Bandlimited impedance inversion: using well logs to fill low frequency information in a time-lapse carbon sequestration model

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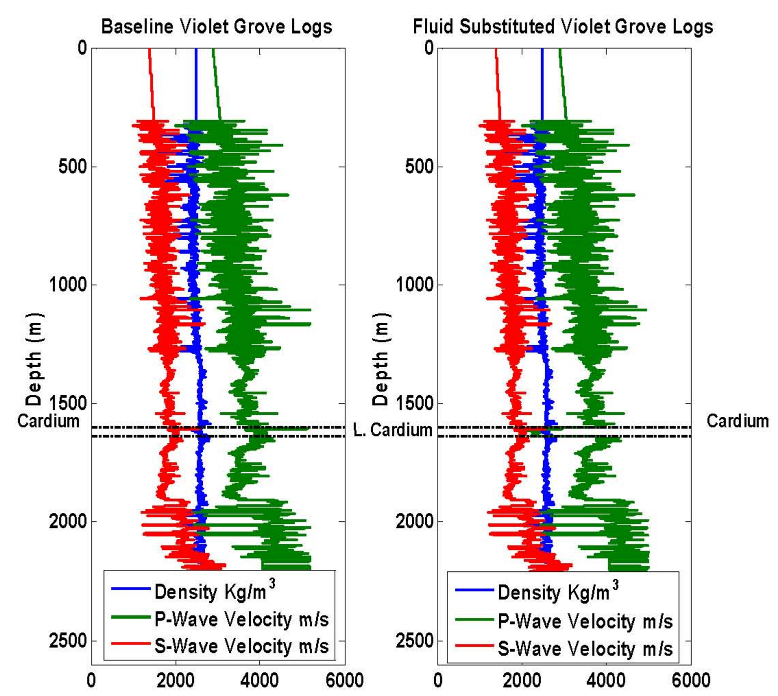
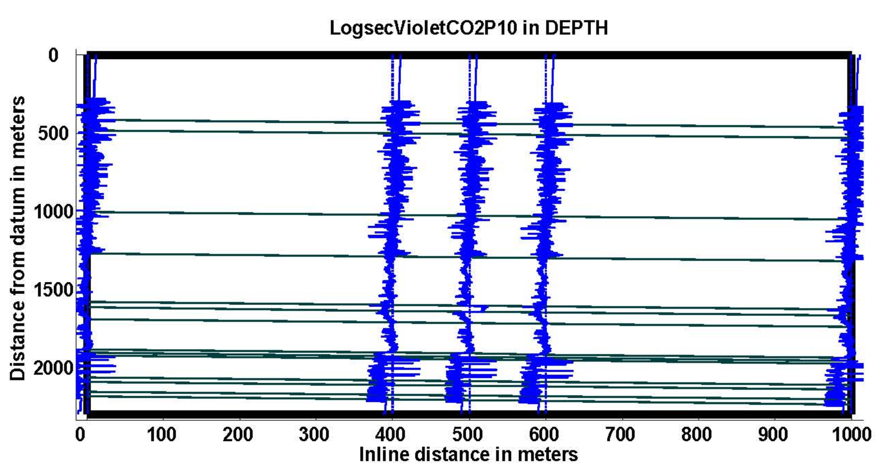
The Model

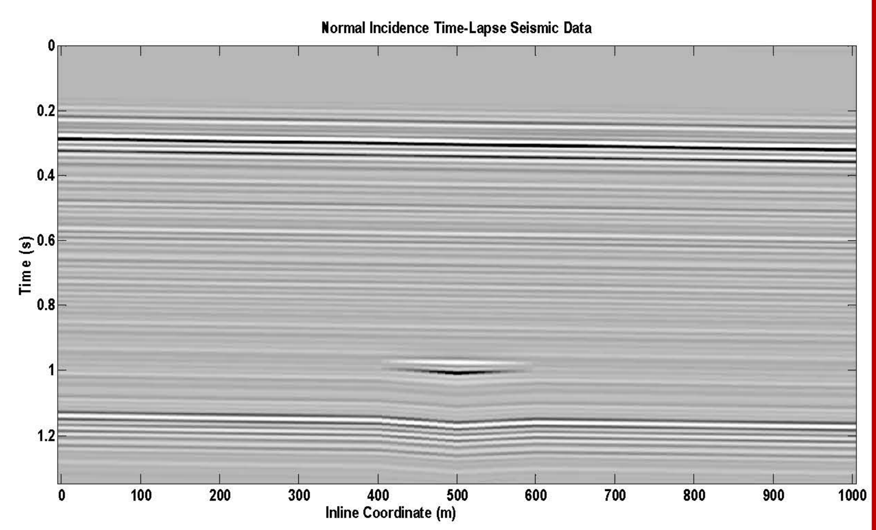
Two logs from the Violet Grove Area in Alberta, Canada were combined to form the baseline log seen in the figure to the right. For the velocity logs a linear overburden and underburden was used where for the density log the mean density was used. To create the monitor log a Gassmann fluid substitution was conducted for a 40m interval at the Cardium formation. 5% of oil and 5 % of brine was replaced by 10% CO_2 in a gaseous state. The P-wave velocity in the monitoring well has a large decrease where as the shear velocity and density log do not show much change.

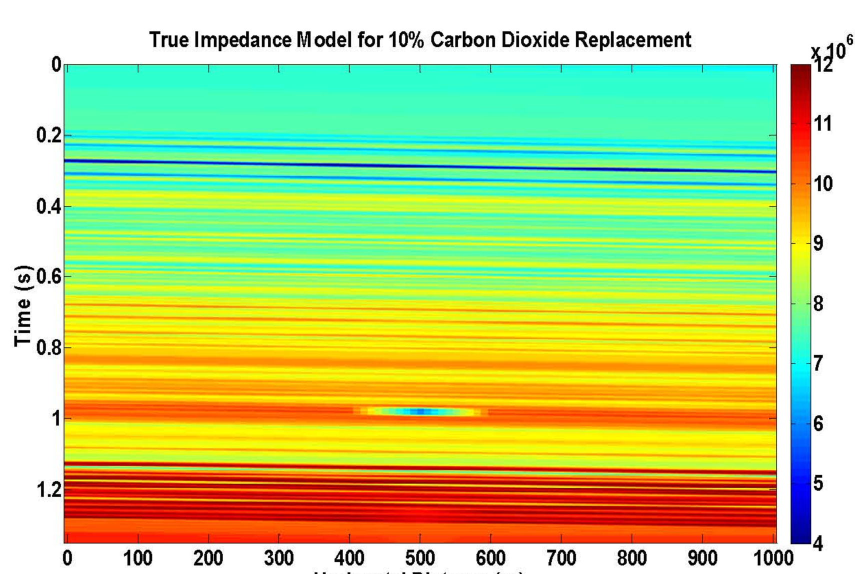




To create the model five logs were placed to define the structure before propagation. The fluid substituted log is located at 500 m. Original logs were placed at 400 and 600 m to limit the extent of the carbon-dioxide plume. Original logs were placed at 0 and 1000 m for structural constraints.

A synthetic seismic section was created from the model using a normal incidence approximation. The reflectivity coefficients were determined and convolved with a [10/15/60/75] zero phase Ormsby wavelet . The injection site can be easily seen as well as a pull down effect caused by the low impedance carbon dioxide.





This figure shows what the true impedance model is. This model started out as the propagated logs but was then filtered with a high band pass filter and resampled to an interval that matched the seismic data. This was done so that a standard comparable section was available to evaluate the quality of the impedance inversions.

Abstract

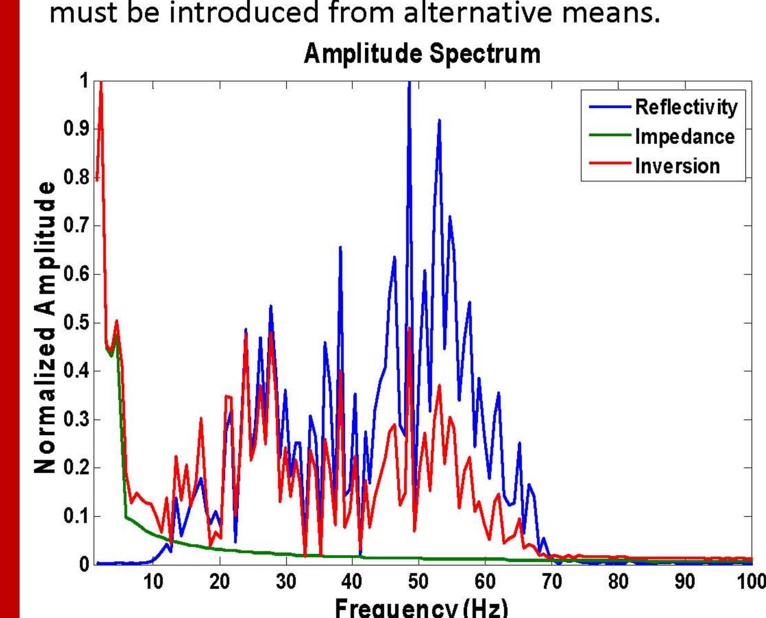
An acoustic bandlimited impedance inversion study was done to compare the results obtained when the baseline log; or alternatively, a monitor log are used to provide the low frequency information for the inversion. The model was created using the baseline log for the regional trend and placing the fluid substituted (monitor) log at the injection site in the center of the section. These wells were then interpolated along a geological section with a 2.8 degree regional dip. This impedance section was then converted to reflectivity and convolved with a zero phase, Ormsby wavelet to create a normal incident synthetic data set. The frequency spectrum of the logs and synthetic data were compared to find a suitable low frequency cut-off value. The low cut-off value of 4.5 Hz was chosen as frequencies higher than this were found to produce low frequency smearing across the section. The inversions were carried out using this low frequency cut-off for the logs and the high frequency cut-off for the seismic data was set at 85 Hz. The baseline inversion had a mean error of 28% at the injection site where the monitor inversion had an error of 23%. Both inversions had a regional error of ±10% when compared to the true impedance given by the model. The cross-correlation between the seismic data and the synthetic seismogram for the monitor inversion case was higher, and the sum of the error between the true impedance and the monitor inversion was slightly lower when compared with the baseline inversion. This shows that the monitor inversion is slightly better than the baseline inversion. It was found that more testing is required, using different models and acquisition geometries to determine which log is better to use in time-lapse studies. The findings of this paper suggest that possibly the best results can be obtained when the baseline log is used for the regional area and the monitor log is used for the injection area.

Theory

One method of acoustic impedance inversion is to exponetiate then integrate the reflectivity coefficients as described in the equation at the right.. I(0) is the impedance at the surface and R(τ) is the reflectivity coefficients. This inversion technique requires that the reflectivity have data at all frequencies especially as the data at frequencies from 0 to 5 Hz contain the trend of the impedance log (Lindseth, 1979). Since seismic data is band limited the low frequency data is not present and must be introduced from alternative means.

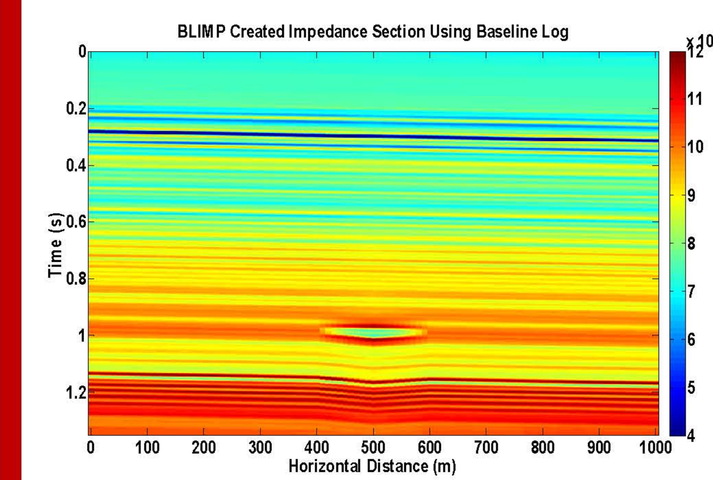
$$I(t) = I(0)e^{2\int_0^t R(\tau)d\tau}$$

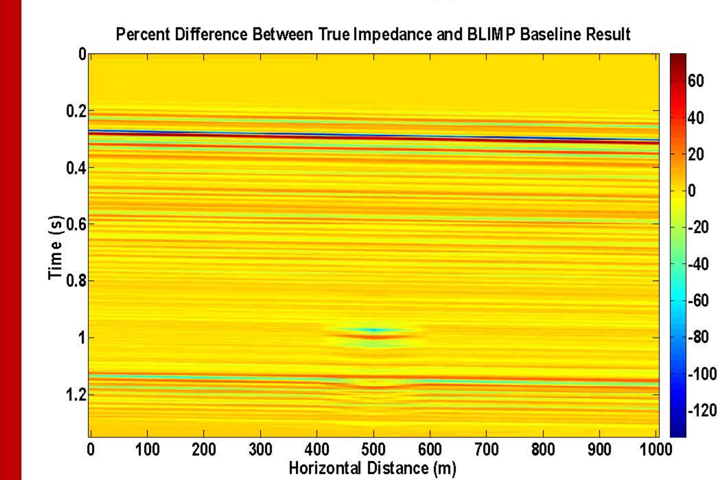
(Oldenburg et al.)



This study uses an approach described in Ferguson and Margrave (1996) where well log information is used to fill in the missing frequencies in the data. To do this the well log data is low pass filtered so all of the high frequency data is removed. The integrated and exponetiated reflectivity is then scaled and the frequency spectrum of this result and the impedance log are added together and then inverse Fourier transformed to finally get the impedance inversion result. The figure to the left shows the impedance log spectrum (green) the reflectivity spectrum (blue) and the inversion result spectrum (red).

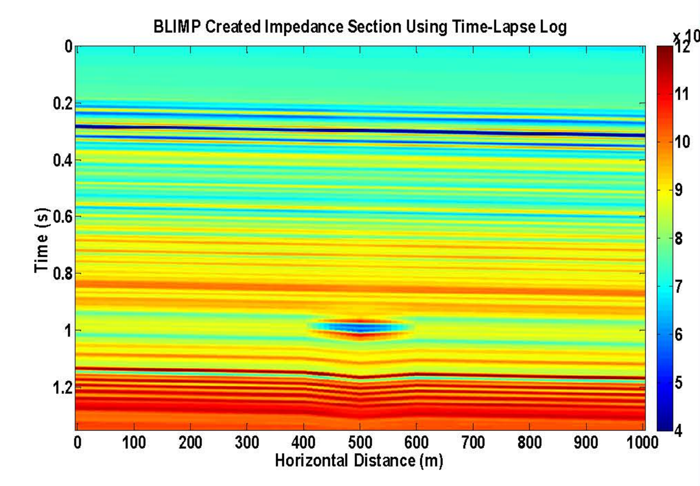
Results

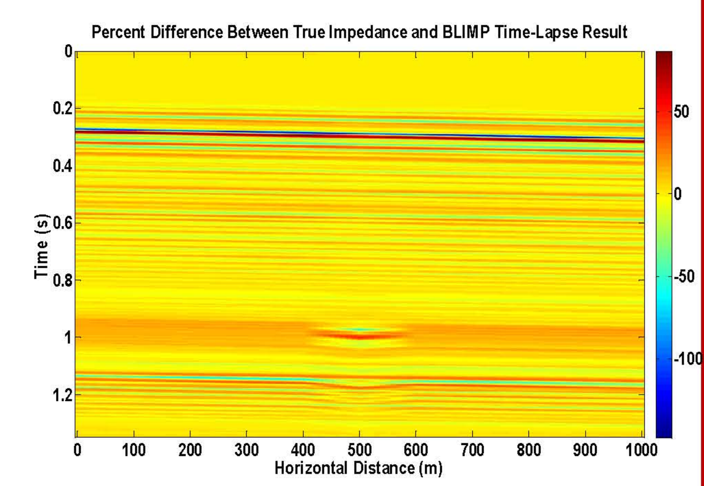




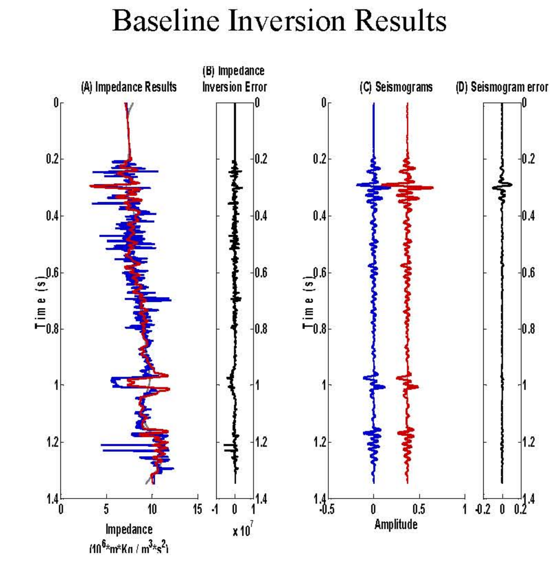
The figure at the top left is the results for the impedance inversion using the baseline impedance log with at low frequency cut-off of 4.5 Hz and a high frequency cut-off of 85 Hz. The figure below it is the percent difference between the true impedance and the baseline inversion result. This result shows that the inversion is comparable to the true impedance as most of the error falls within 10% . Over the injection zone there is an average error of about 28% but can be as high as 56%. The baseline log generally overestimates the injection zone as the CO_2 lowers the impedance in the region. This may cause problems when trying to detect the edge of the carbon dioxide plume.

The figure at the top right is the impedance result using the monitor impedance log with at low frequency cut-off of 4.5 Hz and a high frequency cut-off of 85 Hz. Below it is the percent difference between the true impedance and the monitor inversion result . The monitor inversion also does a decent job of recreating the true impedance. The error for most of the section is within 10% and the average error at the injection zone is 28%. The error in this region can be as great as 76%. There is also a low impedance band that moves across the section at the injection depth. This banding is a result of the monitor impedance log smearing the low frequency trend across the section. This is not ideal as this may be interpreted as carbon dioxide leakage.

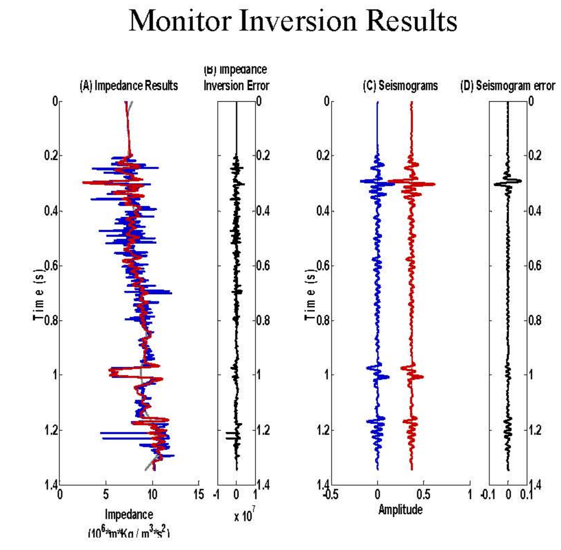




Baseline Inversion Results



Monitor Inversion Results



To better analyze the error that is associated with using the baseline and monitor logs an impedance trace was compared from the injection well location (500 m). The figure at the top shows the error analysis for the baseline log. In (A) the grey curve is the low impedance log that was supplied by the baseline impedance log. The red curve is the baseline impedance result and the blue curve is the true impedance. In (B) the impedance error between the true impedance and the baseline impedance inversion result; the absolute sum of the error was found to be 3.6151 x 10^8. In (C) the seismograms are compared where the blue curve is the seismic data and the red curve is the synthetic calculated from the baseline impedance inversion result. In (D) the error between the seismograms is shown; the cross correlation between these seismograms was found to 0.7640. The figure on the bottom is the same analysis with the monitor impedance log. The total error between the impedance is be 3.3003 x 10^8 and the cross correlation between the monitor seismograms was 0.6754. At this point it is unclear to state when ether the baseline log or the monitor log is best for time lapse inversion as both have benefits and disadvantages, therefore different models need to be explored.

Acknowledgements

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