Predicting Seismic Data Quality from Multispectral Satellite Imagery in Alberta Oil Sands

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Summary

For several years, field quality control metrics have been derived by partial processing of the 3D seismic data concurrent to acquisition in the KOSP (Kai Kos Dehseh Oil Sands Partnership) lands in northern Alberta. Upon examination of the data quality maps, it is clear that there exists some correlation with satellite imagery. Here we present a systematic method for predicting the seismic data quality in areas not yet acquired, based on correlations between the quality metric on existing data and multispectral satellite imagery.

Introduction

Data quality metrics are derived in the field after each shift change during the winter acquisition season. The metric we use is a shot stack RMS amplitude, after predictive deconvolution, NMO, and alignment statics. This has proven to be a good predictor of final data quality on a shot station basis. Although a surface-consistent decomposition into shot and receiver station would be preferable, that is a much bigger problem to solve.

We have noticed previously that to some extent the shot quality metric has an expression on the satellite or aerial imagery. For access planning we typically use LiDAR pulsed laser aerial imagery, which includes a digital elevation model from the laser traveltime, as well as a monochromatic reflectivity image.

We also have available multispectral satellite imagery. From the GeoEye satellite, we have 2 metre spatial resolution from 4 spectral bands plus a panchromatic image. From Landsat 7 we have 30 metre spatial resolution on 7 spectral bands plus a higher resolution panchromatic image. For this study we used the three GeoEye bands in the visible range.

The hypothesis is that multispectral imagery detects vegetation type, as well as vegetation diversity. This in turn represents a classification of the soil and moisture to the depth of the root system. Seismic data quality is strongly influenced by the near surface characteristics of soil and moisture. While the seismic data quality may be influenced by subsurface characteristics below the root system of the vegetation, there may be sufficient information in the vegetation to provide an adequate portrayal of the near surface in many cases, and may serve as a predictor of future seismic data quality, albeit incompletely.

Theory and Method

We have several existing 3D surveys acquired over the past seven winters. For each shot record at some surface location (x_k, y_k) we have computed a data quality value q_k. We also have a gridded vector reflectivity from the satellite imagery $\mathbf{s}_{ij}$.

We also augmented the recorded satellite values with two supplemental attributes meant to represent spatial variability. One is the magnitude of the second derivative of the magnitude of $\mathbf{s}_{ij}$, intended to be a “tree detector”. The second is the magnitude of the spatial derivative of $\mathbf{s}_{ij}$, meant to detect colour changes and represent “vegetation diversity”. The hypotheses of these interpretations of these computed values have not been verified on the ground.

From this point on, we will consider $\mathbf{s}_{ij}$ to be a vector quantity augmented by the addition of these supplemental spatial attributes.

The output from the analysis will be the estimated shot data quality $\tilde{q}_{ij}$ at all grid points (x_{ij}, y_{ij}).

The method used here to estimate the shot quality based on satellite image attributes incorporates basic attribute analysis methods of principal component analysis, change of basis, cluster analysis, and linear predictors.

These steps are:

- Compute a principal component basis from the entire population of attribute points { $\mathbf{s}_{ij}$ }. Obvious from looking at the pseudo-true colour satellite images, the first principal component of this population would be a basis vector representing “shades of green”. The subsequent basis vectors are not obvious.
- Rotate the attribute space onto these new basis vectors.
- Scale each coordinate axis such that the population of attributes has zero mean and unit variance in each of the coordinate directions. This has the effect of normalising the separate attributes, so that the “greenness” of a pixel is no longer such a dominant attribute.
- Run a clustering algorithm on the population of attributes so that there is a partitioning of the attributes into a number “L” of separate sub-populations, each having a relatively similar set of attributes.
- Within each cluster, collect a subset of quality factors whose spatial position is near to the spatial position of a member of the cluster.
- Using that subset of quality factors, estimate a linear prediction function (and associated prediction error) which optimally predicts the quality factor based on the attributes at the corresponding spatial position.
- Once all linear prediction functions have been derived, scan through all grid points at which the attributes are defined (the extent of the satellite imagery), classify each point into the appropriate cluster, based on proximity to the cluster centroid, and apply the linear prediction function pertinent to that cluster to the attributes. This produces an estimate of the shot quality.
- Rescale the estimated quality factors from 0 to 1 such that the cumulative distribution function is linear. This equalises the quantiles for display.
- Using a suitable colour scale, display the estimated quality factors as a map.

The specific methods used for each of these steps will be described in the presentation.

Examples

Shown in figure 1 is a piece of a map of the shot quality metric, computed from shot records acquired in 2011. Pink represents good data quality, black represents poor quality. Blank areas around the survey, and on lakes, are also coloured black.

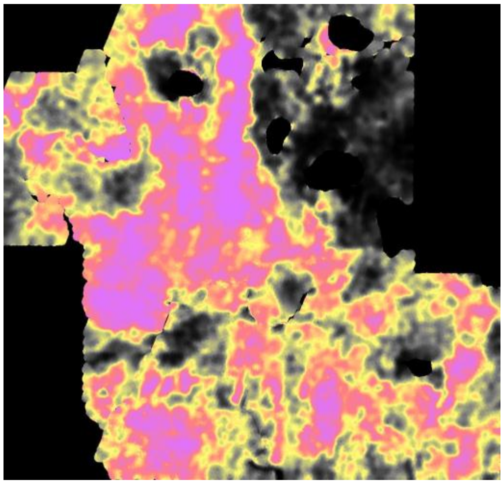

Figure 1: Shot quality metric, map view

Figure 2 is the result of running the prediction procedure from multispectral satellite imagery, to attempt to predict not only the values in figure 1, but also simultaneously to predict the values on several other vintages of seismic acquisition.

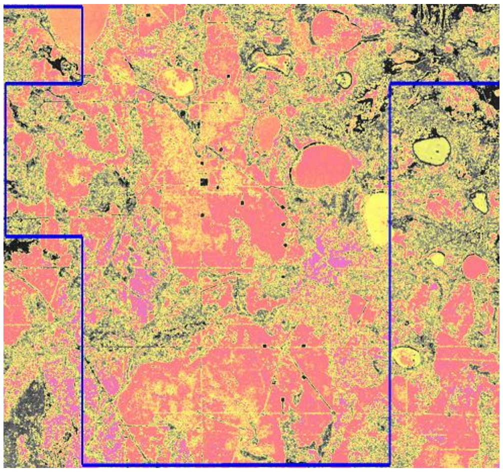

Figure 2: Predicted quality over the existing survey area from figure 1

The satellite imagery includes the lakes, and so predictions are made there. However, these predictions are meaningless; they are not based on any seismic data quality.

Apart from the lakes, there is clearly some correlation between the two images. Most notably in areas of fens the data quality is generally poor. But also some higher, wooded areas with good drainage produce poor data.

The objective of this project is to attempt to predict difficulties in acquisition, so that modifications may be anticipated in sweep parameters and shot and receiver density, increasing fold, and decreasing higher frequencies as necessary. On an area to be acquired during early 2013, the predicted data quality map on one portion is shown in figure 3.

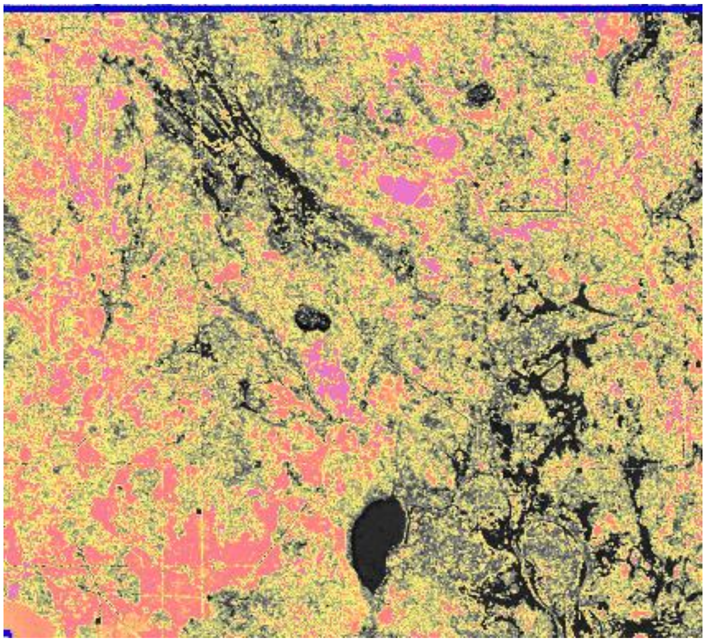

Figure 3: Predicted quality over a planned 2013 acquisition

At the time this abstract is being written, the data in figure 3 has not yet been acquired. Yet we anticipate making modifications to our acquisition parameters based upon the distinction between the good quality pink and red regions, and the poor quality black and grey regions.

Conclusions

The principal objective of this analysis is to provide an estimate for the data quality for the proposed 2013 seismic exploration areas. Areas of concern are noted. Planning for the 2013 program should take into account these areas, with testing at the initiation of acquisition. Possibly higher fold with tighter shot or receiver spacing may remediate the poorer data areas, and possibly denser shots and receivers on adjacent "good" data areas may be exploited by undershooting some poorer areas, possibly slight realignment of cut lines could move the acquisition into more favourable surface conditions.

Warning should be noted that these projections of seismic data quality do not take into account all factors which may affect data quality. The expression of vegetation changes in satellite imagery only takes into account the subsurface down to the depth of the root systems of the plants. Furthermore, certain vegetation types may be more robust in the presence of changes in the soil or water levels.

These projections should be revisited after, and during, the 2013 acquisition for validation or possible modification.

This method is a result from a research program at Statoil, and does not represent current best practice in Statoil.

Acknowledgements

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