Seismic Hodograms in R

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Abstract

Plot hodograms (particle motion) for 3-component seismic data.

1 Example

Start out by calling the RSEIS library,

```
> library(RSEIS)
```

Then load some data and plot. This data is from the Coso Geothermal field in Coso Califormia. The data is sampled at 250 sampled/sec and there are numerous stations recorded on three components. Some stations are too noise for particle motion analysis.

```
> data(GH)
> PICK.GEN(GH, SHOWONLY=TRUE)
>
```

In this case the GH structure holds the phase arrival information as well as the station locations and event location.

```
> print(GH$pickfile$STAS$name)
 [1] "CE1"  "CE4"  "CE3A" "SM5"  "NV6"  "CE2"  "NV1"  "CE7"  "NV10" "CE8"
[11] "NV4"  "NV5"  "NV2"  "CE1"  "CE4"  "CE3A" "SM5"  "NV6"  "CE2"  "CE6"
[21] "CE7"  "CE8"  "NV4"  "NV5"
```

We will choose one station and do the hodogram analysis there, but our analysis could easily be put in a loop to cover all the stations.

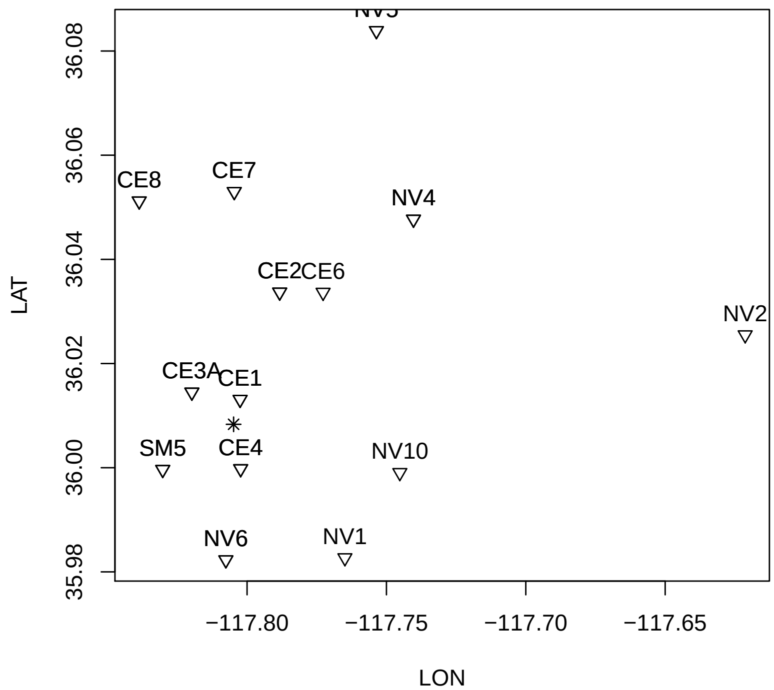
```
> thesta = "CE1"
> iwv  = which(GH$STNS==thesta & GH$COMPS=="V")
> iwn  = which(GH$STNS==thesta & GH$COMPS=="N")
> iwe  = which(GH$STNS==thesta & GH$COMPS=="E")
> data = cbind(GH$JSTR[[iwv]], GH$JSTR[[iwn]], GH$JSTR[[iwe]])
>
>
```

Next we get the station back azimuth to the seismic event, which has been located previously. The information on the location of the seismic event is stored also in the pickfile.

```
> ipphase = which(GH$pickfile$STAS$name==thesta & GH$pickfile$STAS$phase=="P" )
> isphase = which(GH$pickfile$STAS$name==thesta & GH$pickfile$STAS$phase=="S" )
> lat=GH$pickfile$STAS$lat[ipphase]
> lon = GH$pickfile$STAS$lon[ipphase]
> DAZ = distaz(lat, lon,   GH$pickfile$LOC$lat,GH$pickfile$LOC$lon )
>  rbaz = grotseis(DAZ$baz, flip=FALSE)
>
```

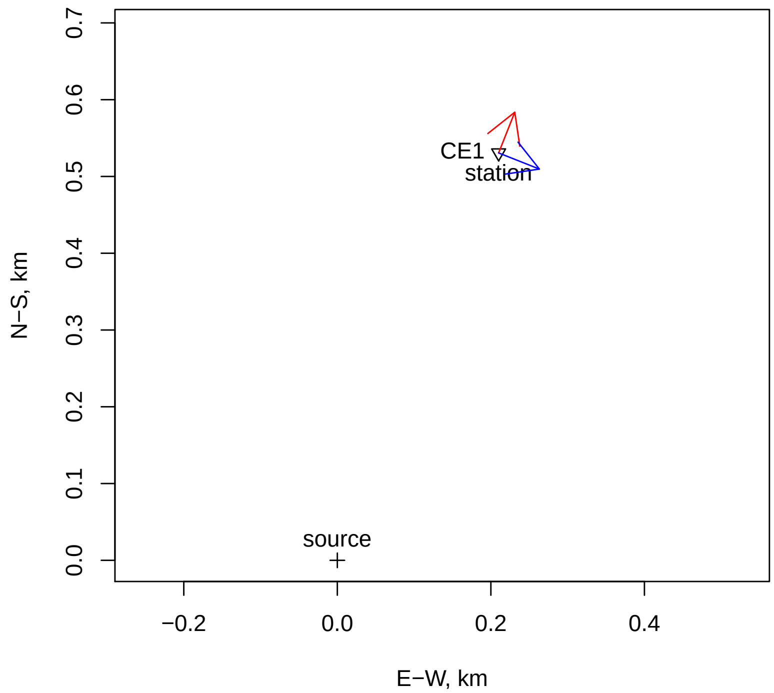
To illustrate the approach we start by plotting a map view of the stations and the earthquake source,

```
> plot( c(GH$pickfile$STAS$lon, GH$pickfile$LOC$lon) , c(GH$pickfile$STAS$lat, GH$pickfi
> points(GH$pickfile$STAS$lon, GH$pickfile$STAS$lat, pch=6)
> points(GH$pickfile$LOC$lon, GH$pickfile$LOC$lat, pch=8)
> text(GH$pickfile$STAS$lon, GH$pickfile$STAS$lat,  GH$pickfile$STAS$name, pos=3)
>
> ##  plot( c(lon, GH$pickfile$LOC$lon) , c(GH$pickfile$STAS$lat, GH$pickfile$LOC$lat))
> ##  text(lon, lat, labels="station")
>
>
```



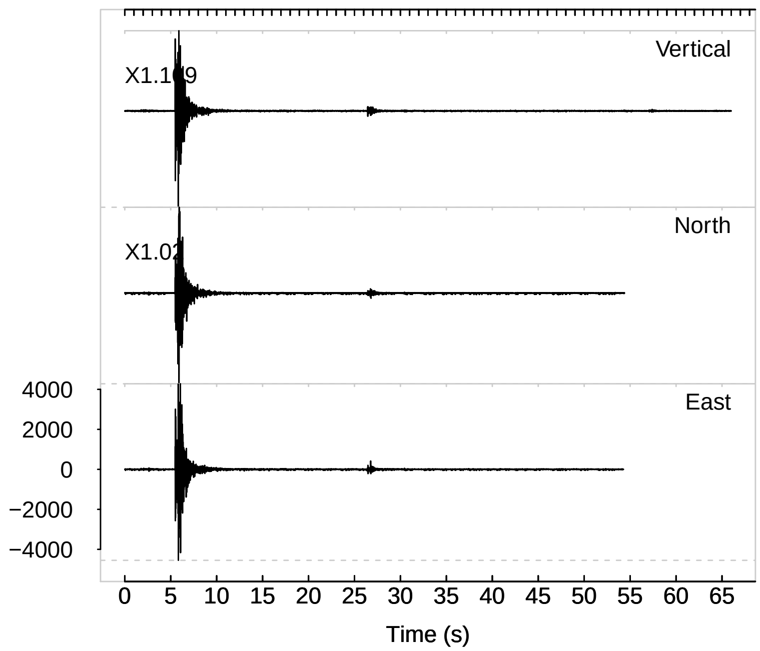
These can be plotted in km rather than LAT-LON by either projection or byu simply using the distances to the stations and azimuths to get the approximate flat orientation. We show the orientation of the horizontal components after the seismogram gets rotated by the designated angle. The red arrow is the radial component and the blue is the transverse.

```
> x = DAZ$dist*sin(DAZ$baz*pi/180)
> y = DAZ$dist*cos(DAZ$baz*pi/180)
> plot(c(0,1.3*x), c(0,1.3*y), type='n', asp=1, xlab="E-W, km", ylab="N-S, km")
> points(c(0,x), c(0,y), pch=c(3,6))
> text(x,y, labels="station", pos=1)
> text(x,y, labels=GH$pickfile$STAS$name[ipphase], pos=2)
> text(0,0, labels="source", pos=3)
> vecs  = rbind(c(0,0,1), c(0,1,0))
> bvec  = vecs %*%  rbaz
> bvec = .1*DAZ$dist*bvec
> arrows(x,y, x+bvec[,2], y+bvec[,3], col=c("red", "blue"))
>
>
>
```



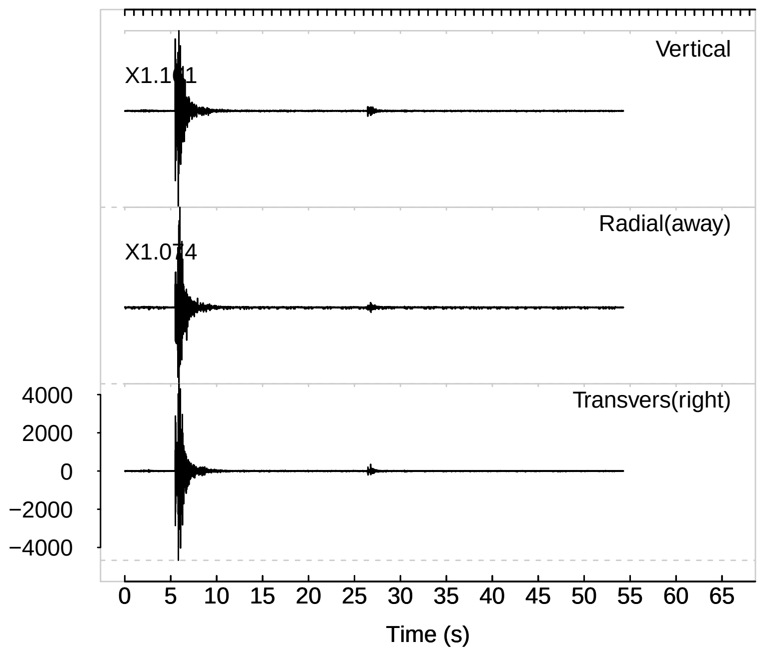
We first plot the data in its original Vertical-North-East orientation,

```
> ## data = cbind(GH$JSTR[[iwv]], GH$JSTR[[iwn]], GH$JSTR[[iwe]])
>
>   vnelabs=c("Vertical", "North", "East")
> rotlabs=c("Vertical", "Radial(away)", "Transvers(right)")
>  xt=seq(from=0, by=GH$dt[iwv], length=length(GH$JSTR[[iwv]]))
>  PLOT.MATN(data, tim=xt, dt=GH$dt[iwv], notes=vnelabs)
>
```



And then we rotate the seismograms so that they are oriented Vertical-Radial-Transverse, is is often done in seismic analysis:

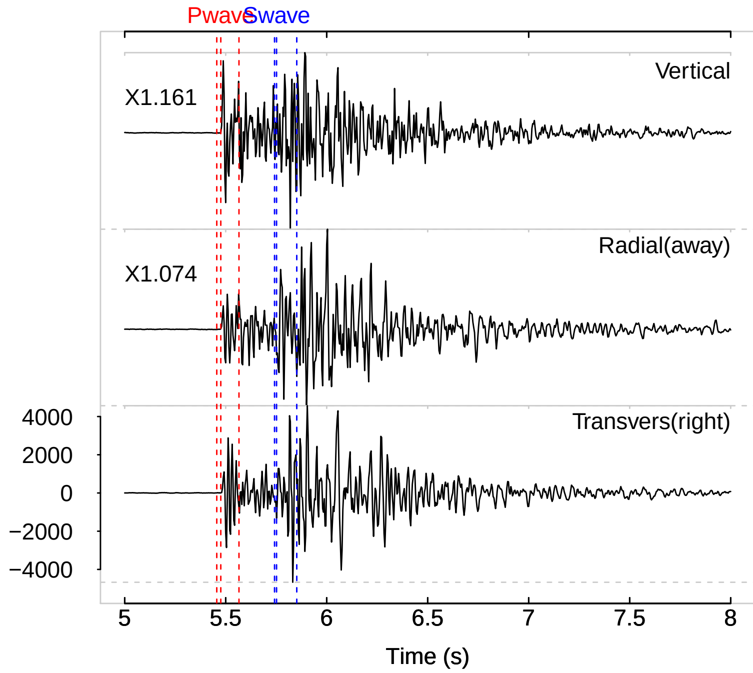
```
> ## data = cbind(GH$JSTR[[iwv]], GH$JSTR[[iwn]], GH$JSTR[[iwe]])
> btemp  = data  %*%  rbaz
>  PLOT.MATN(btemp, tim=xt, dt=GH$dt[iwv], notes=rotlabs)
>
```



Next we extract information from the seismic structure that tells us when the P and S-arrival were estimated. This information is stored in the pickfile structure, but we want to know how many seconds paste the start of the trace the arrivals came in, so we can window that portion of the trace for hodogram analysis.

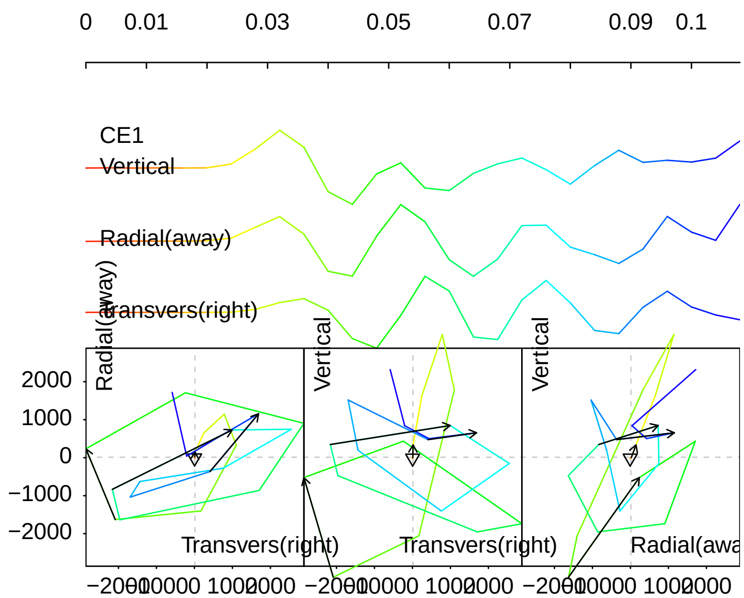
```
> i1 = match(GH$STNS[iwv],  GH$pickfile$STAS$name)
> reft = list(jd=GH$info$jd[iwv], hr=GH$info$hr[iwv], mi=GH$info$mi[iwv], sec=GH$info$se
> ptim = list(jd=GH$pickfile$LOC$jd, hr=GH$pickfile$LOC$hr, mi=GH$pickfile$LOC$mi, sec=G
> stim = list(jd=GH$pickfile$LOC$jd, hr=GH$pickfile$LOC$hr, mi=GH$pickfile$LOC$mi, sec=G
> t1 = secdifL( reft, ptim)
> t2 = secdifL( reft, stim)
>  PLOT.MATN(btemp, WIN=c(5,8) , tim=xt, dt=GH$dt[iwv], notes=rotlabs)
> abline(v=t1, col='red', lty=2)
> abline(v=t2, col='blue', lty=2)
> mtext(side=3, at=t1, line=.1, text="Pwave", col='red')
> mtext(side=3, at=t2, line=.1, text="Swave", col='blue')
> pwin = c(t1-.02, t1+.09)
> swin = c(t2-.01, t2+.1)
> abline(v=pwin, col='red', lty=2)
```

```
> abline(v=swin, col='blue', lty=2)
>
>
>
```



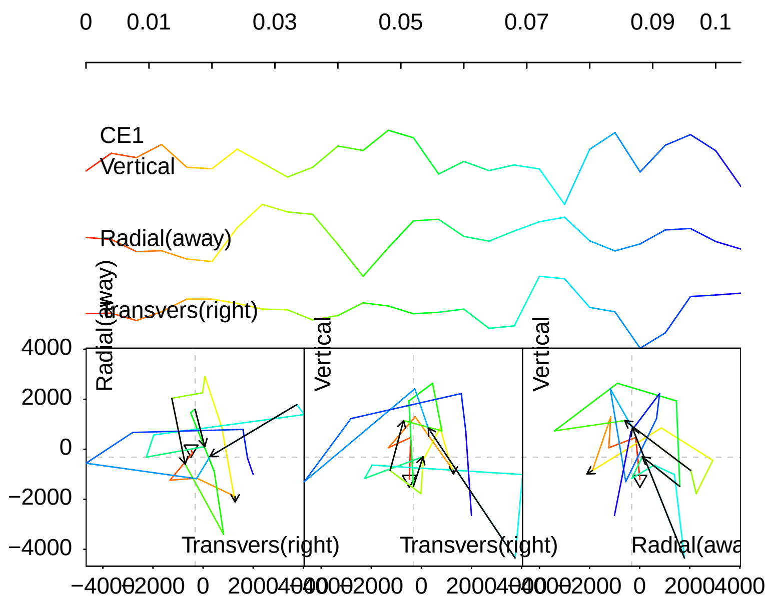
So we now extract that portion and apply the hodogram program on the P-wave arrival

```
> rbow=rainbow(140)[1:100]
> atemp = btemp[xt>pwin[1]&xt<pwin[2]  ,]
> ##  PLOT.MATN(atemp,  tim=xt[xt>pwin[1]&xt<pwin[2]], dt=GH$dt[iwv], notes=rotlabs)
>
>  hodogram(atemp, dt=GH$dt[iwv]  ,labs=rotlabs,  STAMP=thesta,  COL=rbow )
>
```



and on the S-wave arrival

```
> atemp = btemp[xt>swin[1]&xt<swin[2]  ,]
> ###  PLOT.MATN(atemp,  tim=xt[xt>swin[1]&xt<swin[2]], dt=GH$dt[iwv], notes=rotlabs)
>
>  hodogram(atemp, dt=GH$dt[iwv]  ,labs=rotlabs,  STAMP=thesta,  COL=rbow )
>
```



Clearly, a loop can be programed so that all the stations are examined for the particle motion and specific patterns will be revealed.

For example, we may wish to differentiate between direct arrival of body waves and later arrivals of surface waves. The Raleigh wave has retrograde motion int he vertical-radial components, so we expect to see the first motions moving opposite the direction of wave propagation (i.e. towards the source) as the motion is decomposed.

Hodograms can be used to estimate the arrival of a “split shear wave” often used to detect anisotropy in the geologic structures in the subsurface. In some cases anisotropy indicates crack orientation and in the mantle it may refer to fluid flow as olivene crystals align along the direction of flow.