SEISMOLOGY
RESEARCH
CENTRE

Waves

EARTHQUAKE DATA ANALYSIS, LOCATION & MAGNITUDE CALCULATION

PRODUCT USER MANUAL

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History

The Seismology Research Centre

The Seismology Research Centre (SRC) was established in 1976. In 1977 the SRC began developing "Kelunji" digital seismic recorders, starting with the Alpha and Beta tape-based recorders (later renamed Yerilla). The first Kelunji-branded recorder was later referred to as the Classic, which was followed by the D-series, Echo, EchoPro, and the current Kelunji Gecko.

Above: the original 2015 Gecko Compact seismic recorder, next to an iPhone 6 for scale

Data Formats

The Kelunji Gecko was our first recorder to natively store data in **MiniSEED** format. MiniSEED data files do not include information about the recorder or sensor gains and sensitivity factors, but the Gecko stores this information in a simple text file in each data folder. Waves will automatically read the file if it is present, displaying your data in real ground motion units. You can then save this extra data into the file by saving it in PC-SUDS format.

When the Kelunji D-series was introduced in the mid 1990s the SRC decided to adopt a global standard data format for our seismic recorders. The **SUDS** (Seismic Unified Data System) was originally created at the U.S. Geological Survey and adopted for use in the IASPEI Seismological Software Library, where it became known as **PC-SUDS**. It is a very flexible format which contains many fields for information relating to the raw data, which has enabled our Waves software to provide very useful information to Kelunji users.

For more information on SUDS, visit http://banfill.net/?page_id=16

Waves can also read other data formats including: KA1, KA2, Yerilla, SEG-Y, SEG2, GSE 2.0 (AutoDRM), CSS waveform binary (.w), CSS arrival text (.wfdisc) and CSV text. Waves will automatically decompress any files that use .zip, .gz or .xz compression.

Installing Waves

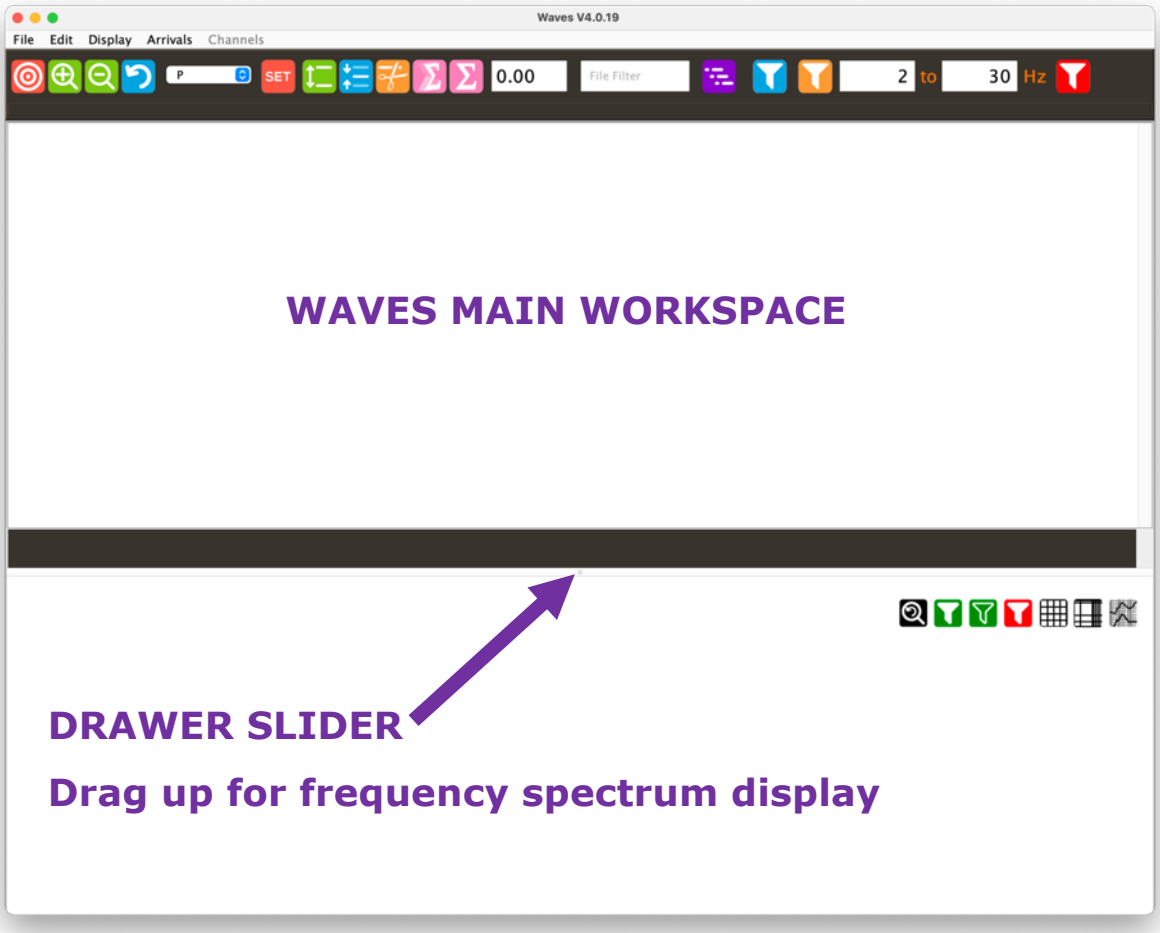
Java Not Required

Waves 4.0 includes everything it needs to run as a stand-alone Windows, macOS or Ubuntu application, so unlike previous versions of Waves you no longer need to have Oracle's Java Runtime Environment (JRE) installed.

Waves Workspace

When Waves starts up, you will be presented with the window below, with a toolbar containing buttons for some commonly used function. The main workspace is where the waveforms will appear, and below this is a pull-up window that reveals the frequency spectrum display.

Drop a MiniSEED, SUDS or other compatible file from your computer's file browser onto the workspace to view the waveform, then start analysing your seismograms.



Toolbar & Channel Buttons

	Shortcut Key	Description
		If you have 3 or more arrival picks, enter Location feature
	Page Up	Zoom in to the timeline (or zoom to selection)
	Page Down	Zoom out of the timeline (centred on click or selection)
	Home	Display full timeline and amplitude
	p, s	Select the arrival types to mark on the time line
	w	Set the arrival marker selected in the drop down list
		Switch between Individual and Fixed Amplitude Scaling
		Switch between Displayed and no Zero Offset correction
		Trim the working file to only the displayed data
	⌘-g	Display the 3D vector sum (peak particle motion)
		Display the 2D vector sum (peak horizontal motion)
		Enter a time correction for the selected station (seconds)
	b or n	Open next file if name includes this text, use (B)ack or (N)ext
	Sort	Re-apply the station order sorting
	g	Filter all channels using the Preset frequency band
	h	Filter all channels to the Custom frequency band specified in fields to the right of the button
	j	Clear frequency filter from all channels
		Per-channel filters – functions as above
	⌘-i	Channel Information
		Flip channel polarity (black arrow up=normal, down=reverse)
		Show/hide channel rotation controls (coloured if changed)
		Show/hide channel elevation controls (coloured if changed)
	k (on), l (off)	Show/hide channel spectrogram plot. Shortcut keys affect all channels – turning all spectrograms on will take some time

Controls

Note: *where you see the ⌘ symbol in this manual, it represents the Control key on Windows and Linux, or the Command key on macOS, unless otherwise specified.*

Zooming & Scrolling

All zoom commands are applied to all channels at the same time.

Scroll-zoom

While holding down the right mouse button or the CONTROL key, roll your scroll wheel to zoom in and out to your cursor's location on the time line. The zoom speed can be adjusted in the "Controls" setting. Note that some touch-based pointing devices (e.g. macOS trackpads) may not behave as expected when scroll-zooming. Double right-clicking your mouse will reset the zoom level to the full timeline, as will clicking the button.

Click-zoom

Clicking and dragging your cursor over the waveform will show a red vertical marker bar. Move to the area you want to zoom into and release the cursor-click to leave a light grey marker line. Click the button or PAGE-UP shortcut key to zoom in to the marker or use the button or PAGE-DOWN shortcut key to zoom out, centred on the marker.

This zoom speed is also adjusted by the zoom "Controls" setting.

Swipe-zoom

Instead of left-clicking and dragging a marker line, you can right-click and drag to highlight an area of interest. After releasing the click, place your cursor over the highlighted section and you will notice that your cursor changes into a magnifying glass. Click to zoom the highlighted area to full window width.

Timeline scrolling

Use the left and right arrows on your keyboard to scroll the time line, or holding down the ALT key and using the scroll wheel.

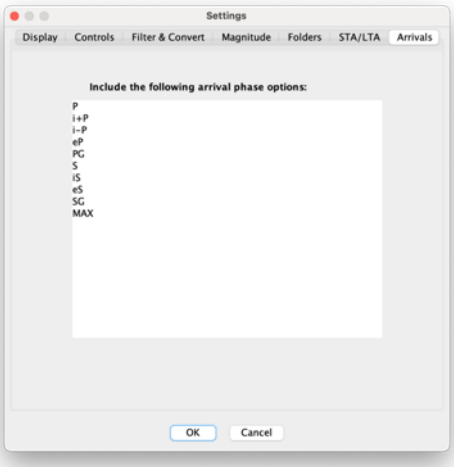
Amplitude scaling

Use the up and down arrows on your keyboard to double or halve the signal amplitude of all channels. Use the button or HOME keyboard shortcut to revert the amplitude.

Picking Arrivals

The main function of Waves is to pick earthquake wave arrival times on the recordings to allow the determination of the location and magnitude of the earthquake. We will cover the basics of picking P and S wave arrivals and calculating earthquake location and magnitude later in this user manual.

To mark a phase arrival time, click and drag the cursor to the point of interest on a channel and release to leave a grey marker line. Select a type of arrival from the drop-down list. This list of arrivals is based on a customisable text list in a (new to Waves 4.0) settings tab.



Once the marker line is in place, click the SET toolbar button (or use the **W** shortcut key) to mark the selected phase time on the station (or channel, in the case of X markers).

You can use keyboard shortcuts to set **P**, **S** and **M**AX arrivals, as well as **X** to mark a channel stacking marker. The most commonly used seismology arrival phase codes are listed in the Arrival Settings list, but you add any text you like into the list to use as a time mark identifier.

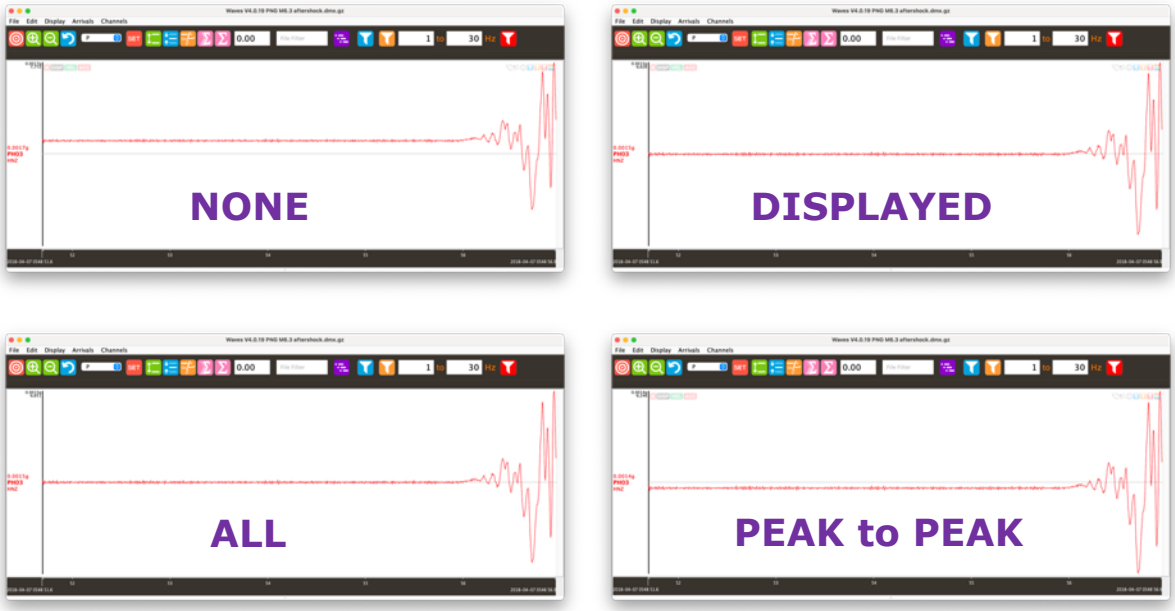
Amplitude Grouping

To maximise the detail of the displayed data, Waves will scale the amplitude of each channel to fill the vertical space allowed for each channel, which means each channel will have an **Individual** peak amplitude scale on the Y-axis. You can choose to group the amplitudes by **Location**, which will scale all channels with the same station and location code to the largest channel's amplitude. You can group **All** channels to the single largest amplitude in the file, regardless of station code. Finally, you can scale Acceleration, Velocity, or Displacement waveforms to a **Fixed** peak value as defined in the "Display" Settings.

Clicking the button will toggle between Fixed and Individual modes, but other modes are available in the Display menu. Channels that have been converted from their natural units (usually velocity or acceleration) to other units will always scale individually.

Zero Correction

When a sensor is plugged into a recorder it will almost always have some level of signal offset, which can be due to the sensor not being perfectly level or the sensor components requiring some sort of electronic adjustment. The raw data is never modified by Waves, only the way it is displayed. Each channel is corrected individually. The offset correction can be based on the zero-offset of the visible data (**Displayed**) or based on the average zero level of the entire record (**All**), or zero-offset connection can be turned off (**None**), or the zero level can be displayed as the mid-way point between the positive and negative displayed peak signal level (**Peak to Peak**) by selecting the mode in the Display menu. The toolbar button toggles between Displayed and None.



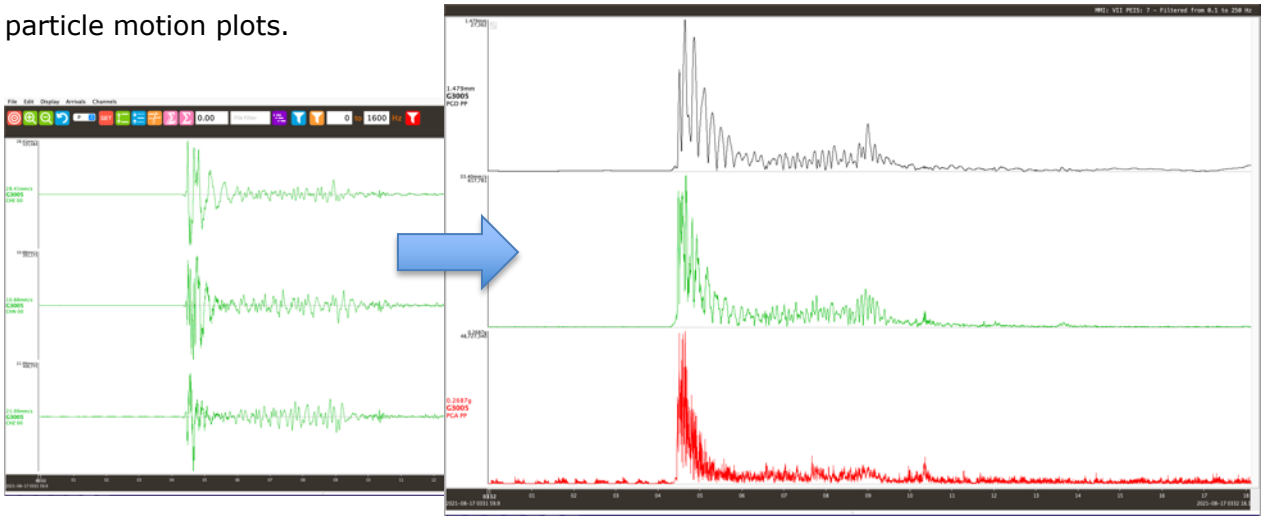
Trim

The tool will delete all hidden channels and data outside the currently visible time line, leaving you with a new file that needs to be saved separately. When using the Trim tool, the original data file is closed, whereas when using the "Copy Visible to New File" in the Edit menu, the original data file remains open in a window behind the new trimmed data file.

Vector Sum

We are often using sensors that record in three dimensions, usually set up in the east-west, north-south, and up-down axes, but sometimes they are aligned relative to a structure or event, such as along a dam or pointing towards a blast. The peak motion from the event will not necessarily be in one of these axes, so to calculate the peak value we can apply a 3D vector sum formula to the data. Kelunji data is recorded in triaxial groups, or you can manually group channels using the channel location code.

By using the Σ button while channel is selected (or choosing "3D Peak Motion Plot" from the Display menu, or using the ⌘-**G** shortcut) a new Waves window is displayed showing the peak particle motion plots.



If the original ground motion units are known, the new window will show the vector sum in the original units as well as the other two related units. In the example above, the original green velocity traces have been summed, and the vector sums of the calculated displacement and acceleration traces are also shown. Without some filtering, integrated ground motion units (going from acceleration to velocity, or velocity to displacement) can contain low frequency artefacts, so Waves automatically applies a 0.1Hz high pass filter to 3D plots, but in "Filter & Convert" Settings you can set the filter band manually (leave blank for no filter).

If you only wish to see the peak motion of the two horizontal channels in the triaxial group, use the Σ button to display a 2D vector sum peak motion plot in the available units.

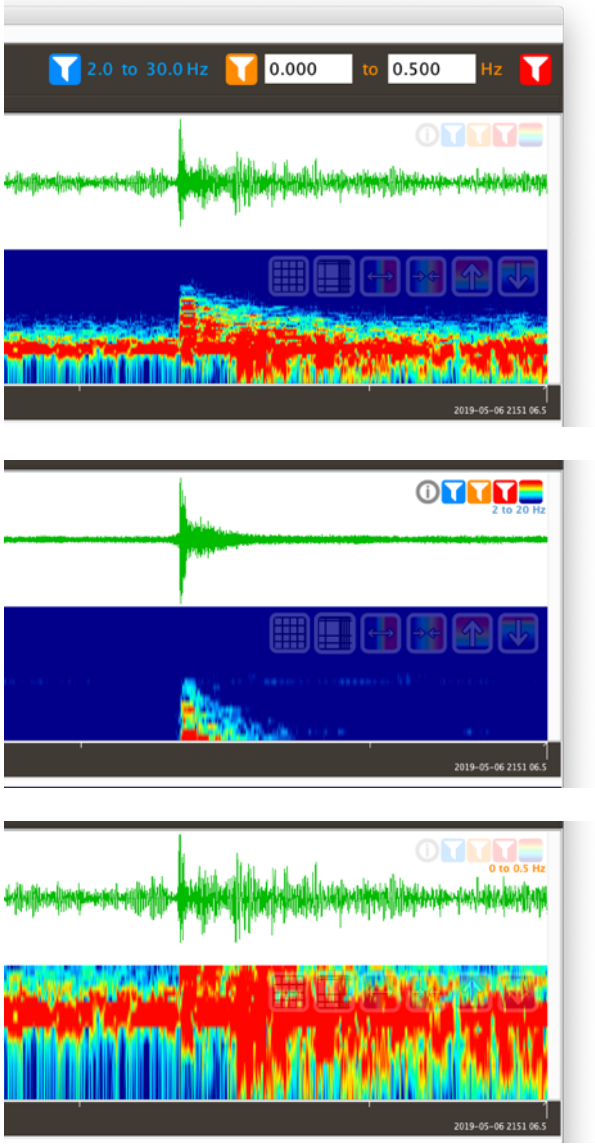
Using the "Sync" feature

Older instruments did not use GPS and relied on internal clocks for timing. Clock errors can be corrected by time-shifting data using the "sync" feature. A Sync value from 0 to 30 seconds shifts the data back in time, and a sync of 30 to 60 seconds will shift data forward. Enter a value into this field and hit Enter to adjust the time line for the selected station code.

File Filter

The **File Filter** field in the toolbar is linked to the file browsing tool in the File menu. If any characters have been typed into this field, when you use the Next File **(n)** or Previous File **(b)** commands, only valid files that contain those characters in the filename will be opened. Leave the field blank to remove the file filter and open the next valid file in the folder.

Frequency Filters



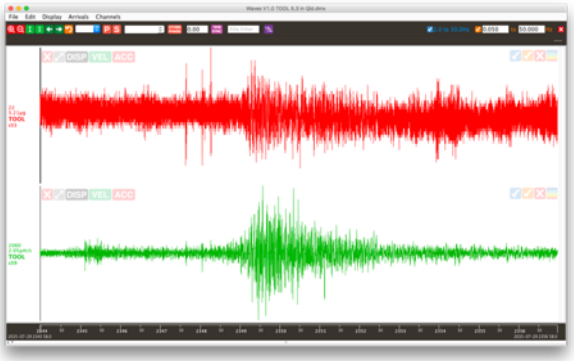
A user will typically be interested in a particular frequency band, so Waves allows the definition of a blue "favourite" Preset band pass filter. Waves also allows the user to set a variable frequency band pass filter by typing values into the fields to the right of the orange button in the toolbar. The red filter button clears the filters. The Toolbar filter buttons will apply to all channels (or all visible channels, according to your "Filter & Convert" Settings which is discussed later in this user manual).

Once a filter has been applied to a channel, the pass band is written in text to below the channel filter buttons so that you are aware that the data displayed has been filtered.

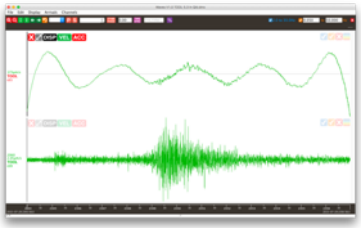
Viewing spectrograms is covered in more detail later in this user manual, but note that the frequency range of the spectrogram will also change according to the channel filter settings to maximise the resolution of the visible frequencies in the spectrogram.

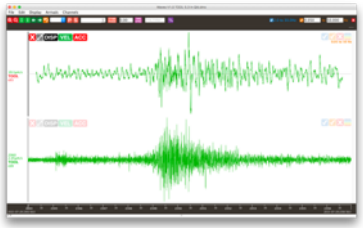
You can enable and disable filters on individual channels by clicking on the small filter buttons in the top right corner of each channel.

To illustrate the effect of the filter when converting data between ground motion units, in the example below the upper trace is a high gain accelerometer and the lower trace is a 1Hz velocity sensor. Converting the acceleration trace to velocity and filtering it from 1Hz to 50Hz yields a similar trace to the seismometer.



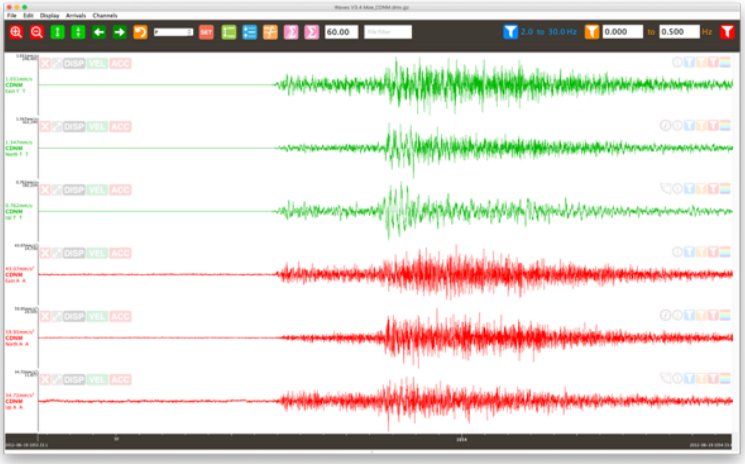
Removing the filter altogether shows the artefacts of integration (below, left), but setting the low end frequency to 0.05Hz (20 seconds, below right) reveals the long period signal. Unit conversion and frequency filtering are very important tools in revealing phase information. Sometimes arrivals are clearer in Displacement. Play with your data and see what you can find!



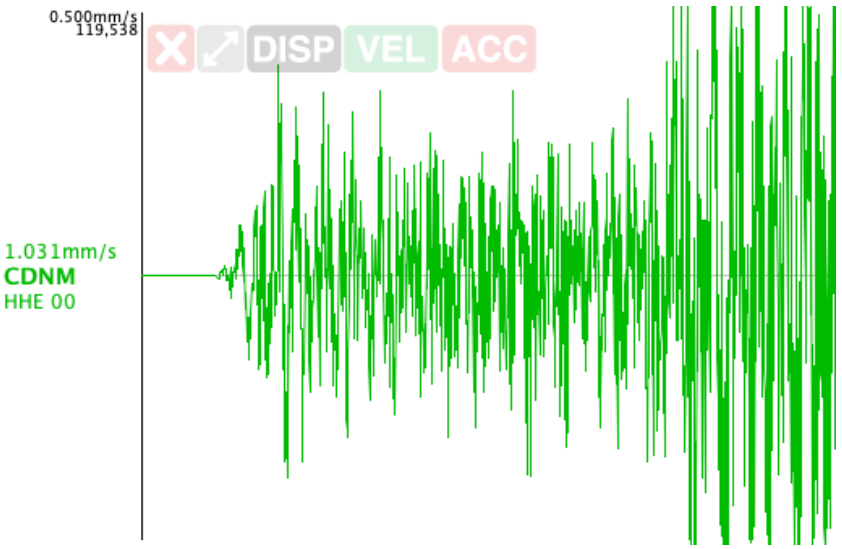


Waveform Display Elements

Once you have opened a waveform file, the data will be plotted in the main Waves window showing the full time line of available data. The basic elements of the display will be described briefly below and expanded upon in later sections of the manual. Channel-specific controls only appear when your cursor is hovering over the channel data. This helps to unclutter the display when many channels are displayed.



Decoding the Y-axis Labels



The station code is displayed to the left of the Y-axis, with the channel name and location ID below it.

The colour of the text indicates the units of the original data (green is velocity, red is acceleration).

The value above the station code is the peak ground motion amplitude of that channel for the displayed time span of data. At the top of the Y-axis you will see a label in black text indicating the maximum displayed units and recorder counts. In the example above, the peak amplitude of the displayed data is 1.031mm/s but the amplitude scale clips because the user has enabled Fixed Amplitude display mode, set to 0.5mm/s.

Display of Ground Motion Units

If a channel is recognised as having units in **velocity**, the trace and station code will be drawn in green. If a channel is defined as **acceleration**, the trace and station code will be drawn in red, and **displacement** in black.

You can convert between these units by clicking on the buttons in the top left corner of each waveform trace. The waveform colour will change, but the station code will remain in the original recorded unit colour. Other recognised units are **pressure, rotation**, and **voltage**. Any unrecognised units are displayed in **dark grey**. The DISP VEL ACC buttons will disappear for pressure, rotation and other units as they cannot be transformed.

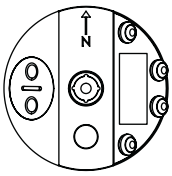
Minimise and Maximise Channels

To the immediate left of these ground motion conversion buttons are the minimise and maximise buttons. Use the ⤢ button to maximise the view of a channel to full screen and the ✖ button to go back. When all channels are shown, use the ✖ button to hide that channel from view. To restore all hidden channels, go to the **Channels** menu and select to show **All** or show **Vertical** channels, or the channels of a specific site.

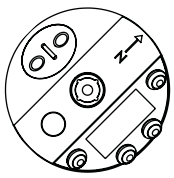
Channel Rotation

If you have opened a triaxial seismogram, the North channel should show a compass symbol, and the vertical channel should show an angle symbol. Click on the symbol to open up the rotation and elevation adjustment controls.

The assumption is that your sensor was oriented aligned to North (0°). By clicking on the purple degree adjustment buttons on the North channel, the seismogram will be rotated around the vertical axis and the North and East channels will change. The rotation icon will change from light to dark to show an adjustment has been made, even after the tool is closed.

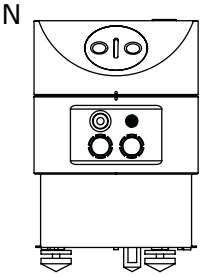


sensor at 0° rotation

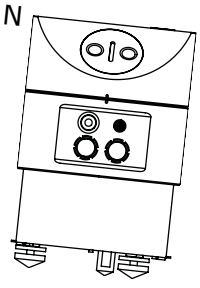


sensor rotated to +45°

Similarly, by clicking on the teal elevation adjustment buttons on the Vertical channel, the seismogram will be rotated around the North-South axis, so the Up and East channels will change. The elevation icon will change from light to dark to show it has been modified.



sensor at 0° elevation



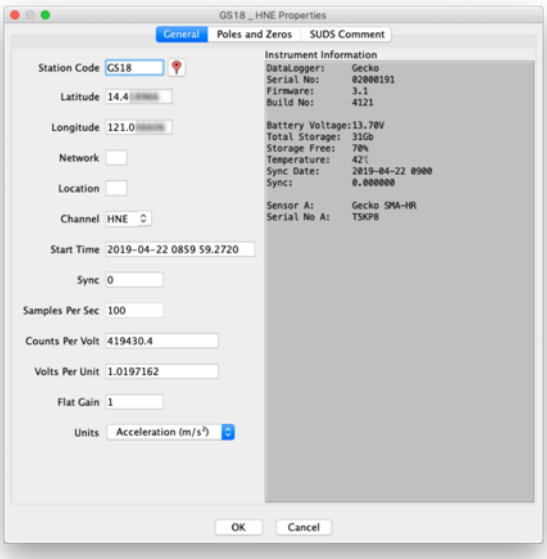
sensor elevated to +6°

Channel Polarity

A sensor is normally set so that a positive signal equates to positive motion in the East, North or Up direction, but this can vary due to sensor orientation or sensor wiring. If you find that a channel has the opposite polarity, you can flip it by clicking on the ⇅ button. If the black arrow is facing up, the original data is being displayed; if the black arrow is facing down it indicates that the reverse polarity data is being displayed.

Channel Information

Once you click on a channel its Y-axis bar will be slightly thicker than other channels to show that information relates to this channel (e.g. the frequency spectrum display or channel information display). When you click on the ⓘ button, type ⌘-I, or select **Channels ▸ Info** a window will pop up displaying extra information about this channel and its station.



The left side of the **General** tab has editable elements related to the Station and Channel codes, as well as scaling factors to allow the raw data counts to be scaled to real-world units. If the GPS position of the station is available, a small marker will appear next to the station name which when clicked will show the station location in your web browser using Google Maps.

You can switch to a different channel that shares the station code and network ID using the drop-down Channel field menu, or click into the field to edit the channel name.

On the right side of the window an Instrument Information pane shows some recorder and sensor parameters, such as battery voltage and temperature, serial numbers, and any other fields that can be decoded from the data file.

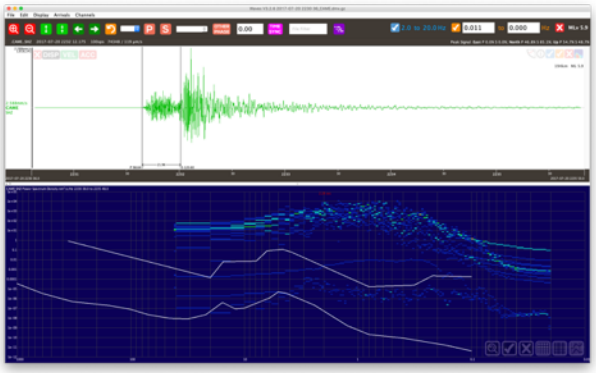
If you need to modify the system response (e.g. if you have opened a data-only MiniSeed file without an accompanying station.xml file) you can modify the displayed fields and click OK to apply these channel settings. If you have a single "Sensitivity" value for your channel, enter it into the "Counts Per Volt" field and put a value of 1 for "Volts Per Unit" and "Flat Gain".

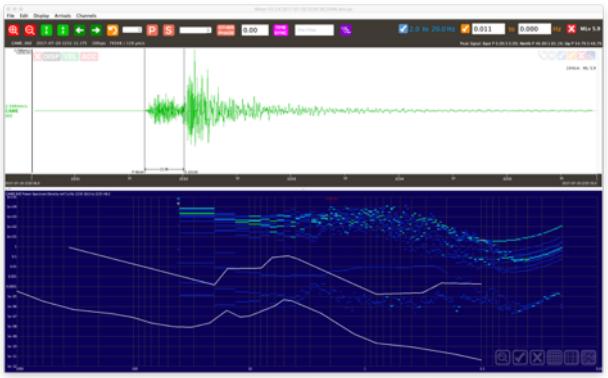
Note that Acceleration units are specified in V/m/s^2, but accelerometers are usually specified in Volts-per-g, so adjust the value accordingly. For example 10V/g = 1.0197162 V/m/s

Poles & Zeroes

The second tab on the Info window is labelled **Poles and Zeroes** and allows you to enter the Poles and Zeroes for the sensor channel group.

Adding this information changes the Power Spectral Density (PSD) plot, as shown in the images below. The left image is the raw data with ground motion scaling only, and the right image has the poles and zeroes corrections applied. The raw time series waveform data is unchanged.





Meta Data and Station.xml

The third tab will have different labels depending on the format of the data file and whether or not it contains meta data. Kelunji D-series, Echo and EchoPro SUDS files Comments field will be displayed in the tab, as will Kelunji Gecko settings.ss file contents.

If you have opened a MiniSEED file from a folder that also contains a related station.xml file, the .xml file contents will be displayed in the tab. If there is no .xml file, Waves will look up the IRIS DMC for a channel that matches the station/network/location ID and automatically populate the meta data fields. Waves will also store the station.xml file in your user/eqsuitefiles/response folder for future use.

Channel Filters

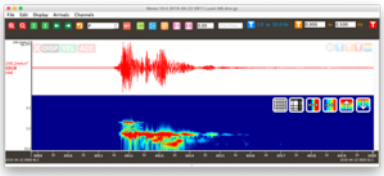
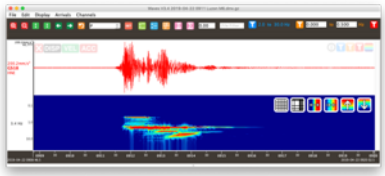
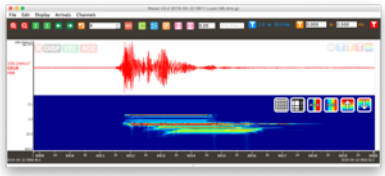
The next three buttons are the individual channel filter control buttons. Please see the earlier section on Filtering to learn about the function of the blue, orange and red filter buttons.

Spectrogram

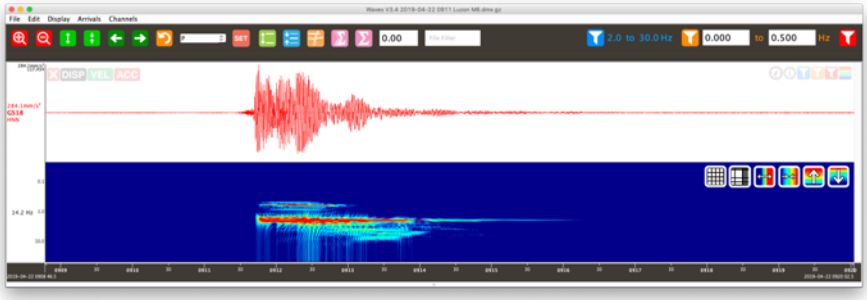
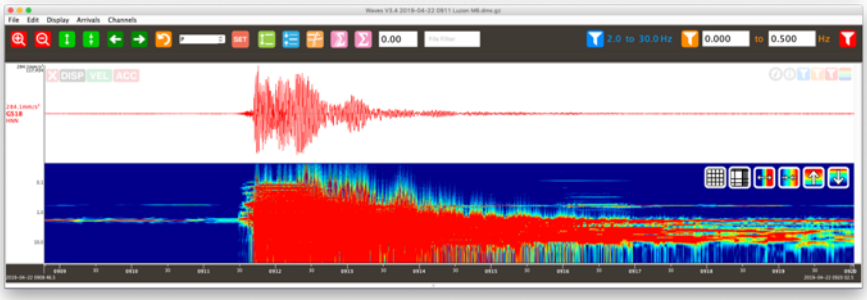
The button will show and hide the spectrogram for a channel. This will split the waveform area into two rows, squeezing the time series ground motion trace into the top half and the time series frequency spectrum into the bottom half. This display mode works best when a channel is maximised. Using shortcut key **K** will open the spectrogram window for all channels (many channels can take some time), and **L** will close all of the spectrogram windows.

By default the scaling of the spectrogram is a log-log plot, best for looking at low frequency signals. You can switch the spectrogram scaling to linear plots by clicking on the button in the top right of the spectrogram, or revert to log plot by clicking the button. The frequency or period of the data under your cursor is displayed to the left of the Y-axis of the spectrogram: shown in Hertz when the value is above 1Hz; and shown in Period (seconds) for values below 1Hz.

The spectrogram shows the intensity of frequency over a sampling period. If the sampling window is too narrow you will see a vertically streaky spectrogram (below, left) and if the sampling window is too wide the spectrogram will appear smeared over time (below, right). You can widen or shorten the sampling window by using the and buttons until you can see the frequency content at a usable resolution.

The spectrogram colours scale to the highest intensity of the displayed data, which can dominate the plot during an earthquake, which can obscure the pre-event and post-event frequencies. You may want to see if there is a change in the natural frequency of your building, which means looking for a shift in this resonance before and after an earthquake. Use the and buttons to increase or decrease the frequency intensity level.

Frequency and Power Spectrum Display

Press the **F** shortcut key to toggle the frequency display window open or closed, or drag up the horizontal divider bar at the bottom of the Waves window. You can adjust the size of this window by dragging the divider bar up or down. Initially it will display a linear-scaled Fast Fourier Transform (FFT) frequency spectrum of the currently selected data.

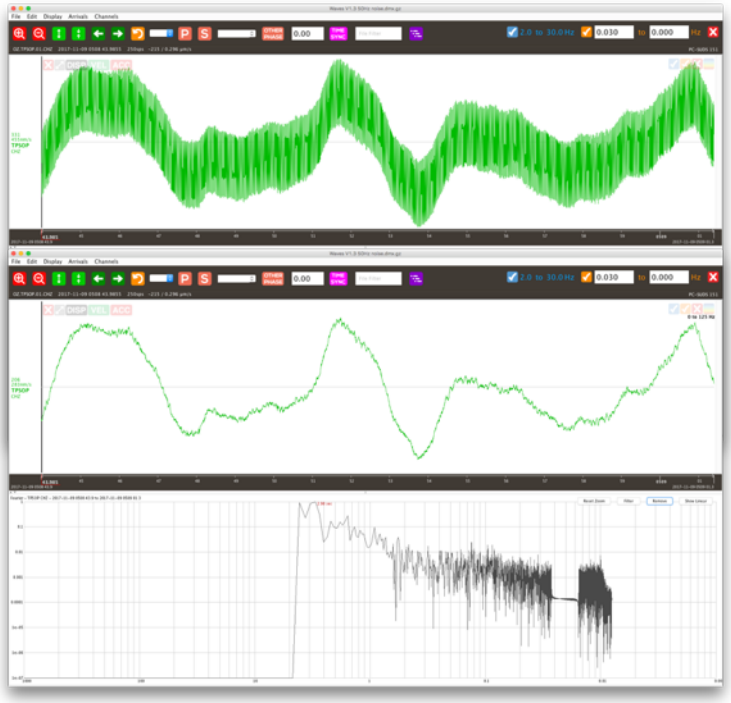
Right-click any channel to display the frequency spectrum for the full time series, or right-click-and-drag to see the frequency spectrum of a selected time period. Note that the selected channel has a thicker Y-axis bar and is named in the top left corner of the FFT window. You can click and drag over a section of the frequency plot, then place your pointer over the highlighted section and click to zoom in for a more detailed view.

 In the top right corner of the FFT window you'll see a toolbar that allows you to edit the view and filter the data. The magnifying glass icon will reset the zoom to the full frequency range.

Filtering in the Frequency Domain

The  button in the frequency window tool bar displays the FFT on a linear frequency scale. Clicking on the  button when displaying linear FFT will change the graph to a log-log plot.

You can use this FFT window to filter your data. Right-click and drag to select a frequency range, then click the  to keep only that frequency range. The time series data will then be redrawn based on the filtered frequency data.

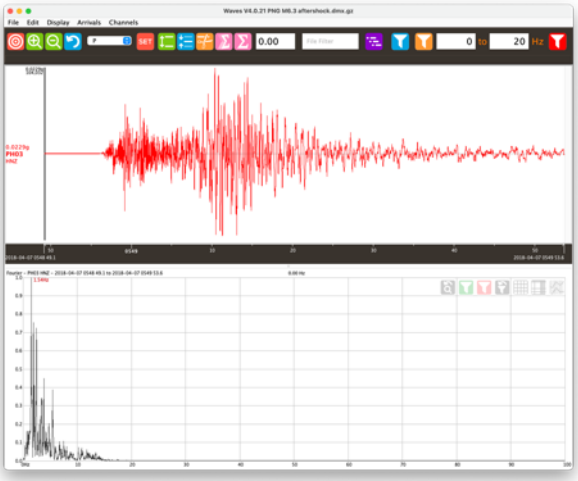


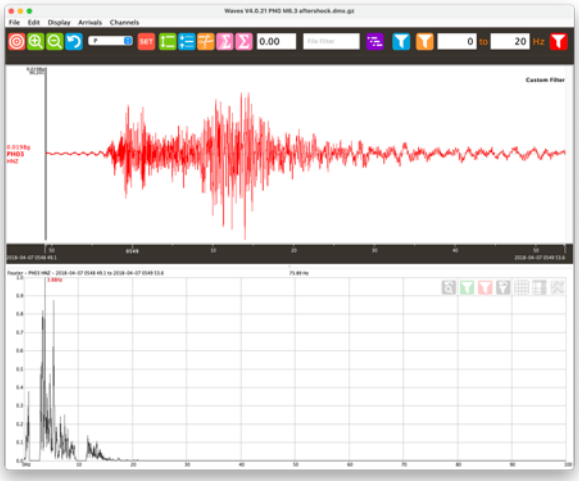
Conversely, click the  after highlighting a frequency range to reject the selected range.

In the example shown, inadequate shielding from AC power results in 50Hz noise dominating the signal.

By click-and-dragging over the anomalous frequency band and clicking the  button in the top right of the FFT window, the highlighted region is dropped out and the time series waveform is then redrawn.

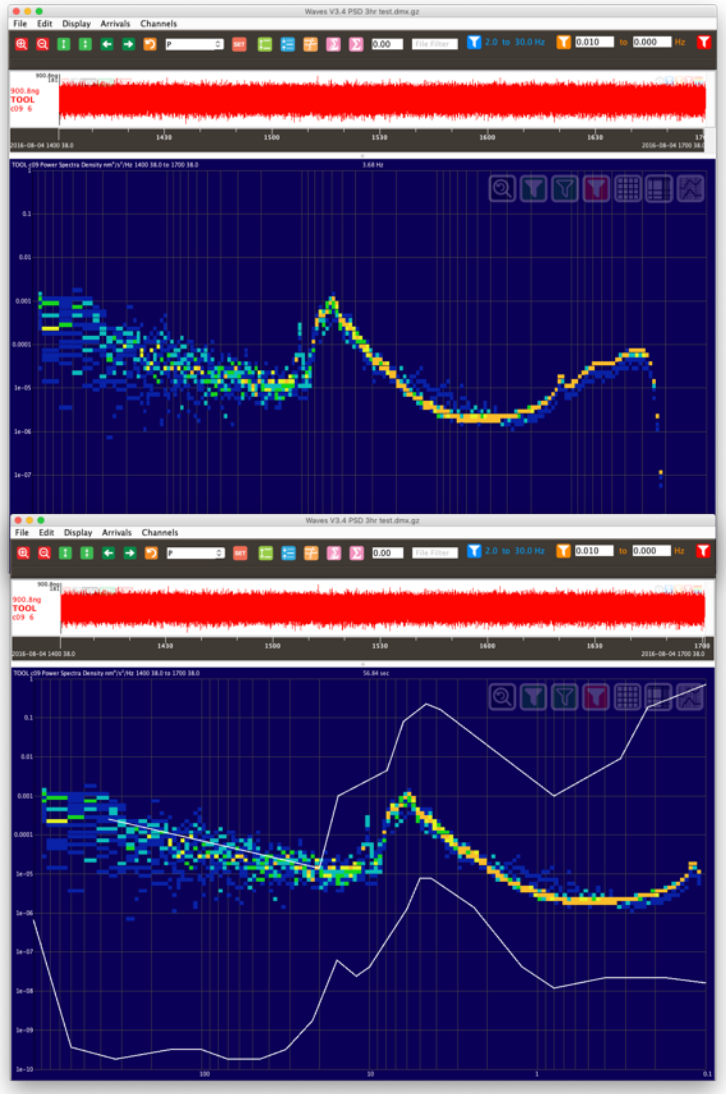
The notch filter can be applied repeatedly over the frequency spectrum, as shown below.





To clear all filters from the channel, click the button in the FFT window or on the channel.

Power Spectral Density Plot



While you are viewing the FFT log plot, click the button again and the graph will toggle to a Power Spectral Density (PSD) plot. The horizontal range of this log-scale plot shows data from a long period to the decade above the Nyqvist frequency. If a band pass filter has been applied, the horizontal scale will span the decades either side of the pass band.

The button shows the PSD relative to the Peterson New Low Noise Model (NLNM) and New High Noise Model (NHNM) curves, from 1000 seconds to 10Hz. You can still zoom and filter the frequency range in the PSD and Peterson Model plot views.

This gives you an idea of the noise level of your station.

File Menu

Opening and Closing Files

You can drag a file from your computer's file browser onto the Waves window to view it.

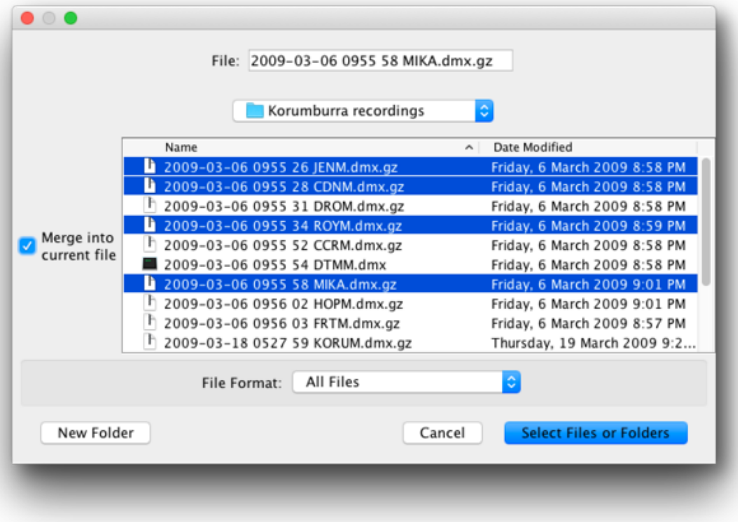
You can also use the **File ▸ Open** menu item (⌘-**O**) to browse your computer for your file. To close the file and go back to an empty Waves window use the operating system's window close button, **File ▸ Close** menu item, or ⌘-**W**.

When you have a file open, you can open another file by dragging it onto the Waves window or using the Open command again, but this will open the file in a new Waves window. If you would like to merge the additional files into the same Waves window, read on.

Merging Files

Waves can merge up to 24 hours of data from many stations into a single file. Kelunji seismic recorders store continuous data in one-minute-long data files, so it is possible that an earthquake recording will straddle two or more files. To make analysis easier you can merge these files together on screen and then save the merged file to your computer.

The quickest way to merge several files into a single viewer window is to multi-select files in your operating system and drag them into the Waves window while holding down the **Control** key on Windows or macOS, or the **Shift** key on Linux.



Alternatively, use the **File ▸ Open** command, select the files you wish to merge using your multi-select file system shortcuts (usually Shift, ⌘ Command or Option-clicking) and tick the "**Merge into current file**" checkbox before clicking the button to proceed.

Merging Folders

If you **File ▸ Open** on a folder or drag a folder containing files onto Waves, all of the contents of the folder (and sub-folders) will be merged into a single (24-hour maximum) timeline. This is a quick way to view an entire hour or day folder from a Gecko's SD card.

When merging, as long as all of the files are within a 24-hour time period, they will be merged onto a common time line, grouped by site code in alphabetical order. Your computer's memory will limit to how much data is practical to open in a single window, which will depend on sample rate, number of stations, and number of channels.

Exporting Data

To quickly save a file to your last "Save As…" folder for later review, use the **File ▸ Auto Save** (**Y**) command. This is useful when you are reviewing a folder full of seismograms using the **N** and **B** shortcuts and you come across a file that you would like to review in detail a bit later. After quick-saving, Waves will automatically open the next file in the folder.

Once you have merged, clipped, or modified your seismogram file you can save it using the **File ▸ Save** command or ⌘-**S**. This will overwrite the file whose name is displayed in the title bar or the Waves window.

"Save As" file and name formatting

If you do not wish to overwrite the file, you can use **File ▸ Save As** or ⌘-**T** to save your data to a new file. In the Save dialog box that pops up there are control options for naming the file. The "SRC" filename format follows the form: **YYYY-MM-DD hhmm ss STATION**

If you are saving a merged file the STATION code in the file name will be one of the channels from the recording, depending on the order in which they were merged by the system.

If you decide to use the "GA" filename format, the file will be named in the form **SITE**YY**DDD_hhmmss** where YY is the last two digits of the year (e.g. 13 for 2013) and DDD is the day number of the year (i.e. 001 to 366).

By default Waves will save files in gzip compressed PC-SUDS format (file extension: .dmx.gz) which embeds station data in the file format. You can also save as a MiniSEED zip file, which creates a zip compressed folder containing the MiniSEED waveform and a companion text file with the station response. Waves can them open compressed files and automatically apply the station corrections. Other text based formats are available, which can be imported into spreadsheets, text processors, or mathematical processing and plotting applications.

See "Basic Analysis" later in this manual to understand how saving a .kml format file from a multi-station waveform with P & S picks can be used to estimate the earthquake epicentre.

CSV file format

When you save your seismogram as a CSV file, it is in ASCII format using commas for separating the values in the file. CSV files are easily read using Excel.

It contains a header that describes the Arrivals contained in the file, a section that describes the time series data in the file, followed by the data points.

Any arrival information contained in the seismogram will be listed in the first section. Each arrival will have its own column detailing the site name, arrival type and time.

The next section describes the time series data, one channel per column. This includes the site name, channel name, the date and time of the first data point (or "sample"), and how many samples there are per second. As you may have merged data of differing sample rates, there may be a variable number of rows per column for a given time period.

The final row before the data points indicates the units of the data, which could be metres (m), metres per second (m/s), metres per second squared (m/s/s), etc. The data is then displayed in these units, one sample per row. All data is saved with zero-offset correction.

```
#csv file
ARRIVALS
PH01,PH01,PH01,#sitename
 , , ,#onset
 , , ,#first motion
P,S,AML,#phase
20180407,20180407,20180407,#year month day
0548,0548,0548,#hour minute
46.469,51.102,46.469,#second
0.005,0.005,0.100,#uncertainty in seconds
 , , ,#peak amplitude
 , , ,#frequency at P phase

TIME SERIES
PH01,PH01,PH01,#sitename
HNE _,HNN _,HNZ _,#component
_,_,_,#authority
20180407,20180407,20180407,#year month day
0548,0548,0548,#hour minute
42.839,42.839,42.839,#second
200.00,200.00,200.00,#samples per second
4258,4258,4258,#number of samples
0.000,0.000,0.000,#sync
m/s/s,m/s/s,m/s/s,

--------,--------,--------,
-0.0006709909,0.0018134047,-0.0010640614,
-0.0006945866,0.0019957353,-0.0011305584,
-0.0007632287,0.0021609052,-0.0012978734,

… more data

0.2632255554,0.4593577981,0.0390293375,
0.2496086955,0.4775865674,0.0227354281,
0.2339282781,0.4935994744,0.0048155603,
 , , ,

END,END,END,
```

Raw Text format

When you save your seismogram as a text file, the fields are tab separated and the data is in raw integer counts as stored by the recorder (not zero-offset corrected by Waves). The conversion factors are listed in the TIME SERIES header section to allow you to turn raw counts into ground motion values. Convert using the operation:

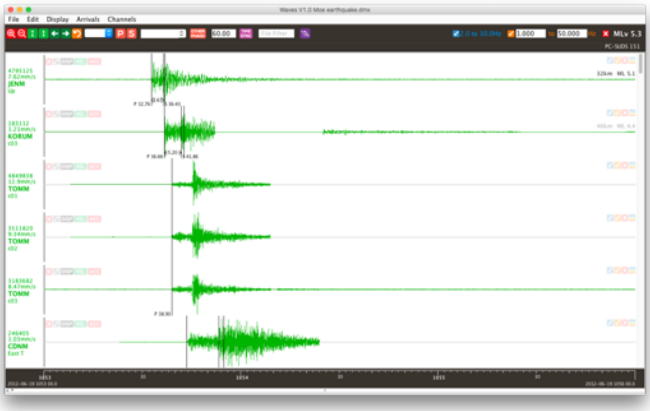
counts **÷** Counts/Volt **÷** Volts/Unit **÷** Flat Gain **=** units

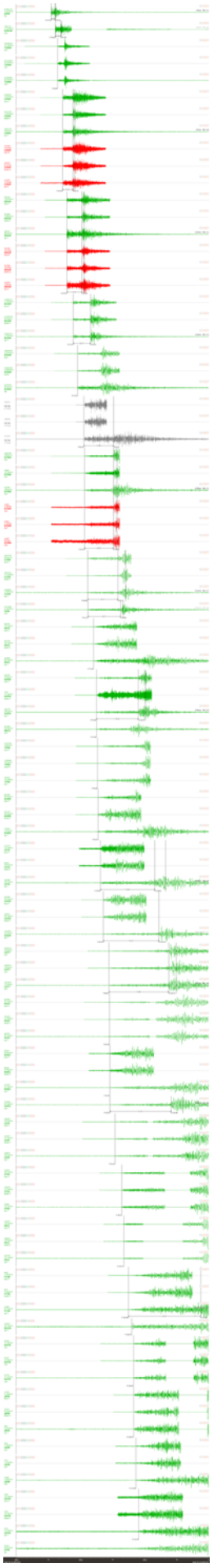
e.g. **2835 ÷ 419430.4 ÷ 1.02 ÷ 1.09** = **0.0060794807 m/s²** *(620µg)*

```
ARRIVALS
PH01            PH01            PH01            #sitename
                                                #onset
                                                #first motion
P               S               AML             #phase
20180407        20180407        20180407        #year month day
0548            0548            0548            #hour minute
46.469          51.102          46.469          #second
0.005           0.005           0.100           #uncertainty in seconds
-----           -----           -----           #peak amplitude
-----           -----           -----           #frequency at P phase

TIME SERIES
PH01            PH01            PH01            #sitename
HNE _           HNN _           HNZ _           #component
_               _               _               #authority
20180407        20180407        20180407        #year month day
0548            0548            0548            #hour minute
42.839          42.839          42.839          #second
200.00          200.00          200.00          #samples per second
4258            4258            4258            #number of samples
0.000           0.000           0.000           #sync
m/s/s           m/s/s           m/s/s           #units
419430.4        419430.4        419430.4        #Counts/Volt
1.020           1.020           1.020           #Volts/Unit
1.090           1.090           1.090           #Flat Gain
-22.2222        -22.2222        -22.2222        #latitude
147.4747        147.4747        147.4747        #longitude


counts          counts          counts
--------        --------        --------
2835            -4858           942
2824            -4773           911
2792            -4696           833
2742            -4568           764

… more data

134228          193893          33672
130927          200633          27422
125860          208443          19633
119512          216941          12037
112202          224406          3683


END             END             END
```

Save Screenshot

Although most computers have a screenshot feature, Waves allows you to save a PNG format image of just the data window, excluding the control panel and window frame. If you have many channels in the scrolling window, the screenshot will be very tall.





Computer window screenshot (above) vs. a Waves window screenshot (right)

Save Fourier

You can also save the data that is displayed in the Fourier transform window to a text file. Right-click on a channel to display the frequency spectrum for the entire channel recording, or right-click and drag a portion of the data you wish to analyse and its frequency spectrum will appear in the Fourier window.

By selecting **File ▸ Save Fourier** the data that is being displayed in the Fourier transform window will be output in three columns, the first showing the frequency point (in Hz) followed by the real and imaginary values of the spectrum.

Print

If you would like to print your waveform you can use the **File ▸ Print** or ⌘-**P** command. It will print effectively the same information as the Waves screenshot, except that it will print up to 9 channels per page to the maximum scale to fill the page.

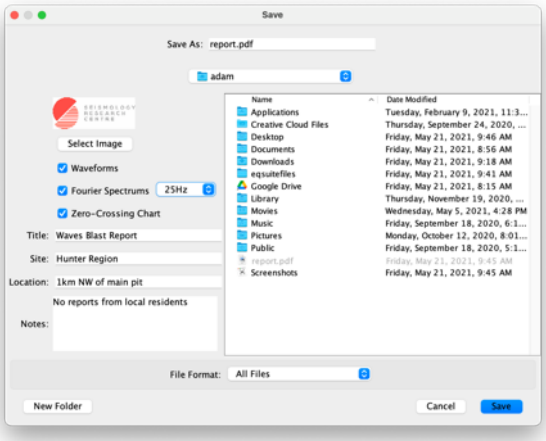
Close and Quit

Close the Waves window using **File ▸ Close** or ⌘-**W** to return to an empty Waves window. Use this command again or **File ▸ Quit** or ⌘-**Q** at any time to quit Waves.

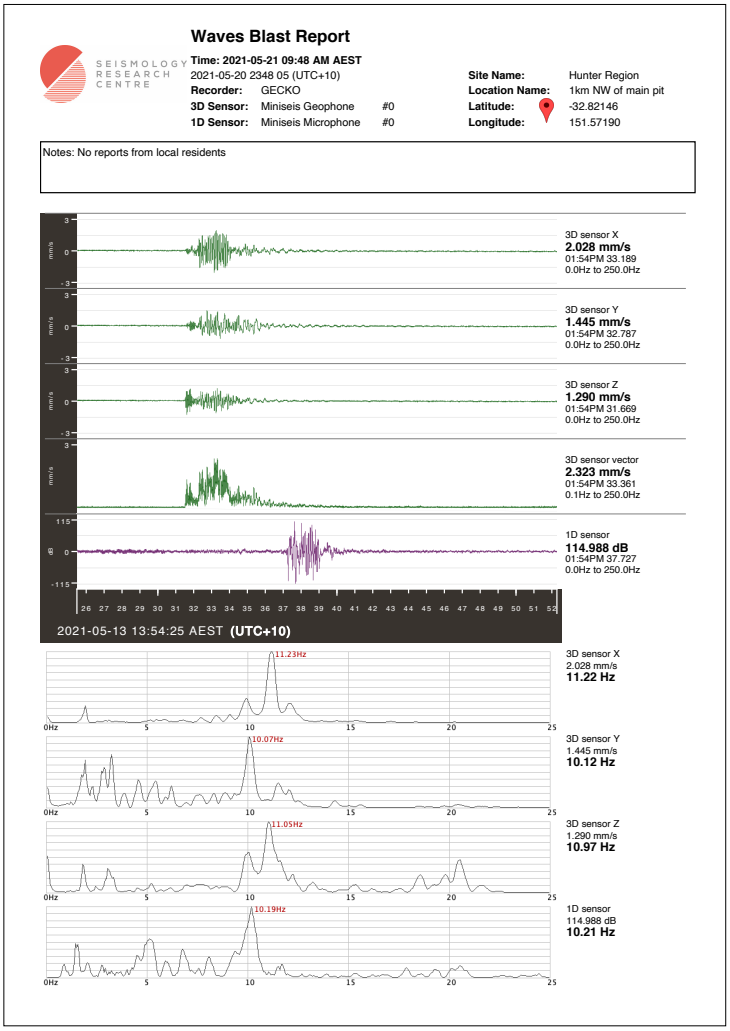
Generate Report

More and more, Gecko recorders are being used for monitoring blasts and vibrations in mines, quarries, and from civil construction and demolition works. Extraordinary events often require a summary report of the data recorded to show whether the ground motion and air pressure vibrations were within permitted levels.

While viewing an event recording in Waves, use the **File ▸ Generate Report** option to open a dialogue box that allows you to customise the content of the report.



You can set a logo to appear on the report, and it will be saved for future reports. Use a JPG or PNG file. It will be rescaled to fit a 120x90 pixel area. The title of the report can also be modified and will also be retained for future reports.



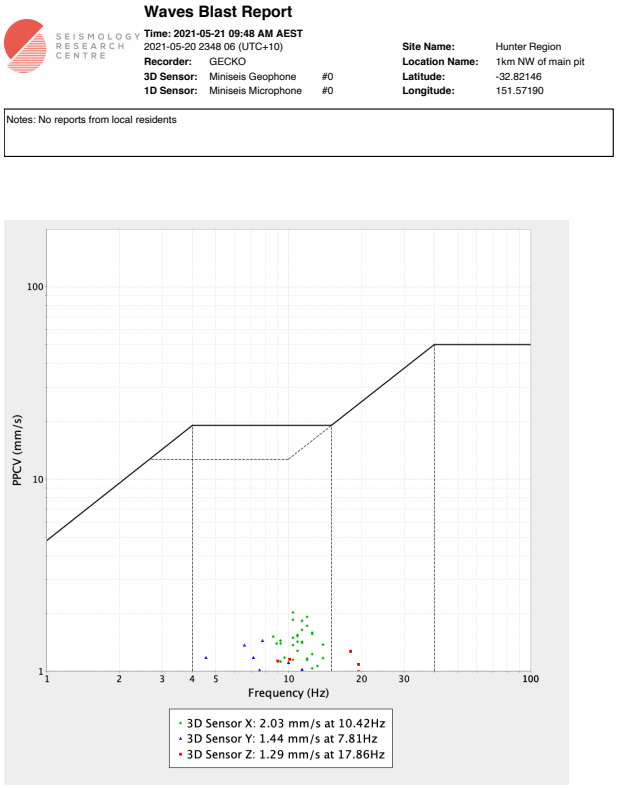
Three free text fields are available per report. Site and Location are 20-character fields, and you can enter about 300 characters in total that will appear over three lines in the Notes field. All of these text fields appear in the header of the report.

The check-boxes allow you to select which sections to include in the report, and the Fourier Spectrum section allows you to select an upper limit to the frequency plot (X) axis to show more detail in the lower frequency range. Depending on your sample rate, the plot limit options will be to 25Hz, 50Hz, 100Hz, 250Hz and MAX (half the sample rate).

A sample of the waveform and Fourier Spectra plots from the report is shown at left.

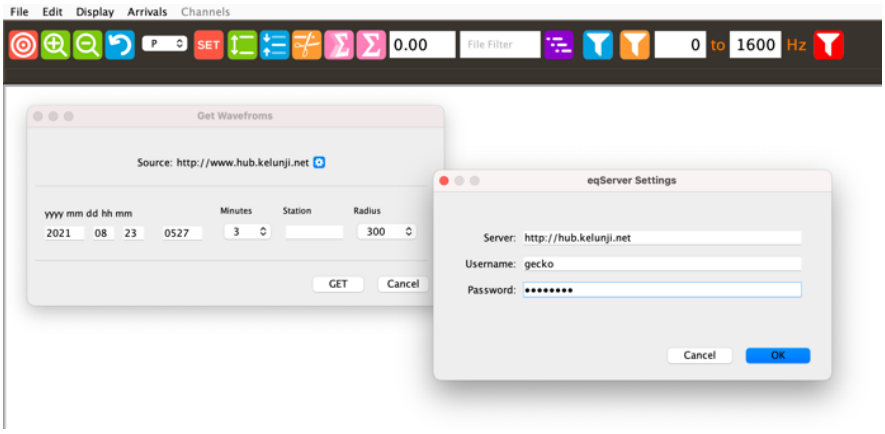
The second page of the report, if enabled, will show a "Zero-Crossing" plot in the style of the USBM RI8507 chart. This is a simplified method of plotting velocity amplitudes by calculating the peak's frequency based on the time between the waveform crossing the zero-line. The plot frequency range is fixed from 1-100Hz and the particle velocity range is from 1-110mm/s. The standard threshold levels for residential structure damage potential is overlaid as a guide to the safe blasting and vibration levels.

If the 3D and 1D sensor name and serial numbers are available, these will be added to the header, along with the geographic location of the station – click the pin icon to open in Google Maps.



Get Waveforms

If data from your seismic monitoring network is being received by the SRC eqServer earthquake observatory data management system, you can extract waveform data from that archive directly from Waves without having to log in to eqServer using a web browser.

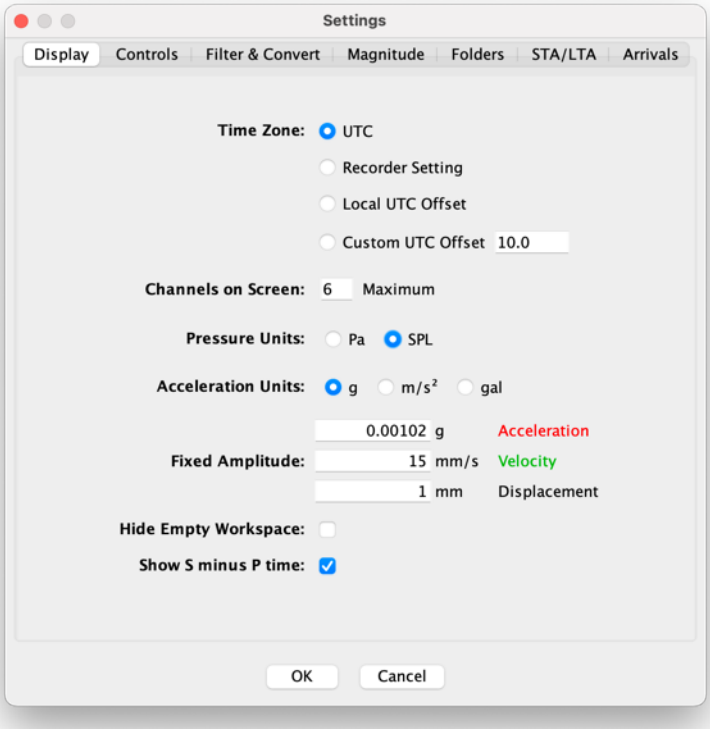


Click on the cog symbol to view the eqServer settings to enter the web address and login credentials of your eqServer. Once connected, set the date, time, and length of the data extraction request. If you leave the station and radius fields empty, all data on the server for that time will be returned, or enter a station code to only return data from stations within the nominated radius of that station. Once extracted, the seismograms will appear in your Waves window, ready for analysis.

Edit Menu

Settings

Display



The first setting in this tab relates to the way the time is displayed. By default Waves displays data in **UTC time**, but if your recorder uses a UTC offset to define local time for file names, you can choose to display data using the stored UTC offset (**Recorder Setting**) or you can get Waves to always display data with a **Custom UTC Offset** (e.g. +10.0 hours for Australian Eastern Standard Time).

There is a minimum vertical space required by Waves to draw a channel, but you can also set it to display a maximum number of channels, for example if you wish to display only 3 or 6 channels on screen at a time. Enter the maximum number of channels you wish to display in the field shown. The remainder of the channels are accessible by scrolling.

When displaying pressure (usually a recording from a microphone), Waves can display amplitude in Pa (pascal) or as SPL (sound pressure level, measured in dB). When plotting acceleration, Waves can display amplitude in *g* (gravity), in m/s^2 (metres per second squared, shown as mm/s^2 or nm/s^2 as required) or in gal (cm/s^2).

As discussed in the Toolbar section on Amplitude Grouping, you can fix the amplitude scale for native acceleration, velocity and displacement data. These fixed values are defined for acceleration, velocity and displacement using the values you enter in the boxes.

When your final waveform is closed, an empty Waves window remains. This empty workspace can be hidden so that only the toolbar remains.

When you mark a P-wave arrival time and an S-wave arrival time, Waves can display the time difference. You can turn the "Show S minus P" feature on and off with the checkbox.

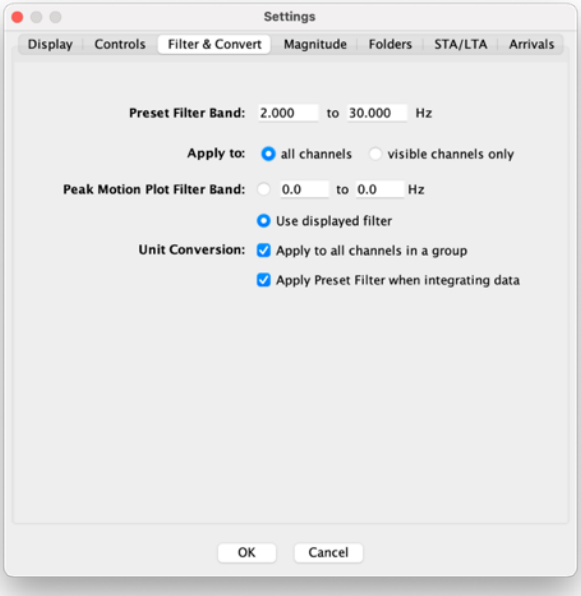
Controls

As discussed in the section on Zooming, the speed of zooming can be customised. This affects the step size of the incremental zoom when using the toolbar buttons or keyboard shortcuts, and also the speed of zooming when using the scroll wheel while holding down the right-mouse-button or CONTROL key.

The size of the steps used to horizontally scroll the time line (by using the toolbar buttons or keypad arrows) can also be adjusted. This also affects the speed of timeline scrolling when using the mouse scroll wheel while holding down the ALT key.

Some pointing devices such as multi-touch trackpads can behave erratically when zooming or scrolling. A scroll-wheel mouse is recommended for the best user experience.

Filter & Convert



You can set the pass band of the frequency range of your favourite Preset filter here. Once defined, these values are displayed in blue in the toolbar.

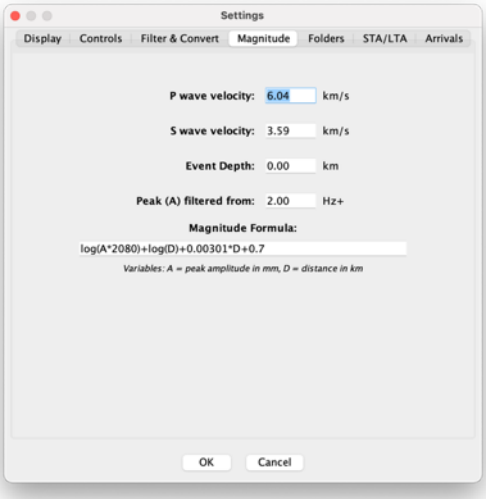
The Toolbar filters buttons can apply to all channels or just those that are currently visible.

When the 2D or 3D vector sum peak particle plots are performed, the integrated data (converting from acceleration to velocity, or from velocity to displacement) can be affected by conversion artefacts that usually need to be filtered out.

This group of settings allows you to choose to automatically apply a preset pass band filter to manually integrated data (when you press the channel DISP VEL ACC buttons, to one all or all grouped channels), or integrate the data based on the current frequency range, which may or may not be filtered.

Magnitude

The P wave and S wave velocity values are used by a simplified method to estimate an earthquake's distance from a station. You can set a single P and S velocity and typical earthquake depth to suit your local region. Changing these will affect the distance and magnitudes calculations.

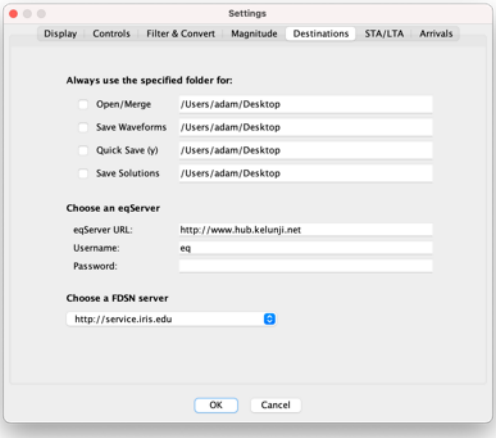


The default formula for local Richter magnitude is: log(**A***2080)+log(**D**)+0.00301***D**+0.7 where **A** is amplitude of the peak displacement of the vertical channel (in millimetres, after being filtered by the customisable high pass filter, default is 2.0Hz+) and where **D** is the estimated distance from the station to the earthquake based on the P & S picks and velocities. You can modify this formula using standard mathematical operations and the A & D variables.

These velocities and magnitude formula are not used by the Location feature introduced in Waves 4.0. It only applies to the time series waveform view for rapid magnitude estimation.

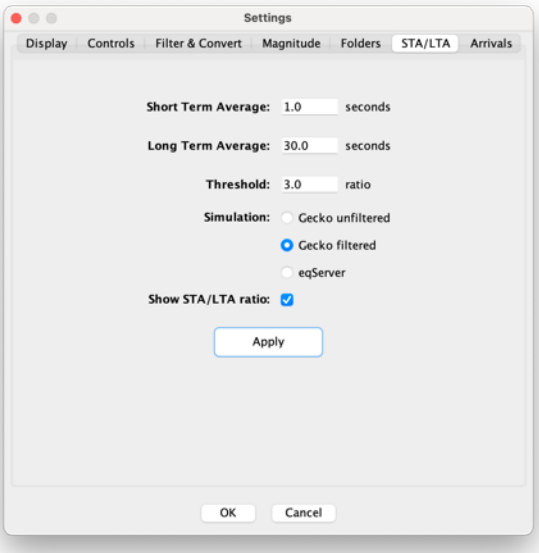
Destinations (formerly "Folders")

You can set Waves to always use a particular folder when opening, saving or quick-saving files. Leaving the boxes unchecked will usually set the destination as the last folder used.



Here you can also define the login details of an eqServer from which you can extract waveform data or to which you can save earthquake location solutions. This tab also allows you to define which FDSN server to search for station response data (Waves was previously hardwired to searching the IRIS server).

STA/LTA

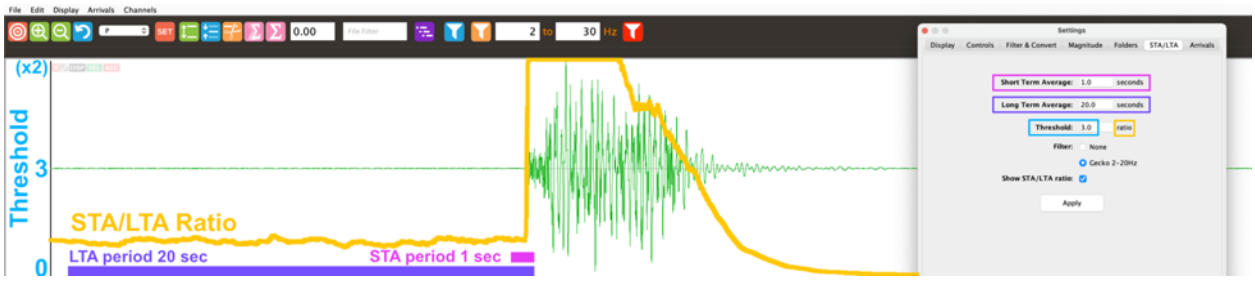


You can modify the STA/LTA settings to help tune a Gecko recorder's trigger routine. After changing one of the settings, click the **Apply** button to see the effect on the yellow STA/LTA ratio plot on the waveforms if you have this display enabled.

The yellow trace overlaid on your ground motion recording is the simulated STA/LTA ratio, which shows you how a Gecko recorder's STA/LTA trigger algorithm would see this data with and without recorder's STA/LTA filter active. eqServer uses a different STA/LTA algorithm to analyse incoming streaming data, so this STA/LTA ratio can also be simulated in Waves. The simulated STA/LTA ratio can be toggled on and off by pressing the "**A**" keyboard shortcut.

STA stands for Short Term Average and LTA for Long Term Average. The STA/LTA Ratio is the average signal level over a short time period (e.g. 2 seconds) compared to the average signal level over a longer time period (e.g. 20 seconds). The ratio of the STA level to LTA level is plotted in yellow on the screen. The scale of this plot is related to the STA/LTA ratio trigger Threshold, which is a level at which you would expect the seismic recorder to declare that an event is happening. The trigger threshold is plotted at the zero-level of the channel, so the Y-axis range is a ratio of zero to twice the threshold level.

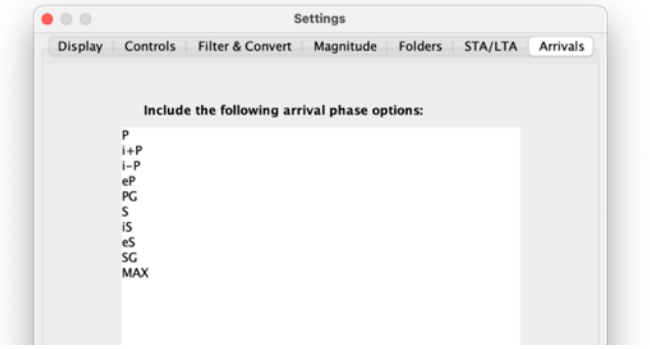
In the example below, the STA setting is 1 second, the LTA is 20 seconds, and the threshold is 3.0. Before the earthquake the STA and LTA values are similar and the ratio of the short term average signal divided by the long term average signal is around 1, but as soon as the earthquake/blast hits, the average signal level in the STA period is many times larger than the average signal in the LTA's previous 20 seconds, so the ratio shoots through the threshold. At this point the recorder would declare a "trigger" and perform any related actions.



Arrivals

The list of arrival phases in the drop-down list in the toolbar is populated by a default list of commonly used phases. These are simply text fields that are assigned to the Set marker.

You can add or remove phases from the toolbar's drop-down list by editing this text field.



Remove Startup Image...

Waves is a free software application that is supported by a 10-second advertisement when the program starts. If you have purchased a product key to remove the pop-up ad, you can enter the code by selecting this menu item or by clicking on the advertisement. Your computer must have Internet access to confirm the validity of your key with our register. Please note that a key can only be used once and is locked to the computer user profile that activates it.

Note that this will not remove the small advertisement that is in the toolbar of the Location feature that was launched in Waves 4.0.

Clip Visible to New File

You may wish to create a new seismogram file with a subset of the data in the currently-displayed Waves data file. You can remove channels or restrict the time period so that you are only left with data relevant to your analysis requirements. The **Edit ▸ Clip Visible to New File** menu item (also accessible using the ⌘-**L** keyboard shortcut) will open a new window that contains only the data visible in the vertically scrolling main window in Waves.

This means that any channels that have been hidden will not be exported to the new window, and only the data from the current timeline zoom level will be exported to the new window. Filter settings will be carried across to the new window, although they can be cleared so that the original raw data can be displayed.

Stack to New File

Seismic recording equipment can be used in exploration applications as well as earthquake seismology. It is not uncommon to record dozens of vertical geophones over a small area to improve the signal-to-noise ratio to better see events.

The method of "stacking" waveforms helps to reduce the random noise as it does not correlate from sensor to sensor, whereas the event signals do correlate.

By marking a common arrival phase on each channel using the **X** keyboard shortcut then initiating the "Stack" menu command, a new window will appear with the waveforms stacked onto the earliest X marker.

Set Arrival Error

After picking P or S arrival, you can right-click and drag to highlight a time span around the marker to indicate your range of uncertainty around your time pick.

By then using the "**E**" keyboard shortcut or selecting the "Set arrival error" item from the Edit menu, the arrival will then be assigned an uncertainty of the greatest deviation from the pick time in your highlighted section. If your earthquake location supports it, this uncertainty value can be assigned to the phase time and weighted accordingly in the location algorithm.

If you mark a P or S arrival time, the default uncertainty will be the time equivalent of two data samples (i.e. ±0.02 seconds for data recorded at 100 samples per second).

If you mark the arrival as an impulsive i+P, i-P or iS, the default uncertainty will be one data sample (i.e. ±0.01 seconds for data recorded at 100 samples per second).

If you mark the arrival as an emergent eP or eS, the default uncertainty will be ten data samples (i.e. ±0.1 seconds for data recorded at 100 samples per second).

Remove Spikes

In digital data it is possible that one or more sequential samples can become corrupted, presenting a "spike" in the data. This feature attempts to correct the data corruption.

Display Menu

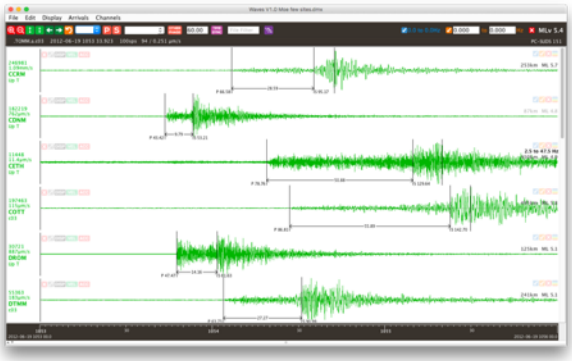
The Display menu is used to modify the way the waveform data or on-screen elements are displayed. Waves and Java version information is available under **Display ▸ About...**

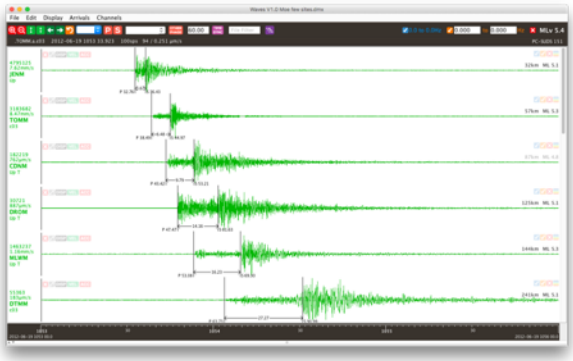
Zero Correction & Amplitude Grouping

See the section on Toolbar Controls that explains these display modes.

Channel Sorting

By default Waves will sort the displayed channels by **Station Code** in alphabetical order.





You can re-order the stations using the **Display ▸ Channel Sorting** menu. If you select to sort by **P arrival** it will use the picked P times to sort the stations in order of distance from the earthquake. If GPS location is embedded in the data, you can sort stations by their **Distance from Closest Station** (the station that has the earliest P time). If you change your P times you can re-apply the menu item to re-sort the channels. If you have started an earthquake location solution (see "Location" section later in this manual), stations with no manually picked P-wave arrival time will be sorted using the expected P-wave arrival time for that station based on the current location solution.

Horizontal and Triaxial Peak Particle Motion Plots

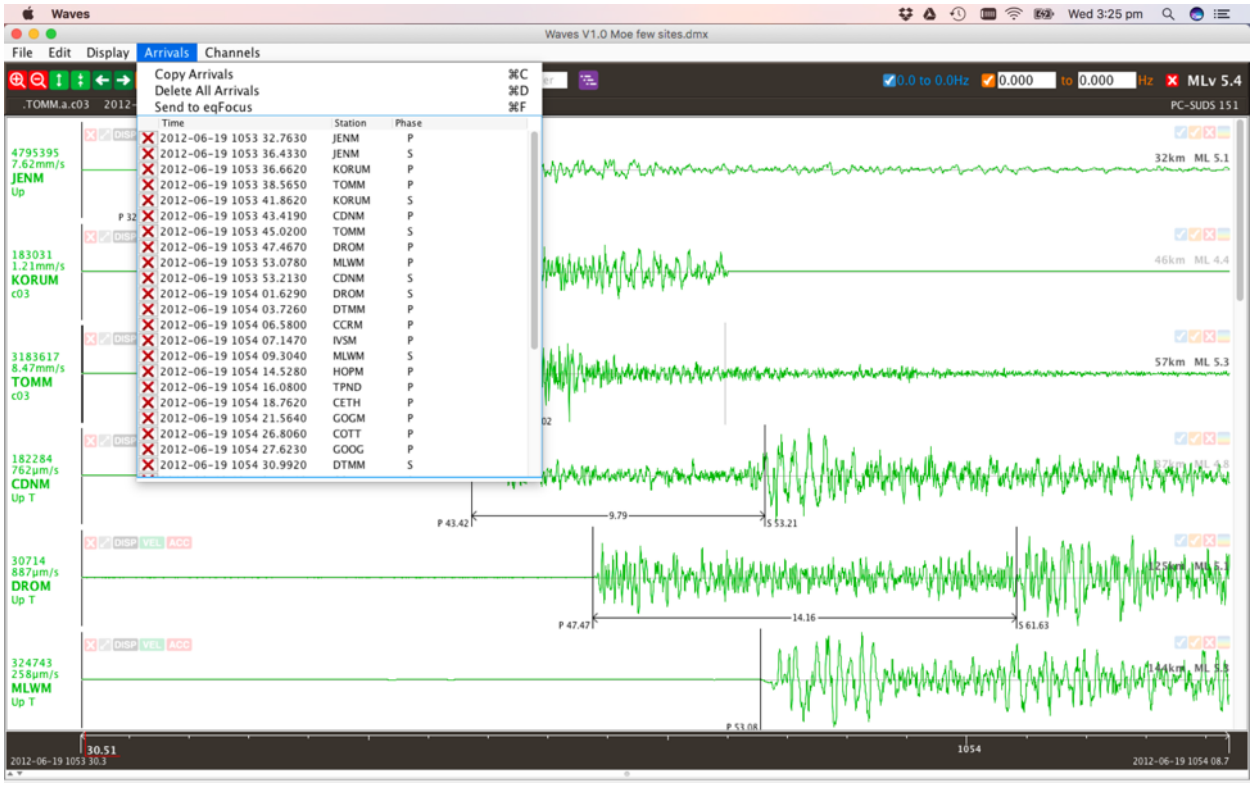
See the section on Toolbar Controls that explains the function of these calculated plots. Activated by these menu items or the 2D and 3D SUM toolbar buttons, the resulting plot appears in a new window. The triaxial plot can be done using the ⌘-**G** keyboard shortcut.

Hide and Show Spectrograms and FFT/PSD

There are also keyboard shortcuts for showing and hiding the frequency plots. Use **K** to open spectrograms on all channels (this can take some time), or **L** to close them. Use the **F** shortcut to open and close the FFT/PSD window which shows the plot of the current channel.

Arrivals Menu

Whenever you pick a phase arrival time, the data is placed in the Arrivals menu. Each phase is time stamped and related to a single station code. You can sort this list by clicking on the Time, Station, or Phase headings.



If you wish to remove an Arrival from the list, click the red **X** next to the Arrival and its marker will disappear from the main window. Be aware that this action cannot be undone.

Use ⌘-**C** (or select the top item in the Arrivals menu) to copy the list of arrivals to the clipboard, which can be pasted into eqFocus for accurate earthquake location and magnitude determination, or the arrivals can be pasted into a text file.

Use ⌘-**D** (or the second item in the Arrivals menu) to clear all arrivals from the window.

If you are also running eqFocus, the ⌘-**F** command will send the arrivals into its Arrivals list.

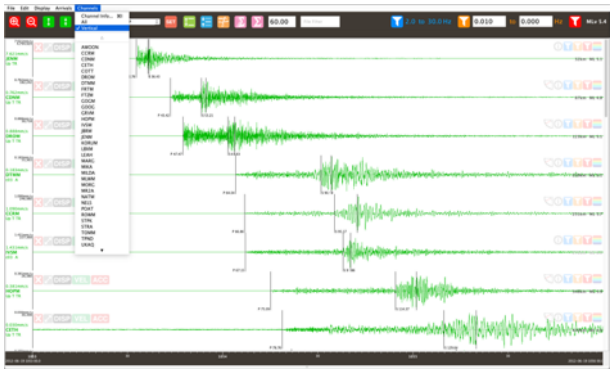
The AML value for a station is the peak displacement of ground motion on the vertical channel, in millimetres, for signals above 2Hz. This is used to calculate MLv magnitude in eqFocus.

A legacy Arrival Code that was used for magnitude determination before displacement conversion allowed MLv was the "MAX" arrival, set by swiping the peak velocity of the waveform and hitting the **M** shortcut key (in the Edit menu). This would store the peak raw amplitude value and the peak frequency in the selection as a method of calculating displacement in eqFocus using response files.

Channels Menu

When a channel is selected, its Y-axis bar is slightly thicker than the others to show that it is selected. You can select the first entry in the Channels menu to see the channel information, which can also be displayed using the ⌘-I keyboard shortcut or the ⓘ button on the channel.

When you are displaying a merged file, each station code in the merged file is listed in the lower section of the Channels menu. By selecting a station code from this menu, you can view just this station in the main Waves window.



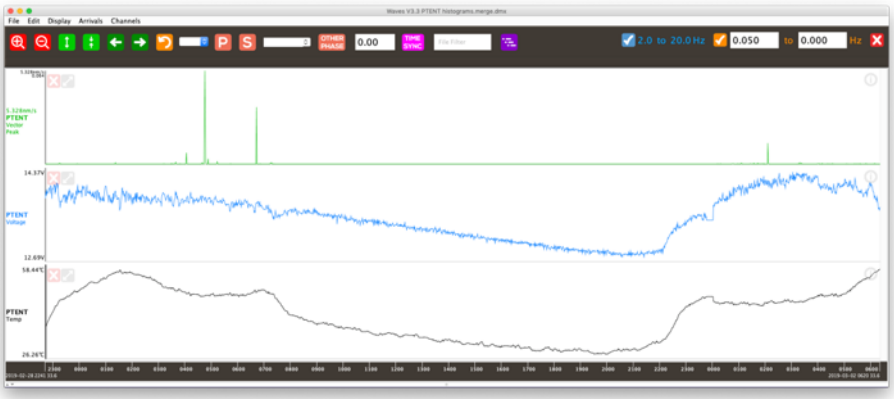
If you wish to return to viewing all sites, use the **Channels ▸ All** menu command.

If you wish to view only the vertical velocity channels (or acceleration channels if velocity is unavailable) to quickly pick arrivals from all of your stations, use the **Channels ▸ Vertical** menu command.

Gecko Histogram Display

The Gecko seismograph produced by the Seismology Research Centre generates a daily CSV file that is updated with a summary line once per minute. Each line records the peak value from the triaxial sensor (vector sum) that occurred in the previous minute, the peak from the uniaxial channel (if enabled), the current input Voltage, Temperature, GPS position and clock information, and the percentage of storage available.

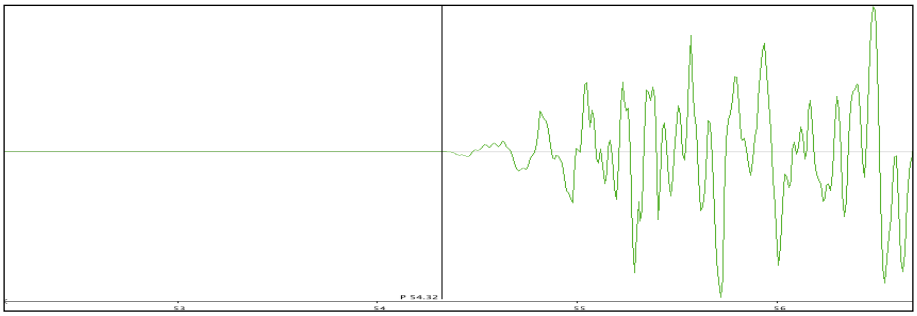
You can open these CSV files with Waves to plot the Vector Peak channel(s), the Voltage and the Temperature to visualise the values over time. To merge more than one CSV file so that you can plot many days of data on screen, hold the Control key (on Windows and macOS, or hold Shift on Linux) while dragging CSV files onto Waves. The amplitude range of each plot scales dynamically – zero to peak for channel data, minimum to maximum for volts and temperature.

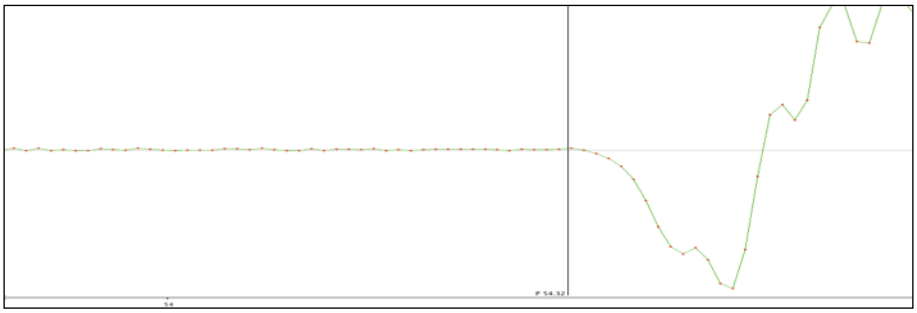


Basic Data Analysis

The P wave

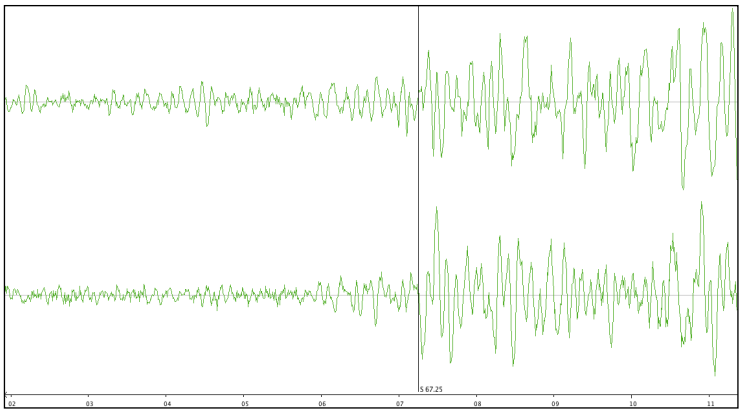
The first earthquake energy wave to arrive at a seismograph is the P (or Primary) wave. As such they are generally easy to pick as there is usually a clear difference between the background noise and the earthquake arrival. The P wave is usually most obvious on the vertical channel of a sensor as the P-wave energy is pulsating in the direction of travel (up to the surface). As you can see from the top image (left), the first vertical marker appears to be before the first arrival, but by zooming in we can see start of the P much more clearly.





The S wave

The next major earthquake energy wave to arrive at a seismograph is the S (Secondary or Shear) wave. These waves are oscillating perpendicular to the direction of travel, i.e. shaking horizontally when it reaches the surface. The S waves (and later surface waves) often do the most damage during an earthquake due to this horizontal shaking and the larger amplitude. The S wave also usually has a lower frequency than the P wave.



Due to its motion, S waves are usually more obvious on horizontal channels, but as the S wave arrives in the coda of the P wave it is often difficult to determine a clear arrival time. Look for a point that correlates across the horizontal channels that features a drop in frequency and increase in amplitude.

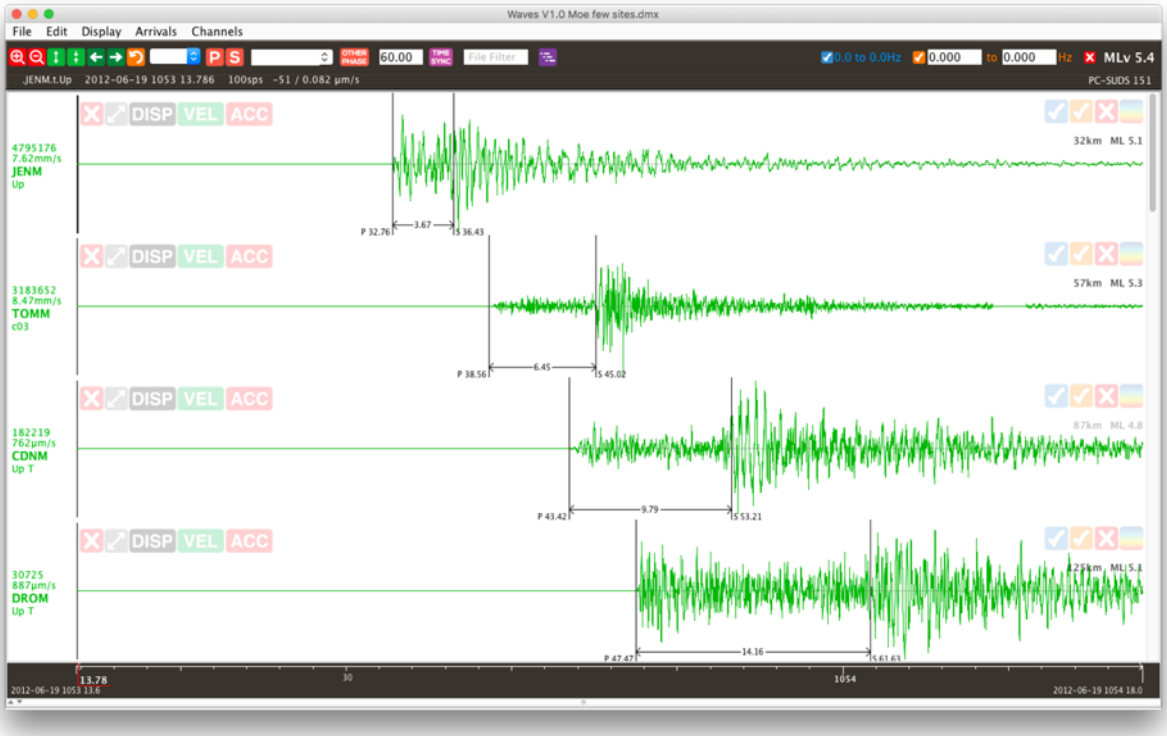
Rough Magnitude Estimation

Before Waves included a dedicated earthquake location feature, we could estimate the magnitude of an event by using the real ground motion units once a P and S wave arrival had been picked. Waves will estimate the distance to the earthquake based on the P velocity and S velocity values defined in the "Magnitude" Settings, then apply the formula to estimate magnitude based on the estimated peak displacement.

The default formula used to estimate MLv is applicable for California (USA), South Eastern Australia, and other regions of the world with similar ground motion attenuation. Richter's formula is limited in that it only really works for events of up to magnitude 6, and for earthquakes within 600km of the station.

This formula is discussed further in the Settings section of the manual, and it can be customised by manipulating the distance and amplitude derived from the waveform.

The distance and magnitude estimate for each station is written on the vertical channel just below the frequency filter and spectrogram buttons.



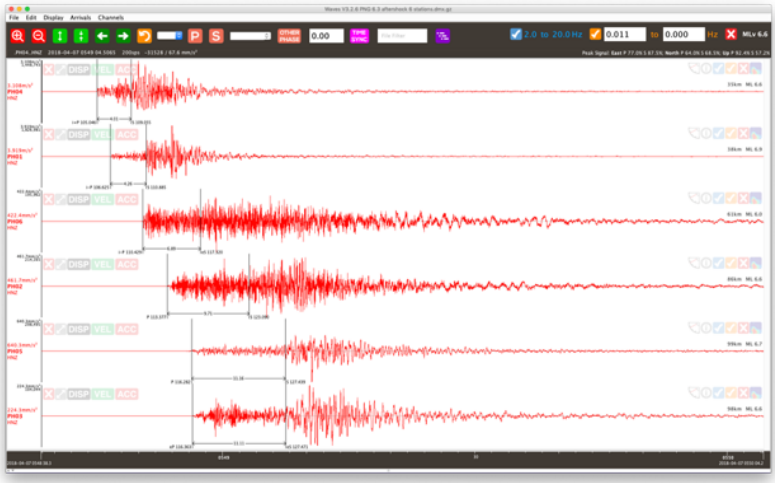
When you have multiple stations in the same Waves window, Waves will take the average of these magnitudes (ignoring outliers, coloured grey) and display the estimated MLv magnitude for the event in the top right corner of the toolbar.

To more accurately determine magnitude using multiple stations, use the Location feature introduced in Waves 4.0.

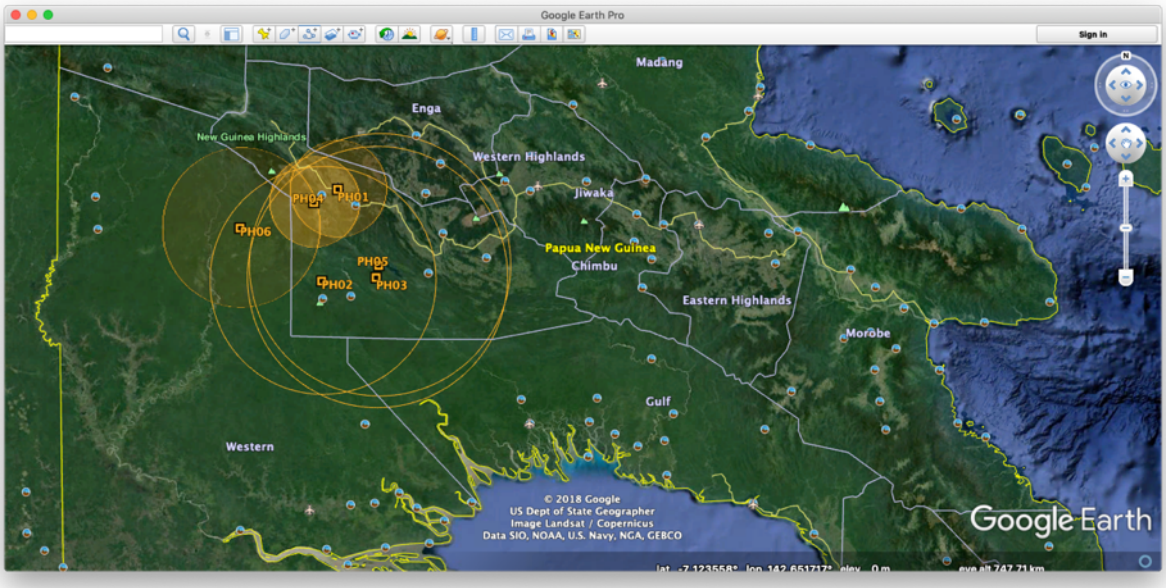
Exporting to Google Earth

Before Waves included a dedicated earthquake location feature, we could estimate the location of an event by using station location and distance based on P and S phase times as discussed in the previous section.

If you have picked a P and S wave arrival time on at least three stations, go to the **File** menu and select **Save As** and select the KML file format to save a Google Earth compatible file.



This KML file contains the station locations and epicentral distance circles for any station that has a P and S phase picked. The circles from the three closest stations are filled with a transparent orange, and where the three circles overlap a darker orange region indicates an area that is likely to contain the earthquake epicentre.

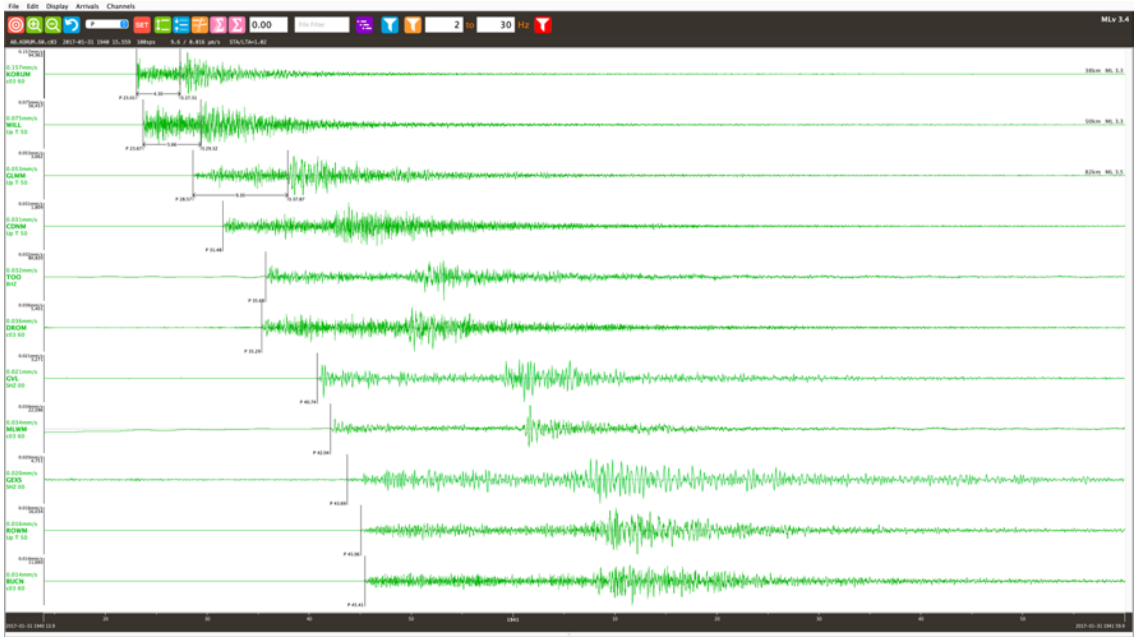


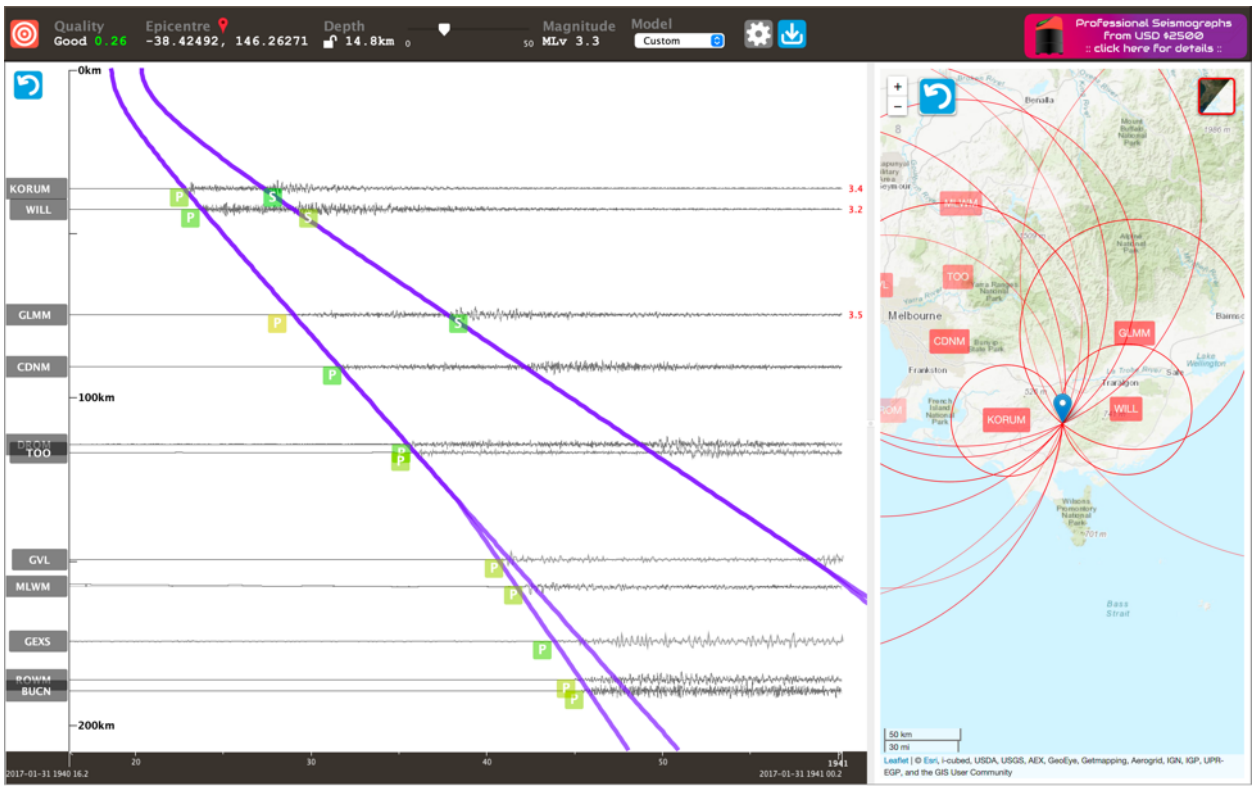
For more accurate earthquake location and magnitude calculation, use the Location feature that was introduced in Waves 4.0.

Accurate Earthquake Location & Magnitude

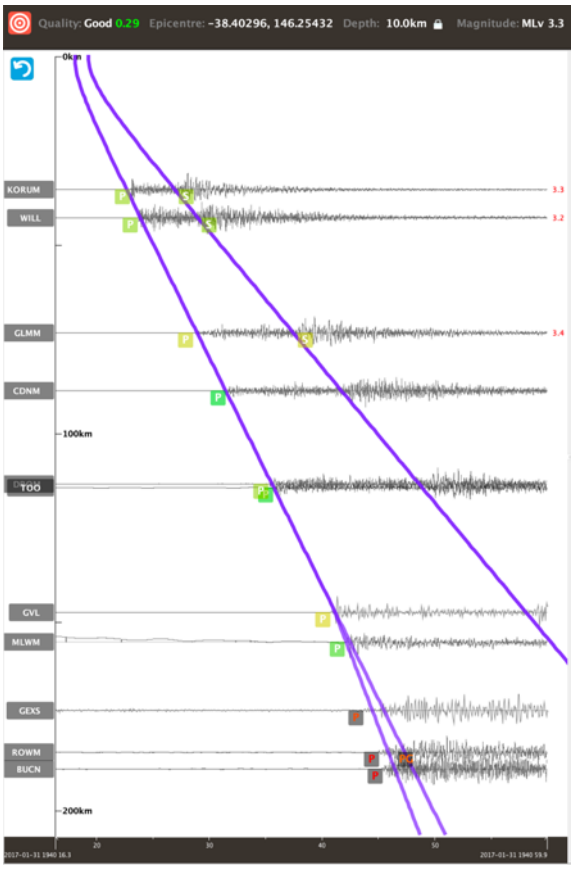
Waves 4.0 introduced the ability to use 1D velocity model and wave inversion to accurately determine the location and magnitude of an earthquake. It brings the algorithms from our past EQLOCL and eqFocus applications to the user-friendly graphical user interface that Waves is known for.

If you have a multi-station recording and have picked at least three arrival times, the new location feature button will switch from the Waveform Analysis view to the Earthquake Location view.





Location Screen



The Location screen plots one channel of waveform data from each station (preferentially the vertical channel) spaced vertically by distance from the estimated earthquake location. The expected P, PG, S and SG arrival time curves - based on the 1D model being used - are plotted on the timeline in purple.

Any P, PG, P and SG phases that have been picked on the Waveform screen will appear on the waveforms in coloured boxes. The colour of the box – a gradient from green to red - reflects how well the picked phase fits with the current solution based on the earth model being used.

If you wish to defer a phase from the solution, click on the coloured box and it will go dark, with the phase name changing to the colour representing how it fits the solution even though it is deferred. Every time you enable or disable a phase, the earthquake solution will be recalculated.

Zooming and Scaling

Use the scroll wheel on your mouse to zoom in and out to your cursor position while over the waveforms. You can also click and drag a box over the waveform area, then click inside that box to zoom to the selection. To reset the zoom to the default view, double-click your right mouse button, use the blue button in the top left corner, or press the HOME on your keyboard.

To increase or decrease the amplitude of the waveform signals, use the up and down arrow keys on your keyboard.

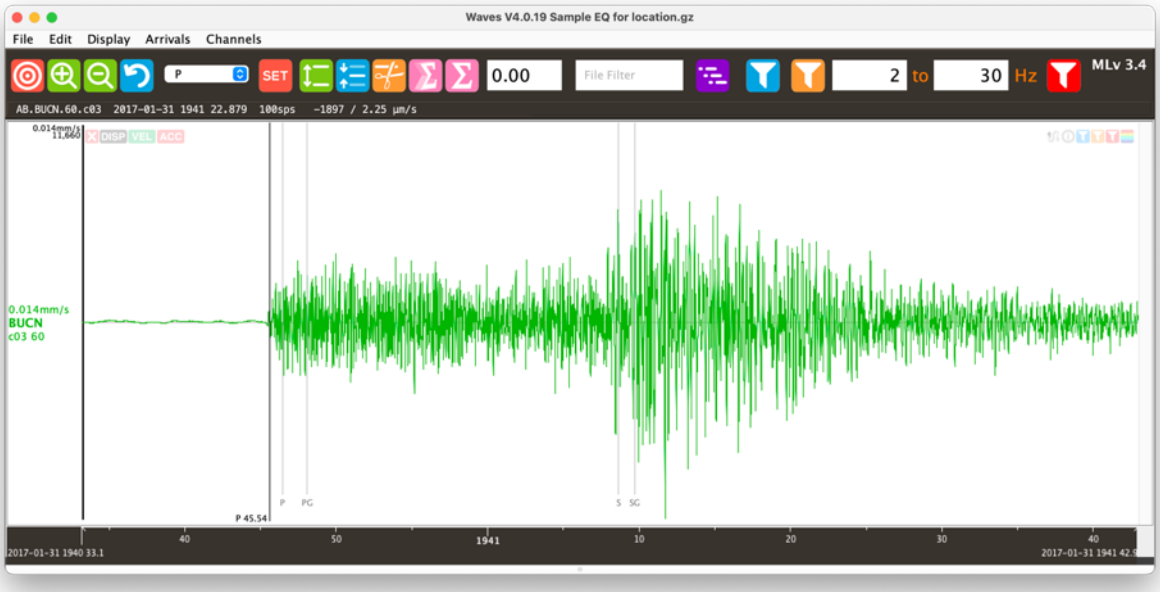
You can zoom the map using the mouse scroll wheel, or by double-clicking a point on the map, or by using the + and – buttons in the top left corner of the map. Reset the map zoom using the blue button in the top left, or right-click on the map and select “Reload page”.

You can click and drag to pan around the map, and change from terrain map view to aerial image by clicking on the view mode button in the top right corner of the map.

You can change the split between waveform and map window size by dragging the vertical divider bar between the windows left and right.

Editing Phase Arrivals

If you wish to edit the arrival phase picks for a station, click on the grey station code box to the left of the distance axis and you will be taken to the Waveform view for that station. Because you have started locating the earthquake, Waves can now show you the phase arrival times the model expects for the station based on the current solution. These expected phases are plotted in grey on the waveform as a guide. This feature can help you see phase arrivals the may be obscured in codas or by background noise.



Once you have finished editing your picks, click the Locate button to return to see what effect this has had on your solution.

Earthquake Depth

The earth model file has a default depth setting of 10km, which you can modify to represent the typical depth of earthquake in your region, or set it to 0km when locating surface blasts. The initial earthquake location solution is locked at this depth, but you may have sufficiently close stations or phases to justify releasing the depth to see if there is a better fit with the model. Click the lock button next to the Depth in the toolbar to unlock and lock the event depth. If the depth jumps to a negative value, it will be displayed in red text.

Use the depth slider to see how the arrivals fit at various depths. The depth will be locked to the value set by the slider

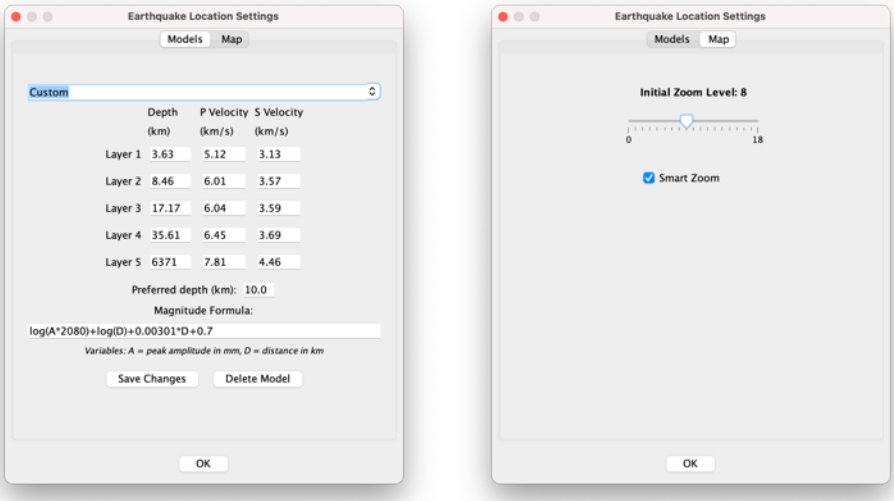
Location Quality

The quality of the solution is the standard deviation from the model of the included phases, in seconds, rated from **Good** (<1.0) to **Fair** (1.0>2.0) to **Poor** (>2.0).

Location Settings

Model

The default 1D layered models included in Waves are based on the **IASPEI** global model, and a **Custom** model that the Seismology Research Centre uses for southeast Australia. You can edit these models or create new models to suit your region of the world. Click on the settings cog in the toolbar to edit, add or delete models.



To add a new model, click on the drop-down menu and select the "New Model" line at the top, then enter a unique name. The values from the previously selected model will copy into this new model. You can enter up to 5 layers of velocity, defining the P and S velocity of each layer to the nominated depth (from the previous layer). Modify these as required, then set the preferred default depth of earthquake for the model.

The final setting that you can modify is the magnitude calculation formula. This formula follows the same rules as the Magnitude settings on the waveform analysis side of Waves, where **A** is amplitude of the peak displacement of the vertical channel in millimetres, and **D** is the distance from the station to the earthquake in kilometres.

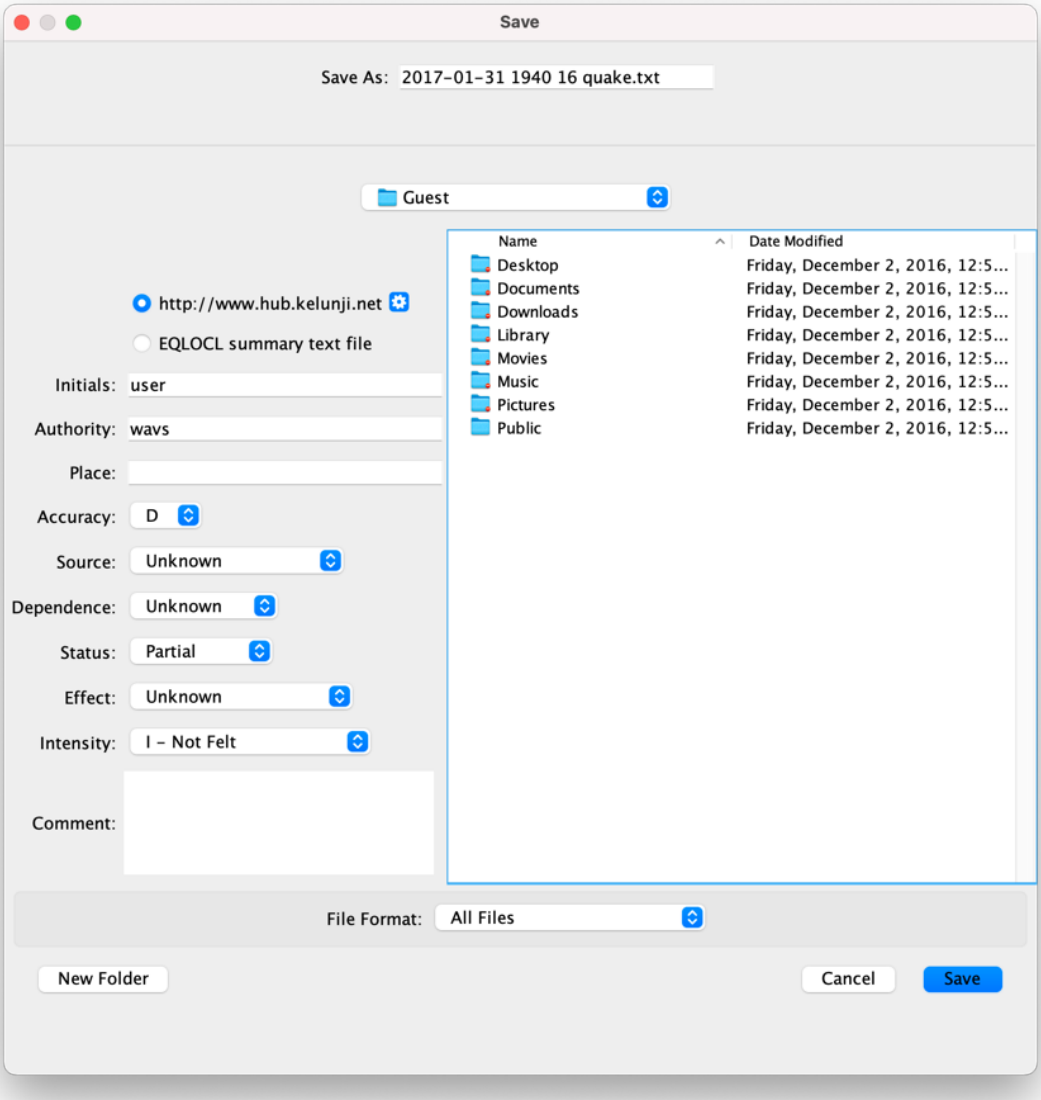
Click **Save Changes** when you're happy with the settings, then click OK to exit back to the Location view to see how the new model fits with your phase picks.

Map Zoom

With "Smart Zoom" enabled, as you refine your location the map will refresh to a zoom level that shows the earthquake location and your network of stations. If you would prefer that the map stays at a specific zoom level, uncheck the Smart Zoom tick box and set the zoom level with the slider. As a guide, the zoom level is displayed under the ± zoom buttons on the map. If you are zoomed to the appropriate level you will be able to see the epicentre move as your location iterates with each change of depth or inclusion/deferral of phase arrival.

Saving the Event Location

Waves 4.2 introduced additional file save features, along with eqServer database integration.



You can save your solution to an "EQLOCL" text file that contains the location and magnitude, along with a number of fields that provide more information about the earthquake. Manually enter a place name from the map, enter any comments in the free text field, and optionally select values from the other drop-down menus to help define the quality of your location. The "Accuracy" of the location is automatically pre-selected.

The saved file does not contain the waveforms, only a text-based event summary. If you go back to the waveform analysis side of Waves and save your waveform file in PC-SUDS format, the file will flag if the phases were included or deferred in your solution so that you can replicate the result from the waveform file. It will not include the model, so if you are sharing your waveforms, be sure to share your model information as well.

Sharing Model Files

The models created by Waves are text files stored in the following location on your computer:

/Users/*username*/eqsuitefiles/waves/models/

To share a model file with a colleague, simply send them the model file you created and get them to copy it into the equivalent folder on their computer.

Station Response Files

If you open a waveform file and Waves cannot find its response file at the selected FDSN server, if you have a copy of the relevant station.xml file you can drag it onto the Waves window, or you can copy it to the following folder on your computer:

/Users/*username*/eqsuitefiles/waves/response/

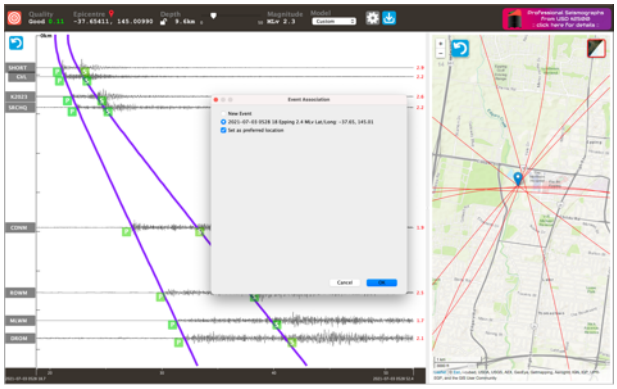
EQLOCL Accuracy Codes

The very first software application developed by the SRC in the late 1970s was **EQLocL** – a program to calculate **E**arth**Q**uake **Loc**ation for **L**ocal events. The algorithms are still at the core of Waves' location feature.

At the time we also defined a system for rating the accuracy of a solution, summarised below. This is how Waves auto-selects the Accuracy of your solution. We still use this today, but you can use the Accuracy code for your own definition or for another purpose entirely.

Conditions		**A**	**B**	**C**	**D**	**E**	**F**	**U**
Local seismological model used		•						
Uncertainty in latitude, longitude, and depth (km) and azimuth (degrees)	<50km, <330°					•		
	<10km, <270°				•			
	<5km, <180°			•				
	<2km, <50°	•	•					
An earthquake did occur, and was probably in this general area							•	
Micro earthquake very close to seismograph								•

Saving to eqServer



If you have an eqServer data management system, it will be creating solutions for auto-detected events. You can save your solution to the eqServer database, optionally associating it with an existing event and setting it as the preferred solution for the event. eqServer will also use its place name database to name the event if you've left it blank.

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