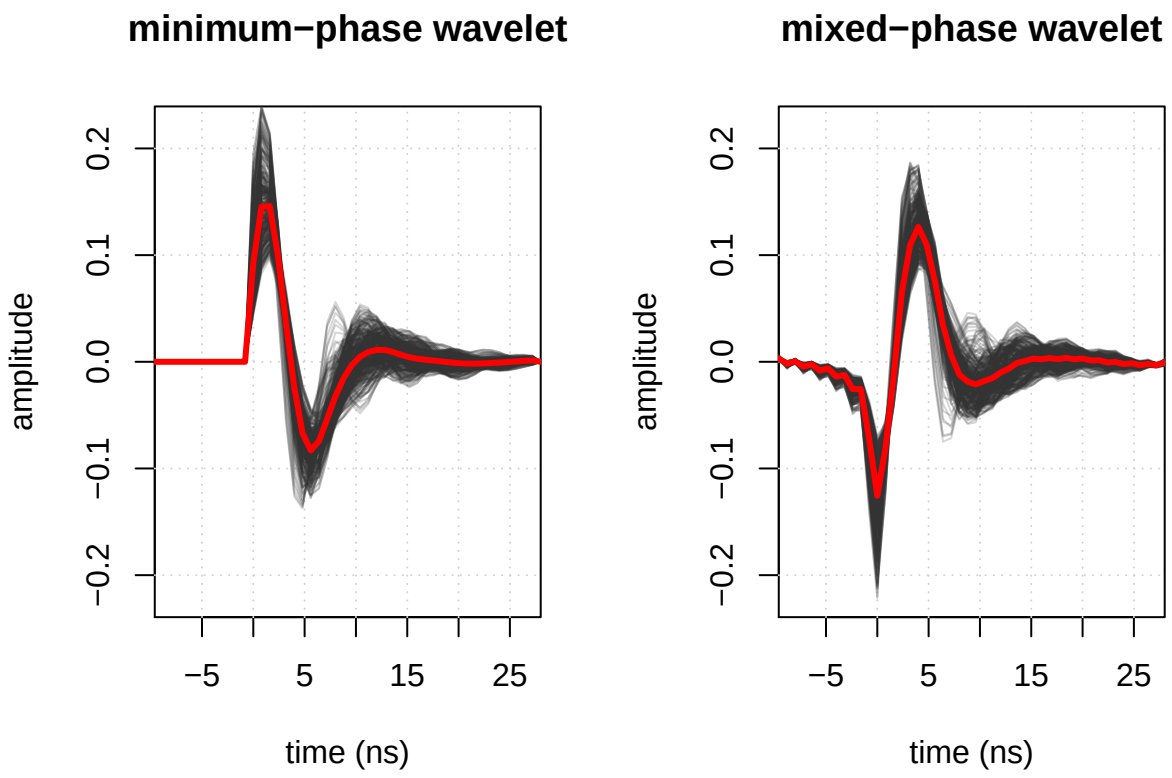
- `fmin`: estimated inverse minimum-phase wavelet
- `wmin`: estimated minimum-phase wavelet
- `optRot`: rotation of the minimum-phase wavelet that maximise the kurtosis
- `wmix`: estimated mixed-phase wavelet (the rotated minimum-phase wavelet)
- `x`: the deconvolued data

You can compare the results with the "minimum-phase deconvolution" also called "spiking deconvolution" by setting in `deconv() method = "spiking"` (in this case, `deconv()` returns only `fmin`, `wmin` and `x`).

Minimum-phase and mixed-phase wavelet

In black the estimated wavelets for each trace, in red the mean wavelet.

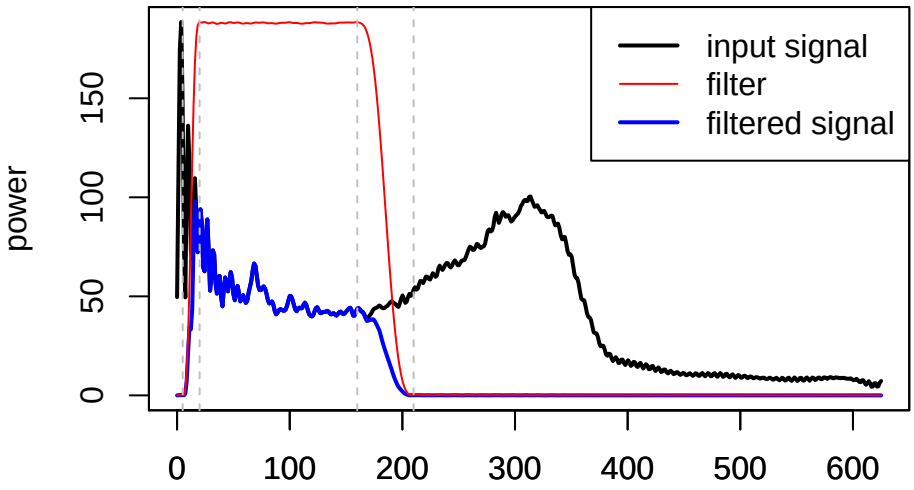
```
w_min <- x_dec$wmin
w_mix <- x_dec$wmix


par(mfrow=c(1,2))
plot(0,0,type="n",xlim=range(w_min$x), ylim = max(abs(w_mix$y))*c(-1,1),
      xaxs = "i", xlab = "time (ns)", ylab = "amplitude",
    main = "minimum-phase wavelet")
grid()
apply(w_min$y,2,lines, x = w_min$x, col=rgb(0.2,0.2,0.2,0.2))
lines(w_min$x, apply(w_min$y,1,mean), col="red", lwd=3)


plot(0,0,type="n",xlim=range(w_mix$x),ylim=max(abs(w_mix$y))*c(-1,1),
    xaxs = "i", xlab = "time (ns)", ylab = "amplitude",
    main = "mixed-phase wavelet")
grid()
apply(w_mix$y,2,lines, x = w_mix$x, col=rgb(0.2,0.2,0.2,0.2))
lines(w_mix$x, apply(w_mix$y,1,mean), col="red", lwd=3)
```



Frequency filter

To remove the high-frequency noise boosted by the deconvolution

```
x7 <- fFilter(x_dec$x, f = c(5, 20, 160, 210), type = "bandpass",
                    plot = TRUE)
```

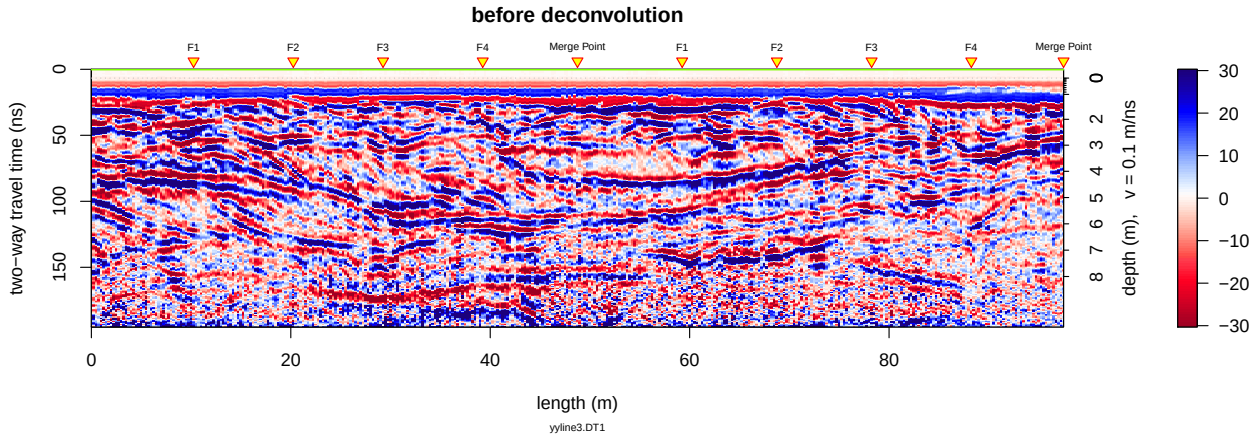


Trace scaling

```
x8 <- traceScaling(x7, type="stat")
```

Comparison

```
plot(x6, main = "before deconvolution", clip = 30)
```




```
plot(x8, main = "after deconvolution",  clip = 2)
```