VolksMeter with one as opposed to two pendulums

Preface
In all of the discussions that follow, remember that a pendulum, which is the seismic element used in the VolksMeter, responds only to horizontal acceleration (with earth tilt being a special case thereof).

For users only interested in detecting an earthquake, the single-pendulum VolksMeter may be the best choice. Seismic waves contain so many polarization states that a single pendulum will usually give a response no matter its orientation.

1 Body waves

Waves that travel `straight' through the earth from an earthquake to the seismometer comprise two parts, the (i) P wave which has a longitudinal polarization, and (ii) the S wave which has a transverse polarization. The S wave travels more slowly than the P wave, so it arrives at the seismometer with a time delay. The duration Δt of this delay is a measure of the distance d between source and observer through the relationship

$$d = \frac{v_p \, v_s}{v_p - v_s} \Delta t \qquad (1)$$

This expression assumes that the speeds of the P-wave (v_p) and the S-wave (v_s) are constant everywhere along the path. Such as assumption is not completely true because a seismic speed is proportional to the square root of the ratio of elastic constants to density. These change with depth and material type. Note also, that the distance computed by this equation is not along the surface of the earth but rather along the path traveled by the body waves. Because of refraction (bending of the path due to speed variation with depth) the path is not a straight line. Complications of this type mean that earthquake locations are not estimated on the basis of Δt; rather triangulation is used, based on data from a network of sensors.

The direction of earth particle motion is parallel to the direction of propagation for the P wave and for the S wave it is perpendicular. Only the body waves disturb a seismometer if the instrument is close to the earthquake (ignoring surface waves that may come along much later after circling the earth). One or the other of the P and S waves will generally cause an instrument response, although the relative size of the response to P and S waves will depend on the pendulum's orientation relative to the direction of the earthquake. For individuals especially interested in estimating distance to an earthquake on the basis of the Δt discussed above, the two-pendulum instrument is to be preferred; since the `clarity' of the waves is not generally the same from both pendulums. In the discussions that follow, the direction to the earthquake, relative to the instrument, will be referred to as the `angle of incidence'.

2 Microseisms

Much of the surface of the earth vibrates nearly all the time, largely because of ocean waves that communicate with the solid earth beneath the waves. These vibrations, which are called microseisms, fall into two major period groupings-the (i) primary ones with a period in the 10 - 20 s range and the (ii) secondary ones from 4 - 10 s. There is also long-period noise in the band from 20 - 40 s that shows seasonal variability. The secondary microseisms evidently derive from swells near the coastline, whereas the other types are related to ocean wave activity in deep water.

For horizontal seismometers there is considerable anisotropy associated with these noises, at least for the secondary microseisms observed in Macon, Georgia, as illustrated in Fig. 1.

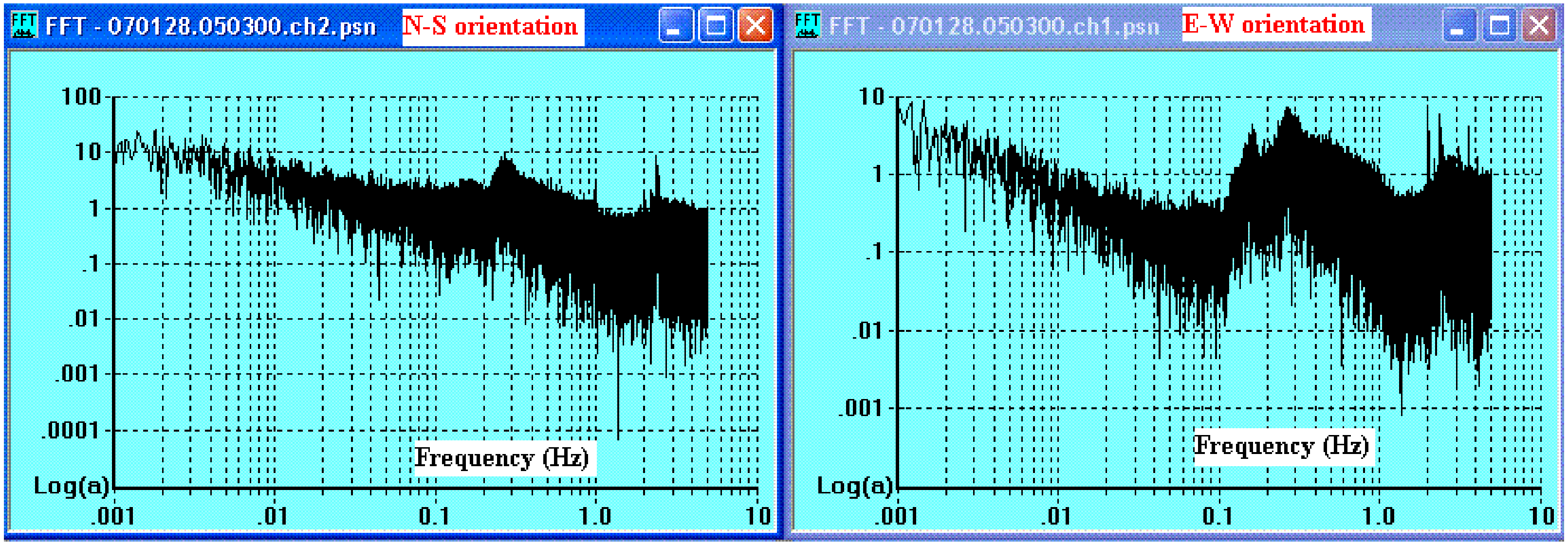


Figure 1. Illustration of the difference in response to secondary microseisms between the North-South pendulum and the East-West pendulum for a VolksMeter located in Macon, Georgia.

Before discussing the microseisms, let us note that there are several peaks and lines that are common to the two pendulums and which derive from disturbances to the building which houses the instrument. The line at 2.339 Hz (along with the local noise hump on which it stands, is virtually identical for the pair. The 2 Hz sharp, strong line in the E-W record is almost totally missing from the N-S record. Similarly, the 1 Hz line in the N-S record is at or below the noise level in the E-W record.

There are also some dramatic differences in the two spectra at long to very long periods. In particular notice the dramatic difference in the slopes of the two graphs in the range from 0.1 - 0.001 Hz.

Now consider the microseisms. The peak at 3.8 s (0.26 Hz) is clearly visible in both records. Although the absolute intensity for this peak is about the same for both, it is much more visible in the E-W record because of the substantially lower noise on both sides of the peak. Because of the side-noises, the peak at 6.4 s, which is also visible in both records; is just barely recognizable in the N-S record.

2.1 Using WinQuake for spectral analysis

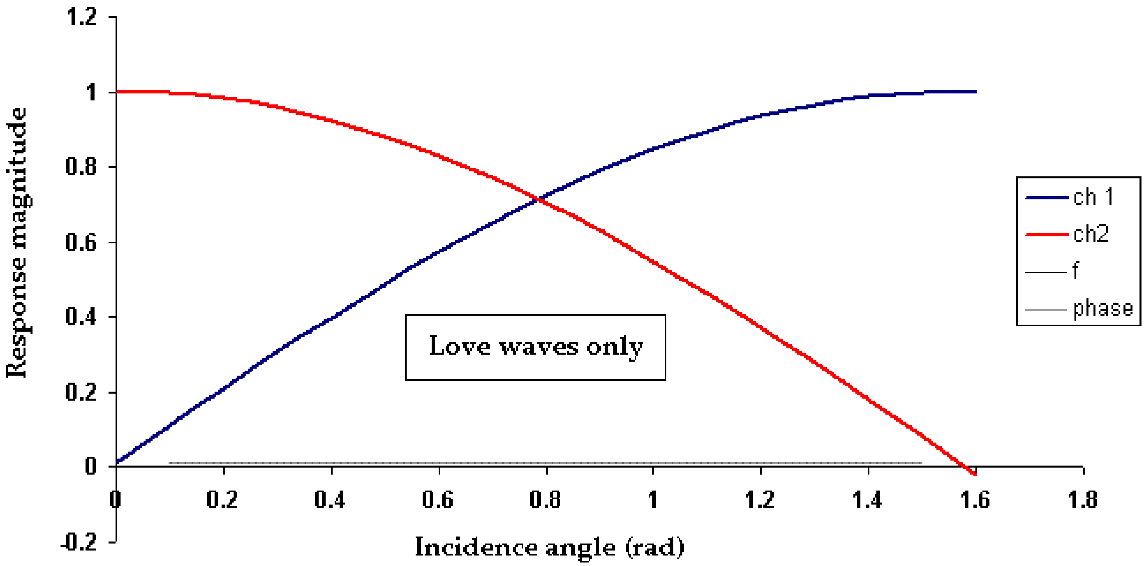
This is an opportune time to discuss features of WinQuake and the software tools it uses, based in the FFT-that generated Fig. 1. The first thing the user of the VolksMeter should note when it comes to spectral analysis-is that the raw data records must be high pass filtered at a suitably low frequency before the FFT is performed (discussed elsewhere in this manual). After thus filtering, the spectrum is computed by `clicking' with the left mouse button on one of the two FFT icons located on the toolbar. If the entire time record is displayed, then the left icon is selected. If the x-scale capability has been employed, then the right icon is selected (the left one visible without highlight, no longer active).

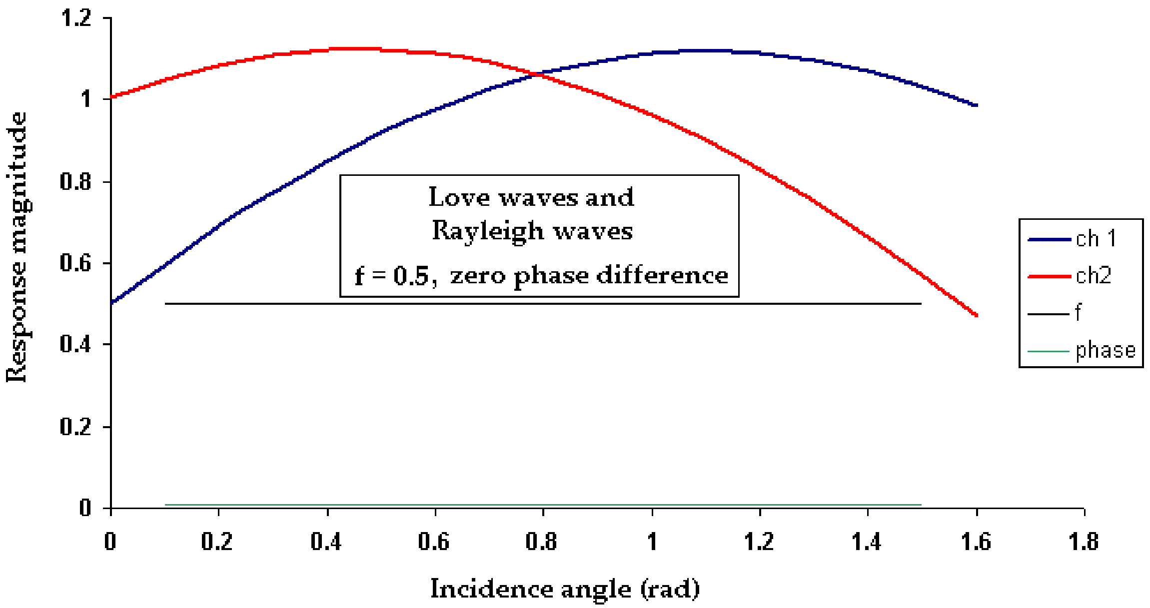
Once the spectrum has been displayed, the frequency of any piece of it may be determined by placing the tip of the arrow-head cursor at the line or object of interest. The numerical value of the frequency/period corresponding to that position is then shown at the top of the frequency graph.

3 Surface waves

When body waves from an earthquake superpose at the surface of the earth, they combine to form surface waves of two different polarization types, the (i) Love wave, and (ii) the Rayleigh wave. Like the body S wave, the Love wave is transverse (with horizontal particle motion of the earth's surface), and it generally has the greatest influence on a horizontal seismometer (assuming optimal angle of incidence). The Rayleigh wave involves mostly vertical particle motion, and one might thus conclude that it cannot drive a horizontal seismometer. This conclusion is incorrect, since Rayleigh waves have a horizontal component of acceleration because the particle motion is elliptical, with the major axis of the ellipse being vertical. The ratio f of the horizontal component to the vertical component can be distributed through a fairly large range of values because of inhomogeneities of the earth. For the graphs that follow the ratio is assumed at f = 0.5.

If the Love wave were the only surface wave disturbance of importance to a horizontal seismograph, then the output of a single pendulum instrument would be in accord with the top graph of Fig. 2.


Response magnitude
Incidence angle (rad)
Love waves only
ch 1
ch2
f
phase
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


Response magnitude
Incidence angle (rad)
Love waves and
Rayleigh waves
f = 0.5, zero phase difference
ch 1
ch2
f
phase
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


1.8
1.6
1.4

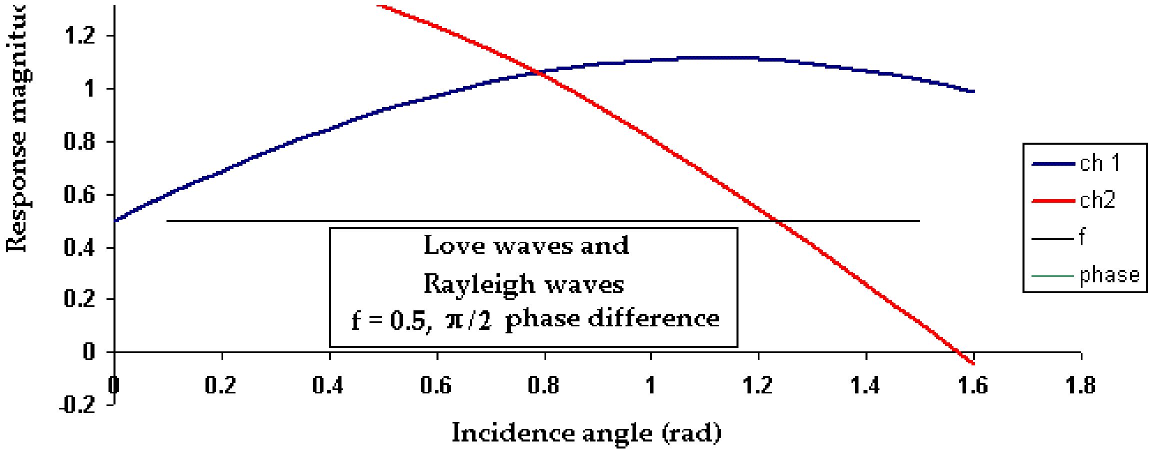


Figure 2. Illustraton of the difficulties of estimating direction to an earthquake, even when using a two-pendulum instrument.

It is seen from the top graph, that a Love-only wave would give rise to extreme variations in the response magnitude, according to the value of the incidence angle. For the graph shown, two pendulums in quadrature are indicated; i.e., the pendulum corresponding to the red curve swings at right angles to the pendulum corresponding to the blue curve. Only the component of the horizontal acceleration that is perpendicular to the plane of pendulum motion is able to excite the pendulum. Thus when one pendulum is excited at the maximum (1), the other one shows no motion whatsoever. With the addition of the Rayleigh wave, everything changes. Each pendulum is now excited through the superposition of each of the two components capable of driving it-one from the Rayleigh-wave horizontal component and the other from the Love-wave. The manner in which the superposition is either in-phase or out-of-phase or somewhere in-between depends on the phase difference between the waves, as shown in the middle and lowest graphs of Fig. 2.

As might be expected from the lowest two graphs of Fig. 2, estimating direction to an earthquake could be a formidable task, even if the Love and Rayleigh waves were of the same frequency and monochromatic, as was assumed for the construction of the figure. In fact the waves are far richer in complexity than this assumption, as is now shown with an example.

Shown in Fig. 3 is a portion of the records collected by a two-pendulum VolksMeter in Macon, GA following the Hawaii Islands earthquake of 15 October 06.

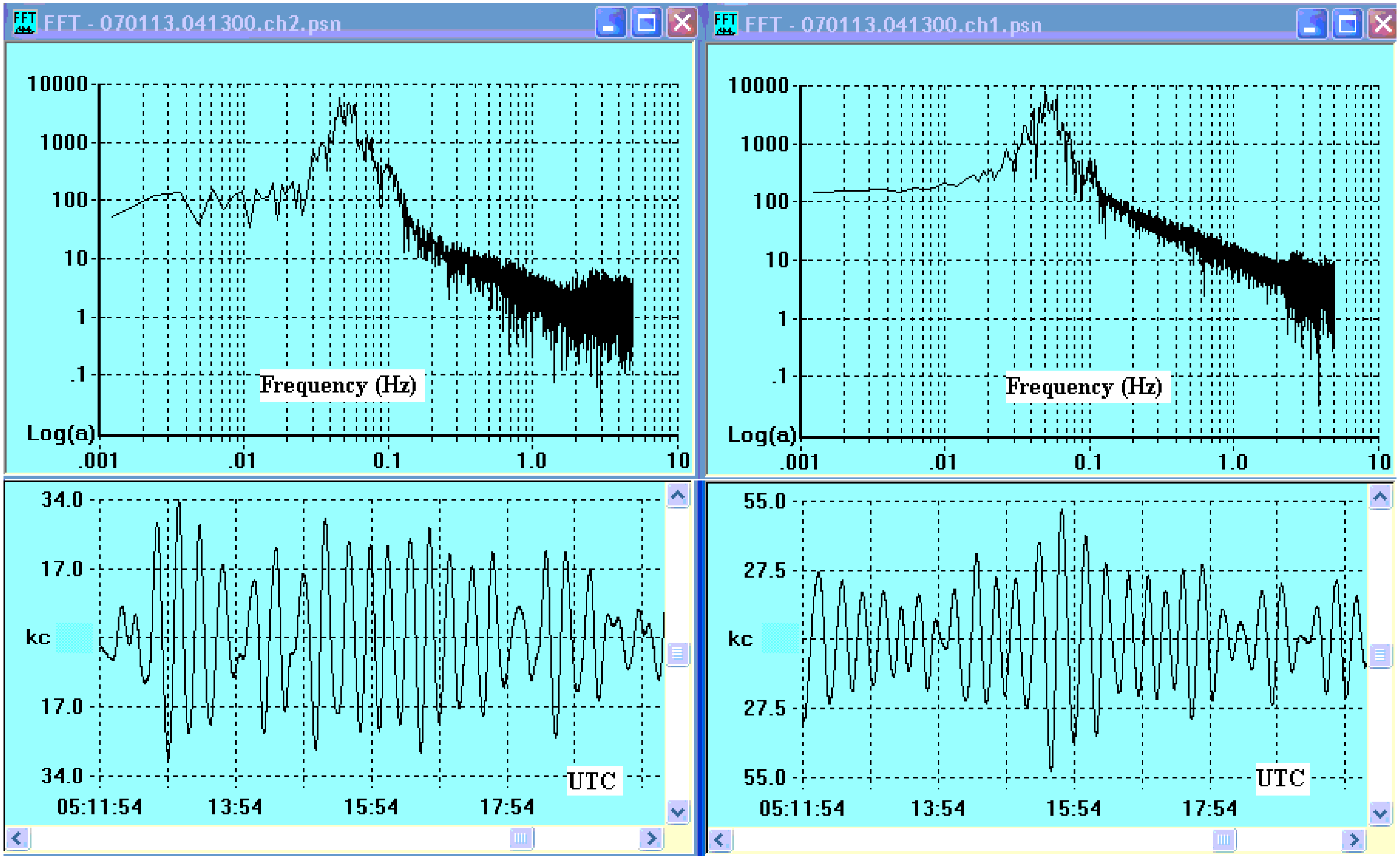


Figure 3. Time-domain (500 s duration) and associated frequency-domain portions of records following the Mag. 6.7 earthquake of 15 October 06 off the Kona Coast of Hawaii. Low-pass filtering was done at 0.1 Hz.

The record segments selected for Fig. 3 correspond to the time when the surface waves were at their maximum amplitudes. It is seen that there is no obvious correlation between the time records from the two pendulums, as would be expected if the response were from only a Love wave.

Another earthquake record for which little direct correlation between the N-S and E-W pendulum responses was found was the Kuril Islands earthquake of 13 January 07, shown in Fig. 4.

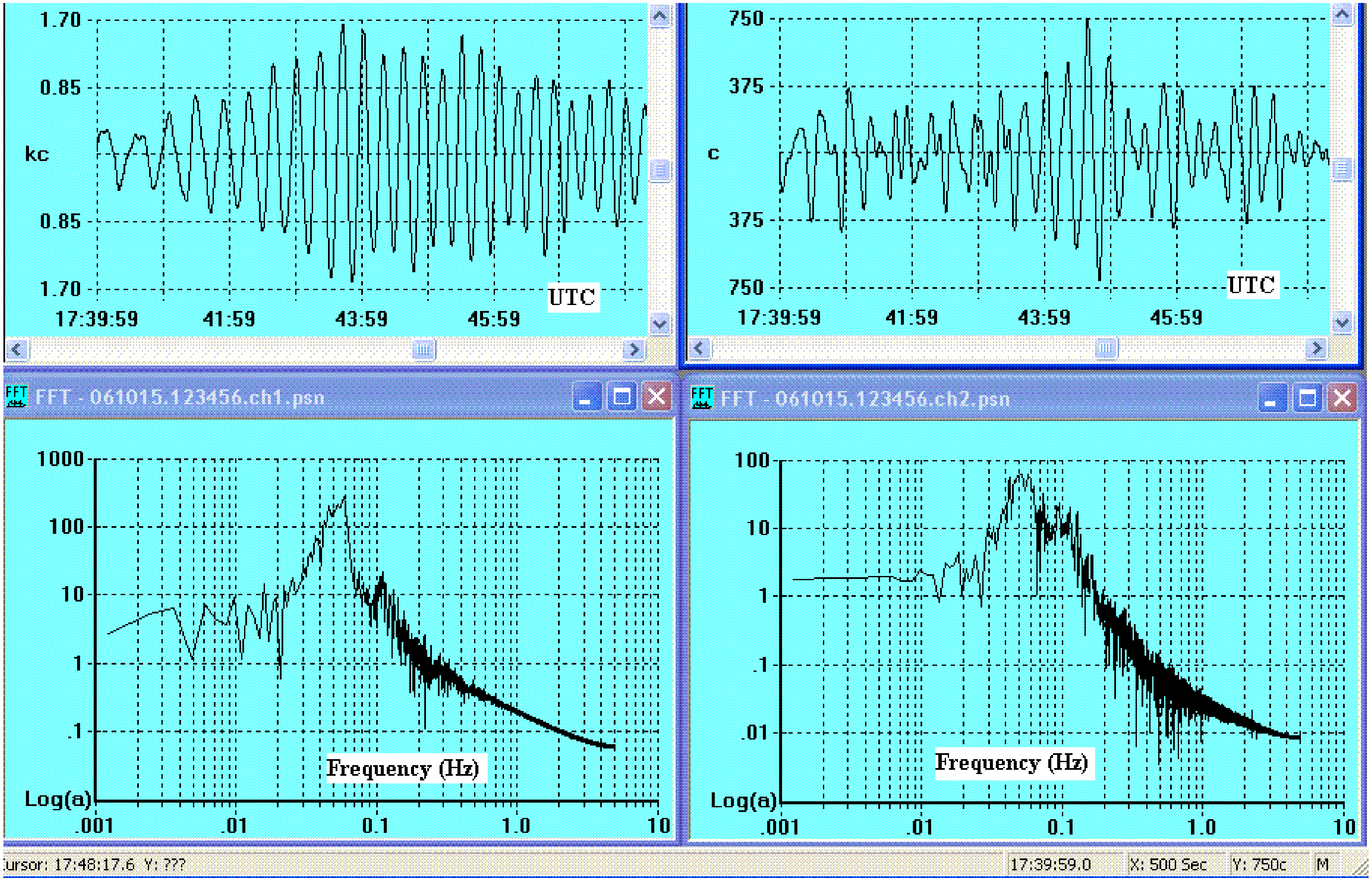
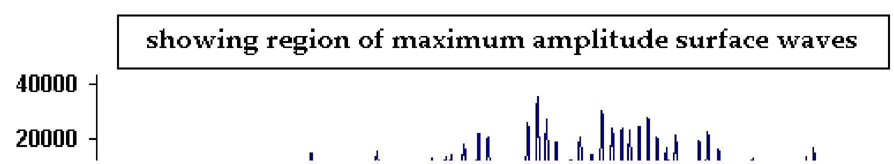


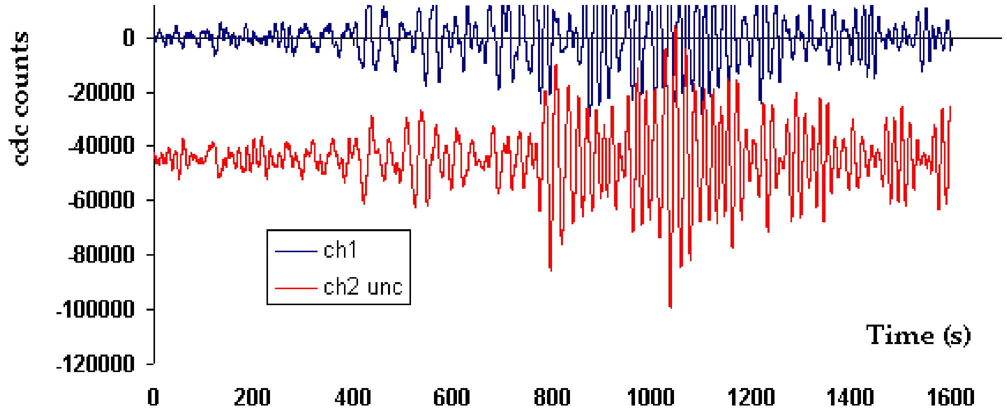
Figure 4. Time-domain (500 s duration) and associated frequency-domain portions of records following the Mag. 8.1 earthquake of 13 January 07 east of the Kuril Islands. Low-pass filtering was done at 0.1 Hz.

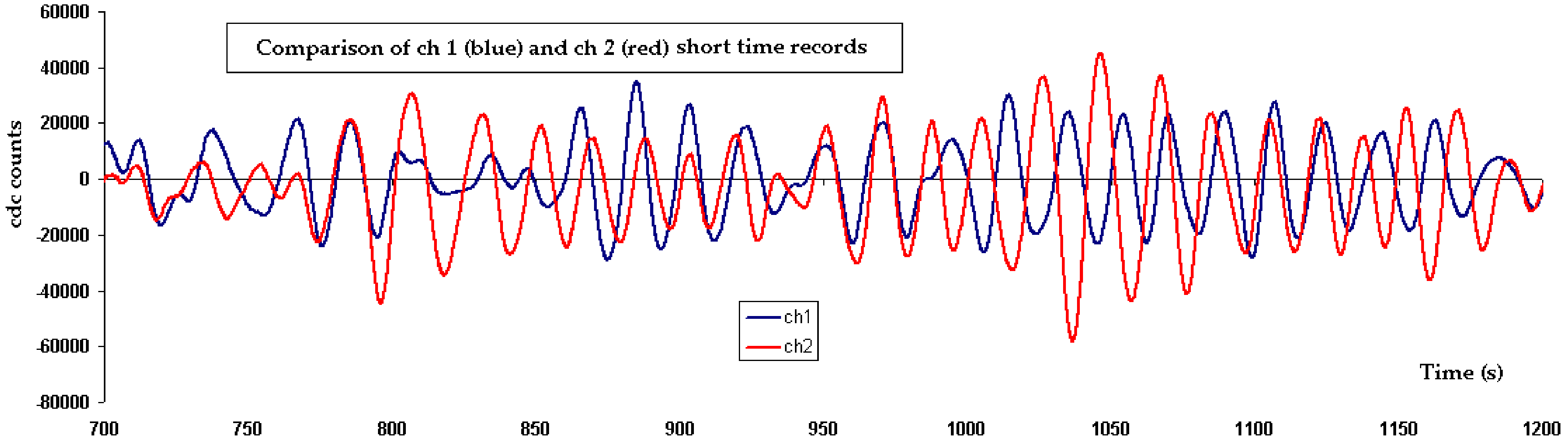
4 Using Excel with WinQuake

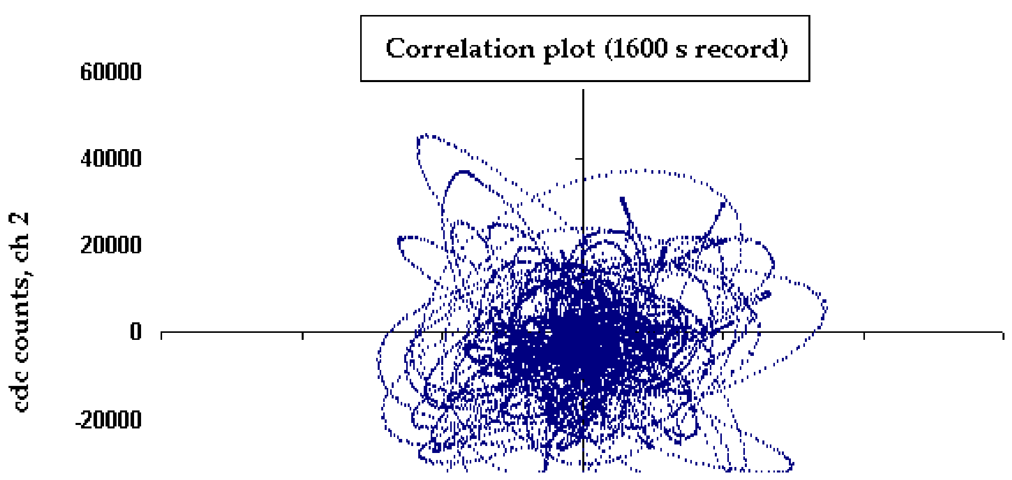
Sometimes it is useful to output data from WinQuake for purpose of analysis with various sophisticated algorithms built into Excel. Frequency data is directly exported as a text file by clicking on the `export' icon. To deal with time data, one first uses the `save' icon and selects `text' from among the several save-file possibilities indicated. When exporting the text files into Excel, use the `delimited-tab-comma' option.

An example of some things that can be done with Excel are shown in Fig. 5.




cdc counts
0
-20000
-40000
-60000
-80000
-100000
-120000
ch1
ch2 unc
Time (s)
0
200
400
600
800
1000
1200
1400
1600


Comparison of ch 1 (blue) and ch 2 (red) short time records
cdc counts
60000
40000
20000
0
-20000
-40000
-60000
-80000
ch1
ch2
Time (s)
700
750
800
850
900
950
1000
1050
1100
1150
1200


Correlation plot (1600 s record)
cdc counts, ch 2
60000
40000
20000
0
-20000

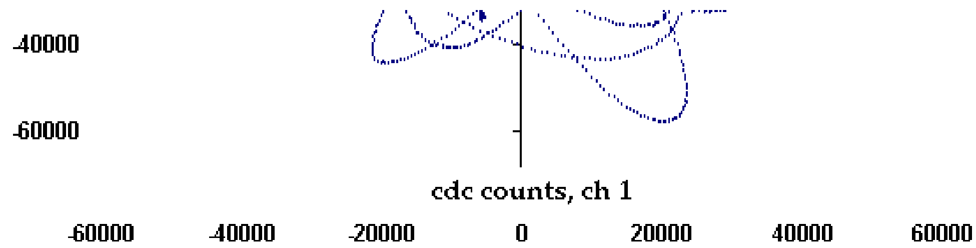


Figure 5. Examples of Excel analyses that can be done with text data outputted from WinQuake.

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On 28 Jan 2007, 16:00.