

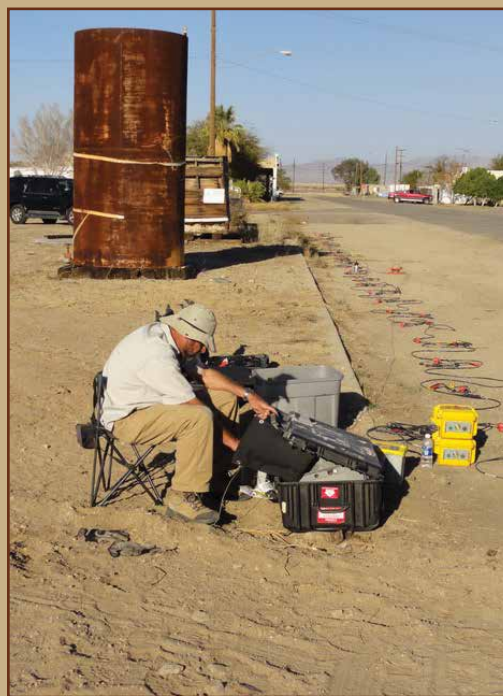
Graphical Dispersion Plot Editor (DPE) for Seismic-Site Characterization by Using Multiple Surface-Wave Methods

MULTIPLE METHODS

ACTIVE



PASSIVE



Open-File Report 2020–1065

Cover. Left, Photograph showing Antony Martin (midground) and Will Dalrymple (foreground) of GEOVision, collecting active-source MASW data with a linear array of seismometers. Right, Photograph showing Antony Martin monitoring equipment during ambient-noise (passive) data collection at the same site. Photographs by Alan Yong, U.S. Geological Survey.

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By Devin McPhillips, Alan K. Yong, Antony Martin, and William J. Stephenson

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Abbreviations

DPE	Dispersion Plot Editor
ESAC	extended spatial autocorrelation
MASW	multichannel analysis of surface waves
RDC	representative dispersion curve

Graphical Dispersion Plot Editor (DPE) for Seismic-Site Characterization by Using Multiple Surface-Wave Methods

By Devin McPhillips,¹ Alan K. Yong,¹ Antony Martin,² and William J. Stephenson¹

Introduction

To understand the behavior of potentially damaging ground motions during earthquakes, seismic-site effects are routinely characterized by using the dispersion of surface waves. Many methods exist to measure dispersion (for example, Stokoe and others, 1988; Foti, 1999; Park and others, 1998, 1999; Okada, 2003; Louie, 2001; Martin and others, 2014). These methods have various advantages and disadvantages, but they all yield dispersion data that must be inverted for shear-wave velocity. This report presents a graphical tool for efficiently removing spurious data as well as combining data from multiple methods prior to inversion (Yong and others, 2013; Martin and others 2017; Yong and others, 2019).

The Dispersion Plot Editor (DPE) program presented here (version 1.5) is coded in Python 3, which is open source and platform independent. DPE accepts input dispersion data as one or more delimited text files. The program plots the data in useful forms, including both scattered points and an interpolated heat map. The user selects points to delete by drawing arbitrary shapes with the mouse cursor. After the spurious data are removed, the user may represent the acceptable data with a dispersion curve (Yong and others, 2013). The acceptable data and the representative dispersion curve are output as separate comma-delimited text files. Images of the plotted data and the representative dispersion curve may also be saved.

There are several potential sources of spurious dispersion data. For example, the local site conditions may not conform to the routine assumption of a flat, layered, one-dimensional half-space. In addition, different methods of measuring dispersion data are sensitive in different frequency bands. The dispersion signal may be contaminated by noise, causing error in data selection. In some instances, it may be especially difficult to discriminate the fundamental mode from higher modes, but typically only the fundamental mode is used in velocity inversions (Tokimatsu and others, 1992).

Spurious data may be identified and mitigated by combining dispersion data derived from multiple methods at a single site (Martin and others, 2017; Yong and others, 2019). For example, passive source methods usually resolve lower frequencies, and consequently deeper structure, than active source methods (Stephenson and others, 2005; Yong and others, 2013; Martin and others, 2017). Combining dispersion data from both active and passive methods produces the best possible resolution over the largest possible frequency domain. In addition, the overlapping region of intermediate frequencies provides an opportunity to verify the interpretation of fundamental-mode data (Martin and others, 2017; Yong and others, 2019).

An important limitation of the multiple-method approach is that it yields datasets with too many points for easy inversion. The forward-model calculation of dispersion data from a layered velocity model is computationally intensive (Haskell, 1953). As a result, the time required for global inversions of large numbers of points is commonly prohibitive. Regularized linear inversions provide a faster alternative but may not yield accurate results, especially when the velocity structure is complex. To circumvent this limitation, dispersion data are commonly summarized and reduced by using a combination of manual editing and polynomial fitting. This approach yields a representative dataset composed of the minimum number of points that are amenable to rapid inversion. Furthermore, experience has shown this approach to yield accurate results (Martin and others, 2017; Yong and others, 2019).

We anticipate that the DPE will be easily incorporated into many different site-characterization workflows because of its graphical implementation on an open-source platform. The Python language, in particular, is widely used in geophysical-data processing (Beyreuther and others, 2010; Megies and others, 2011; Krischer and others, 2015). We also hope that the availability of this tool will speed the adoption of multiple-method site characterization as a standard practice, yielding more accurate and reliable results (Yong and COSMOS Guidelines Facilitation Committee, 2016; 2017; 2018; Yong and others, 2018).

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Method for Calculating the Representative Dispersion Curve

The most important output of the DPE program is the representative dispersion curve (RDC; Yong and others, 2013; Martin and others, 2017; Yong and others, 2019. The RDC (1) combines dispersion data produced by multiple methods and (2) reduces the total number of points in the dataset prior to inversion. Inversion of the RDC should yield a robust shear-wave velocity model with minimal computational time. Both of the two methods for calculating the RDC are implemented in the DPE program, and both methods use a weighting scheme described in the subsequent section.

Joh (1996) introduced a piecewise polynomial fit as a means of reducing the number of points in a dispersion dataset prior to inversion. An adapted version of this method was implemented here. By default, the data domain is in units of frequency, but the user may alternatively choose to work in velocity-wavelength space. First, the domain of the data is divided into a user-defined number of log-width bins. Logarithmic bins are used because high frequencies typically yield much more data than low frequencies, especially for active-source measurements, so log-width bins tend to distribute data more evenly. The data are then fit to weighted second-order polynomials with one polynomial associated with each bin. To achieve a smooth curve, however, each polynomial is fit not only to the data in a single bin, but simultaneously to the data in adjacent bins. The user controls the smoothness of the RDC by adjusting the number of adjacent bins included in the polynomial fits. The RDC is calculated by evaluating the appropriate polynomial at the midpoint of each bin except at the boundaries of the domain, where the polynomials are evaluated near the edge of the bins to preserve the original domain size in the RDC. The standard deviation of the data in each bin is reported as a measure of the local precision of the RDC.

As an alternative to the piecewise polynomial method, the user may calculate the RDC by using weighted-mean values. In this approach, the data are also binned logarithmically. The weighted mean of the data in each bin is calculated and reported at the midpoint of the bin; these data form the RDC. Unlike the polynomial method, no additional smoothing is imposed. The standard deviation of the data in each bin is also reported as a measure of the local precision of the RDC.

If neither the piecewise polynomial nor the weighted-mean methods are acceptable, the user may calculate the RDC by using an alternative method outside the DPE program. DPE outputs the complete edited datasets as delimited text files for this purpose.

Weighting the Data

The DPE employs a compound weighting scheme. The polynomial-fit routine searches for the parameters that minimize the sum of the weighted squared errors, E :

$$E = \sum_j W_j^2 |y_j - p(x_j)|^2, \quad (1)$$

where

y_j is an observation,
 $p(x_j)$ is a prediction at the frequency x_j , and
 j is the index of a point within the domain of this polynomial fit.

The fit domain consists of a log-width bin and adjacent bins as defined by the user. Points on the weighted-mean RDC are calculated by using a similar weighting term

$$y = (\sum W_k)^{-1} (\sum W_k y_k), \quad (2)$$

where k is the index of a point within the current bin, and the compound weight, W , at any point (j or k) is defined as the product

$$W = ab, \quad (3)$$

where a and b vary according to the input datasets. The first component weight, a , is applied automatically to ensure that all input datasets have equal influence on the result, even if one dataset locally consists of many more points than another dataset. The value of a is identical for all points in the fit domain that are derived from the same input dataset and is calculated as the inverse of the total number of points in the fit domain in each dataset. The second weight, b , is defined by the user in the interval from zero to one for each input dataset. Although b is set to 1 by default, it is sometimes useful to manually adjust the weighting if the user has a reason to favor one dataset over another. Data collected on a two-dimensional array, for example, might be given more weight than data from one-dimensional array.

System Requirements and Installation Instructions

DPE was written and tested in the Anaconda distribution of Python 3; any computer system capable of running this distribution should also run DPE. Acceptable operating systems include Windows 7, macOS 10.10+, and many Linux distributions. DPE should also run in other distributions of Python 3, although it has been minimally tested. The essential libraries are PyQt 5, NumPy, SciPy, Matplotlib, and Pandas. In particular, PyQt 4 is not acceptable. A disadvantage of the Python language is that it is not fully backwards compatible. The Anaconda Distribution is freely available at <https://www.anaconda.com>.

Installation of DPE simply requires copying the source files to a folder in Python's path; it is recommended to dedicate a folder to DPE alone. There are four source files: `dpeExe.py`, `mplwidget.py`, `dpeUi_v1p5.py`, and `dpeAppFmwk_v1p5.py`. Because Python requires no explicit compiling by

the user, these files are ready to use and also readable by the user. To run DPE, call `dpeExe.py` from the command line. For example:

```
:DPE dmcphillips$ python dpeExe.py
```

Input and Output Conventions

Acceptable input files include any delimited text file, but they must have at least two columns and a header row with column labels. Only “Velocity,” “Frequency,” and “Wavelength” are accepted as labels (DPE ignores columns beyond the third one), but the order of the columns and the delimiter do not matter. For example:

Velocity	Frequency	Wavelength
560	5.76	97.1
552	5.80	95.2
...

The user has considerable flexibility for loading input files in DPE. For example, the user may enter a list of N individual file names. Alternatively, the user may use

pattern-matching tools such as wildcards from the `glob` module (<https://docs.python.org/3/library/glob.html>) to load multiple files simultaneously. This method may be useful if the user wishes to edit many dispersion data files with systematically organized file names.

Output files are written as comma-separated values. By default, DPE writes N output files corresponding to the number of input datasets when users save their work. The output files include “_trim” in the file names. Users may also specify a filename to use for additional output files containing the RDC. The RDC file has four columns listing data for each bin: velocity, frequency, wavelength, and standard deviation. The fourth column is a measure of the data scatter around the RDC. Because DPE ignores the fourth column, the RDC file may be subsequently loaded for additional editing.

Quick-Start Guide

The following steps describe the use of DPE (fig. 1). A more detailed example is presented in the next section. First, install and launch DPE from the command line.

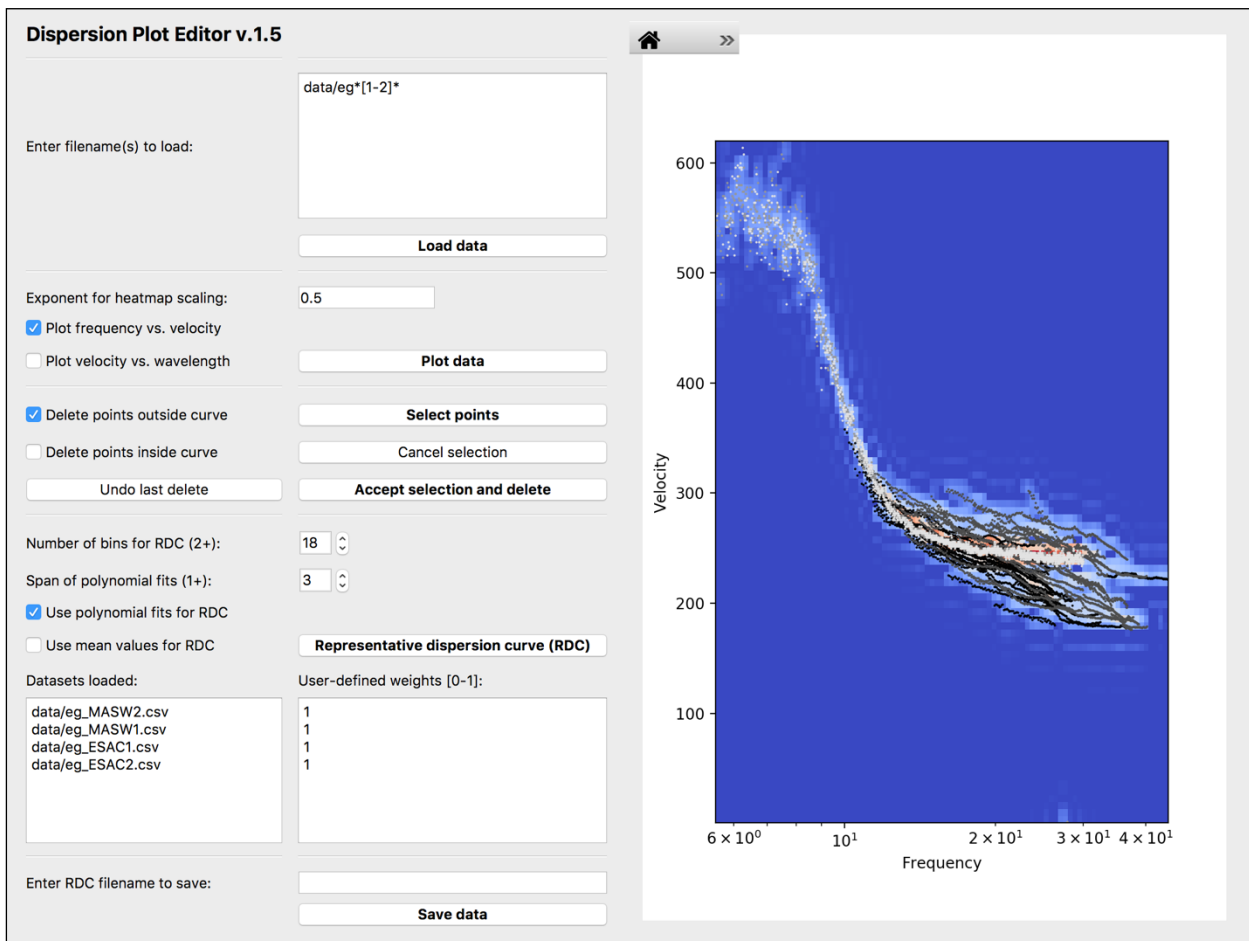


Figure 1. Screenshot showing example of the Dispersion Plot Editor (DPE) version 1.5 graphical interface after loading and plotting data. Input filename includes wildcards and the path name for the subdirectory containing the data files. MASW data are plotted as dark gray points in the lower half of the plot; ESAC data are plotted as very light gray points. To provide a constant frame of reference, the heatmap itself, which shows the densities of all points and is shaded, is not updated as data are edited.

1. **Load data.** Type filenames into the text box, one per line, taking care to include any subdirectories (for example, data/file1.csv; data/file*.csv). Clicking the “Load data” button more than once will overwrite previously loaded data with new data.
2. **Customize plotting options.** Choose an exponent for the heat-map color scaling; values between 0.1 and 0.9 commonly reveal multiple data modes best. Use the check boxes to indicate whether to plot frequency versus velocity (the default choice) or velocity versus wavelength.
3. **Plot data.** The “Plot data” button plots currently loaded datasets. Each dataset has a unique grayscale value. Click again to change plotting options or clear an undesirable RDC.
4. **Select valid data.** Use the checkboxes to indicate whether to select and delete points inside or outside a selection curve. Click “Select points” to activate the selector tool. Draw a curve on the plot while holding down the left mouse button. Click “Cancel selection” to start the process anew. Click “Accept selection and delete” to delete the selected data and plot the remaining data again (note that the heat map does not change). Click “Undo last delete” to revert. This process can be repeated as many times as necessary, alternating between deleting points inside and outside the selection curve. Consider saving the trimmed data now rather than later in the process.
5. **Define RDC methodology.** Use the checkboxes to indicate whether to use the polynomial or mean-value method for calculating the RDC. If desired, adjust the user-defined weights in the text box. RDCs are usually best defined by the use of 12–24 bins. For piecewise fits, polynomials should usually span fewer than about 5 bins.
6. **Calculate the RDC.** Click “Representative dispersion curve (RDC)” to calculate and plot the RDC by using the current options and data. Consider changing the method and clicking again to view alternatives. Click “Plot data” to clear the RDC plots.
7. **Save data.** To save the RDC and trimmed data, type one filename for the RDC in the text box and click “Save data.” To save only the trimmed data, simply click “Save Data” at any time. Clicking more than once will cause the program to overwrite existing files.
8. **Save plots.** Use the “Save” option in the toolbar located above the plot to save an image of the plot itself.

When one project is complete, close DPE and launch a fresh window before loading new datasets.

Workflow Example

The capabilities of DPE are presented here with a detailed workflow for combining active and passive data, trimming spurious points, calculating a RDC, and saving the results in an output file. This example is directed at the novice Python user and formatted for macOS 10.10+. Although DPE may be called from an interactive environment such as Spyder, it is usually more efficient to call DPE directly from the command line of a terminal application. To start, navigate to the DPE directory, and list its contents in a terminal application:

```
:~ dmcphillips$ cd Documents/PYTHON/DPE
:DPE dmcphillips$ ls
dpeAppFmwk_v1p4.py
dpeExe.py
dpeUi_v1p4.py
data
mplwidget.py
```

The directory “data” contains five text files, data from active-source Multi-channel Analysis of Surface Waves (MASW) (Foti, 1999; Park and others, 1999) and passive-source Extended Spatial Auto-Correlation (ESAC) (Okada, 2003) measurements, respectively:

```
:DPE dmcphillips$ ls data
eg_ESAC1.csv
eg_ESAC2.csv
eg_MASW1.csv
eg_MASW2.csv
eg_MASW3.csv
```

If all the files are present, call DPE:

```
:DPE dmcphillips$ python dpeExe.py
```

This action should launch the graphical interface in a new window. For this example, consider the file eg_MASW3.csv to be part of a different site-characterization project. Load only the four relevant datasets all at once by using wildcards (*) and brackets ([]). In the uppermost box, type:

```
data/eg*[1-2]*
```

and click the “Load data” button. This command creates four datasets in DPE: two consisting of passive-source data (ESAC) and another two consisting of active-source data (MASW). It also populates the “Datasets loaded” and “User-defined weights” boxes. Note that the use of wildcards (*) and brackets ([]) is not required; entering all four complete filenames, or any combination of complete filenames, wildcards (*), and brackets ([]) would also work. See the documentation for the glob module for additional information (<https://docs.python.org/3/library/glob.html>). To plot the datasets in frequency space, simply click “Plot data” (fig. 1). Otherwise, check the “Plot velocity vs. wavelength” box before clicking “Plot data.”

Each dataset is plotted as points with the same grayscale value. The heatmap plotted behind the points is calculated jointly from all of the datasets and is useful as a visual aid for interpreting different modes in the dispersion data. The color scale can be adjusted by changing the exponent on the power-law color normalization. This exponent is commonly called the gamma value, and a value of 1 yields a linear color scale. Smaller values are useful for highlighting sparse data.

Next, select and delete spurious data. Click on the the “Select points” button. This enables the cursor to draw on the plot while the left mouse button is depressed. Draw a curve around the high-quality data (fig. 2); there is no need to close the curve. In this example, higher modes are trimmed from high-frequency data, and noise is trimmed from low-frequency data. If the selection looks unsatisfactory, click on the “Cancel selection” button. Otherwise, click on the “Accept selection and delete” button. The plot is redrawn without the spurious data. Note that the heatmap remains unchanged. It is also possible to specifically delete small groups of points

by checking the “Delete points outside curve” box. To zoom into a small area, use the Zoom tool in the menu on the top left corner of the heatmap (fig. 3). Users can select and delete points in as many iterations as necessary.

After the spurious data have been removed, calculate the RDC from the acceptable data. First, enter the number of bins by using the spinner box (a good starting point is 12–24). Second, choose the span of the polynomial fits in terms of a specified number of adjacent bins. Third, select the user-defined weights for each dataset by typing a number between 0 and 1 in the “User-defined weights” box which is adjacent to the list of the loaded datasets. In this example, the passive and active datasets are given equal weight. Finally, click “Representative dispersion curve (RDC)” (fig. 4). If the RDC is not ideal, click “Plot data” to replot the edited data without the RDC, and try again by using different parameters.

When the RDC is satisfactory, save the data. To save only the edited datasets, simply click “Save data.” This command saves the edited datasets by appending “_trim” to the filename.

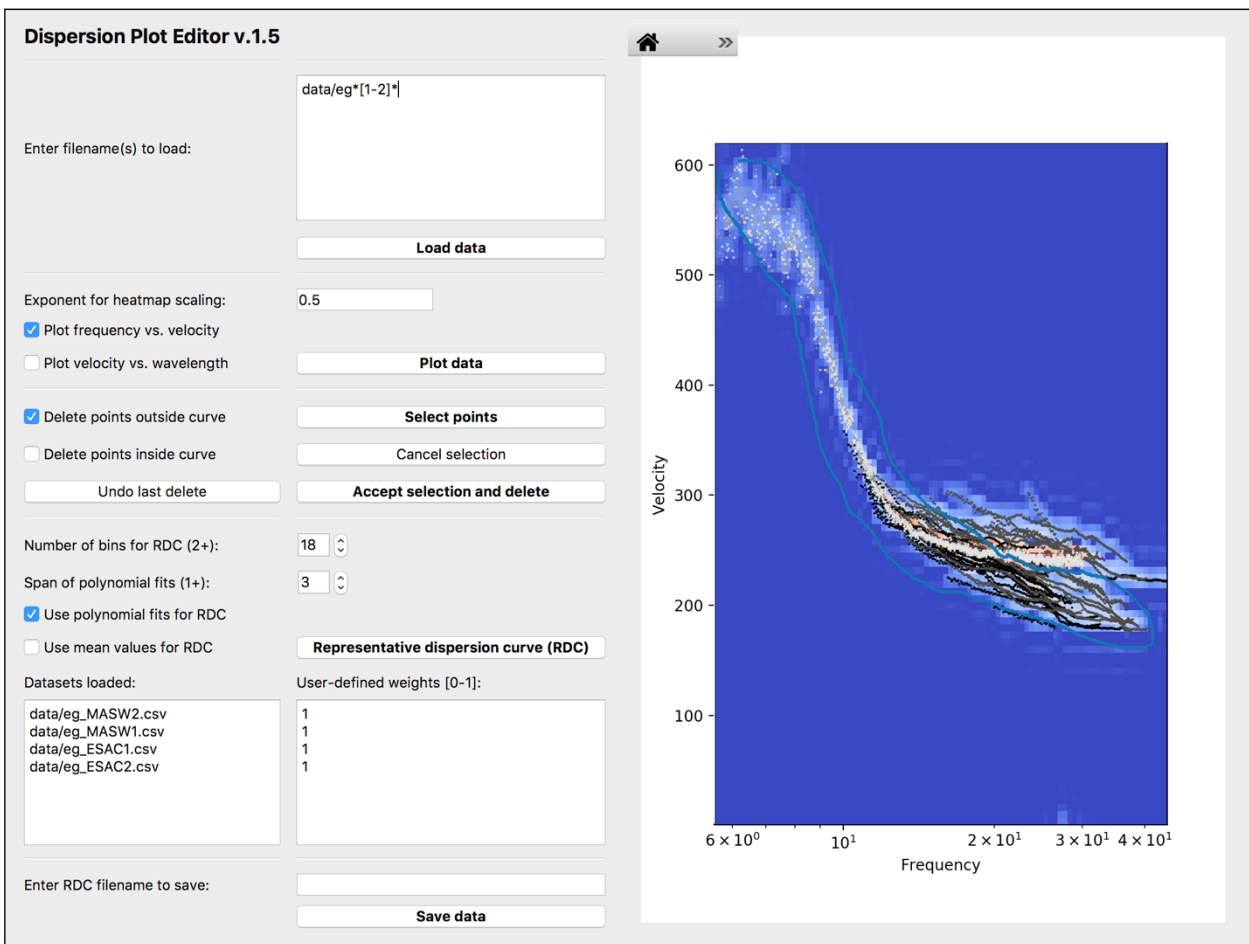


Figure 2. Screenshot showing example of data selection and deletion. Draw a curve to select data after clicking “Select points.” In this case, the data outside the shape, which are primarily higher modes in the MASW data, will be deleted.

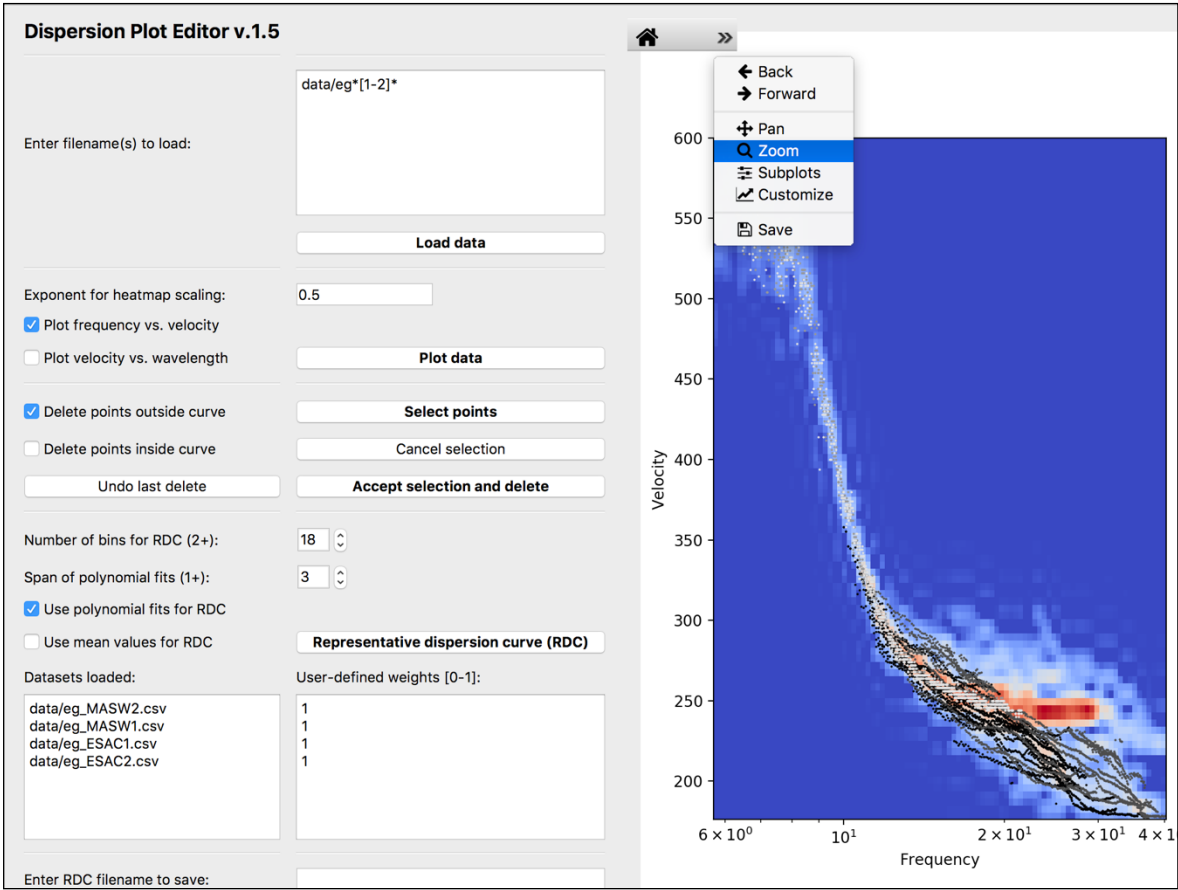


Figure 3. Screenshot showing example following the first deletion of spurious data. The user may focus on details of the plot by using the zoom tool and delete data by using as many iterations as necessary.

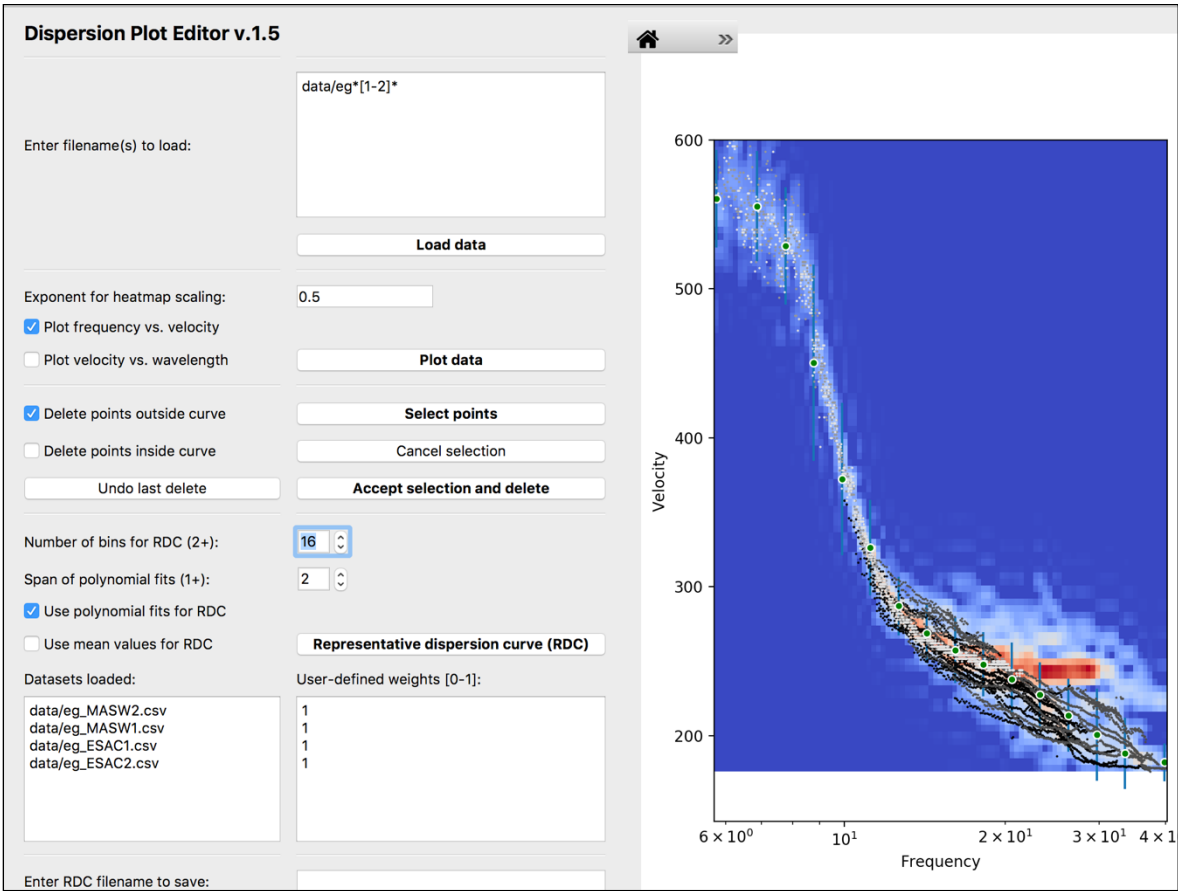


Figure 4. Screenshot showing example of a representative dispersion curve (RDC) plot. This example uses 16 log-width bins and fits a polynomial through data in one adjacent bin on each side of each bin. Blue bars represent the range of the data in each bin at two standard deviations. All of the user-defined weights are equal to the default value of 1.

To save the RDC as well, enter one filename, including any necessary directories, in the lower box, and click “Save data” (fig. 5). Check that the save was successful.

```
:DPE dmcphillips$ ls data
eg_ESAC1.csv
eg_ESAC2.csv
eg_MASW1.csv
eg_MASW2.csv
eg_MASW3.csv
eg_ESAC1_trim.csv
eg_ESAC2_trim.csv
eg_MASW1_trim.csv
eg_MASW2_trim.csv
testOutRDC.txt
```

Troubleshooting

For simplicity, DPE employs minimal error checking beyond the native libraries. If the program is not behaving as expected, check the terminal window for error messages. For novice users, perhaps the most common errors result from mistakes in the path and filenames. Recall that filenames entered in DPE must include the prefix “data/” if a subdirectory of datafiles is in use. Microsoft Excel is sometimes useful for constructing input files by using “Save as” and selecting the “.csv” extension.

The DPE codes are available by request for no cost. Please report bugs to dmcphillips@usgs.gov.

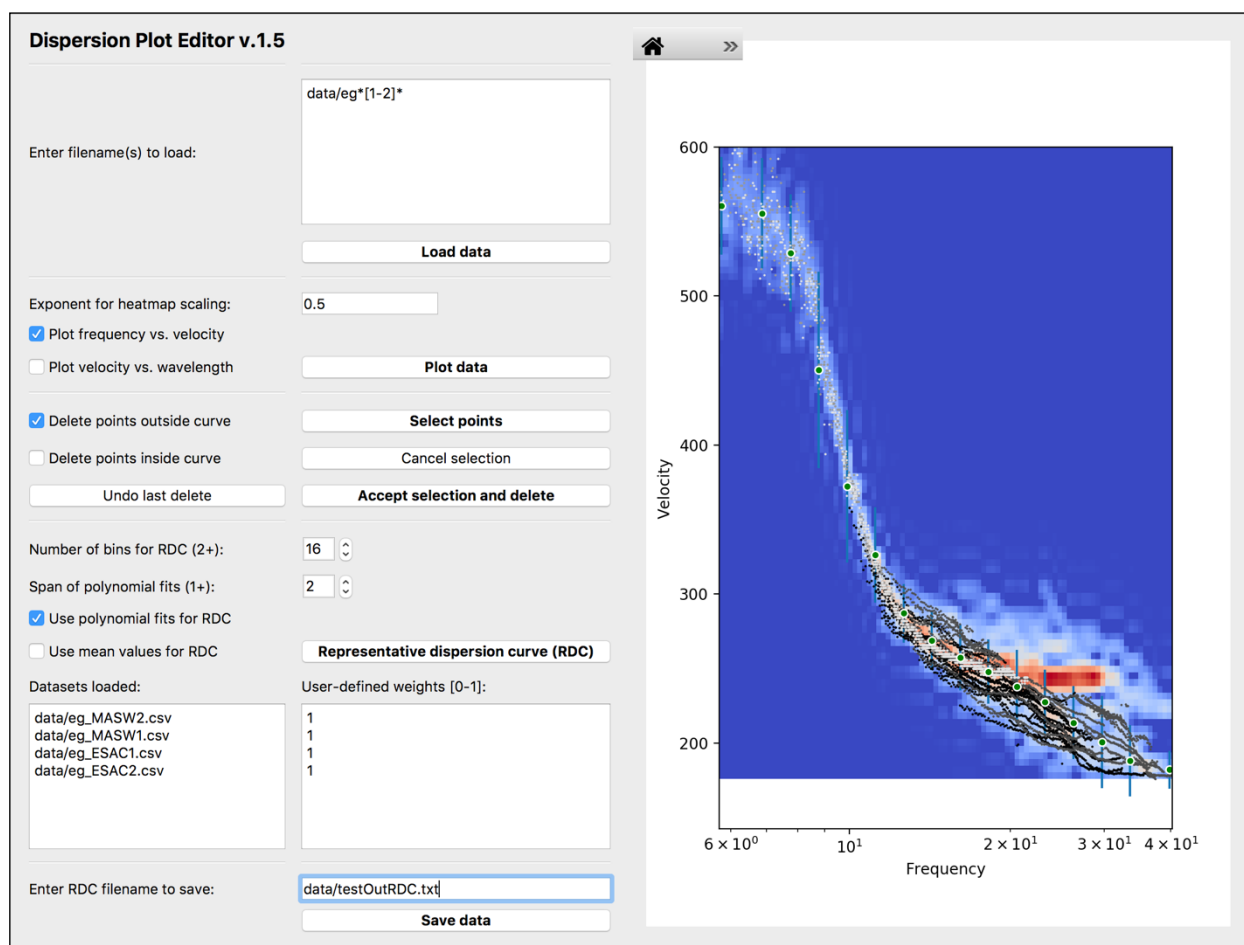


Figure 5. Screenshot showing example of saving data. Enter output filename for the RDC. Save both the RDC and all edited datasets by clicking on “Save data.”

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