Mermaid Data Processing Tutorial

Photo Frederik Simons

Mermaid: 5-6 year battery life

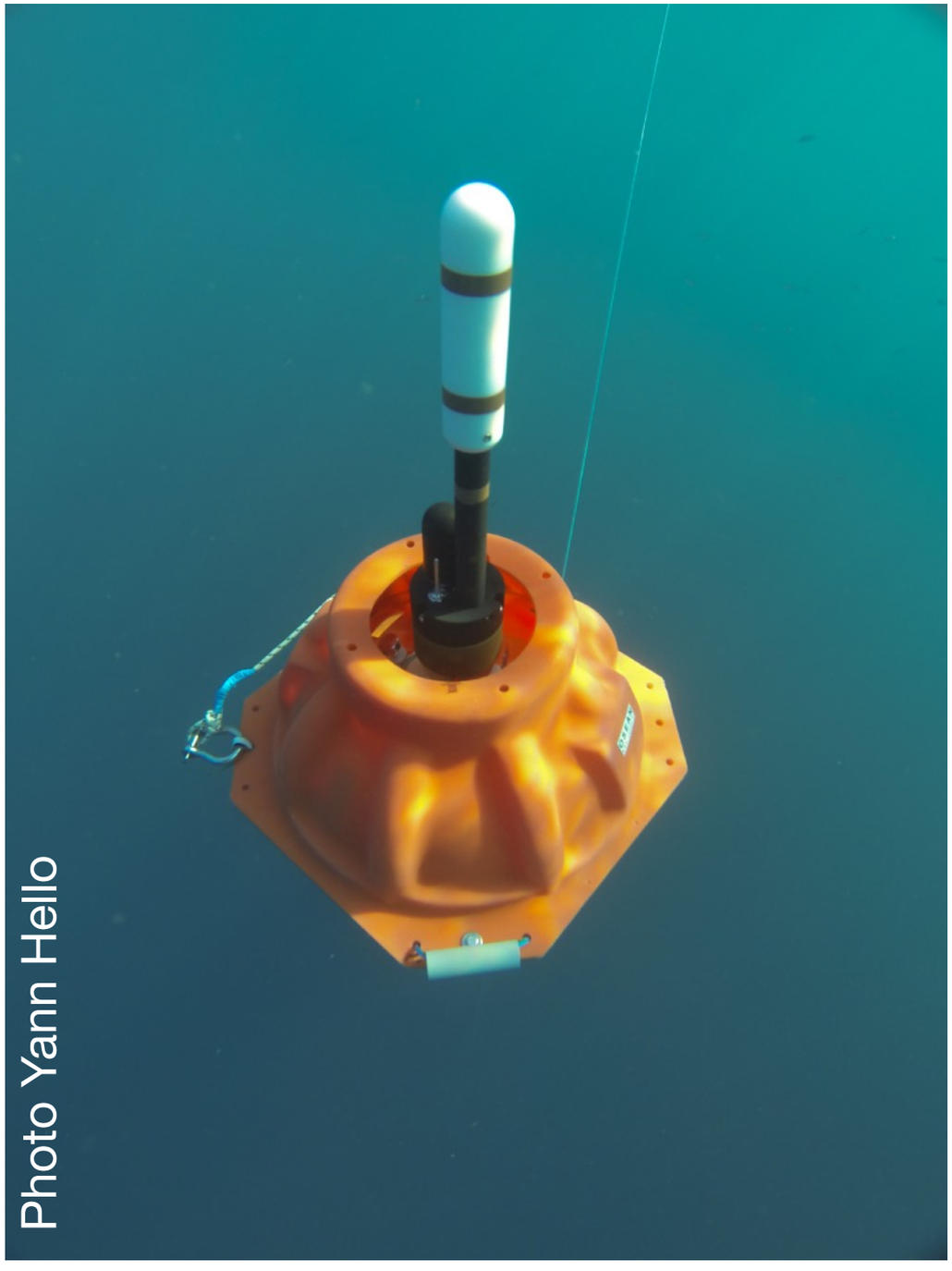
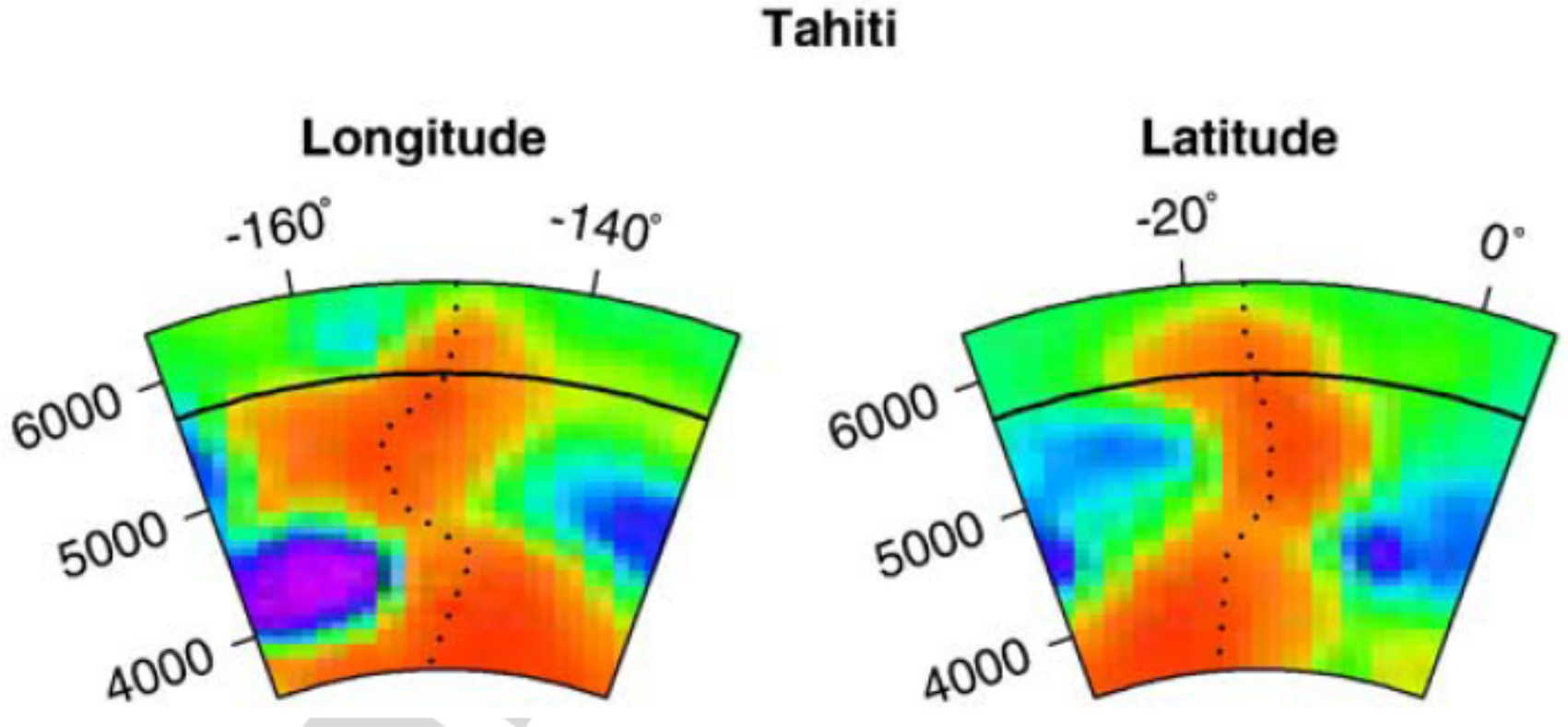


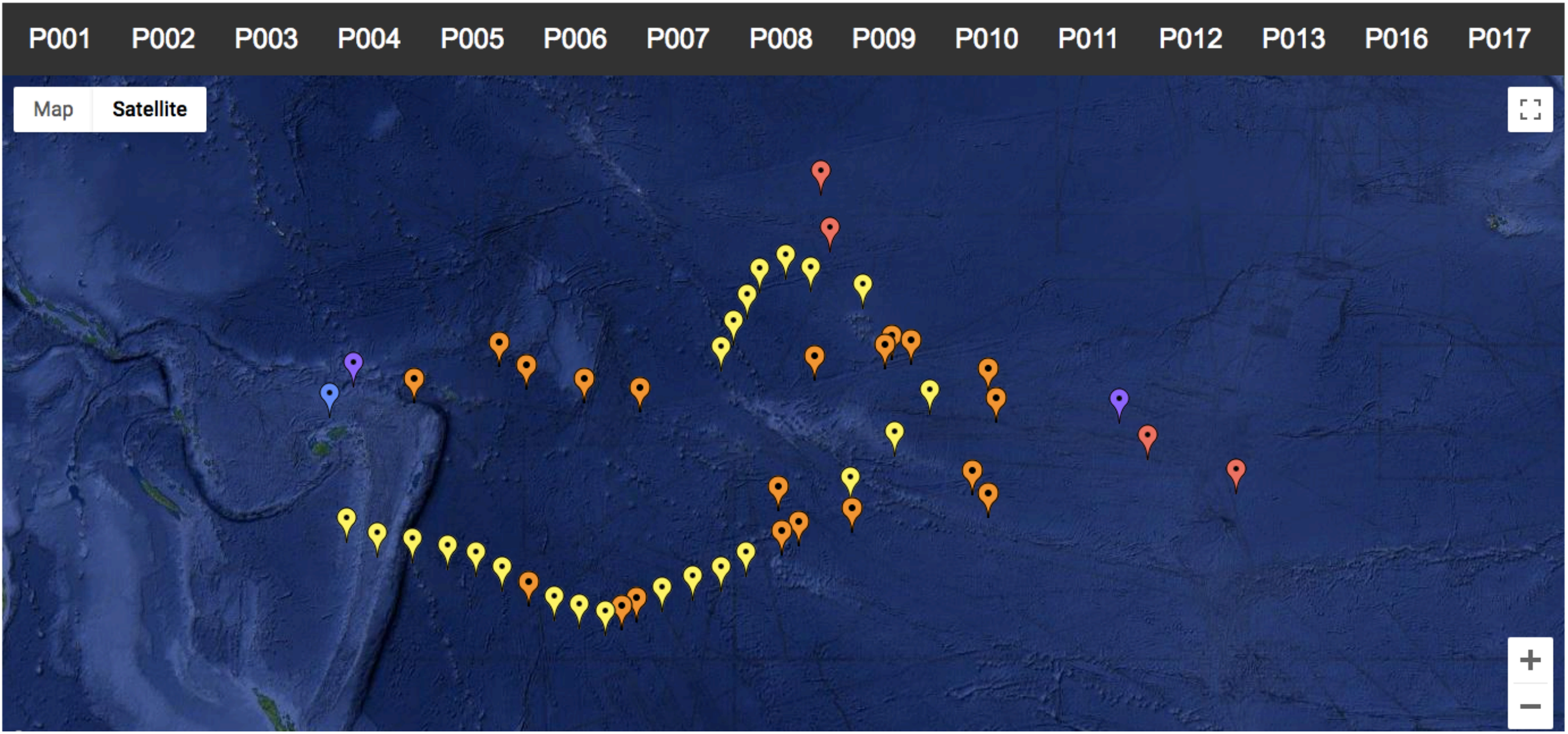
Photo Yann Hello

Target of SPPIM: the superplume



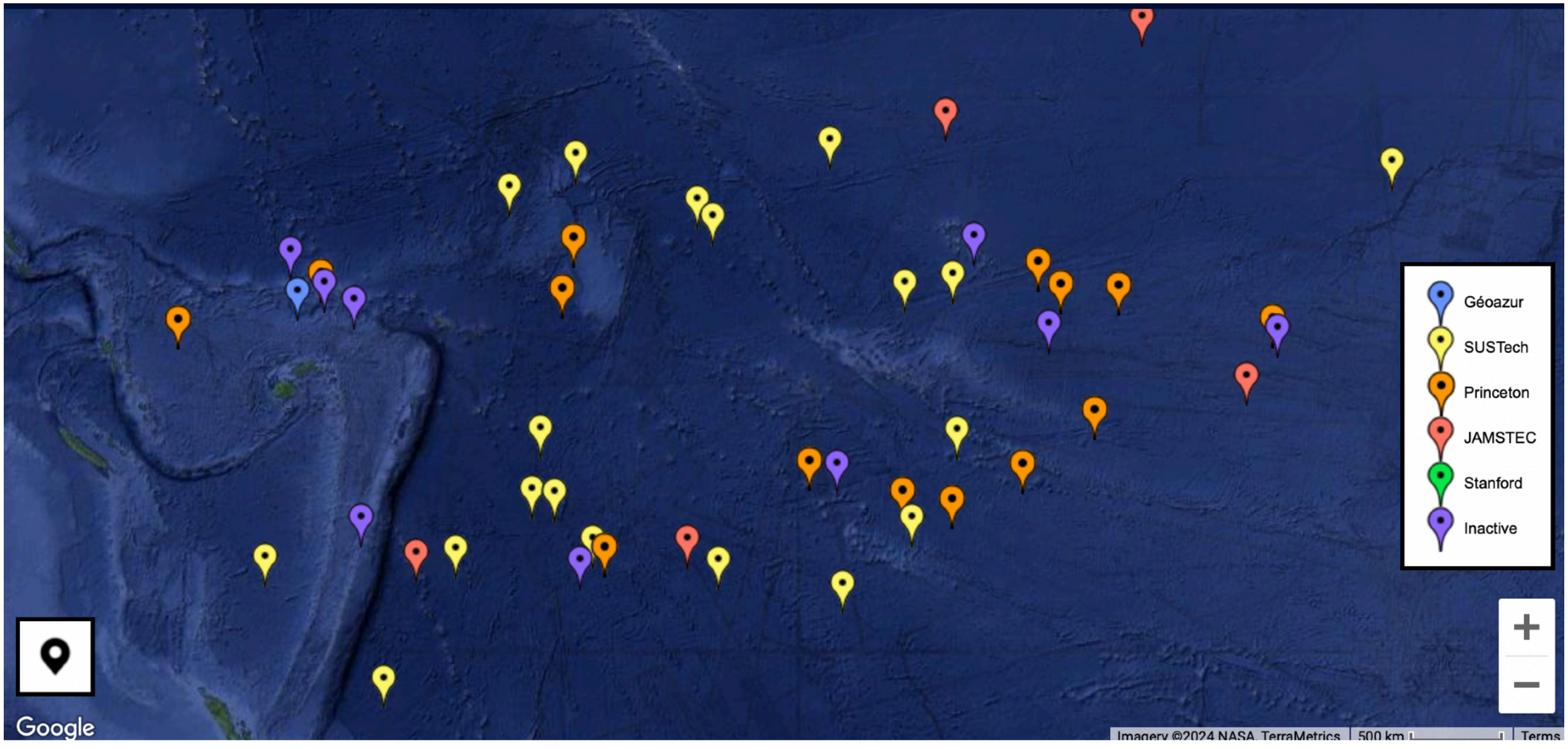
Nolet et al 2006

September 2019: Network Complete!

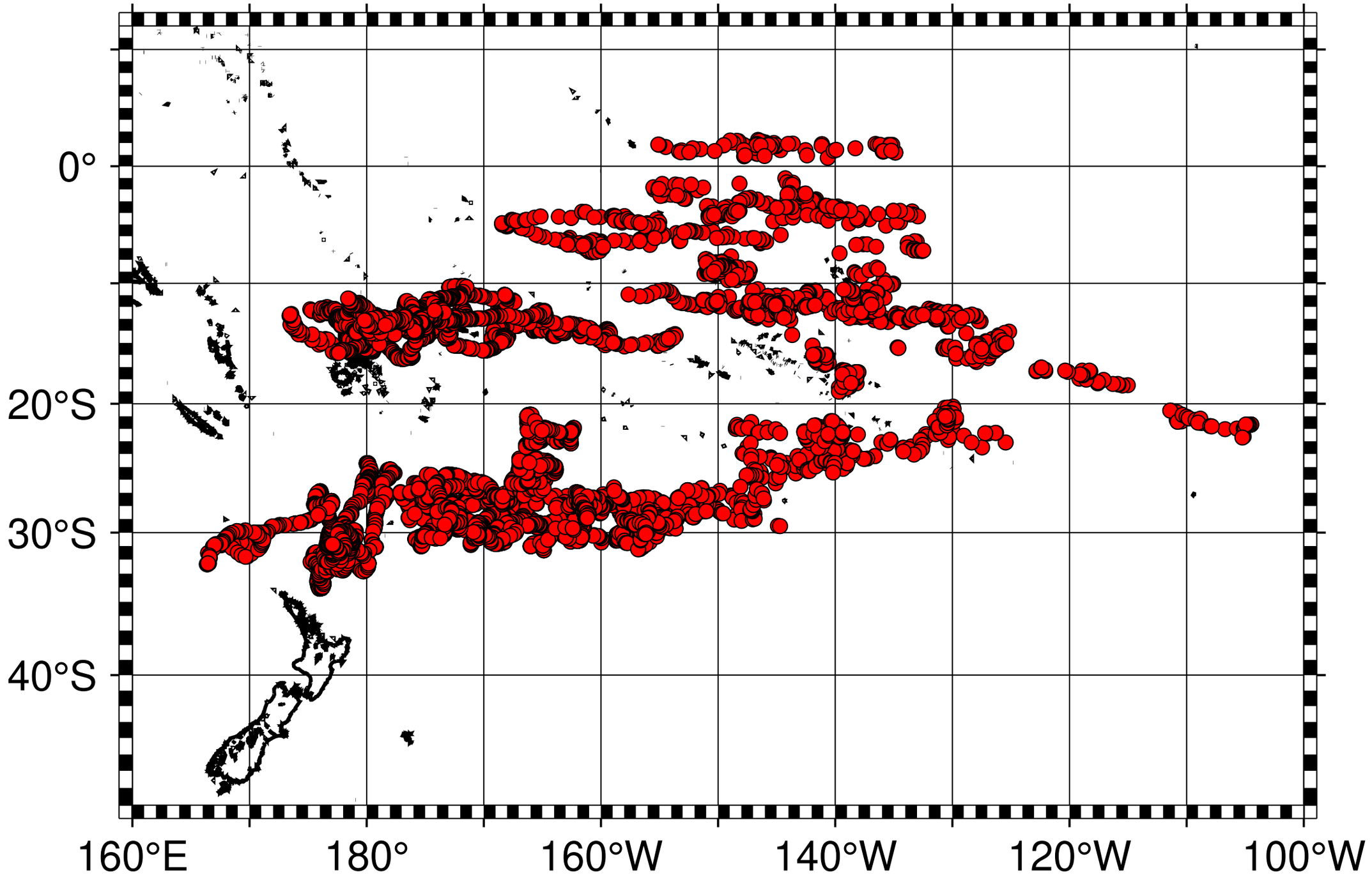


https://geoweb.princeton.edu/people/simons/earthscopeoceans/

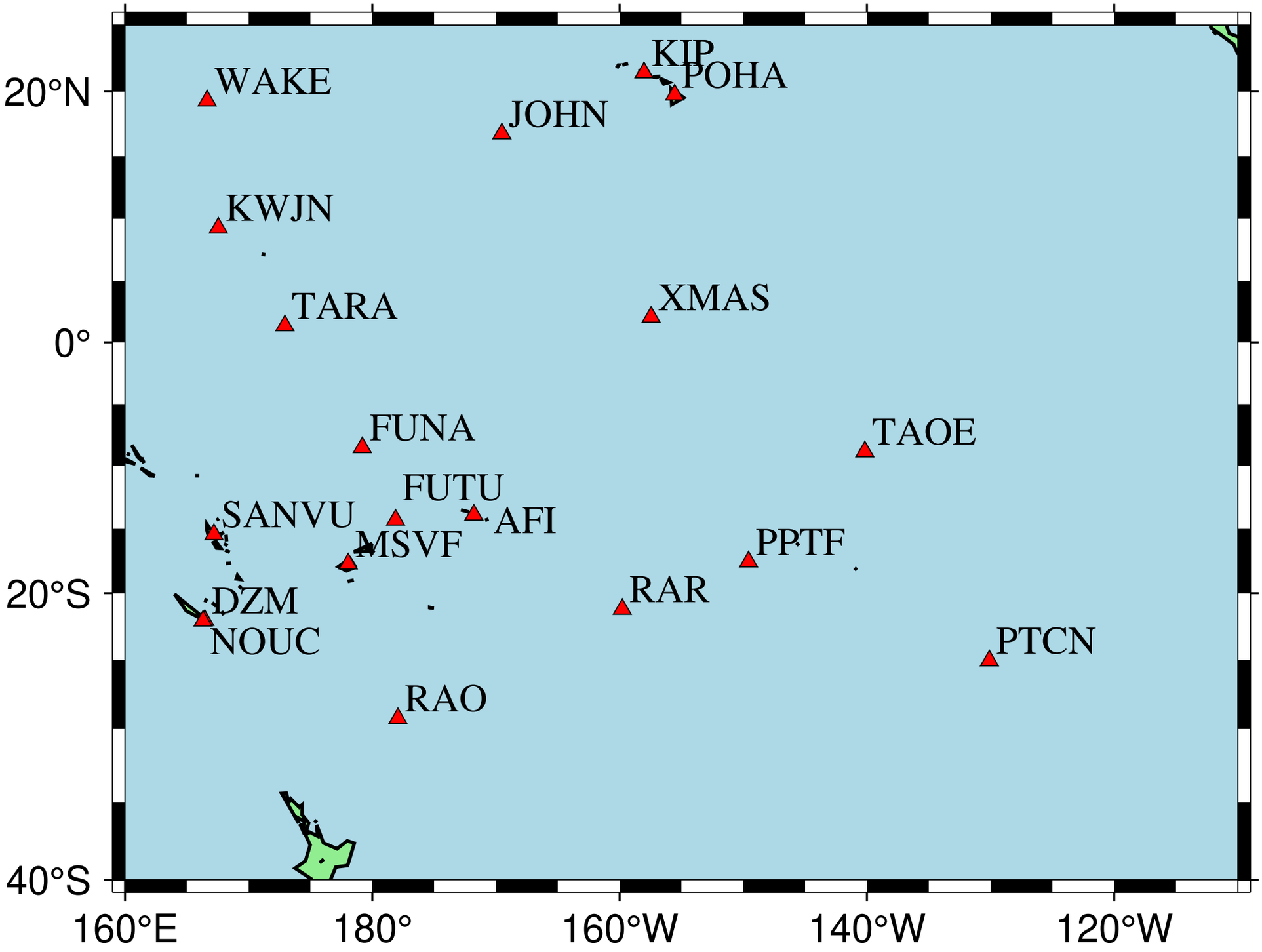
May 2024: still going strong



Seismogram locations



GSN stations - why also use island stations?



Island stations (including Australia) are useful because:

- Some have them have low noise and show how the onset looks
- Even the noisy ones can show the polarity of the onset, useful if Mermaid is nearby
- At the time of inversion, adding island picks allows us to correct the origin time and hypocenter

However: if in any doubt, skip them and do not spend any energy in trying to find a difficult onset. There are plenty island stations and their information is duplicated.

COURSE 1: explain our system of picking (sections 1-3)

HOMEWORK 1: simple picks with few difficulties (1 hour)

COURSE 2: explain the tricks of picking (section 4)

HOMEWORK 2: some more difficult cases (<2 hours)

COURSE 3: discussing the homework cases, planning final picking, and what I expect

HOMEWORK 3: the final picking

1. Get ready

You need a machine that accepts common Linux commands

And create a base directory from where you shall work

```
auguste@augustes-macbook-air ~ %
auguste@augustes-macbook-air ~ % mkdir SPPIM
auguste@augustes-macbook-air ~ %
```

(SPPIM means: South Pacific Plume Imaging with Mermaids,
but you may call the base directory any way you like)

Move Install.tar into the base directory and type

> tar -xvf Install.tar

The directory *PickingCode* contains all the software you need in the form of executable scripts and Fortran programs

To compile, do the following:

1. If necessary, replace *gfortran* in the Compile_all script with your local compiler (or get *gfortran* from https://fortran-lang.org/learn/os_setup/install_gfortran/#)
2. Make sure you have a directory ~/bin where the binaries can go
3. Make sure ~/bin (or $HOME/bin) is in your path (type *echo $PATH).* If it is not add it to ~/.bash_profile or ~/.bashrc
4. Replace the reference to libsacio.a in *Compile_all*
5. Type *./Compile_all* to compile. This will replace the (green) executables with versions that can run on your machine. They are linked to ~/bin.
6. If you do not have 'gv' (ghostview) to view pdf plots, alias your own pdf viewer to gv at the start of script *dopick*, eg: *alias gv 'ghostscript'*, or (on Macs): *alias gv* '*open -a "Preview"*'*.* On linux systems you may also have to make sure *gv* runs in background so that plots do not disappear (add & after each call to gv in script *dopick).*
7. The script Compile_all creates links to ~/bin; if they do not work, **copy** the executables and scripts from *PickingCode/* into *~/bin*

All plotting and picking is done using GMT and SAC

Make sure you have a recent version of **GMT**.

The codes were tested with GMT 6.4.0, but any version that accepts the `modern' GMT commands should work.

You can download GMT from
https://www.generic-mapping-tools.org/

The codes were tested on **SAC** version 102.0

You can obtain SAC from
https://ds.iris.edu/ds/nodes/dmc/software/downloads/sac/

Note — if you do not have GMT the package will still work if you comment the 6 lines: pltres add_to_datafile*[0-9] in script *dopick*

SAC

Download the manual from
https://ds.iris.edu/files/sac-manual/sac_manual.pdf

Familiarize yourself with the following commands (case insensitive):

- READ or r - to read one or more seismograms
- HIGHPASS or hp - to high pass filter the seismograms
- PLOT or p - to plot them, one after the other
- PLOT1 or p1 - to plot them all in the same window
- PLOT1 RELATIVE of p1 rel - to line up plots after ‘xlim’
- XLIM or xlim - to set the window’s time limits
- xlim t0 -10 t0 +20 to plot from 10s before to 20s after P
- LISTHDR or lh - to list all header variables
- QDP OFF - to disable quick and dirty plotting (***always* use this**!)

HINT

If there are commands that you always use (like QDP OFF) you may wish to store them in a file ~/.sacrc and use an alias for SAC, e.g.:

```
alias sac='/usr/local/sac/bin/sac /Users/yourname/.sacrc’
```

My own *.sacrc* file reads as follows:

```
xdiv nice power off
ydiv nice power on
xlabel "Time (sec)"
color black increment list red green blue magenta cyan black
fileid type list kstnm gcarc az
qdp off
funcgen impulse
lh default columns 2
```

VI

At the end of picking an event, you are given a chance to edit with *vi* the standard errors for certain picks, or to eliminate the pick altogether by changing the standard error to 999 seconds.

If you are not used to *vi*, there are two options:

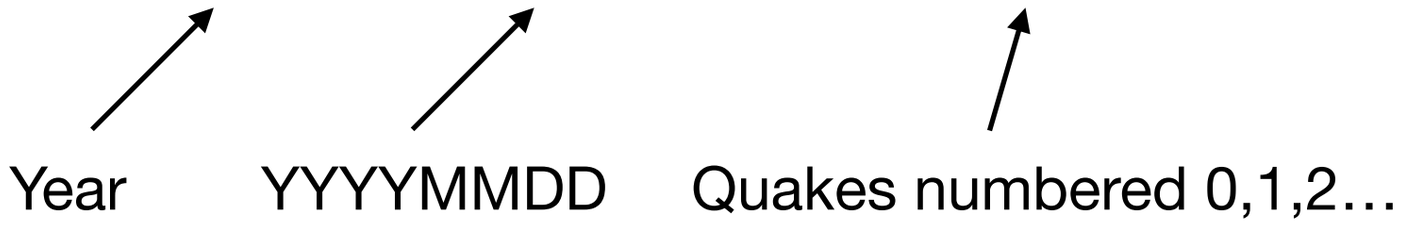
- Edit script *dopick* (in your bin directory) and replace every call to *vi* with your favourite editor, or
- Familiarize yourself with a few basic *vi* commands, notably:

- *:q* to quit *vi* without changes or *:wq* to write the changes and quit
- (if you did change things but do *not* wish to save them type *:q!*)
- Navigate to a particular word with the arrows, or *w* (forward) or *b* (back)
- *r* to overwrite a single character, *x* to delete a character
- *R* to overwrite multiple characters, followed by *Esc(ape)*
- */* to find, e.g. */RAR* to find a line with station RAR

See also https://www.redhat.com/sysadmin/introduction-vi-editor

You should now have everything ready to start observing:

- You have GMT, SAC and the programs installed and working
- *If* you can work with two separate screens, ***do so***!
- You will receive your own copy of the data in the base directory that you created, with:
- Data directories e.g. 2019/20190110/DATA/Q00



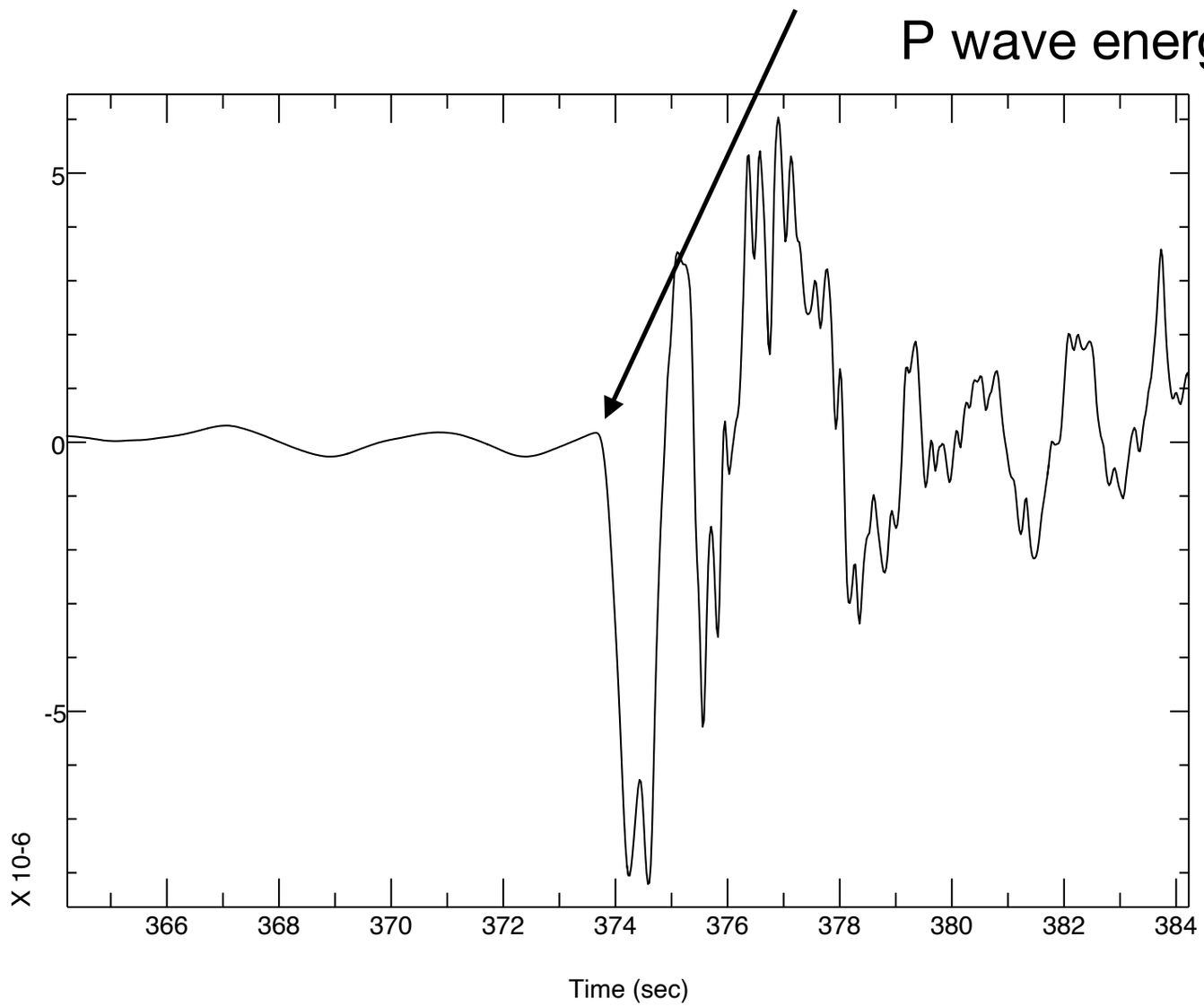
Did you encounter any problems?

email me: nolet@princeton.edu

2. Onsets

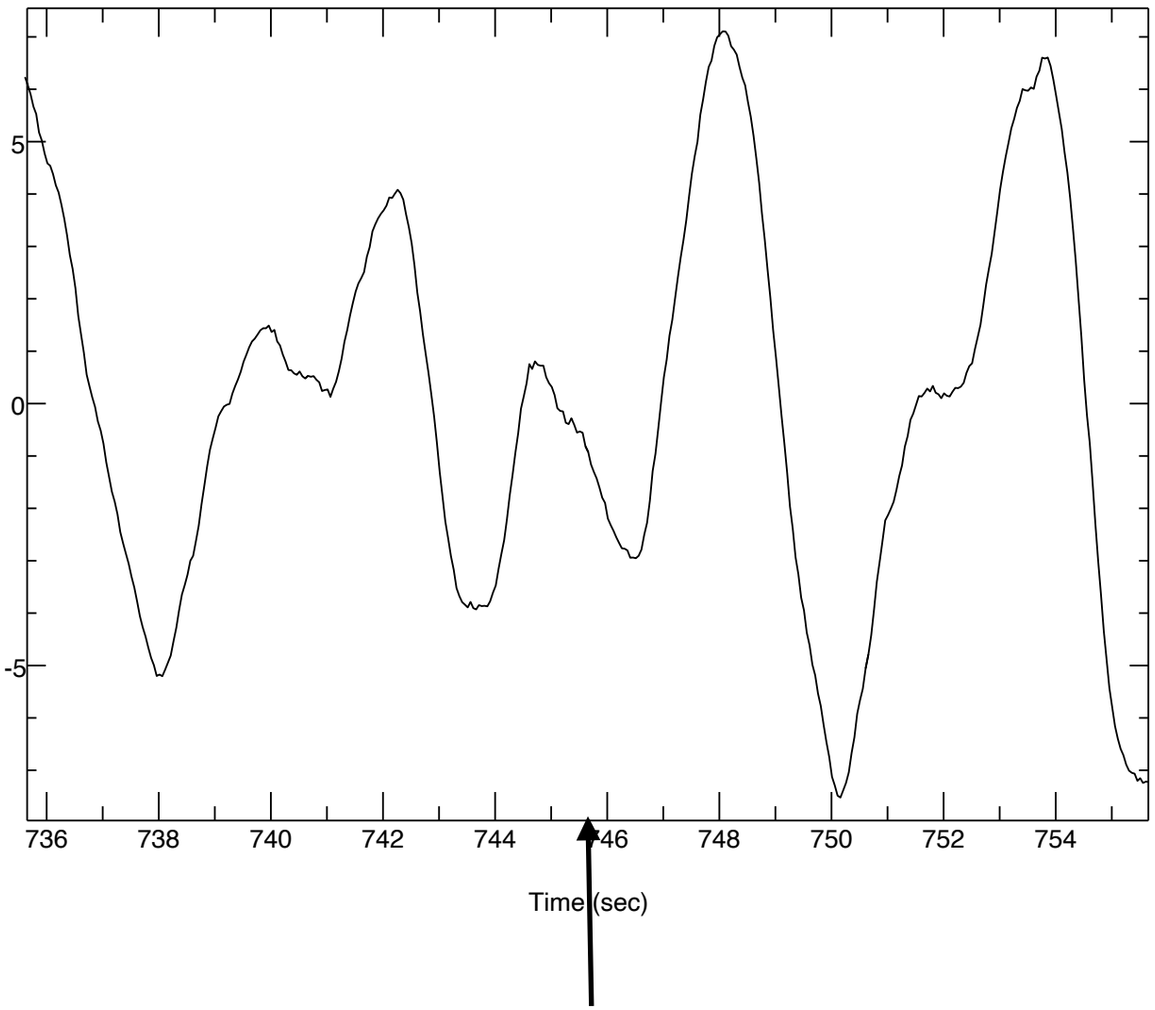
The simple definition

The *onset* is where the very first P wave energy arrives



Onsets incorporate very high frequencies and satisfy ray theory (Snell's law)

Complication I



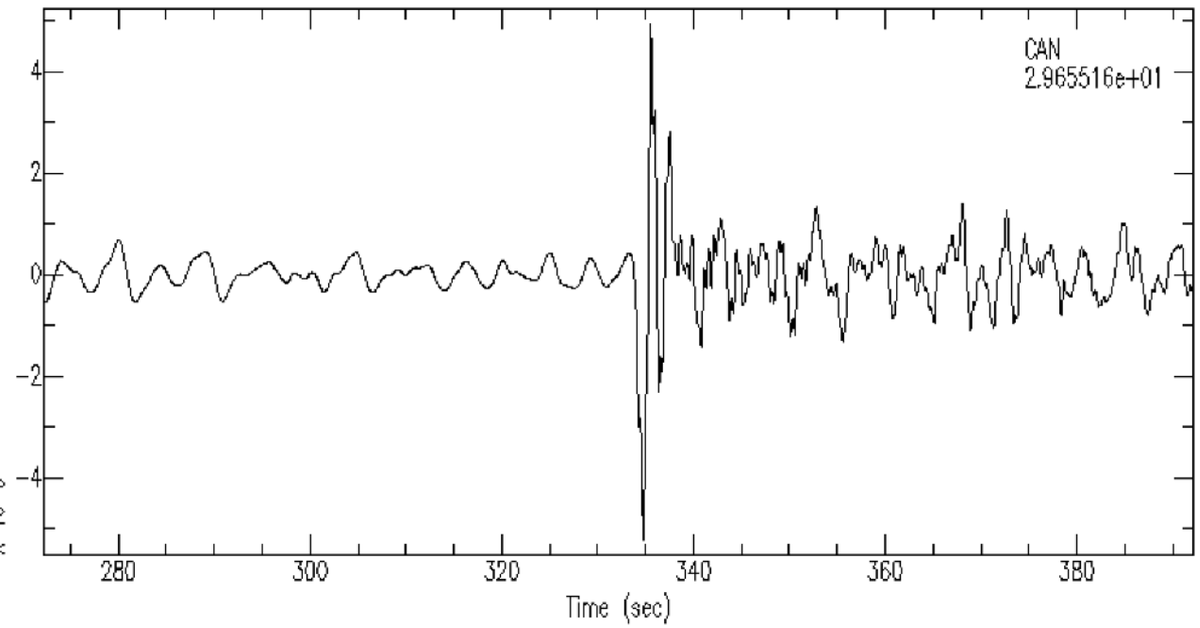
Predicted arrival time
for model AK135

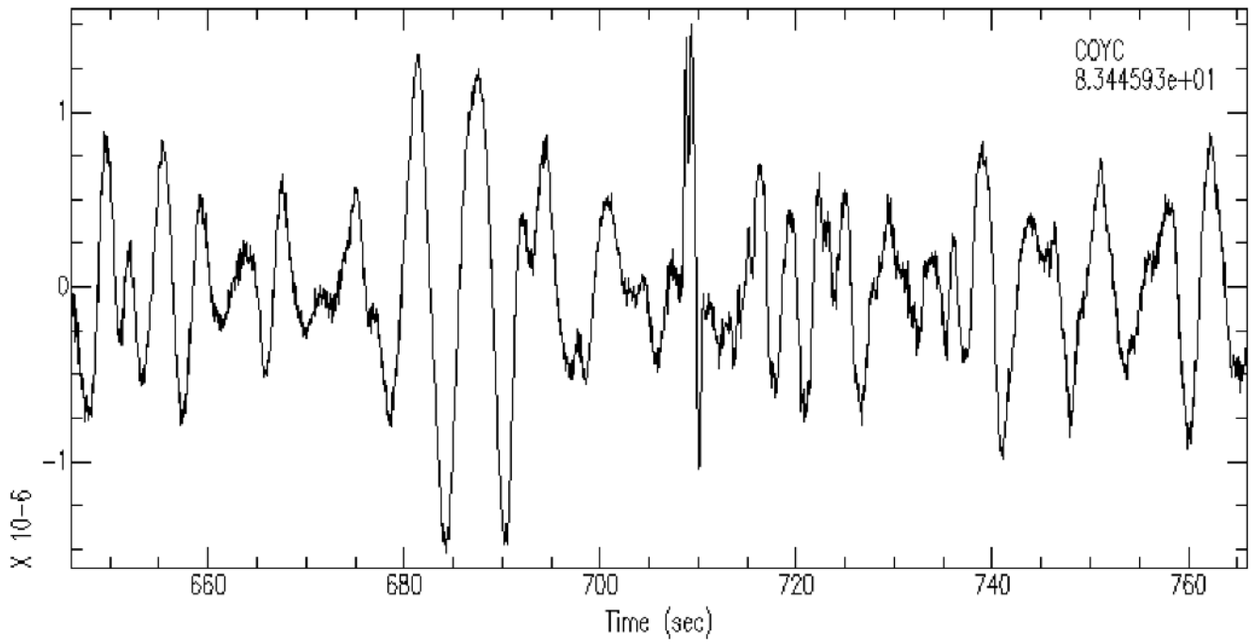
There are several complications one needs to be aware of.

The noise may be very much higher than the onset signal

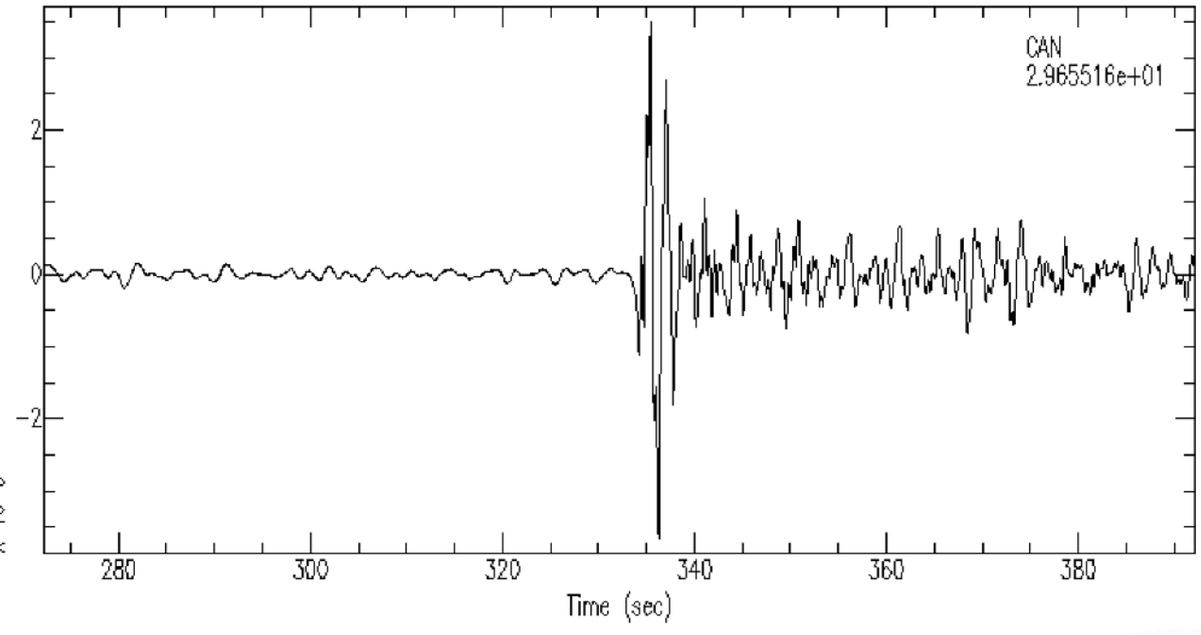
This is especially a characteristic of island stations, OBS and Mermaids

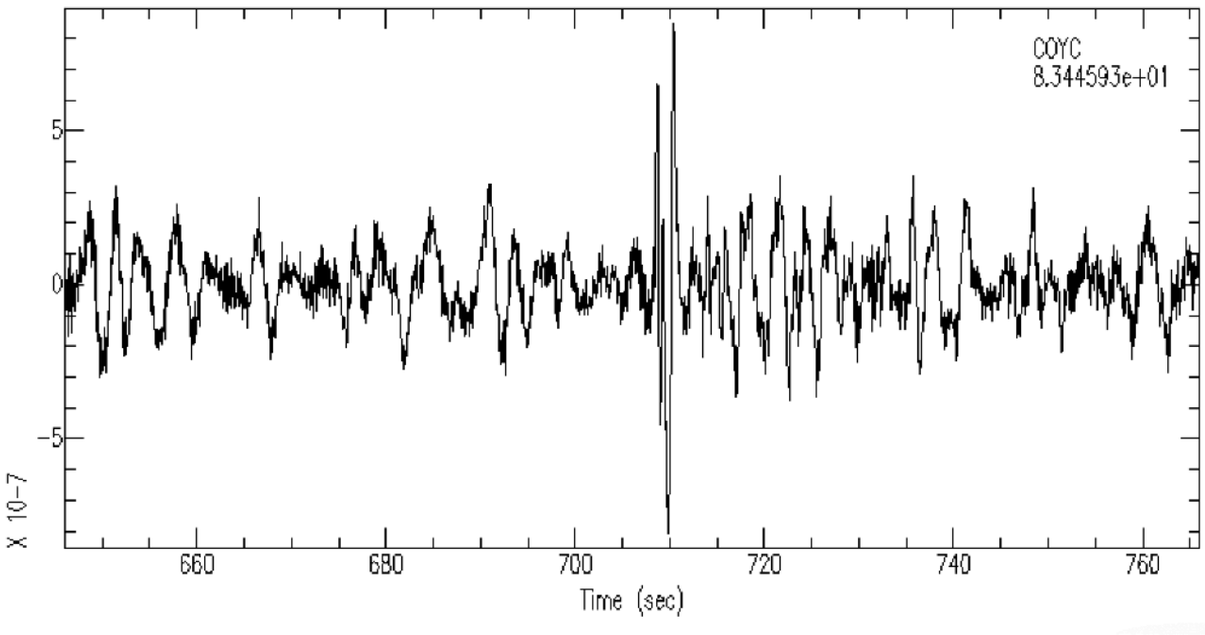
Two examples of noise in GSN stations, unfiltered:



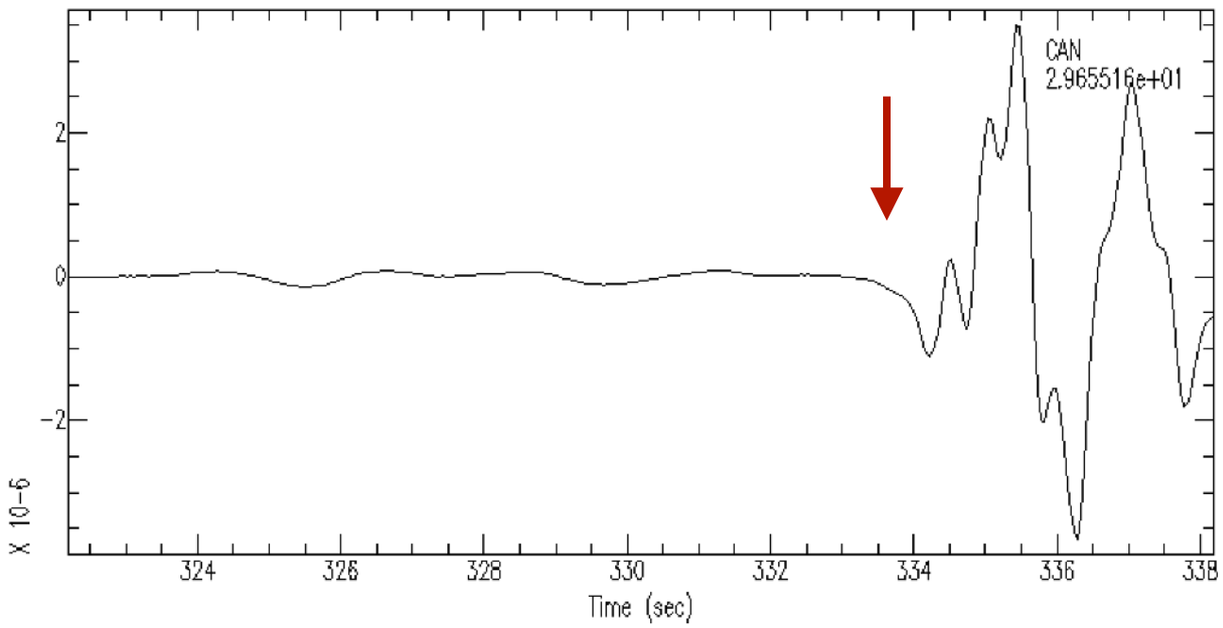


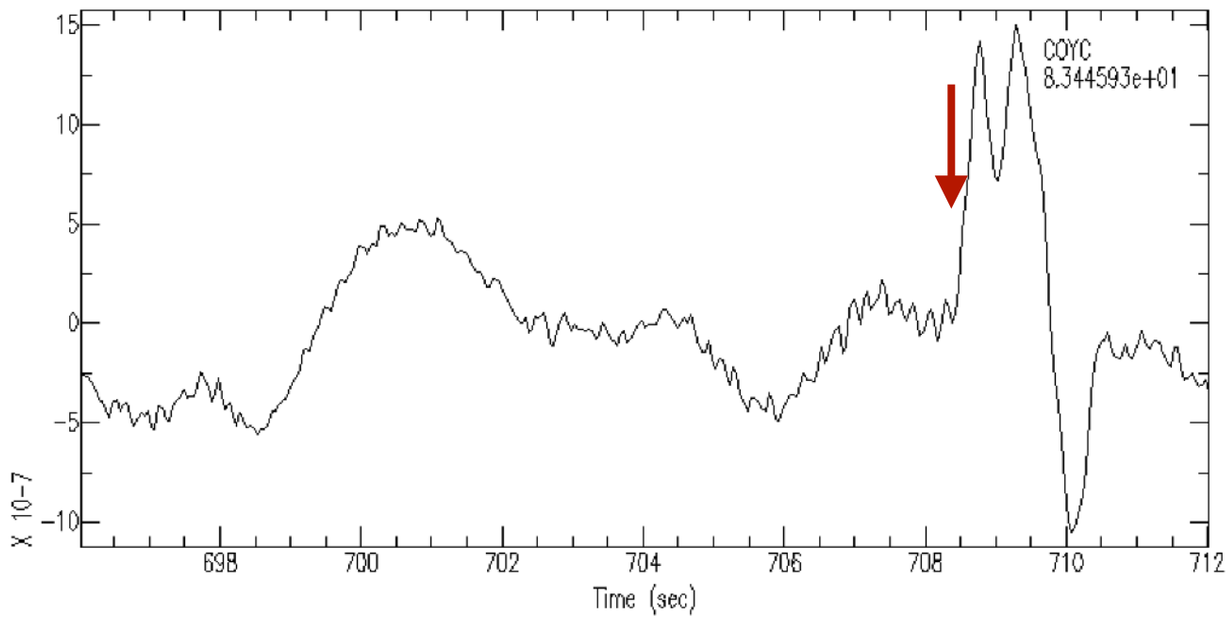
And after high-pass filter 0.5 Hz:



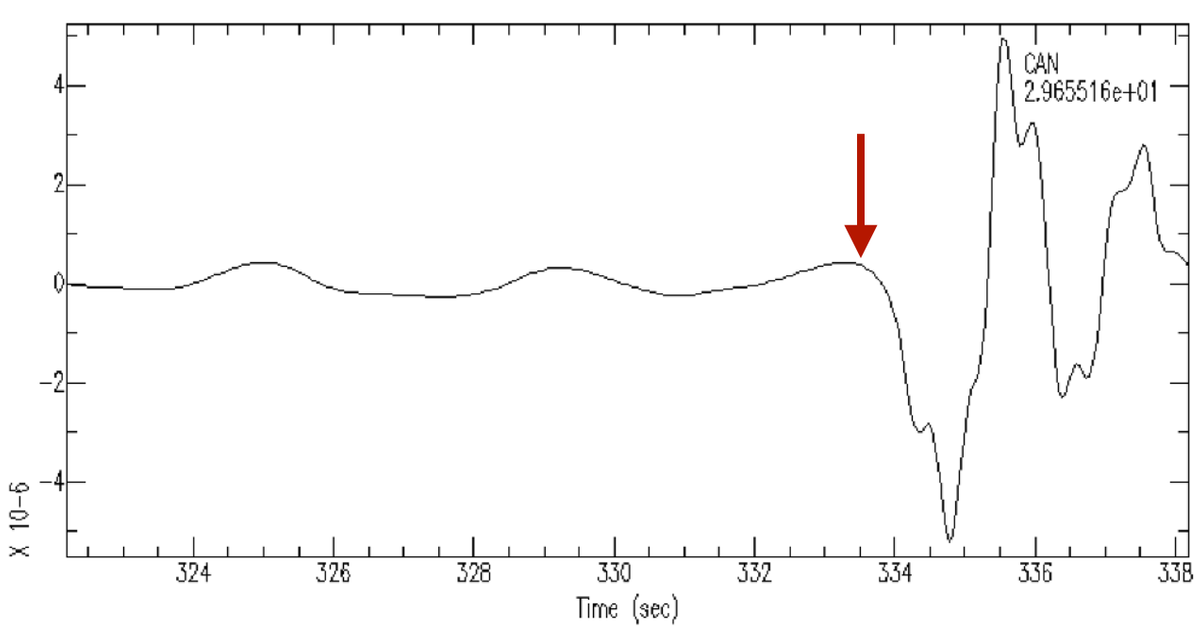


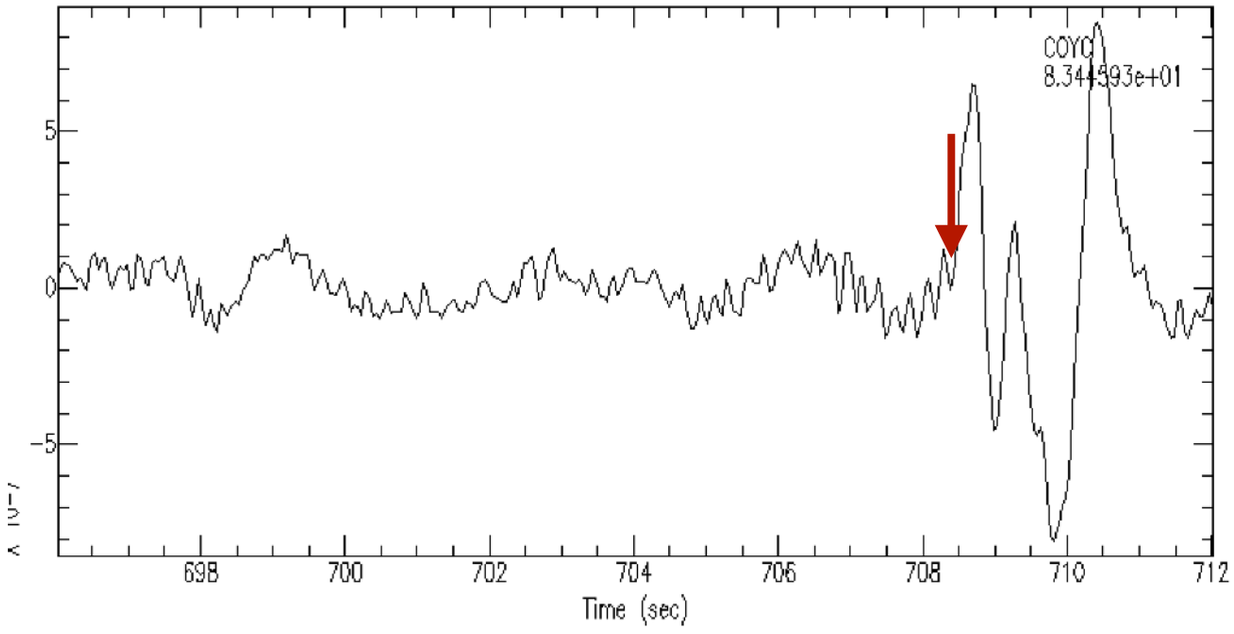
After blow-up both are ‘pickable’, either filtered





or unfiltered





Rule of thumb #1:

If you think you can pick the onset within 0.5s uncertainty, go ahead

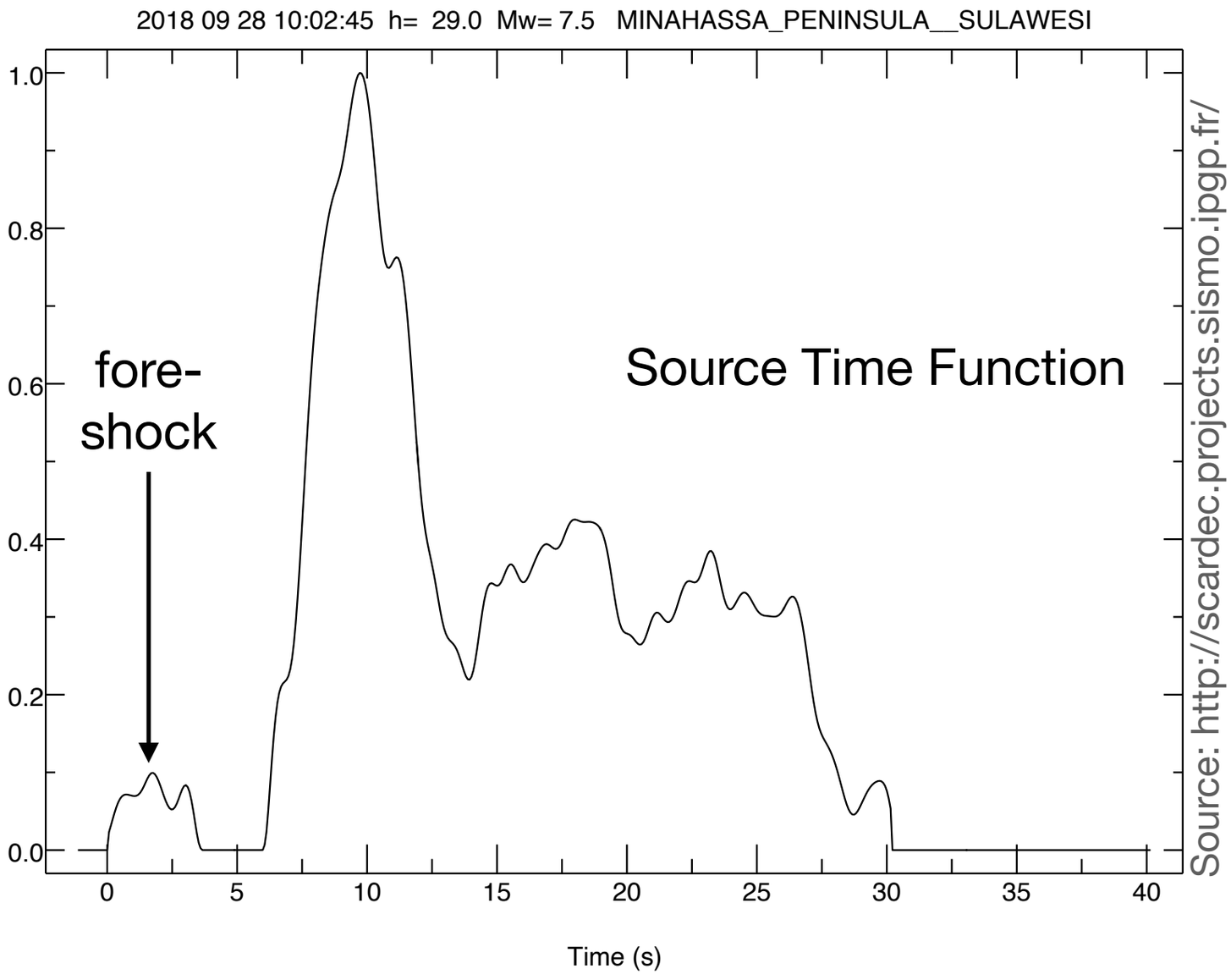
Rule of thumb #2:

There are plenty island station seismograms, *skip them when in doubt*. Only Mermaids are worth the time for extra scrutiny.

Rule of thumb #3:

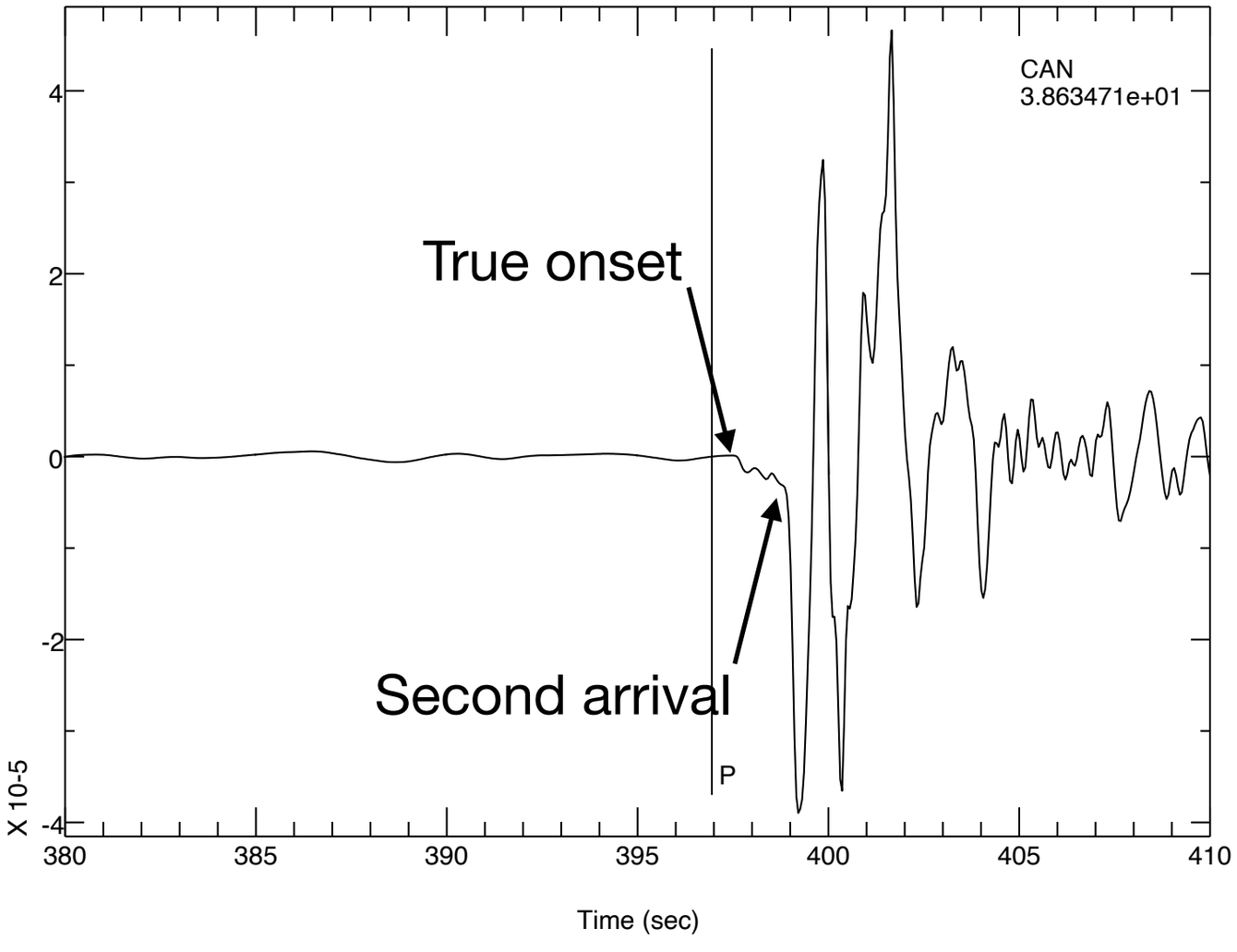
Pick the *filtered* record only if the pre-onset noise is well below 0.5 Hz (peaks separated by more than 3 or 4s).

Complication II



A weak foreshock may only be visible in the near field of the quake if it is very weak (or may at least confuse you)

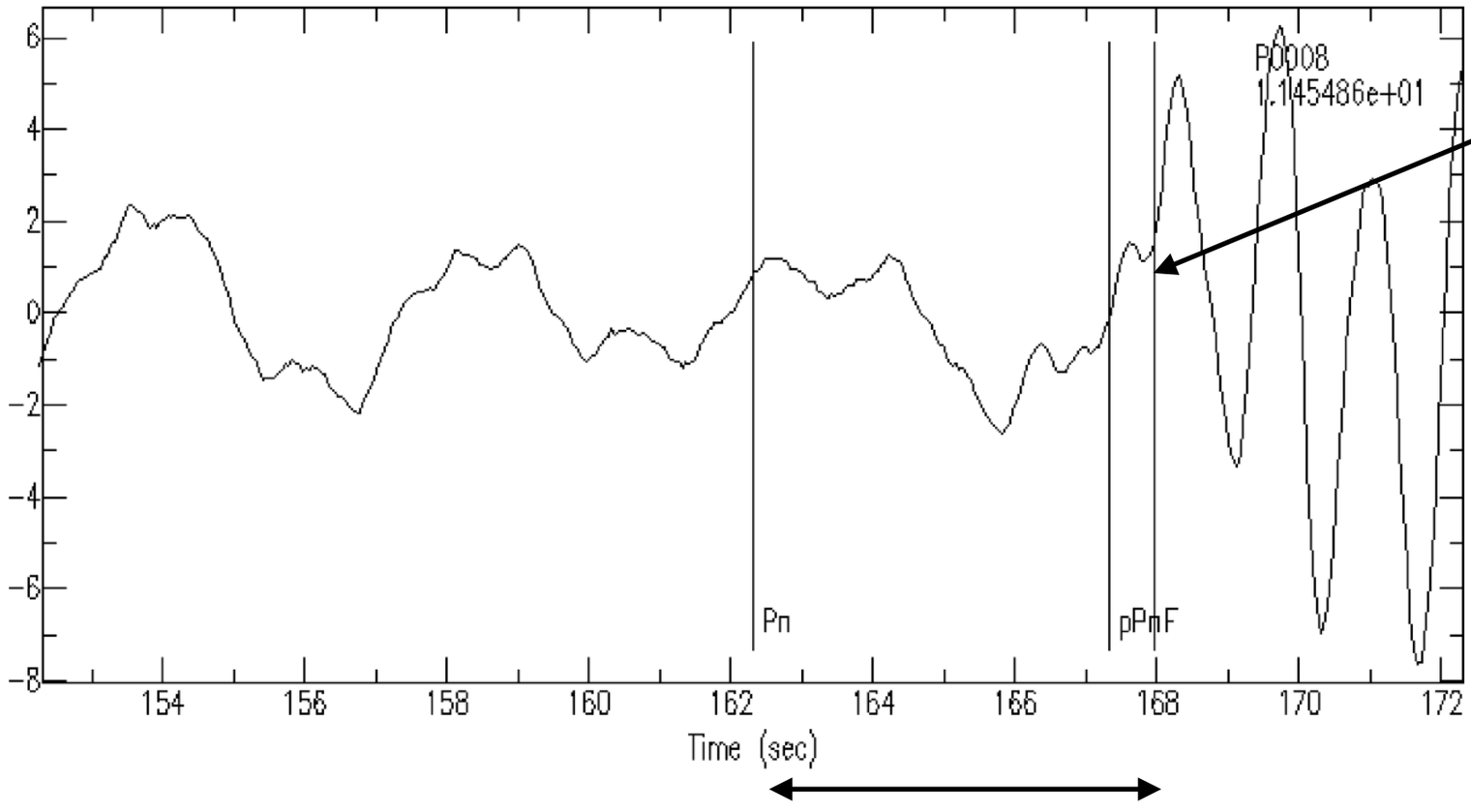
Complication III



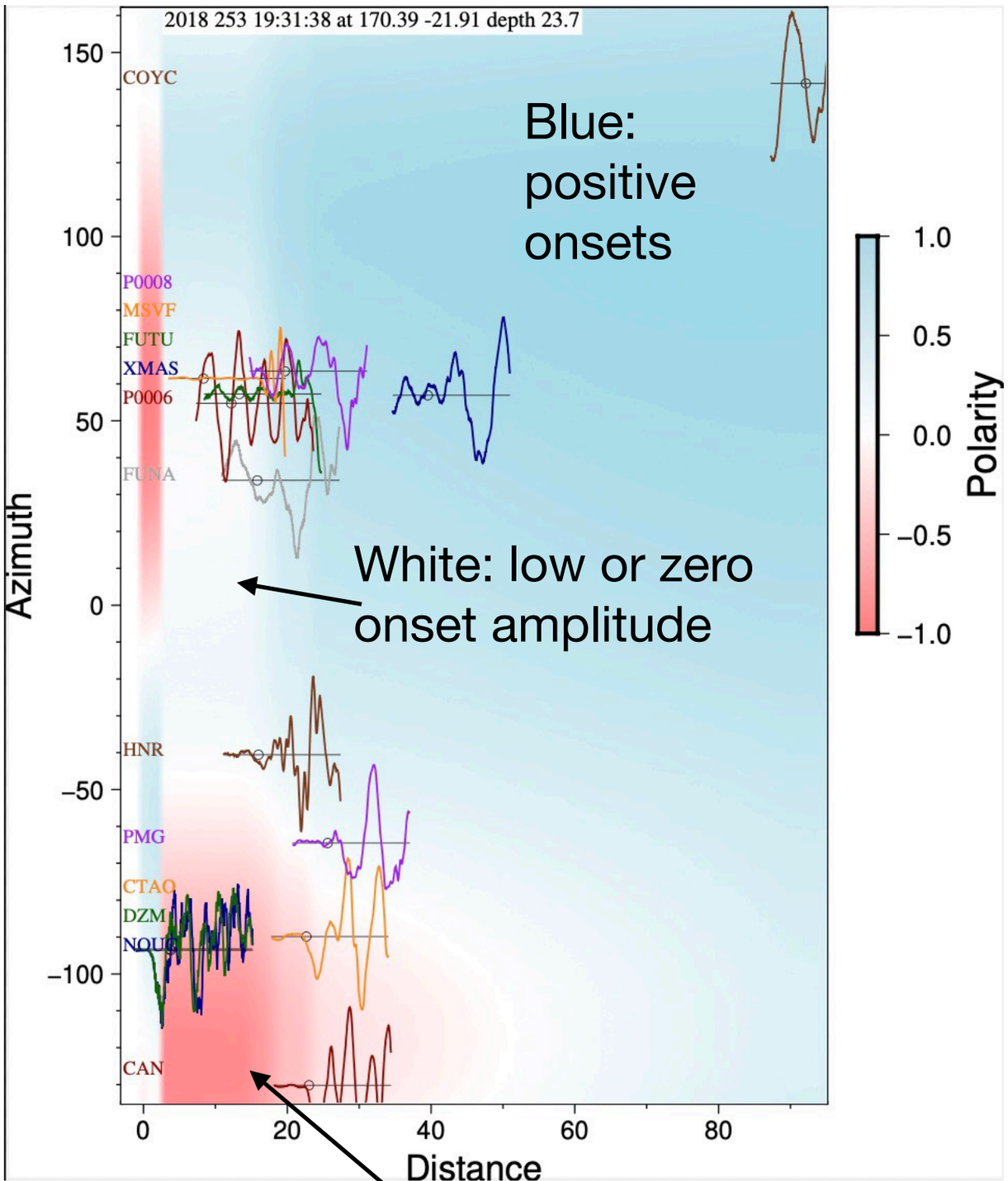
The first energy emitted may arrive following more than one trajectory (multipathing) with the first (“true”) onset often of very low amplitude.

Complication IV

If P is in a node of the radiation pattern,
pP is easily mistaken for P



This delay of 6s is possible at close distances but generally rare.
Check nearby records to clarify. Reject as uncertain if too ambiguous.



For strong enough events the radiation pattern can be predicted from the published moment tensor

In that case you can evaluate the risk of being at the node (white) and picking a later arrival instead of the first energy

In summary

- Noise will be the most frequent complication
- For shallow events pP may be close to and stronger than P -> risk of misidentification
- We shall review several tools to help you identify an onset correctly
- Very weak foreshocks are rare, but multipathing may look like a foreshock

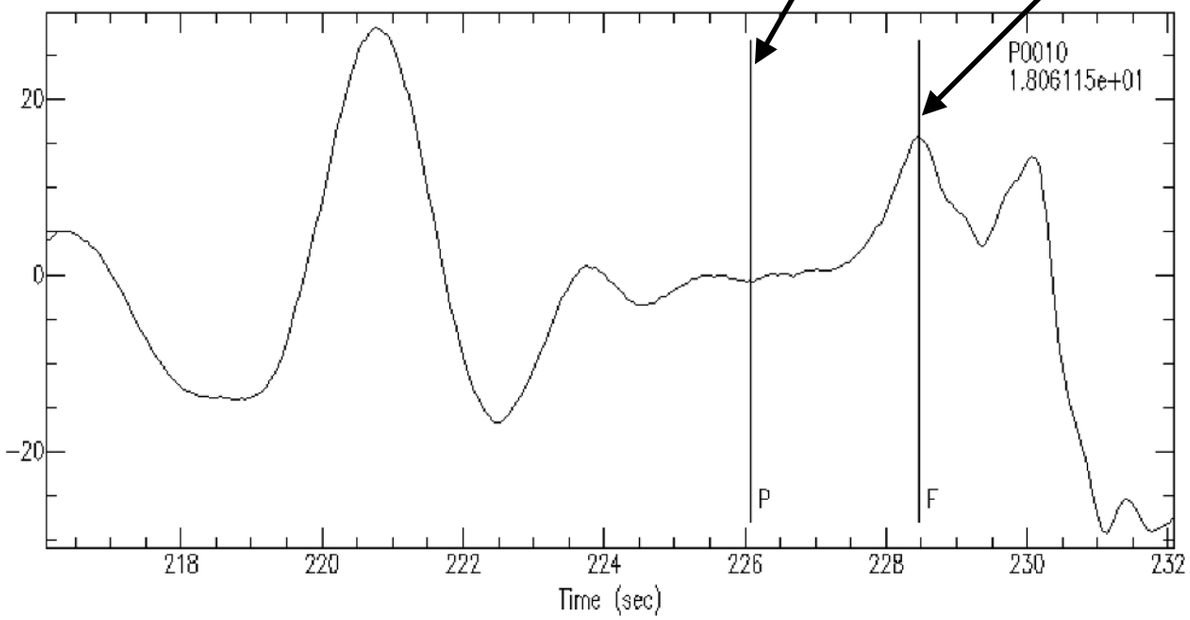
Helping hands

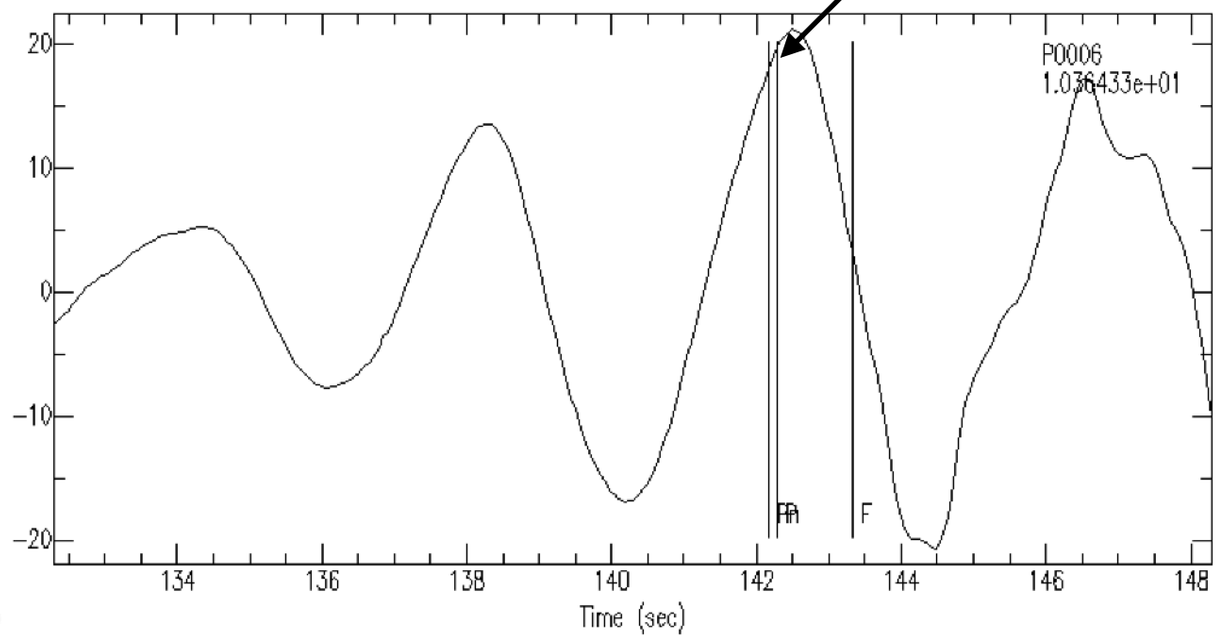
Predicted time(s) for P, Pn, pP are indicated

Automatic pick (Mermaids only) is indicated by F

P, Pn overlap

Unfiltered

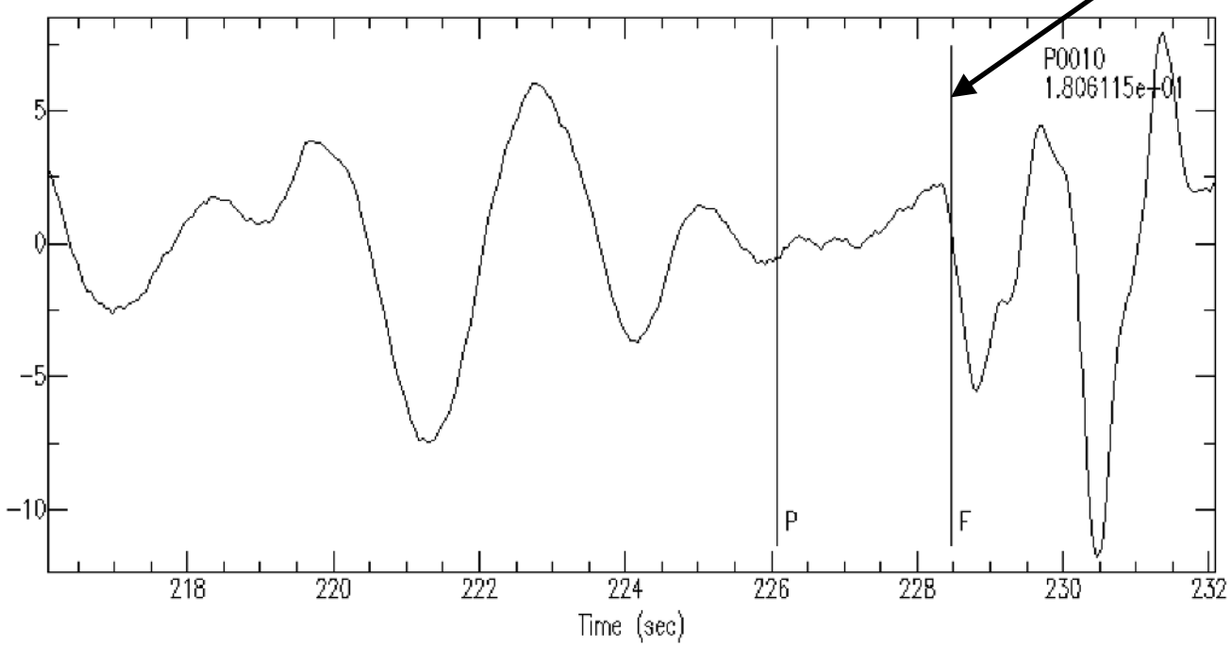


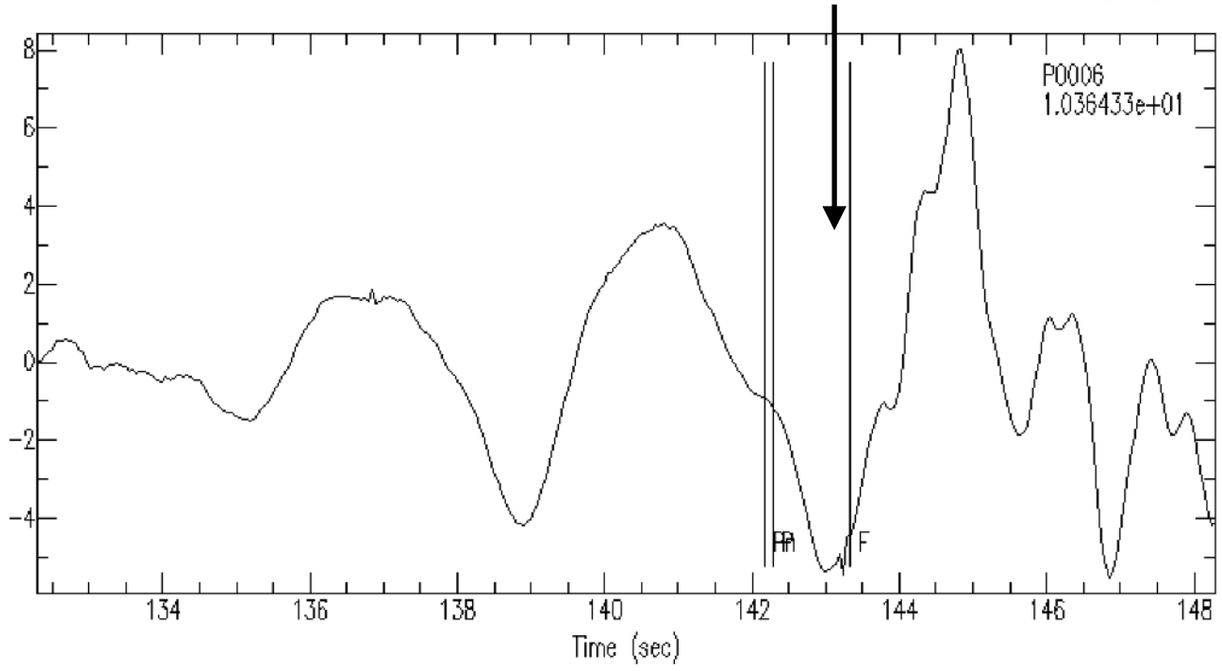


Filtered

F is often 0.2-0.3s late

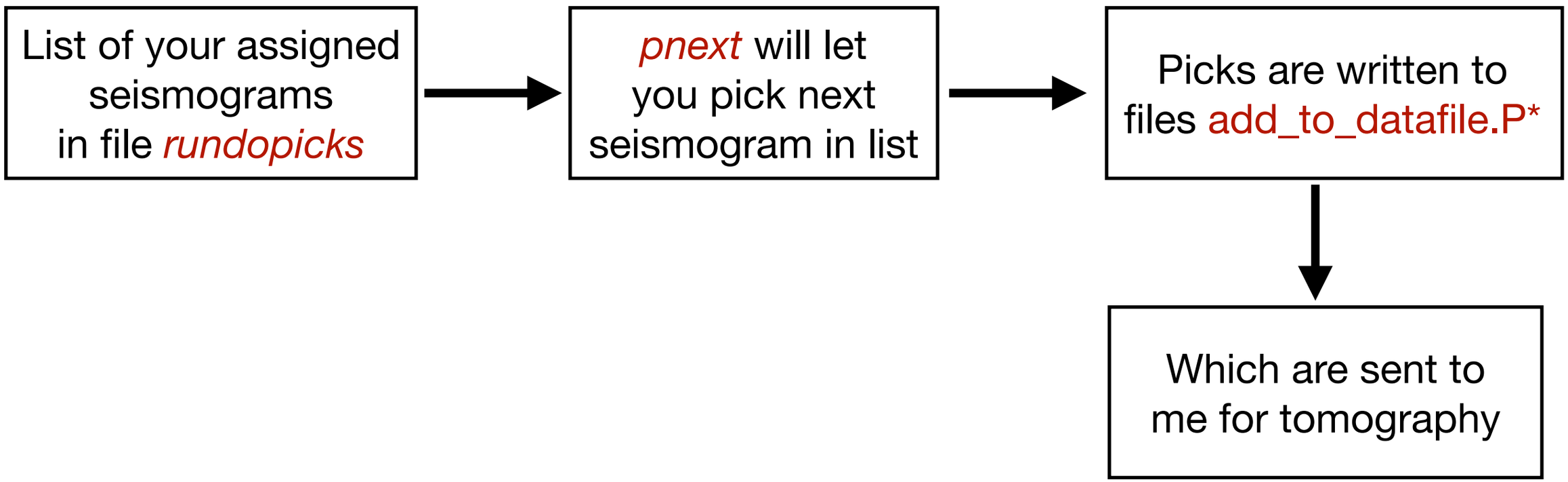
Onset not clear





3. The Tools

- The software tools are designed to make onset picking *easy and efficient*



The workhorse is `under the hood”

One command to do picking:

`dopick 2019/20190110/DATA/Q00`

*is incorporated in the program <**pnext**>*
and automatically proceeds through all
steps that otherwise have to be done
manually. No need to call it by yourself.

What is under the hood?
(read this only if you wish to know)

- *pnext uses script dopick and brings up:*
- *Plots of all the SAC files on a map*
- *Plots of all SAC files in delta-azimuth plane*
- *Plots of predicted polarity in that plane (if moment tensor is available)*
- *“Pickhelp” plot of `nearby’ seismograms*
- *Source time function (if available)*
- *SAC ppk plots for picking*
- *editing of standard errors in the add_to file (if needed)*
- *plot of residuals for quality check*
- *copy of add_to file into ADDTOS/*
- *automatic edit of rundopicks (see next slide)*

pnext also keeps track of the events you have already picked, and every time you call *pnext* it will select the next event to pick.

Its administration is in file *rundopicks*

Do not edit this file yourself!

The picking

Every SPPIM participant has his own list of seismograms to pick (they are listed in *rundopicks*). Again: do not edit this file, it is managed by program *pnext:*

```
auguste@augustes-macbook-air SPPIM % pnext

------------------------------------------------------------
Running PPK on 2018/20180824/DATA/Q00
ls: No match.
2018 236
  9  4  6  619
  -11.035  -70.781
   618.2      7.1      18770  h,Mw,ievt
Pause:
Pause:
```

HINT: *For optimal flexibility*, use a separate window and use copy and paste to go in the Qnn directory that has the seismograms, in this example:

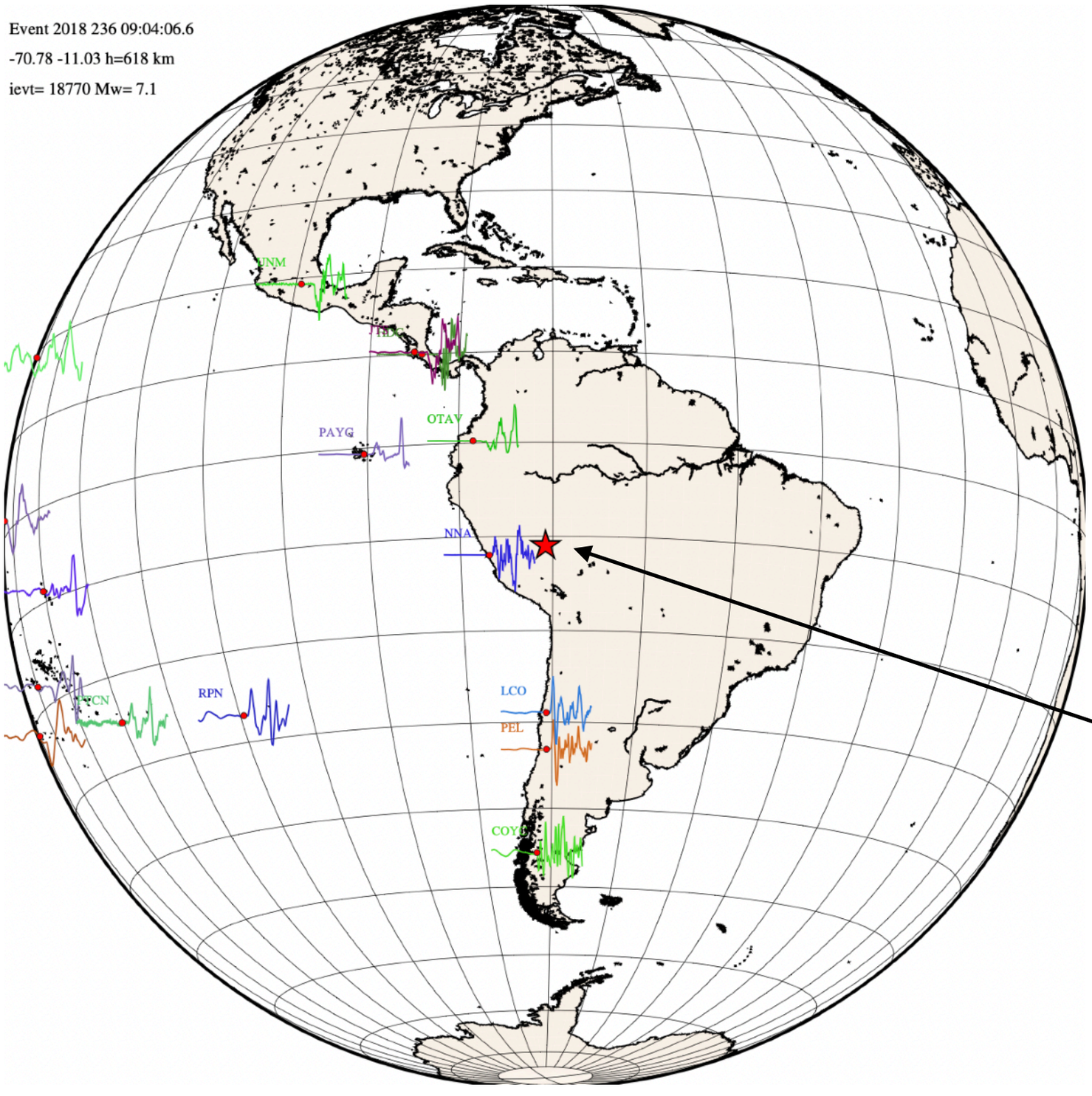
cd 2018/20180824/DATA/Q00

WHY? This will allow you to play with filters on SAC files without interfering with the picking (which is done in the window brought up by pnext)

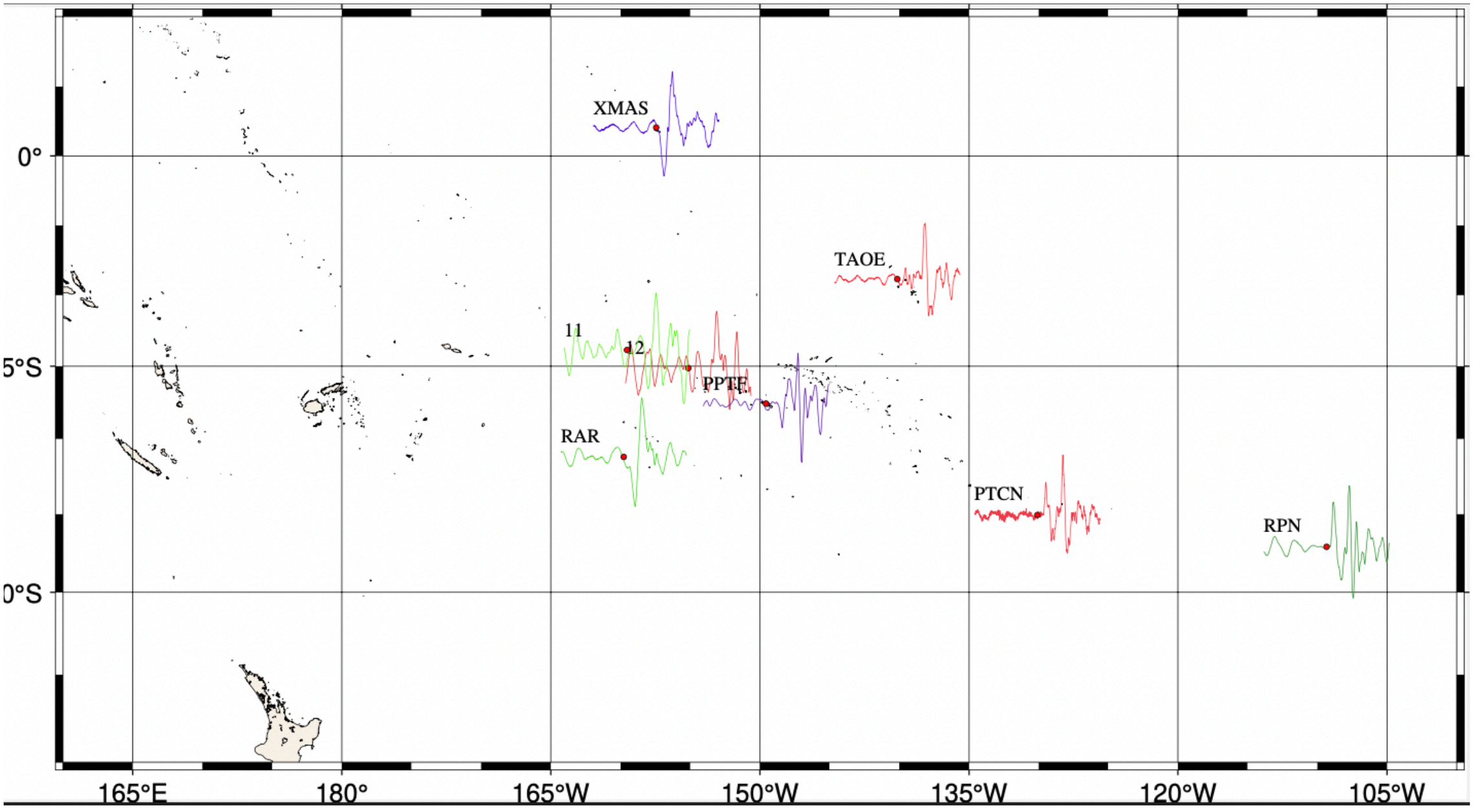
- **The Qnn directory has**:
- The Mermaid records in files ending in **.sac*
- A selection of GSN stations with file names ending in **.SAC*
- Information on the event in a file named *quake*
- Information on the Mermaid in a file *out.cfneic*
- Various plot files ending in **.pdf*

When in the base directory, hit *return* after each *Pause:* this will give you the next plot

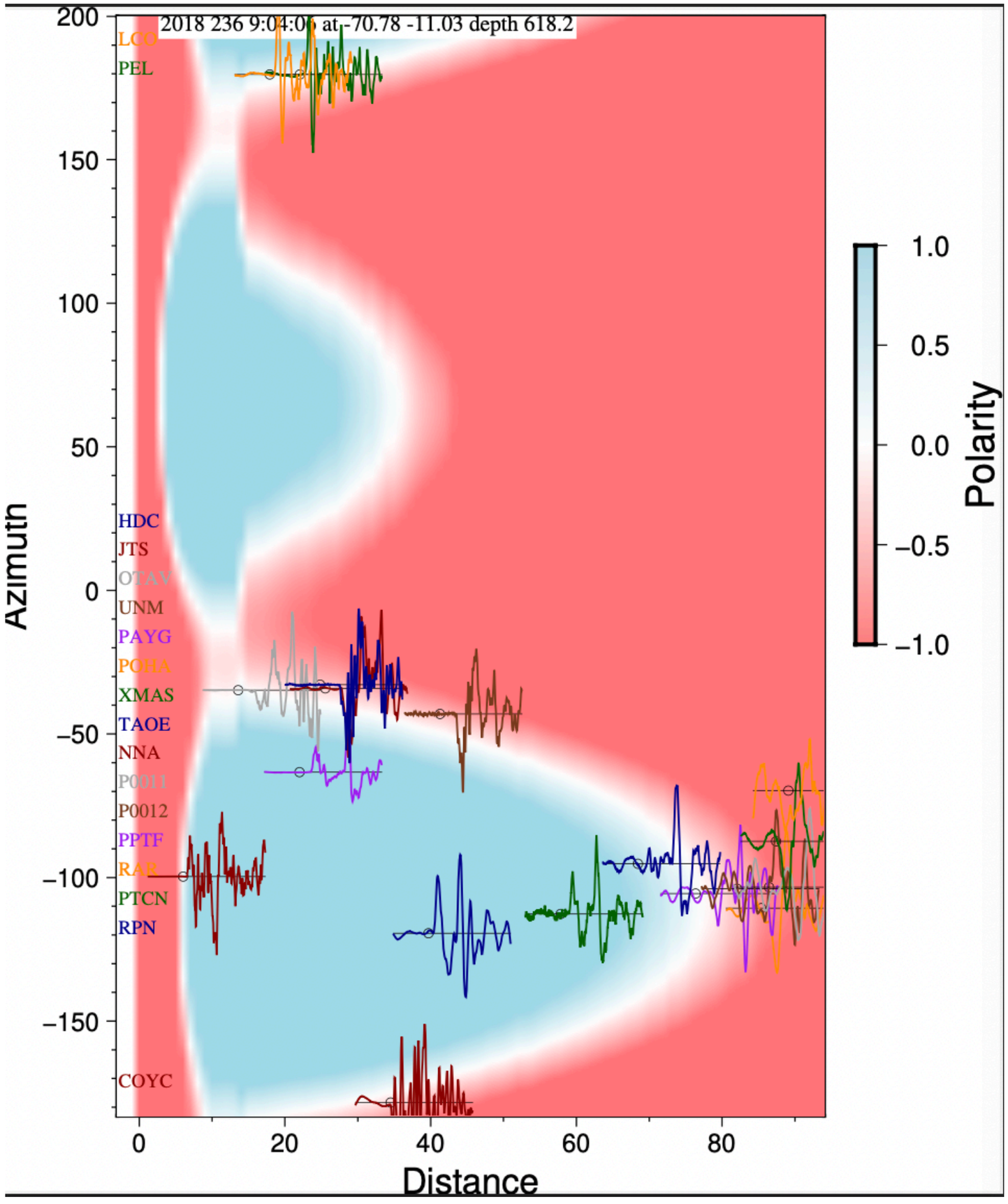
Step 1: Brings up plots — hit <Return> after Pause: to get the next one



The *global plot* is centred on the quake (red star) and shows only the FDSN stations in the SPPIM area that have low noise



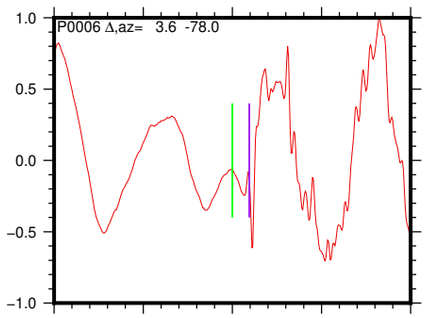
The *local plot* is limited to the SPPIM area
and shows both Mermaids and low noise FDSN stations
Mermaids are labeled with a number, island station with the FDSN code

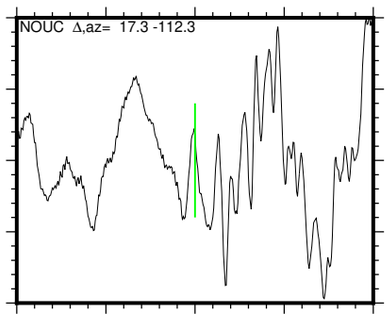


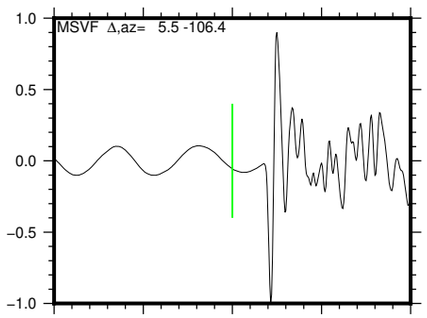
The next plot shows polarity if a moment tensor is available.

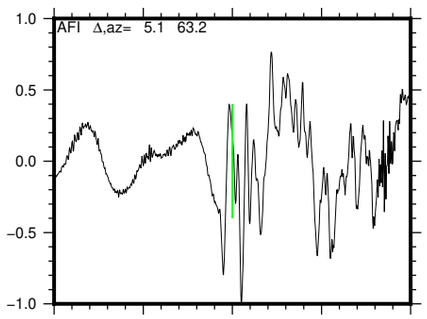
Blue: prediction up
Red: down

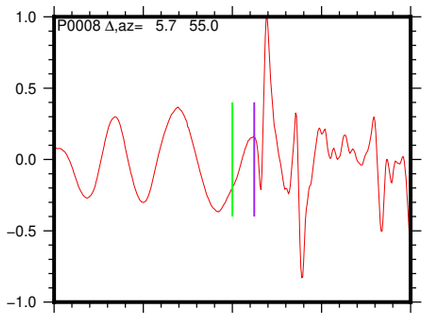
If not it will just plot the seismograms in the Δ-azimuth plane

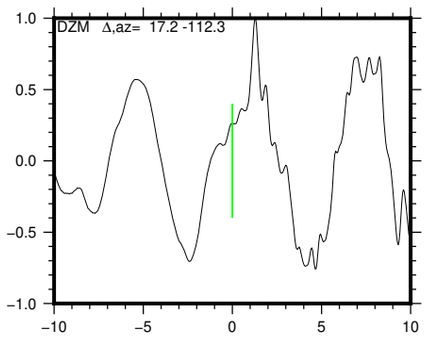






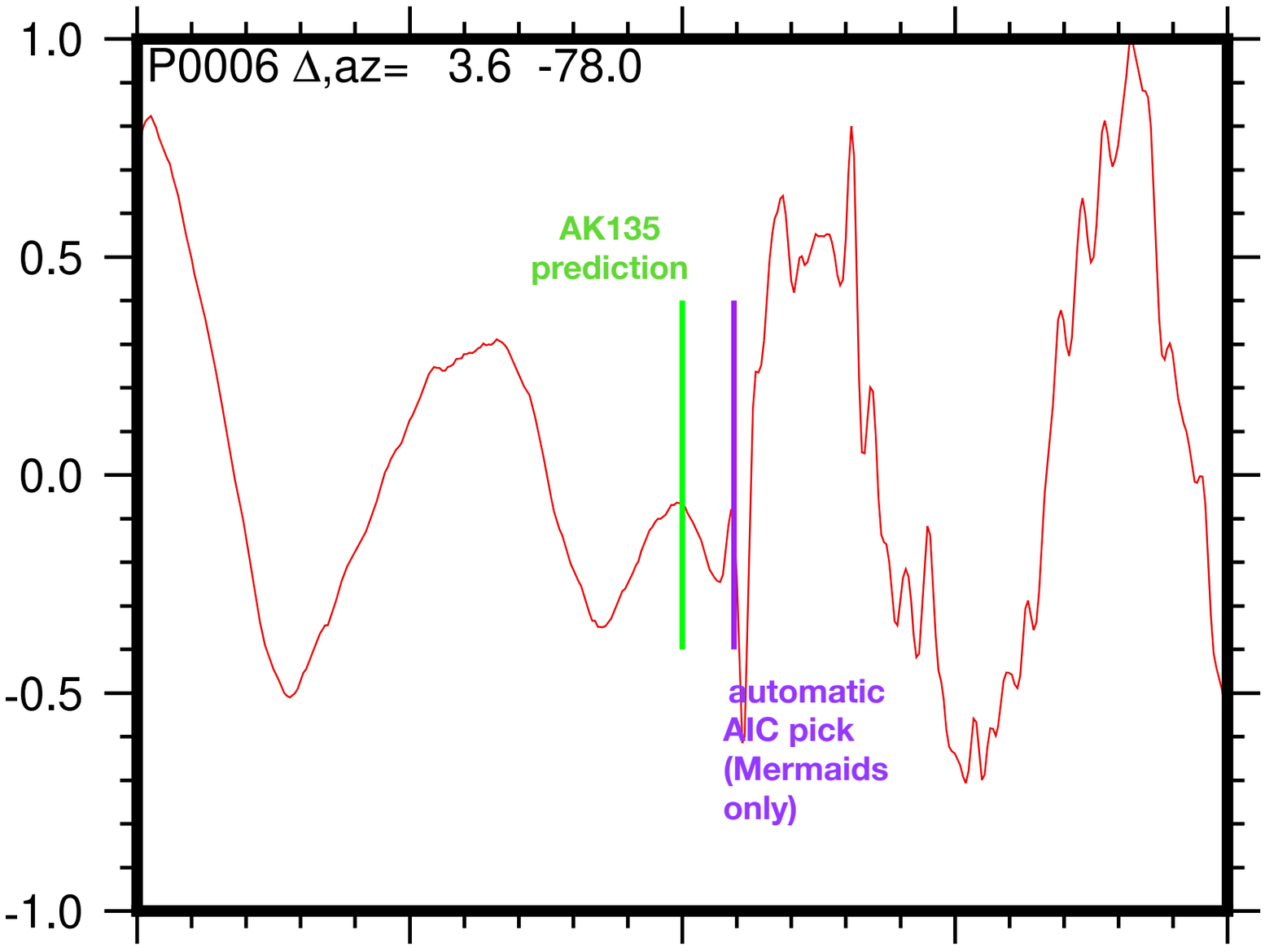




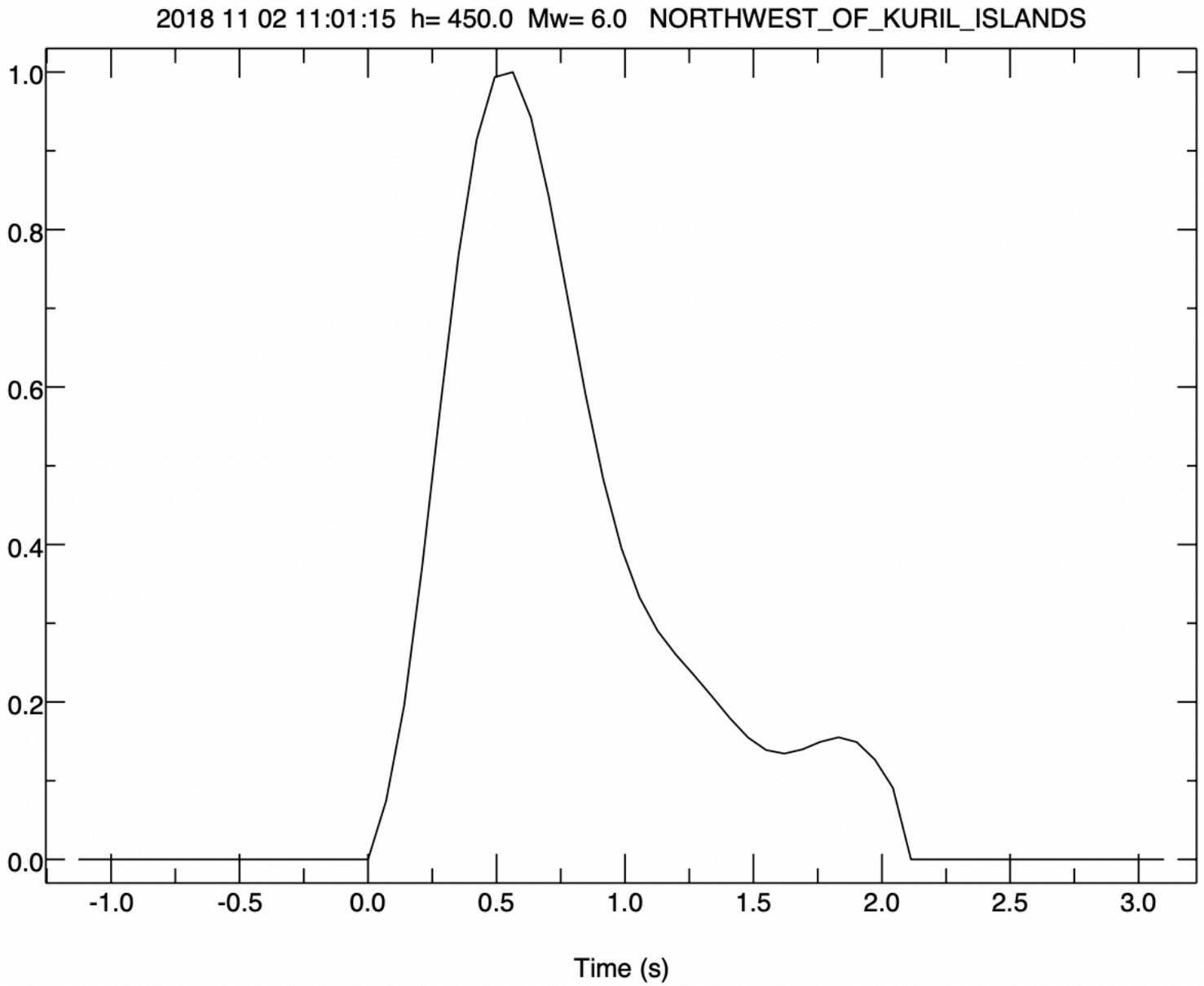


Pickhelp plots

The plots *ppltn.pdf* show the data in a sequence that allows for easy comparison between nearby stations



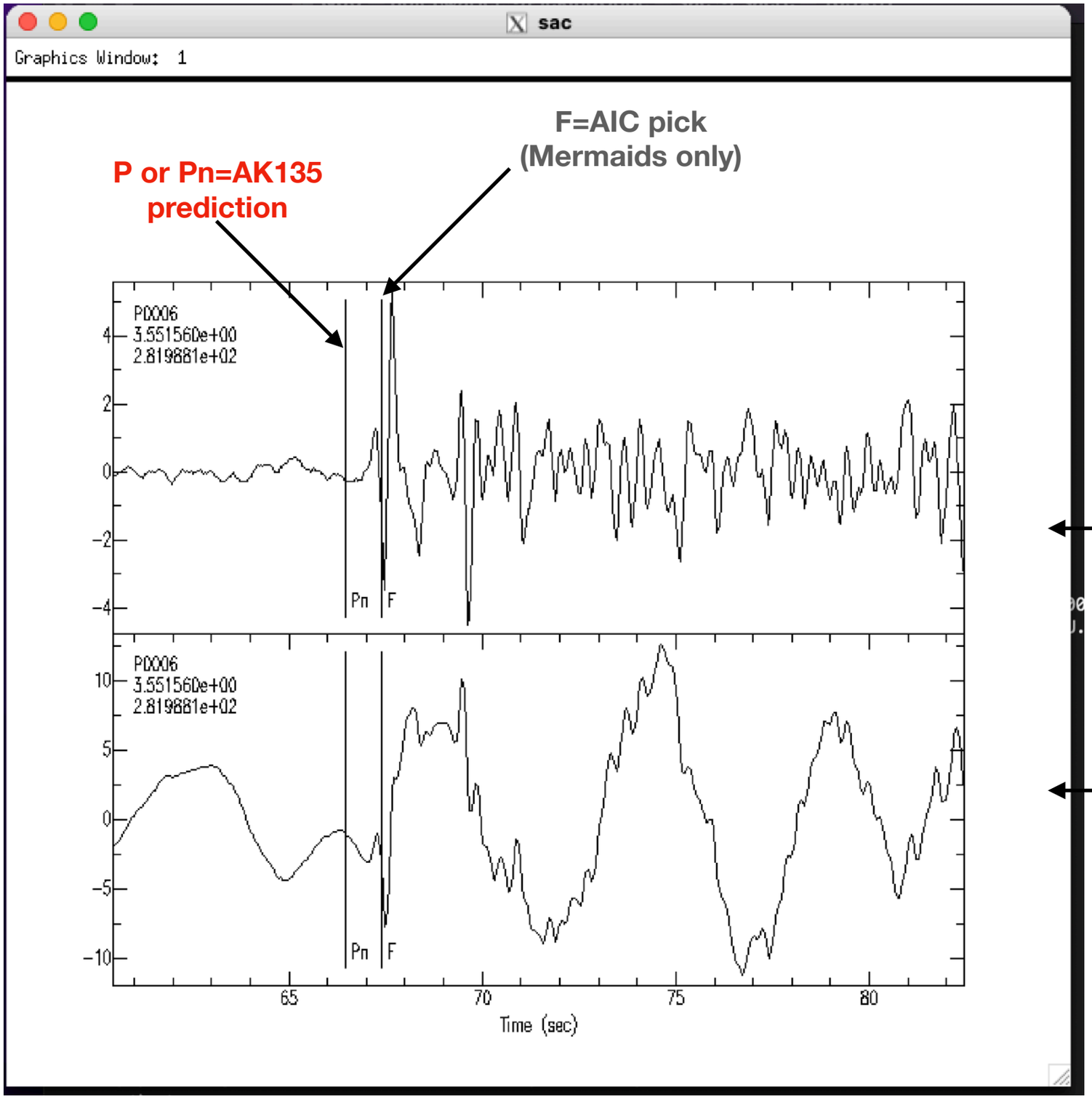
If a source time function is available, this plot will also appear



Source time functions allow you to see if there may be a small foreshock that drowns in the noise at larger distances. We shall discuss this later.

The plots *stf.pdf* are from http://scardec.projects.sismo.ipgp.fr/

Step 2: Brings up SAC for picking



- *Point crosshair*
- *Type ‘L’ (or A) to pick*
- *Type ’N’ for next*

High-pass filtered (1 Hz)

Unfiltered record

You can pick from either one. Only the time is important, the amplitude is ignored.

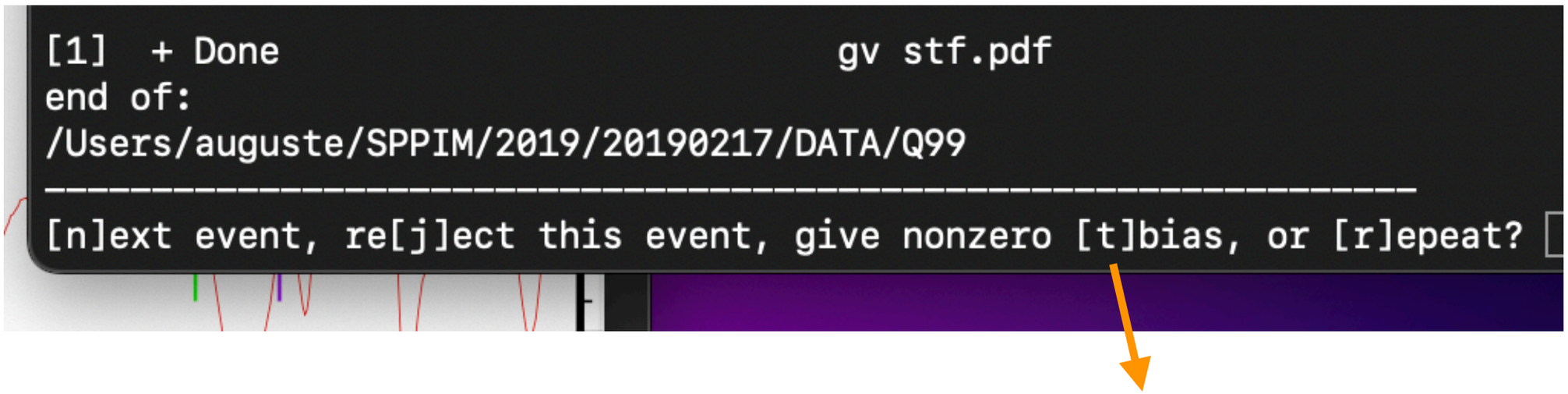
What may go wrong

[1] You picked a wrong time. *Solution*: just pick again and the earlier pick will be ignored

[2] You did not wish to pick this seismogram but inadvertently hit a key and SAC recorded a pick. *Solution: note down the name of the station. At the end of picking, when vi comes up, change the standard error for this station to 999.*

[3] Seeing the nature of the onset in some later records, you realize you should have picked some earlier picks differently. *Solution: type **r** at the end to **r**epeat the picking. Pass over the good picks (simply type n) but redo the ones that need change.*

After the last seismogram has been picked, you are asked if you are finished for this quake **(n),** or if you have second thoughts and wish to go over the seismograms again **(r).** You can also decide to reject this event **(j)**



The **[t]** option will be discussed later

If you repeat with **r,** you are asked for *tbias,* usually you just give 0:

```
Give tbias for rdapf2, or 0: 0
```

after which SAC comes up again. You'll see your current picks labeled with `A'. If you want to change it, move the cursor where you wish it to pick and type `L', otherwise type `N' to go to the next plot.

If you finish with **n,** vi comes up so you can edit the add_to file (*if needed).*
Do not change anything, except - *and only if necessary - the errors* that follow the arrival time (yellow circle)

Increase this error for very doubtful picks (*rarely needed!*)

```
  2018286  002008   18822   1 HNR      IU       BHZ  -13.698  167.315  204.5   -9.439  159.947 -0.100   1   0   0 P   5.8
2     0.000     0.000
          1
  118.14      0.57     1.00  0      0.0
          0
  2018286  002008   18822   1 PMG      IU       BHZ  -13.698  167.315  204.5   -9.405  147.160  0.090   1   0   0 P   5.8
2     0.000     0.000
          1
  259.68      0.57     1.00  0      0.0
          0
  2018286  002008   18822   1 CTAO     IU       BHZ  -13.698  167.315  204.5  -20.088  146.255  0.283   1   0   0 P   5.8
2     0.000     0.000
          1
  268.63      0.57     1.00  0      0.0
          0
  2018286  002008   18822   1 NOUC     G        BHZ  -13.698  167.315  204.5  -22.099  166.307  0.137   1   0   0 P   5.8
2     0.000     0.000
          1
  119.55      0.57     1.00  0      0.0
          0
  2018286  002008   18822   1 DZM      G        BHZ  -13.698  167.315  204.5  -22.072  166.444  0.878   1   0   0 P   5.8
2     0.000     0.000
          1
  118.79      0.57     1.00  0      0.0
          0
  2018286  002008   18822   1 MSVF     II       BHZ  -13.698  167.315  204.5  -17.745  178.053  0.701   1   0   0 P   5.8
2     0.000     0.000
          1
  158.01      0.57     1.00  0      0.0
          0
```

When in doubt, leave the add_to file unchanged, simply leave vi with :q or Esc :q

The <add_to> file is what I need for inversion.

It lists an error computed by program rdapf2 that assumes:

- An (estimated, average) pick error of 0.4s
- An average crustal correction error at inversion time of 0.4s
- A mermaid location error from out.cfneic

For individual stations, this error can be edited
but do this only for highly uncertain picks

If the location error is small, the total error in the add_to file is 0.57s

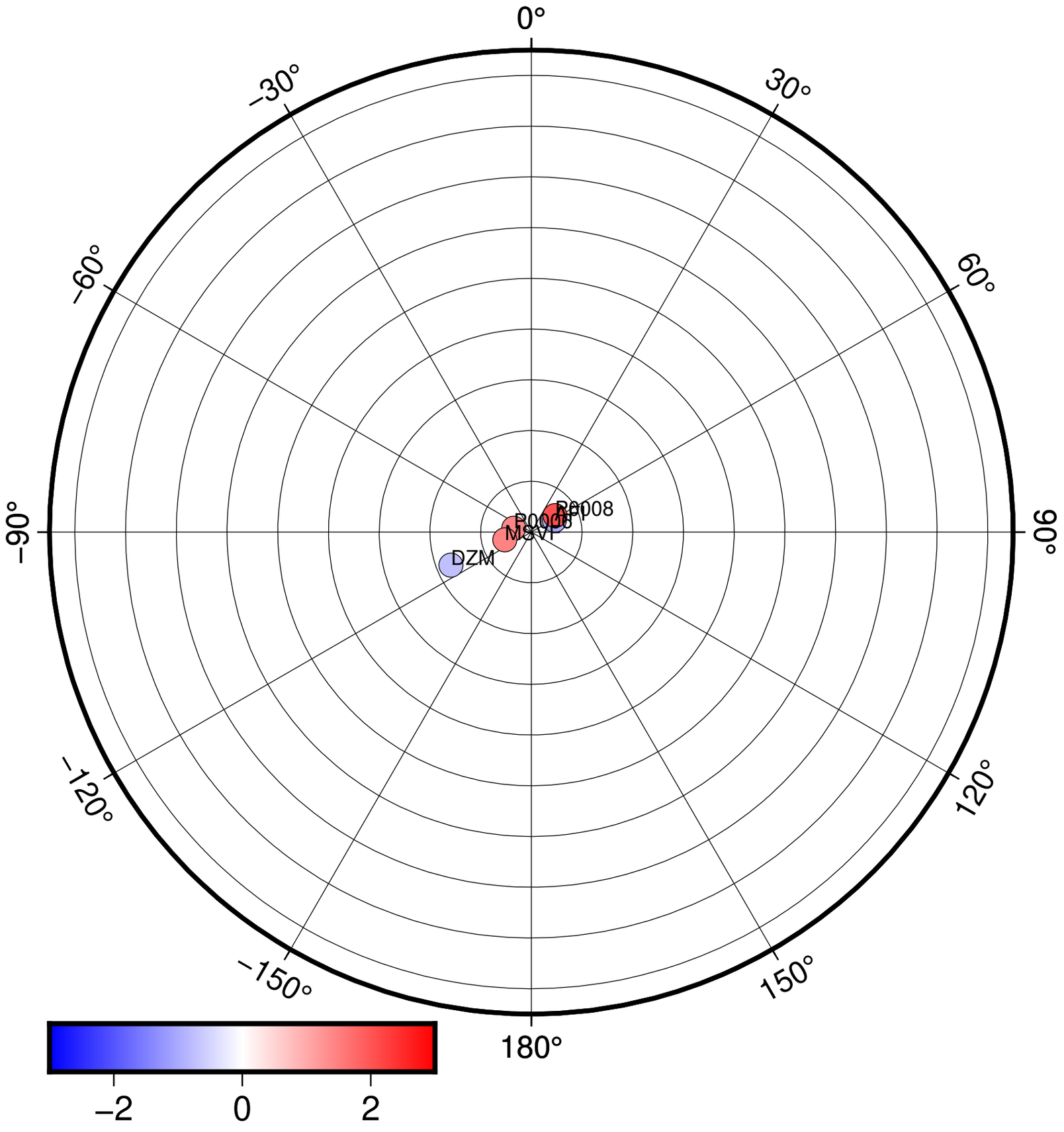
Only if the Mermaid recorded the seismogram far away from the surfacing location will you see a larger error.

The add_to file is copied to a directory:

ADDTOS

in your base directory

After leaving vi, a distance-azimuth plot shows residuals (in sec)



Red is slow
Blue is fast

Your homework

- Install the software if you have not yet done that
- Untar homework1.tar in your base directory
- Copy rundopicks.course1 to rundopicks
- Type pnext (while in the base directory) and start picking
- Repeat pnext and pick next event until you are done
- I chose some easier records, but pick only the onsets you trust.

  We shall look at more difficult ones in the next course
- When ready, make a tar file: tar -cvf yourname.tar ADDTOS
- Send file yourname.tar to nolet@princeton.edu