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dipartimento di matematica e geoscienze

The DMG Quick Reference Manuals

XFTAN

Frequency-time analysis, forward modeling and inversion of group velocity dispersion curves

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Foreword

XFTAN2008 was originally developed as a porting to Mac OS X of the Linux software created by Boris Bukchin and Alexei Egorkin for the frequency-time analysis of high-frequency records.

Then, the forward modeling of dispersion curves was added to XFTAN2009, allowing the user to define a layered structure and have the theoretical dispersion curve of the fundamental mode for that structure superimposed to the FTAN diagram.

In XFTAN2010, the hedgehog inversion algorithm has been implemented for the inversion of the experimental dispersion curve identified by the user on the FTAN diagram.

The program then evolved into XFTAN, with the addition of new features to the user interface, bug corrections and other minor modifications.

The XFTAN user interface

The user interacts with XFTAN through a graphic interface, that allows for the full processing of the signal. Launch XFTAN and the main window will appear.

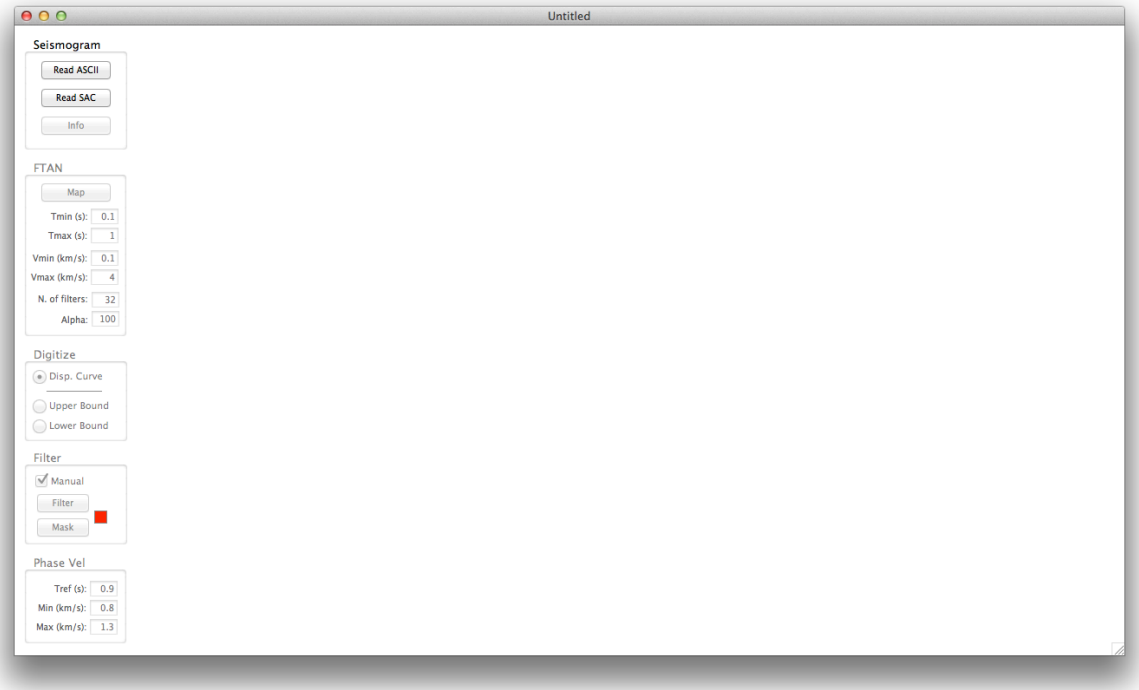
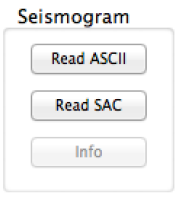


Figure 1. The main window as it appears at the program launch.

Seismogram control group



The user has the choice to import a seismogram in FTAN ASCII format (file extension .ft) using the “Read ASCII” pushbutton, or to import a SAC binary seismogram (file extension .sac) using the “Read SAC” pushbutton.

Both little-endian and big-endian SAC seismograms can be read, provided their header includes the data required (epicentral distance, number of samples and sampling interval).

The seismogram is read in and shown, but no automatic processing is started, as the user has first to adjust the parameters for the frequency-time analysis, that become available in the FTAN control group as soon as the seismogram is read.

The “Info” button becomes active when a seismogram is read. When pushed, it opens a sheet where the number of samples, the sampling interval, the time of the first sample, the epicentral distance of the seismogram being processed, and the seismogram samples, are listed.

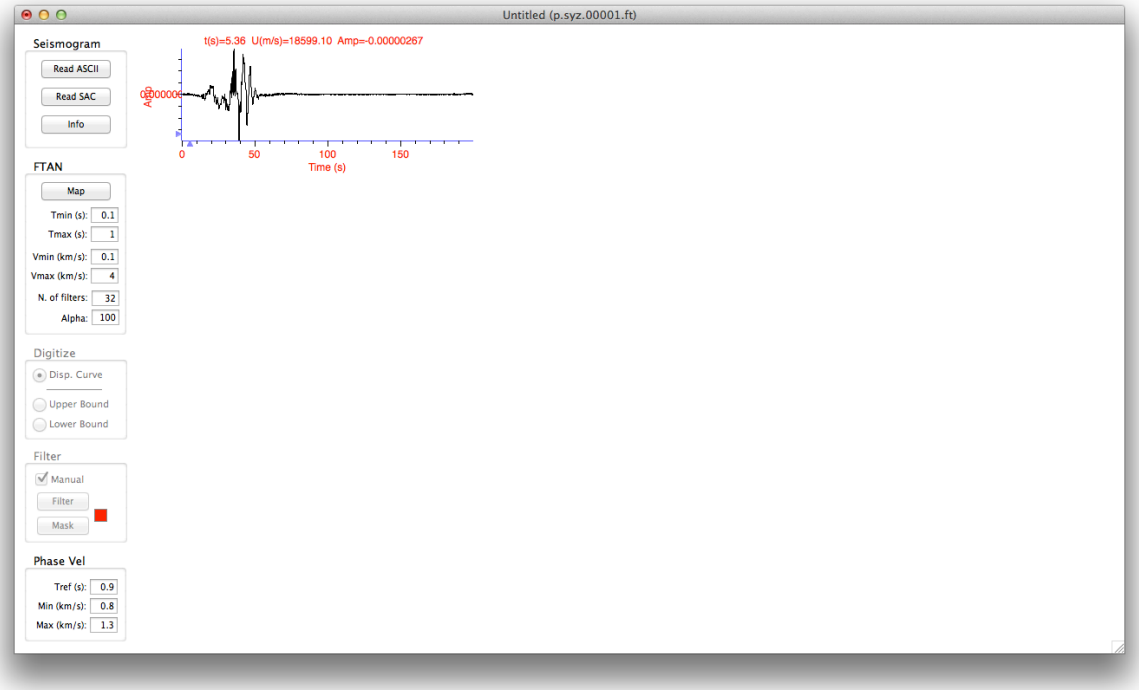


Figure 2. The main window after a seismogram has been read

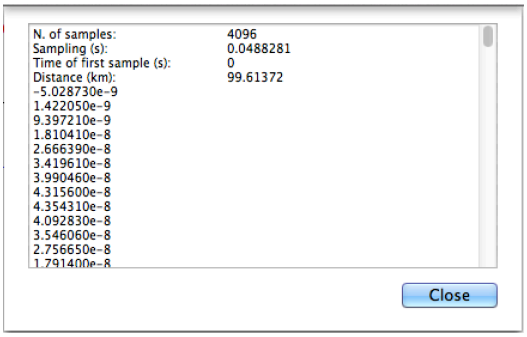
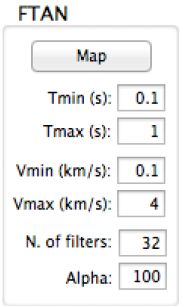


Figure 3. The sheet window shown after pressing the "Info" button

FTAN control group



This set of controls allows to define the desired range for period T and group velocity U, the number of Gaussian filters to be used in the frequency-time analysis (32 is strongly suggested), and the Alpha value that defines the width of the filters.

The FTAN map for the considered seismogram is generated by pushing the "Map" button. The FTAN map is shown, together with the Fourier amplitude spectrum of the signal, plotted to the right of the seismogram plot. In addition, a default structural model is also presented, for which the theoretical group velocity dispersion curve of the fundamental mode can be computed.

When right-clicking on the FTAN group control, a contextual menu allows to copy and/or paste the values of the FTAN parameters to/from the clipboard. This is typically used to transfer the parameters between different XFTAN windows opened at the same time.

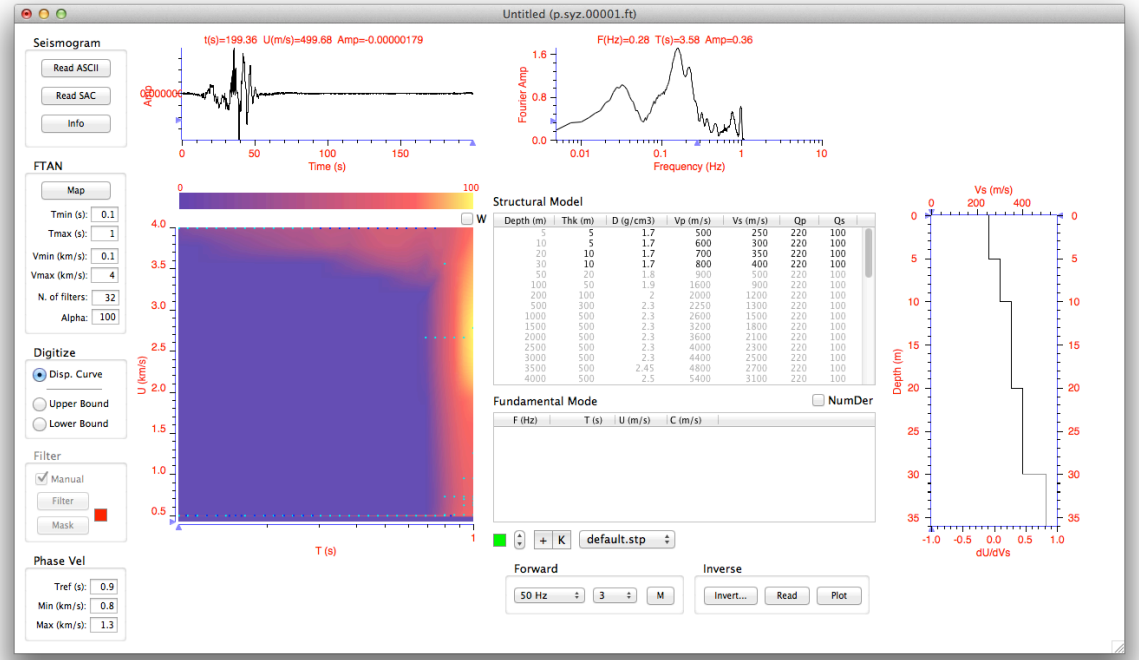


Figure 4a. The main window after the FTAN map has been requested, with improper ranges for periods and group velocity.

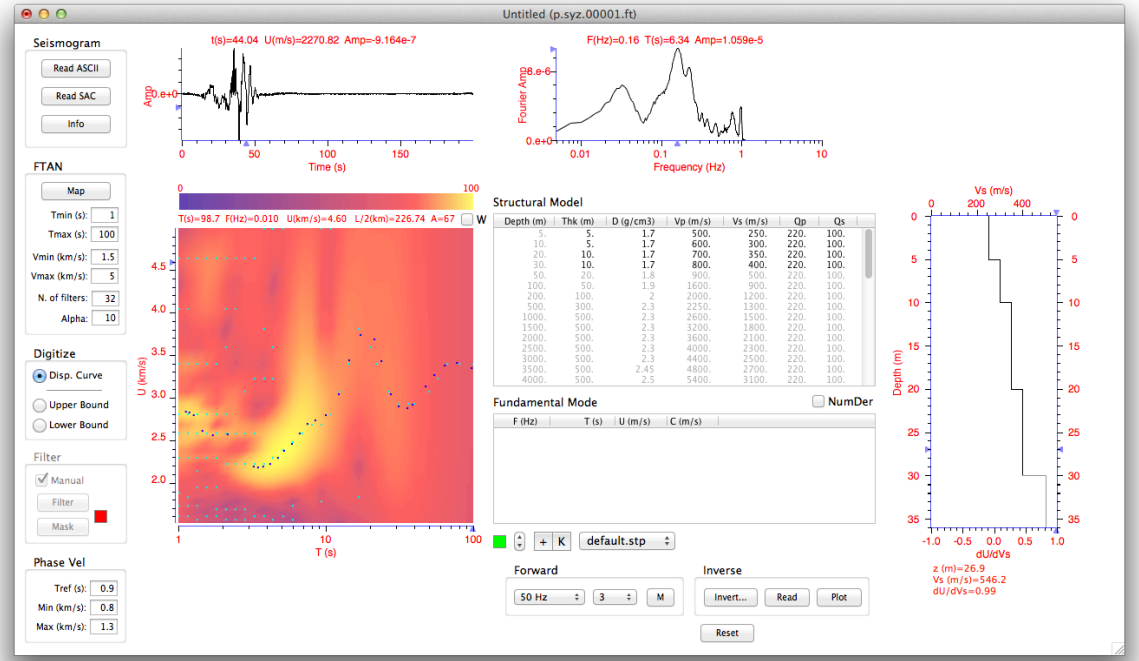


Figure 4b. The main window after the FTAN map has been plotted again, with adjusted FTAN parameters.

The yellow areas in the FTAN map are those associated with the energy arrivals. The Alpha parameter, that controls the width of the bandpass filter, must be properly chosen so that the dispersion characteristics become evident in the map. Alpha values larger than necessary (narrow band filters) tend to stretch the yellow areas along the group velocity axis (Figure 5a), while low Alpha values (wide band filters) stretch the yellow areas along the period axis (Figure 5b).

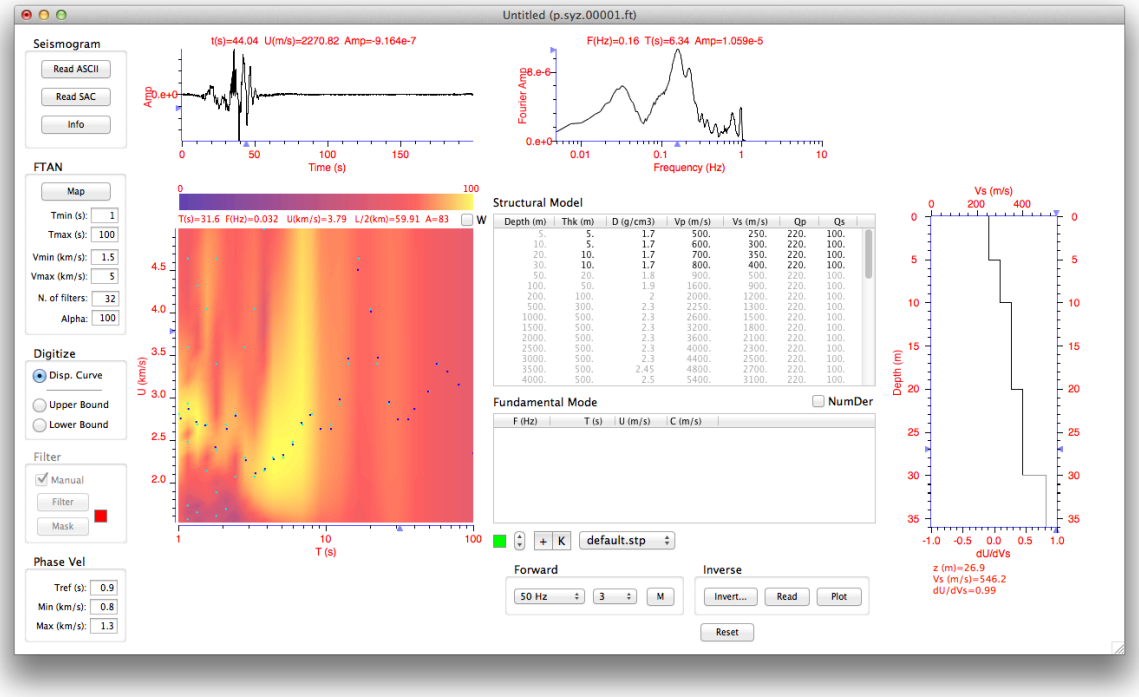


Figure 5a. Alpha value too big: yellow areas are stretched vertically along the U axis..

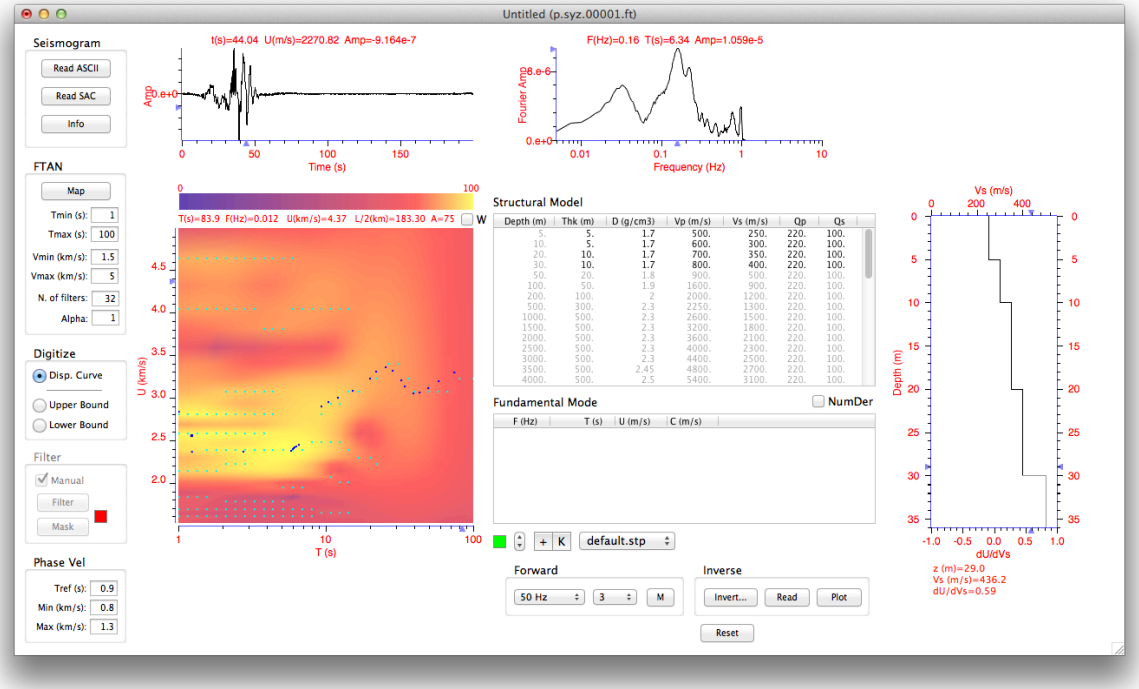
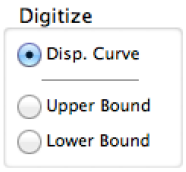


Figure 5b. Alpha value too small: yellow areas are stretched horizontally along the T axis..

In the FTAN map, small cyan dots indicate relative maxima for a given filter central period, while small blue dots indicate the absolute maximum for the visible period associated with a filter, that is the period corresponding to the largest energy spot that each filter allowed to pass. If the filter is too wide (too small Alpha value) the blue dots tend to distribute unevenly in the map (see Figure 5b).

Digitize control group



This group of controls influences the digitization process on the FTAN map. Two operational modes are possible:

- digitize a dispersion curve for subsequent manual filtering
- digitize a mask defined by an upper and a lower limit, for automatic filtering

The manual filtering gives more control to the user and is the recommended filtering method. After the digitization option has been selected, the user can click on the FTAN map to add points to the dispersion curve or the mask. For the mask definition, both upper and lower bounding curves must be digitized.

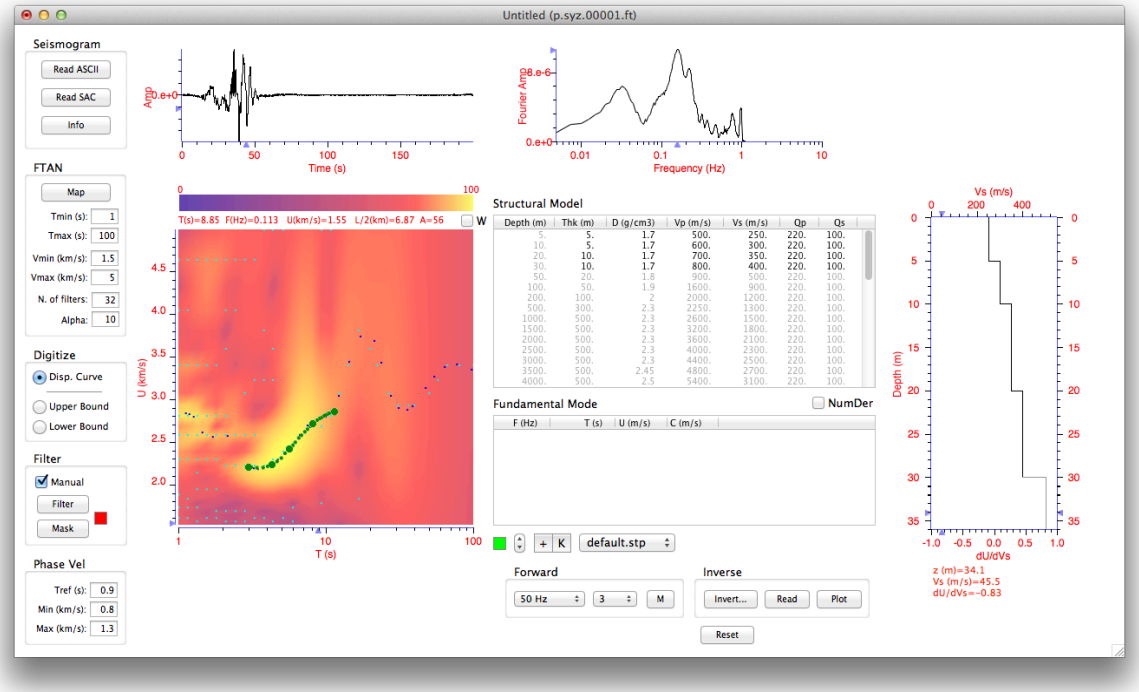


Figure 6. A dispersion curve (large green dots) manually digitized over the FTAN map following the energy arrivals associated with the fundamental mode. Small green dots are interpolated with a spline by the program.

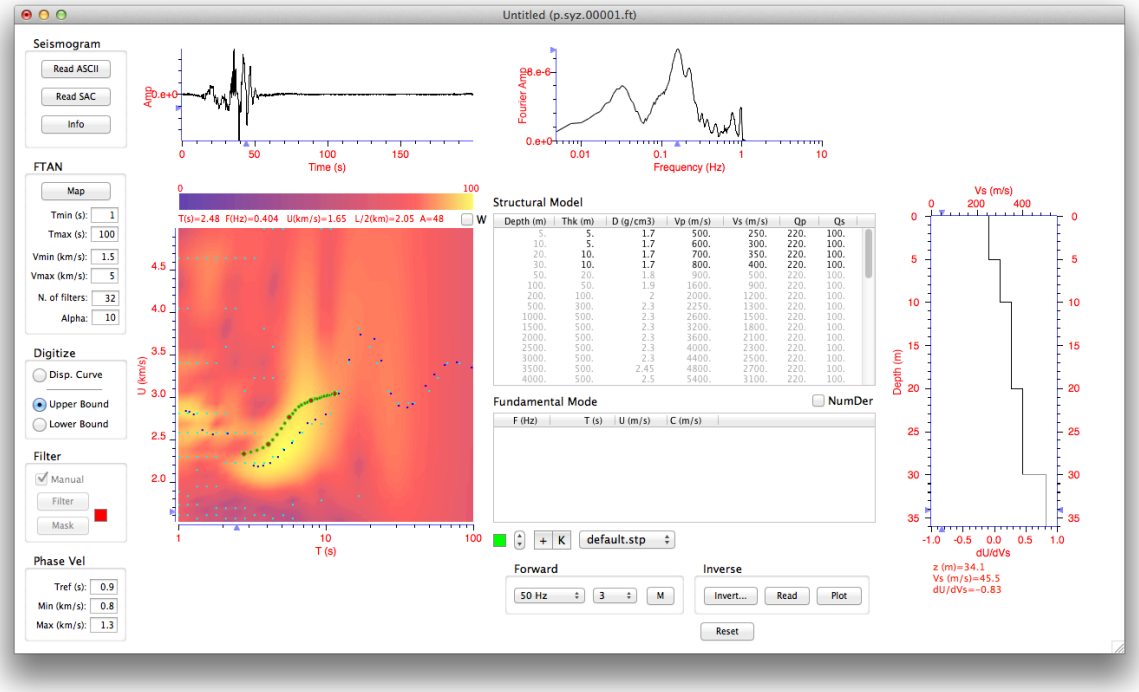


Figure 7a. The upper bound of a mask (red/green dots) digitized over the FTAN map following the energy arrivals associated with the fundamental mode.

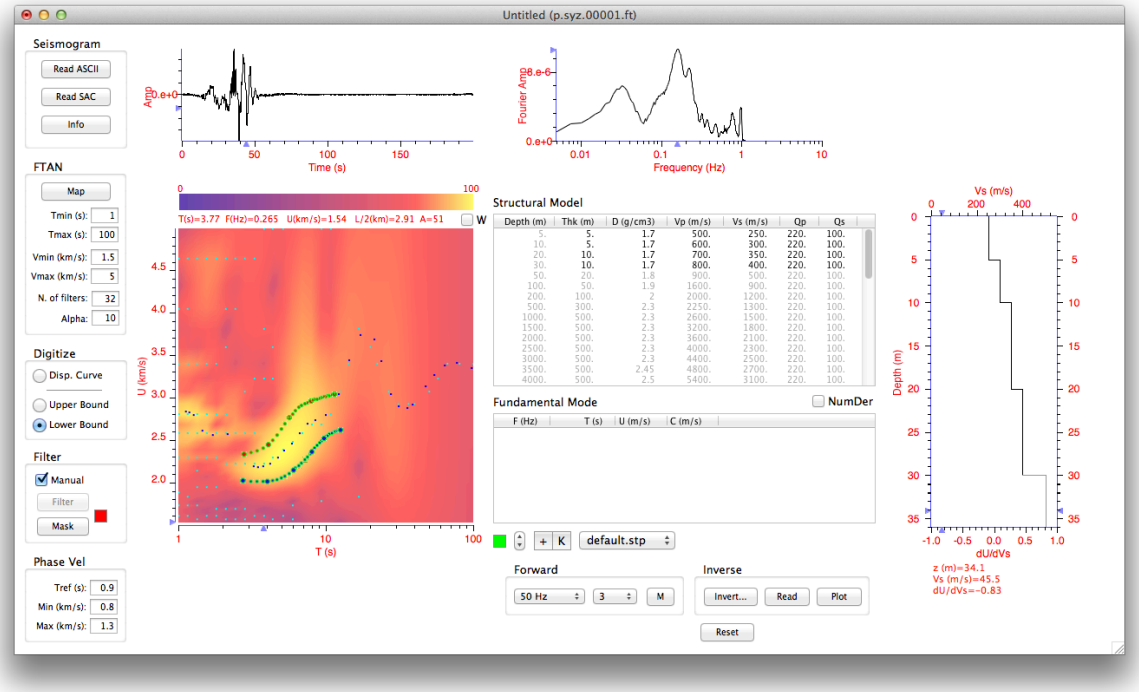
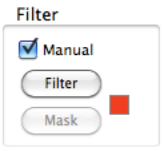


Figure 7b. The lower bound of the mask (blue/green dots) digitized over the FTAN map to complete the mask digitization started in Figure 7a.

Filter control group



After the dispersion curve or the mask have been digitized, this group of controls allows for the manual filtering or the mask filtering of the signal.

Clicking on the colored square allows to chose a different color for the plotted filtered signal.

Pushing the “Filter” button after the dispersion curve has been digitized brings into view the floating filtering sheet. If the dispersion curve has been properly digitized, like in Figure 8a, the reference green line is located in correspondence of the clear peak of the phase equalization curve. The four red lines indicate the filter limits automatically proposed by the program. They can be redrawn by the user by clicking four times in the phase equalization sheet. The filter is built with zeroes before the leftmost and after the rightmost red lines, ones between the two inner red lines, while a cosine shape is used to smoothly transition from zero to one and back to zero in the in between areas.

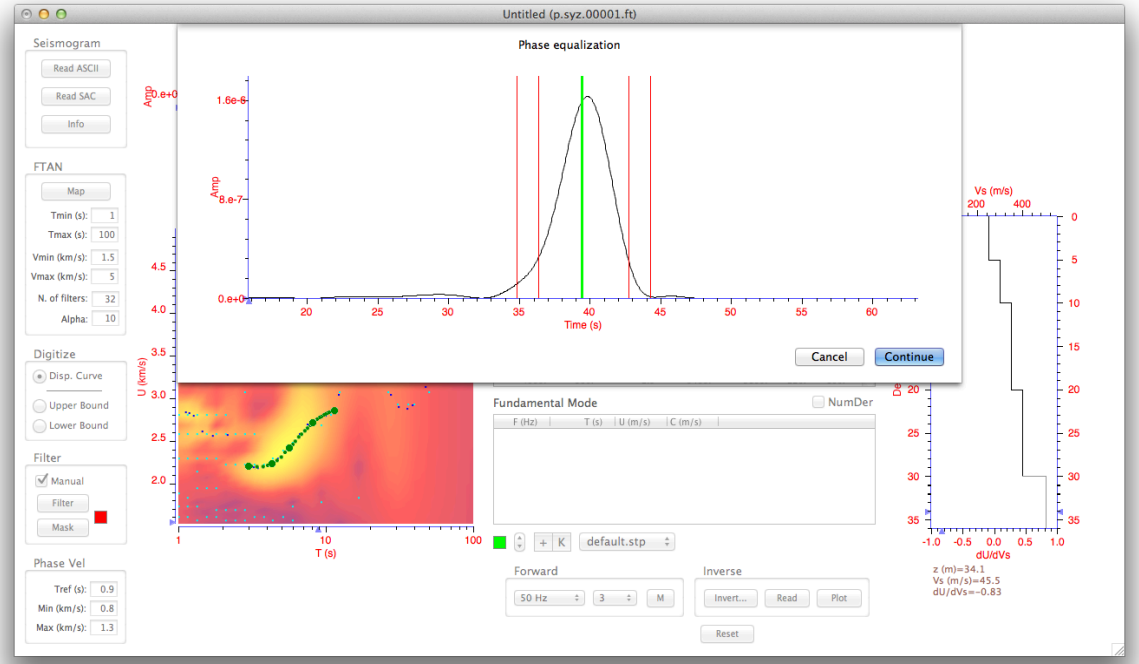


Figure 8a. Floating filtering performed using a properly digitized dispersion curve. The green line is centered on the peak of the phase equalization curve.

If a dispersion curve has been digitized with velocities higher than those indicated by the yellow spots and the small blue dots of the FTAN map, like in Figure 8b, the reference green line appears too early with respect to the peak of the phase equalization curve.

The opposite happens if the digitized dispersion curve is too slow, like in Figure 8c: the reference green line appears too late with respect to the peak of the phase equalization curve.

In both cases the amount of shift of the green line will be somehow proportional to the misfit between the true dispersion relation and the dispersion curve digitized by the user.

The user can digitize the dispersion curve, push the “Filter” button to check the floating filtering in the phase equalization sheet, and then decide to continue or cancel the operation based on the position of the green line with respect to the peak of the phase equalization curve.

If the user draws a dispersion curve totally unrelated with the FTAN map, like in Figure 9, the phase equalization curve does not present a clear peak

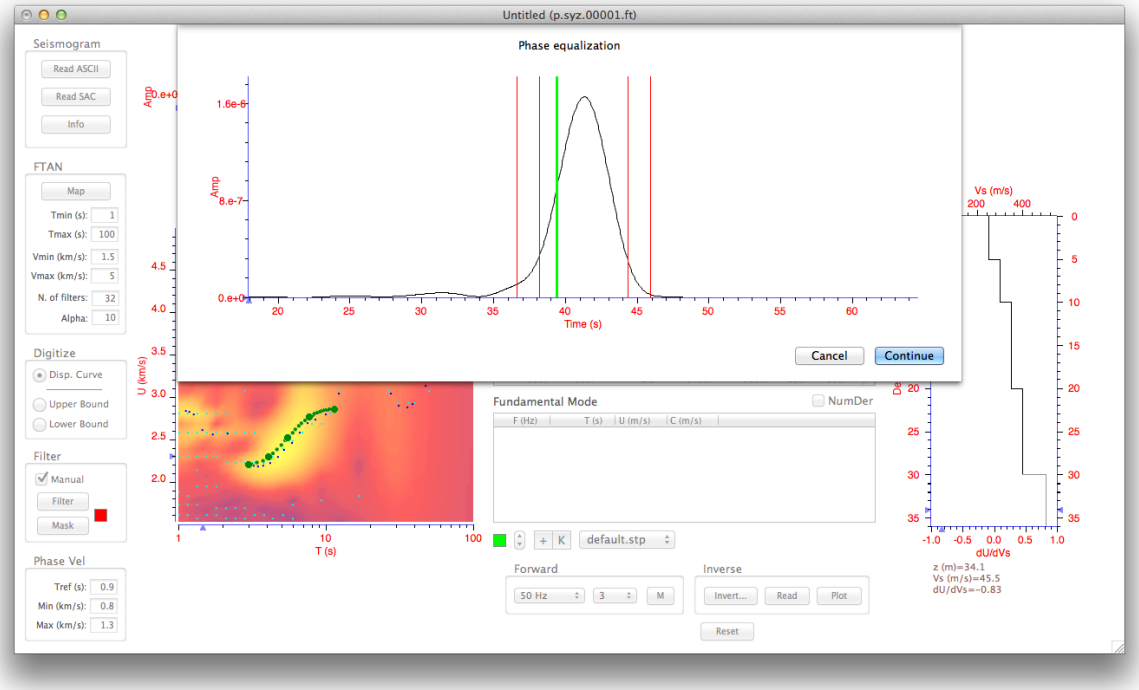


Figure 8b. Floating filtering performed using a digitized dispersion curve faster than the FTAN map suggest. The green line appears earlier than the peak of the phase equalization curve.

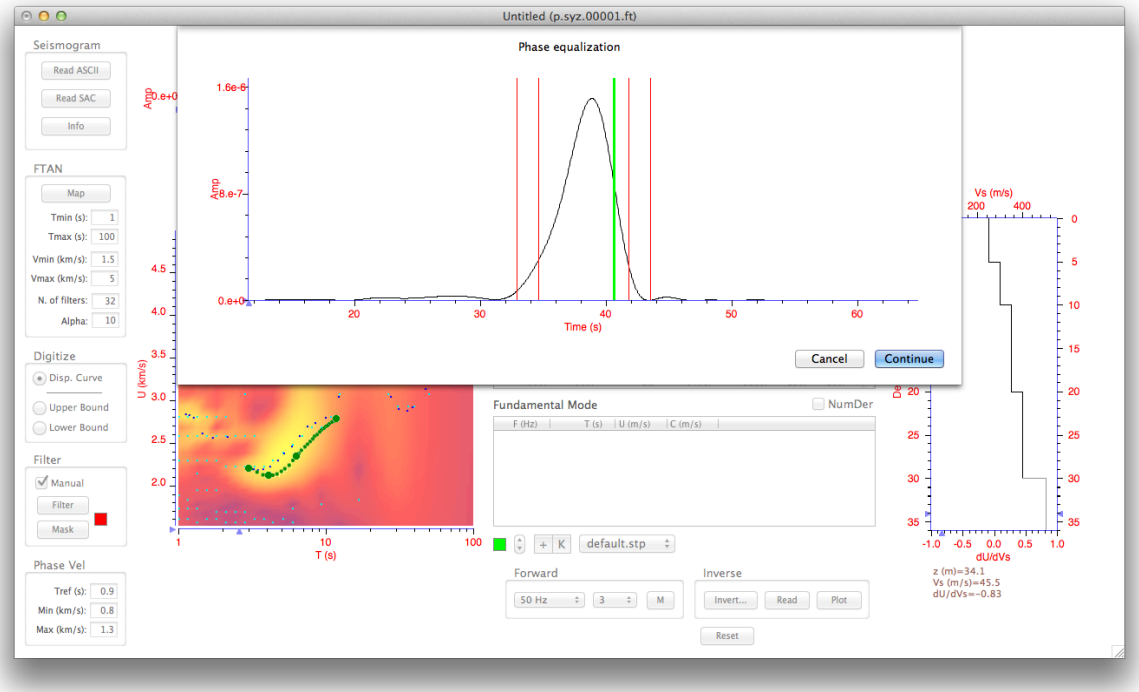


Figure 8c. Floating filtering performed using a digitized dispersion curve slower than the FTAN map suggest. The green line appears later than the peak of the phase equalization curve.

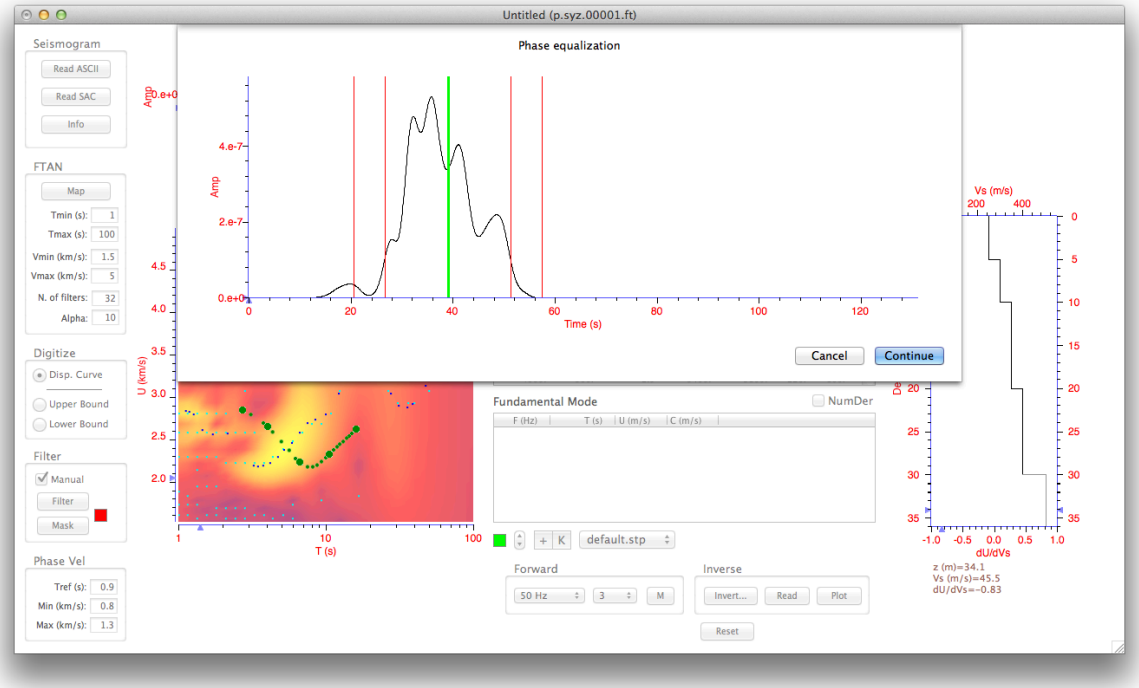


Figure 9. Floating filtering performed using a digitized dispersion curve unrelated with the FTAN map dispersion features. The phase equalization curve does not show a clear peak.

Once a good dispersion curve has been digitized, the floating filtering operation can be completed by pushing the “Continue” button. The result of the floating filtering based on the dispersion curve digidized in Figure 8a is shown in Figure 10.

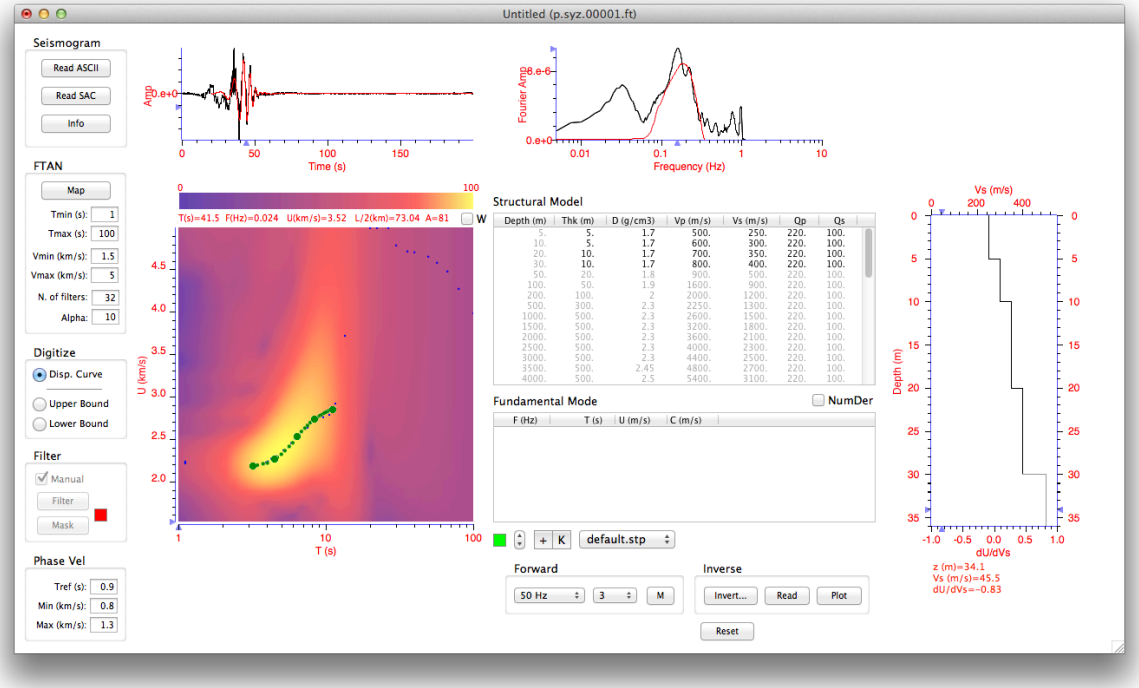


Figure 10. Completed floating filtering operation based on the dispersion curve of Figure 8a. In the FTAN map the yellow spots unrelated with the dispersion curve have been cancelled. The filtered time series and its Fourier spectrum are plotted over the original signals, using the color specified in the Filter control group (red in this example).

The filtering is also possible with the “Mask” button, once the upper and lower bounds of the mask have been digitized (see Figure 7b). The result of this filtering is shown in Figure 11. The filtered signal is rather similar to that obtained with the floating filtering, but the user does not have the control on the quality of the digitization given by the phase equalization, so the mask filtering should generally not be used.

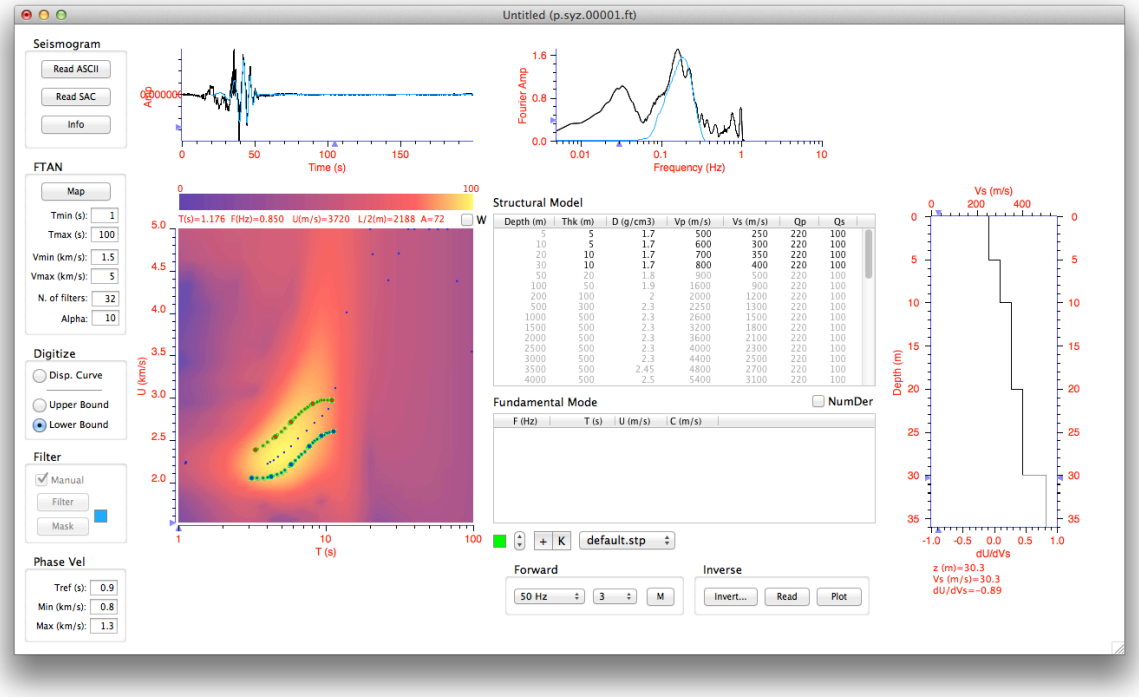
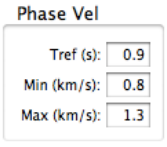


Figure 10. Filtering performed using the digitized mask.

Phase velocity control



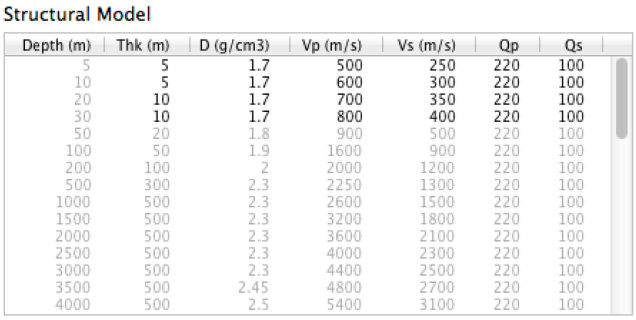
It is possible to define a reference period from where to start the identification of the phase velocity curve. At that period, the phase velocity value is searched within the velocity range defined by the user.

The reference period must be as close as possible to the largest period shown in the FTAN map for which energy arrivals can still be identified.

The phase velocity range has to be defined so that it should contain the phase velocity of the fundamental mode. If properly set, a phase velocity curve will be stored in a file named dc.phv when the FTAN map is generated.

Structural model list control

This controls appears after a FTAN map has been produced, and allows to define the properties of the structural model used for the forward modeling of the group velocity dispersion curve of the fundamental mode. The layers in black are referred to as “the structure”. They can be edited interactively by the user (added, deleted, modified) and will be the only layers considered as variable in an inversion process.The layers in grey are referred as “the reference structure”, used to complete the structure at depth. They cannot be edited interactively, and will not be considered in an inversion



process. Both the structure and the reference structure can be imported from a *.stp* file (for its definition have a look at the DSTXQuick1Dmodes manual) by right clicking on the control and selecting the proper item of the contextual menu.

When right-clicking on the structural model control, a contextual menu is available that allow several operations (import/export of the structure and of the reference structure, copy/paste operations on the structure layers etc).

It is possible to define more than one structural model, and manage the structure set, by acting on the controls.

The colored square can be clicked to select the color of the structure plot and of the dispersion curve plotted over the FTAN map.

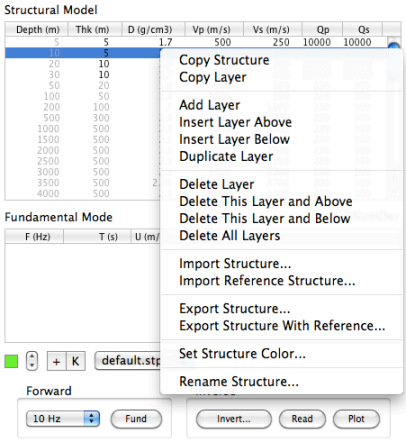
The up/down arrows allow for the selection of the previous/next structure in the structure set.

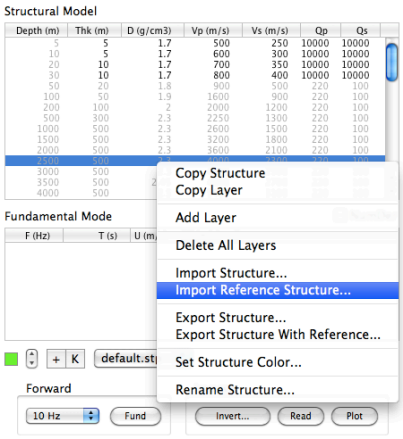
The “+” button adds a new structure to the set.

The “K” button keep the currently shown structure and deletes all the others structures of the set.

The popup menu allows the direct selection of any structure defined in the structure set.

A contextual menu can be obtained by right-clicking on the structural model list control. Its content depends on the item on which the right-click is made (a structure layer or a reference structure layer), and allows to add or delete layers, import or export the structure or the reference structure, copy and paste layers or the whole structure, etc.

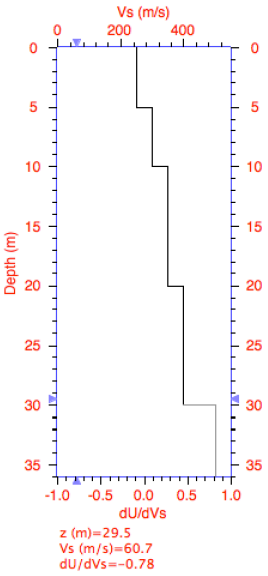




Changes applied to a layer parameter in the listbox will be reflected in the structure plot, and vice versa.

Structural model plot control

The S-wave velocity of the structural model is plotted in this control. The plot is automatically updated as the user updates the Vs values in the structural model list control.

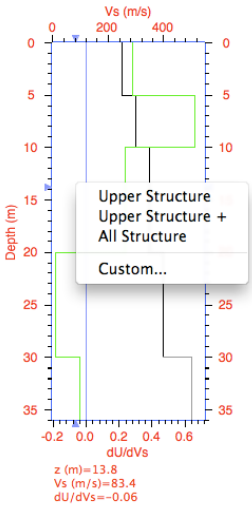


The synchronization between the plot and the list holds the other way around too. The user can click on a segment of the structure plot and drag it around to adjust the Vs of the layer or its thicknessl: the list control will be updated accordingly.

The layers belonging to the reference structure, plotted in grey, can not be dragged around. The editable layers are plotted with the color of the square positioned below the fundamental mode dispersion control.

When modifying the Vs of a given layer, the Vp of that layer will change as well, so to keep the Vp/Vs ratio constant. This can be overcome if the user holds the *alt* key while dragging around the selected velocity segment. In such a case, only the Vs will be modified in the list control.

A contextual menu can be obtained right-clicking (or ctrl-clicking) on the structure plot, that allows the redefinition of the depth axis. Custom values must be given in meters.



Upper Structure	The user-editable part of the structure
Upper Structure +	The user-editable part of the structure, plus a little bit...
All Structure	The complete structure, reference structure included
Custom	A user defined depth

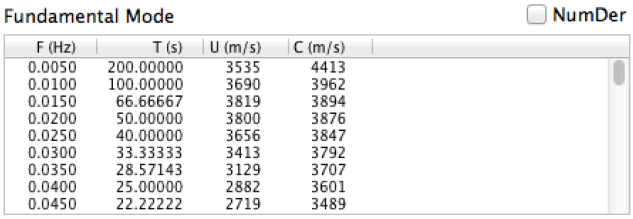
Forward modeling control group

Once at least one structural model has been defined, the “M” pushbutton will generate the dispersion curve for the structure selected in the popup menu described among the structural model controls.

The dispersion computations will be performed up to the frequency specified in the leftmost popup menu (0.1 Hz, 1 Hz, 5 Hz, 10 Hz, 20 Hz, 50 Hz). The rightmost popup menu allows the choice of computing just the fundamental mode (1), or for the fundamental and the two first higher modes (3). For complicated structural models, it’s better to limit the computations to the fundamental mode only.

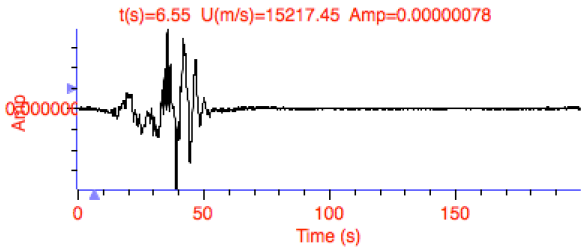
Fundamental mode dispersion control

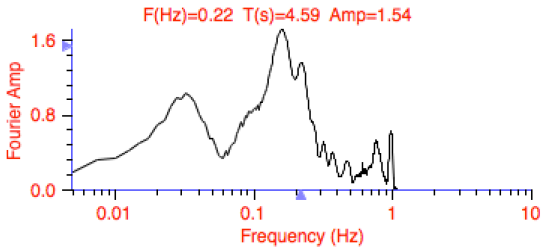
This control will list the group and phase velocity dispersion curve generated by pressing the “M” button of the forward modeling control. Only the fundamental mode is listed even if the computation of the first three modes has been asked. By selecting one frequency in the list, the partial derivative dU/dVs for that frequency will be plotted in the structural model plot control. The derivative is computed analytically, unless the NumDer control is checked to force a numerical computation of the derivative.



It is strongly suggested to use the analytical approach for the derivative computation.

The seismogram and the Fourier amplitude plots



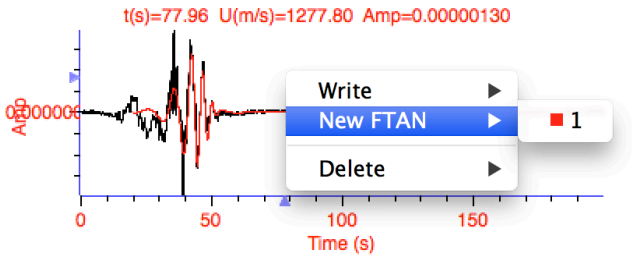


The seismogram plot appears immediately after a seismogram is read. The Fourier amplitude spectrum is shown after the FTAN filtering is performed.

Moving the mouse over the seismogram plot or the Fourier spectrum plot, the time/amplitude or the frequency/amplitude values will be shown above the plot frame. A basic interaction with each of the two plots is possible:

alt-click	zoom in
alt-shift-click	zoom out
click and drag	shift along X-axis
command-click	reset to full time range

If a filtered seismogram has been obtained by FTAN filtering (the red signal in the example), a contextual menu becomes available on the seismogram plot. It allows to write the filtered seismogram in ASCII format for further processing, or to delete it, or to process it in a new window where the same FTAN parameter used in the current window are adopted.



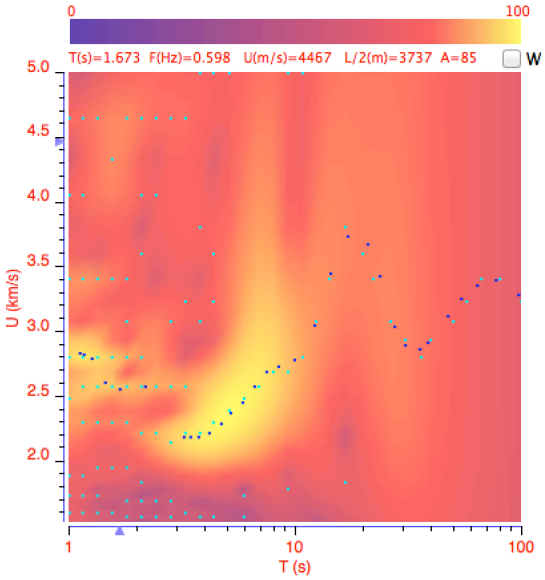
The FTAN map plot

The FTAN map appears after a FTAN map is requested. The map shows the energy arrivals in the range of periods and group velocity selected by the user. The higher amplitudes of the FTAN map are shown in yellow.

If the dispersion features are not evident in the FTAN map, the user may try to recreate the FTAN map changing the Alpha value of the filters.

When the energy alignments are visible, they can be associated with the group velocity dispersion curves of the modes of a layered structural model, equivalent to the real structure between the source and the site of the recording.

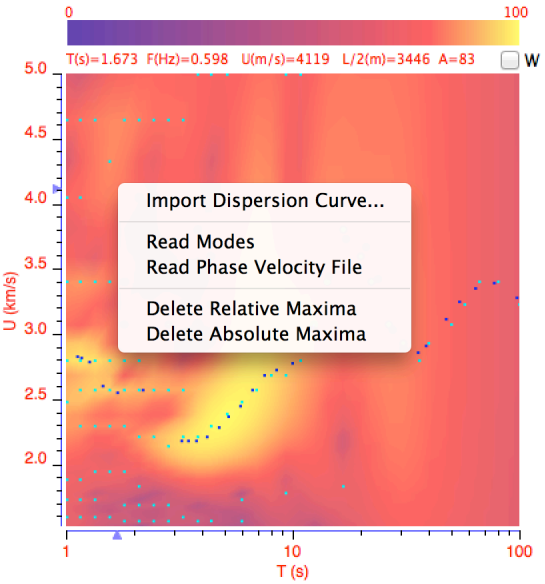
Moving the mouse over the FTAN map, the values of period T (and frequency F), of the group velocity U and of the amplitude A of the energy arrival (expressed in decibel, normalized to 100 for the absolute maximum of the map) are shown.



If the “D” key is kept pressed while moving the mouse over the FTAN map, and the theoretical fundamental mode for structural model is already computed, the partial derivative dU/dVs for the period corresponding to the mouse position is computed on the fly and plotted over the structure plot.(see the Section about partial derivatives).

In the FTAN map, small cyan dots indicate relative maxima for a given filter central period, while small blue dots indicate the absolute maximum for the visible period associated with a filter, that is the period corresponding to the largest energy spot that each filter allowed to pass. If the filter is too wide (too small Alpha value) the blue dots tend to distribute unevenly in the map (see Figure 5b).

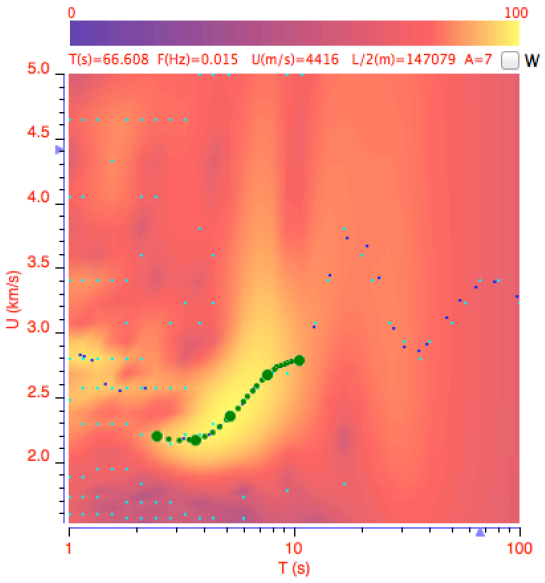
A contextual menu is available to perform several operations: more contextual menu items can appear if other data are plotted over the map (e.g. a user-defined dispersion curve, a set of modes, a mask).



Dispersion curve digitization

A dispersion curve can be digitized by the user by clicking on the FTAN map with the mouse. Big green dots are the points selected by the user. The program automatically generates a cubic spline, shown with small green dots, that passes through the digitized points.

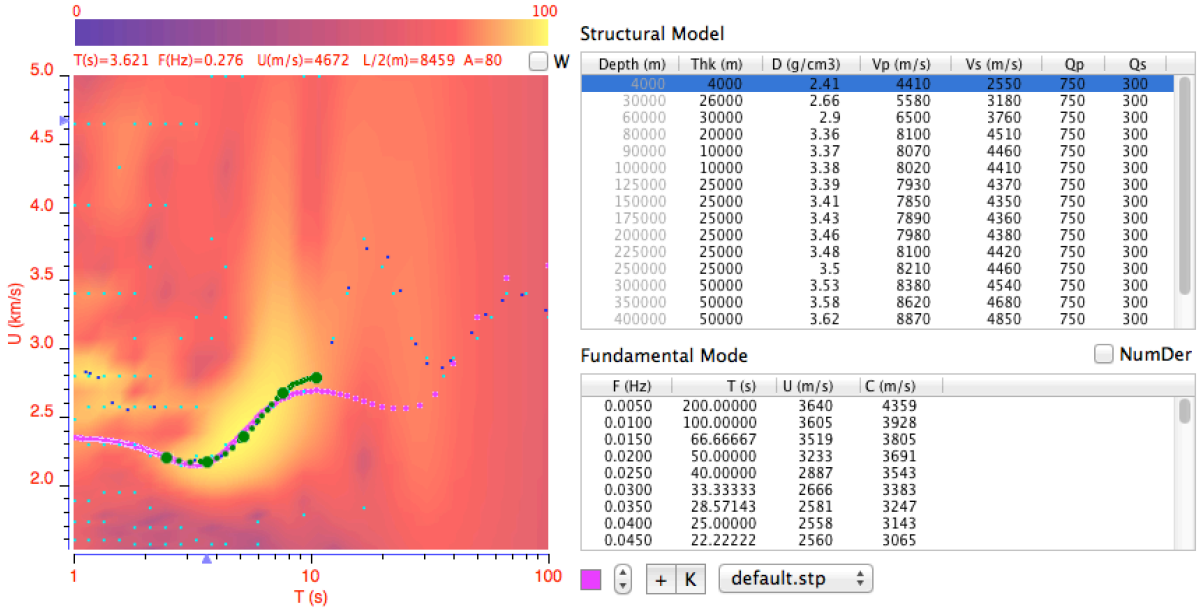
Once the curve has been digitized, the user can click and drag each big green dot to a new position, to better match the dispersion curve visible in the FTAN map. The spline will be automatically updated.



A simple click on a digitized point, with no dragging, will remove that point from the digitized dispersion curve. If two digitized points are very close in their T, the spline interpolation can produce large oscillations in the interpolated curve. This should be avoided.

Theoretical dispersion curve

A theoretical dispersion curve computed for the 1D layered structural model defined by the user can be superimposed to the FTAN map (purple dots in the example below, where the structure actually used for the computation of the theoretical seismogram is used).

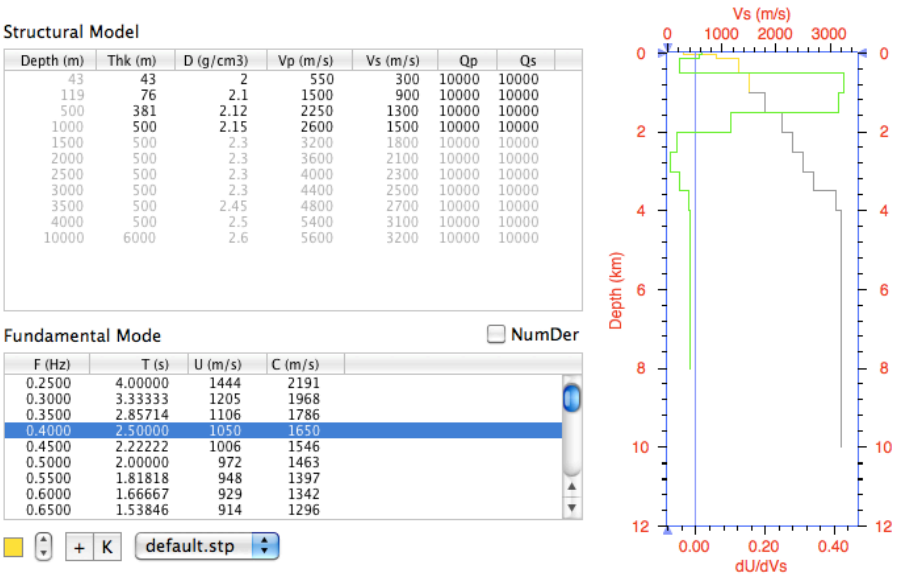


Once the structure is defined, the theoretical fundamental mode can be computed by pushing the “M” pushbutton of the Forward modelling control group, after selecting the highest frequency of interest in the dedicated popup menu.

The fundamental mode is computed on the fly. Frequency F, period T, group velocity U and phase velocity C are shown in the dedicated listbox, and the group velocity dispersion curve is plotted on the FTAN map.

Partial derivative computation

As seen already, selecting a frequency in the fundamental mode listbox, the partial derivative dU/dVs is shown in the structure plot

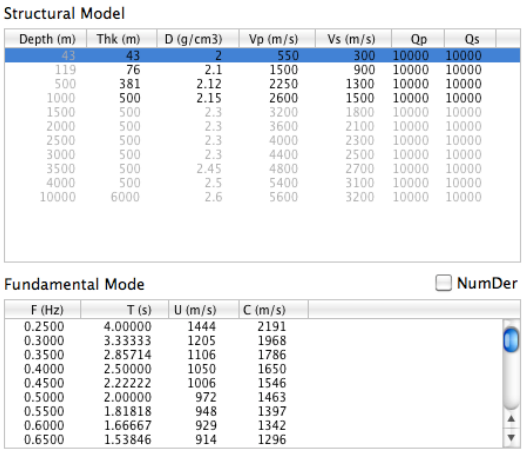


In the example, the partial derivative is plotted in green for the frequency of 0.4 Hz. In the plot, the yellow line shows the Vs of the user-editable layers, the gray curve shows the Vs of the reference structure and the vertical light blue line shows the zero of the derivative plot.

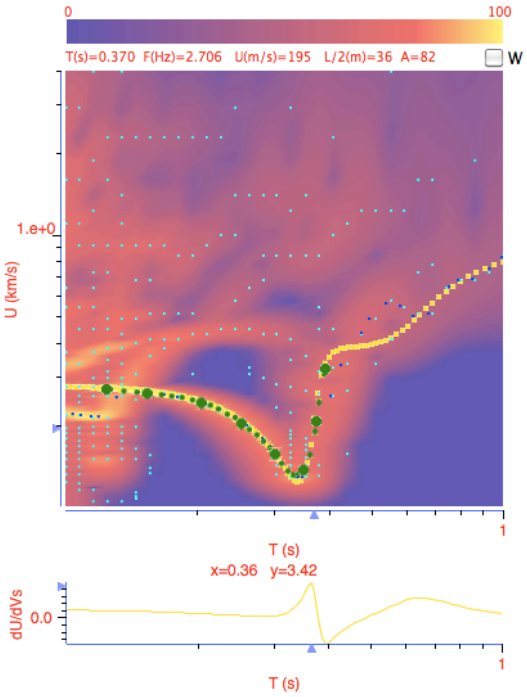
The analysis of the partial derivative at different periods is useful to identify the resolving power that can be expected in the inversion of the dispersion curve. Only the layers for which the derivative is large in the period range where the FTAN map shows remarkable energy arrivals can be resolved.

Another convenient way to compute the partial derivative is to move the mouse over the FTAN map while keeping the “D” key (for “Derivative”) pressed.

A different view of the partial derivative is possible. Instead of showing the partial derivative for all the layers at a given period, it is possible to obtain the partial derivative for a single layer for all the periods considered in the FTAN map. To do so, it is enough to keep the “D” key pressed while selecting a layer in the structure listbox.



If the theoretical fundamental mode has been already computed, the partial derivative for the selected layer (the uppermost layer in the example) will appear right below the FTAN map, showing which periods (if any…) are the most indicated to resolve that layer.



Saving a project

Each time a FTAN analysis is performed on a signal, a folder is created where the output files are stored. The folder name is the same as the name of the seismogram, with the extension ".Results" appended.

After having read in a seismogram, selected the proper ranges of the FTAN map and performed the FTAN analysis, defined the properties of the structural model and performed the forward modeling of the dispersion of the fundamental mode, all the above can be saved into a so called FTAN project file (standard extension .ftan).

Next time you'll want to review the work done, a simple double-click on the .ftan file icon will launch XFTAN and the main window will be populated exactly as it was when the original analysis was performed.