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SIGNAL ANALYSIS AND HYDROTHERMAL SURFACE FEATURES

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1 Abstract

Recently, sophisticated electronic loggers have become available that are capable of collecting immense amounts of data that can easily overwhelm the unprepared operator. Such loggers are increasingly being used in the study of hydrothermal surface features. Techniques for dealing with the resulting deluge of data can be found in the discipline of signal analysis.

It is the purpose of this paper to demonstrate the application of concepts and techniques generally used in signal analysis to the study of measurements made of a hydrothermal surface feature.

2 Signal Analysis

In signal analysis there are three key terms; the input, the system and the output. A system is composed of a number of state variables which are related to one another by operators, and are subjected to the inputs, x, producing outputs, y. In general the inputs and outputs are functions of time called signals. Signals can be described in either the time domain or the frequency domain[1].

The manner in which input, x, is transformed by the system to become output, y, is defined by the system transfer function. The system has a specific structure made up of a number of parameters, or constants, which determine the magnitude and shape of modulation induced by system operators. Affects of these operators are: attenuation, distortion, interference, and noise.

Information is conveyed through the system by the signals. Rapid information transmission is achieved by signals that change rapidly. But for systems that have energy storage components (and are not lossless) a change in stored energy requires a definite amount of time. Hence, an upper limit exists for signal speed, above which the system will cease to respond. A measure of a signal's speed is its bandwidth, the width of the signal's spectrum. Similarly, the rate at which a system can change stored energy is reflected by its usable frequency response, measured in terms of the system bandwidth [1].

3 Description of Inferno Crater Lake

Inferno Crater Lake is the water body found in the wedge shaped Inferno Crater in Waimangu Scenic Reserve. This lake exhibits water level changes of upto 10 m and changes in water temperature from 30°C to 80°C. When overflowing the lake has a volume of 65000 m^3 and a surface area of 7500 m^2. A pseudo-cycle of hydrothermal activity at the lake has been identified with a period of roughly 42 days (see figures 1, 2 and 3. The primary source of energy and mass for the lake is a vent, called Matua, in the bottom of the crater.

In 1988 an electronic logging system was installed at this lake [2]. This system can sample measurements from 16 sensors every 30 seconds, representing 2 million data points for one cycle of activity. Lake dependent variables measured by the logging system include the temperature at a number of sites in the crater basin and the differential pressures measured with gas-purge instruments between the lake edge and two sites in the lake. The temperature measurements are used to calculate lake temperature and the differential pressure measurements yield lake level.

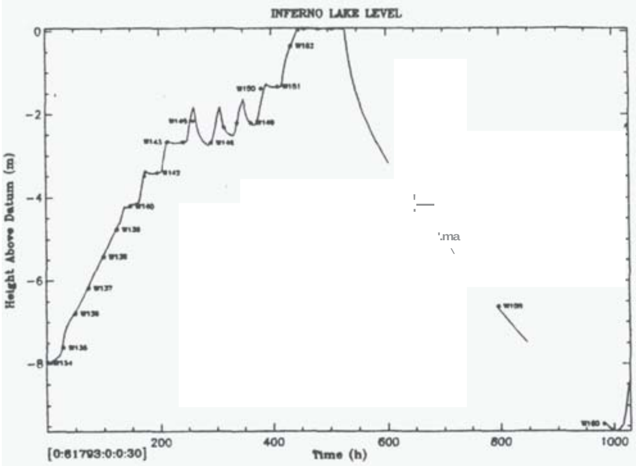

Figure 1: Reduced lake level.

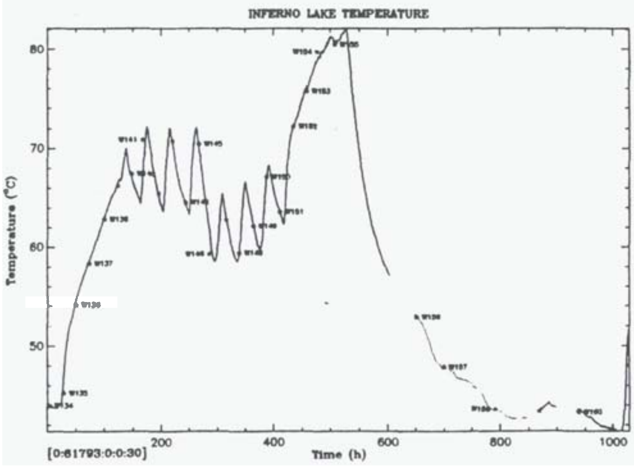

Figure 2: Reduced lake temperature.

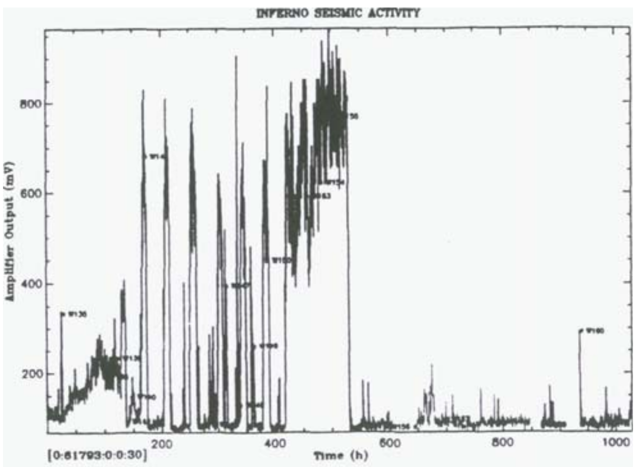

Figure 3: Seismic activity.

4 Digital Filtering

Observations of Inferno Crater Lake indicate that the temperature response time for the whole lake including the temperature transducers is about 7 minutes. Water level response time for the lake, feed vent and pressure transducers is about one minute. Hence the *bandwidth* or the width of the signal spectrum available when using the lake temperature and water level to transmit signals is limited to frequencies less than 17 mHz (1/(1 min)).

Plots of the *power spectral density* for the lake level and lake temperature during the first 4380 minutes of the recession stage of the cycle are given in figure 4. The data was processed by preforming a Fast Fourier Transform (FFT) analysis, and using the Welch method to preform a power spectrum estimation [5]. Successive sets of 256 minutes with an overlap of 128 minutes, were Hanning windowed, FFT'd and accumulated. The 95% confidence intervals are displayed on the power spectral density curves.

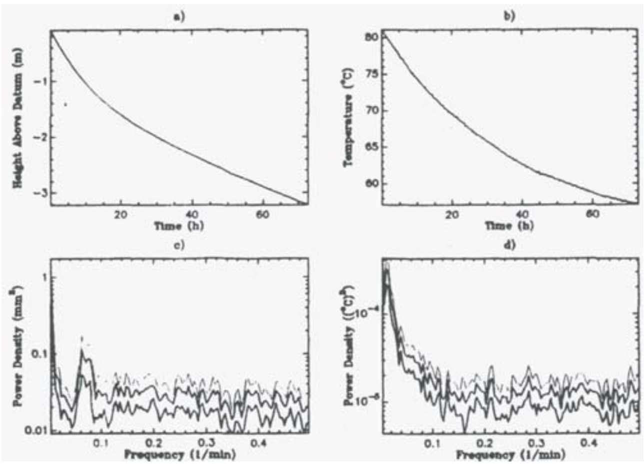

Figure 4: Lake level and lake temperature arid for the recession stage and their respective power spectral densities.

The power spectral density of the water level, plotted in figure 4 c), displays an interesting peak at frequencies between 0.8 and 1.7 mHz (0.5 and 0.1 (1/min)). This peak is caused by the finite resolution of the analogue to digital converter (ADC) within the logging system.

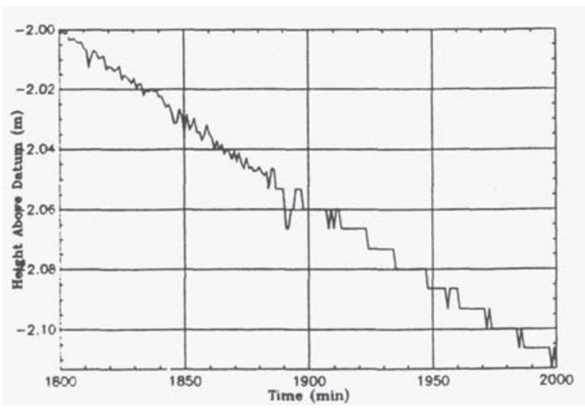

Figure 5: Reduced, but unfiltered, lake level data showing tlie change in logger resolution.

At about 1880 minutes into the recession stage tlie lake level receded below the pipe end of one of the gas-purge instruments (see figure 5). From then, measurements of the water level were preformed solely by the other instrument. The ADC range used for tie latter instrument had a resolution of 0.174 mV, equivalent to 0.7 mm of water. Hence, depending upon the rate at which the water level receded an apparent signal was detected that shifted in frequency from 1.7 to 0.8 mHz (1/(10 min) to 1/(20 min)). The increase in amplitude, of the peak, towards the lower frequencies corresponds with the greater time spent at the lower rates of water level recession (see figure 4 a)).

This peak provides calibration information for tlie powrr spectral density. Using this, it is obvious that significant spectral components arc substantially absent for frequencies greater than 1.7 mHz (1/(10 min)). The frequencies above 0.8 mHz (1/(20 min)) are in this instance considered to be "noise" wliicli can be removed from the data by the application of a low pass filter. This noise is generated by sources within the lake and the measuring instruments. They include: tlie formation of bubbles in the gas-purge instrument, the effects of lake surface wave motions, tlie nonuniform water density, surges in the outflow and the finite resolution of the logging system.

An Finite Impulse Response (FIR) low pass filter with a pass band of 0 to 0.56 mHz 1/(30 min), a transition hand of 0.56 to 1.11 mHz (1/(30 min) to 2/(30 min)), and a stop band from 1.11 mHz upwards was constructed using the Remez Exchange Algorithm [4]. Two such fitters were constructed one of length 64 points, tlie other 128 points (see figure 6 a), b), c), and d)). The longer filter is preferred, because accumulated error from tlie residual high frequency components remaining in the 64 point filter resulted in significant error when long runs of data were processed. However, for shorter data runs the loss of the 128 points required to fill the filter could not be tolerated arid therefore, the shorter filter was used.

The results of applying tlie 64 point and 128 point filters to the recession water level arc plotted in figures 6 e) and f) respectively. These can be compared with the same data plotted unfiltered in figure 4 c).

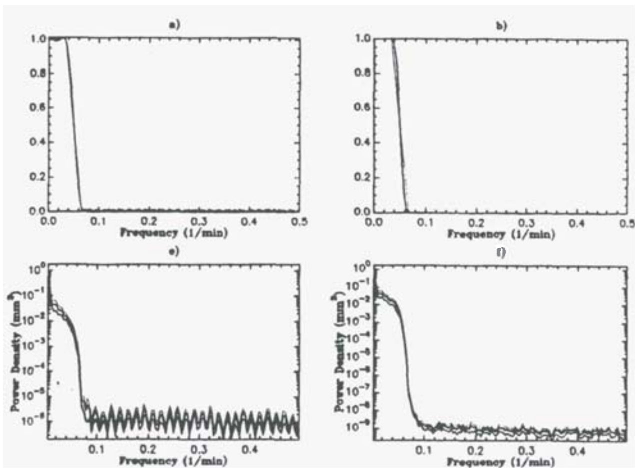

Figure 6: The 64 and 128 point FIR low pass filters, aiid filtered data power density spectra.

5 Enthalpy Calculations

The enthalpy of a fluid entering a reservoir, such as a lake, can be determined from a simple application of tlie laws of energy and mass conservation. In the case of a geothermal lake, tlie primary source of energy and mass is the fluid entering it via submerged springs. If all the energy contributions from secondary sources and sinks for such a lake can be accounted for and removed from the increase in stored energy, the remainder is the energy vented into the lake. The vented mass for the lake can be obtained from the mass balance equation, and the ratio of vented energy to vented mass is the enthalpy of the vented fluid [3].

In the case of Inferno Crater Lake, the mass gained from peripheral springs and lost by seepage is insignificant. Therefore the mass entering the lake from the vent is

$$M_f = \Delta M_C - M_p + (M_e + M_d). \quad (1)$$

where:

- M_f = input of steam and water from the vent,
- ΔM_C = increase in the lake mass,
- M_p = the precipitation,
- M_e = the surface evaporation, and
- M_d = the overflow.

Similarly the energy entering the lake from the vent is

$$Q_f \;=\; \Delta Q - M_p h_r + M_d h_C - Q_r + (M_e h_v + Q_c). \quad (2)$$

where:

- ΔQ = increase in the stored energy of the lake,
- Q_r = nett radiated energy received,
- Q_c = energy lost by conduction,
- h_p = is the enthalpy associated with precipitation M_p,
- h_C = is the enthalpy of the lake water, and
- h_v = is the water vapour enthalpy, $L + h_C$.

All the terms on the right hand sides of equations (2) and (1) are measurable. Hence the enthalpy of the incoming vented lake fluid can be calculated from

$$h_f = \frac{Q_f}{M_f}. \quad (3)$$

The derivatives ΔM_C and ΔQ could be calculated from the differences between successive points. However, such an operation introduces considerable high frequency noise. Instead the derivatives were computed by applying differentiating low pass filters with bandwidth specifications the same as above. The filters were constructed using the Remez Exchange Algorithm and were of lengths 64 and 128 points. These differentiating filters are plotted in figure 7. Plots a) and b) compare the digital filters with ideal differentiating filters.

The plots in figure 8 are of the computed vent variables: vent fluid enthalpy, vent mass flow, and the hydrostatic pressure at the vent (assuming no sediment load in the water). The line on the enthalpy graphs represents the minimum fluid enthalpy necessary for two-phase conditions to occur at the vent.

The box at the bottom left of the plots contains: the start time and stop time in minutes since the start of the cycle; the length of the filter used, if any, to filter the data; the period equivalent to the cutoff frequency, in minutes for the low pass filter; and the number of minutes between samples.

References

[1] A. Bruce Carlson. *Communication Systems*. McGraw Hill, 1975.

[2] J.T. M^cLeod. Instrumental monitoring of hydrothermal surface features. In *10th New Zealand Geothermal Workshop 1988*. New Zealand Geothermal Institute, 1988.

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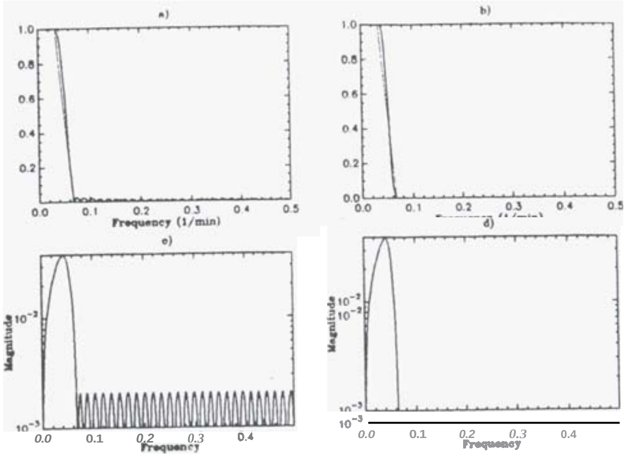

Figure 7: The 64 and 128 point FIR low pass differentiating filters.