

Lunar & Solar Tidal Pressure Viewer Java Applet

by John R. Victorine

Introduction

The continuous pressure monitoring in the lower Arbuckle was set up because a large rate and high volume brine disposal in the area is believed to be responsible for the induced seismicity.

“The assumption in the case of the testing in the Arbuckle is that the observed pressure is being transmitted at depth in the basement where faults are critically stressed, requiring a small force to move. To date the vast majority of earthquakes have occurred in the shallow basement.”

Quarterly Report-19, 2016. Trilobite Testing of Hays Kansas installed the pressure gauge in the Wellington KGS 1-28 at about 5020 feet depth from surface. The instrument is programmed to sample every second with an accuracy of 0.1 psi. About a week of pressure data is sent to KGS as a Comma Separated Values (CSV) file.

A Java computer program was developed to analyze the pressure data from the Wellington KGS 1-28 to understand the pressure changes, to remove solar & lunar Tidal pressures along with barometric pressure changes. The idea is that if you can remove or explain the natural every day influences you are left with the geological influences and maybe you might be able to identify fluid movement due to brine injection, micro quake swarms, etc. Figure 1 is an illustration of the raw pressure measurement in psig units over a 4 day period, 30 July to 2 August 2016.

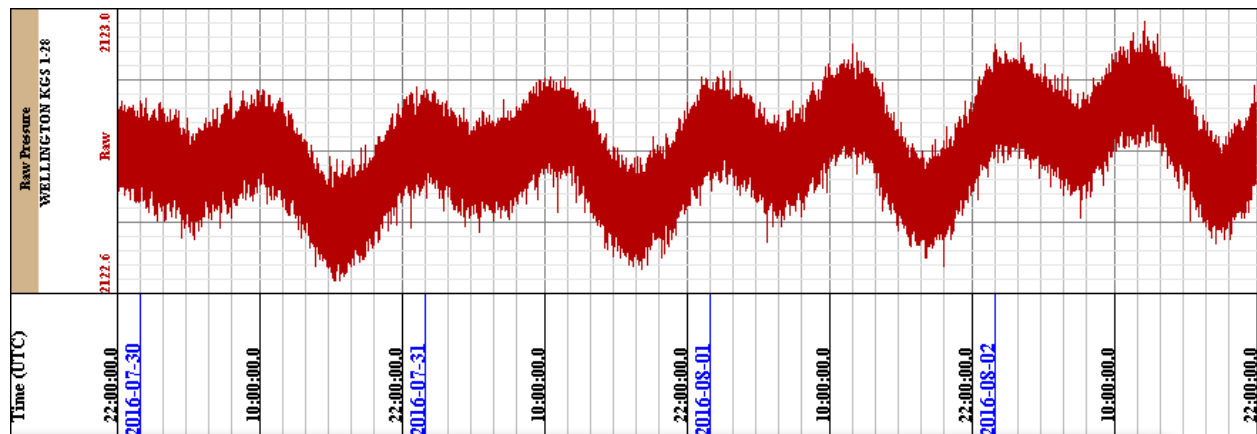


Figure 1: Raw Pressure Data Measurements in the Wellington KGS 1-28 between 30 July to 2 August 2016.

The computer program will filter the noise from the raw pressure data, compute the lunar & solar tidal pressures along with the barometric pressures influence, and then subtract that from the raw pressure data. In an ideal situation if these are the only pressures influencing the pressure measurements then the pressure data should result in a straight line.

The first step was to filter out as much of the measurement noise in the Raw Pressure data. Playing with a simple square pulse filter of varying width gives varying improvements to the Pressure data, see figure 2. The best result was the 1000 points (1000 seconds) square pulse

applied to the raw data. This method removed most of the noise, without removing signals that may be of interest down the line. You can see the lunar and solar cycle in the pressure wave as well as “noise” on top of that signal or is it barometric pressure or something else.

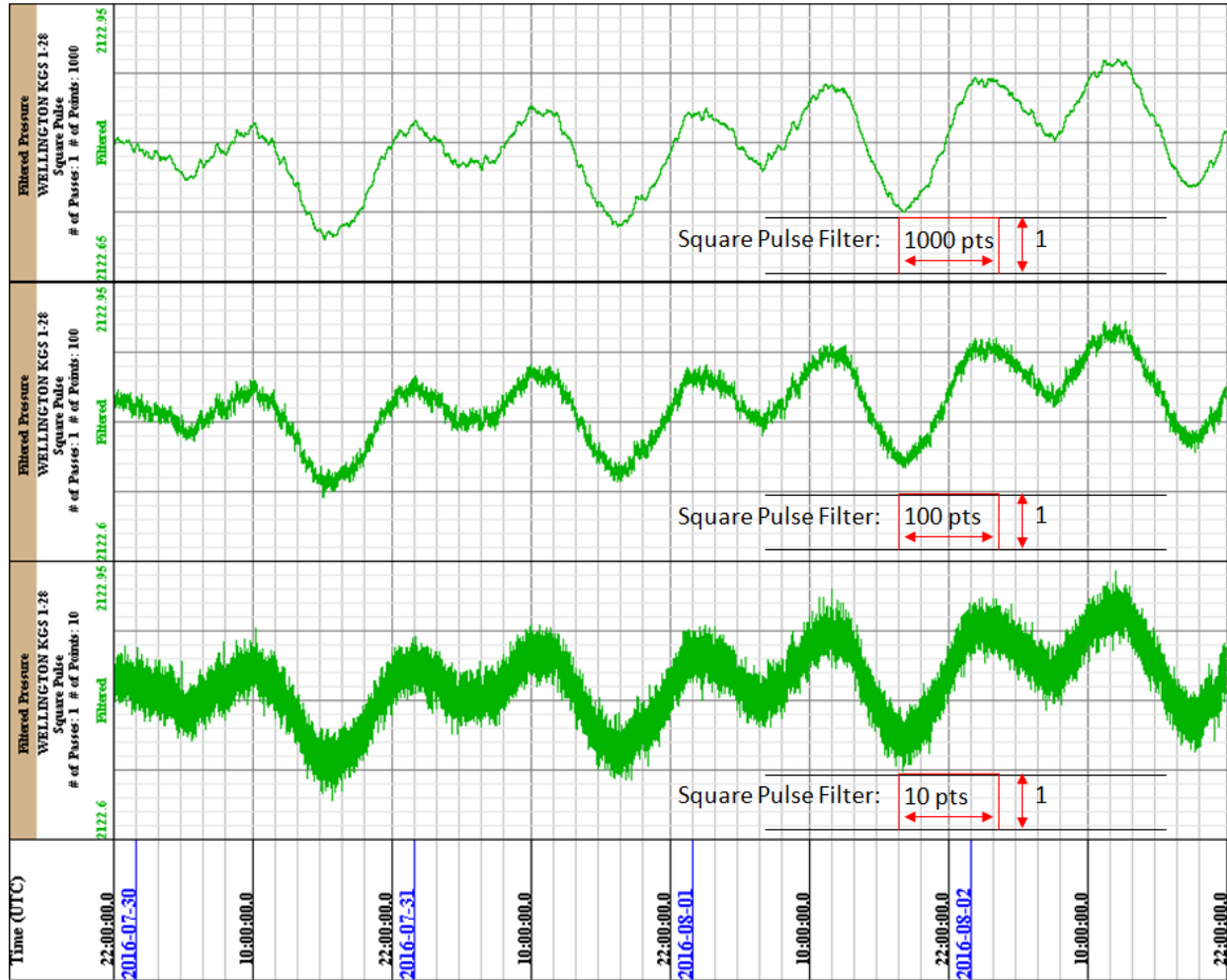


Figure 2: Varying widths of Square Pulse filter on Raw Pressure Data.

²It is well known that the sinusoidal water level variations observed in open wells are directly related to lunar & solar tidal influence. It is also believed that the tidal effects are related to the characteristics of the formation and to the fluid contained in the formation. The lunar & solar attraction of the earth generates a state of stress on the earth's surface which induces a radial deformation of the earth. As the gravitational force of attraction between two masses is inversely proportional to the square of the distance between these two masses, the potential derived from this force will be inversely proportional to the distance between the two masses. In Bredehoeft¹ he attributes to Love³ (pg 52) that the tide generating potential W may be approximated with sufficient accuracy as a spherical harmonic of second degree,

$$W = 0.5 * (GM_b/D_b) (a/D_b)^2 (3 \cos^2 \beta_b - 1) \quad (1)$$

where G is the Gravitational Constant = $6.67408 \times 10^{-11} \text{ [m}^3\text{]/}\{\text{[kg]}\text{[sec}^2\text{]}\}$

M_b - Mass of the body
 D_b - Distance between earth and body
 a - Earth Radius = 6.371×10^6 [m]
 β_b - angle between earth and body

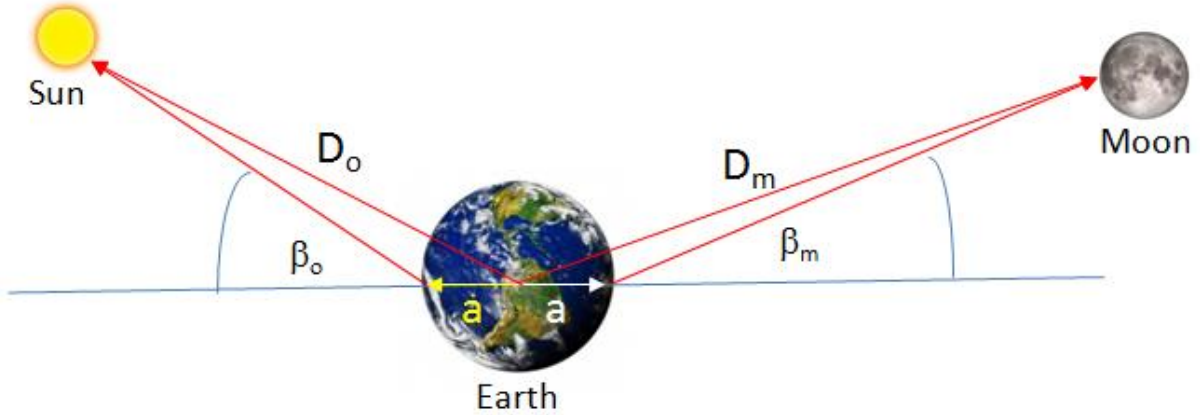


Figure 3: Geometry of the Sun and Moon with respect to Earth.

Expanding $\cos(\beta_b)$ with respect to earth's latitude and longitude,

$$\cos(\beta_b) = \sin(\lambda_e) \sin(\lambda_b) + \cos(\lambda_e) \cos(\lambda_b) \cos(\omega t - \phi_b) \quad (2)$$

where β_b - angle between earth and body

ω - frequency of the Earth's rotation = 1.1600804×10^{-5} [Hz]

λ_e - latitude of the Wellington KGS 1-28 = 37.3194833 degrees

λ_b - latitude of the body, which is "moving" up and down with respect to earth with time

ϕ_b - longitude of the body, which is "moving" around earth with time

Lunar tidal influence is about twice as strong as the solar tidal influence, but not insignificant as some authors imply. Using the tide generating potential constant $(GM_b/D_b) (a/D_b)^2$ for both the moon and the sun,

M_m - Mass of the moon = $7.34767309 \times 10^{22}$ [kg]

D_m - Average distance between earth and moon = 3.84402×10^8 [m]

M_o - Mass of the sun = 1.989×10^{30} [kg]

D_o - Average distance between earth and sun = 1.495979×10^{11} [m]

	Moon	Sun
$(GM_b/D_b) (a/D_b)^2$	3.504275 [m/sec] ²	1.69404 [m/sec] ²

Bredehoeft¹ states that the dilatation in an aquifer will depend not only on the tidal strain but also on the effect of change in internal fluid pressure produced by the tidal dilation. The aquifer will be subjected to tidal strains latitudinal and longitudinal directions that are almost entirely determined by the elastic properties of the earth as a whole. Love³ (pg53) showed that the

dilation can be related to the disturbing potential by introducing a fourth Love number, $F(r)$, where

$$\theta = F(r) * (W / g)$$

Takeuchi⁴ evaluated $F(r)$ by numerical calculations indicating that near the earth's surface the dilatation is given by

$$\theta = (0.49 / a) * (W / g) \quad (3)$$

where a is the earth's radius, g is the acceleration due to gravity (9.8 m/sec^2) and W is the lunar & solar tide generating potential. Bredehoeft continues to derive the effects of the dilation as change in pressure of the earth tide in an aquifer system and shows that the earth tide P is,

$$P = \rho gh = \theta / (C_w \phi) \quad (4)$$

where ρ is the density of the fluid in the borehole, g is the acceleration due to gravity and h is the height of the fluid above the aquifer, ϕ is the porosity of the aquifer, θ is the volumetric strain at the surface of the earth, C_w is the compressibility of the water. The compressibility of the rock itself was neglected because Bredehoeft assumed that the change in rock matrix volume was small compared to that of the water volume.

The lunar & solar tide generating potential, W_b , equation used in the Java Web App is as follows,

$$W_b = 0.75 * [GM_b/D_b] * [a/D_b]^2 * \{ \begin{array}{ll} (3*\cos(2*\lambda_b) - 1) * (3*\cos(2*\lambda_e) - 1) / 12.0 & \text{Long term cycle} \\ + \sin(2*\lambda_b) * \sin(2*\lambda_e) * \cos(wt - \phi_b - \phi_{corr}) & \text{Diurnal } \sim 1 \text{ day cycle} \\ + \cos^2(\lambda_b) * \cos^2(\lambda_e) * \cos[2*(wt - \phi_b - \phi_{corr})] \} & \text{Semi-diurnal } \sim 1/2 \text{ day cycle} \end{array}$$

where G is the Gravitational Constant = $6.67408 \times 10^{-11} \text{ [m}^3\text{]/}\{[\text{kg}][\text{sec}^2]\}$

M_b - Mass of the body

D_b - Distance between earth and body varying with time

a - Earth Radius = $6.371 \times 10^6 \text{ [m]}$

ω - Frequency of the Earth's rotation = $1.1600804 \times 10^{-5} \text{ [Hz]}$

λ_e - Latitude of the Wellington KGS 1-28 = $37.3194833 \text{ degrees}$

λ_b - Latitude of the body, which is varying with time, and computed from the declination [degrees].

ϕ_b - Longitude of the body, which is varying with time, computed from right ascension.

ϕ_{corr} - Correction angle due to the “starting time” of pressure data file.

The total generating potential W is the sum of lunar (W_m) and solar (W_o) potentials, i.e. $W = W_m + W_o$. Substituting the total generating potential W into equation (3) and then into equation (4) gives the pressure due to earth tide as follows,

$$P = (0.49 / a) * (W / g) / (C_w \phi)$$

where in Wellington KGS 1-28 at 5020 feet below the surface in the Arbuckle formation the water temperature is 133.01 °F from the Temperature Log, log date 3 March 2011 by Halliburton, gives a water compressibility (C_w) of 0.4437 [1/GPa] and the Porosity of the aquifer (ϕ) is about 0.09 [PU].

The apparent latitude and apparent longitude of the Moon and Sun is computed using the equations from ⁵“How to compute planetary position” by Paul Schlyter.

The slope is computed by taking the first 1000 points (1000 seconds) and computing the average and then taking the last 1000 points (1000 seconds) and computing the average, then visually modifying the starting pressure and ending pressure with respect to the filtered pressure curve after the lunar & solar pressure is subtracted to represent the slope of the filtered pressure data.

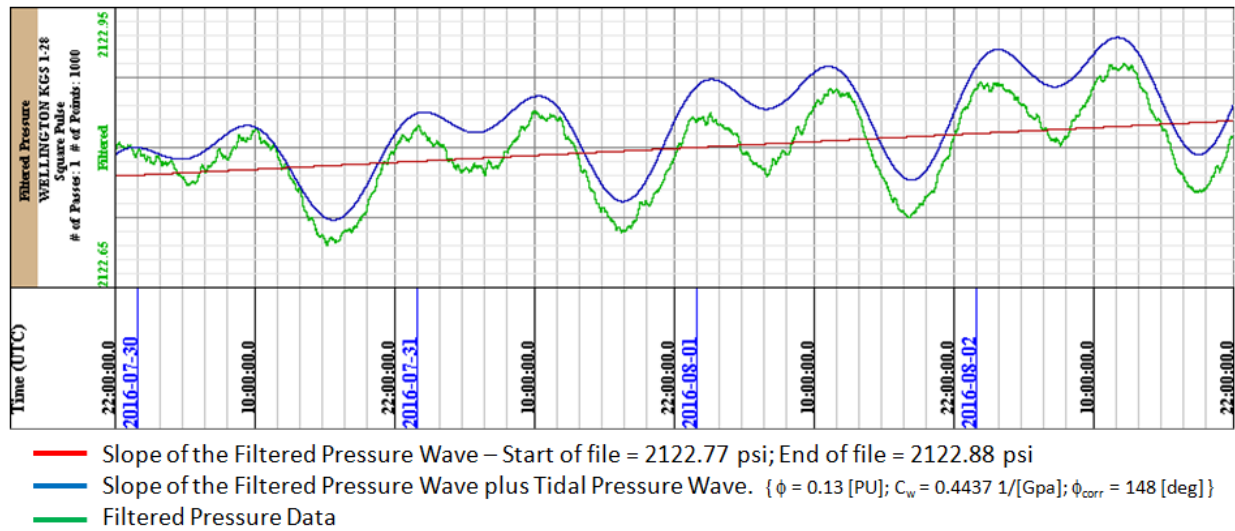


Figure 4: Filtered pressure data with the computed lunar & solar pressure wave.

The last step in the program is to subtract the lunar & solar tidal pressure wave from the filtered pressure wave, which should show the data to be linear. The data is not totally linear, which suggest there is something else pulling and pushing the pressure curve. The project does not have a barometric pressure meter on the Wellington KGS 1-28 so barometric pressure measured at Strother Field Airport, Hackney, Kansas is used, which is 24.2335 miles to the Southeast of the well. If there were major pressure fronts or large storms then the barometric pressure from Strother Field Airport should suggest the changes in the deviation of the filtered pressure wave after the lunar & solar wave is subtracted. The pressure change from the surface pressure and the pressure measured at the pressure sensor is just the weight of the water column above the sensor, i.e.,

$$P_{\text{sensor}} = P_{\text{atmosphere}} + \rho gh.$$

where ρ is the density of the fluid in the borehole g is the acceleration due to gravity (9.8 m/sec²) and h is the height of the fluid above the pressure sensor.

We do not have the exact height of the water column above the pressure sensor, so the only way to incorporate the barometric pressure influence at the pressure sensor is to estimate what the measured pressure data should be at the sensor. The atmospheric pressure at Wellington KGS 1-28 is about 14.11 psi from the calculation of ideal altitude versus pressure curve. Ideally if the lunar & solar pressure curve is subtracted from the measured data then the measured data should be a straight line. It is basically a straight line in the image below (figure 5) but there are deviations.

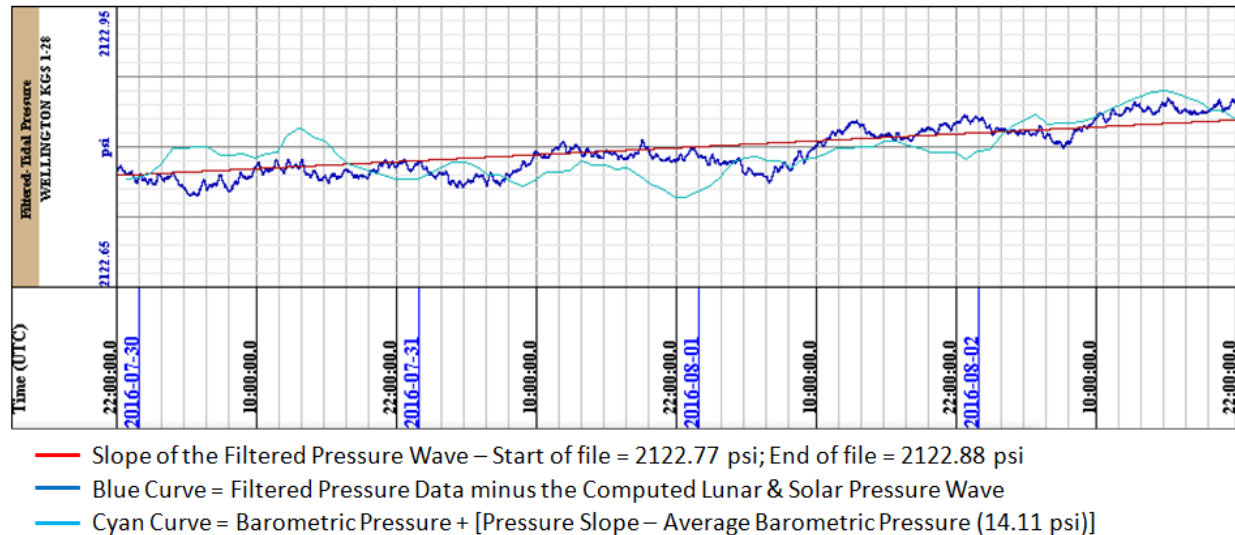


Figure 5: Lunar & Solar Pressure Wave removed from measured pressure data.

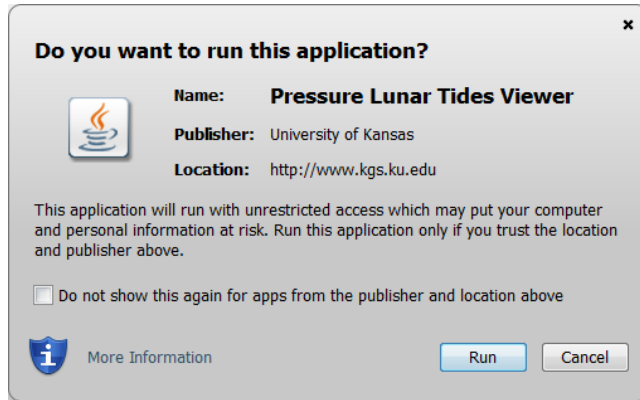
A pressure curve is constructed by adding the barometric pressure measured at Strother Field Airport with the difference of the Pressure Slope and 14.11 psi the average ideal barometric pressure at this elevation and overlaying that on the measured data. It can be seen that there is some comparison with the measured data. Ideally if the barometric pressure is measured at Wellington KGS 1-28 then the computed barometric pressure should line up exactly with the linear pressure curve and any deviations from that would be other geological effects, i.e. fluid movement, etc.

References:

- 1) Response of Well Aquifer Systems to Earth Tides by John D. Bredehoeft, Journal of Geophysical Research, Vol 72, No 12 June 15, 1967.
- 2) The Earth Tide Effects on Petroleum Reservoirs, Thesis submitted to the Department of Petroleum Engineering of Stanford University by Patricia C. Arditty, May 1978
- 3) Love, A. E. H., Some Problems of Geodynamics, 180 pp., Cambridge University Press, Cambridge, 1911, <https://archive.org/details/cu31924060184367>
- 4) Takeuchi, H., On the earth tide of compressible earth of variable density and elasticity, Trans. Am. Geophys. Union, 31, 651-689, 1950.
- 5) How to compute planetary positions by Paul Schlyter
<http://astro.if.ufrgs.br/trigesf/position.html>

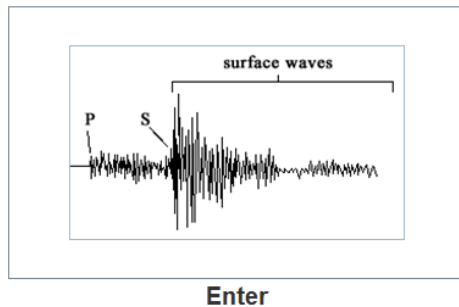
Lunar & Solar Tidal Pressure Profile Applet

To access the Lunar & Solar Tidal Pressure Profile Viewer web site, go to the web address http://www.kgs.ku.edu/PRS/Ozark/Software/PSI_Tides/. At the top of the web page there is a menu "Main Page|Applet|Download|Help|Copyright & Disclaimer|". Select the "Applet" menu



option a "Warning - Security" Dialog will appear (*"Do you want to run this application?"*). The program has to be able to read and write to the user's PC and access the Kansas Geological Survey (KGS) Database and File Server, ORACLE requires this dialog. The program does not save your files to KGS, but allows you to access the KGS for well information. The program does not use Cookies or any hidden software. The blue shield on the warning dialog is a symbol that the Java web app is

created by a trusted source, which is the University of Kansas. Select the "Run" Button, which will display the Seismic Image Icon Button in the "Enter" Panel illustrated below,



The Applet automatically downloads the necessary data from the Kansas Geological Survey (KGS) ORACLE database to access the Raw Pressure/Temperature & Barometric Pressure Files that are stored on the KGS Server. To access the pressure/temperature file information, ORACLE PL/SQL stored procedures were created that loads the file information in an Extensible Markup Language (XML) data stream, which the applet will then parse and store in data structures. Click on the

seismic wave icon button to display the Pressure Data Control Dialog. The Applet will then make a PL/SQL request for all the Raw Pressure Files with the following URL request,

http://chasm.kgs.ku.edu/ords/iqstrat.co2_pressure_files_pkg.getXML

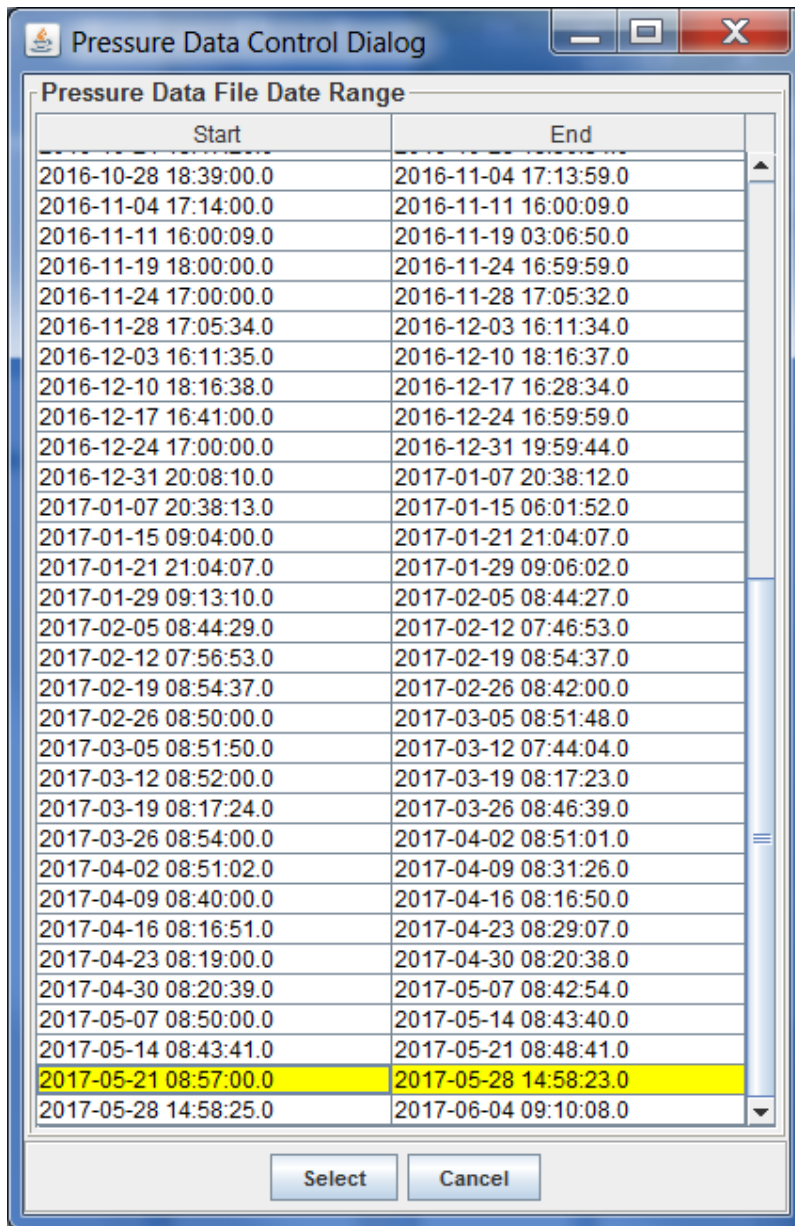
This above stored procedure will generate a XML data stream with all pressure files location on the KGS Server as well as the date ranges the pressure/temperature data was measured. The Applet also makes the request for the Barometric Pressure Data using two more PL/SQL request one for the Wellington KGS 1-28 barometric pressure sensor

http://chasm.kgs.ku.edu/ords/iqstrat.co2_barometric_files_pkg.getXML?sLOC=Wellington%20KGS%201-28%201-28

and the second for the Strother Field Airport, Hackney, Kansas Barometric pressure data,

http://chasm.kgs.ku.edu/ords/iqstrat.co2_barometric_files_pkg.getXML?sLOC=Winfield%20KS

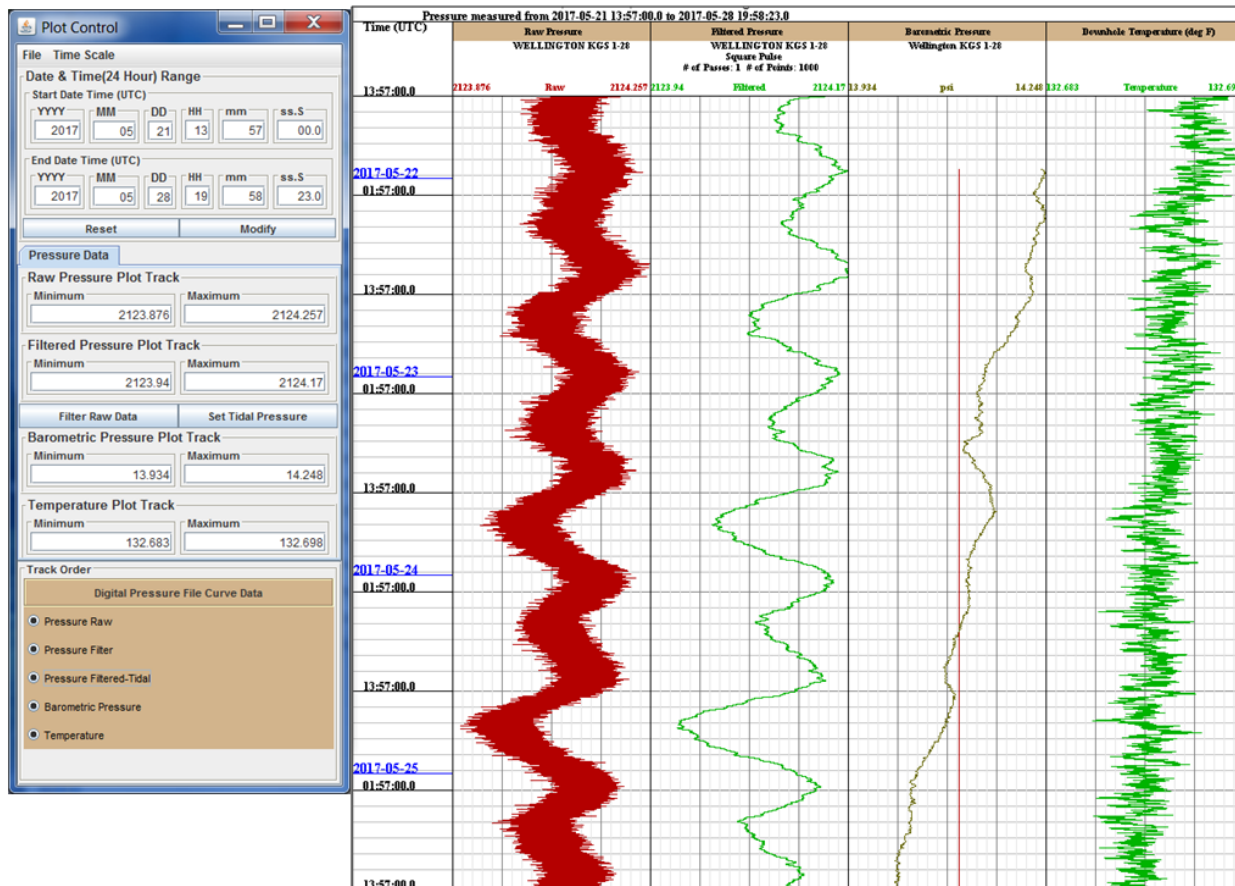
which was the closest airport to the Wellington KGS 1-28 before a Barometric pressure gauge was installed. Both URL calls retrieve the location of the all the barometric files stored on the KGS Server. The program decides if it can not find the barometric file from the KGS 1-28 sensor, then it will look for a file from the Strother Field barometric file.



The Pressure Data Control Dialog will be displayed showing the File Date Ranges for all the pressure / temperature files that have been uploaded to the KGS Server. The user only needs to highlight the date range of interest and click on the "Select" button.

The Applet will automatically load all the files necessary to plot the Pressure / Temperature data in the profile plot. The program will then apply a simple square pulse filter on the raw pressure

data of 1000 points in width or 1000 seconds since the data is measured every second, see figure 2 above. The pressure/temperature data is then plotted in a profile plot format by time.



Initially only the raw pressure/temperature & barometric pressure data is plotted in the profile plot. The user can compute the lunar & solar pressure curves by selecting the “Set Tidal Pressure” button on the Plot Control dialog. The Plot Control dialog provides the ability to change how the raw pressure data is filtered, presently the default is a square pulse of 1000 points (1000 seconds), which is shown in the second plot track above. The red line in the 3rd plot track is the average barometric pressure at the altitude of the Wellington KGS 1-28 or 14.11 [psi]. The temperature data is not filtered in any way it is just plotted as a reference.

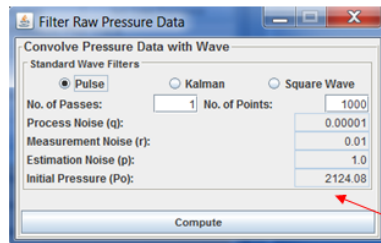
Plot Control Dialog:

Menu Options

File – Create PNG image of plot

Time Scale – Vary the vertical time scale to number of minutes or hours per inch.

Filter Raw Pressure Data – Allows the user to choose the filter method for reducing the raw pressure data.



Change the minimum and maximum of the Barometric Pressure Plot Track

Change the minimum and maximum of the Temperature Plot Track

Turn Plot Tracks on or off – Radio button is selected plot track is displayed.

Change the start and stop date/times in the profile plot.

Modify button - alters the start and stop date/times in the plot.

Reset button - sets the original start and stop date/times in the plot.

Change the minimum and maximum of the Raw Pressure Plot Track

Change the minimum and maximum of the Filtered Pressure and the Filtered minus Tidal Plot Tracks

Tidal & Barometric Pressure Dialog –

Allows the user to modify the lunar & solar tidal pressure parameters.

Tidal & Barometric Pressure Dialog:

Wellington KGS 1-28:

λ_e - Well Latitude = 37.3194833 [degrees]

P_b - Average Barometric Pressure at Well Altitude = 14.11 [psi]

Temperature at 5020.0' is 133.01 [deg F] from the Temperature Log,
log date 3 March 2011 by Halliburton

ϕ - Porosity at 5020.0' is about 0.12 [PU] to 0.13 [PU]

Barometric Efficiency Factor is automatically computed from the ratio of the corrected pressure without tidal pressure and barometric pressure. Should be < 1.0.

$$w = \frac{P_{cmax} - P_{cmin}}{P_{bmax} - P_{bmin}}$$

where
 w = Barometric Efficiency
 P_c = Tidal Pressure Removed
 P_b = Barometric Pressure

$$P = (0.49 / a) * (W / g) / (C_w \phi)$$

P is the lunar & solar tidal pressure
 W is the sum of the lunar & solar tidal potential
 a is the earth radius
 g is the acceleration due to gravity
 C_w is the compressibility of water at formation temperature
 ϕ is the formation porosity

ϕ_c - Correction Phase is basically an iterative process to move the lunar & solar pressure wave to match the measured pressure wave.

Compressibility (C_w) computed from Water data (supplementary) by Martin Chaplin (<http://www1.lsbu.ac.uk/water/data1.html>)

Presently this program is only reading data from the Wellington KGS 1-28, but it can be modified in the future to monitor any well. A number of the text fields in the Tidal & Barometric Pressure Dialog are presently set, there are only a few text fields that the user really needs to change,

Porosity [PU] affects the overall peak to peak height increase Porosity lowers the Lunar & Solar Pressure, initially set to 0.1, change to 0.12 [PU].

Correction Phase [degrees] moves the Lunar & Solar Pressure Wave train forward.

Start Pressure & End Pressure for the slope is initially computed by taking the first 1000 points (1000 seconds) and computing the average and then taking the last 1000 points (1000 seconds) and computing the average. The user can be tweaked the slope to better fit the filtered minus tidal pressure and the altered barometric pressure in second plot track. The lunar and solar pressure is added to that value so it can be plotted against the filtered pressure data.

Finding the Lunar & Solar Tidal Pressure:

